Vehicle Transport Futures:

U.S. and China Scenarios based on CarCarbon© –
An Alternative Vehicle & Fuel Choice Model
with Energy & Emissions Analysis Outputs

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1. Introduction

This report presents the results of the third year of study by a research team at the Center for Energy and Environmental Policy, University of Delaware, funded by a generous grant by the BP Foundation. The purpose of this study is to examine the climate change implications of the introduction of hydrogen fuel cell vehicles into the U.S. transportation sector. The previously developed first year report focused on how state policy may interact with the development of a hydrogen economy. Our second year report created a modeling tool to quantitatively measure the carbon impacts of hydrogen fuel cell vehicles on U.S. fleets. (Waegel et al, 2006b; Waegel et al, 2005) This third year report presents a more complex and flexible model intended to handle a large range of vehicles, fuels and technologies and corresponding policy scenarios.

The model, dubbed *CarCarbon*, can be used as a projection tool to shed light on the future of vehicular transportation. Specifically, CarCarbon provides projections regarding types of vehicles people will be driving in future years and the effect these vehicles will have on carbon dioxide emissions and energy consumption. The model relies on a number of attributes, such as vehicle ownership growth, fuel economy trends, the price of fuels, and many others in order to create a projection of market demand for various vehicle technologies, such as gas-electric hybrids, gasoline internal combustion engines (ICEs), or hydrogen fuel cell vehicles. The market demand for the various technologies is combined with the expected growth rate of the vehicle ownership each year in order to create a 25-year annual “snapshot” representative of the on-road vehicle population. With this data, it is possible to predict the emissions of the vehicle population in each year and the amount of fuel being consumed.

Through this model we may determine the effects of policy on future emissions and energy consumption of the United States. The effects of a gasoline tax, incentives program for hybrid vehicles, or the rising costs of gasoline may be determined by including them in the model and comparing the projection to a baseline scenario based on a business-as-usual set of assumptions and predictions. Thus, not only does this model provide a picture of what will happen if no changes are made, it also shows how the future can be guided via progressive policy initiatives and which policy methods will have the greatest effect.

The remainder of this document describes CarCarbon in detail, including the mechanics and improvements over our previous model. Also described is the baseline scenario, which will form the basis for all future scenarios conducted with the model. The report section on the baseline scenario includes the inputs, assumptions, and inherent projections that were used to fortify the baseline as well as the resulting outputs. It shows a future with increasing fuel economies, greater use of alternative fuels, and, despite these factors, continued rises in carbon dioxide emissions and reliance on foreign energy sources.

2. CarCarbon

CarCarbon employs a complex structure of equations, inputs and algorithms in order to accurately model the adoption of new technologies into the U.S. vehicle fleet. Figure 1 identifies the structural flow of the new model. Consulting this diagram in conjunction with the following model description will assist in understanding the basic structure and development of CarCarbon.

CarCarbon has a number of very strong areas that can be necessary for the accurate prediction of technology adoption in the vehicular market. A first of these areas in CarCarbon is the ability to reflect the different factors affecting acquisition and retirement of new vehicles into the general pool of passenger cars, trucks and sport-utility vehicles (SUVs). A total of 15 vehicle technology types are incorporated into the model: conventional gasoline (CG); conventional diesel (CD); dedicated ethanol (EtOH); dedicated biodiesel (BD); hybrid gasoline electric (HEV); hybrid ethanol electric; hybrid biodiesel electric; flex ethanol; flex biodiesel; dedicated compressed natural gas (CNG); dedicated liquid natural gas (LNG); flex CNG; flex LNG; flex liquid petroleum gas (LPG); and hydrogen (H_2). It is the researchers' opinion that this vehicle technology list incorporates all possible types of fuels and motive technologies which may be developed in the passenger and commercial vehicle sectors within a reasonable timeframe.

A second major area in CarCarbon is the ability to incorporate fuel blending in fuel options. Even better, blends can remain constant or change over the course of the timeline of the model. As each of the technologies can handle different blends and different fuels, each is capable of being blended at different levels. This is particularly important for examining ethanol-gasoline blends, biodiesel-petrodiesel blends, and hydrogen from different sources. The H_2 option is especially important as it allows for variations to occur in how H_2 is being secured. The variation in the blends can measurably affect the emissions levels from the vehicle pool and the ability to vary blends in fuel also illuminates important differences in how vehicle technology and fuel choice synergistically affect the emissions profile of a vehicle pool.

A third major area in CarCarbon is the ability to account for variability in inputs across the projection period. Inputs which can be varied over time include: vehicle prices; expected vehicle lifetimes; average miles driven annually per vehicle; fuel prices; vehicle type fuel economies; fuel blends; fueling availability; and make and model availability. This capability gives the model a great deal of flexibility and enables more realistic scenario designs.

A fourth major area in CarCarbon is the incorporation of vehicle aging and eventual retirement; namely, the method by which vehicles are removed from vehicle pools over time. Vehicle types can be tracked through their lifetime, from manufacture to scrapping. A "skewed" normal distribution is utilized to determine the rate of retirement. This reflects a low retirement rate in early years due to car accidents and unusual mechanical problems, a high retirement rate in the middle years, and a low retirement rate in later years on the assumption that the majority of vehicles do not last beyond an "average" expected lifetime. Under the model, most retirements occur within two years of the expected lifespan of the vehicle. This method of vehicle retirement presents a realistic portrait of vehicle pool trends for privately owned vehicles.

The final and most significant area is the utilization of algorithms and formulas originally developed in the TAFV Alternative Fuels and Vehicles Choice Model (Greene, 2001). Greene's model was first developed in the early 1990s to calculate the change in market share amongst competing technologies. The change in market share is calculated through a dynamic process influenced by numerous factors including: vehicle cost; fuel cost; fueling availability; luggage space; fuel economy; make and model availability; maintenance cost; multi fuel capability; home refueling capability; range; top speed; and acceleration. These factors are all monetized (evaluated on how a change in the factor would relate to a change in willingness to pay) by multiplying them by a coefficient that is determined by examining market trends for those factors

that cannot be directly monetized and by examining the price elasticity of vehicle demand based on initial cost. In this way, all factors are represented in a utility function which is employed to predict market shares. The utilities of the factors are combined in the model to give each vehicle-fuel combination an aggregate utility.

The market shares cannot be determined by direct comparison of the individual utilities, however. Instead market shares are determined in a decision tree, with each fork in the tree splitting the market share between two branches. For example, luggage space may be an important factor in the decision between an SUV and a sedan, but it will not influence the decision to utilize ethanol or gasoline, which is instead decided by fuel price. Thus the decision tree is divided into tiers, with each tier covering a basic set of choices. In Greene's model, the top tier is small sedans, large sedans, small light trucks, and large light trucks. This was never built into his actual model, however, and the tree simply begins with the assumption that sedans are being chosen. In the future it is theoretically possibly to expand his model to cover this first tier but, for now, an alternative has been enacted to cover the broader categories of sedans and SUVs.

As seen in Figure 2 the initial decision for modeling purposes is amongst basic technology-fuel sets. In Greene's model this decision covers four basic technology sets: electric vehicles (which we have removed); hydrogen fuel cell vehicles; dedicated alternative fuel vehicles; and conventional fuel capable vehicles (some of which may be flex fuel vehicles). Once the choice has been made among the technology-fuel sets, the second choice refines the on-board technology. For example, assuming that conventional fuel capable vehicles are chosen in the initial step; the next step is to determine whether or not the vehicle will operate on a conventional liquid fueled engine, a hybrid engine, or a gaseous engine. The third choice is to determine the specific fuel capability of the vehicle. Assuming that a conventional liquid fuel engine is chosen (for example), the model considers whether the vehicle will have a standard gasoline engine, a flex fuel E85 capable engine, or a diesel engine. The final step choice is to determine the fuel mix being used in the engine, if necessary.

The market shares are determined from the bottom of the tree moving upward. At the base level – fuel choice – each fuel has a utility determined by summing the relative factors multiplied by their coefficients. Market share within the fuel choice step is determined by the relative utility of each choice compared to others within that decision node. Once the market shares for that node have been determined, the next node up is addressed. Each choice within this node has a utility, but it is determined not only by the factors relevant to that choice but also by the mean utility of the pending choices further up the tree. Thus the choice between a conventional gasoline engine and a conventional diesel engine is not only determined by comparing the traits of those technologies but also by comparing the mean utility of fuel choices. This continues all of the way up the tree until each decision node has its market shares predicted. The overall market share of each technology may be determined by multiplying the market shares for each decision node lead.

One point of interest that helps to reassure the validity of this method is to examine price elasticity at each level of the tree. At the higher level of the tree, price elasticity is relatively low, while at lower levels of the tree price elasticity is relatively high. This concept holds true in real-world applications; if a vehicle-purchaser is deciding between an SUV and a sedan, then price difference between the two options would need to be relatively large to encourage a switch from one to the other as they are two very different technology types in terms of performance. But when deciding fuel choice, say between conventional diesel and BD20, it would only take a small price difference to encourage a large level of switching between the two. Thus, as decisions are made on lower levels of the tree and the differences between the vehicles narrow, it takes an ever greater difference in utility between options to affect market shares. Figure 2 more closely examines the decision making process performed in Greene's model. Its

placement within the overall model may be seen as those areas encompasses by the dashed red line in Figure 1.

Figure 1: CarCarbon Structural Flow Chart

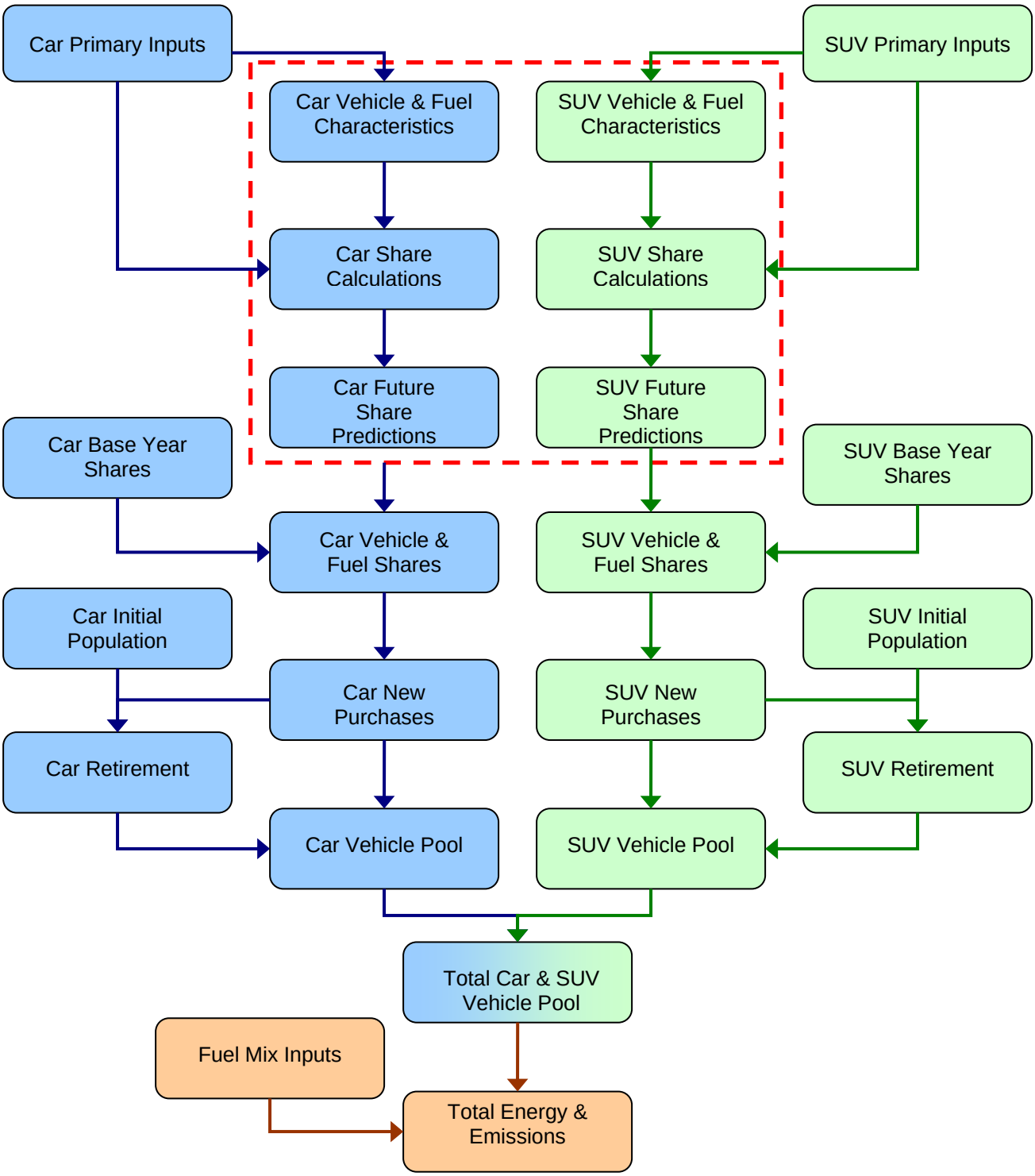
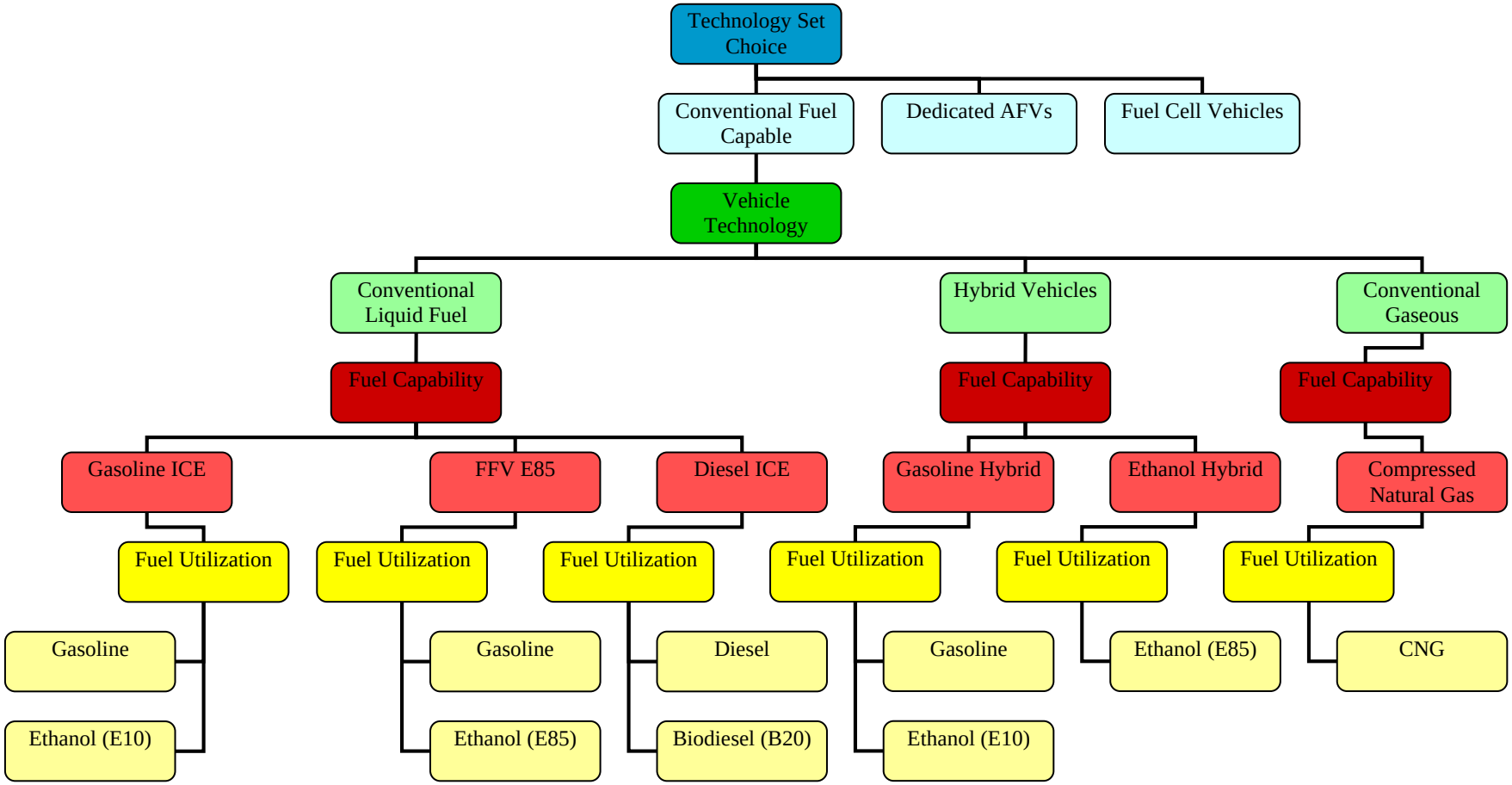


Figure 2: Greene's Decision Tree



Source: Greene, 2001 (N.B. This figure only displays a single branch of the three Technology Set Choices)

2.1. Vehicle Pool and Emissions

In order to project beyond a single year's change in market shares, our model takes the formulas and algorithms adopted from Greene's model and conducts 25 calculations - once for each year of the 25-year simulation. Each run of Greene's model refers to the time variable inputs discussed above and to the market shares of the previous year. These market shares are then utilized to determine what percentage of each of the 15 examined vehicle types will make up the number of new vehicles purchased that year. The number of new vehicles purchased that year is equal to the total number of vehicles retired that year from all technology types [replacement] added to the number of vehicles that would need to be purchased to make the fleet grow at a certain rate for that year [growth]. The growth rate of the vehicle pool is determined by the user as a percentage for each year and can be positive or negative. The vehicle pool for each technology is tracked separately with the number of vehicles of that technology type in any given year equal to the number of vehicles from the previous year minus the number of vehicles being retired that year plus the number of new vehicles of that type being purchased that year.

With the total number of vehicle technology types known for each year, it is then possible to determine the emissions of each technology type and the entire pool. The basic algorithm is:

$$CO_2 = [\text{\# of Vehicles}] * ([\text{Annual Miles}] / [\text{Miles / Gal}]) * [CO_2 / \text{Gal}]$$

Results may be obtained relatively easily from the model. The number of vehicles of each technology type is known from the calculations of the model. The annual miles driven and the fuel economy (MPG) are two of the inputs to the Greene model. And the emissions factor (CO_2 / Gal) can be determined by the fuel blend being used on average for each technology type. The amount of carbon dioxide per unit of fuel was gathered primarily from two sources. The values for hydrogen from different sources originate from the 2004 National Academies Report on the Hydrogen Economy and the remainder of the values were pulled out of the GREET model (Argonne National Laboratory, 2007). This calculation can then yield CO_2 emissions for each technology type for 25 years. The placement of this equation within the overall model may be seen in Figure 1 as the block entitled 'Total Energy and Emissions' as the end of the flow chart.

3. The U.S. Scenarios

3.1 Introduction

The United State's represents one of the largest sources of carbon dioxide emissions in the world, a significant portion of which is accounted for by its transportation sector. Fully one third of all emissions in the U.S. come from the use of motorized vehicles. Unlike the electrical generation sector and the industrial sector, which have infrastructure that is expected to last for decades, the transportation sector has the unique opportunity of turning over and retiring all of its courses of carbon dioxide every decade or so. This provides the opportunity for significant rapid change in the carbon dioxide emissions profile from this sector as compared to any other carbon source.

U.S. policy is capable of exerting a significant level of control over the path the future transportation sector develops along. Through the application of mandates, tax credits, subsidies, and taxes, policy is capable of developing the technologies and behaviors that are desirable while suppressing those that are viewed to be harmful. But in order to gauge the effect of these policies, it is important to first understand where the transportation sector would be headed if it were allowed to develop with little to no interference other than those policies that could be considered business-as-usual.

3.2. The U.S. Baseline Scenario

The baseline scenario for the United States presents a projection representative of what may come to be if no major policy, social, or technological changes are made in the next 25 years. The data in the scenario is best divided into inputs and outputs. In the baseline scenario the major inputs are the cost of the fuels, the fuel economy (or efficiency) of the different vehicle types, the prices of the vehicles themselves, the availability of the fuel, and the number of makes and models there are of each technology type. It was assumed that the number of miles driven annually by each vehicle would remain constant. Given that this is supposed to represent a baseline scenario with little to no change to the current trends, this scenario's inputs tend to be relatively static, with only minor changes, reflecting historical trends occur. As a result, the outputs of the scenario are also relatively static showing slow and steady changes.

The outputs of the scenario are the market share and absolute number operating of the different vehicle types, the amount of energy being consumed by each vehicle type, and the amount of carbon dioxide being released by each vehicle type. Additionally, since no major technological or social changes are assumed to occur, all technology types that are not currently being used at some reasonable level or expected to be used at a significant level in the near future were excluded. Thus the technologies considered were: (1) conventional gasoline ICE; (2) conventional diesel ICE; (3) flex fuel gasoline-ethanol ICE; (4) flex fuel diesel-biodiesel ICE; (5) hybrid gasoline-electric; and (6) hydrogen fuel cell.[1] The following pages are a description and explanation of the inputs used and the resulting outputs.

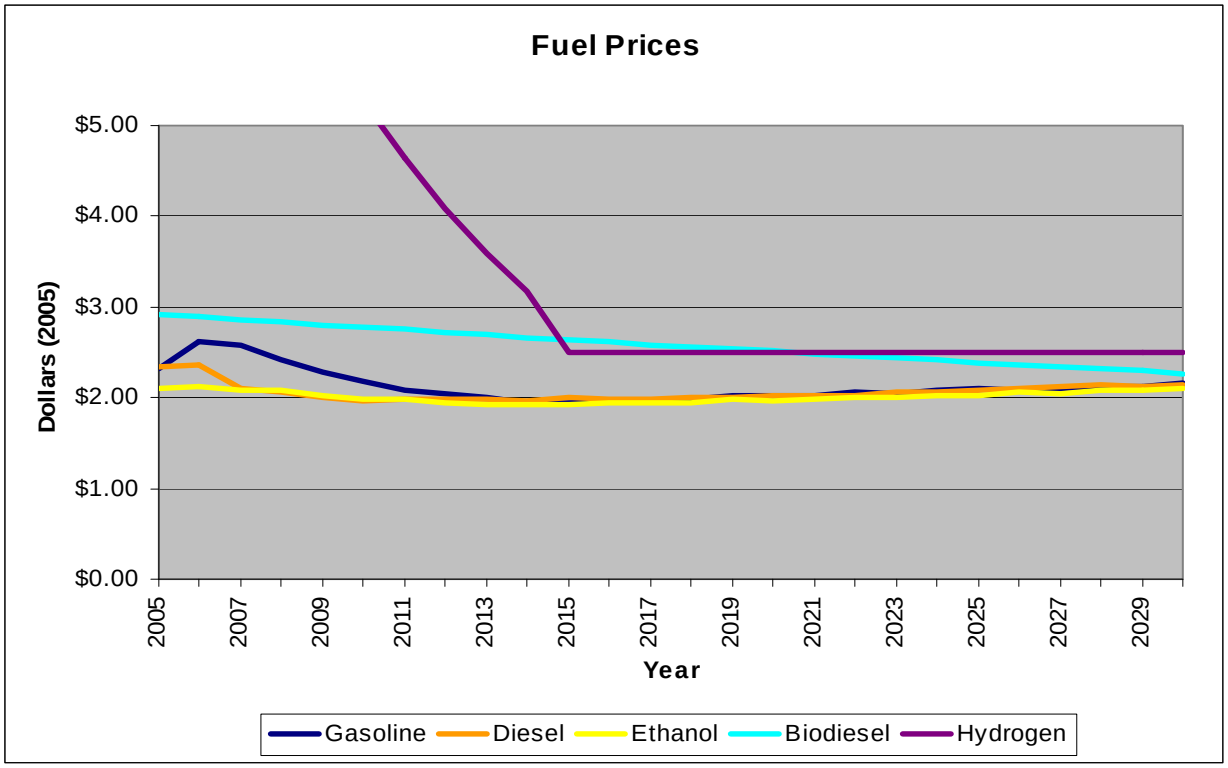
[1] All other technologies were removed from the model by setting their vehicle prices at $1,000,000 and as a result they accounted for a constant zero percent of the market share.

3.2.1. Fuel Cost

Since numerous projections of fuel costs already exist, it was decided to rely on an previously published projection rather than attempting to create a new fuel cost projection. The projections made in the Annual Energy Outlook published by the Department of Energy's Energy Information Administration, was deemed to be the most reliable source. The 2007 edition of the Annual Energy Outlook included fuel price projections for all but one of the pertinent fuels to be utilized in the scenario: gasoline, diesel, ethanol, and biodiesel. (EIA, 2007) The only fuel price that was not present was a projection of the cost of hydrogen. Given the relatively early stages of development for this technology, no reliable, peer reviewed or widely accepted price projection has been made. Instead, to determine the values to use in the model, the price goals defined by the DOE's Hydrogen program were utilized. (EERE, Hydrogen, Fuel Cells, Infrastructure and Technologies Program). The prices are illustrated below in Figure 3. They are shown in a more relative sense in dollars per BTU in Figure 4.

One concern of ours regarding the DOE's projection is the trend in diesel and gasoline prices. Their projection shows the current annual average of these prices accurately, but their projection shows a future decrease in price, which is expected to remain at that lower level. While this projection for oil prices seems to contradict our basic expectations of future oil prices, what is more disturbing has been the trend in oil projections made in the Annual Energy Outlook over the past several years. This data can be seen below in Figure 5. What is disturbing about this data is that it shows that the DOE consistently predicts that the current gasoline prices are the peak of a small bump and that beginning in the next year the prices will begin to decline and level off at some lower price. This graph shows, however, that they have been consistently incorrect in this projection and that the peaks they are describing each year are instead, just points on an upward slope that does not seem to have any predictable end.

Figure 3: U.S. Baseline, Fuel prices in 2005 dollars per gallon



(Source: EIA, 2007; EERE, Hydrogen, Fuel Cells, Infrastructure and Technologies Program)
(Note: dollars per kg for hydrogen)

While this fuel price projection does raise some concerns, it is still the most reliable source of future fuel price information that we were able to find. Because of this, the reference case outlined in the 2007 *Annual Energy Outlook* is the one that will be used in the baseline scenario for the United States. Another scenario showing the rising gas prices illustrated by the 'high price' projection in the Annual Energy Outlook will be created to show the effects of a steadily increasing price for crude oil and petroleum products.

Figure 4: Projected price of the fuels expressed in 2005 dollars per BTU

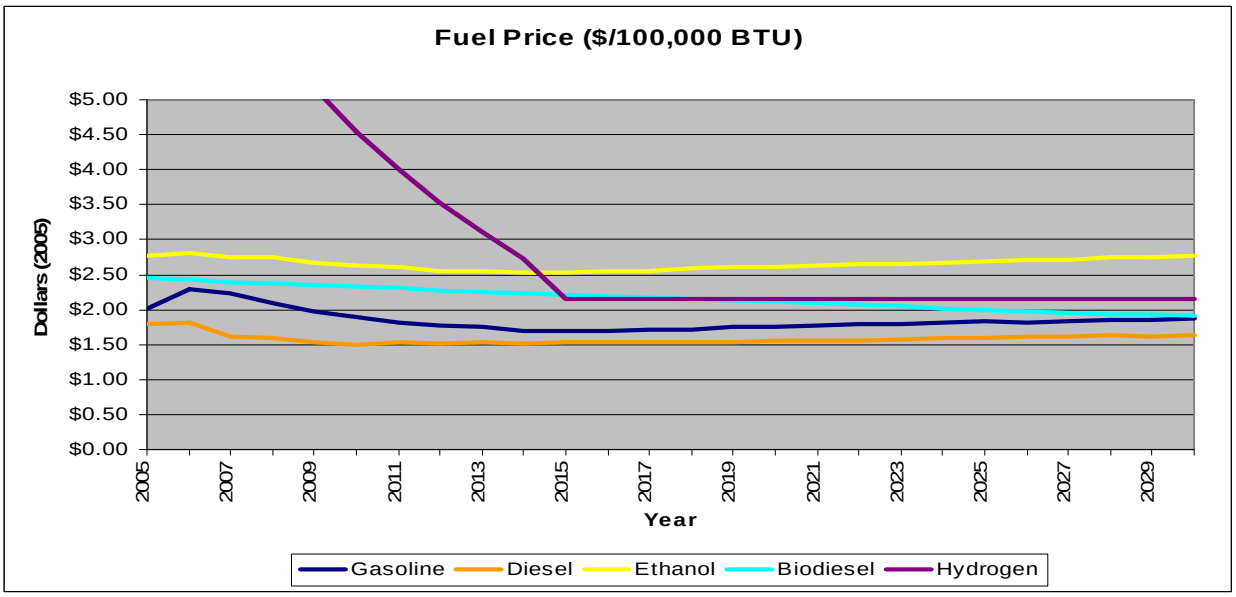
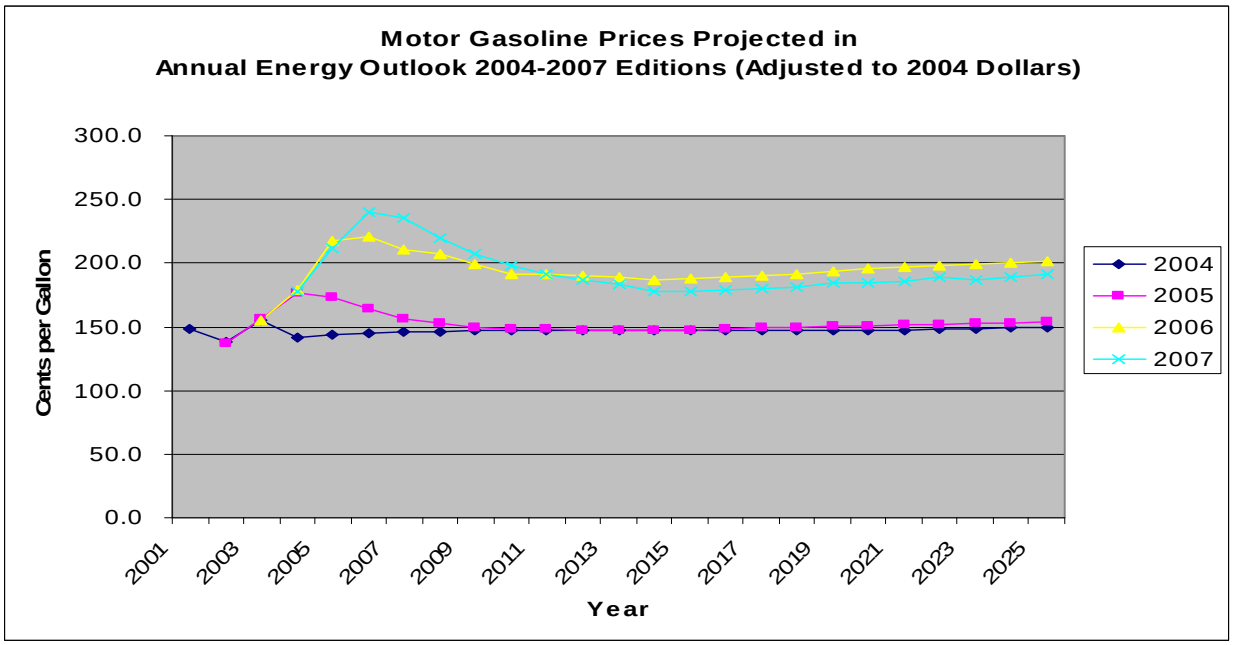


Figure 5: Projections of gasoline prices made in the Annual Energy Outlook in the 2004-2007 editions



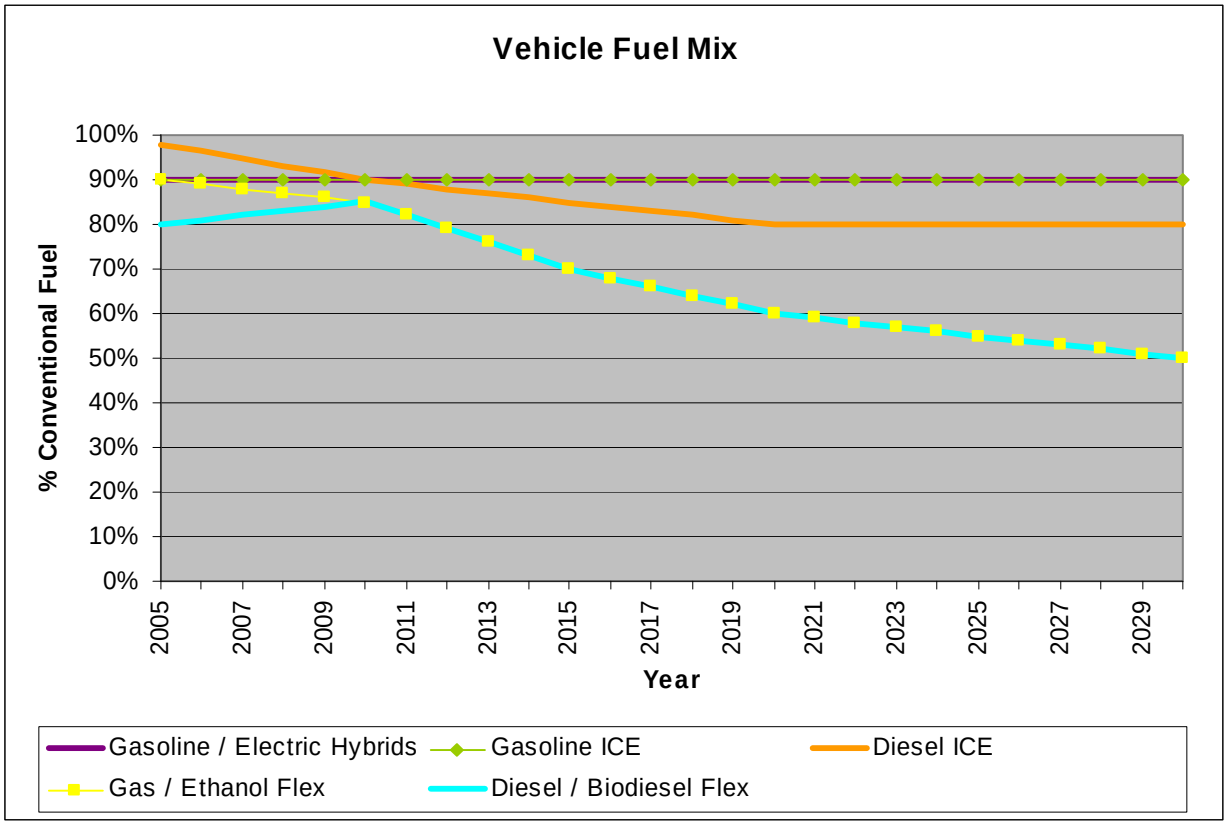
Source: EIA, 2007; EIA, 2006; EIA, 2005; EIA, 2004

3.2.2. Fuel Mixing

One of the options that was not included in the model created for the 2005-06 report was the ability to show the effects of blending fuels for use in the same type of vehicle. History and studies have shown that many vehicle technologies can accept a range of different fuel blends and these blends will all have varying environmental effects. Such fuel mixing is currently being utilized in the U.S. through the low level blending of ethanol with gasoline and the low level blending of biodiesel in diesel. Technologically, according to engine manufacturers, both conventional diesel and conventional gasoline ICE's are capable of accepting up to 20% and 10% of the biofuels respectively. With some small technological modifications these numbers could rise.

Additionally, with the utilization of flex fuel vehicles, or vehicles that can run on either fuel, the potential for fuel mixing rises dramatically so that ICE's can run on either entirely petrofuels, entirely biofuels, or a blend. By introducing fuel mixing to the model we can now more accurately gauge the economic and environmental effects of this growing trend. The projections for fuel mixing in the different technologies are displayed below in Figure 6.

Figure 6: U.S. Baseline, Blend of Bio vs. Petro Fuels



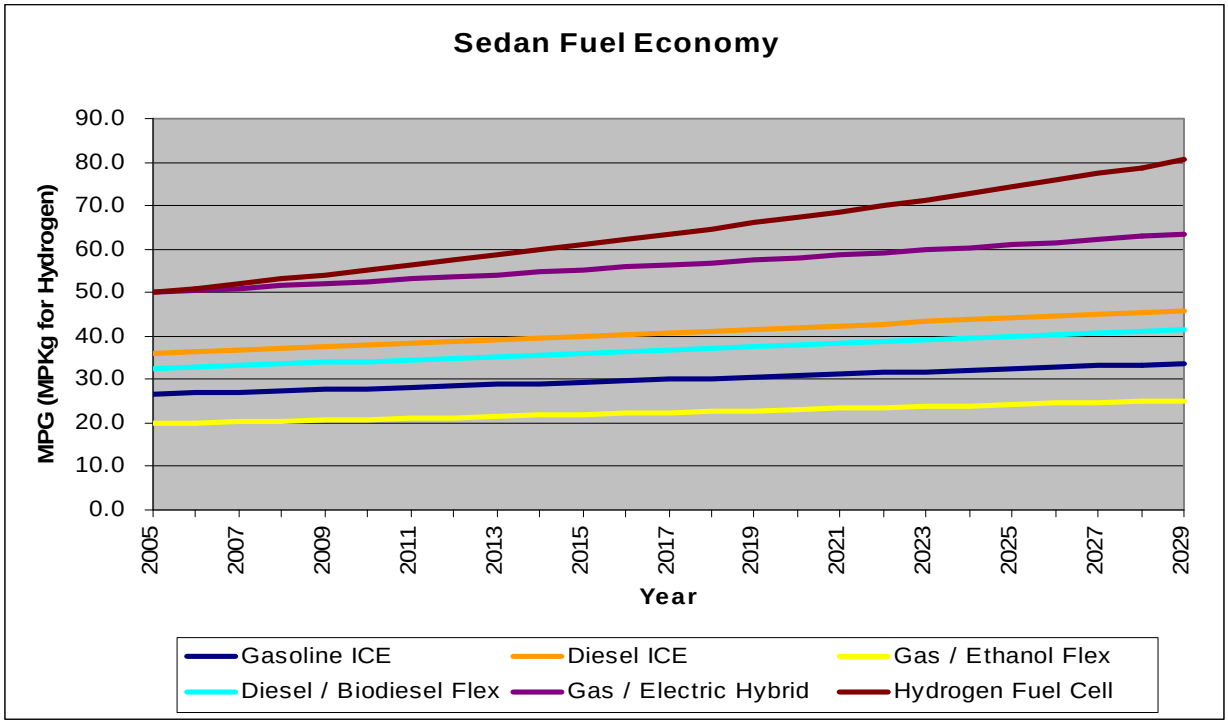
Source: Alternative Fuels Data Center, 2006

As can be seen, the level of fuel blending remains heavily weighted towards petro fuels, especially in the non-flex fuel capable vehicles. These conventional vehicles are assumed to remain at the current levels of technology and without small but significant technological alterations using higher blends of biofuels will either damage the vehicle or, at the very least, void manufacturers warranties. The use of biofuels in flex fuel vehicles begins at levels similar to those of conventional vehicles, as has been shown in studies of flex fuel fleets and individual vehicles. The level of fuel blending in the flex fuel vehicles is assumed to increase to 50% for both ethanol-gasoline and biodiesel-diesel flex fuel vehicles by 2030 as the technology becomes more prevalent and the current political support for biofuels continues. Gasoline-electric hybrids are assumed to use the same fuel mixture as conventional gasoline ICE's.

3.2.3. Vehicle Efficiencies

The fuel economies of the various technologies play an important role in any model studying vehicle populations and carbon dioxide emissions. The fuel economy not only controls the amount of carbon dioxide emissions per mile of travel, but it also is the second largest source of cost after the initial vehicle price. In a time when fuel prices are both volatile and, on average, rising, fuel economy of vehicle technologies is playing an ever increasing role in the public's vehicle selection. This can be demonstrated by the unexpected and sudden success of hybrid vehicles and the new emphasis on fuel economy in car commercials. The fuel economies used in the U.S. baseline scenario can be seen below in Figures 7 and 8, showing sedan fuel economies and SUV economies respectively.

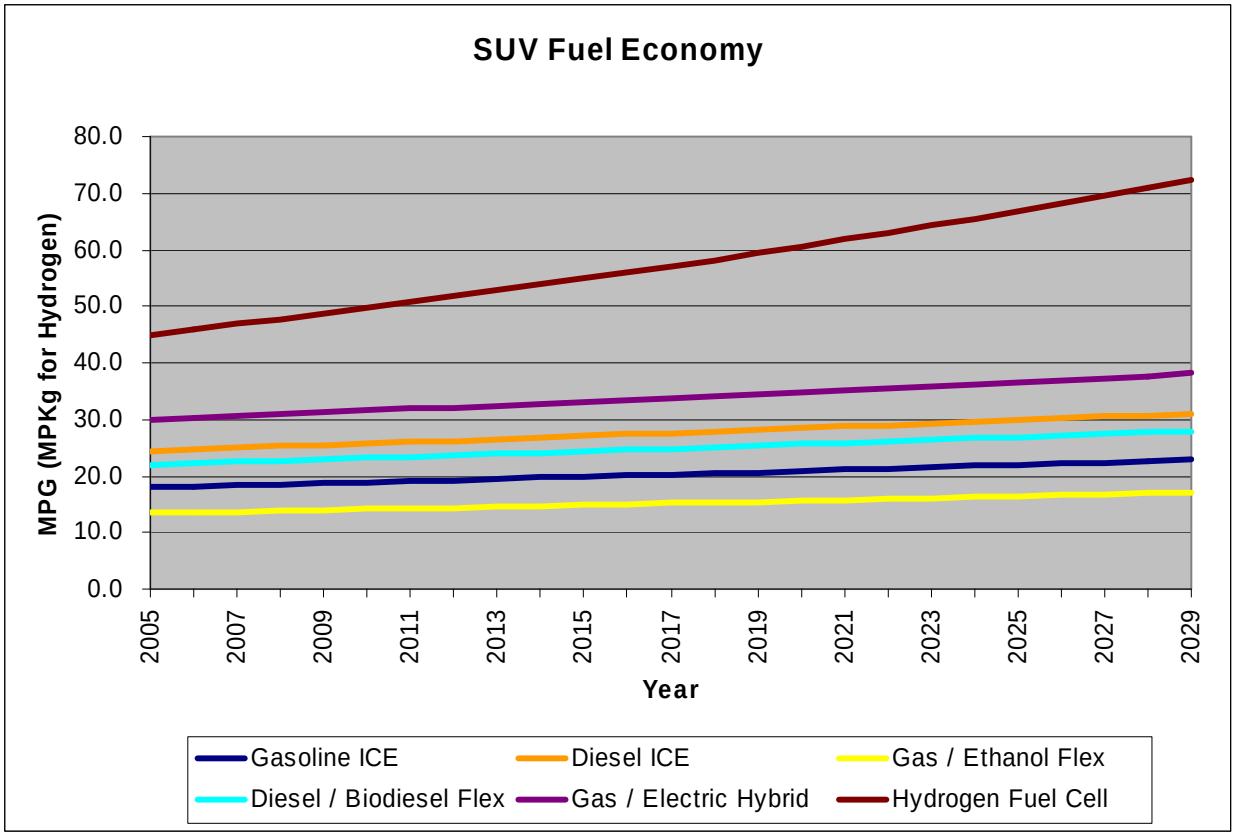
Figure 7: U.S. Baseline, Sedan Fuel Economy



Source: EERE, 2007; Davis and Diegel, 2007

The initial fuel economies for Year 1 were determined through data obtained from the 2007 Fuel Economy Guide which provides the fuel economies for all vehicles currently being marketed. From this data a weighted average based on the numbers of each make and model on the road was constructed, creating the initial values for the model. Hydrogen vehicles are currently all prototypes still, the initial value of 50mpkg was compiled from an average of those prototypes. From the base year, all of the fuel economies were assumed to increase at a rate of 1% a year, except for hydrogen which is assumed to increase at 2% a year due to its higher theoretical efficiency; 1% was chosen due to historical trends and technological feasibility.

Figure 8: U.S. Baseline, SUV Fuel Economy

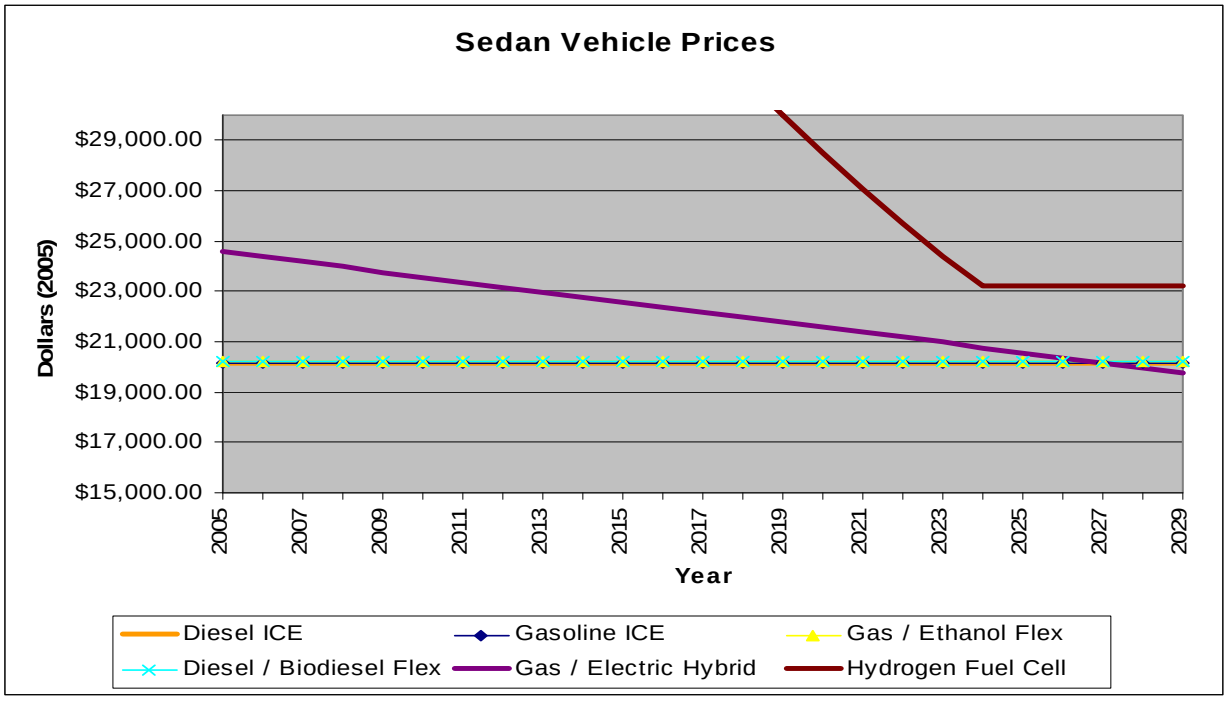


Source: EERE, 2007; Davis and Diegel, 2007

3.2.4. Vehicle Prices

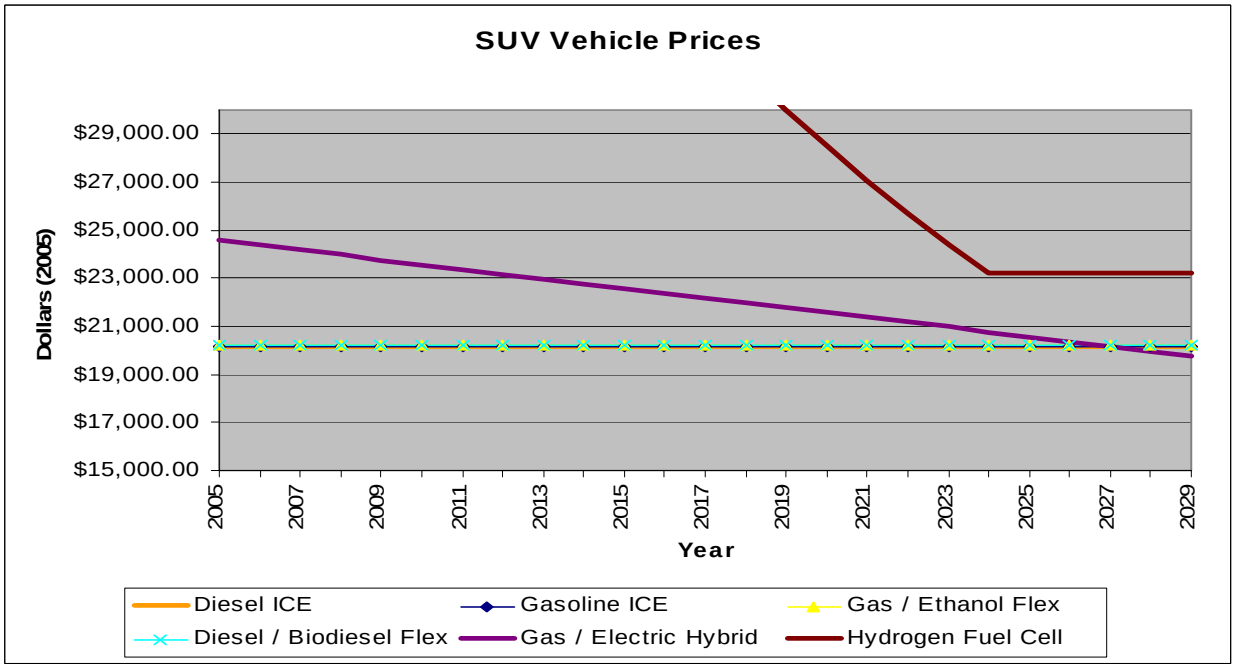
Vehicle prices have proven to be the most sensitive factor in our model. Since all other factors are converted into an eventual monetary value in order to determine overall utility, the price elasticity observed in the vehicle market is utilized to determine the elasticity of all factors. All initial prices, except for hydrogen vehicles, are calculated by averaging the MSRP for all non-luxury midsize sedans and SUVs. In our baseline scenario, all of the technologies are assumed to have a constant and equal value throughout the model. The two exceptions to this are gasoline-electric hybrid and hydrogen vehicles.

Figure 9: U.S. Baseline, Sedan Vehicle Prices (2005 Dollars)



Source: Davis and Diegel, 2007; EERE, Hydrogen, Fuel Cells, Infrastructure and Technologies Program

Figure 10: U.S. Baseline, SUV Vehicle Prices (2005 Dollars)



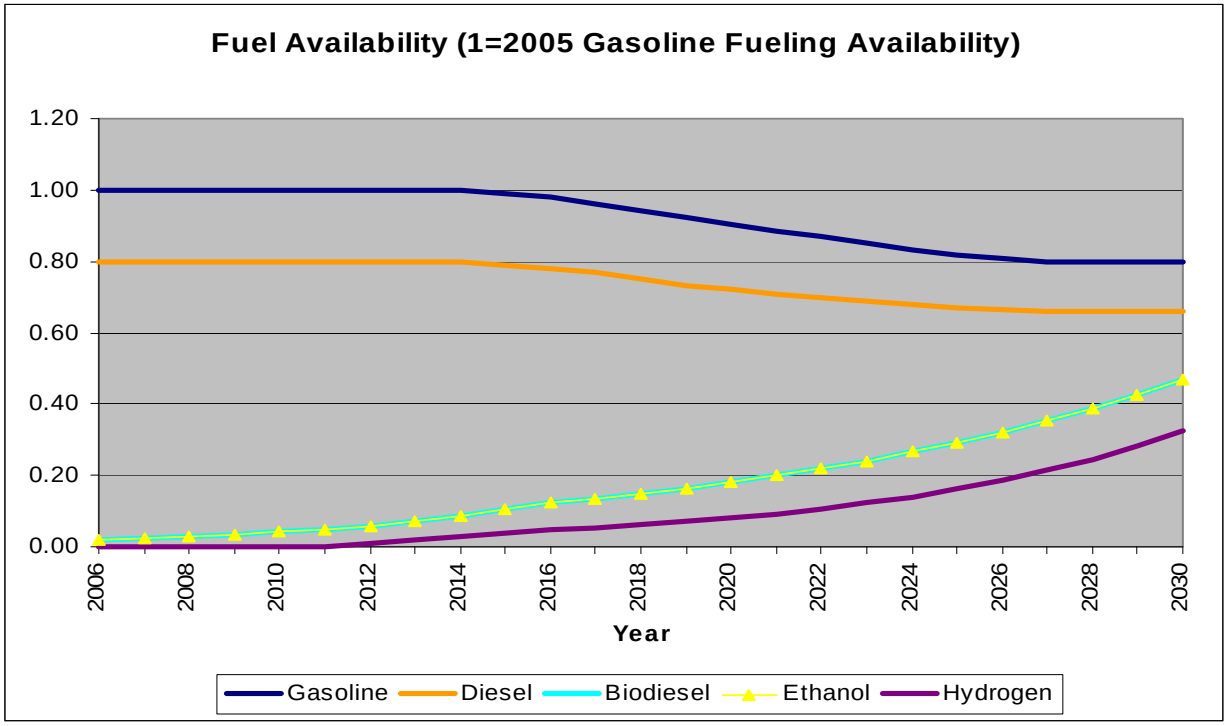
Source: Davis and Diegel, 2007; EERE, Hydrogen, Fuel Cells, Infrastructure and Technologies Program

Currently a premium of, on average, $4,500 is paid for a hybrid vehicle as compared to a conventional counterpart and hydrogen vehicles, being at the prototype stage, cost upward of a million dollars. The premium for gasoline-electric hybrid vehicles is assumed to steadily erode away until finally completely disappearing in the 23rd year of the projection, 2028. Hydrogen vehicles go through several stages of price drops, eventually reaching $23,000 by the end of the study. It is primarily for this reason that they play an essentially non-existent role in our baseline scenario. All other vehicle prices are assumed to be constant due to a lack of major technological or policy shifts. These prices do not include any incetives or subsidies in the baseline scenario.

3.2.5. Fueling Availability

In Greene's initial study it was concluded that fueling availability played a significant factor in the lack of adoption of new technologies if the fueling availability was 10-20% or lower compared to the current availability of gasoline. After this level has been reached, however, any further increases play a much less significant role in assisting or hindering the purchase of a technology. For the initial values, gasoline was set at 100%, diesel at 50%, ethanol and biodiesel at 2%, and hydrogen at 0%. Over time the availability of gasoline is assumed to drop to 62% and diesel is kept at one half of gasoline's availability. Biodiesel and ethanol rise at a rate of 20% for the first 10 years and then 10% for the remaining 15 years, eventually reaching 47% availability. Hydrogen reaches 4% availability after 10 years and then rises by 15% a year, eventually reaching 33% availability in 2030.

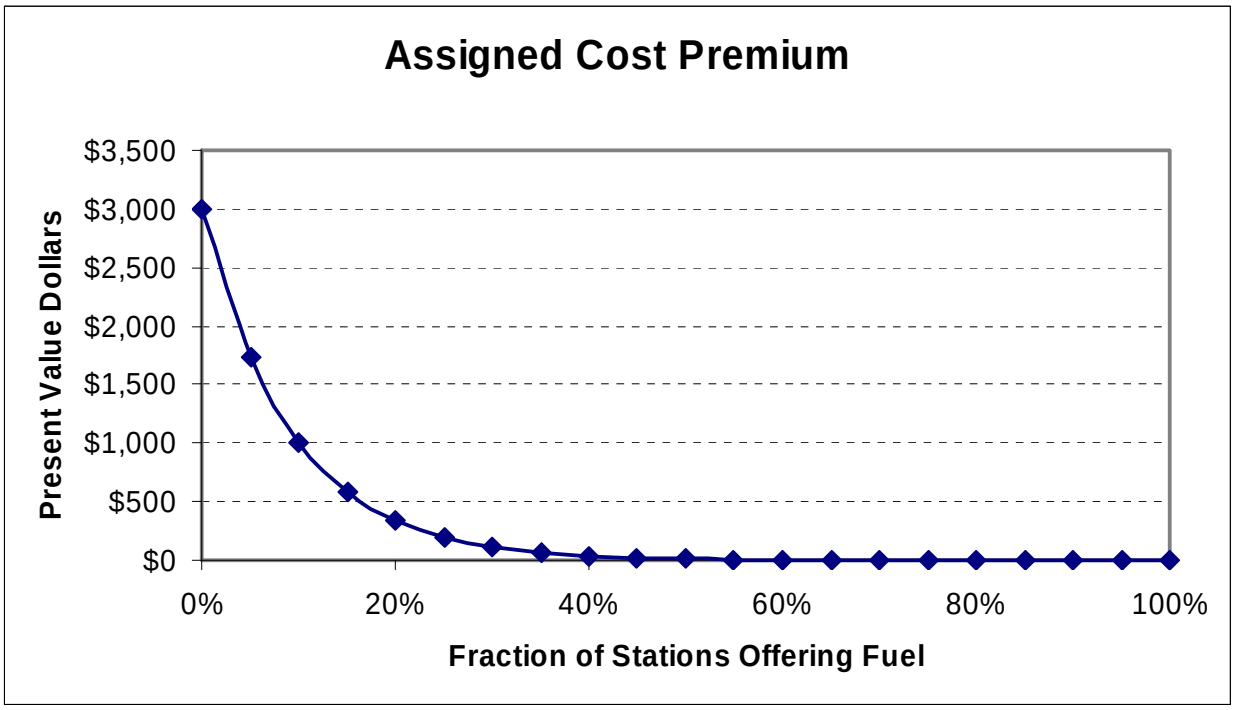
Figure 11: U.S. Baseline, Fueling Availability



Source: Alternative Fuels Data Center, 2007

Fueling availability is one of the more difficult variables to project given that its values are not independent of the outputs of the model. The fueling availability will not only help to determine the number of vehicles of each technology type on the road but will also, in turn, be determined by the makeup of the vehicle pool. In this there is a chicken vs. egg conundrum and as such only a conservative projection may be made for this input. It is thus fortunate that the results of the model are not sensitive to this input except in those cases where it is below 20%. This is due to the nature of the model. Since all inputs are given a certain cost in order to weight them, a cost curve was implemented in Green's model in order to give varying costs to different levels of fueling availability. This is shown below in Figure 12.

Figure 12: Fueling Availability Cost Curve



Source: Greene, 2001

3.2.6. Make/Model Availability

Make and model availability is similar in respect to fueling availability. It is far more sensitive at low levels and it also suffers from a chicken vs. egg situation, making it difficult to project. For the initial levels, an actual count of the different makes and models offered of each vehicle type was made using the 2007 Fuel Economy Guide issued by the Department of Energy. The vast majority of the alternative vehicle technologies (including diesel) started below 10 makes and models available. Gasoline-electric hybrids were available in 7 makes and models for sedans and 8 makes and models for SUVs. Ethanol-gasoline flex fuel vehicles were available in low numbers in sedans, but had 20 makes and models available as SUVs. Hydrogen fuel cell vehicles were initially unavailable as both sedans and SUVs, and only a few biodiesel flex fuel vehicles were available as sedans or SUV's.

Figure 13: U.S. Baseline, Sedan Make/Model Availability

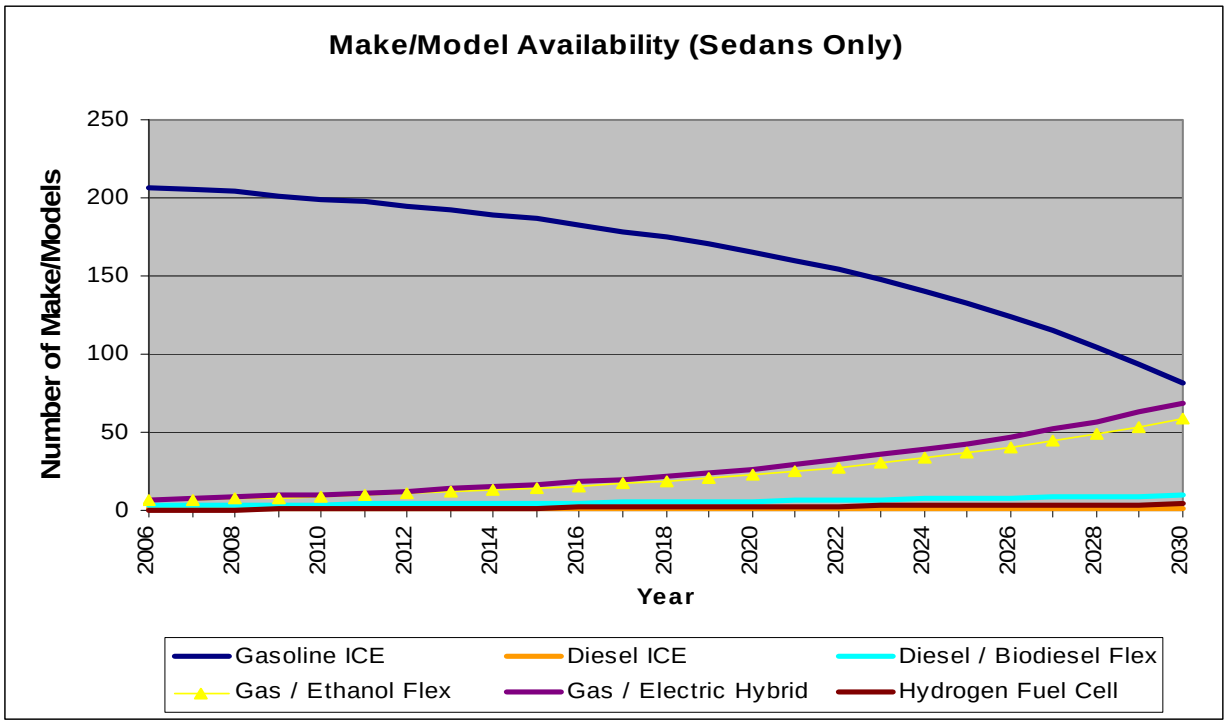
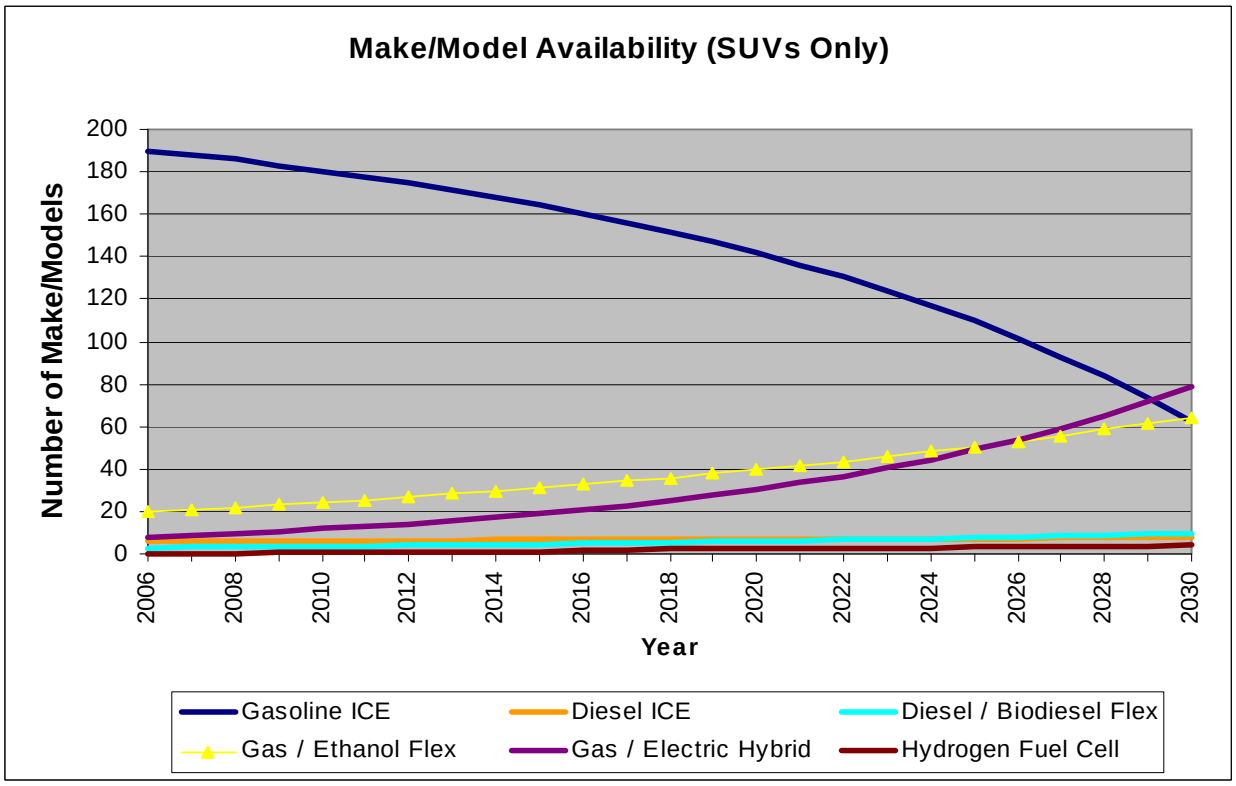
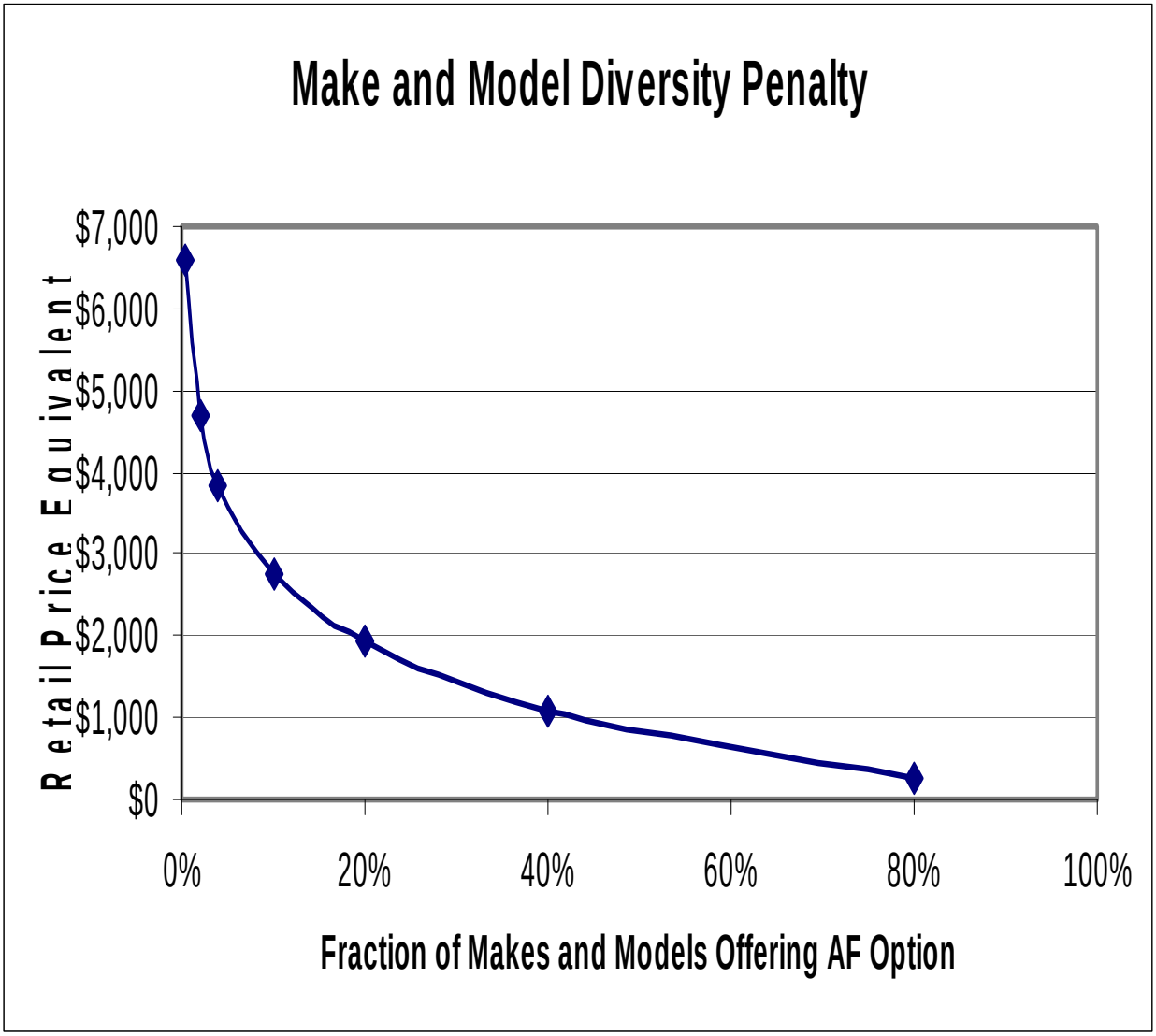


Figure 14: U.S. Baseline, SUV Make/Model Availability



In the baseline scenario the number of flex fuel makes and models was expected to increase at 5% a year while the number of gasoline-electric hybrid vehicles was expected to increase at 10% a year. Conventional diesels remain constant through the study. Hydrogen vehicles are introduced as only 1 model in year 10 and this grows to 4 models by 2030 at the end of the projection. The number of gasoline makes and models decreases as the alternative increase so that the overall number of makes and models remains relatively constant.

Figure 15: Make/Model Availability Premium



Source: Greene, 2001

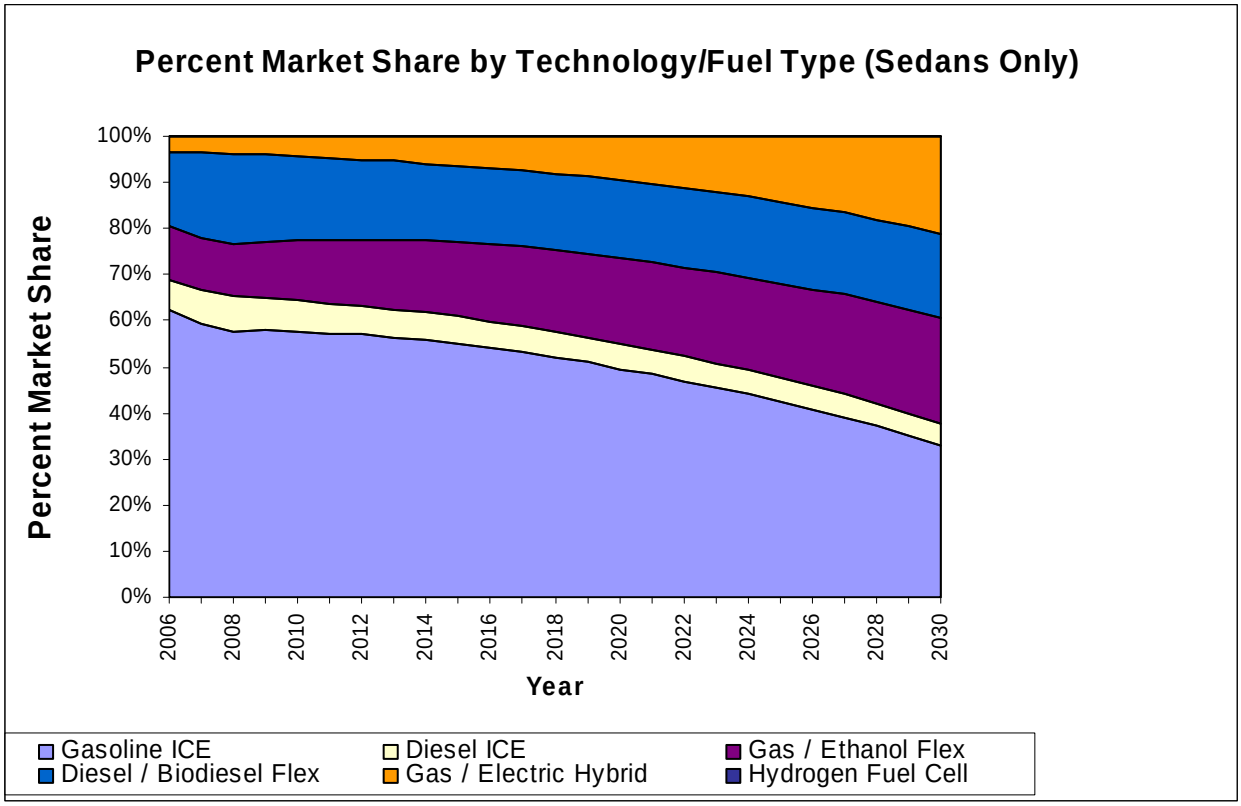
3.3. U.S. Baseline Scenario Results

The following subsections within Section 2 describe the resultant outputs from the CarCarbon model based on the inputs that have been described above. They represent the predictions of the model and the energy, emissions, and vehicle populations that accompany those predictions. Combined, they form the predicted results of continuing along a business-as-usual pathway in terms of our transportation and energy policies.

3.3.1. Number of Vehicles

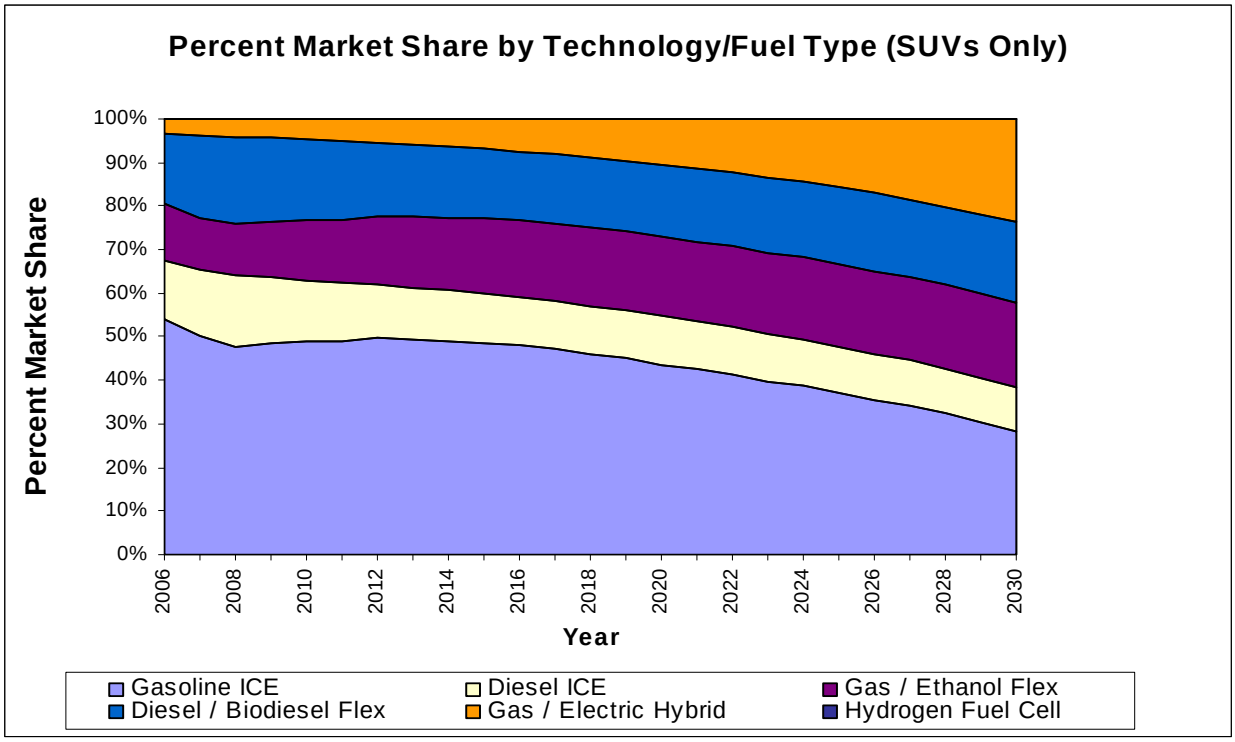
The results of the model for the number of vehicles may be displayed in two ways. The first is as the percentage market share for each year. This is the breakdown in percentages of the vehicles purchased according to technology type. This is shown in Figures 15 and 16. The second way of displaying the data is to show the total number of vehicles on the road of each technology type. So not only does this show the vehicles that were purchased in that year but also all the vehicles that were purchased in all previous years that have yet to be retired, broken down by technology type. This data is shown in Figures 17, 18, and 19.

Figure 16: U.S. Baseline, Sedan Market Share



(N.B. Model Predicted No HFCV Penetration)

Figure 17: U.S. Baseline, SUV Market Share



(N.B. Model Predicted No HFCV Penetration)

The market shares by technology shows a steady annual decrease in the market share of conventional gasoline ICE's. The remainder of the market share is made up by a smaller yet persistent level of diesel vehicles, equal and relatively constant levels of flex-fuel vehicles, and a steadily increasing percent market share of hybrid vehicles. The primary promoter of change in this scenario is the decreasing level of premiums for gasoline-hybrid electric vehicles. This leads to gasoline-electric hybrids accounting for a growing portion of the overall market share.

The other noticeable impact occurs in year 4 when the rate of decrease in market share for conventional gasoline ICE's slows in sedans and partially reverses in SUV's before continuing to decrease. This occurs due to the EIA 2007 Annual Energy Outlook projection of gas prices. During this period the EIA projects that gas prices will drop from their current peak and then level out. This slows the growth of all other alternatives.

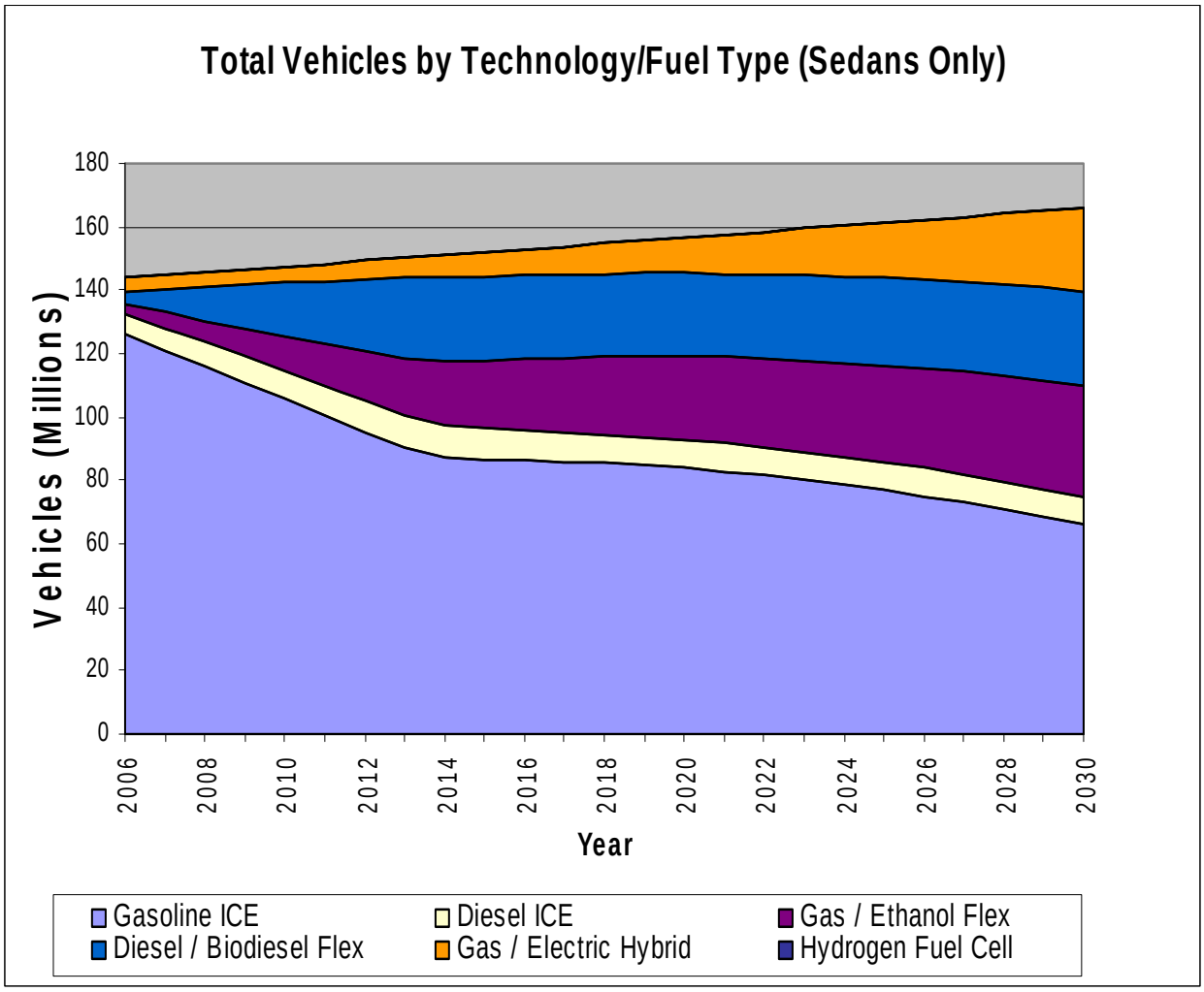
Examining the graphs which show the total number of vehicles on the road rather than market shares (Figures 17, 18, and 19), it is obvious how there is a significant delay *before* market shifts translate into real change. While the absolute number of gasoline ICE's does decrease starting in year 1, the vehicle population does not begin to really resemble the projected market shares until year 10 (2015) by which time the majority of the vehicles from the initial vehicle pool will have been retired.

Also of interest is the difference between the absolute number of conventional gasoline ICE's in the sedan pool as compared to the SUV pool. While the sedan gasoline ICE's steadily decrease in the absolute number on the road, the SUV pool conventional gasoline ICE vehicles decrease for the first ten years before continuing to rise. This is due to the tremendous rate of growth which SUV's have historically been experiencing over the last two decades, even in the era of rising gas prices. This shows that not only must the types of vehicles being sold change, but so must also the rate of growth our vehicle pools are experiencing. Alternative fuel vehicles

cannot create a change in our effects on the environment for as long as they merely account for a portion or even all of our vehicle growth, they must also supplant some of the absolute number of vehicles currently on the road.

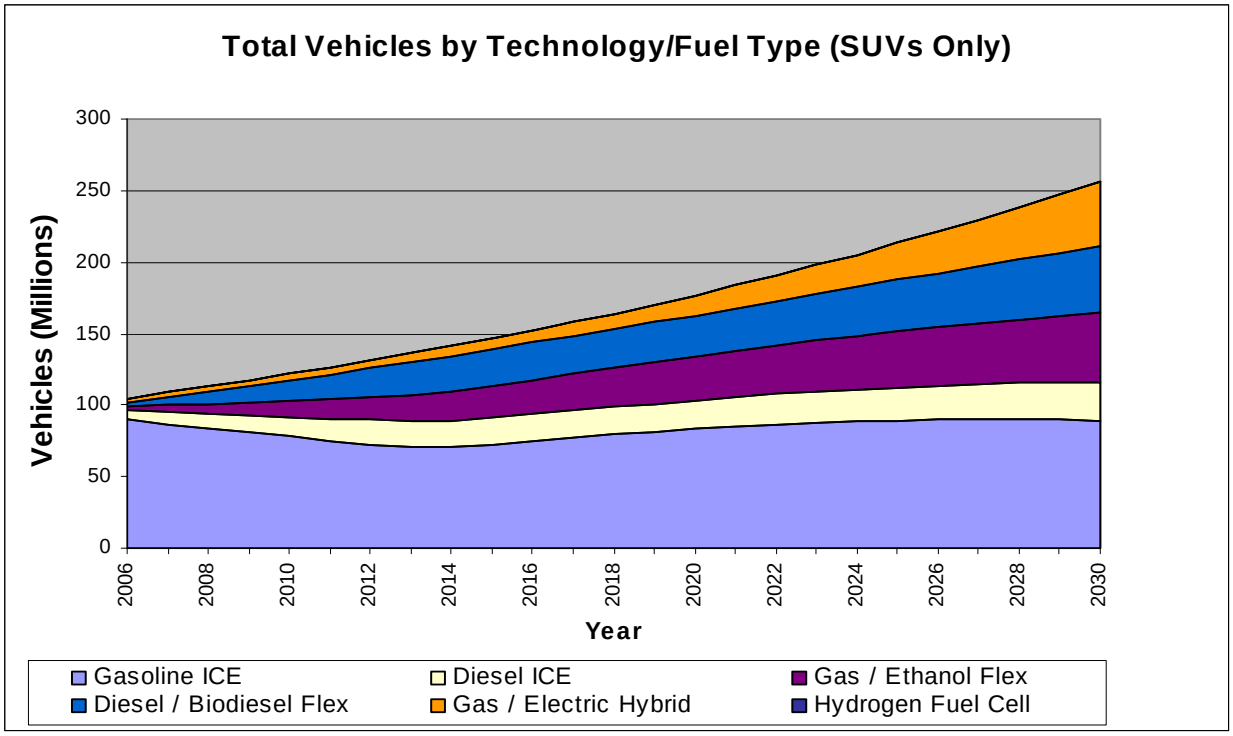
Hydrogen fails to enter into this scenario completely. This is due to several different factors, all of which combine to prevent their entry into the market. These primarily include: vehicle cost, fuel availability, and make and model availability. Costs are assumed to stay relatively high compared to the other technology types, despite lowering in their absolute price dramatically. Because of this, fuel availability and make and model availability are assumed to remain low. This indicates that it is only through an intense policy program and political intervention will hydrogen be able to enter into the market in any significant manner by 2030.

Figure 18: U.S. Baseline, Sedans by Technology Type



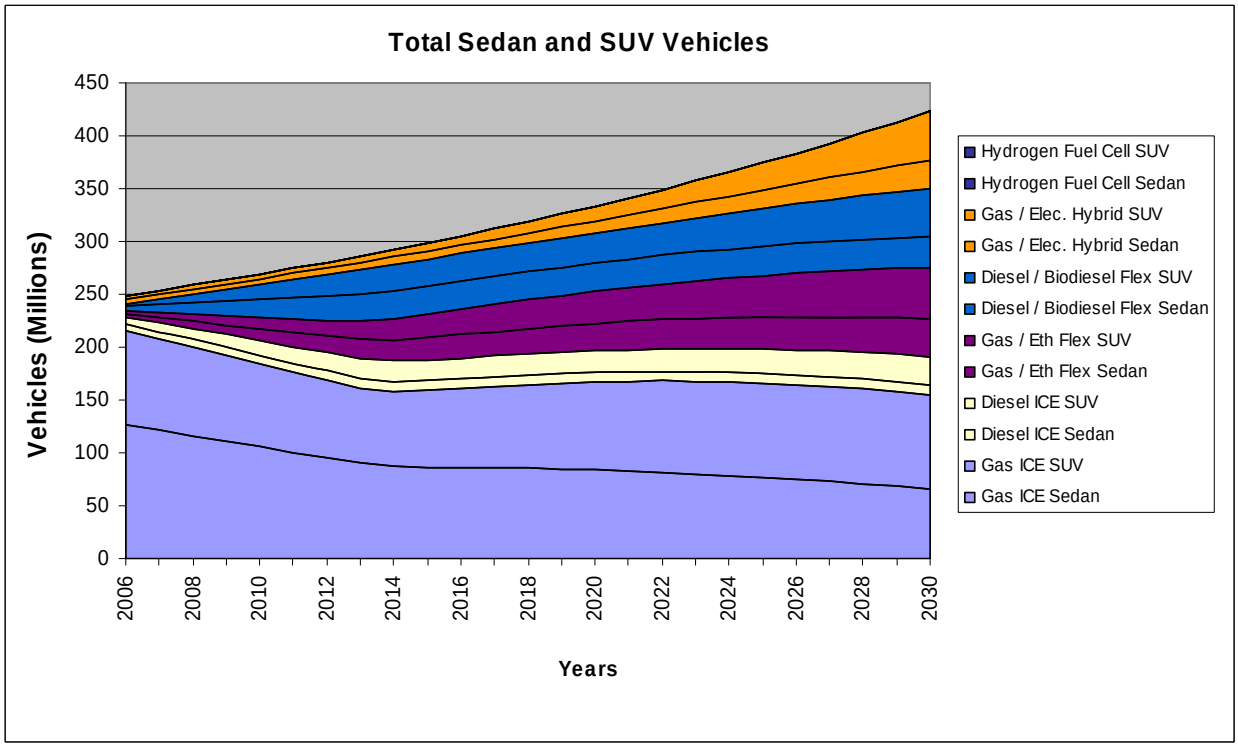
(N.B. Model Predicted No HFCV Penetration)

Figure 19: U.S. Baseline, SUVs by Technology Type



(N.B. Model Predicted No HFCV Penetration)

Figure 20: U.S. Baseline, All Vehicles by Technology Type



(N.B. Model Predicted No HFCV Penetration)

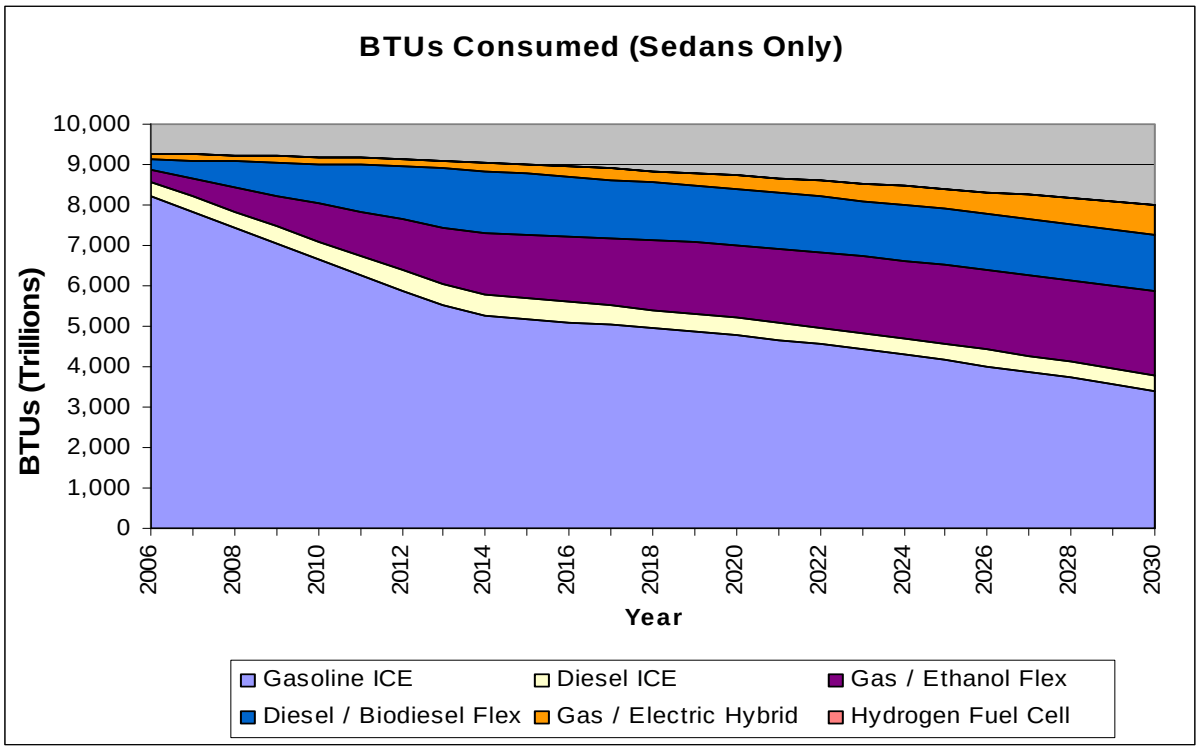
3.3.2. Energy Consumed by Vehicle Type

A second factor to consider is the total amount of energy being consumed by the different technology types. All of the fuels consumed were converted into BTUs so that they could be equally compared. This shows some interesting facts. First is that the number of BTUs being consumed by the sedan pool actually decreases (Figure 20), despite the fact that the absolute number of sedans on the road increases. This is due entirely to the fact that the number of conventional gasoline sedans is decreasing and being replaced by alternatives and that any growth in this pool is made up entirely of alternatives which are more efficient.

Efficiencies also improve in the SUV pool, but due to the much higher rate of growth as compared to the Sedan pool it can be seen that the number of BTUs consumed increases along with the number of SUV's on the road. (Figure 21) While it can be inferred that the number of BTUs consumed by the SUV pool decreases compared to a scenario in which no alternatives are introduced, the level of BTUs consumed still increases compared to the initial value, although there is a slight decrease in BTUs of gasoline being consumed.

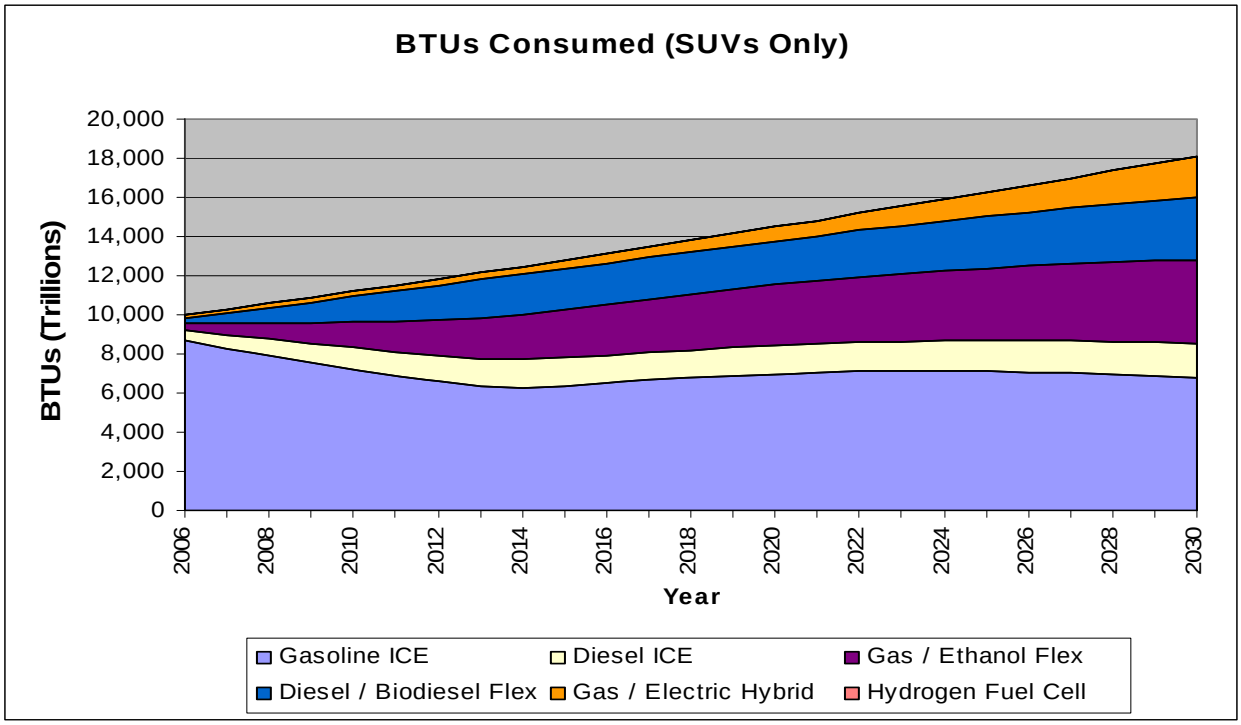
The combined graphs (Figure 22) show a steadily increasing level of BTU consumption, although there is a significant overall decrease in the level of BTUs of gasoline consumed. This represents a significant improvement over the U.S.'s current situation in terms of energy imports and energy security. It shows a scenario in which fossil fuel imports are decreasing as domestic sources of energy increase.

Figure 21: U.S. Baseline, Sedan Energy Consumption



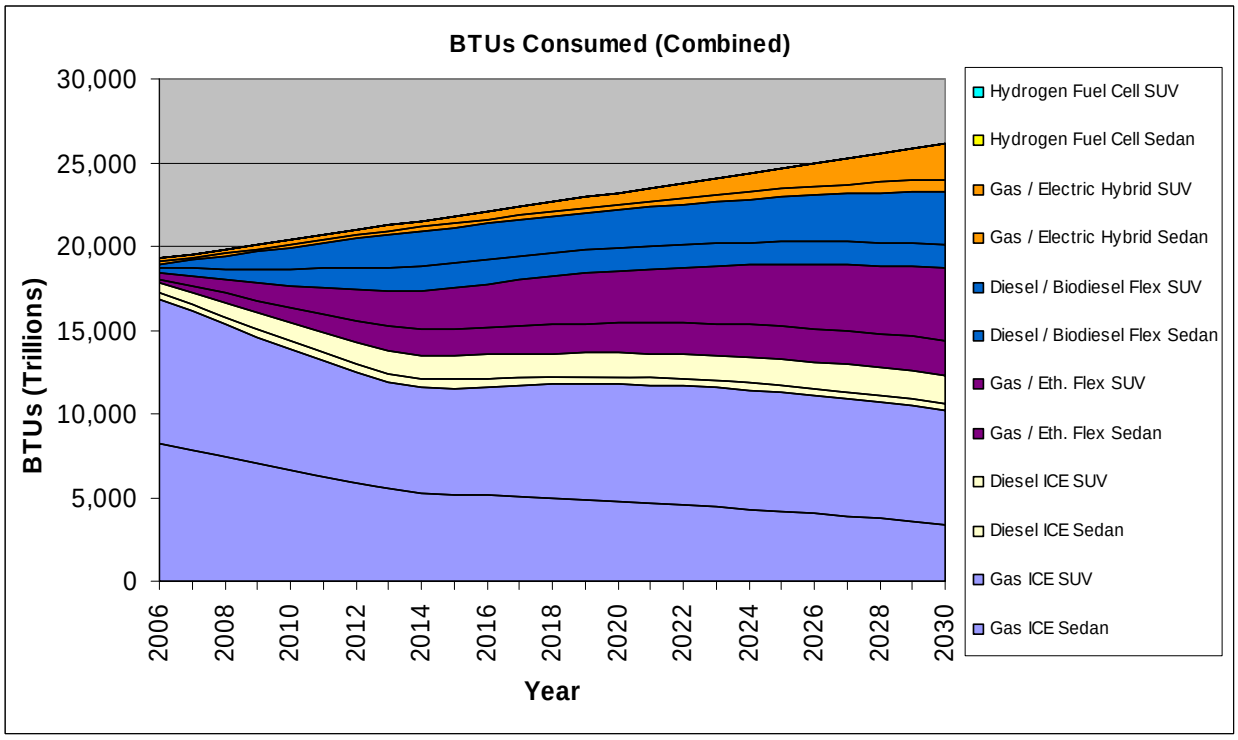
(N.B. Model Predicted No HFCV Penetration)

Figure 22: U.S. Baseline, SUV Energy Consumption



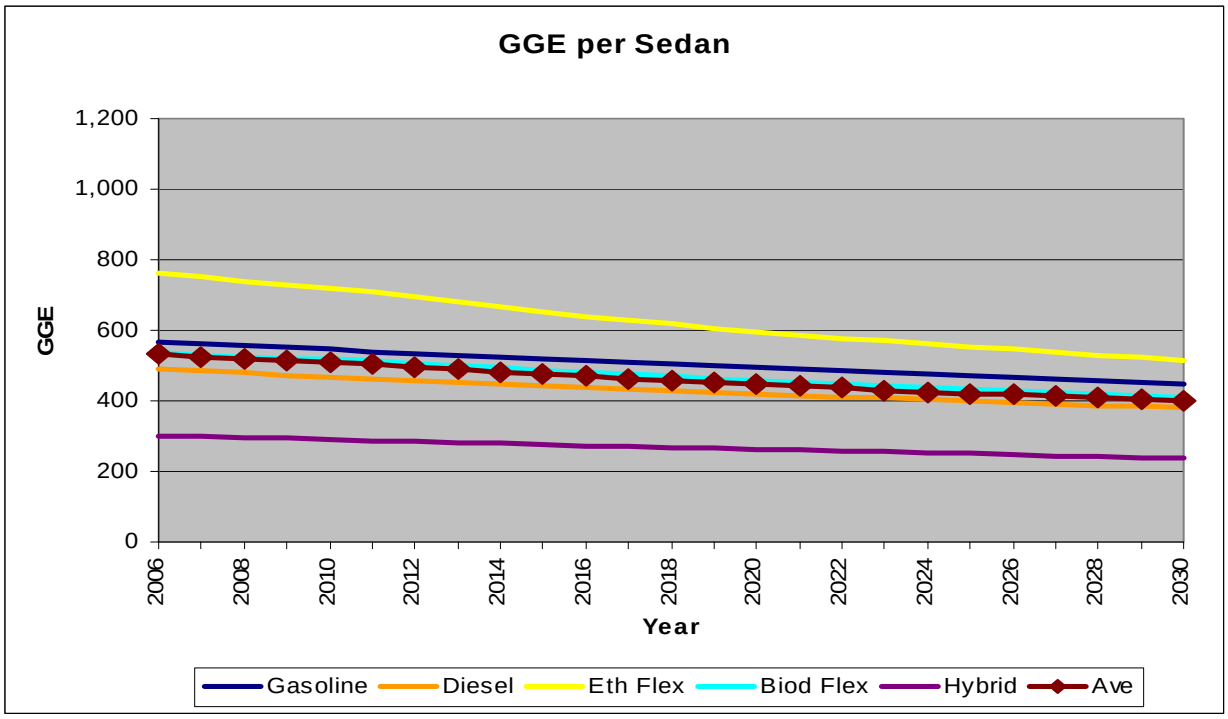
(N.B. Model Predicted No HFCV Penetration)

Figure 23: U.S. Baseline, All Vehicle Energy Consumption



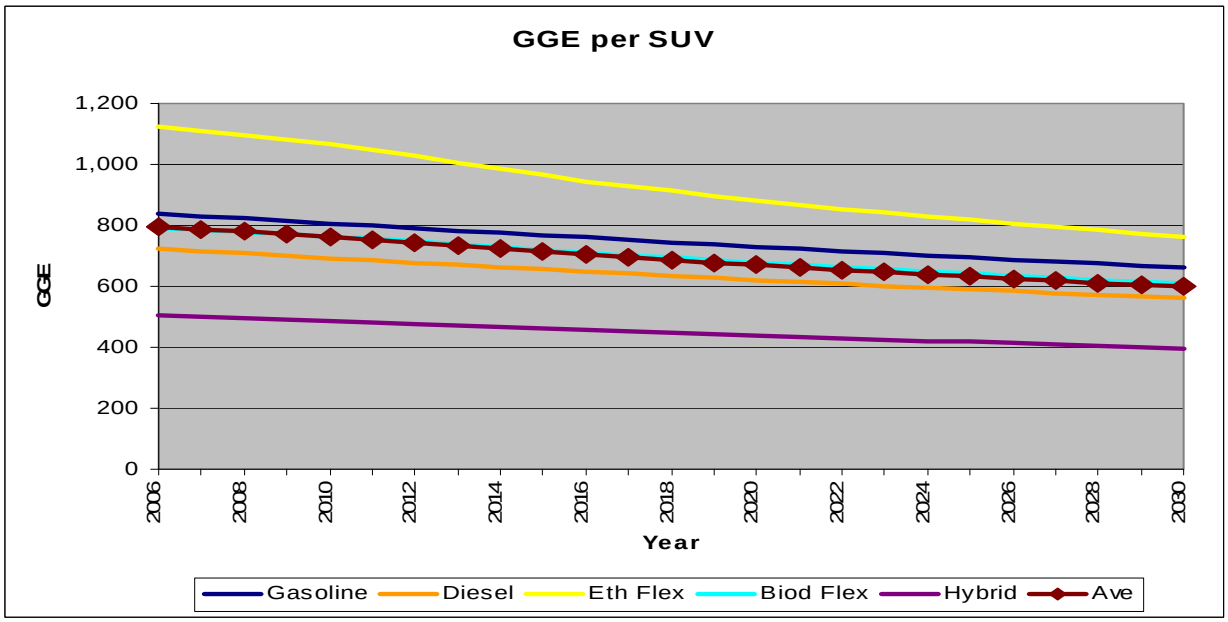
(N.B. Model Predicted No HFCV Penetration)

Figure 24: U.S. Baseline, Gallons of Gasoline Equivalent Consumed by Vehicle Technology Per Sedan



(N.B. Model Predicted No HFCV Penetration)

Figure 25: U.S. Baseline, Gallons of Gasoline Equivalent Consumed by Vehicle Technology Per SUV



(N.B. Model Predicted No HFCV Penetration)

3.3.3. Energy Consumed by Fuel Type

The energy consumption of the baseline scenario may be viewed in an additional manner by examining the raw amount of fuel being consumed in each year of the scenario. This is of particular interest when considering energy security and sustainability. This data can vary significantly compared to the BTU's consumed by the different technology types due to fuel mixing. So while the previous section displayed energy consumption in terms of the vehicles running, this section displays the total amount of each type of fuel being consumed across all technology types, thus summing the gasoline consumed in Gasoline ICEs, Gas / Electric Hybrids, and Gas / Ethanol Flex vehicles, and so on for all the different fuels.

As can be seen in Figure 24, there is a dramatic decline in the gasoline consumed by sedans, almost 40%. At the same time the utilization of other alternatives remains relatively low, but it is through their combined substitution and through fuel economy improvements that the usage of gasoline is able to be so reduced. Figure 25 shows that, even with greater levels of usage of alternative fuels, gasoline consumption rises at an alarming rate, primarily due to the high growth rate of the SUV population. These values combine in Figure 26, which shows the total consumption of all fuels. As can be see, while the consumption of gasoline in the final year of the projection is lower than that of the first year, it is on the rise and is on track to continue rising beyond current levels. The combined fuel consumption is largely dominated by the SUV fuel consumption, especially in later years of the scenario.

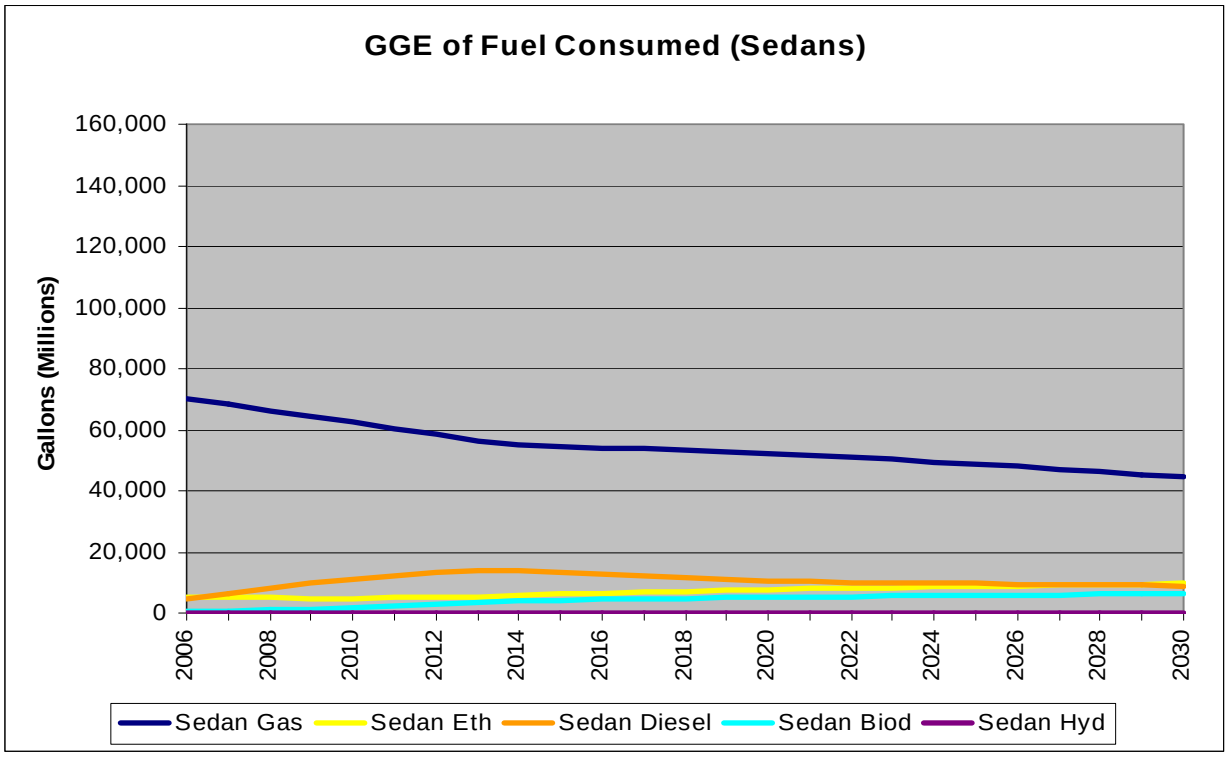
Below, Figure 23 shows the conversion factors for all relevant fuels into Gallons of Gasoline Equivalent (GGE). This figure shows how many gallons of gasoline are equivalent to a single gallon of another fuel. Numbers that are greater than 1 show that the other fuel has a greater energy content per gallon than does gasoline, while numbers that are lower than 1 show that the fuel has a lower energy per gallon than gasoline does. The units of fuel are converted into GGE in order to display the energy values on an equal ground in terms of total energy consumed.

Figure 26: GGE Conversion Table

Fuel (1 Gallon)	Gallons of Gasoline Equivalent (GGE)
Gasoline	1.000
Diesel	1.135
Ethanol	0.658
Biodiesel	1.037
Hydrogen	1.008

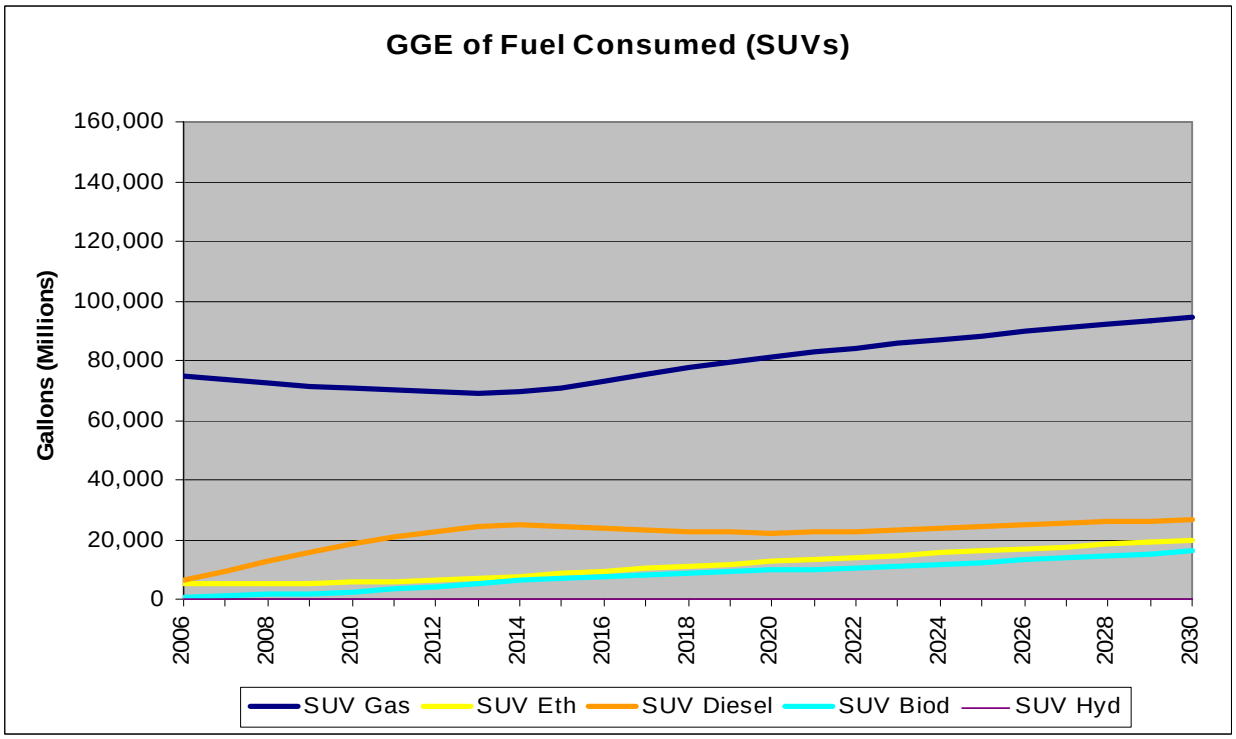
Figure 27 and Figure 28 show the same data as Figure 24 and 25 only they are normalized so that they show the per vehicle values for GGE consumed and the data is also divided by the technology type rather than the fuel type. Thus this data shows the average energy being consumed on an annual basis by a Gasoline ICE, Diesel ICE, Ethanol Flex Fuel, Biodiesel Flex Fuel and Hybrid Gasoline-Electric vehicles. This data is interesting because it shows the decreasing per vehicle fuel consumption while the aggregated data shows overall increases in fuel consumed. This indicates that rising emissions are due, not by changing technology, but rather by the overall increase in Total Vehicle Miles Traveled due to rising vehicle populations.

Figure 27: U.S. Baseline, Sedan Fuel Consumption



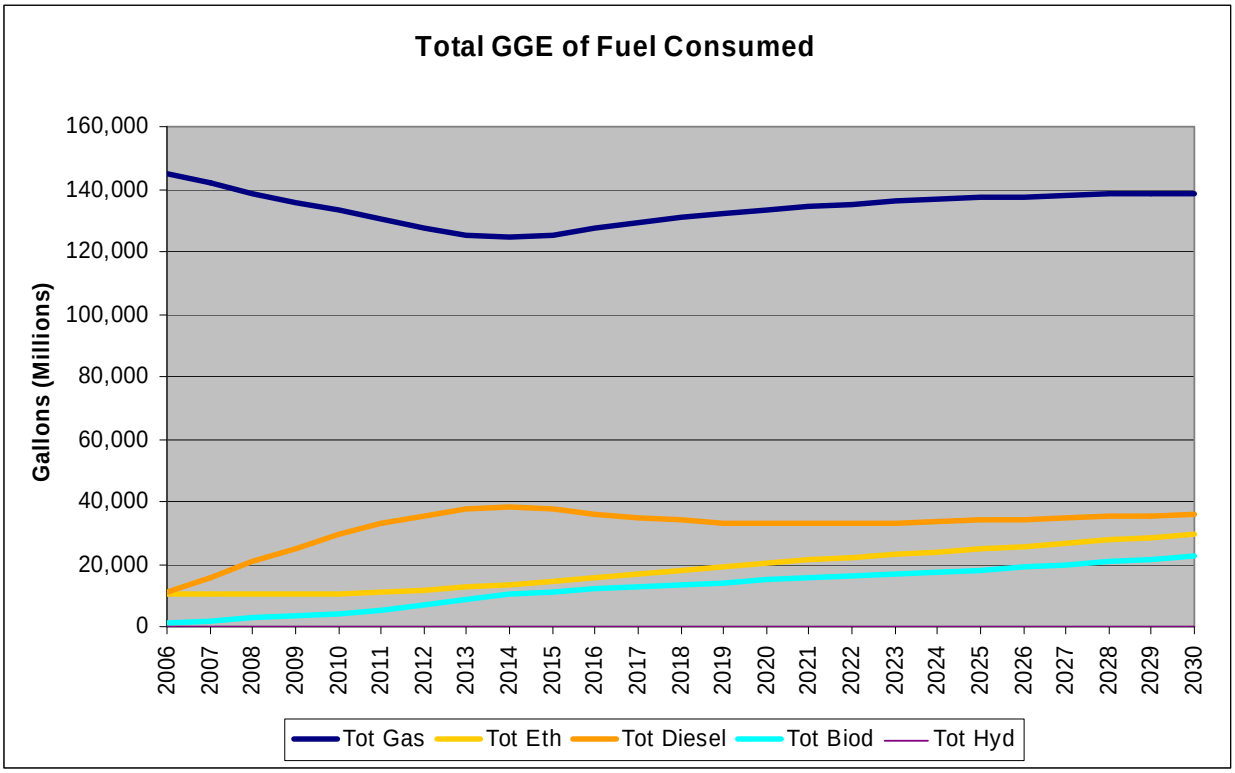
(N.B. Model Predicted No HFCV Penetration)

Figure 28: U.S. Baseline, SUVs Fuel Consumption



(N.B. Model Predicted No HFCV Penetration)

Figure 29: U.S. Baseline, All Vehicle Fuel Consumption



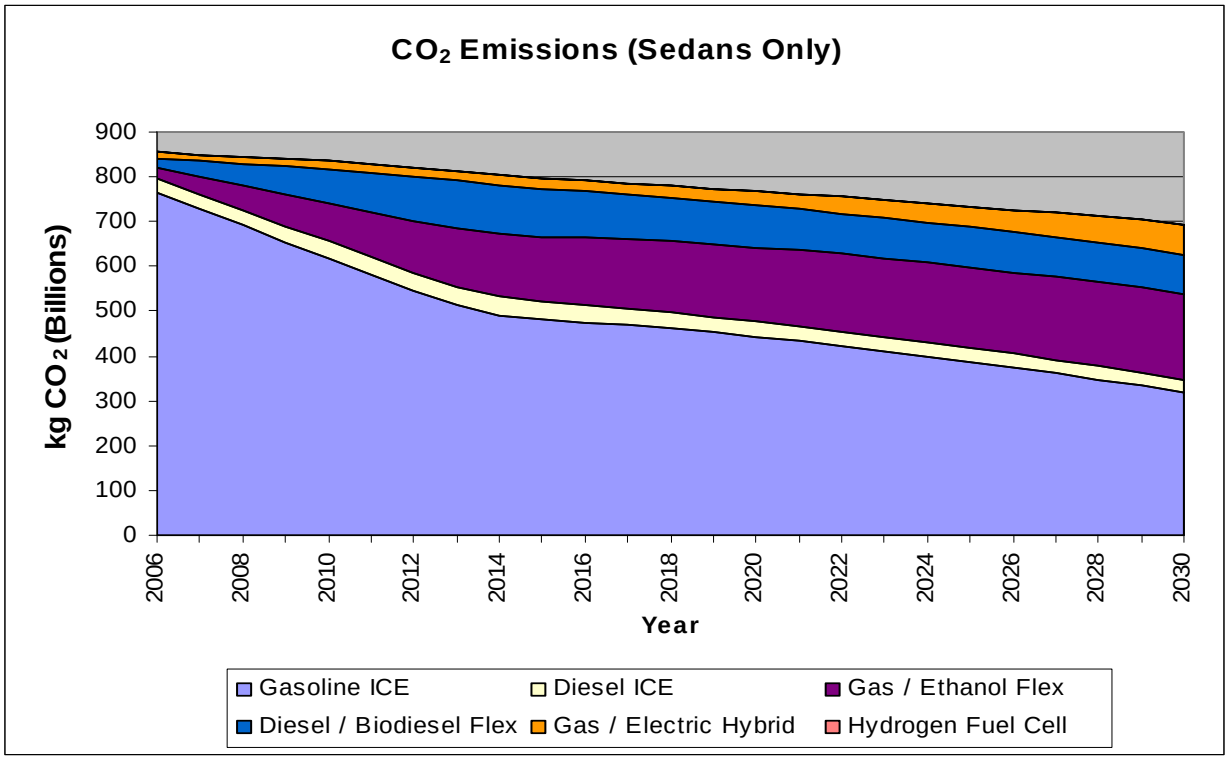
(N.B. Model Predicted No HFCV Penetration)

3.3.4. CO_2 Emissions

Despite significant introductions of gasoline-electric hybrid, biodiesel-diesel flex, and ethanol-gasoline flex vehicles, the baseline scenario shows continued increases in carbon dioxide emissions. The pattern followed is very similar to the one seen in the consumption of BTU's, which is not surprising. The carbon dioxide emissions from sedans show a slow and steady decrease while the carbon dioxide emissions from the SUVs show significant increase. The emissions combine to show moderate increases in carbon dioxide from the overall pool of vehicles and continued unsustainability and danger from climate change.

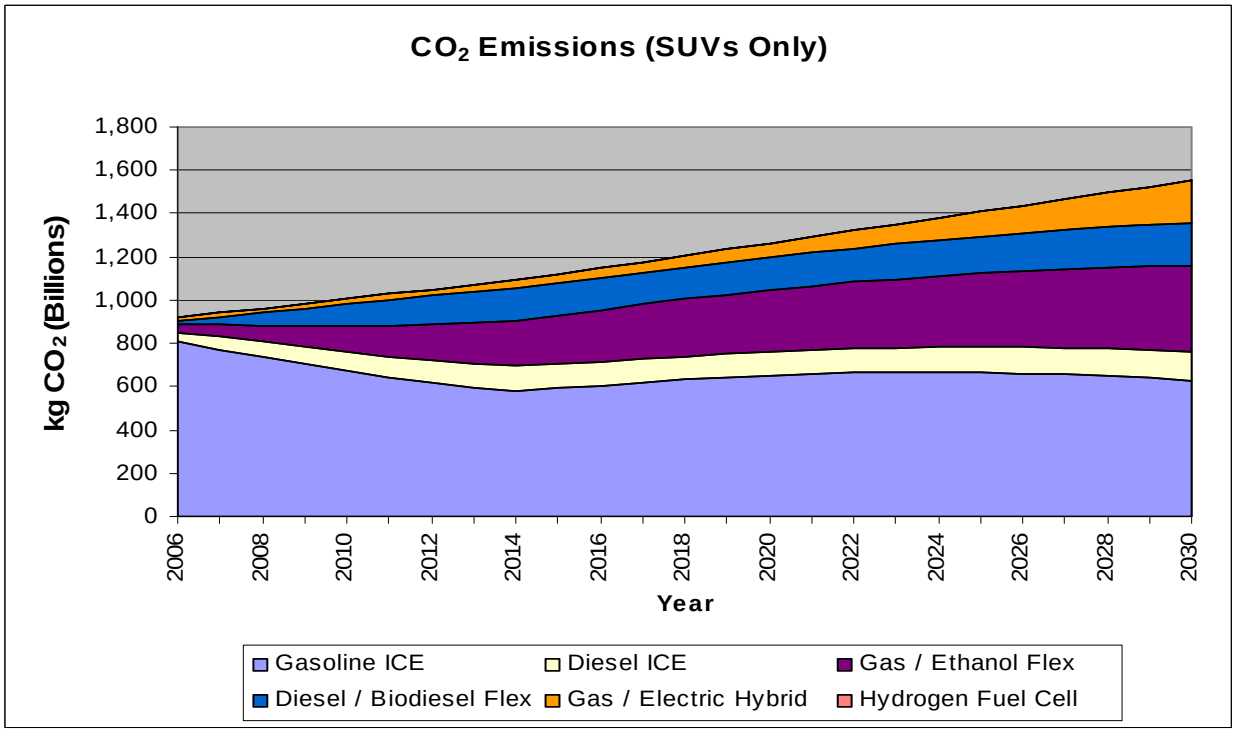
The majority of the emissions throughout the scenario come from the use of petroleum, either through the used of diesel fuel or gasoline. All five of the technologies that make up the vast majority of the overall emissions use either gasoline or diesel. Even those technologies that could use entirely biofuel (flex ethanol and flex biodiesel) are using at least 50% petrofuel at the end of the study. Despite a drop in emissions from sedans, the overall growth rate of the SUV pool overcomes any technological benefits that are gained in the mild transition to alternative technologies. Most of these benefits are realized in the first ten years of the projection as the vehicle population transitions over to match the vehicle market shares predicted. After this occurs then the growth rate of the vehicle pool overcomes the modest efficiency and fuel choice improvements that occur, resulting in continued growth of emissions.

Figure 30: U.S. Baseline, Sedan CO_2 Emissions



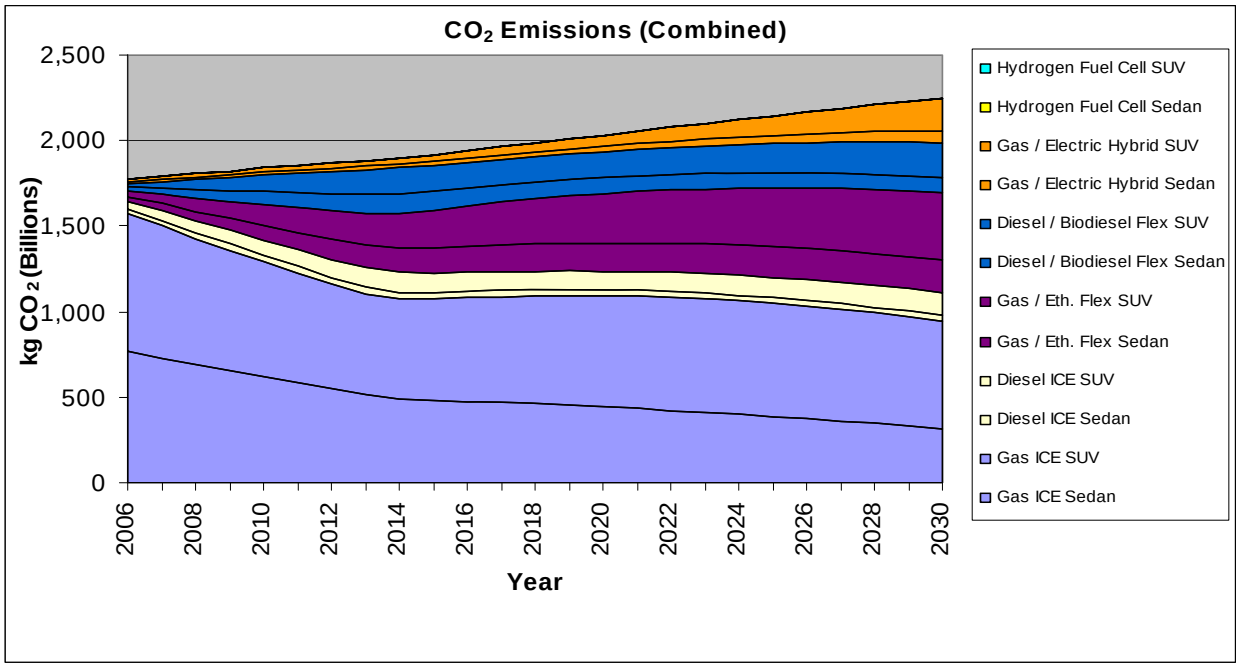
(N.B. Model Predicted No HFCV Penetration)

Figure 31: U.S. Baseline, SUV CO_2 Emissions



(N.B. Model Predicted No HFCV Penetration)

Figure 32: U.S. Baseline, All Vehicle CO_2 Emissions (N.B. Model Predicted No HFCV Penetration)



(N.B. Model Predicted No HFCV Penetration)

3.3.5. Normalized Emissions

While the preceding graphs show the dilemma of growing carbon emissions in the baseline scenario, it is important to illustrate that the growth in emissions is primarily due to the fact that the number of vehicles on the road is increasing, according to historical trends, and that on a per vehicle basis, emissions are actually decreasing annually. The following graphs (Figures 32 and 33) show carbon dioxide emissions on a per vehicle basis. They also include an "average" line, which shows the average level of emissions being emitted amongst the technologies. This decrease is due to two factors which have already been discussed, greater fuel mixing with lower carbon fuels and the gradual increase in efficiency experienced by all technologies.

These two figures illustrate the fact that technology improvements are occurring, and that because of them any single car on the road in the future will have decreased emissions compared to its counterpart that is on the road today. Despite this and despite the fact that the baseline scenario shows a trend of switching to the lower emission technology types, the aggregate level of carbon dioxide emissions continues to grow. This clearly shows that real changes in the U.S. emissions future cannot occur through the intervention of technology alone.

Figure 33: U.S. Baseline, CO_2 Emissions Per Year Per Sedan

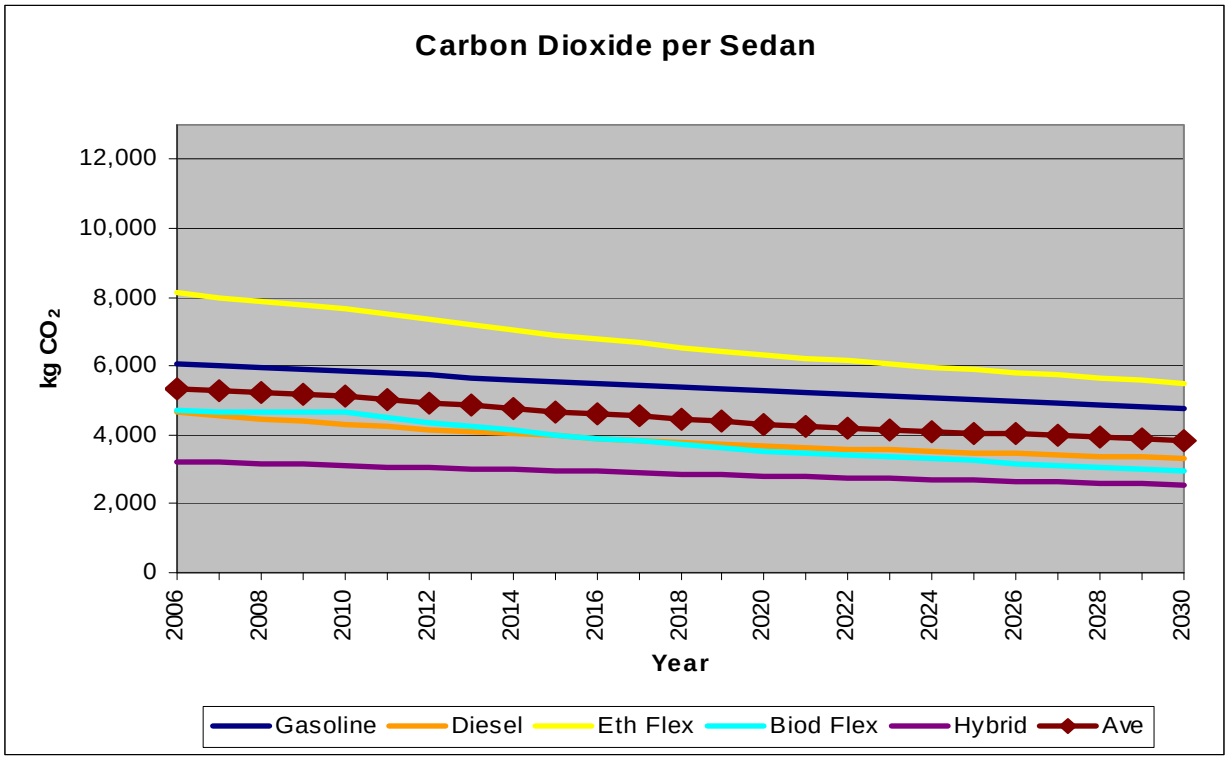
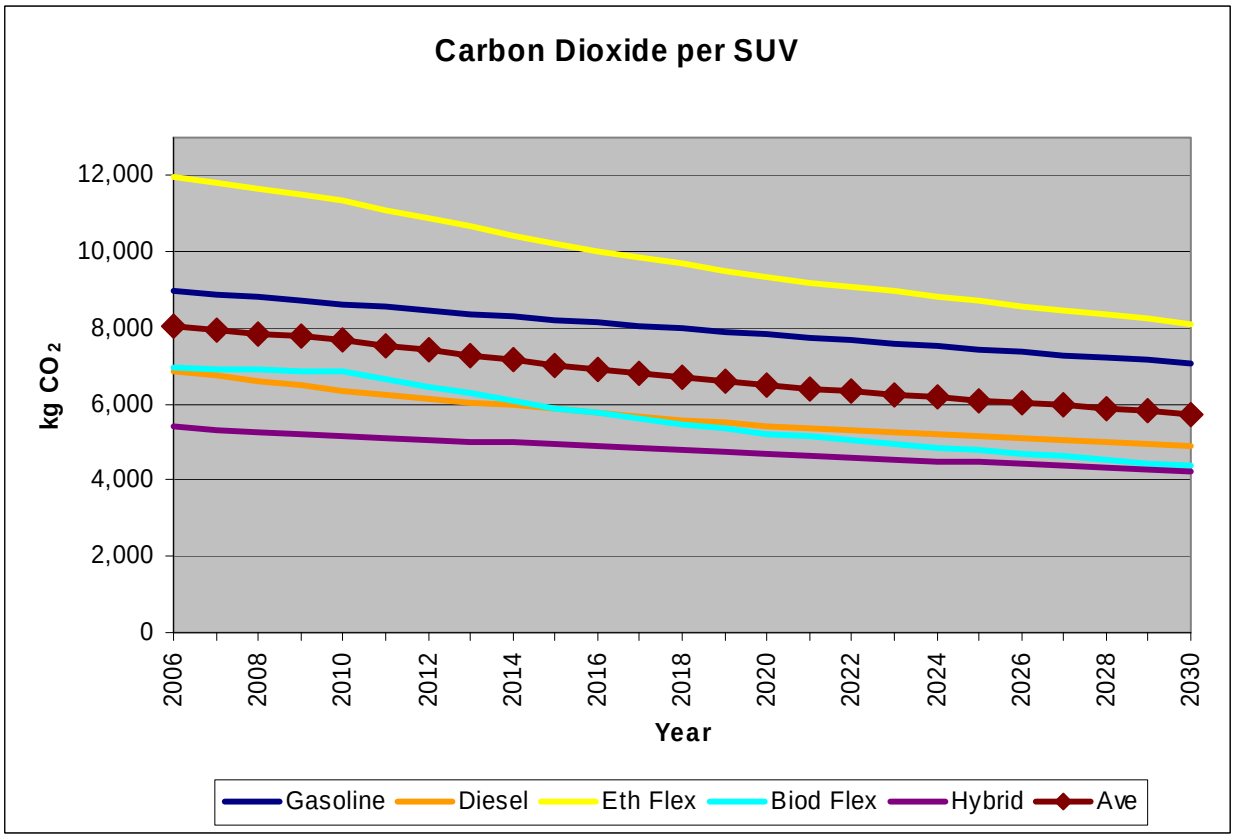


Figure 34: U.S. Baseline, CO_2 Emissions Per Year Per SUV



Despite increases in nearly every factor that would lead to decreased overall emissions levels, the growth rate of the SUV vehicle pool easily overwhelms these combined improvements leading to a state of rising annual emissions. This shows that technological improvements alone, as they are proceeding currently, cannot lead to a future of decreasing carbon emissions. In order to obtain that outcome their must be even greater technological innovation, policy intervention, or a drastic change in societal consumptive patterns.

3.4. U.S. Sensitivity Analysis

With the baseline scenario created, the next important step before being able to proceed to the creation of alternative policy and technology scenarios is to identify those areas of the baseline scenario that are most easily affected by change, and thus those areas that would be the most responsive to an alteration of the baseline scenario. A sensitivity analysis was performed in order to obtain this information and is presented below.

3.4.1 Area of Focus

Due to the multi-variable nature of the CarCarbon model, spanning a 25 year period, a complete sensitivity analysis would require thousands of outputs and tests be examined. This was not within the scope of this study, nor would it be necessary in order to create the scenarios that needed to be constructed. Therefore, a sensitivity analysis including three of the technology subsets and the six variables that were preliminarily identified as the most important to the outputs were selected and tested. The sensitivity of the six variables was determined by examining the effect that altering them had on the numbers of vehicles purchased within the technology sets and the overall effect that was had on the carbon dioxide levels. These values were compared to the values within the baseline scenario in order to give them a sense of scale.

The three technology sets chose to examine were Gasoline ICE, Ethanol Flex Fuel, and Gasoline-Electric Hybrid vehicles. These were chosen because of their representative nature of all the technology sets. Gasoline ICE vehicles were an obvious choice due to their current dominance in the U.S. market place. Determining what variables will have the greatest effect on gasoline ICE vehicles will play an important role in the creation of any future scenario. The inclusion of ethanol flex fuel vehicles is meant to represent those technologies that currently represent a challenge to the dominant technology in almost every respect but which have yet to gain a significant foothold in the market place. Finally, gasoline-electric hybrid vehicles represent those technologies that are competitive with gasoline ICE vehicles in many respects but lag behind in one or two significant aspects, in this case, the vehicle price.

The variables which were altered for each of these technology types included: 1) the price of the vehicles; 2) the price of the fuels; 3) the availability of the fuel; 4) the number of makes and models of that technology type; and 5) the fuel economy of the vehicles. A final variable that was examined, but which could not be applied individually to all the technology types, was the growth rate of the fleet as a whole. This final factor can be considered as separate from the other five due to its role in the model. The following tables show a full list of all the variables in the CarCarbon Model, along with a description of whether or not the variable was included in the sensitivity analysis and why. The final list of variables examined included all of the time sensitive variables and none of the variables which are constant through time.

Figure 35: Time Sensitive Variables

Variable	
Vehicle Price	Included. Early testing showed a high level of sensitivity to this particular variable. So due to both experience and the theoretical expectations of the model it was included.
Fuel Price	Included. A similar level of sensitivity was noted in early testing as with vehicle price. Additionally high levels of variance in fuel price in the baseline scenario between the fuels and a future expectation of volatile fuel markets led this to be included.
Fuel Economy	Included. Due to its impact on both fueling costs and range, this variable has a significant impact on several sections of the model, thus for theoretic reasons, it was viewed to be important to the sensitivity of the model. Additionally, significant variance occurs between the technologies and is possible in future variations of each technology.
Fuel Availability	Included. This variable is viewed as a necessary but not sufficient factor in the adoption of a technology due to the high nature of the penalties applied to low levels of fuel availability and nearly non-existent penalties applied to mid-high levels of fuel availability. It was uncertain how sensitive this variable would be to smaller changes.
Make/Model Availability	Included. Structured very similarly to fuel availability, this variable was included for the same reasons.
Sedan Pool Growth Rate	Included. This variable, along with the SUV pool growth rate, is viewed to have a tremendous impact on carbon dioxide emissions. It does not impact the market share distribution between the technologies, instead it proportionally increases or decreases the overall numbers of the technologies. It was included with the expectation that it would have a direct and significant impact on carbon dioxide emissions.
SUV Pool Growth Rate	Included. Structured in exactly the same fashion as sedan pool growth rate and included for the same reasons.

Figure 36: Non-Time Sensitive Variables

Variable	
Maintenance Cost	Excluded. Maintenance costs in the baseline scenario are low compared to other costs and relatively constant across the different technology types.
Home Refueling Capability	Excluded. None of the technology types examined in this study have this option as a reasonable possibility, thus it was excluded from the sensitivity analysis. Additionally, it is by nature a digital variable, being either a 1 or a 0, with no in between, thus cannot be varied by plus of minus 10%.
Luggage Space	Excluded. This variable is relatively constant across the technology types.
Multi-fuel Capability	Excluded. Similarly to home refueling capability, this variable is digital, 1 or 0. Additionally, it is intrinsic to the nature of the technologies, and not something that could be realistically varied.
Acceleration	Excluded. This variable is relatively constant across the technology types.
Top Speed	Excluded. This variable is relatively constant across the technology types.
Tank Size (Range)	Excluded. This variable is relatively constant across the technology types. Additionally, given the nature of the cost curve for this variable, a plus or minus 10% change to the levels of tank size will not cause a change in cost due to increased or decreased range.

3.4.2. Methodology

In order to judge the relative impact of changing the different variables, it was important that they all be altered by a percentage amount rather than by an absolute value. It was decided that a modest plus or minus 10% would accurately reflect the type of changes that would likely come about in most scenarios and would be large enough to gauge the effect on the models outputs.

The baseline scenario was systematically altered by altering the specified input (i.e. vehicle price, fuel price, etc) for each technology type in turn, at both plus and minus 10%. The inputs for both sedans and SUVs were altered simultaneously and for the entire 25 year span of the projection. The effect of this alteration was then gauged by the change in the number of vehicles in each year of the projection for that particular technology type and by the overall change in carbon dioxide emissions from the aggregated technology types for each year of the study. This data was extracted and entered into a separate spreadsheet where all of the values were converted into a percentage change from the baseline values.

3.4.3. Results

The results of the sensitivity analysis are displayed in the tables and graphs below. The tables show a simple ranking of the effect the inputs had on the technologies as well as a weighted impact based on the average percentage change from the baseline, while the graphs show the level of impacts as well as the order. Both the tables and the graphs are split into two,

showing the effect on the number of the vehicles as well as the effect on carbon dioxide emissions.

As was expected, some clear trends are displayed, but the results of changing the inputs across the different technologies are not identical. Vehicle price is the input that most clearly dominates in both the number of vehicles and the amount of carbon dioxide emitted. Not only does this variable usually have the greatest impact, but the level of the impact, especially on the number of vehicles, far overreaches that of the other variables. The other clear trend is in the very low impact of fuel availability, which failed to register a significant change in either the number of vehicles or carbon dioxide emissions in all cases. The three other variables affecting the individual technologies, fuel price, fuel economy, and make/model availability, all show significant levels of impact but no clear trends as to an order of importance present themselves. A further discussion of the results for the three separate technologies follows.

Figure 37: Ranking of Impact on Vehicle Numbers

	Gasoline ICEs	**Ethanol Flex Fuel**	**Gas-Electric Hybrids**
1st	17.1- Vehicle Price	51.4- Vehicle Price	58.0- Vehicle Price
2nd	4.7- Fuel Economy	14.8- Fuel Economy	6.5- Fuel Economy
3rd	2.9- Fuel Price	3.9- Fuel Price	3.1- Make/Model
4th	1.6- Make/Model	3.2- Make/Model	1.3- Fuel Price
5th	0.0- Fuel Availability	0.0- Fuel Availability	0.0- Fuel Availability

Figure 38: Ranking of Impact on Carbon Dioxide Emissions

	Gasoline ICEs	**Ethanol Flex Fuel**	**Gas-Electric Hybrids**
1st	4.2- Fuel Economy	2.9- Vehicle Price	1.9- Vehicle Price
2nd	0.9- Fuel Price	1.0- Fuel Economy	0.9- Fuel Price
3rd	0.5- Vehicle Price	0.3- Fuel Price	0.7- Fuel Economy
4th	0.1- Make/Model	0.2- Make/Model	0.1- Make/Model
5th	0.0- Fuel Availability	0.0- Fuel Availability	0.0- Fuel Availability

The gasoline ICE vehicle numbers were very strongly impacted by changes in vehicle price, with the expected results of a lowering in price leading to a higher number of vehicles on the road. All of the other variables registered relatively low impact on vehicle numbers. Surprisingly, the dramatic rise in the number of gasoline ICEs does not correspond to an equivalent rise in carbon dioxide emissions, but rather causes a slight decrease in the level of carbon dioxide emissions. This is due to the fact that the primary competitor for gasoline ICEs is the ethanol flex fuel vehicle, which has a lower fuel economy and only slightly lower carbon per unit of fuel, thus leading to an actual increase in emissions. The increase in gasoline ICE's comes primarily at the expense of the increase in ethanol flex fuel vehicles that occurs in the baseline scenario.

The only factor to have a significantly large impact on the level of carbon dioxide emissions in gasoline ICE's is a change in the fuel economy. As expected, increasing the fuel economy decreases emissions and vice versa. A change in the fuel economy is able to have such a significant impact on carbon dioxide emissions when applied to gasoline ICEs because they account for such a large portion of the vehicles on the road, so that the change in

emissions as compared to the change in fuel economy is almost linear. This effect decreases over time as the market share of gasoline ICEs decreases.

Figure 39: U.S. Sensitivity Analysis, % Change Carbon Dioxide From Gasoline

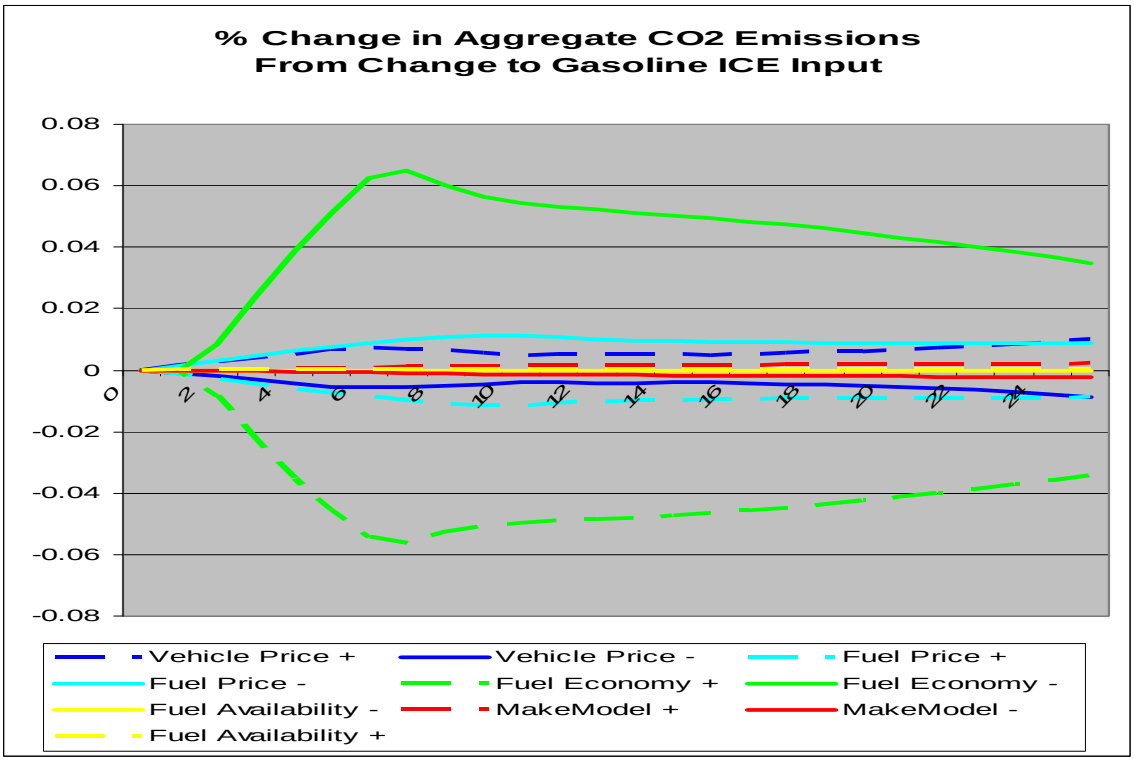
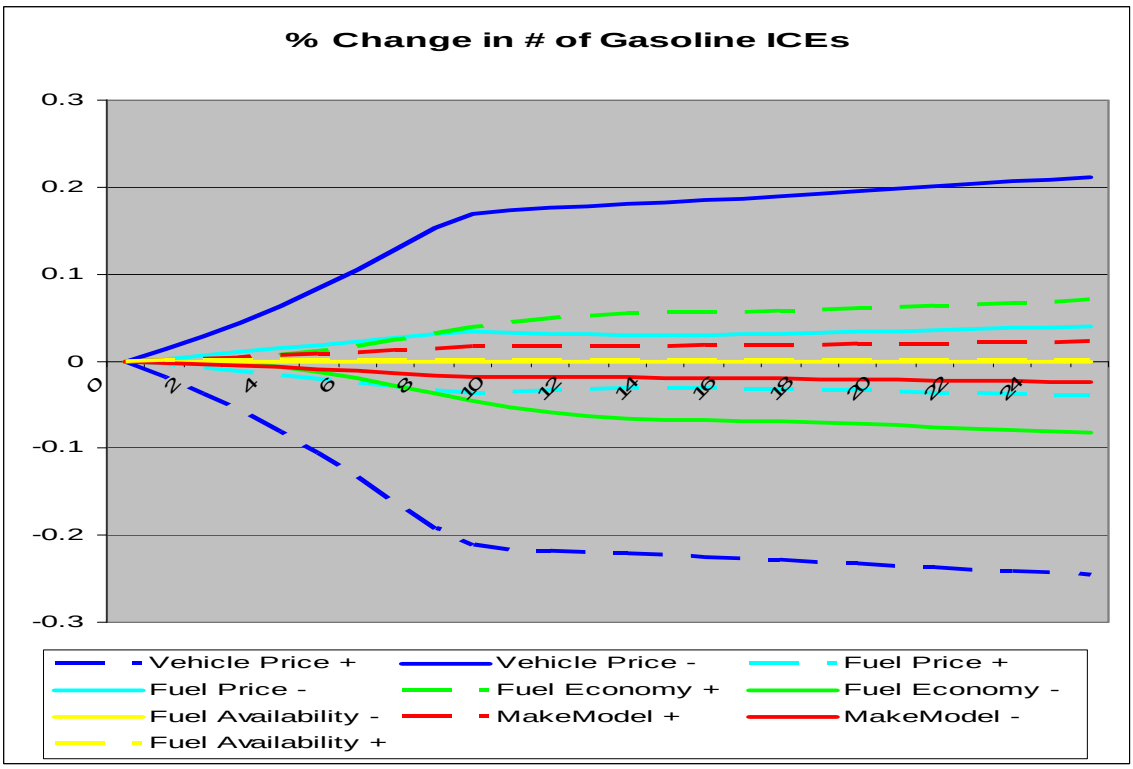


Figure 40: U.S. Sensitivity Analysis, % Change in Vehicles From Gasoline



The number of ethanol flex fuel vehicles is most strongly affected by the vehicle price. Unlike in gasoline ICEs, however, a second input has a significant impact on the number of vehicles, fuel economy. This is likely due to the fact that the fuel economy of the ethanol flex fuel vehicle is its primary drawback compared to its main competitor, the gasoline ICE. Fuel price and make/model availability both have relatively small impacts, while fuel availability has almost no impact at all.

It is interesting to note that increases in the number of ethanol flex fuel vehicles corresponds to a relative increase in the levels of carbon dioxide emissions, with the sole exception of the scenario in which the increase in vehicles is prompted by an increase in the fuel economy. Thus it stands to reason, that, unless significant improvements are made to the fuel economies of ethanol flex fuel vehicles, increasing their numbers on the road by replacing gasoline ICEs will either increase carbon dioxide emissions, or at best, have no effect on them at all. Overall, the effects on the aggregated carbon dioxide emissions are lower than the effects of changing gasoline ICEs inputs, but this is primarily due to the fact that ethanol flex fuel vehicles account for a much smaller market share.

Figure 41: U.S. Sensitivity Analysis, % Change in Vehicles From Ethanol

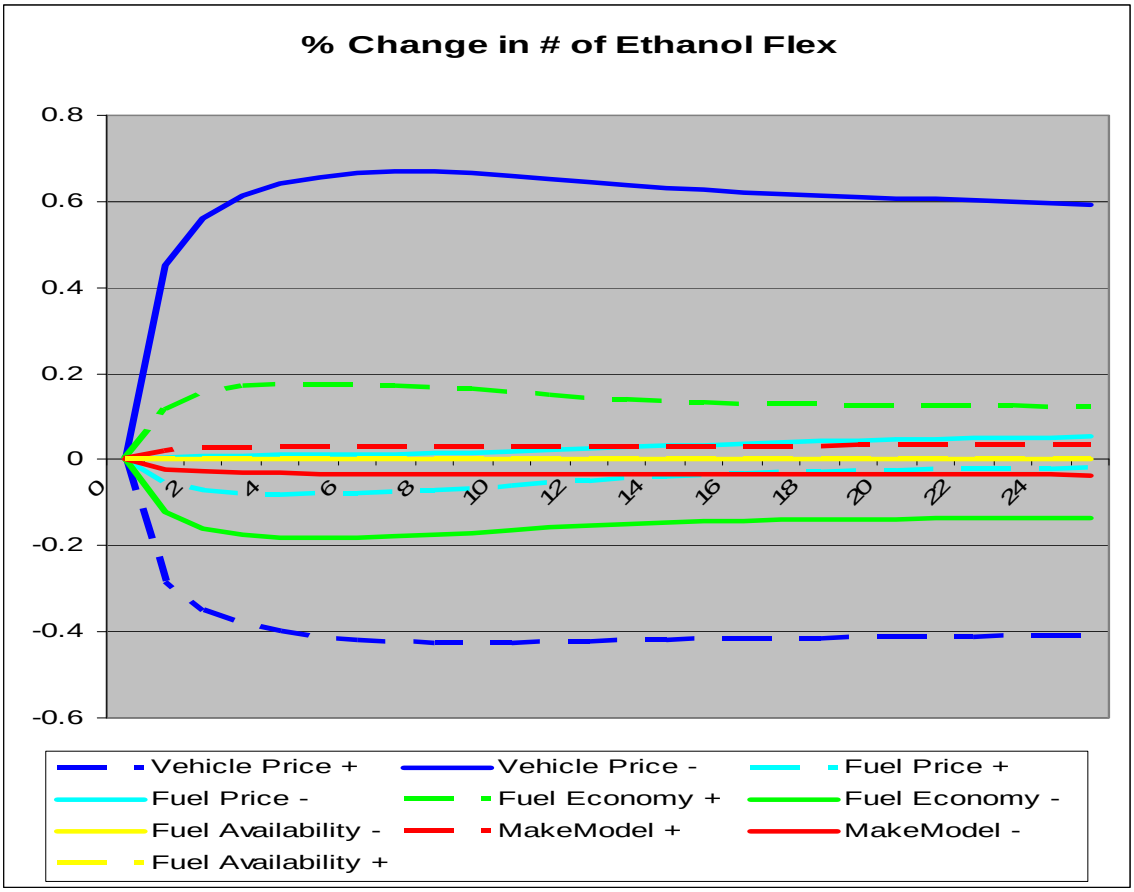
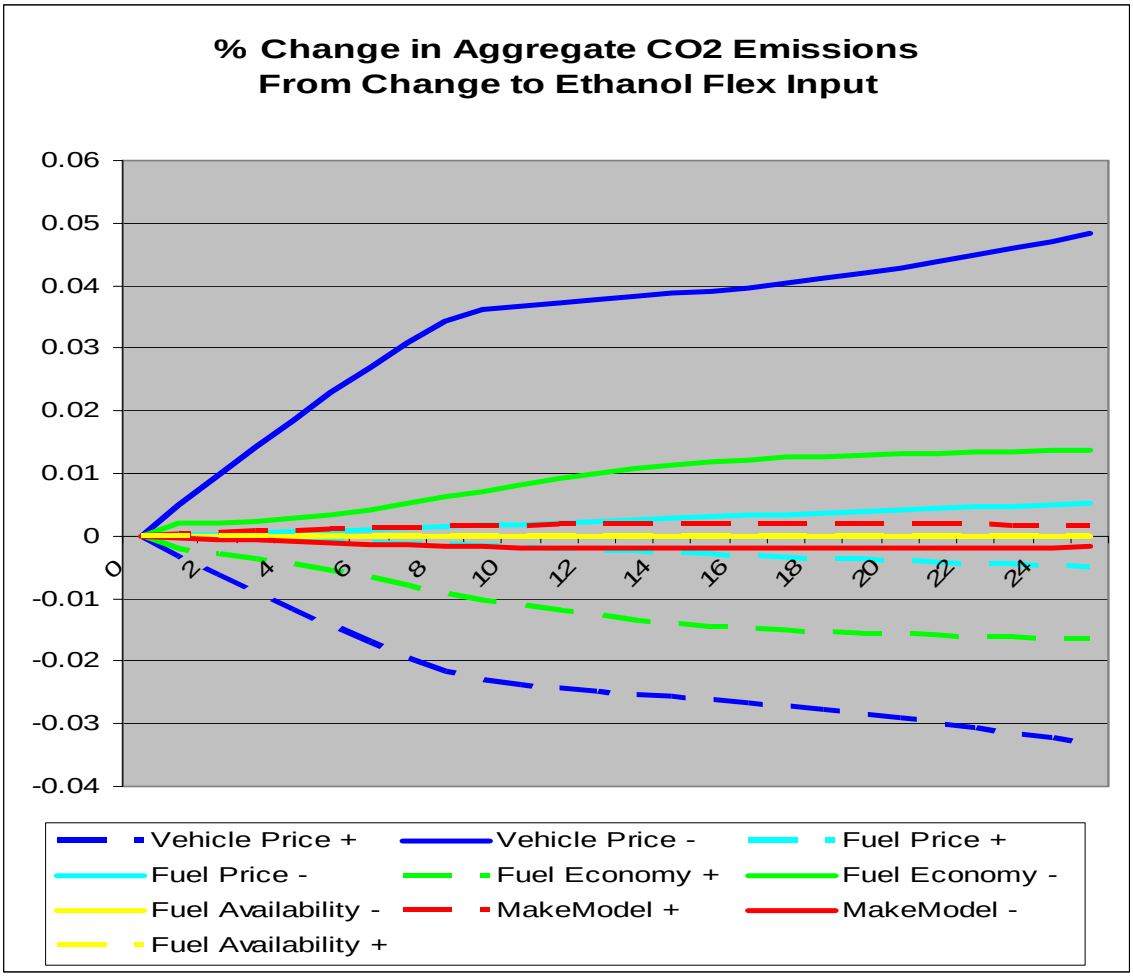


Figure 42: U.S. Sensitivity Analysis, % Change in Carbon Dioxide From Ethanol



Gasoline-electric hybrid vehicles are most strongly affected by vehicle price, but are also significantly impacted by fuel price and make/model availability. The gasoline-electric hybrids are superior in most ways to the gasoline ICE, except in terms of the vehicles cost, so this result is not surprising. The peak in the effect is caused by the fact that, in the baseline scenario, the premium paid for hybrid vehicles decreases over time and thus the impact of the 10% drop or rise in the vehicle price decreases in importance as that premium naturally disappears.

Any rise in the number of gasoline-electric hybrids corresponds to a moderate change in the aggregated carbon dioxide emissions. As expected, any rise in the number of hybrid vehicles causes emissions to drop and vice versa. Even though the number of hybrids on the road may double (as is seen during year 9 or the projection when the vehicle price is dropped 10%) this still only corresponds to a relatively low change in emissions due to the fact that they still account for such a small portion of the market. But, while this drop or rise in emissions may be relatively small compared to the change in the number of vehicles, it is still would represent a significant accomplishment in terms of overall carbon dioxide control.

Figure 43: U.S. Sensitivity Analysis, % Change in Vehicles From Hybrids

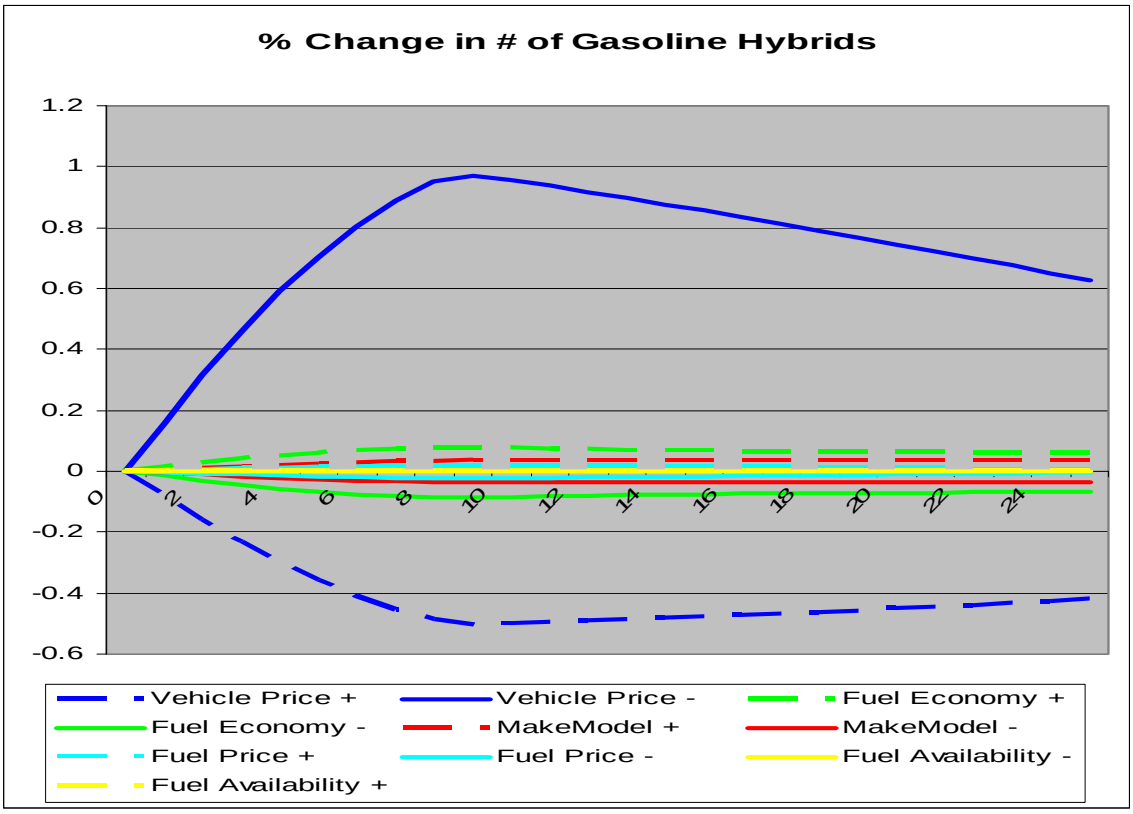
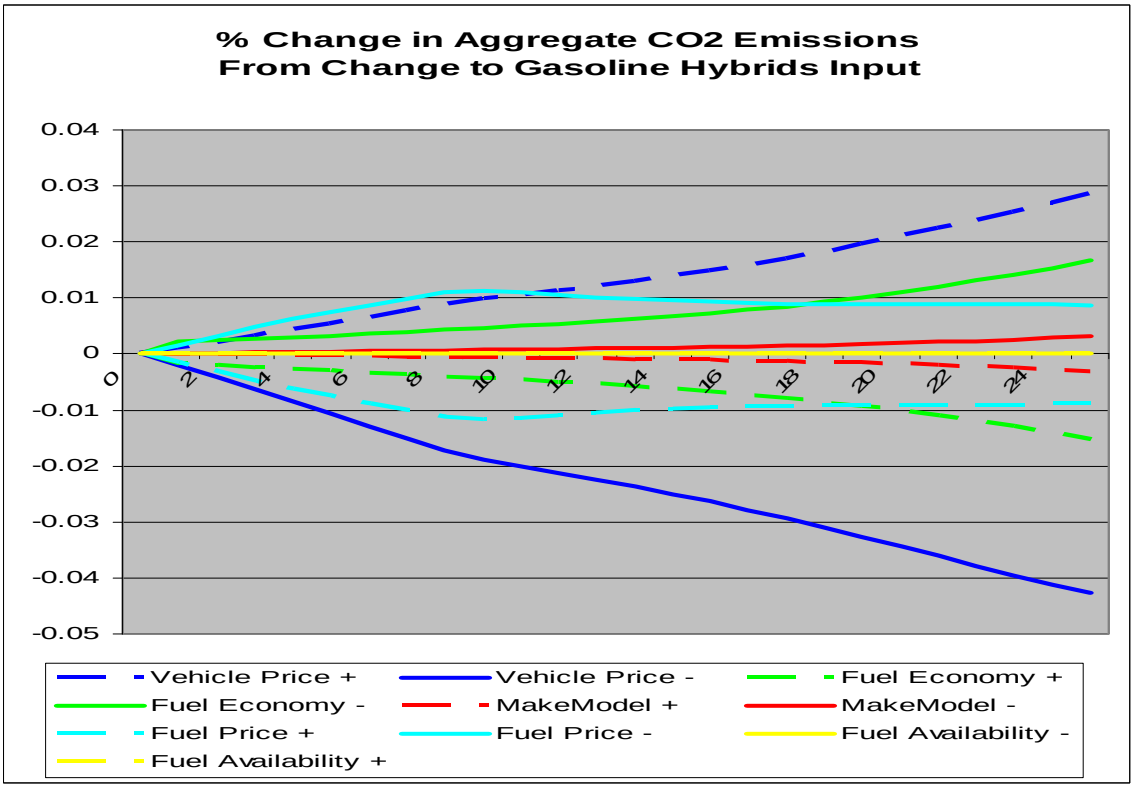


Figure 44: U.S. Sensitivity Analysis, % Change in Carbon Dioxide From Hybrids



The final results to display are those showing the sensitivity of changing the vehicle pool growth rate. Since this input cannot be changed separately for the different technology types, it was changed for the aggregate, and also for separately for the sedan and SUV pools. As was expected, increases in the vehicle pool growth rate lead to an increase in the number of vehicles on the road, as well as an increase in the amount of emissions. The market shares or the different technologies remained constant.

The most important point to draw from this data set is to see how, unlike in the other inputs, a drop in vehicle numbers leads to a nearly equivalent drop in carbon dioxide emissions. When the other inputs were changed, the carbon dioxide emissions only changed a small fraction of the amount that the number of vehicles changed. Additionally, it can be seen by the graphs that the SUV pool growth rates account for the much larger portion of the aggregate change than the sedan growth rate and thus should be the focus of any changes to the vehicle pool growth rates.

Figure 45: U.S. Sensitivity Analysis, % Change in Vehicles from Growth Rate

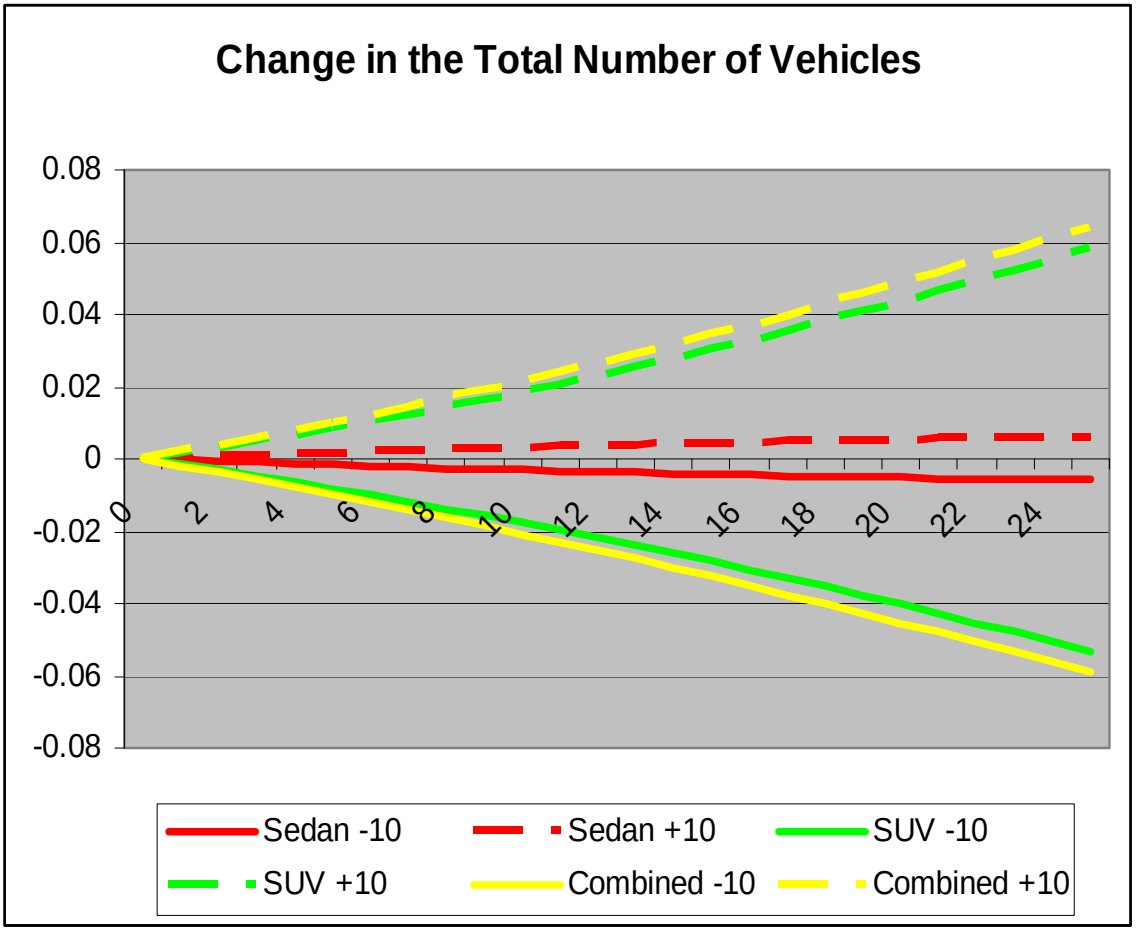
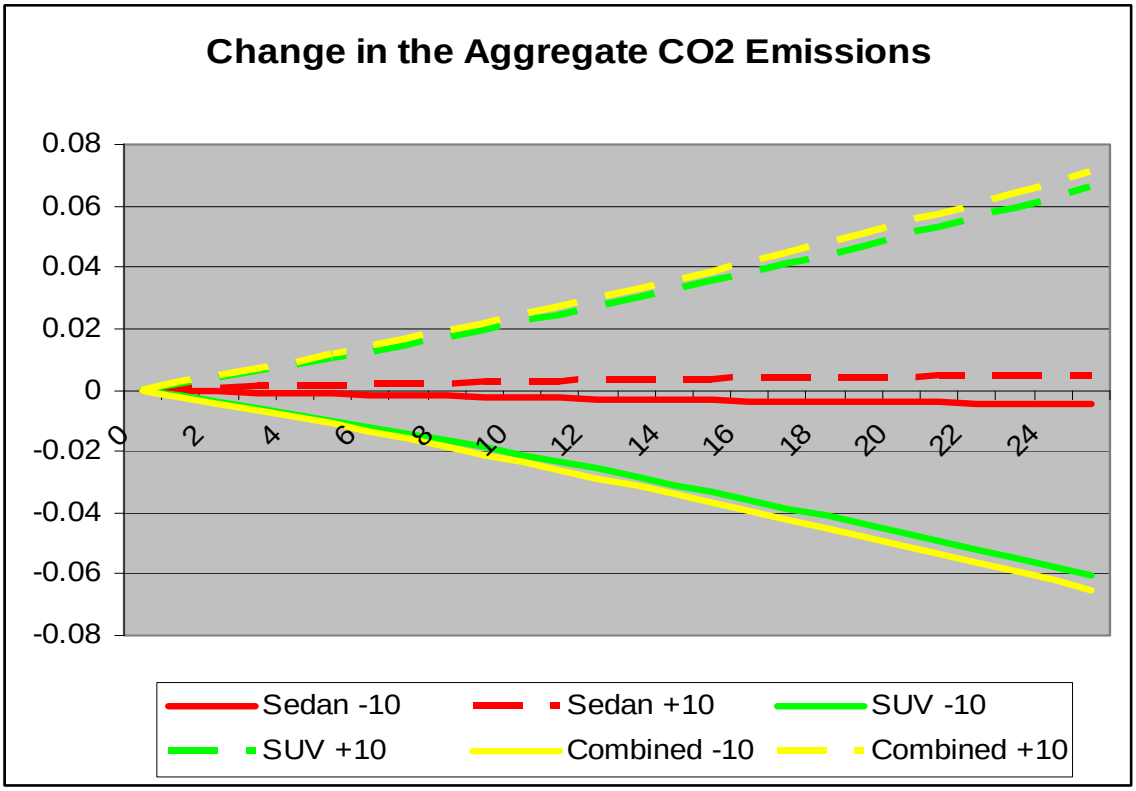


Figure 46: U.S. Sensitivity Analysis, % Change in Carbon Dioxide Emissions From Growth Rate



3.4.4. Conclusions

There are several important conclusions to draw from this sensitivity analysis. The first is in the level of impact that the various inputs have on the results. Obviously, the input with the greatest level of impact is vehicle price and the input with the lowest level of impact is the fuel availability. The vehicle price makes sense because in the baseline scenario, it is an input that is relatively similar for many of the different technologies, and thus a small change is able to shift the balance of favor easily. The fuel availability results are also not too surprising, given the nature of the input. Fuel availability is an input that is extremely sensitive over a very small range of its possible values and completely insensitive for the rest of the majority of its possible values. In the baseline scenario the impact of fuel availability shifts from a major negative to nearly no impact at all in just a few short years and its impact may be more measured by the year in which it crosses that point than its absolute value at any given time.

This leads to the second major conclusion. The manner in which the sensitivity analysis was conducted does not cause this crossing point to shift significantly and thus there was little change in the sensitivity analysis based on fuel availability. The order of the other inputs in terms of importance is insignificant but it is important to note that they are capable of causing a moderate impact. The level of impact seems to not only correspond to the importance placed on the inputs by the coefficients in the algorithm that calculates market share, but also to the setup of the baseline scenario, so that those technologies which are similar to their competitors in many ways will be more significantly impacted.

The third significant point that may be drawn is in noting whether or not there is a corresponding or contradictory change in carbon dioxide emissions based on whether or not the

number of vehicles went up or down. This, once again, it primarily a factor controlled by what the next closest competitor is, as that will be the technology that will make up most of the difference in any change in the vehicle numbers. If the technology doing the replacing is of a lower emissions impact then the overall emissions will go down and vice versa.

The impact that these results have in shaping our scenarios is several fold. Not only do the scenarios consider the base ranking of the different inputs in terms of their impacts as shown in this analysis, but also the condition of the baseline scenario and how a shift in an input, small or large, will be able to affect the introduction of new technologies. Those areas of particular interest should be those in which two competitors are similar in many ways and one might be given an advantage. The scenarios also consider situations in which there exists a technology which is superior to gasoline ICEs, but is held back by one or two significant factors. It will then be determined to what measure those factors would need to be changed in order for the other benefits of the technology to outweigh them.

3.5. Alternative U.S. Scenarios

The baseline scenario is only a benchmark, and thus additional scenarios have been created that gauge the effects of policies, social trends, and technology improvements compared to the baseline. Due to the complexity of the model there are a large number of potential alternative scenarios that could be enacted. However, there are several that seem important to explore that the model is particularly suited to develop. These scenarios will allow the policy maker to gauge the environmental and economic impact of policies and will be useful in helping to focus the efforts and energies towards those polices that are the most effective.

3.5.1. Increasing Fuel Economy

In 1974, Congress took action to increase the fuel economy of the nation's passenger vehicle fleet to an average of 27.5 miles per gallon (mpg) by 1985, nearly double the existing fuel economy (NHTSA, 2005). This increase was to occur in stages over the intermediate years. While this goal was not fully realized and stable until 1990, it was achieved in a relatively short period of time. Increasing the fuel economy of the passenger fleet is one of the quickest and effective short term means of reducing environmental impact and energy security concerns of the transportation sector as increases in fuel economy translate directly into fuel savings.

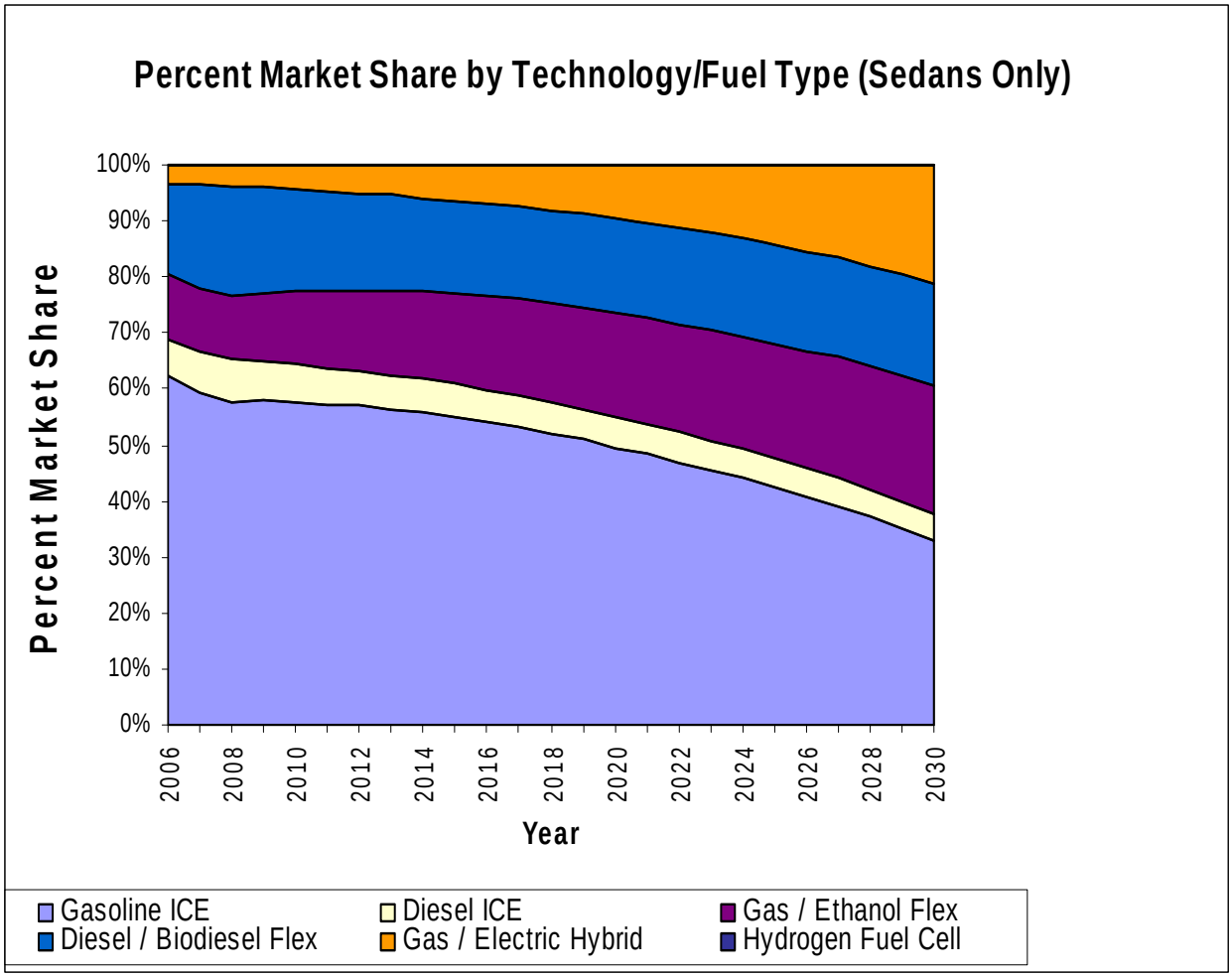
Many environmentalists, politicians, and academics have called for Congress to act again to raise the fuel economy of the national fleet, seeing it as a simple, relatively inexpensive, and effective means of easing our foreign-fuel dependency as well as reaping significant environmental impacts. The desire for more fuel-efficient cars can also be seen in the general public through the success and popularity of hybrid gasoline-electric vehicles, which has been propelled by a combination of rising gasoline prices and increased environmental consciousness. Congress has indeed taken note of these factors and over the course of 2007 has come close to passing bipartisan legislation to mandate the increase of the U.S. fleet fuel economy by 10mpg for light trucks and passenger cars by 2020, to an average of 35mpg, and by 4% each year thereafter (Mufson, 2007).

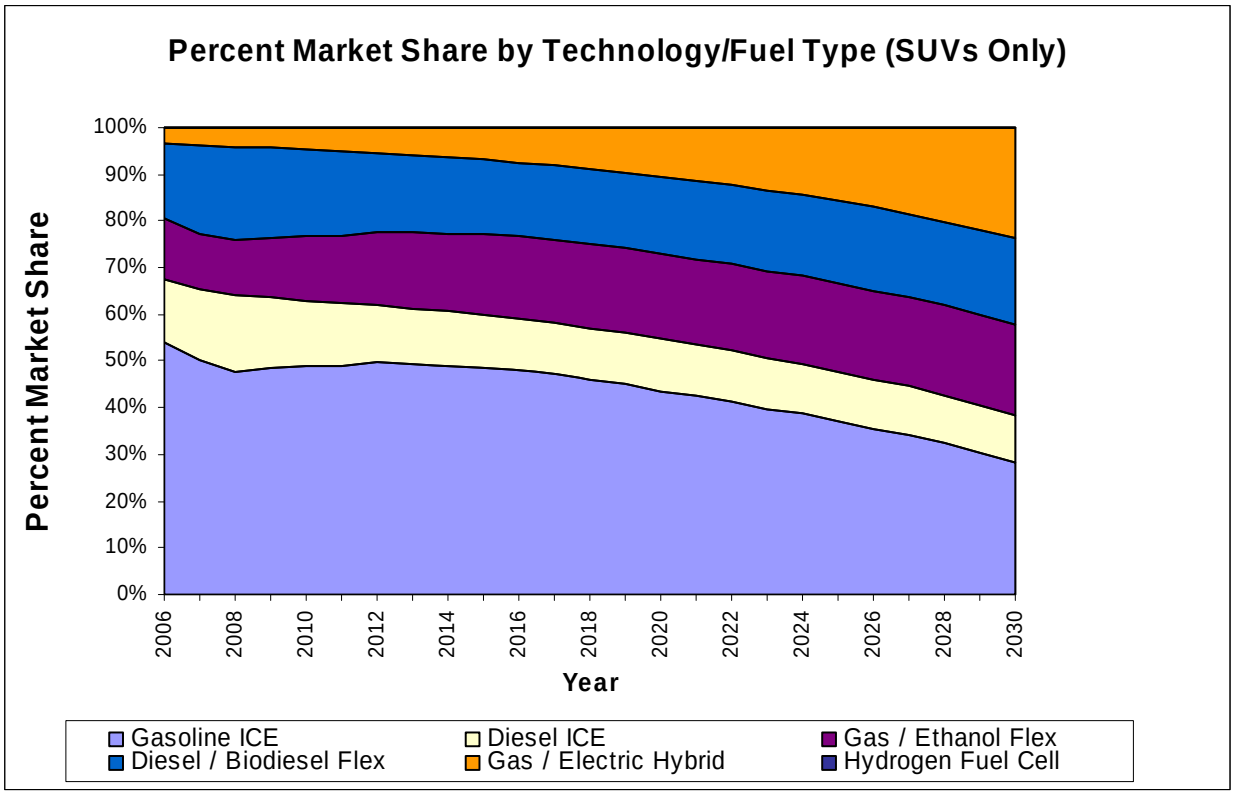
On December 27, 2007 the House sent the bill to President Bush and if approved would represent the first CAFE standard increases in the U.S. in 32 years (Washington Post, 2007). While it yet remains to be seen whether or not the bill will become law, the legislation provides an important framework for developing a scenario showing how an increase in fuel economy will affect the U.S. fleet vehicle market shares and emissions. One important note to make is that the increase in fuel economies applies only to new vehicles being added to the fleet and thus a

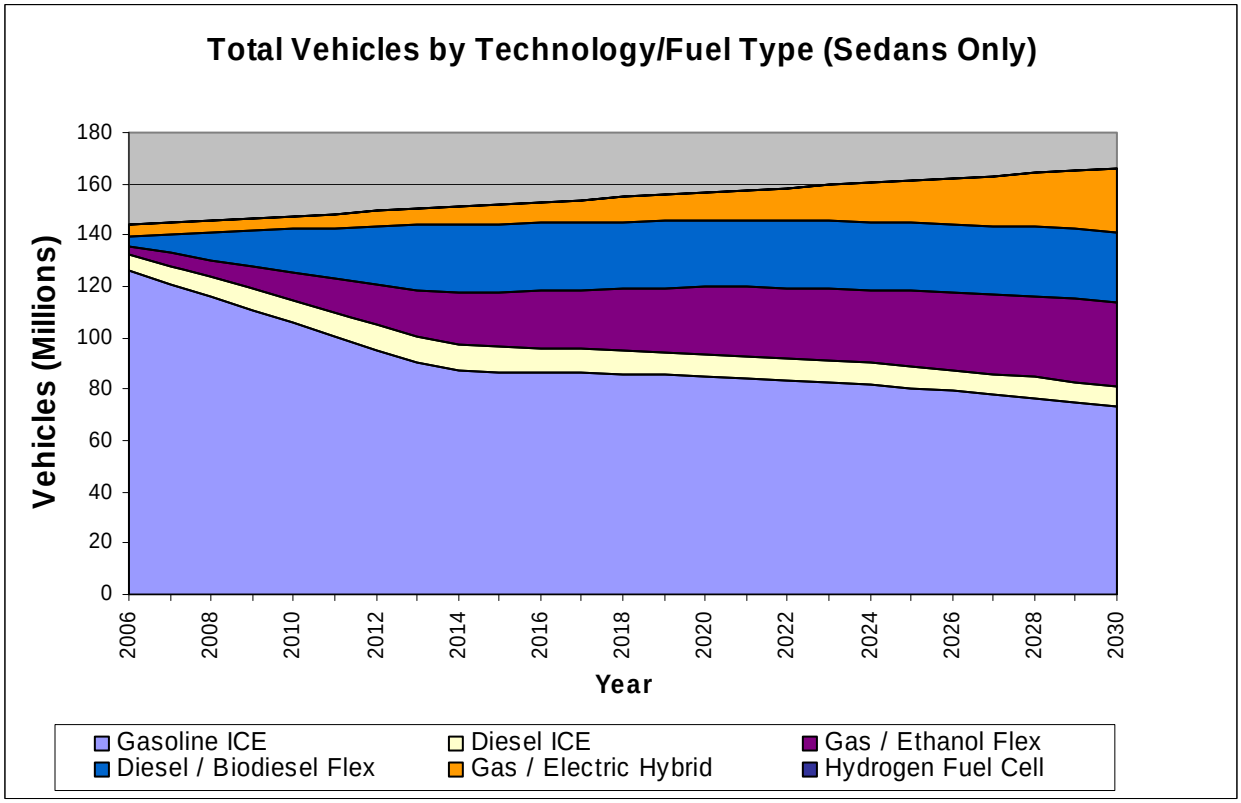
significant lag will occur between average fuel economies on the road versus average fuel economies coming off of the production line. This lag is completely dependent on the retirement rate and average lifespan of the vehicles in the fleet. In our baseline scenario, the average lifespan is set at 10 years for both sedans and SUVs of all technology types. Thus any fuel economy increases would not be fully realized until a period of time equal to this average lifespan has passed.

As compared to our baseline scenario, in which fuel economies were set to slowly increase over time, reaching 33.8mpg for sedans and 22.9mpg for SUVs and light trucks by 2030, this legislation represents a modest increase over projected fuel economies for sedans and a significant increase for SUVs. With the proposed legislation set to take effect in 2010, and with the assumed 10 year lag between parity between the on-the-road fleet versus the production line fleet, this would mean that in a scenario modeling the effects of this legislation, fuel economy increases would begin in 2010, but not achieve their 2020 production line goal in the on-the-road fleet until 2030.

Figure 47(a-g): U.S. Alternative Scenario, Increasing Fuel Economy




Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
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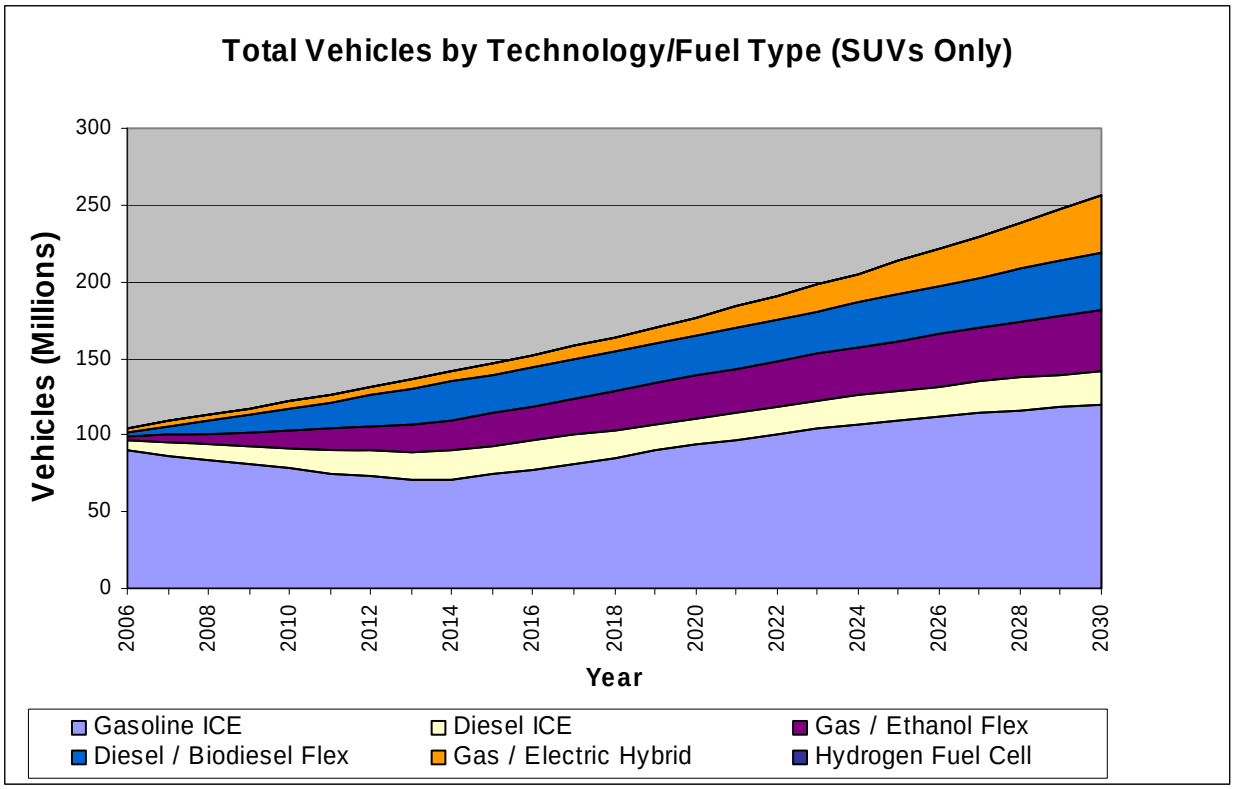
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
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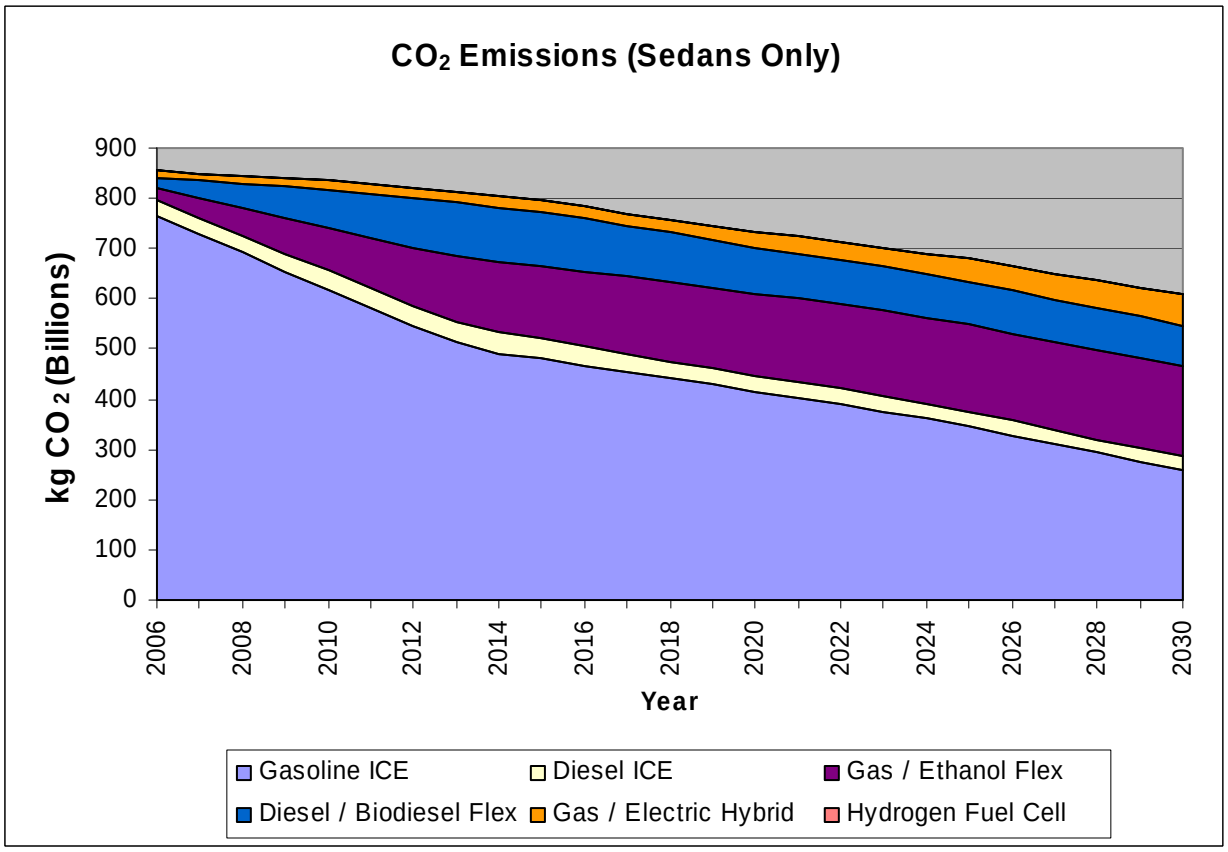
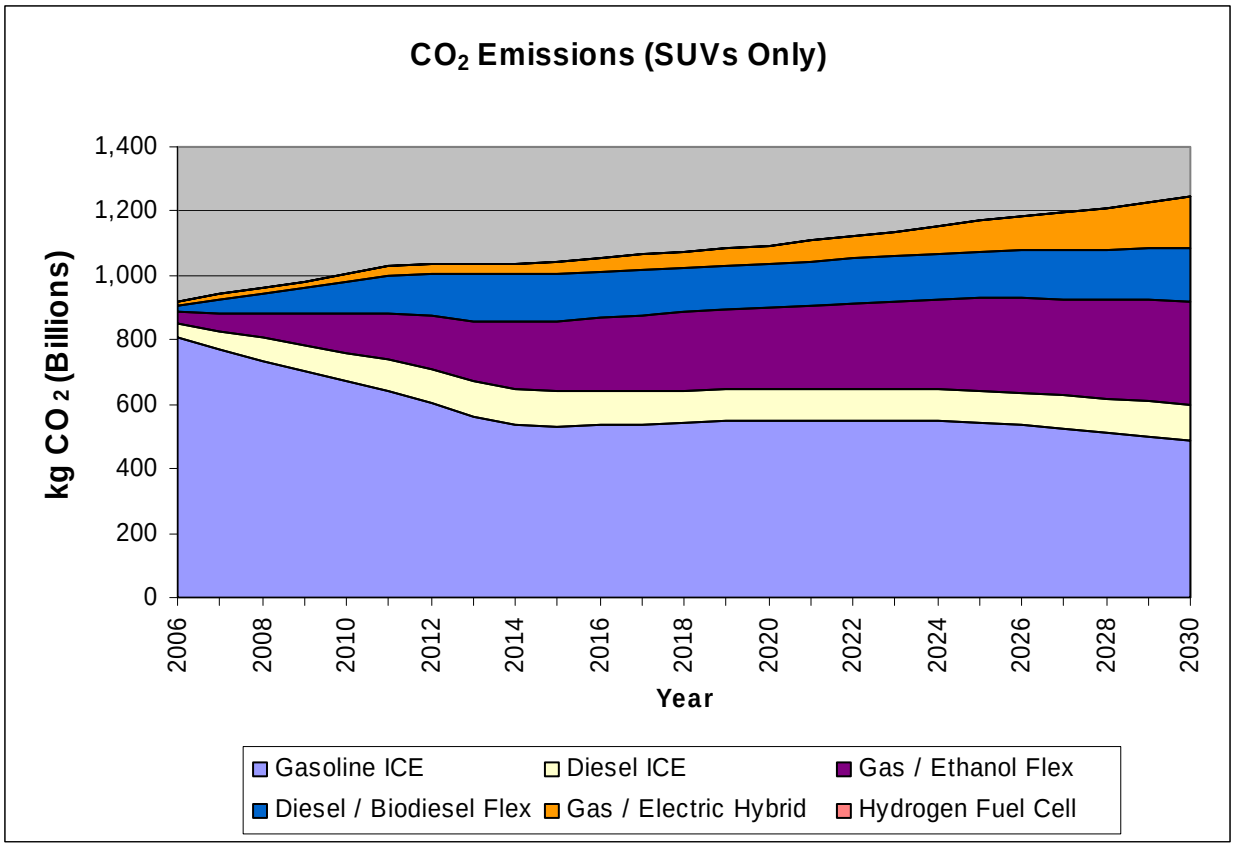
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO 2 (Billions)
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

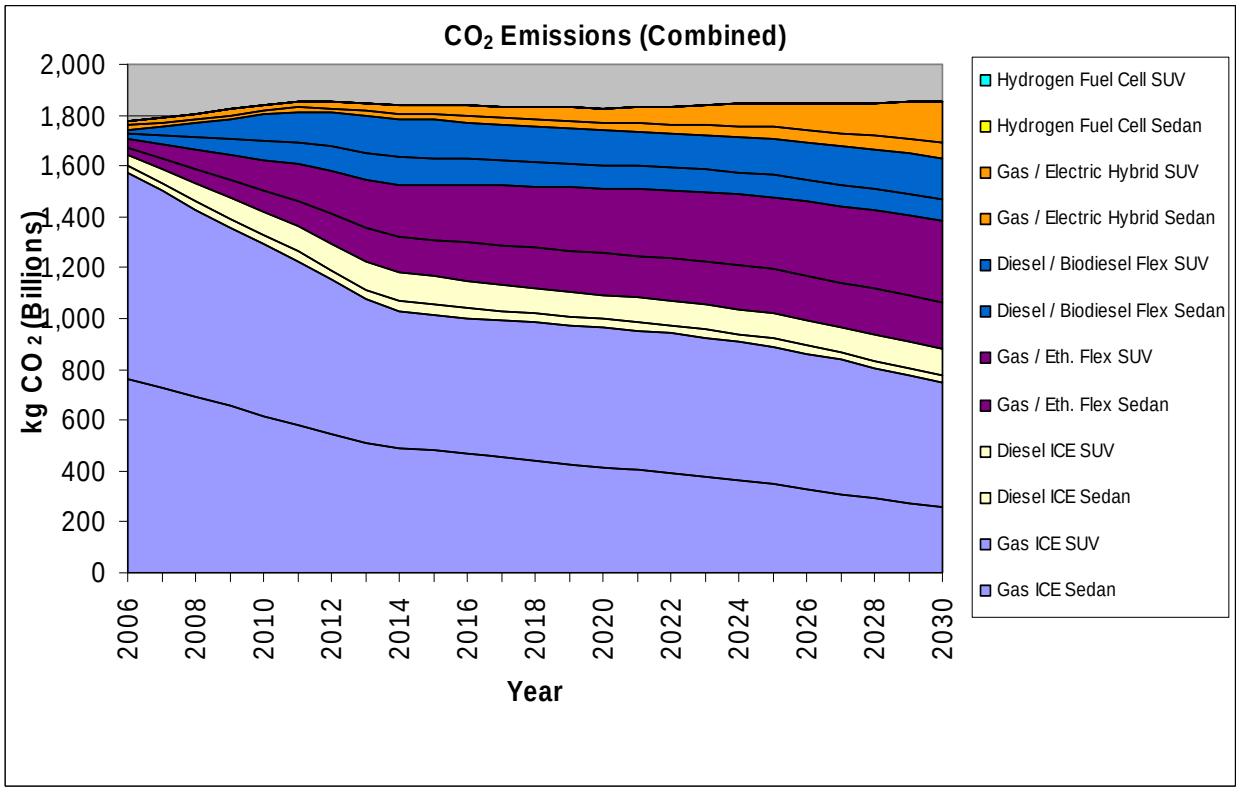

CO2 Emissions (Combined)
kg CO 2 (Billions)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan

Figure 48: U.S. Alternative Scenario, Increasing Fuel Economy Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	393	4,030
% Reduction	17.5%	8.1%

As can be seen by the above graphs and table, increasing the CAFE standards to the level recently proposed in the U.S. legislature would have a dramatic effect on carbon dioxide emissions over the course of this projection. The CAFE standard increase leads to a leveling off of the annually emitted carbon dioxide from the total fleet, so that in the 25th year of the projection, the carbon dioxide emissions are 17.5% lower than they would otherwise have been and the summed carbon dioxide emissions from all 25 years have been reduced by 8.1%.

While this policy does not lead to an overall reduction in the annual level of carbon dioxide emissions compared to the first year of the projection it does prove to be a powerful policy tool in helping to curb the growth of emissions that occurs due to a growing vehicle population. What this policy does not accomplish is any sort of dramatic shift in the vehicle market shares. Gasoline ICE and diesel vehicles decline at approximately the same rates as they do in the baseline scenario.

Thus, while this policy does seem to be important in the near term for curbing our growing emissions from the transport sector, it will be generally ineffective in speeding a transition towards alternative domestically available fuels, such as hydrogen or biofuels. As such, it is an important short term strategy, but cannot be viewed as a long term solution as it does not address the question of long term sustainability and energy security. In terms of efficacy at reducing carbon dioxide emissions bother over the course of the study as well as in the final year for the projection, this scenario, by far, achieves the best results.

3.5.2. Increasing the Number of Makes and Models

One of the factors that was identified as having a significant impact on the market shares of alternative vehicle adoption was the availability of a variety of makes and models for consumers to choose from. This is especially important at the lower levels of make and model availability (<10) where there is often not enough variety to meet the varying needs of a diverse population. A larger number of makes and models within a production line allows for consumers to choose amongst a greater range of slight variations within the different vehicles, allowing them to find a vehicle that more closely meets their optimal desire.

While alternative vehicle technologies – especially hybrid gasoline-electric vehicles – have made gains in the public sector for many decades, their primary utilization has been in government and corporate fleets. Government agencies in particular have had a federal executive order since 1992 for a certain number of their fleet to be made up of alternative vehicles (75% of all light duty vehicles) (AFAVDC, 2007) and many states and municipalities have similar mandates for their fleets. A common issue that has been cited in the efforts of the agencies to meet these mandates, however, has been the lack of available alternative vehicle makes and models to meet their goals (Rivers, 2003).

The scope of this problem has ranged from having to purchase vehicles that did not meet the agencies' wants, such as having to buy larger, less fuel efficient sedans, to not having being able to purchase vehicles that would meet the agencies' needs. The primary cause of this has been the relatively low public demand for these vehicles, which has made it difficult for the manufacturers to justify AFV production lines for the lack of an economy of scale. Thus, when

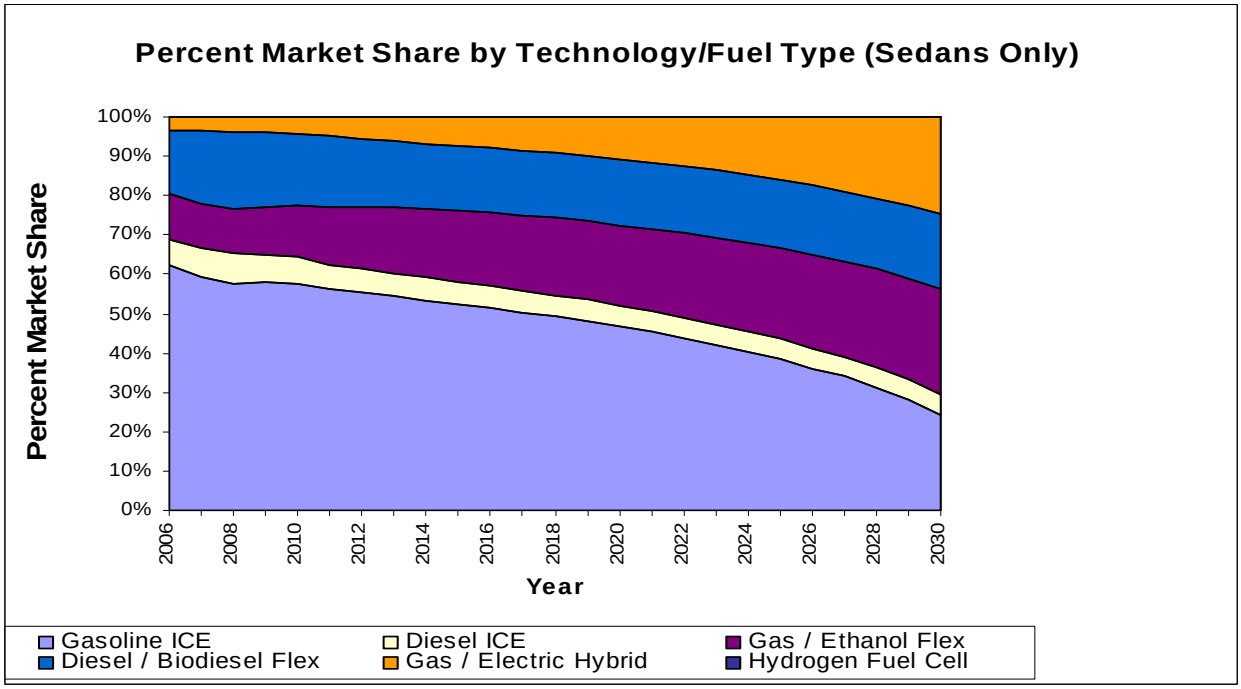
agencies have to purchase AFVs, they are often faced with the prospect of purchasing vehicles that do not exactly meet their needs and are more expensive (Rivers, 2003).

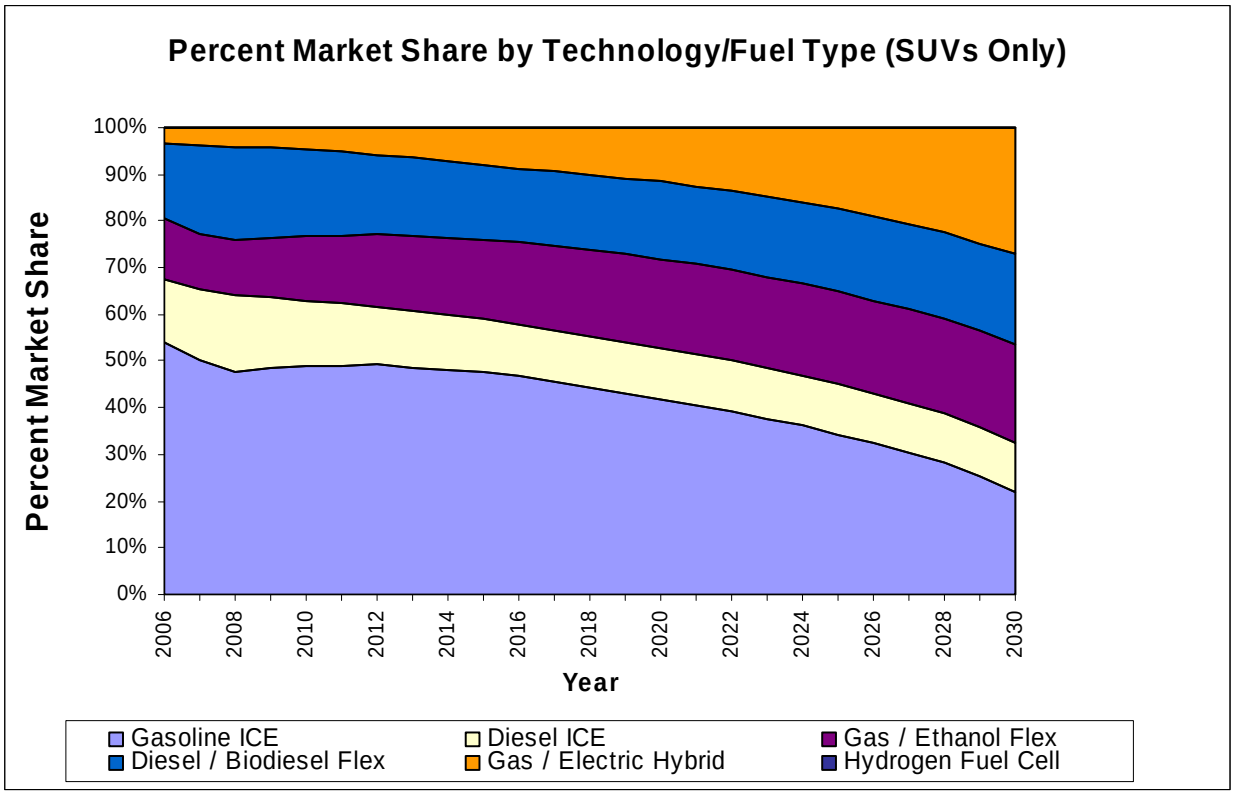
These same barriers affect the public domain as well, and thus a government mandate to the manufacturers to produce a greater number of alternative vehicle makes and models could lead to a greater public acceptance and adoption of these technologies. The primary opposition to this effort would arise from the auto manufacturers on the basis that these new production lines, having low economies of scale, would be more expensive and thus would be in lower demand. Thus the mandate would almost certainly have to be accompanied by a subsidy or incentive for the production or purchase of these vehicles in order to make the public adoption of the vehicles occur. Current federal incentives for the purchase of alternatively fueled vehicles are based on the incremental cost of purchasing that vehicle compared to a conventional vehicle. For a typical passenger vehicle, the credit is equal to 50% of the incremental cost of adopting that technology compared to a conventional vehicle and is capped at $5,000, although typically the incentives are far lower than $5,000 (AFAVDC, 2007).

Since the majority of these vehicles are flex-fuel vehicles capable of running on a range of fuel inputs of mixes of entirely gasoline or nearly all biofuel, the creation of fueling infrastructure would not raise a significant barrier to the adoption of those vehicles, though it would mean that any environmental or energy security benefits gained from the increased adoption of these vehicles would be dependent on the availability of the alternative fuels, which in many areas of the country is nearly non-existent.

In our baseline scenario, several alternative fuel vehicles have already achieved a significant number of makes and models by the beginning of the projection, such as E85 flex-fuel SUVs. Others, however, have not. In this scenario, a federal mandate will enact a rule saying that by 2020, 30% of the makes and models produced must be alternative fuel capable and that this value will increase by 2% each year thereafter. Current market proportions of these makes and models would be maintained. This will be accompanied by the application of the existing alternative fuel vehicle tax credits provided by the federal government.

Figure 49(a-g): U.S. Alternative Scenario, Increasing Makes/Models




Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
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Year
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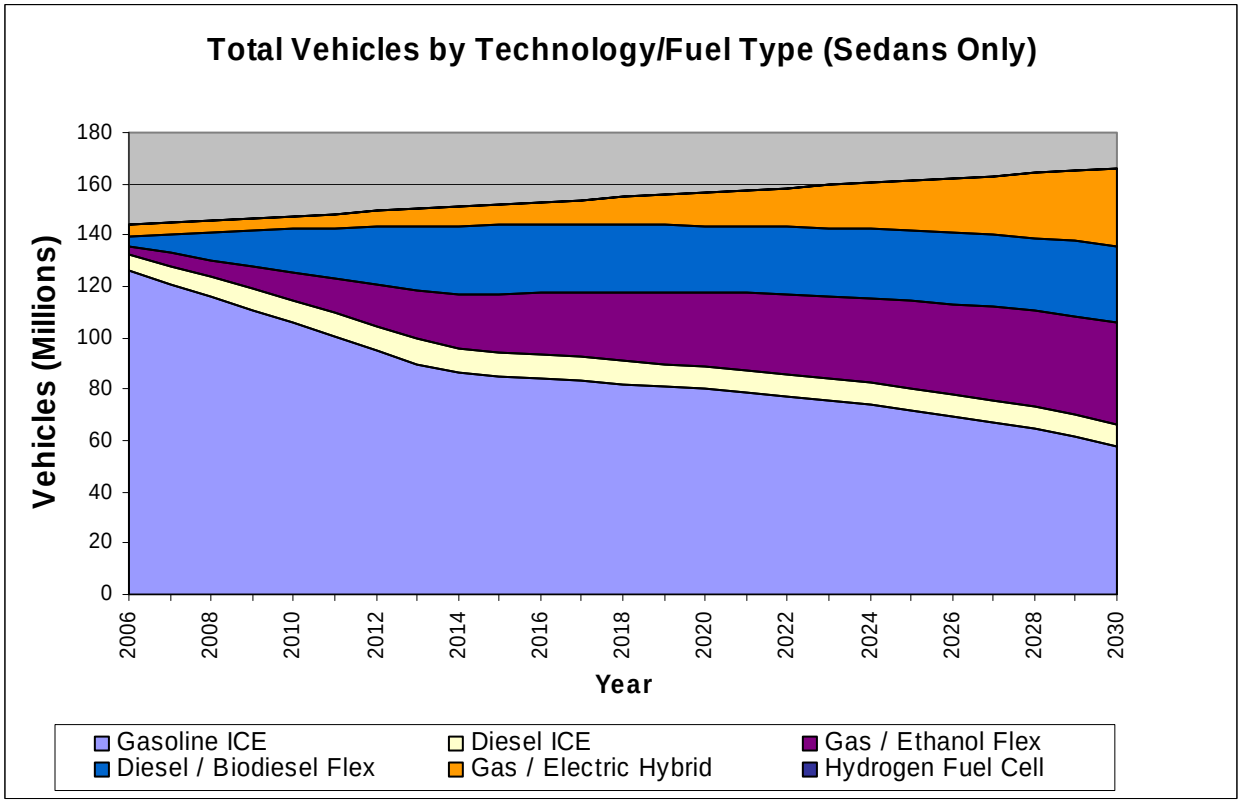
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
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140
120
100
80
60
40
20
0
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2008
2010
2012
2014
2016
2018
2020
2022
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Year
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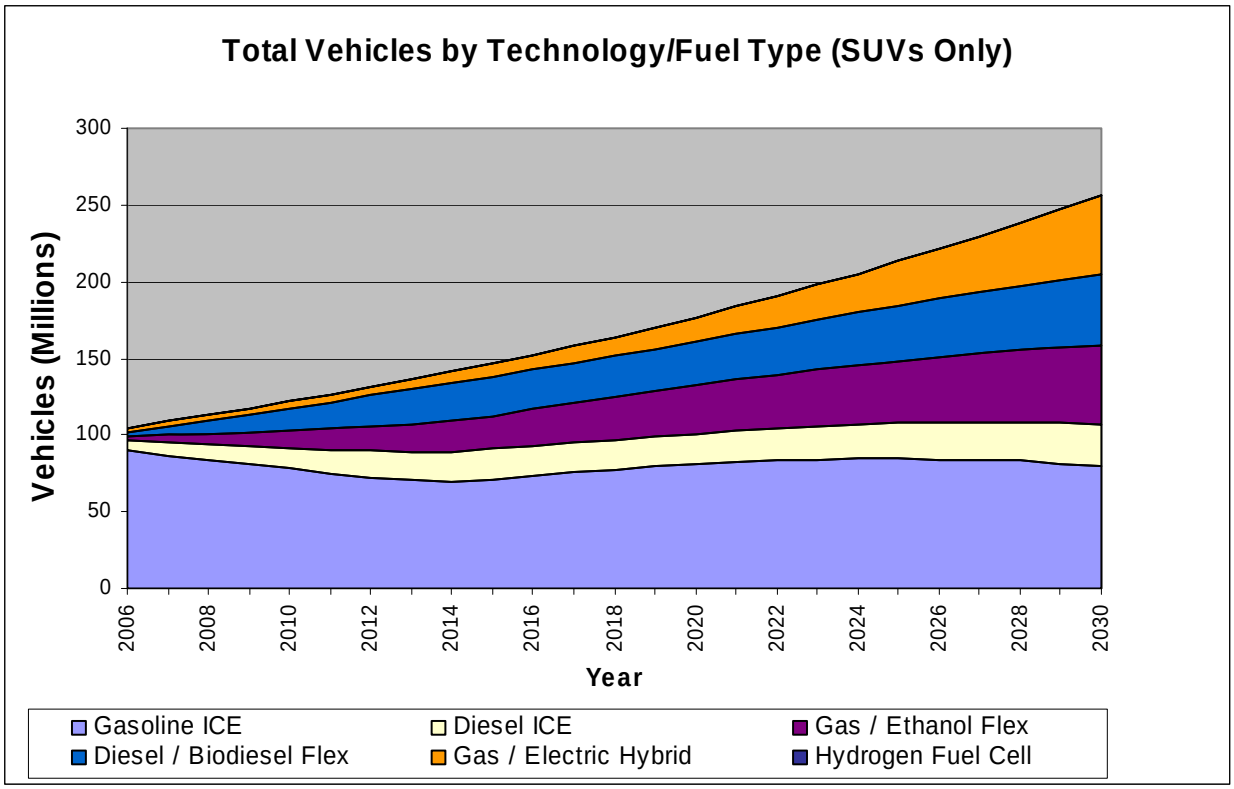
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
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2012
2014
2016
2018
2020
2022
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2030
Year
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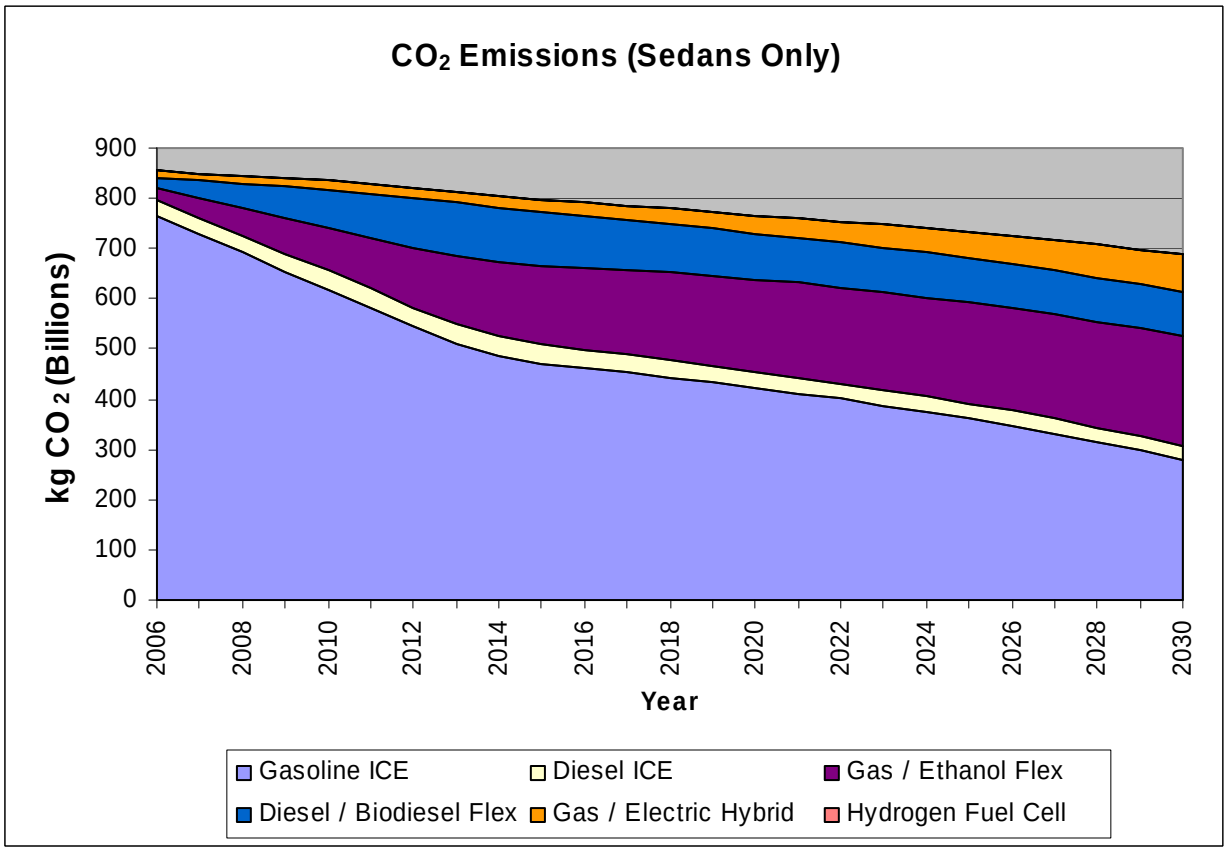
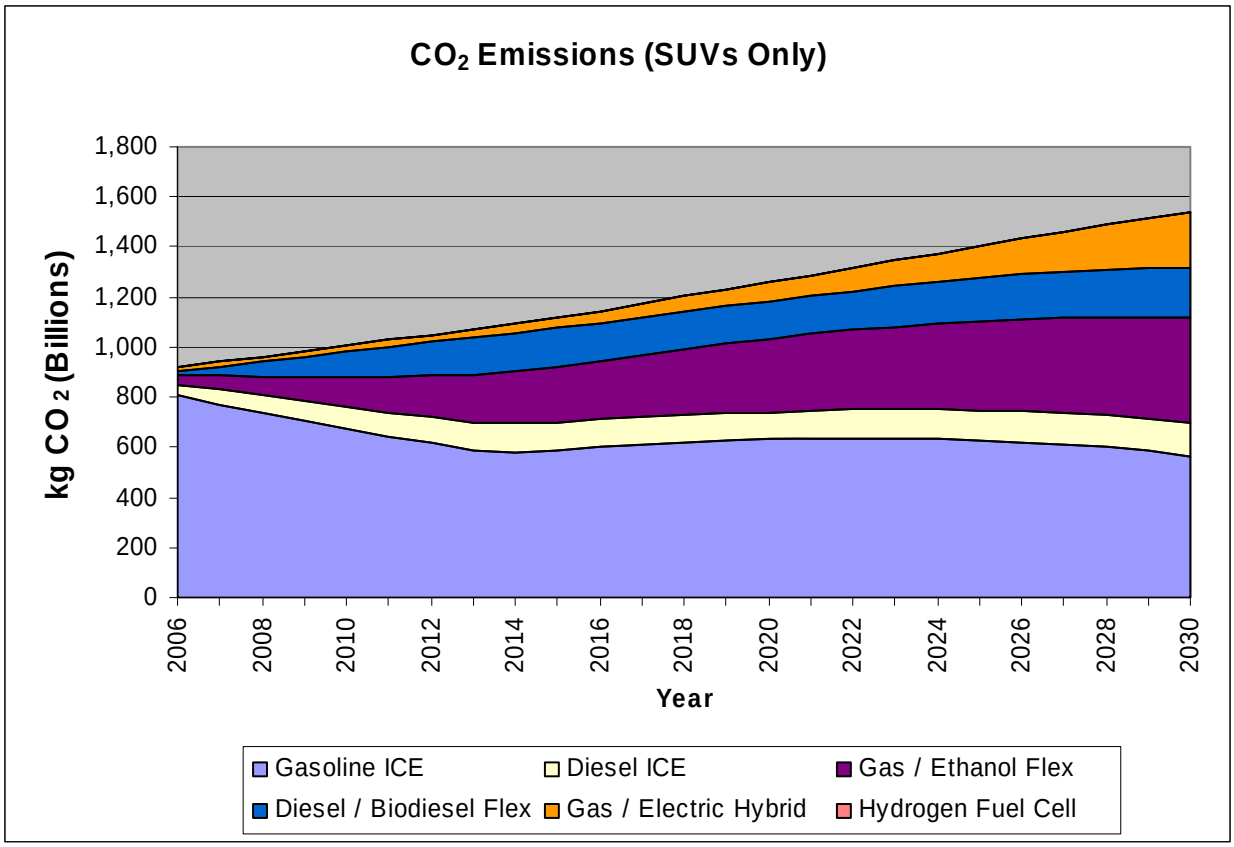
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

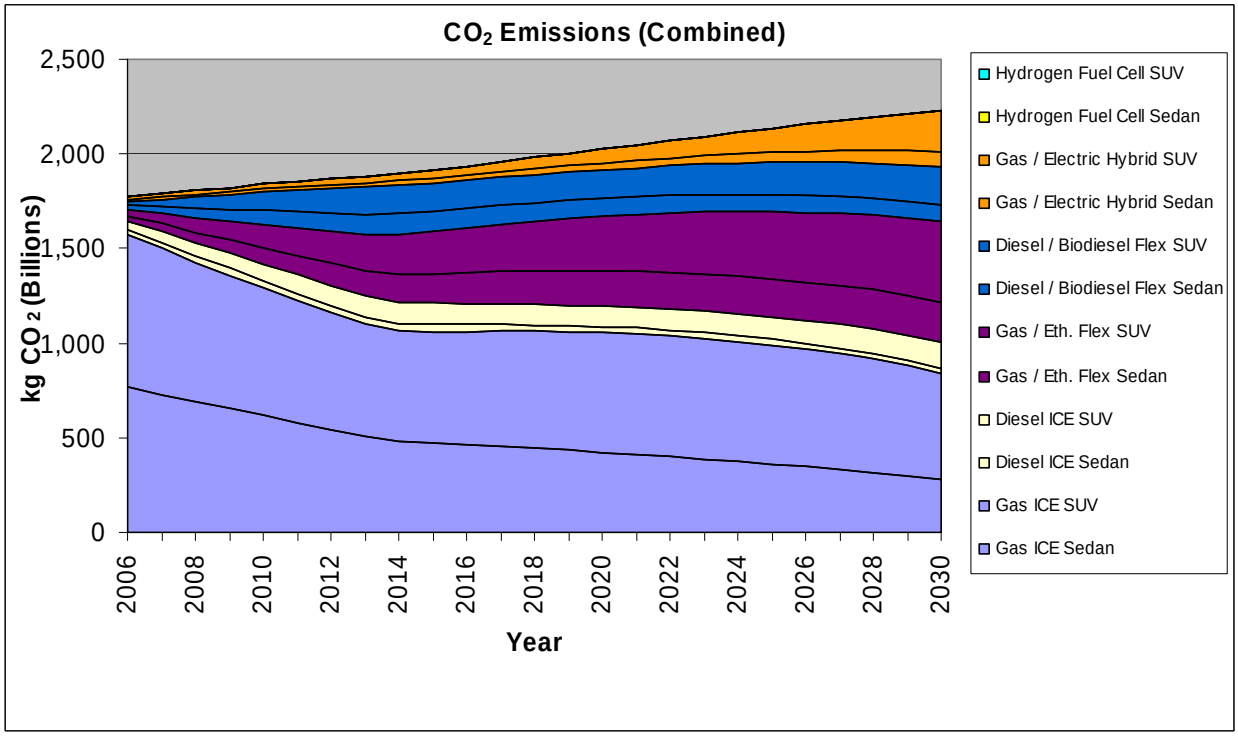

CO2 Emissions (Combined)
kg CO2 (Billions)
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan

Figure 50: U.S. Alternative Scenario, Increasing Makes/Models Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	20	125
% Reduction	0.9%	0.3%

Increasing the number of makes and models achieves only modest results as compared to the baseline scenario. As there are no dramatic technological improvements being assumed in this scenario, any change in carbon dioxide emissions must result from the market shift to less polluting vehicles and fuels. Mandating a higher percentage of makes and models to be flex fuel capable does encourage such a shift but not to any extreme level as compared to the baseline scenario.

With only a modest change in the passenger fleet vehicle market shares and no technological improvements to lower emissions, this scenario ends up representing the second least beneficial policy tool available. Such a heavy handed mandate would surely be resisted and, as it projected to do little to improve the national greenhouse gas emissions profile, it would be inadvisable to proceed with such dramatic measures.

Overall, this scenario is ineffective, representing neither a near term, intermediate term, nor a long term solution or part of the solution to reducing carbon dioxide emissions. This is primarily due to the fact the in the baseline scenario, the number of alternative makes and models are already expected to exceed the threshold level that would have otherwise created a barrier to their adoption in the fleet. Once this threshold has been surpassed, then adding additional makes and models does little to improve their market shares.

3.5.3. Increase in Fuel Mixing

While a great deal of attention has been paid to the implementation of flex fuel vehicles in the national fleet, there is also a great deal of potential for the application of fuel mixing in the conventional fleet. An internal combustion engine can be designed to run on almost any highly combustible liquid, the exact chemical nature of the fuel is relatively unimportant. Thus is it possible to actually mix fuels together and use them in a conventional engine, provided that the physical properties of the mixture do not vary too far from the original.

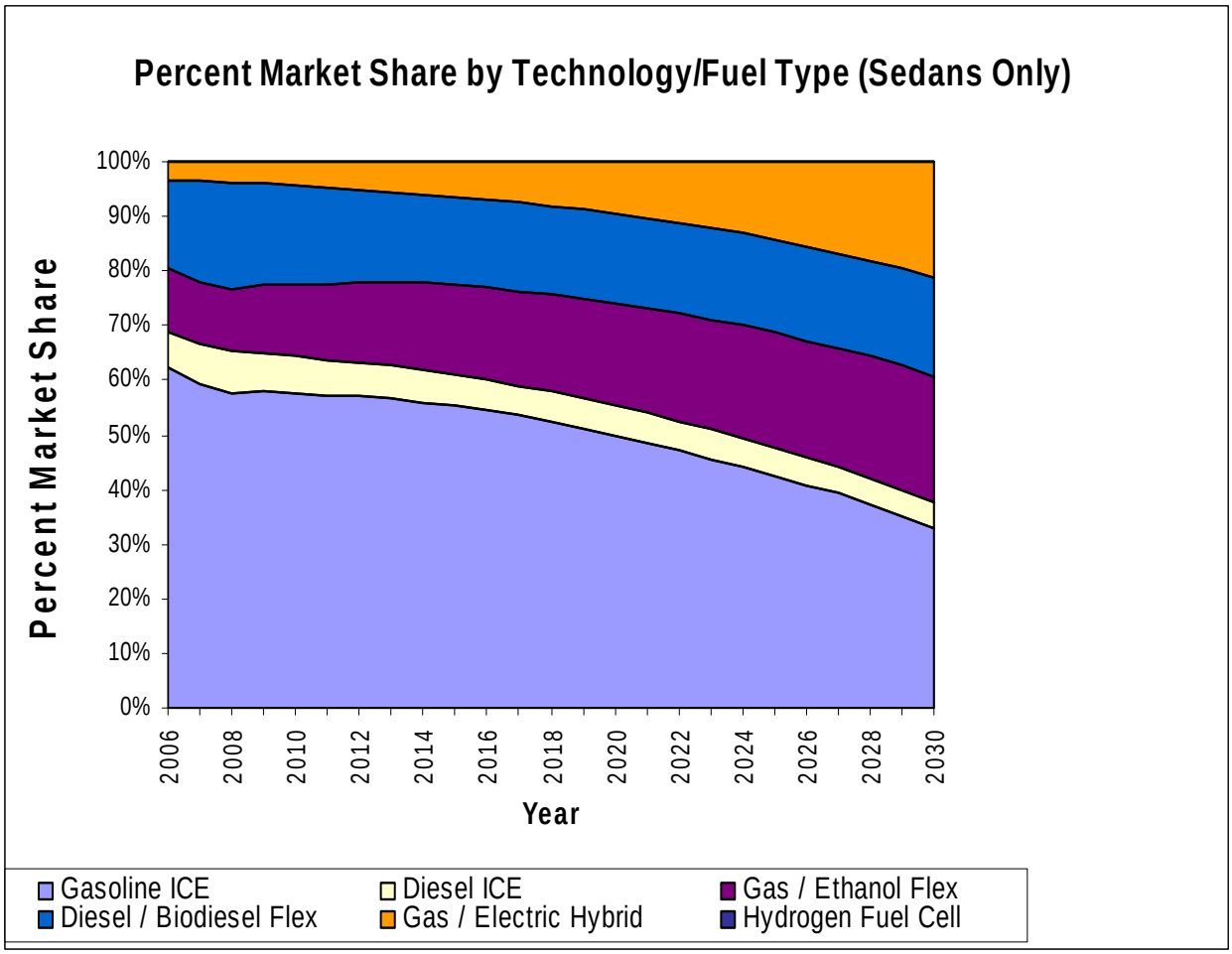
This concept has already been widely applied in low levels around the country with ethanol being mixed in small amounts with gasoline and biodiesel being mixed in small amounts with diesel. Ethanol and biodiesel are not chemically equivalent to gasoline and diesel, however, and because of the differences there is a limit to the amount of mixing that may occur for a conventional engine to still be able to operate on the fuel. This limit is 20% ethanol in gasoline and as much as 50% biodiesel in diesel.

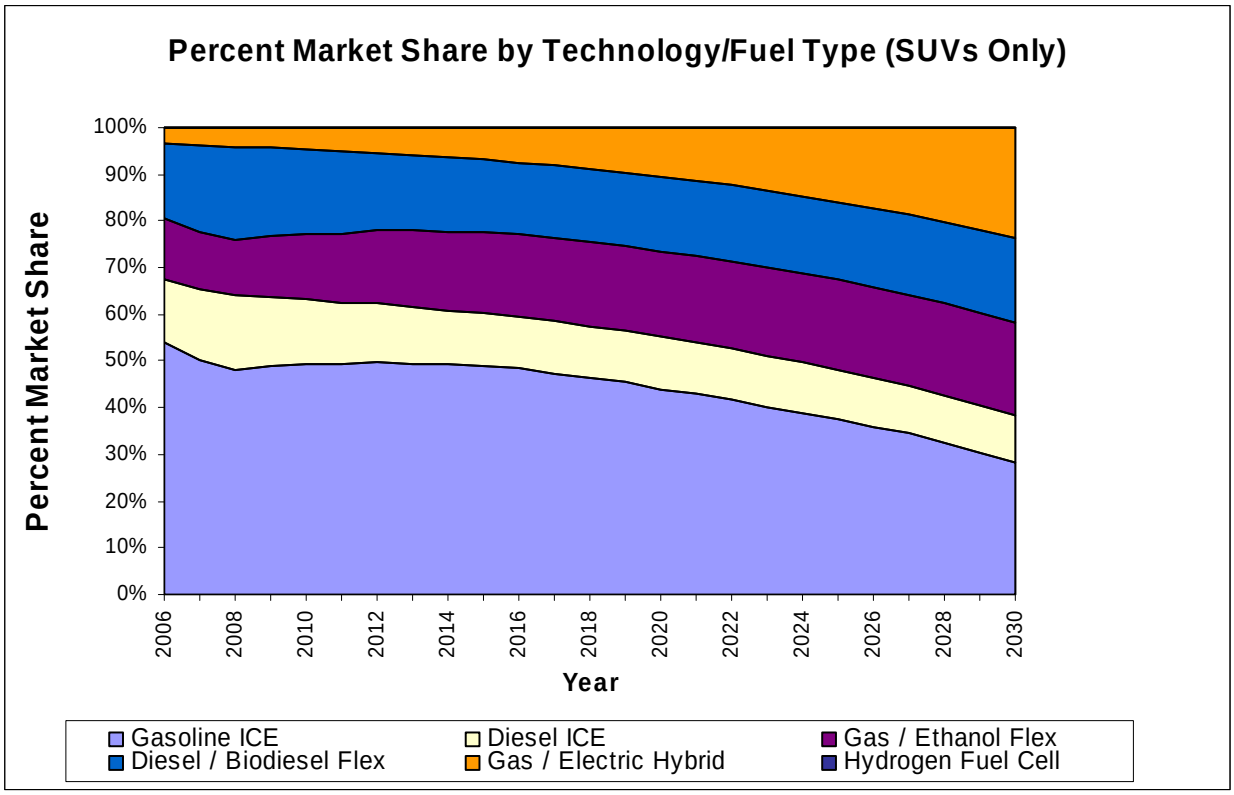
The current mixing levels, however, do not come even close to approaching these amounts. Currently, ethanol is found in levels as high as 10% in many states while biodiesel rarely exceeds a level of 5% (Harrow, 2007). Thus there is a significant potential for increasing the levels of the renewable biofuels in conventional fuels. The attractiveness of this scenario is in its relative immediacy as compared to options involving a technology shift at the vehicle level. Vehicle pool shifts require a significant period of time to allow for the natural retirement of the existing fleet. Fuel is turned over at a much faster rate, however. Despite the relative speed with which the fuel mixture could be changed, it would still require a period of at least several years in order to build the infrastructure and grow the crops in order to produce the fuel in the amount that would be needed to make up a significant portion of the national fuel mix.

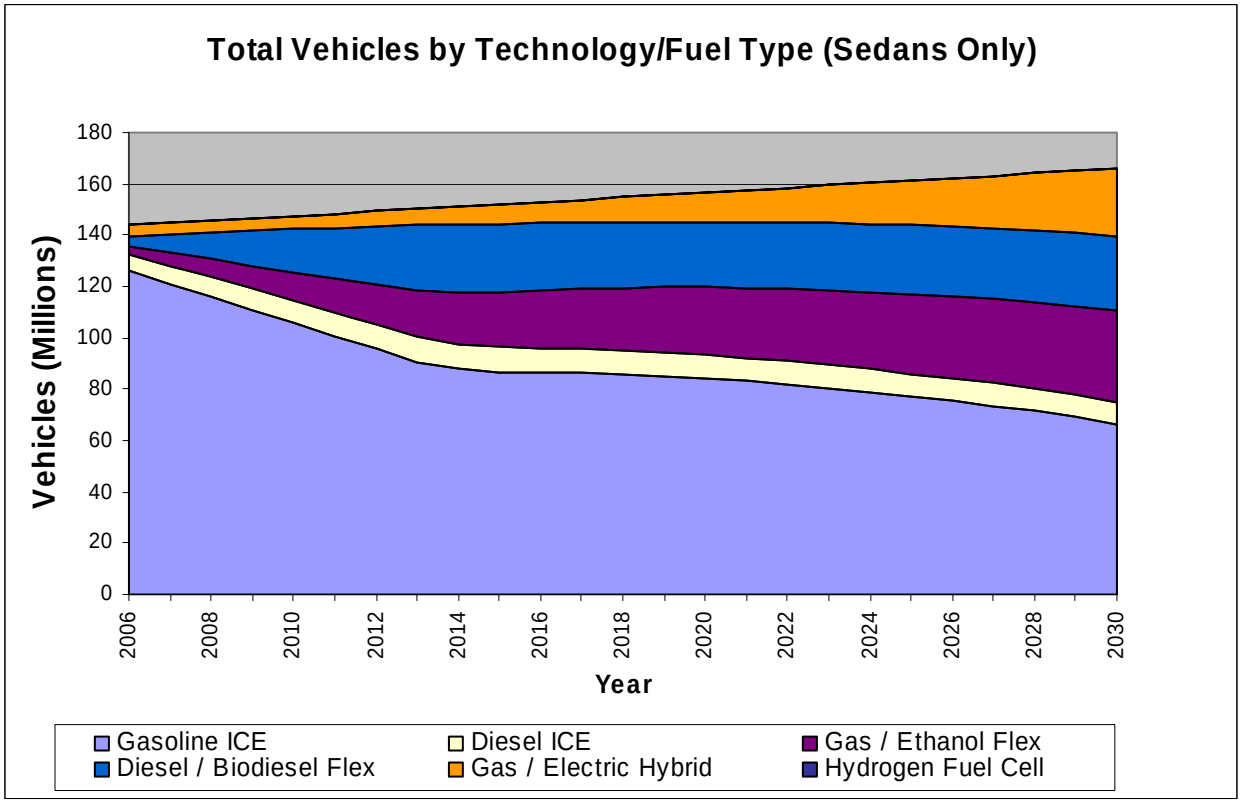
Renewable Fuel Standards, which mandate a specific level of biofuels to be included in all conventional fuels, have been implemented in various states already; Oregon, Pennsylvania, New Mexico, and other states and municipalities across the country have created renewable fuel standards requiring low levels of mixing in all fuel sold in their states (NPRA, 2007). Additionally, the creation of a national-level renewable fuels standard has been debated. Usually these plans are linked to an area's ability to produce a significant amount of the fuel before the mandate goes into effect in order to ensure that the supply will be sufficient for the amount required.

In the baseline scenario, ethanol is added to gasoline in a mixture of 10% and biodiesel is mixed with diesel in a mixture of 20% by 2015, after which these amounts remain level. Additionally, in flex fuel vehicles, neither ethanol nor biodiesel are ever utilized more than 50% of the time. This scenario assumes that a Renewable Fuel Standard was set at the national level and put into effect over the next five years; achieving mixtures close to the technological limits for mixing with fuels for use in conventional fossil fuel vehicles and increasing their usage to 75% in flex fueled vehicles by 2020. This will, by default, alter the price of the fuels, change the overall emissions profile, and lead to a decreased dependence of foreign sources of oil.

Figure 51(a-g): U.S. Alternative Scenario, Increase In Fuel Mixing




Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
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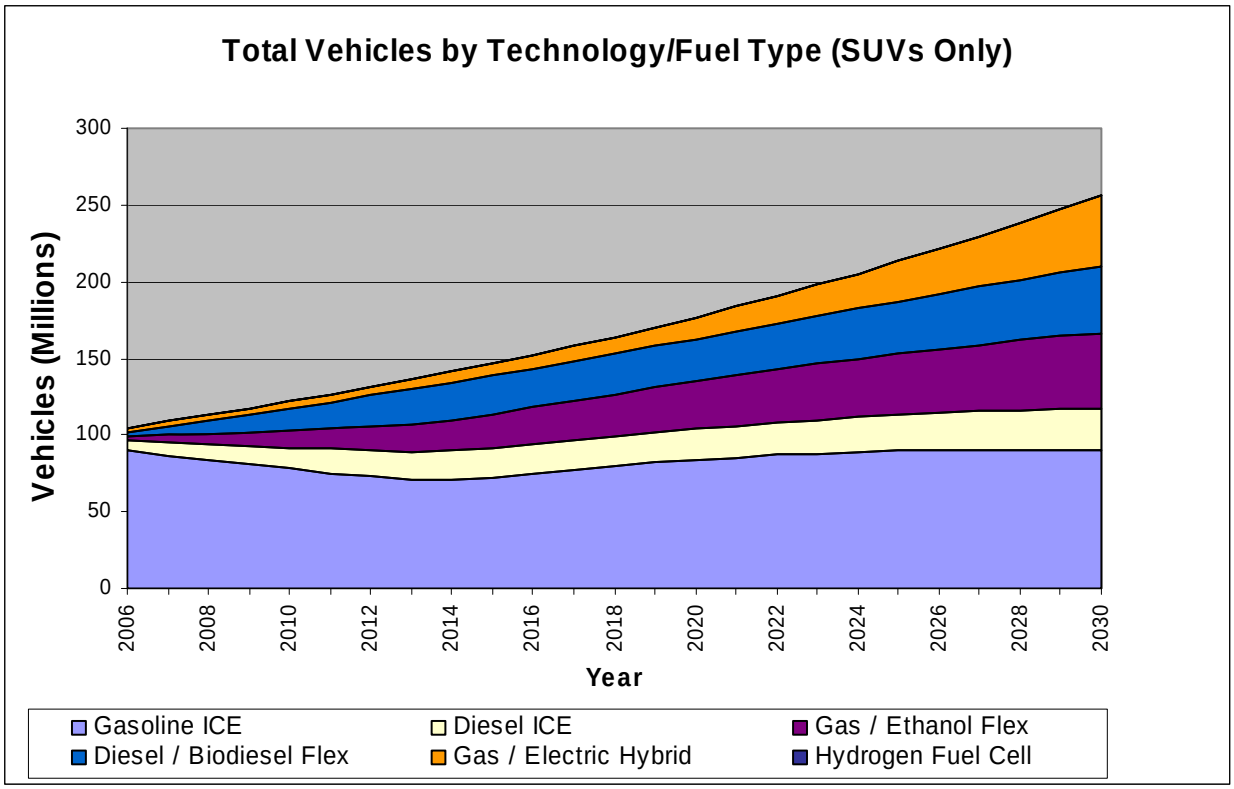
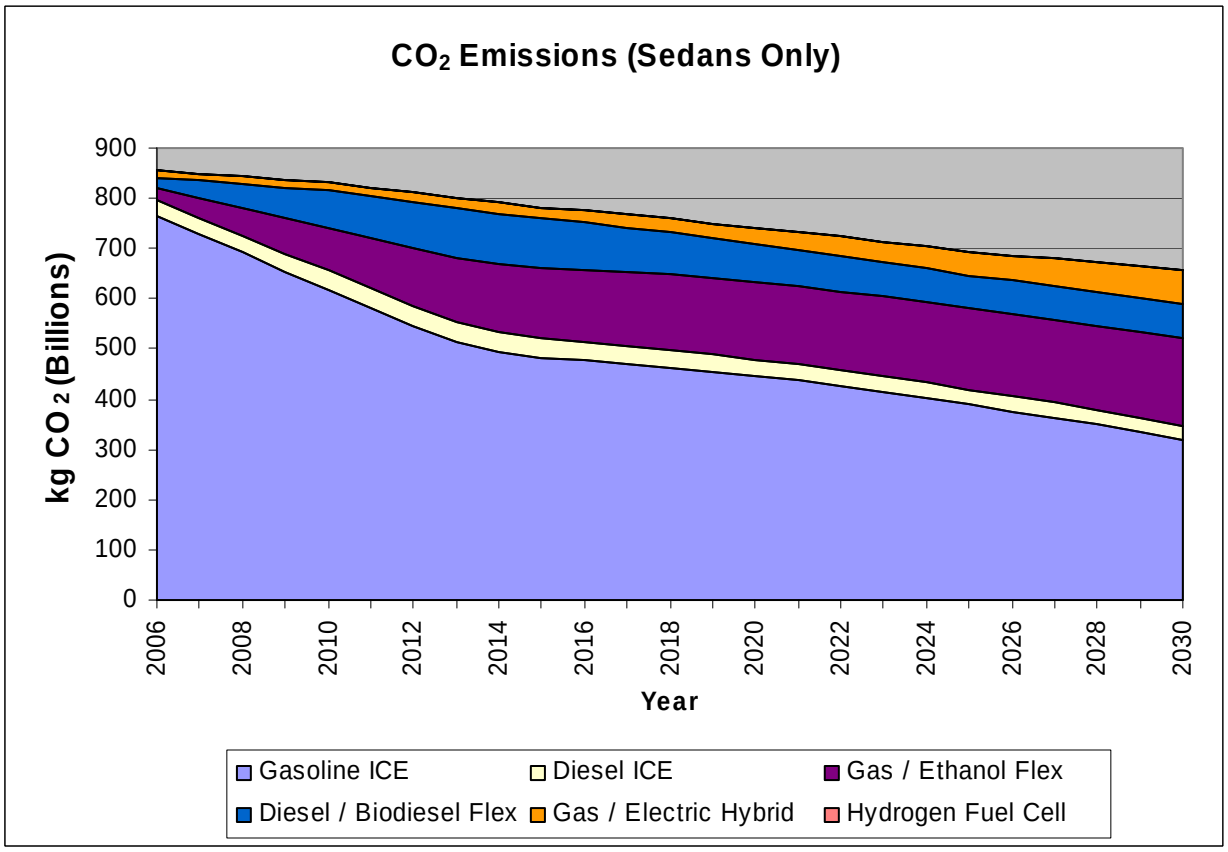
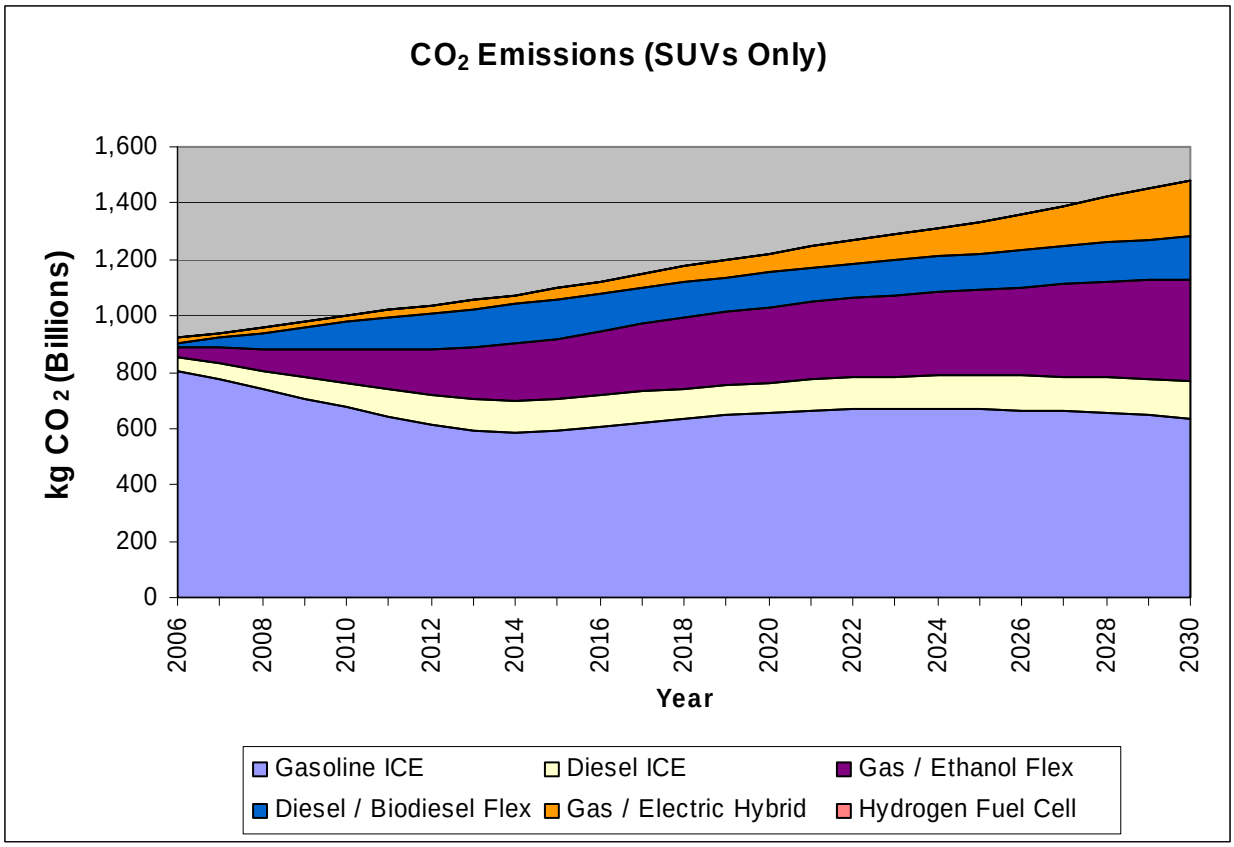
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

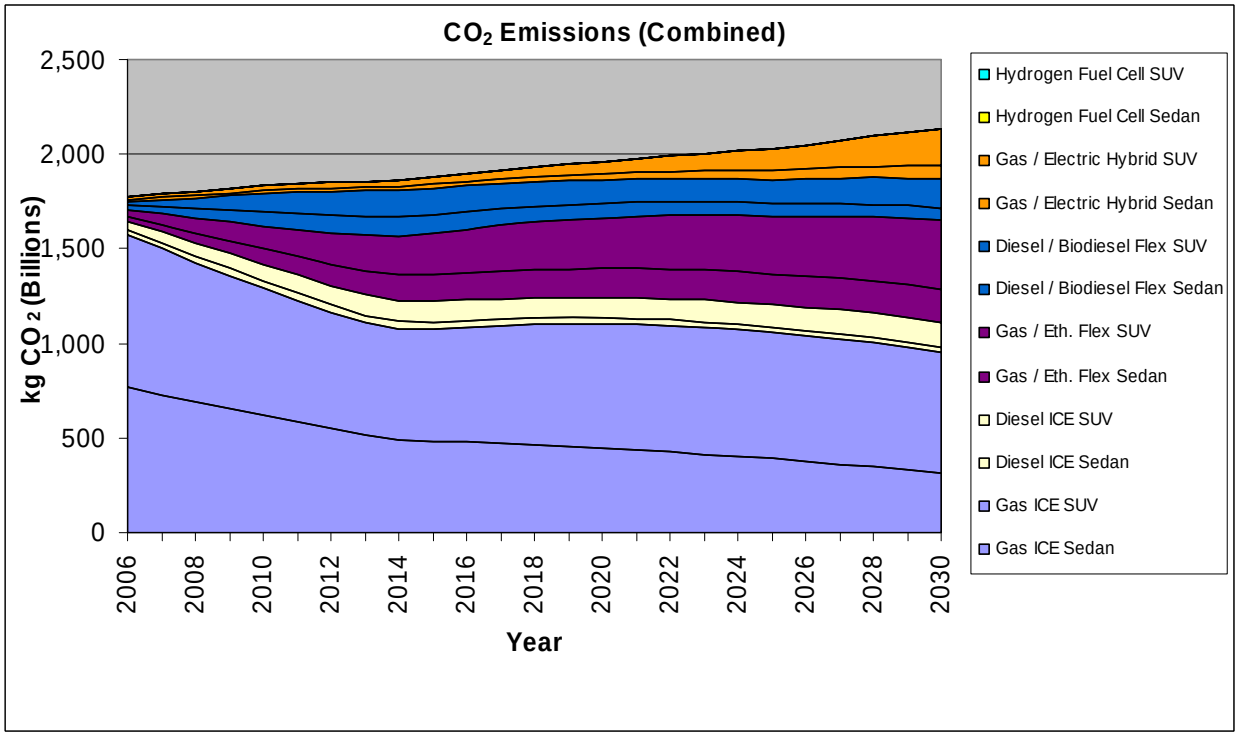

CO2 Emissions (Combined)
kg CO2 (Billions)
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan

Figure 52: U.S. Alternative Scenario, Increase in Fuel Mixing Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	113	1,465
% Reduction	5.0%	2.9%

Increasing the level of fuel mixing proves to be a moderately successful policy given the baseline scenario. The decreases in carbon dioxide emissions are due primarily to the increased use of biodiesel in flex fueled diesel/biodiesel vehicles. This decrease in emissions from the biodiesel flex fuel vehicles is actually large enough that it is offsetting an increase in emissions coming from the ethanol-gasoline flex fuel vehicles.

This scenario clearly shows the mixed and uncertain benefits of policies encouraging the growth of the biofuels sector in this country. While the fuel source is technically renewable, the manner in which it is harvested and refined may not be. Some fuels, such as ethanol, can lead to increased lifecycle emissions as compared to gasoline, especially when coupled with the lower energy content, and thus lower fuel economy, of ethanol. Biodiesel, on the other hand, while still a source of some carbon dioxide emissions from harvesting and refining leads to an overall reduction in carbon dioxide emissions.

Additionally, this study does not examine issues such as food versus fuel, energy security issues, or the economics of switching from an imported energy source to a domestically available one. Ultimately, the primary conclusions that can be drawn are that biofuels do represent a potential method of lowering carbon dioxide emissions, but that they do not represent a magic bullet. By themselves, they can only represent a modest decrease in emissions as compared to the baseline study and even then they do not lead to an absolute reduction in carbon dioxide emissions as compared to the first year of the study. This scenario also shows that when examining the potential use of biofuels, biodiesel is currently the better choice in terms of greenhouse gas control, though more efficient methods of ethanol production, such as the development of commercially viable cellulosic ethanol may change that.

3.5.4. Tax Credits for Alternative Vehicles

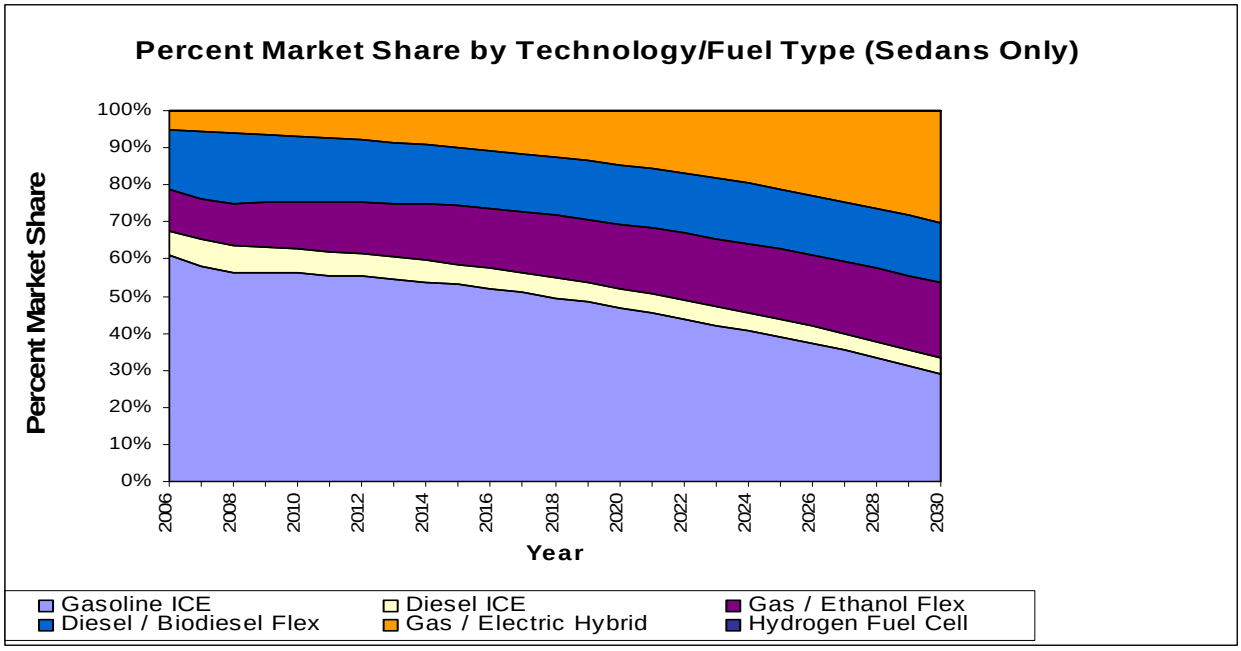
Vehicle price was definitively the most important factor in determining the market shares of different technologies in the fleet. Thus the application of tax credits towards the purchase of alternative vehicles can be expected to be one of the more effective means of encouraging a market shift away from conventional vehicle technologies. This has, in fact, been the favored means in U.S. policy for promoting the adoption of alternative fuel vehicles and hybrid vehicles, with significant federal tax credits available as well as numerous state level credits.

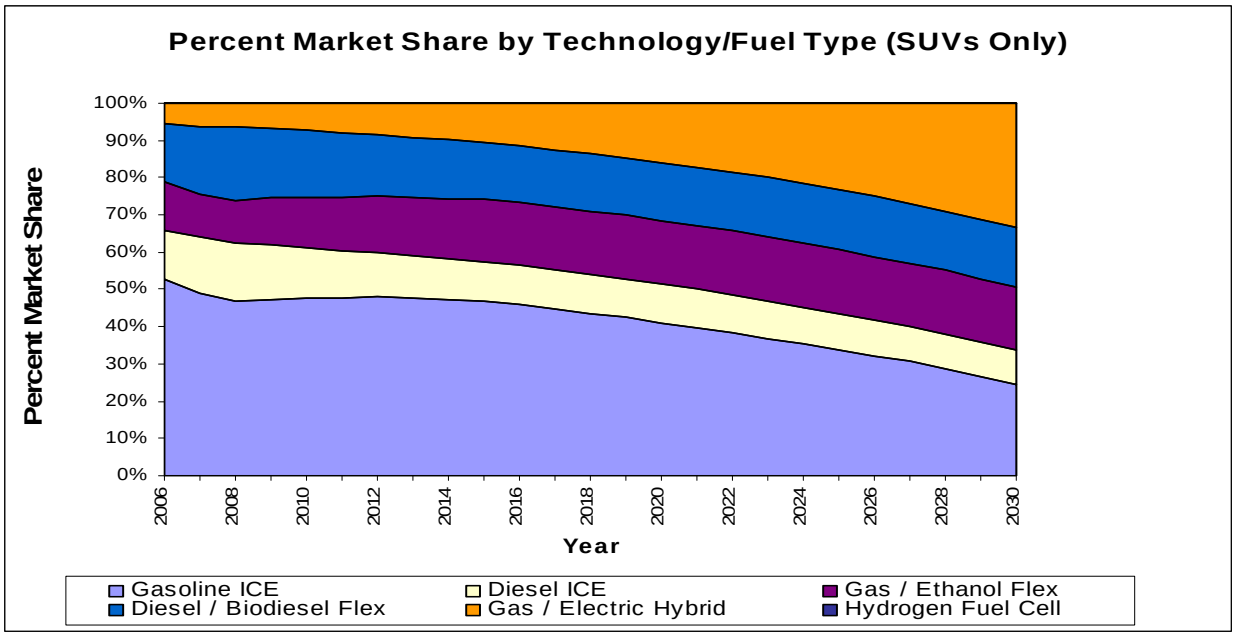
The need for a tax incentive of some sort is quite important for the early adoption of alternative vehicles. Alternative vehicles almost always have a premium price attached to them making them cost a few hundred to several thousand dollars more than an equivalent conventional vehicle. This cost difference is often a significant barrier and it prevents the adoption of the technology despite other potential benefits, such as increased gas mileage, environmental concerns, or the ability to refuel at home. When the vehicle price becomes closer to that of the conventional vehicles however, the advantages can cause a dramatic shift in market shares.

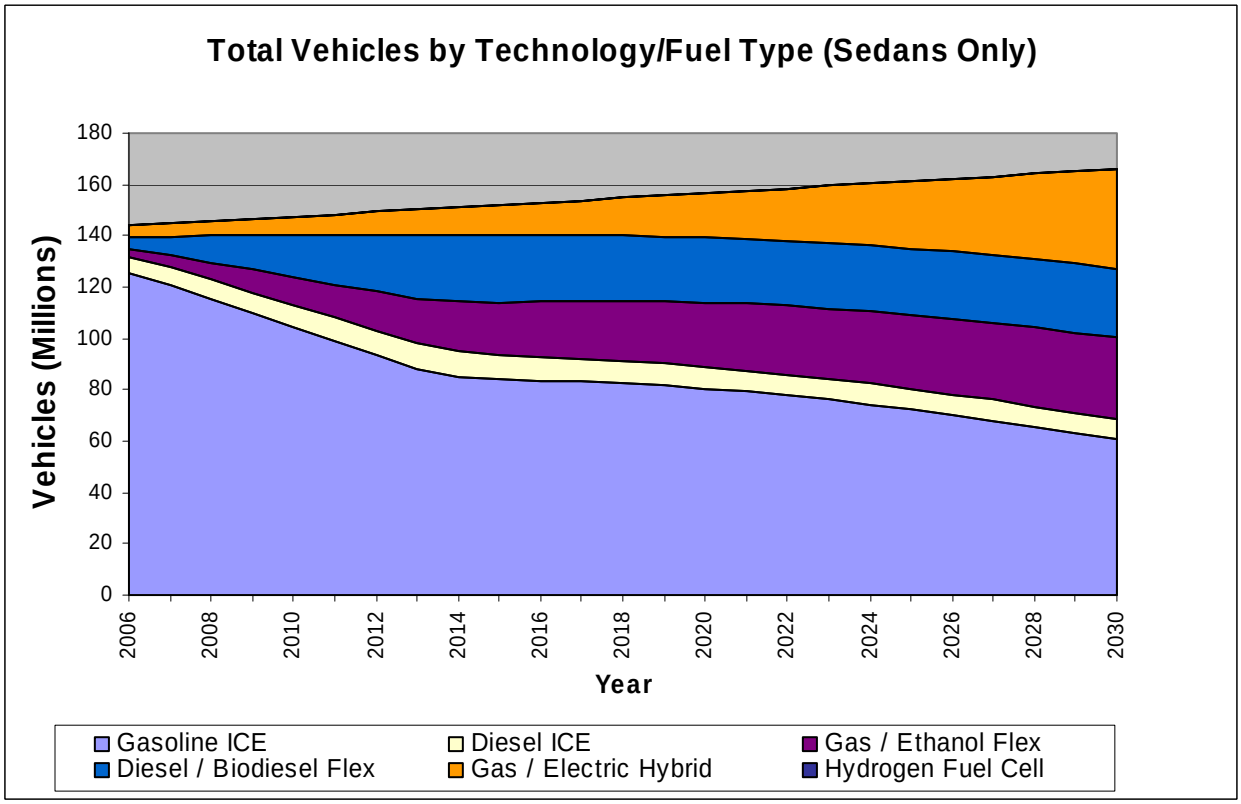
This policy type has seen recent success in the promotion of hybrid gasoline-electric vehicles. Federal tax credits were offered through EPAct 2005 beginning in 2006 at levels ranging from $250 to $3,150 for purchasers of hybrid gasoline electric vehicles depending on the environmental benefits being provided by the vehicle compared to a similar conventional vehicle (EERE, 2007). These credits were designed to be phased out over time, being cut to 50% after the first 60,000 vehicles from each manufacturer were sold, then being cut to 25% six months later, and then cut entirely after an additional six months has elapsed.

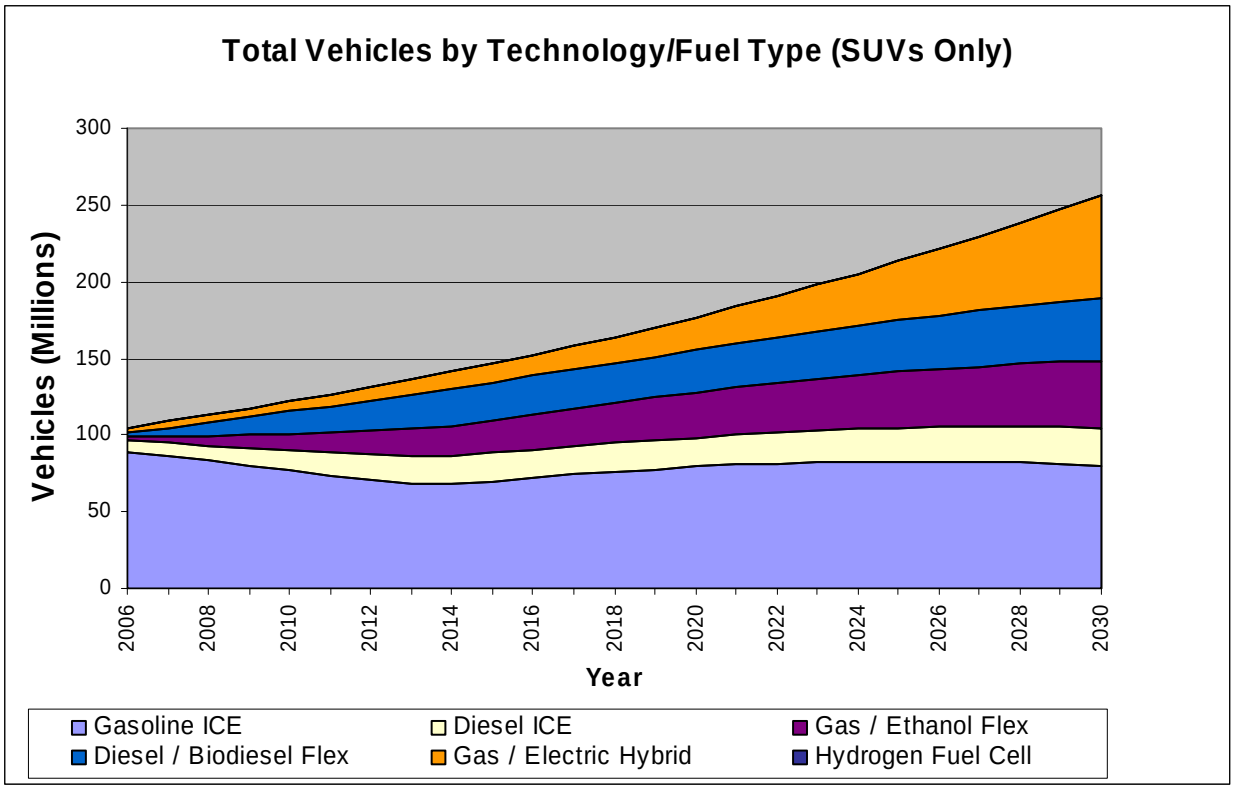
This scenario examines the potential for these incentives if they were to remain in effect for a much greater period of time. In order to gauge the variety of effects that could occur, three sub-scenarios will be examined. In the first scenario, the average incentive offered by the EPAct 2005 bill, which is $1,560, will be applied to all hybrids for the duration of the projection. In the second sub scenario, the maximum incentive offered by the EPAct 2005 bill, $3,150, will be offered for the duration of the study. In the final sub scenario, a phased incentive will be offered, where for the first 10 years the $3,150 credit will be offered, and then for the next ten years the $1,560 credit will be offered. This phased credit will attempt to take advantage of the growing economy of scale which is expected to decrease the premium paid for these vehicles as time passes and achieve similar results for less tax incentives offered.

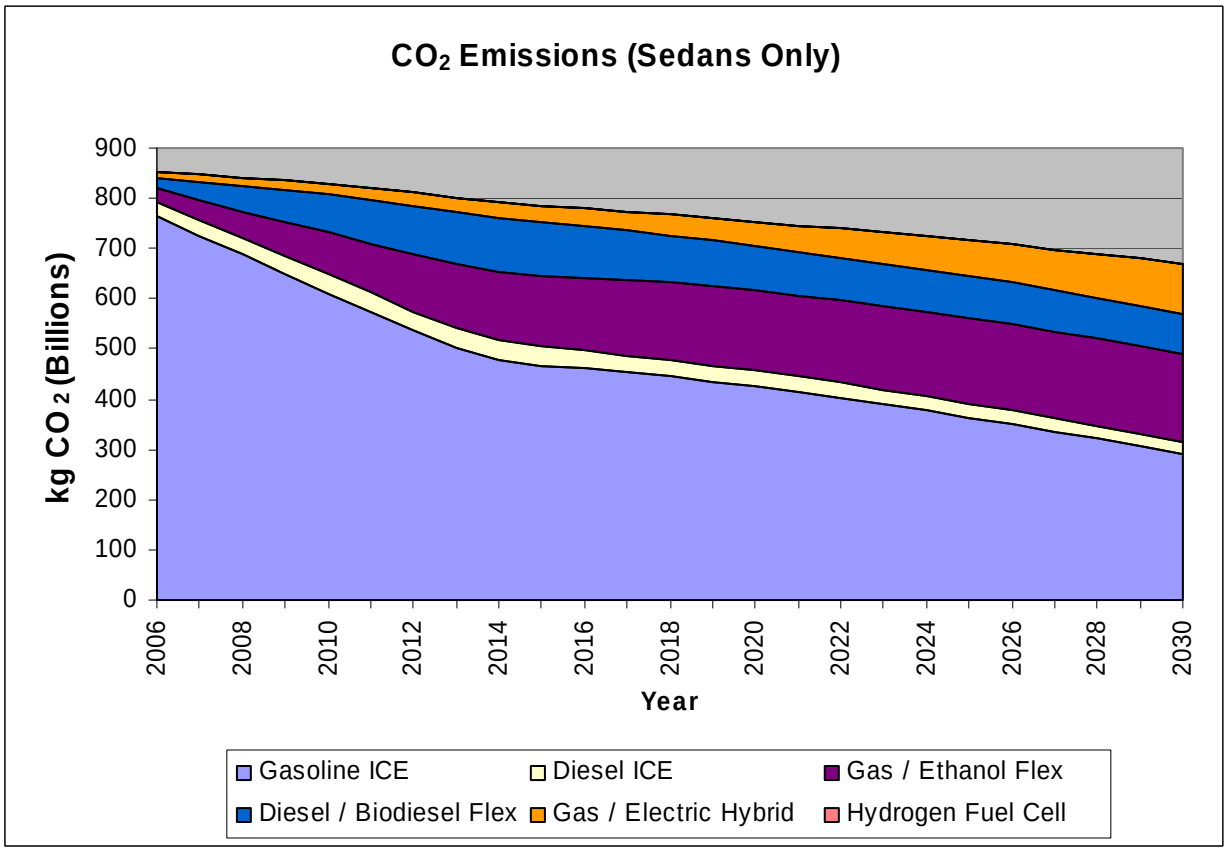
Figure 53(a-g): U.S. Alternative Scenario, Vehicle Tax Credits, Low Incentive

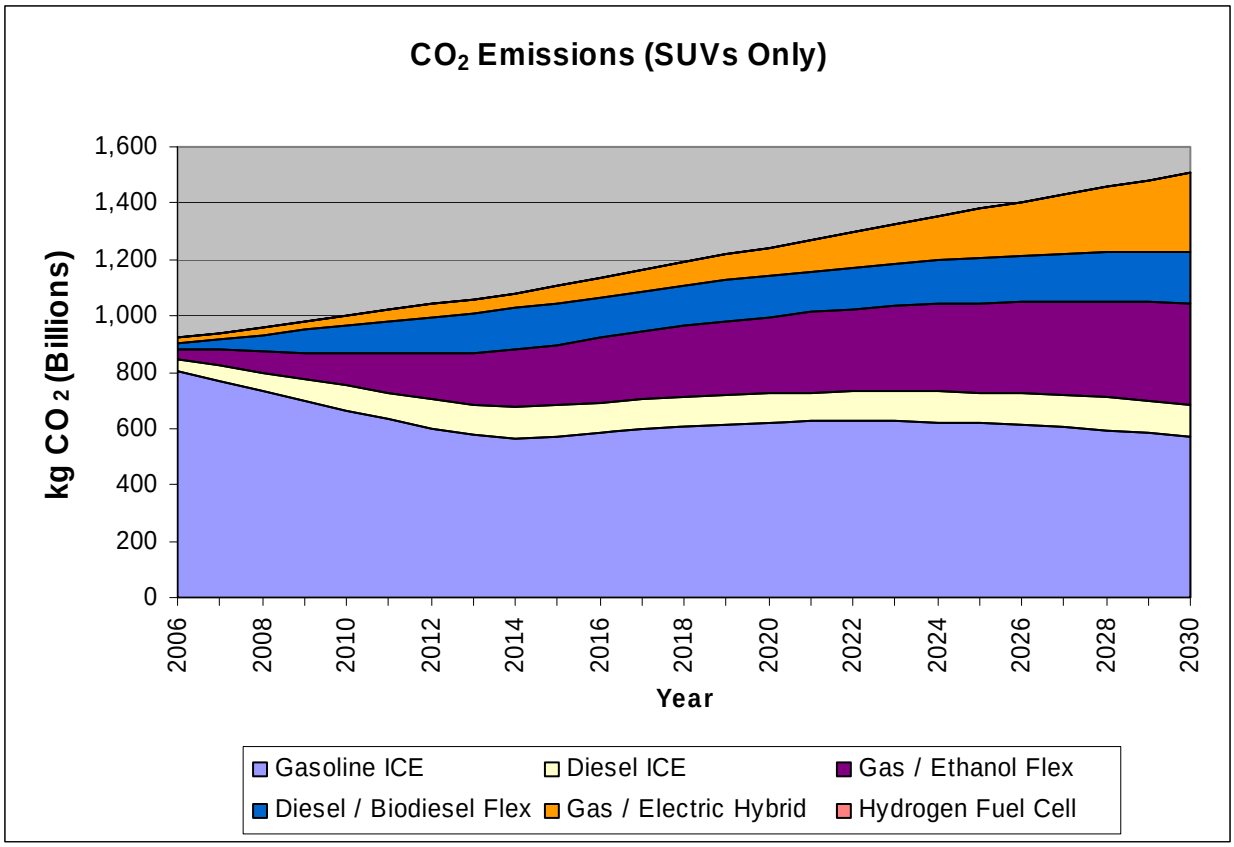



Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell



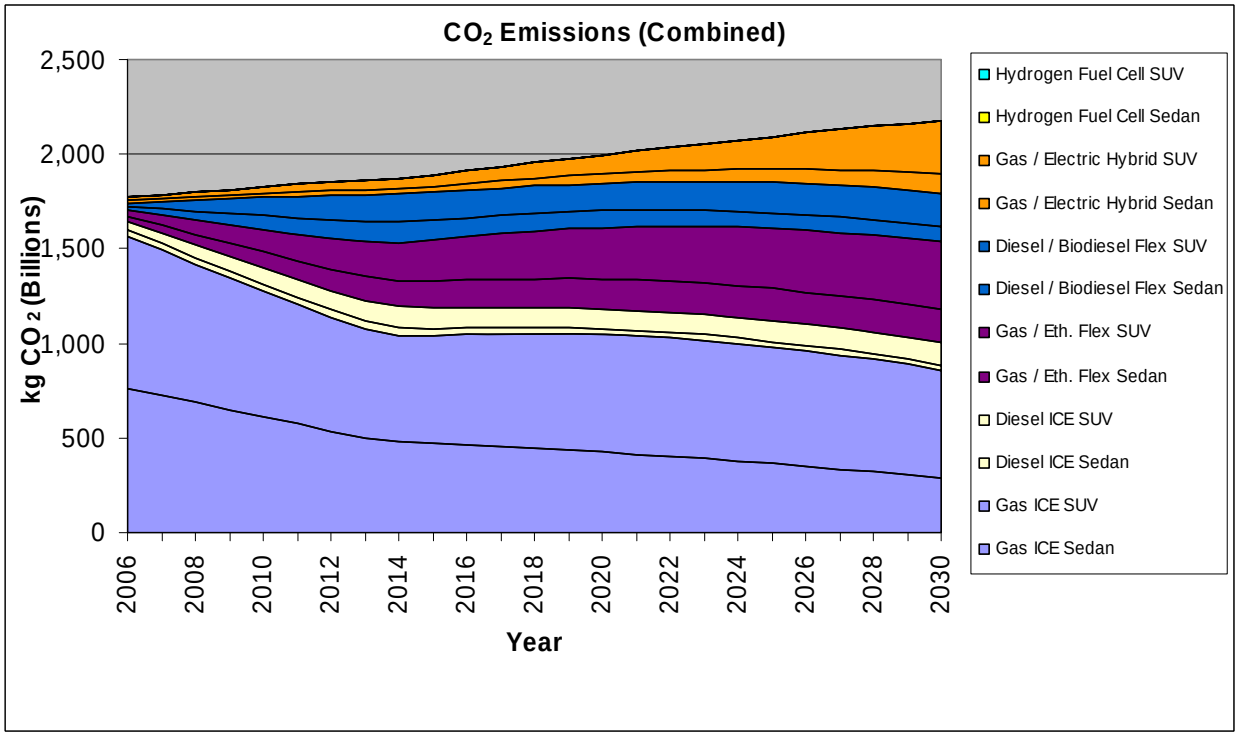
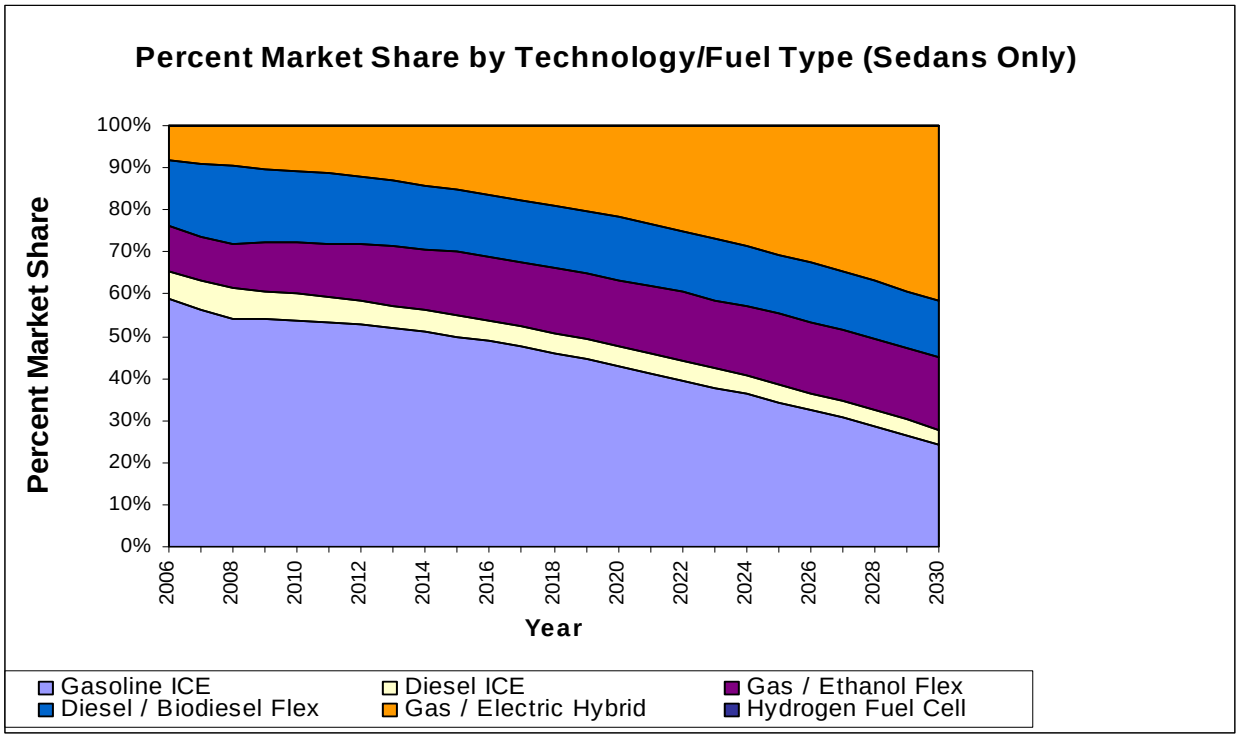


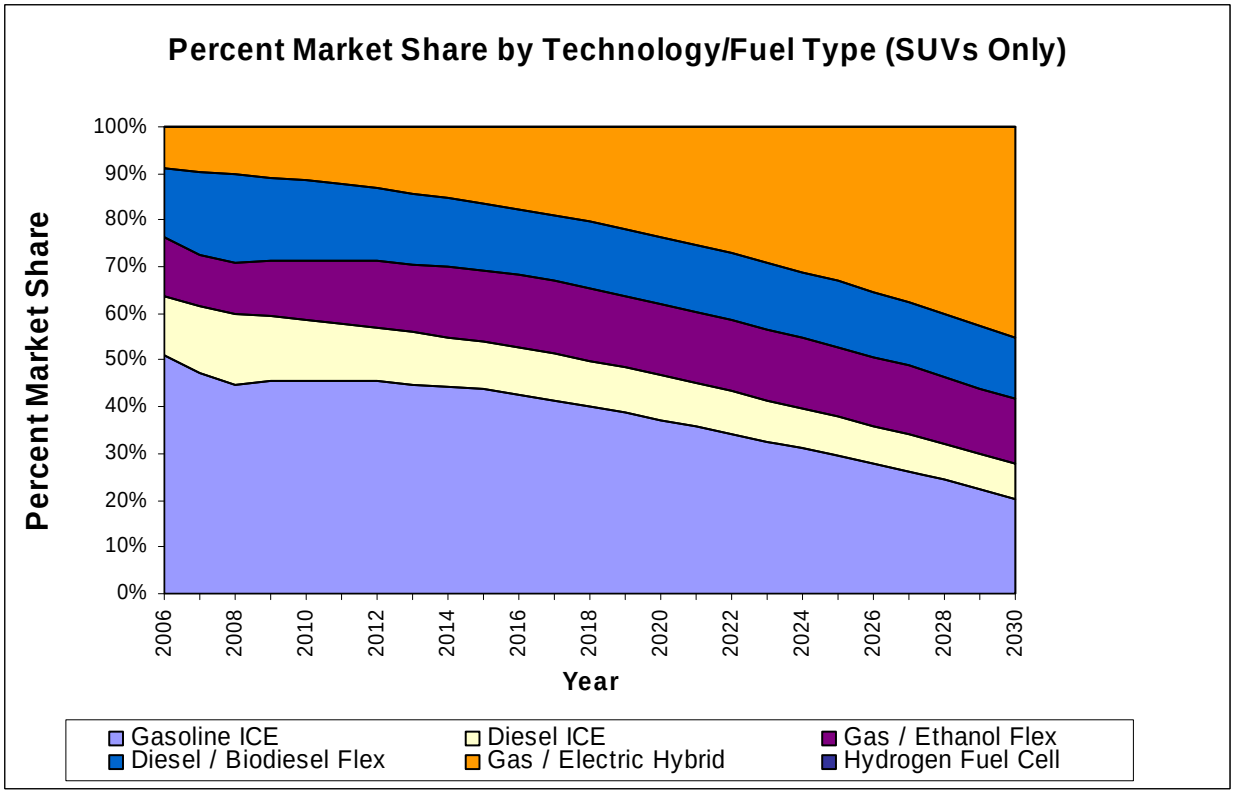
Figure 54: U.S. Alternative Scenario, Vehicle Tax Credit, Low, Summary Chart

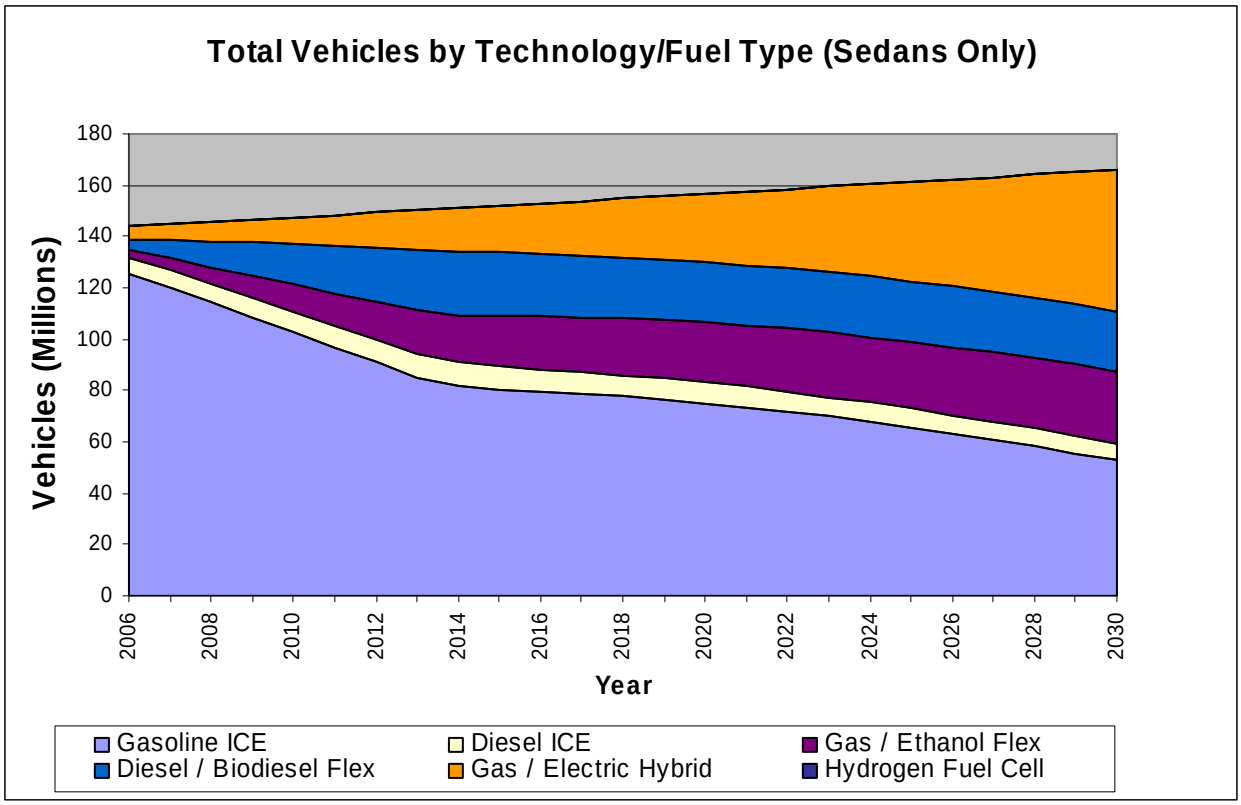
	Year 2030 Emissions	Aggregate Emissions

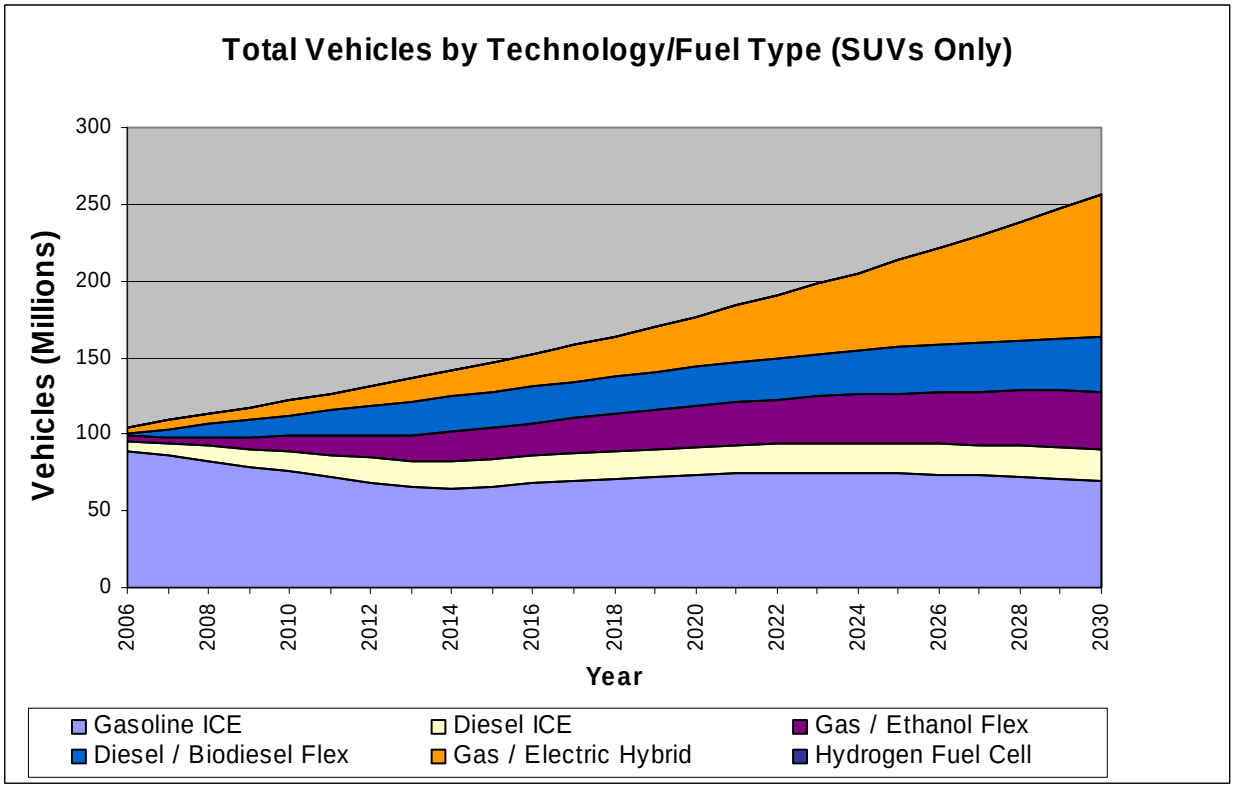
Amount Reduced (Million Metric Tons)	70	800
% Reduction	3.1%	1.6%

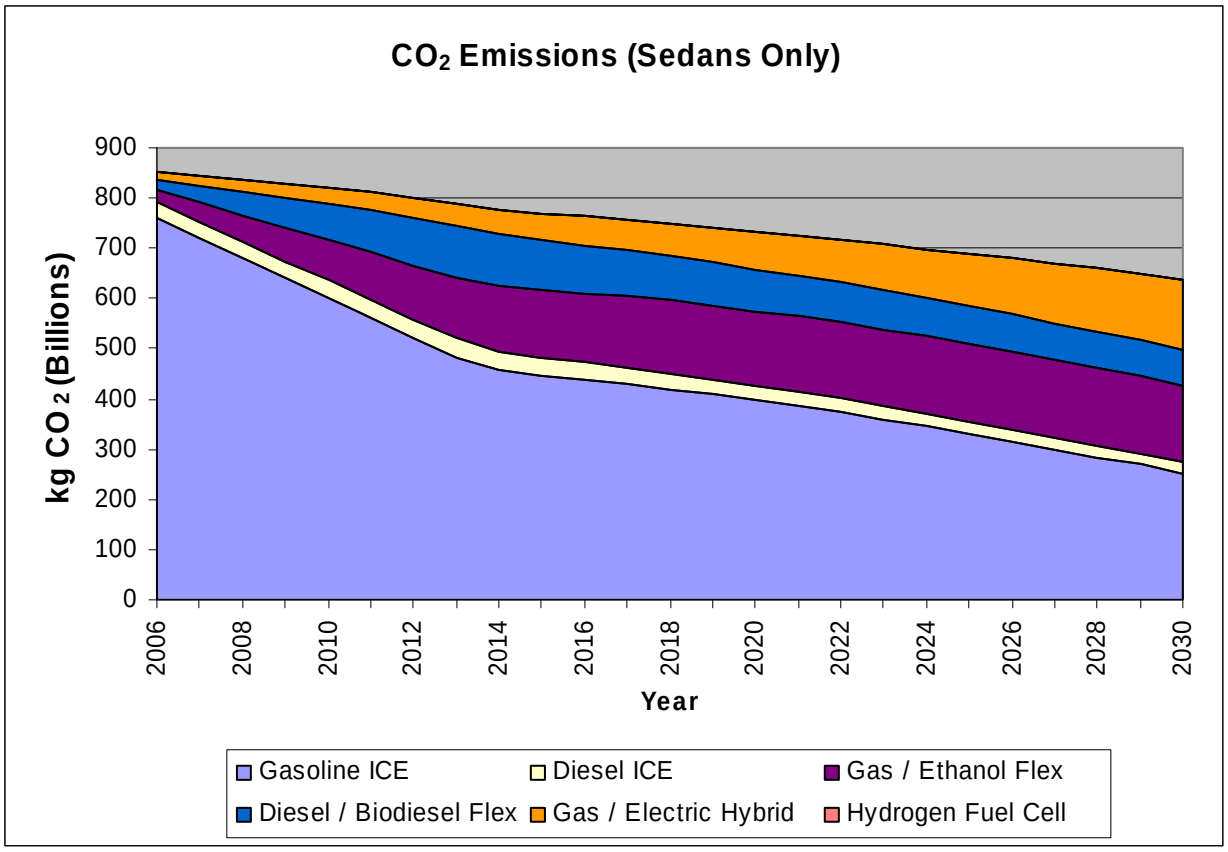
Figure 55(a-g): U.S. Alternative Scenario, Vehicle Tax Credit, High

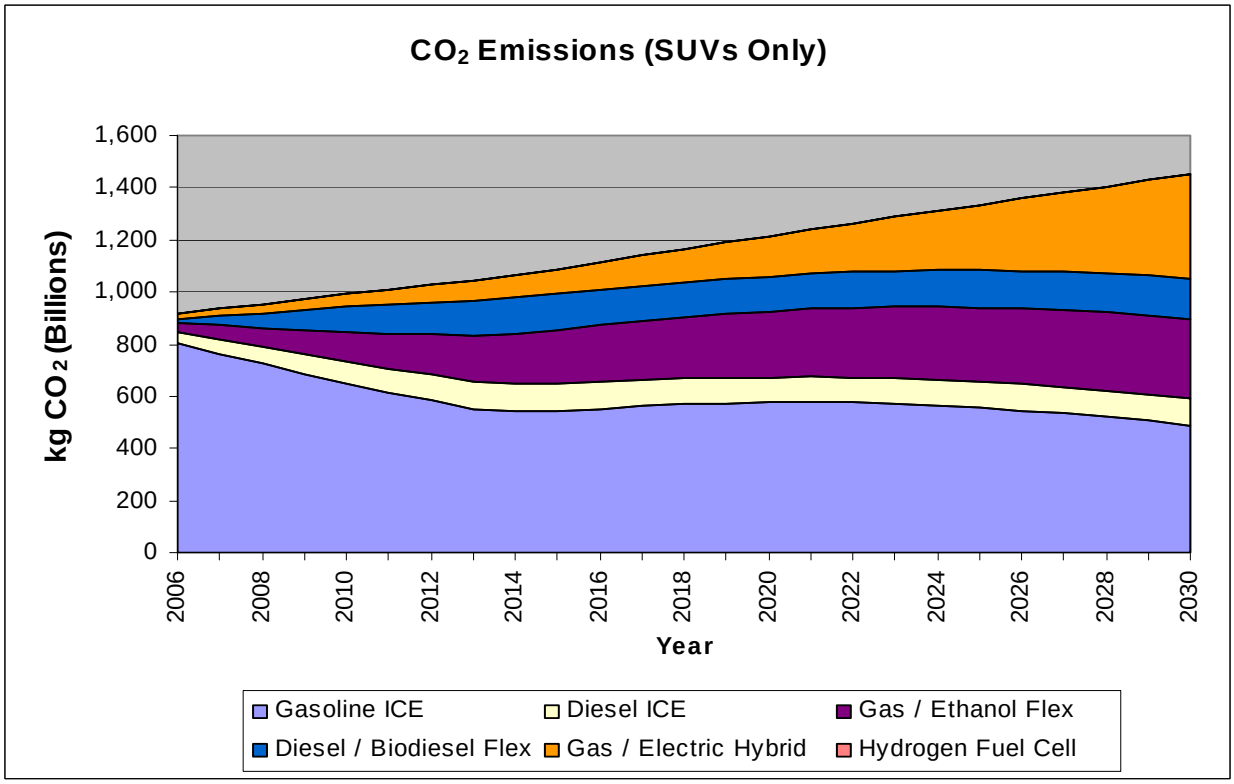





Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
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2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

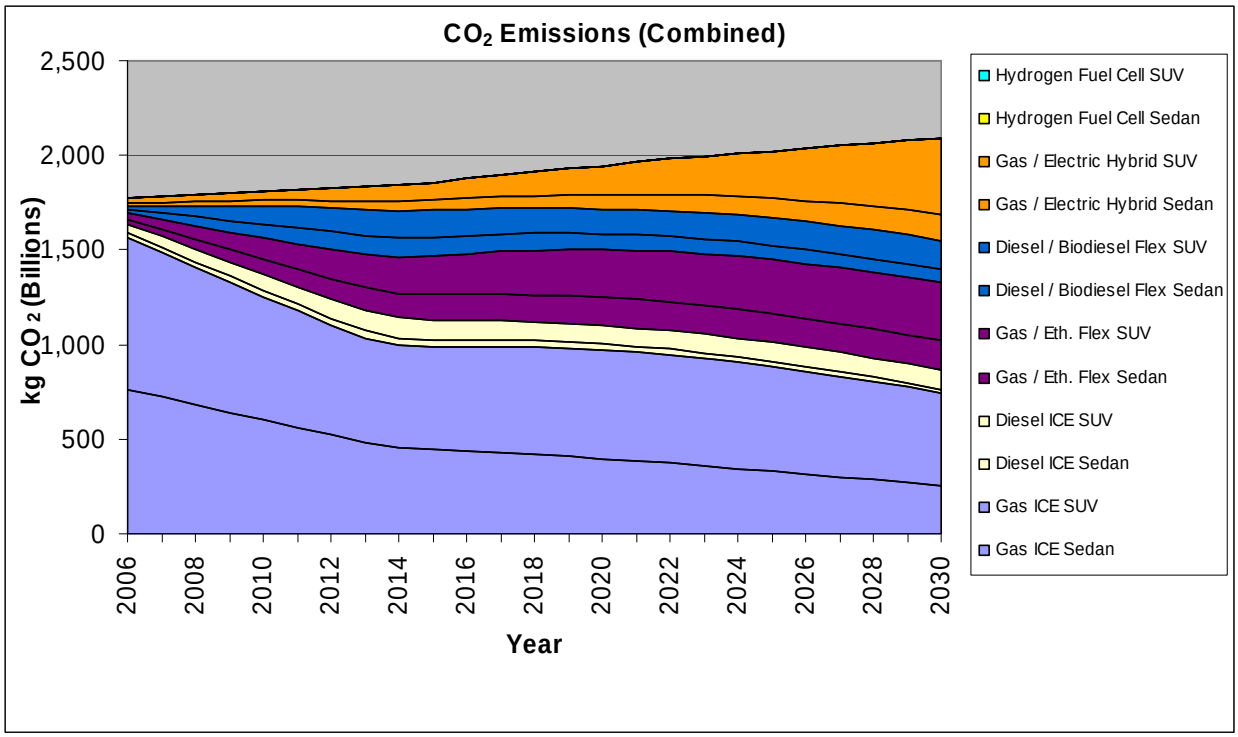
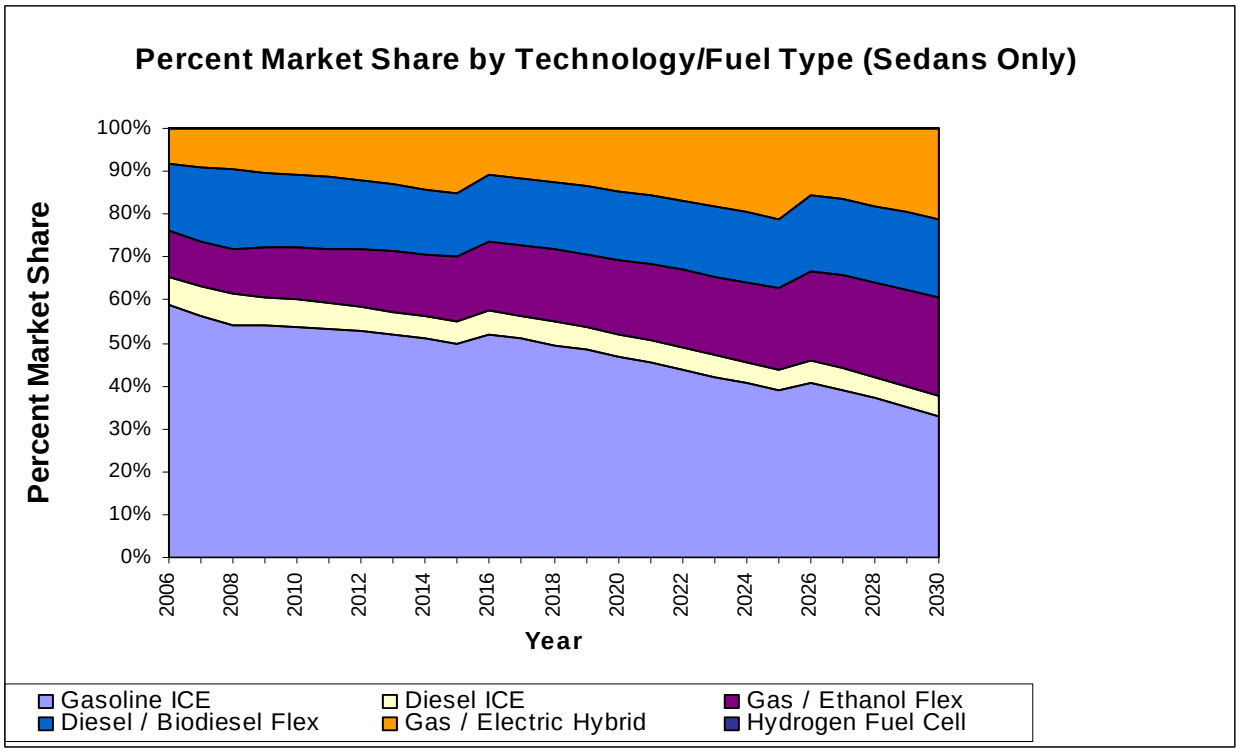
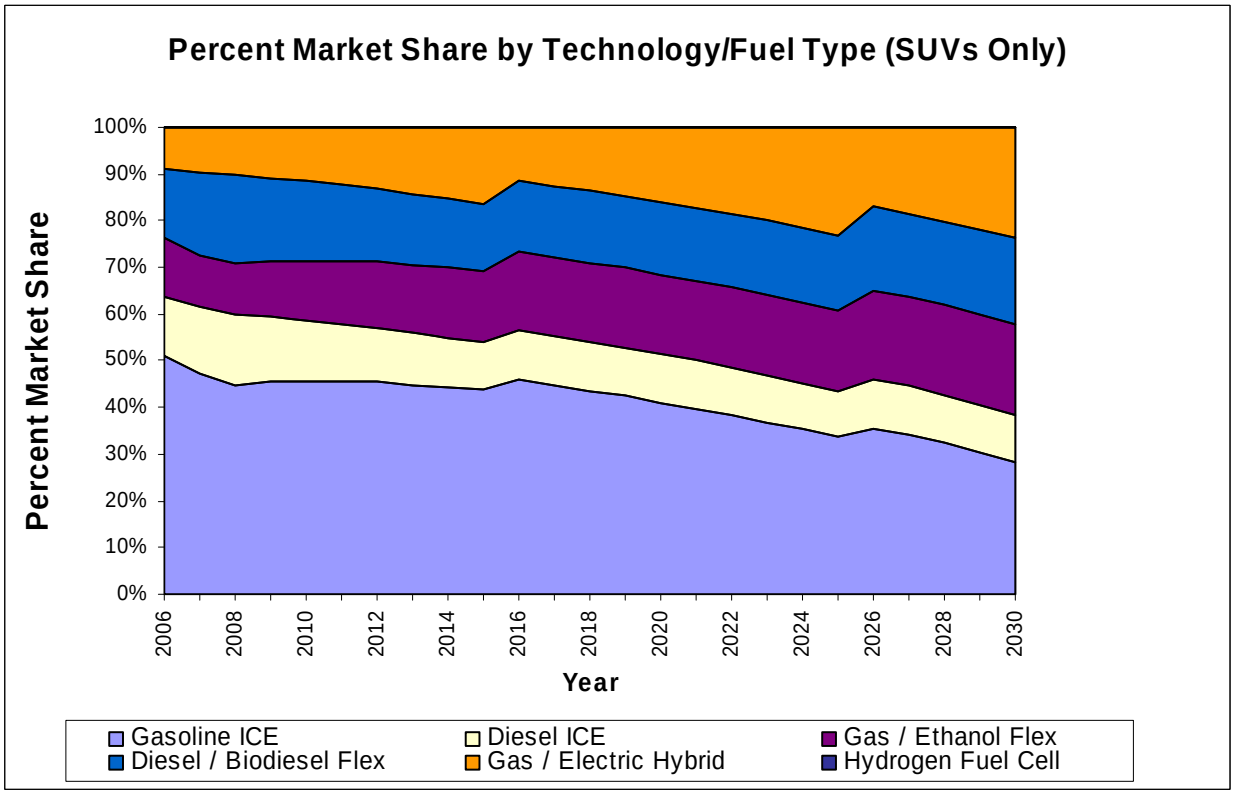


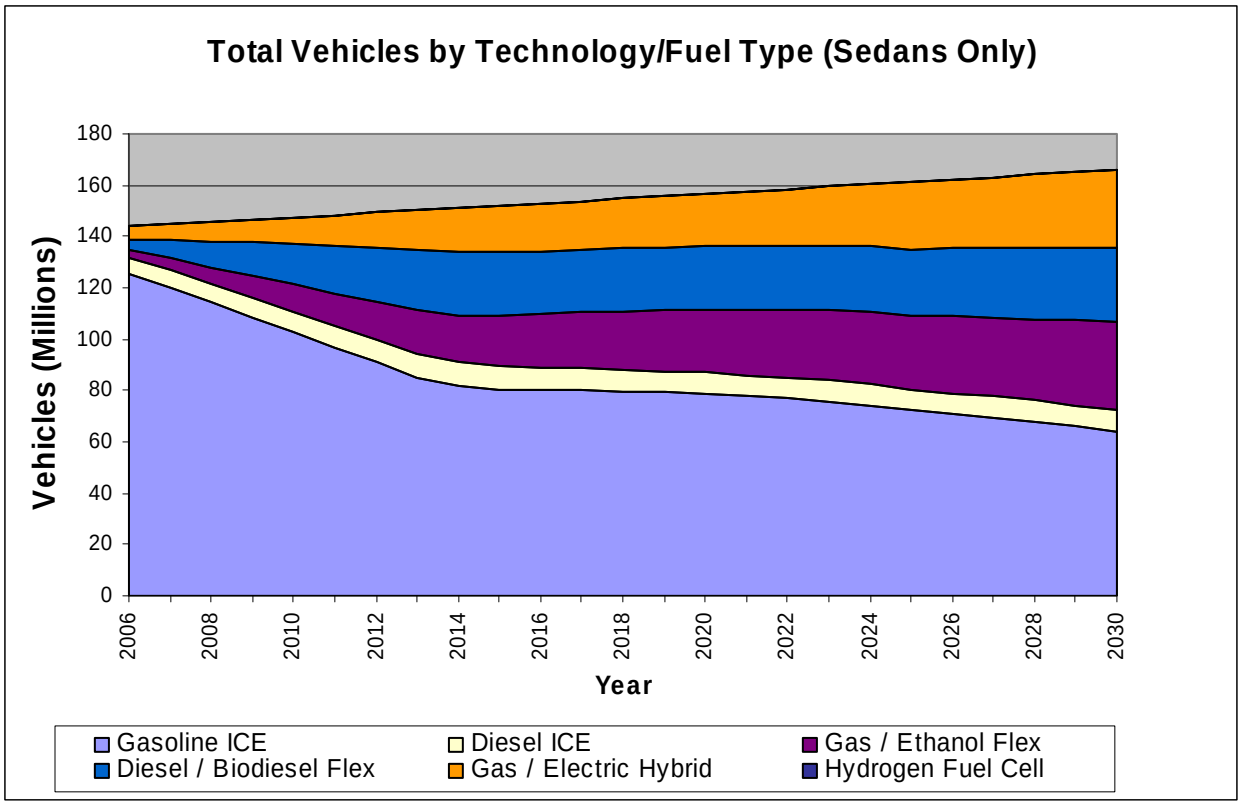
Figure 56: U.S. Alternative Scenario, Vehicle Tax Credit, High, Summary Chart

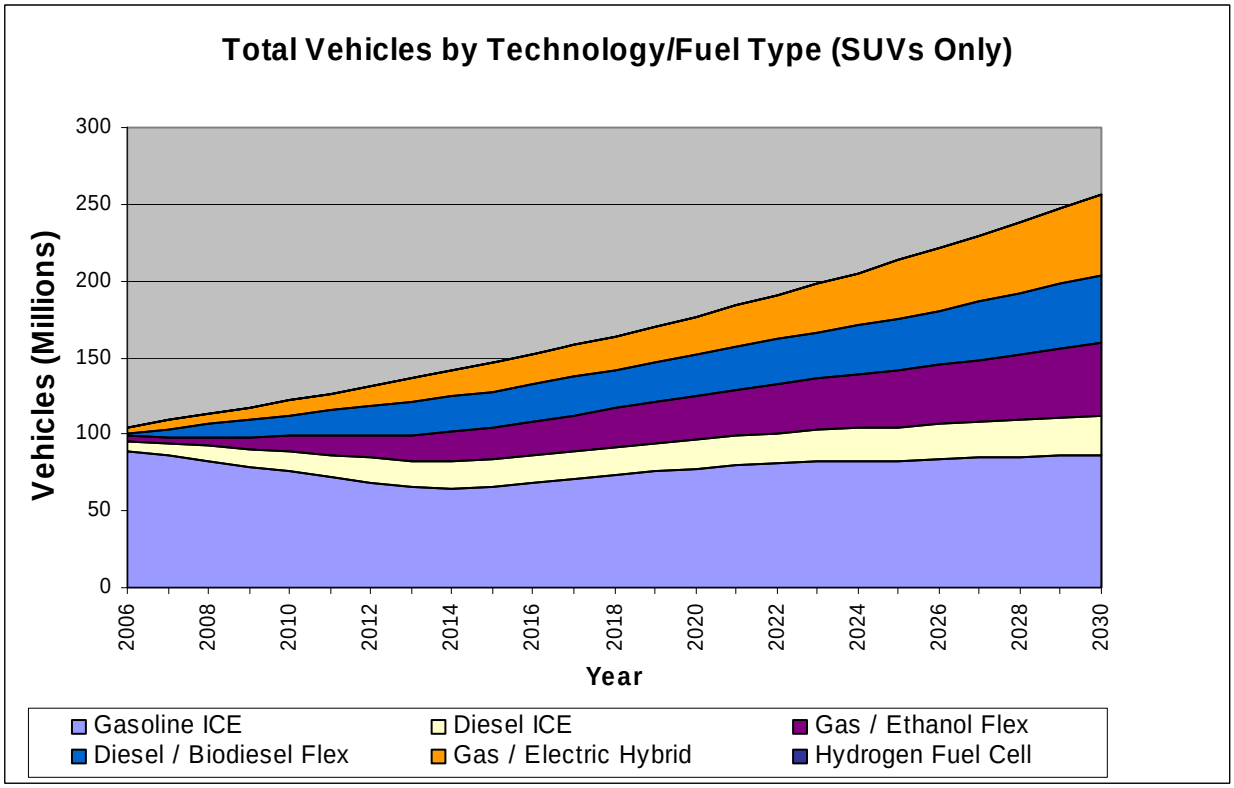
	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	161	1,933
% Reduction	7.1%	3.9%

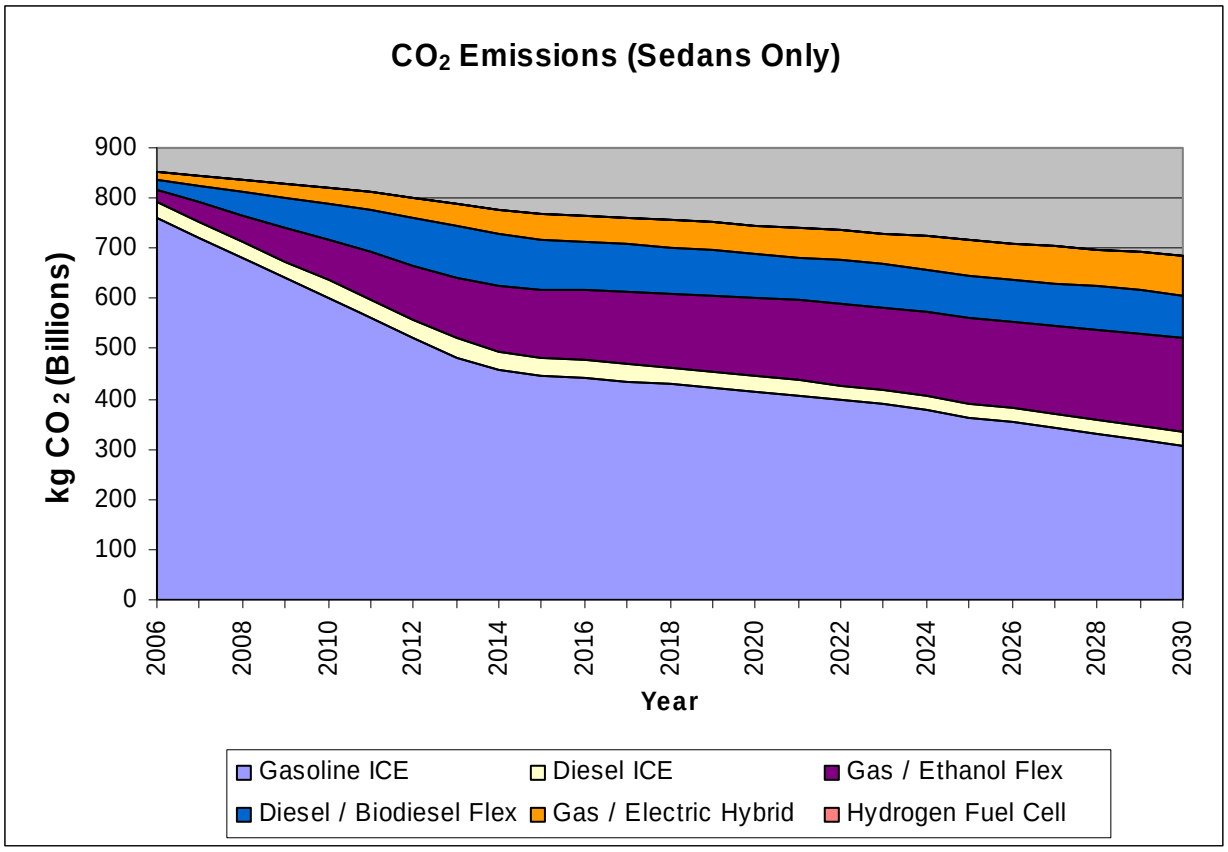
Figure 57(a-g): U.S. Alternative Scenario, Vehicle Tax Credit, Phased

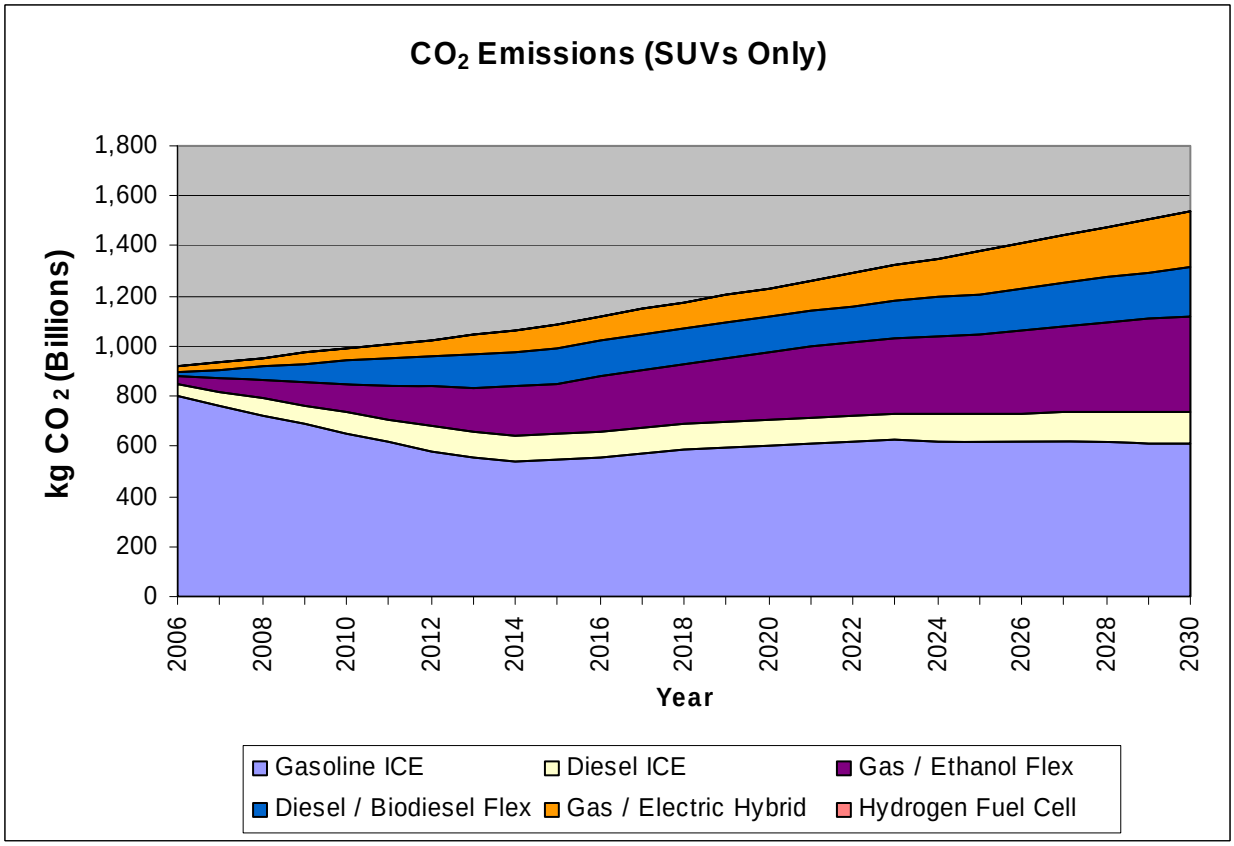





Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

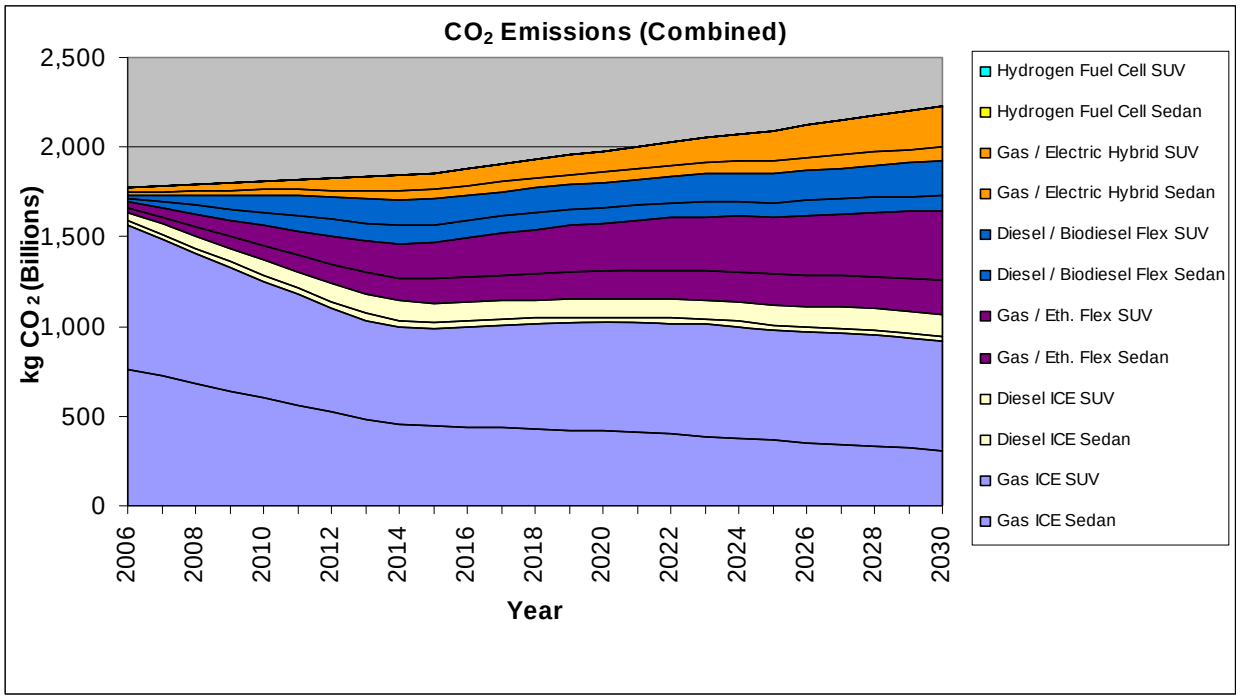


Figure 58: U.S. Alternative Scenario, Vehicle Tax Credit, Phased, Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	24	998
% Reduction	1.1%	2.0%

Vehicle tax credits prove to be one of the most effective means of encouraging a market shift from an established technology to a newer technology that, while technologically superior, may have a premium attached to the price. Especially in the high level tax incentive scenario, a dramatic level of development is capable of occurring in the hybrid gasoline-electric vehicle market as compared to the baseline, achieving a greater than 40% claim of the market share as compared to approximately a 20% market share in the baseline scenario.

This policy tool was also successful at reducing carbon dioxide emissions, once again, particularly in the high level incentive scenario. This policy looks to be particularly successful as a long term method of encouraging the adoption of vehicles with a declining premium. In the two scenarios (high and low incentives) where the incentive was permanent and kept at a steady state, the market share of these vehicles rapidly expanded as the vehicle price naturally dropped, bringing it into competition with conventional vehicles when combined with the incentive. This allows for the rapid growth and market domination of the technology in a relatively short period of time.

The technology chosen for this scenario, hybrid gasoline-electric vehicles, provides a clear technological advantage over conventional vehicles in terms of carbon dioxide emissions due to their superior fuel economy. Therefore, the ability to bring this technology relatively rapidly into the market in significant quantities shows a great deal of potential for helping to curb greenhouse gas emissions in the short and intermediate term. A long term solution, however, would require a further market shift to a vehicle that did not run on fossil fuels if it was to be sustainable over time.

The phased incentive scenario displays an interesting property of the technology. Since the adoption of hybrid gasoline-electric vehicles is primarily hindered by the premium paid over the cost of a conventional vehicle, and because this premium decreases, an incentive can be

used to spur market development in the short term before allowing the natural market forces to take over as the premium disappears and still achieve significant results. While the phased incentive in this scenario does not achieve as a substantial result as did the constant high level incentive, it was not expected that it would. Instead, its performance as compared to the low level incentive was of interest.

What makes the phased incentive so attractive in this case is that the high level incentives early on spur market growth and then begin to decline as the market develops before disappearing entirely. Thus the market does not come to depend on a permanent distortion in order to be successful and valuable tax dollars are not being detained permanently. Additionally, the higher level incentives are being paid out at the period of time when the number of vehicles is at its lowest and no incentives at all are being paid out when the number of vehicles is at it's highest. Thus, it ends up being less costly and more effective over the course of the study than the lower level incentive on its own.

3.5.5. Carbon Tax on Conventional Fuels

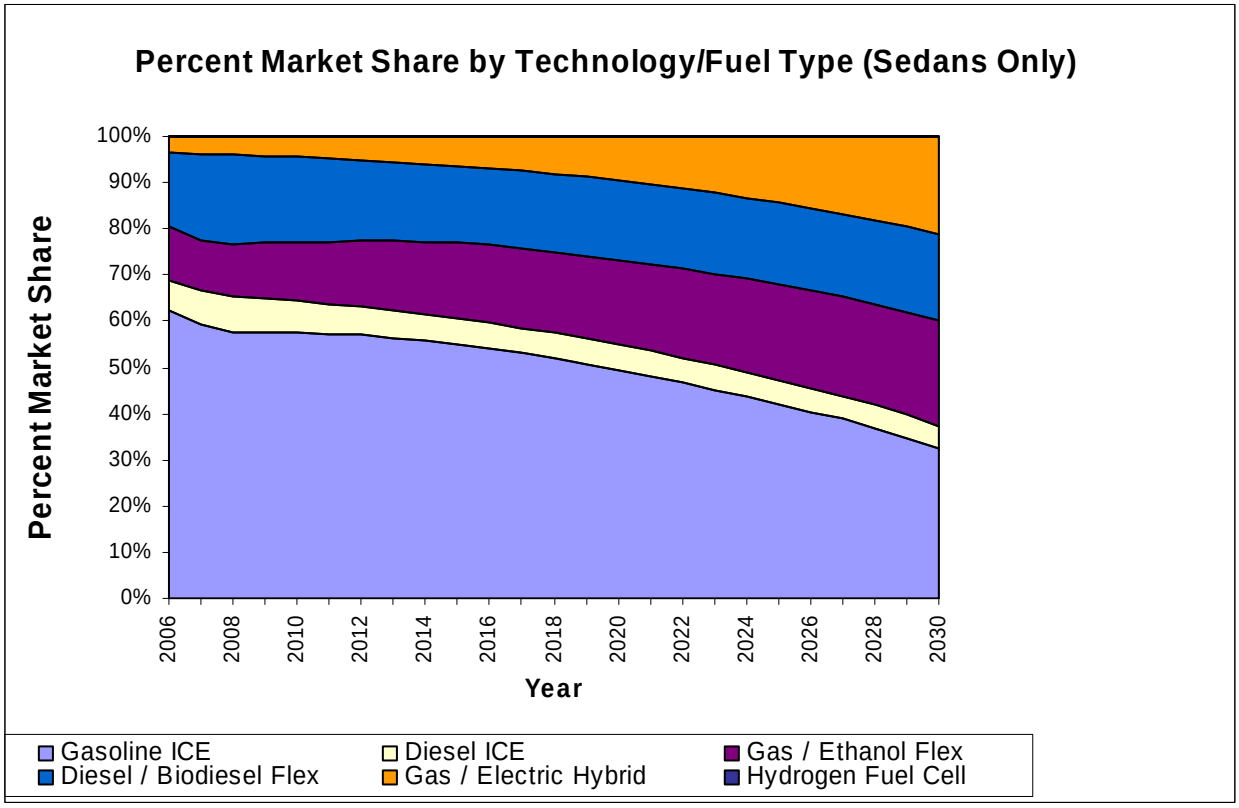
While the U.S. political scene has been highly resistant to the imposition of a carbon tax on transportation or the energy sector, carbon tax policies are used extensively internationally, especially in Europe. Unlike an incentive or subsidy, which seeks to encourage a behavior by making it more attractive, this policy would discourage the use of fossil fuels by making them increasingly expensive. Recent history has indicated that this technique might be particularly useful in the current energy climate given the effect that rising gas prices has had on the purchases of higher fuel efficiency conventional vehicles and hybrid gasoline-electric vehicles. This rapid rise in concern over fuel economy bore out even when the actual monetary benefits of this altered behavior were uncertain. The desire to pay less "at the pump" seems to be a greatly desired aspect of vehicle ownership.

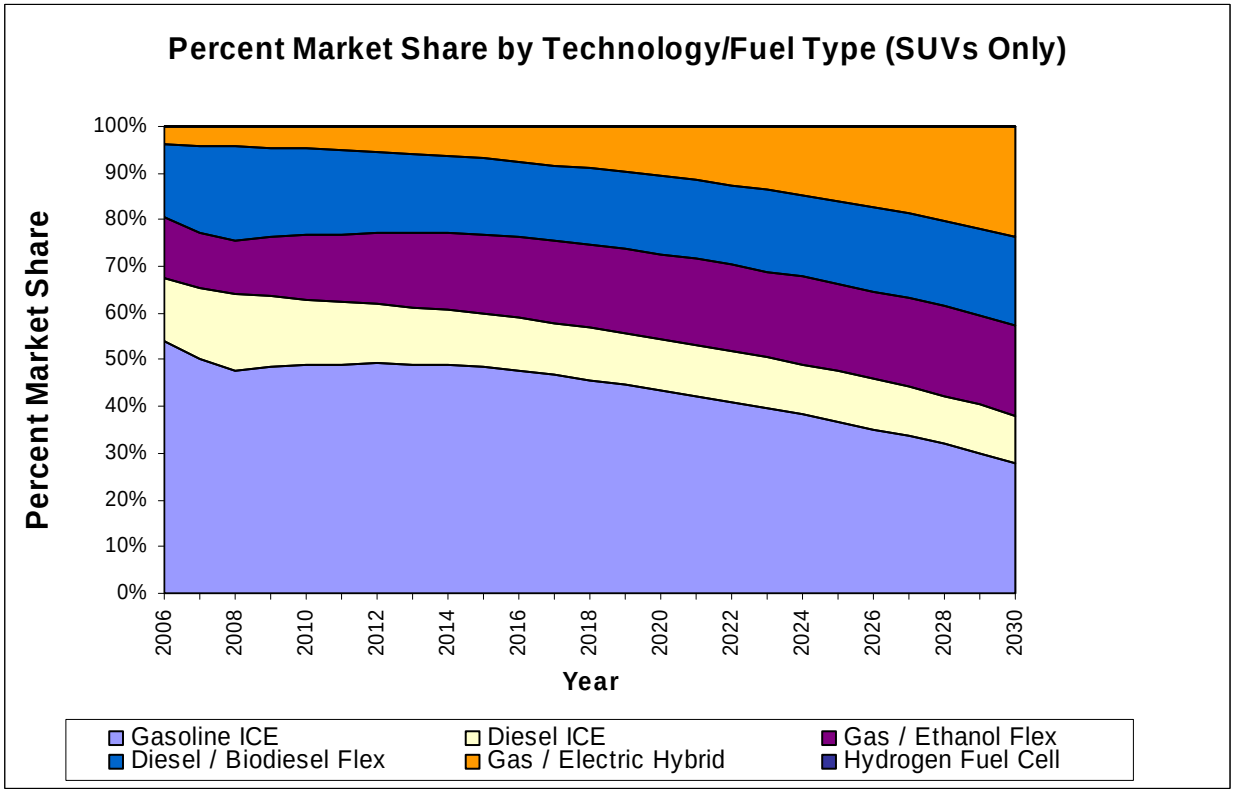
There are several ways in which a carbon tax could be applied to fossil fuels. The two primary methods that might be applicable in this scenario would be to either apply a flat dollars-per-ton of carbon, which could be applied to all energy sources, or to focus in on fuels and apply a dollars-per-gallon tax. Given the limited scope of this model and the relative equivalency of the two methods, the method to be utilized in this scenario will be the dollars-per-gallon of fuel method. In terms of their overall effect the two methods are equivalent and expressing the tax in terms of dollars per gallon is substantially easier to conceptualize.

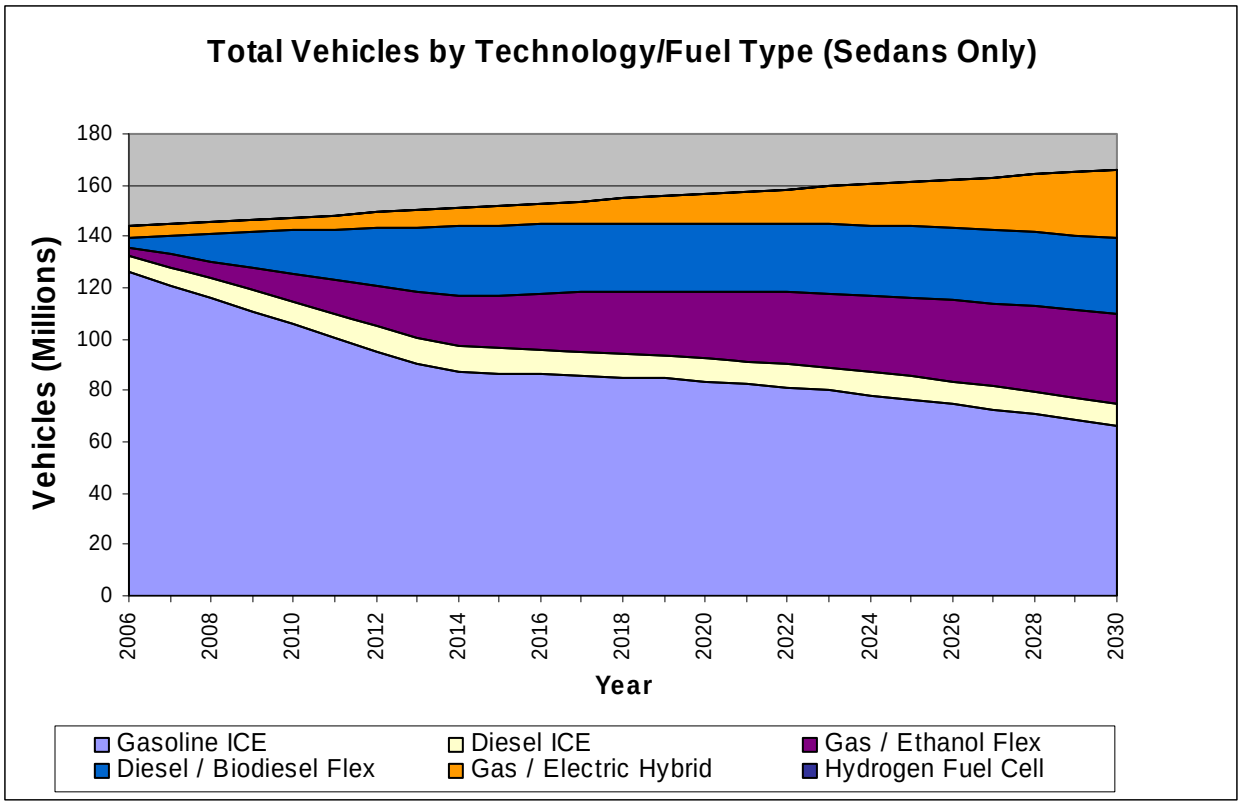
In order to gauge realistic levels for this tax, it was important to examine real-world examples of how policies of this type have been implemented or proposed. As mentioned previously, a large number of European and other countries have either implemented or proposed carbon taxes on gasoline in the past. Sweden, for example, has a carbon tax on gasoline equivalent to $1.45/gal; Japan has a carbon tax on gasoline equivalent to $1.29/gal; and the United Kingdom has a carbon tax on gasoline equivalent to $2.52/gal. This level of taxation is typical of many European countries (RECCEE, 2007). The U.S., however, has been highly resistant to even far lower levels of taxation on their gasoline. In 1993, President Clinton proposed a tax on fossil fuels based on their BTU's with an additional tax for fossil fuels used for transportation. The tax for passenger car gasoline would have been equivalent to $0.068/gal and yet it could not pass through the legislature.

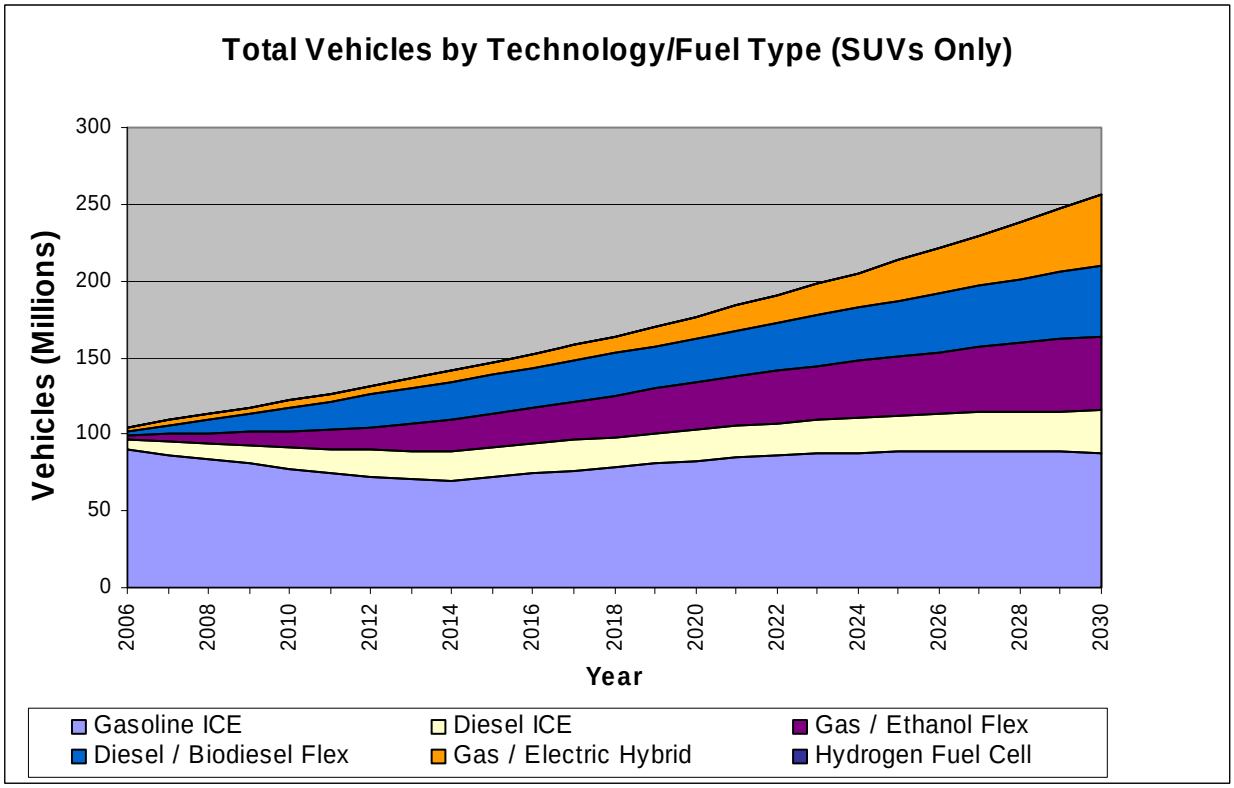
This scenario will contain three sub-scenarios based on these real-world examples. The first sub-scenario will assume that Clinton's proposal had passed and an almost 7 cent tax will be applied to the baseline cost of gasoline. The second scenario will assume that a steep tax is applied to gasoline, based on the United Kingdom's gasoline carbon tax of $2.52. The third and final scenario will adopt Japan's more moderate carbon tax on gasoline of $1.29. This will provide a low, middle, and high scenario for carbon taxation of gasoline and give a broad range of examples for what might be accomplished with this particular policy tool.

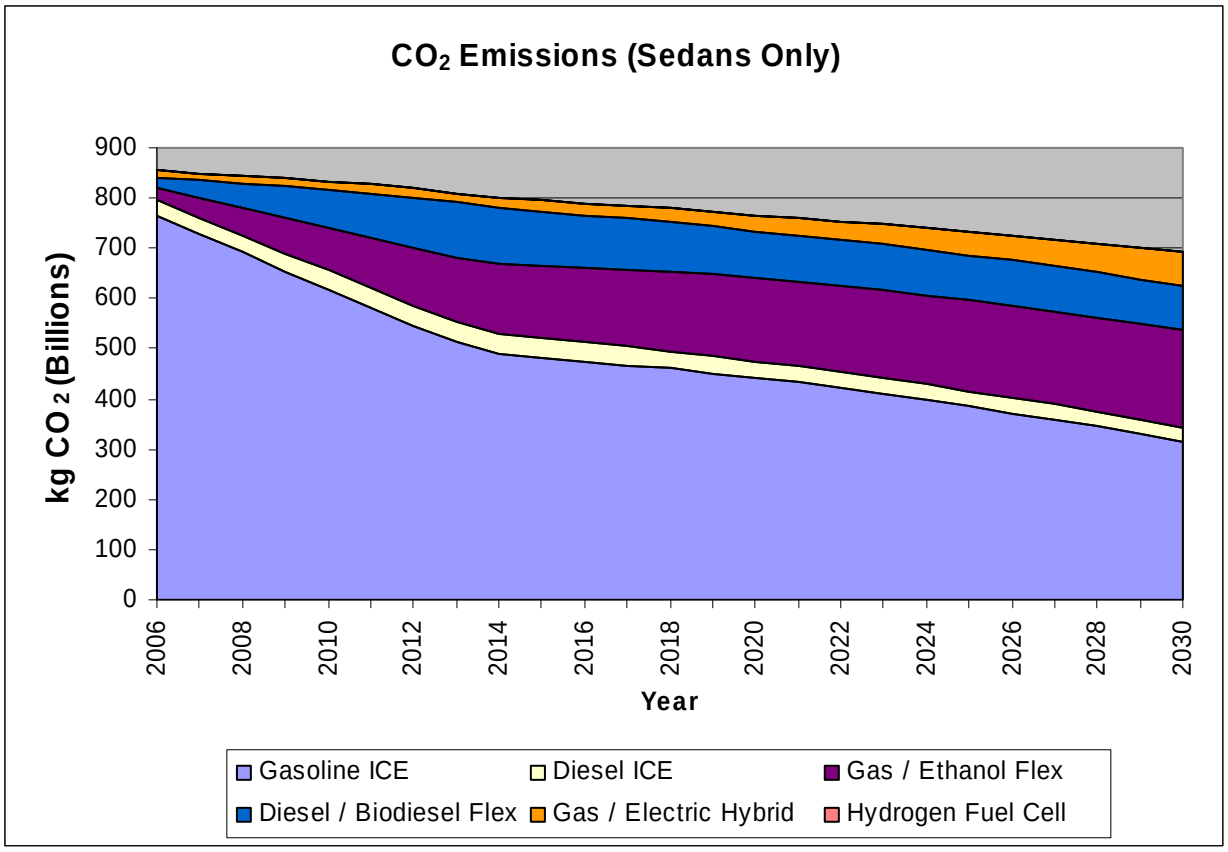
Figure 59(a-g): U.S. Alternative Scenario, Carbon Tax, Low

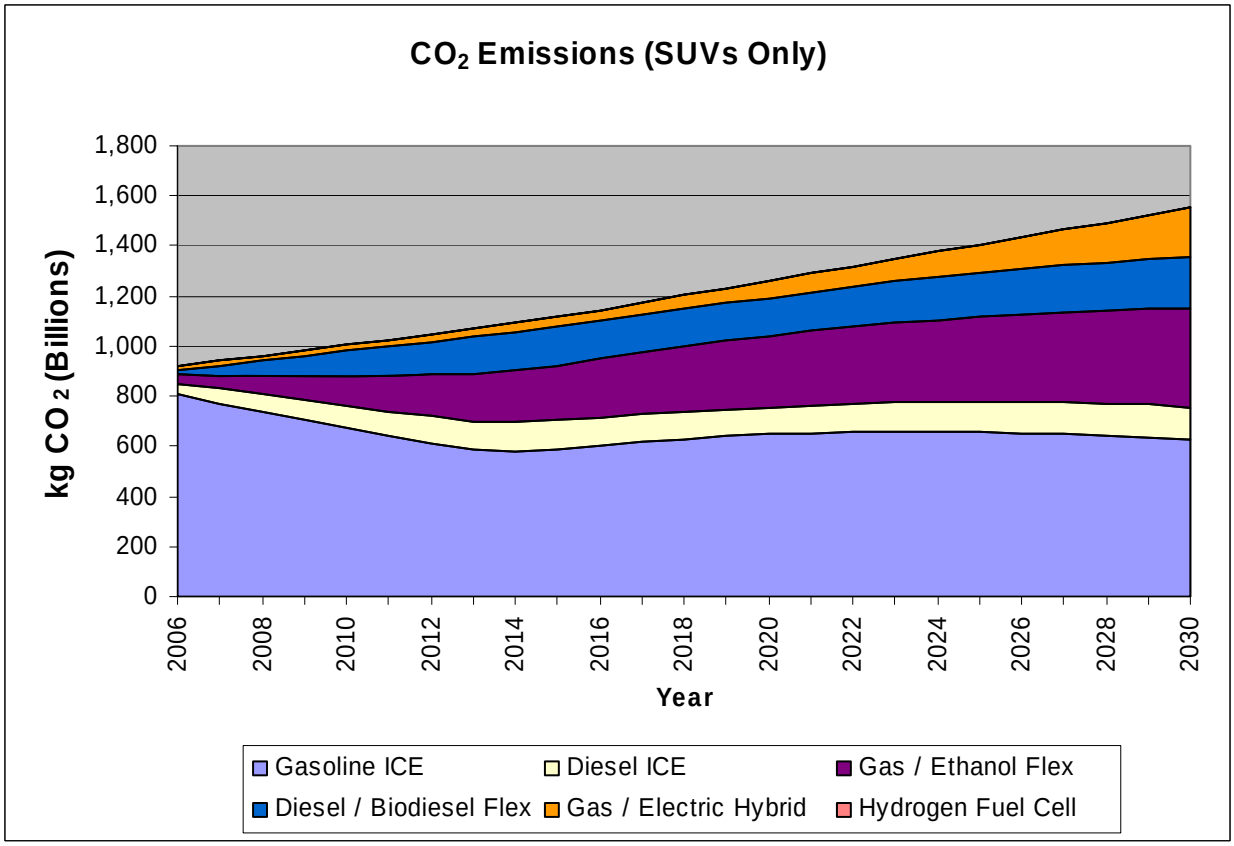





Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

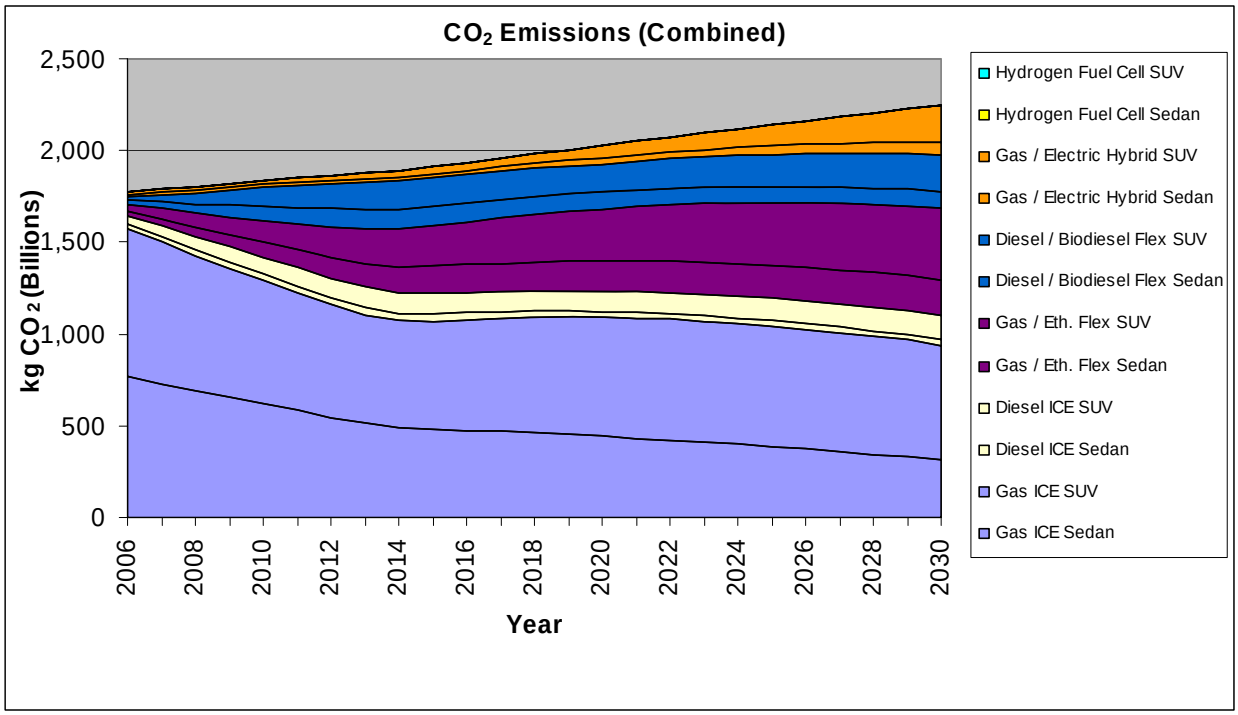
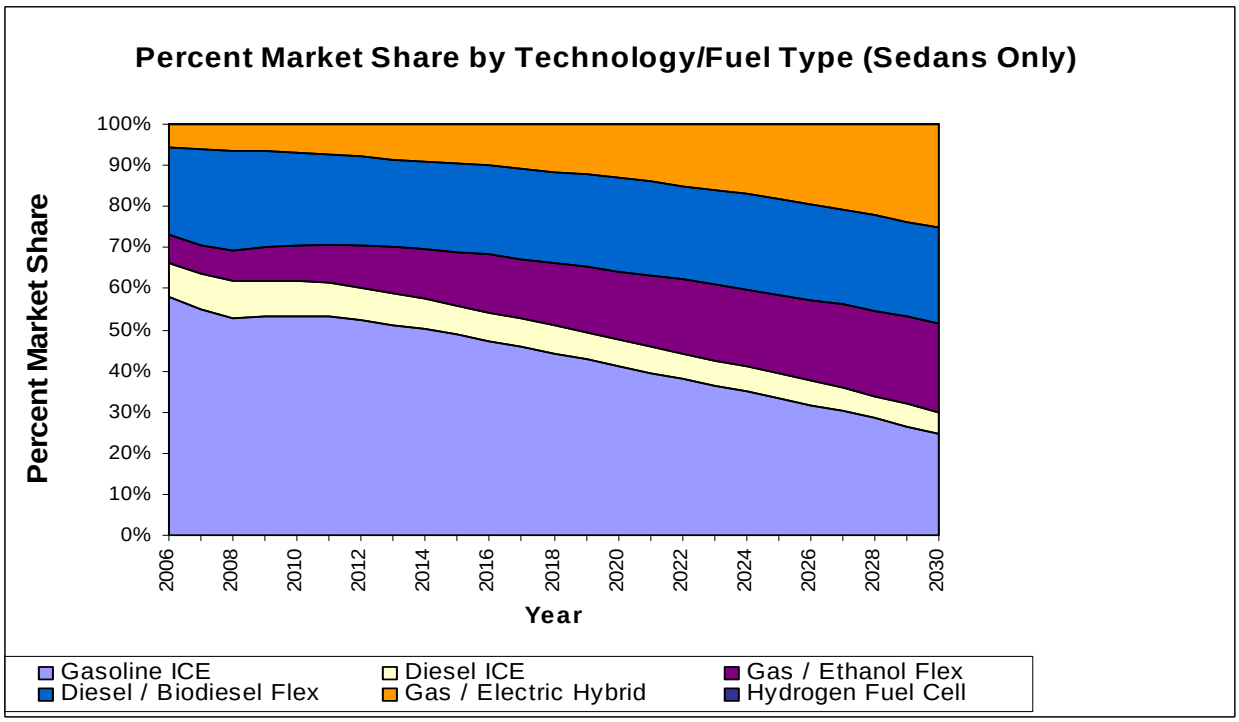
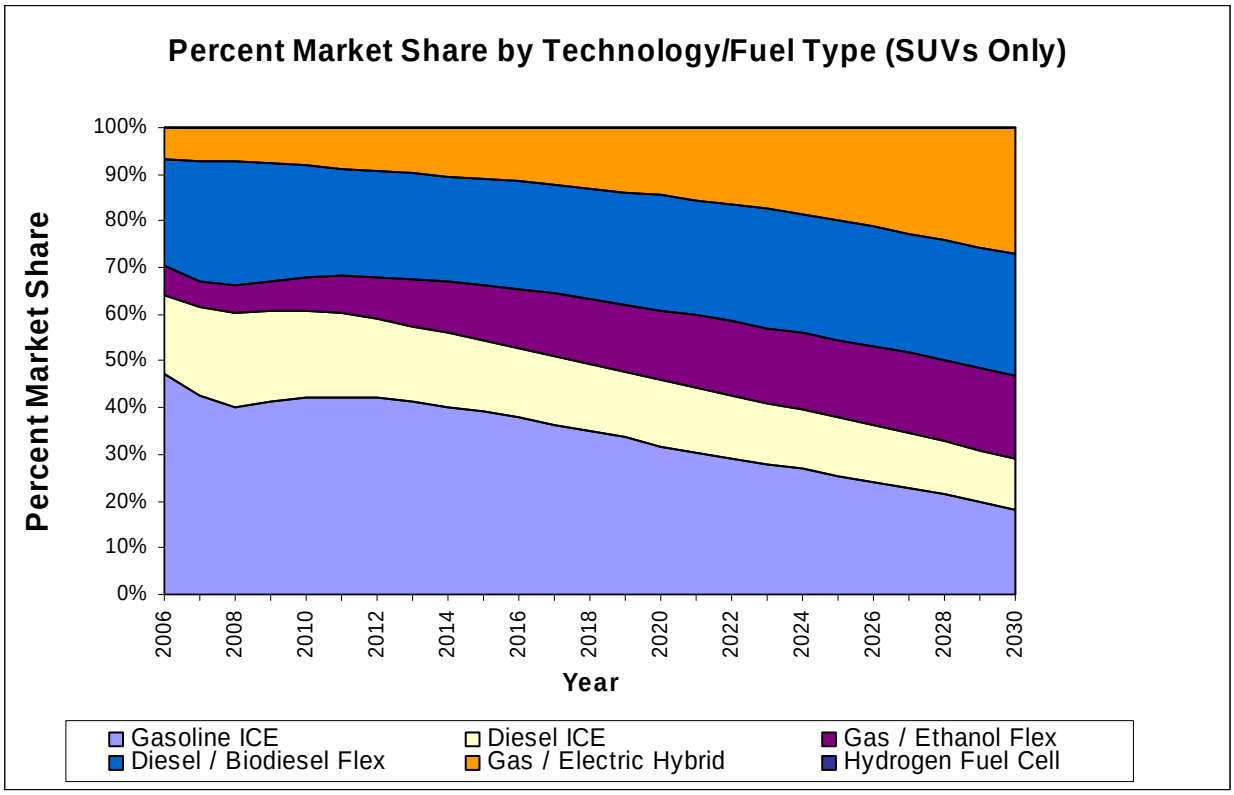


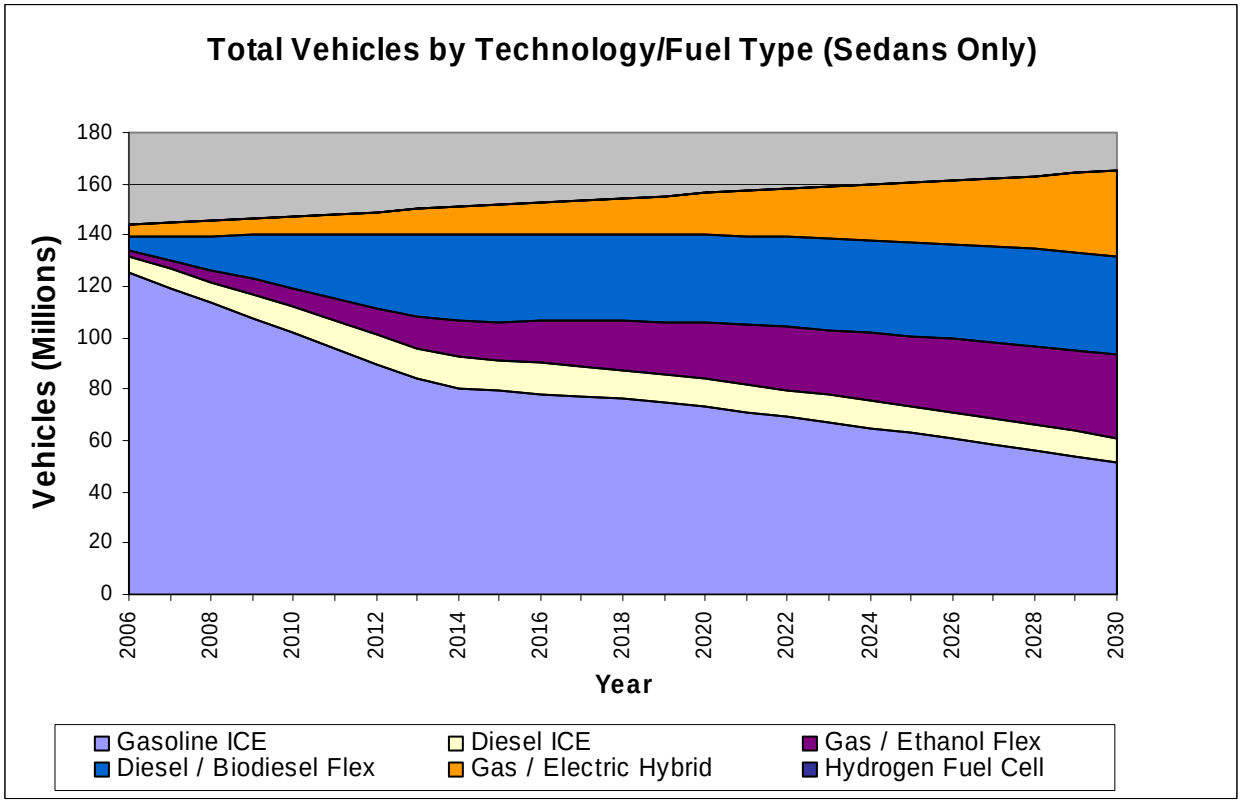
Figure 60: U.S. Alternative Scenario, Carbon Tax, Low, Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	4	67
% Reduction	0.2%	0.1%

Figure 61(a-g): U.S. Alternative Scenario, Carbon Tax, High




Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
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2026
2028
2030
Year
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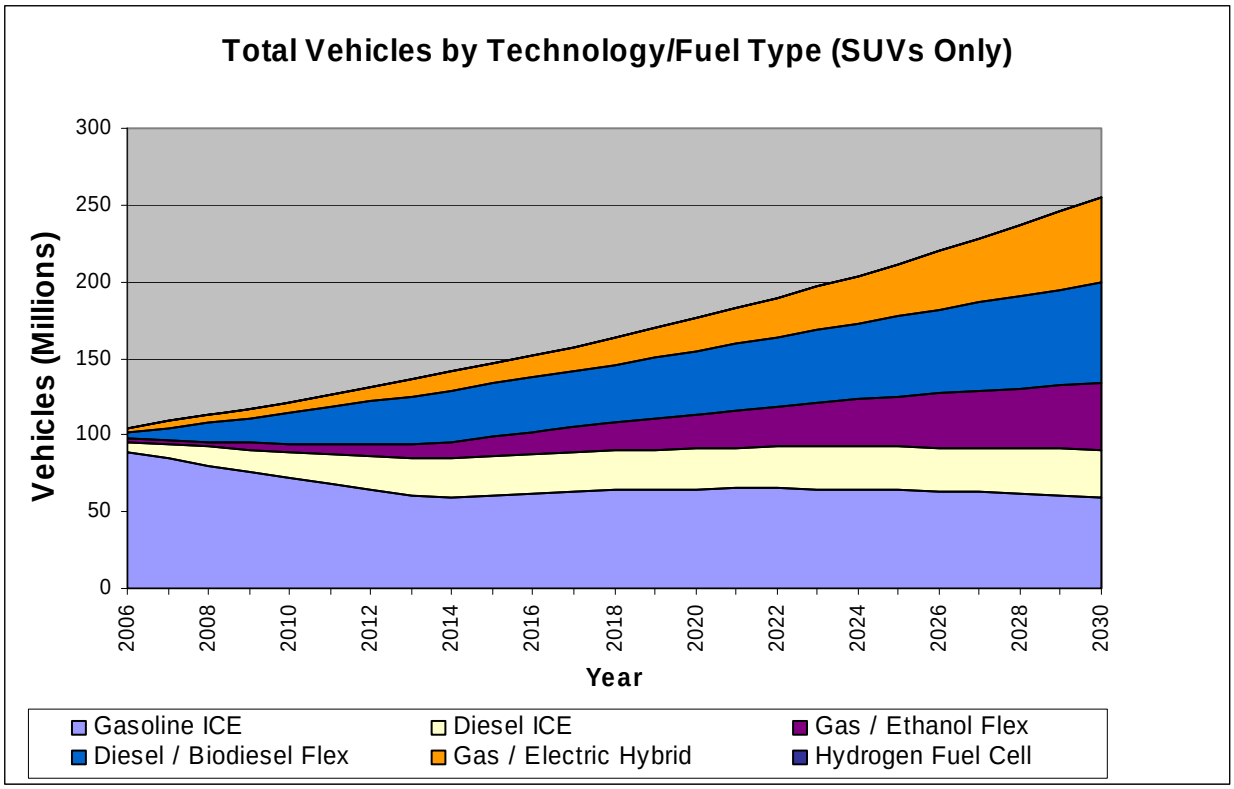
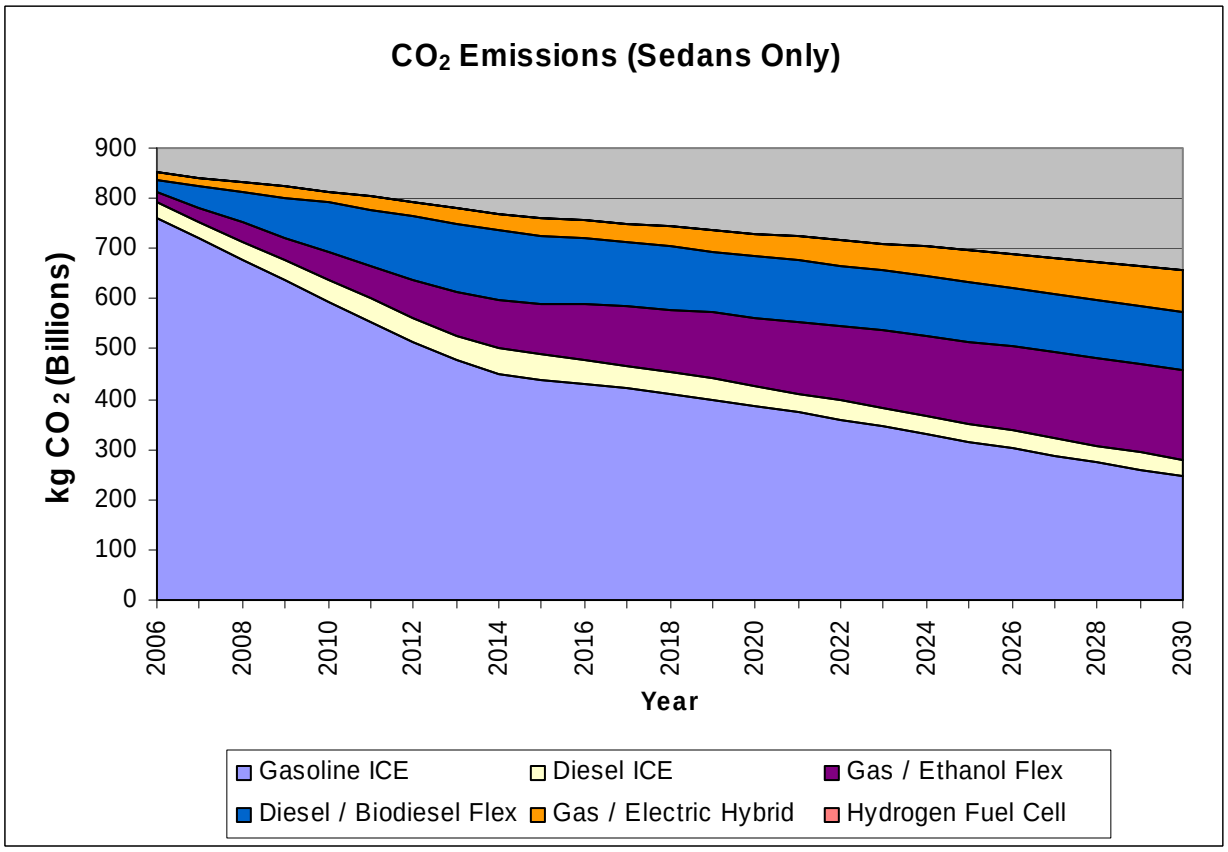
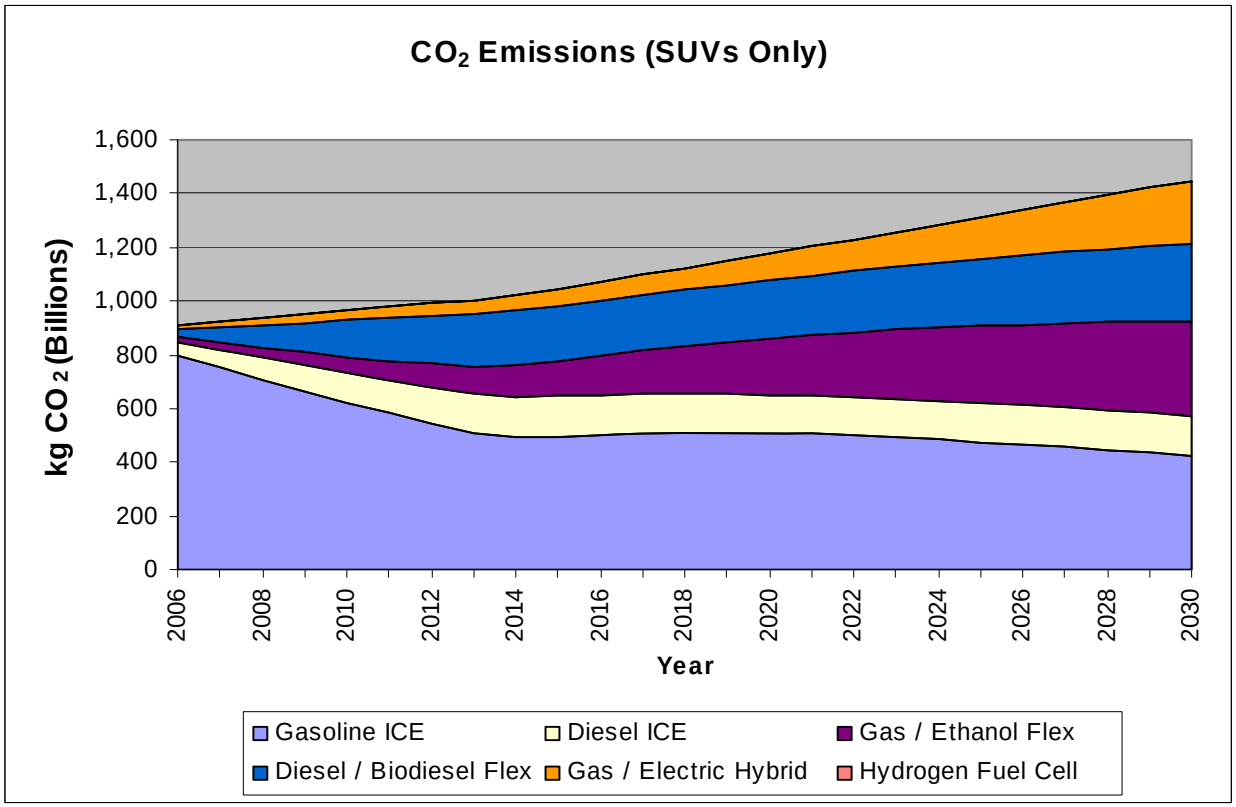
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell



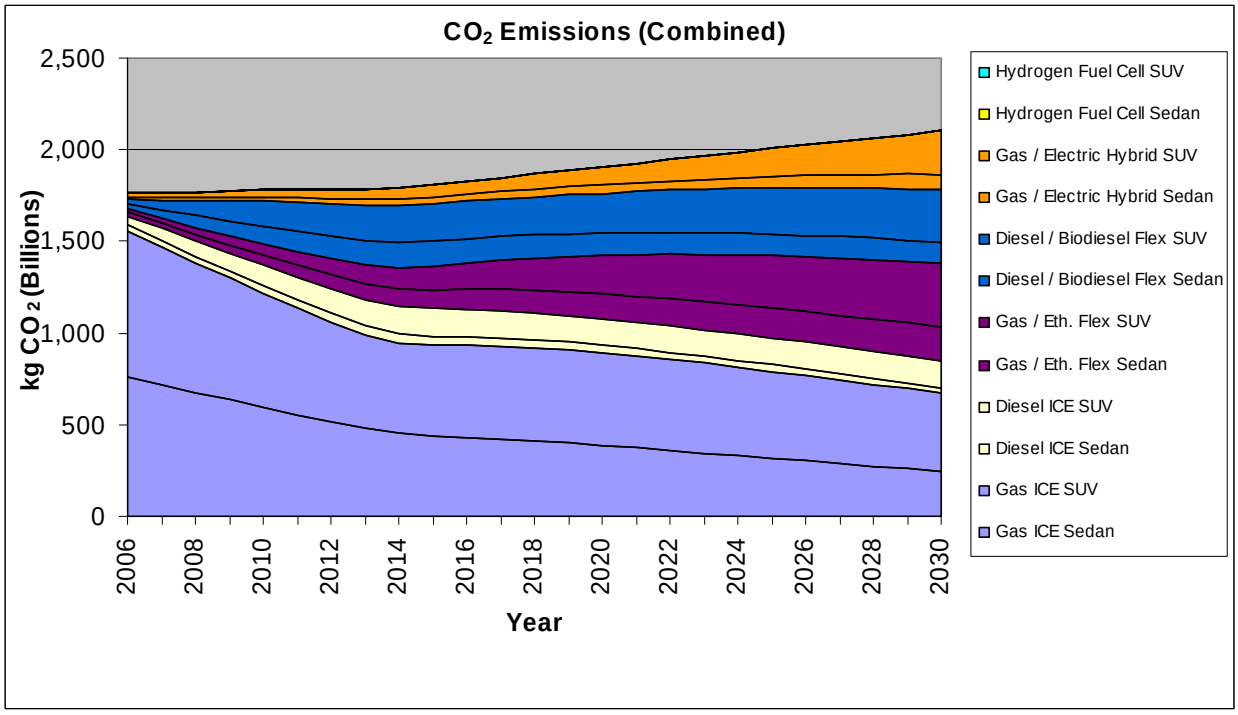
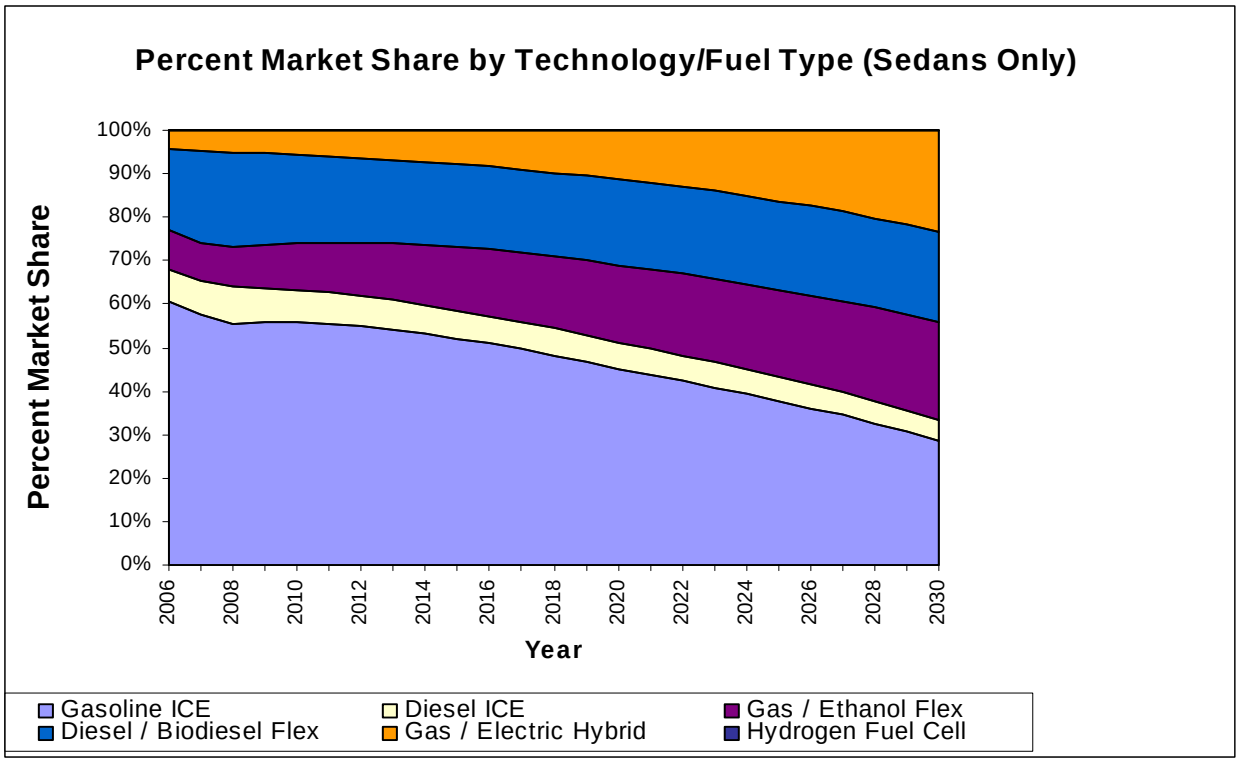
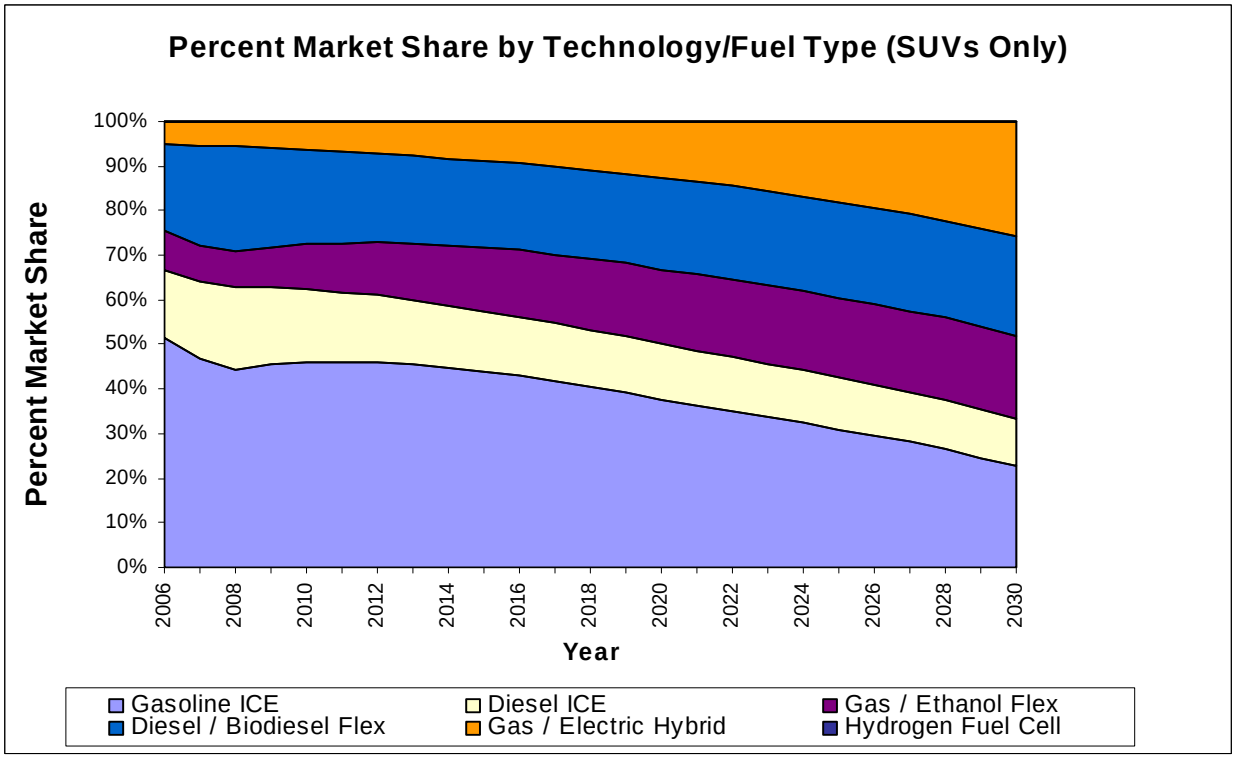


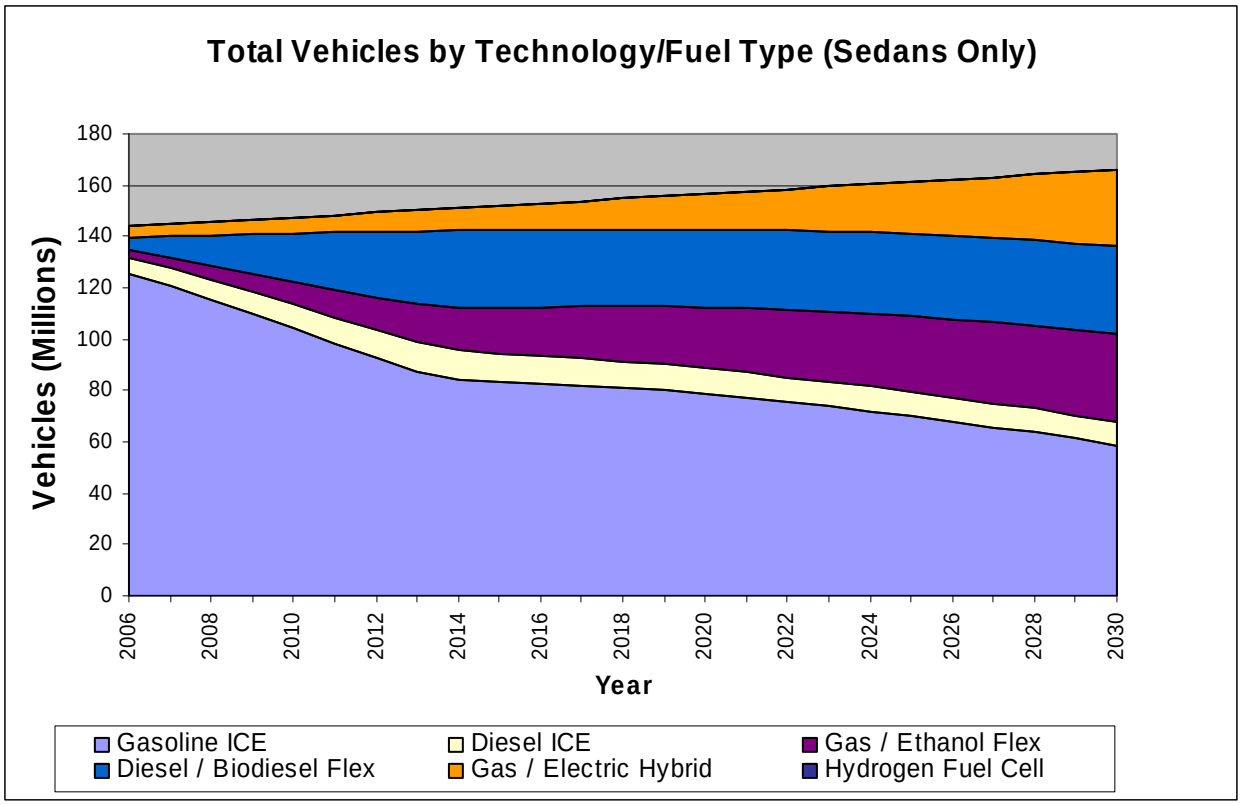
Figure 62: U.S. Alternative Scenario, Carbon Tax, High, Summary Chart

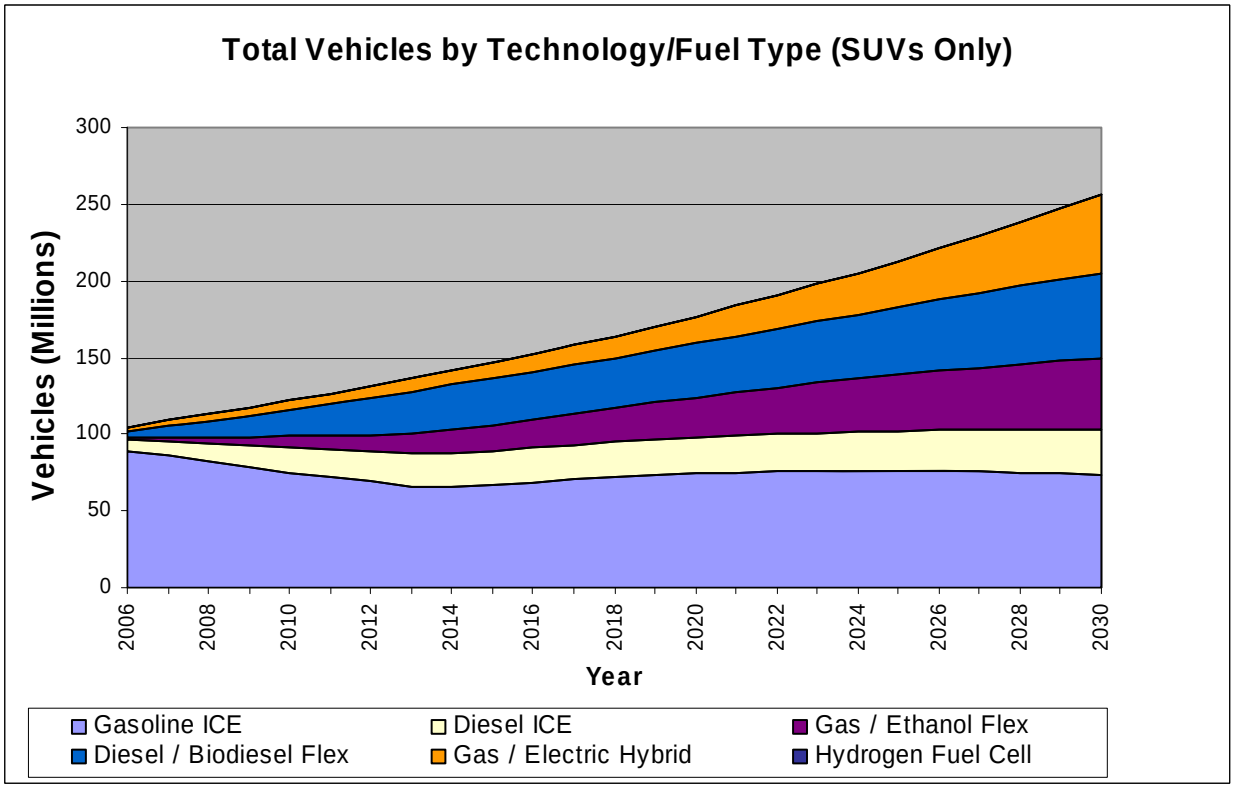
	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	135	2,517
% Reduction	6.0%	5.0%

Figure 63(a-g): U.S. Alternative Scenario, Carbon Tax, Mid






Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
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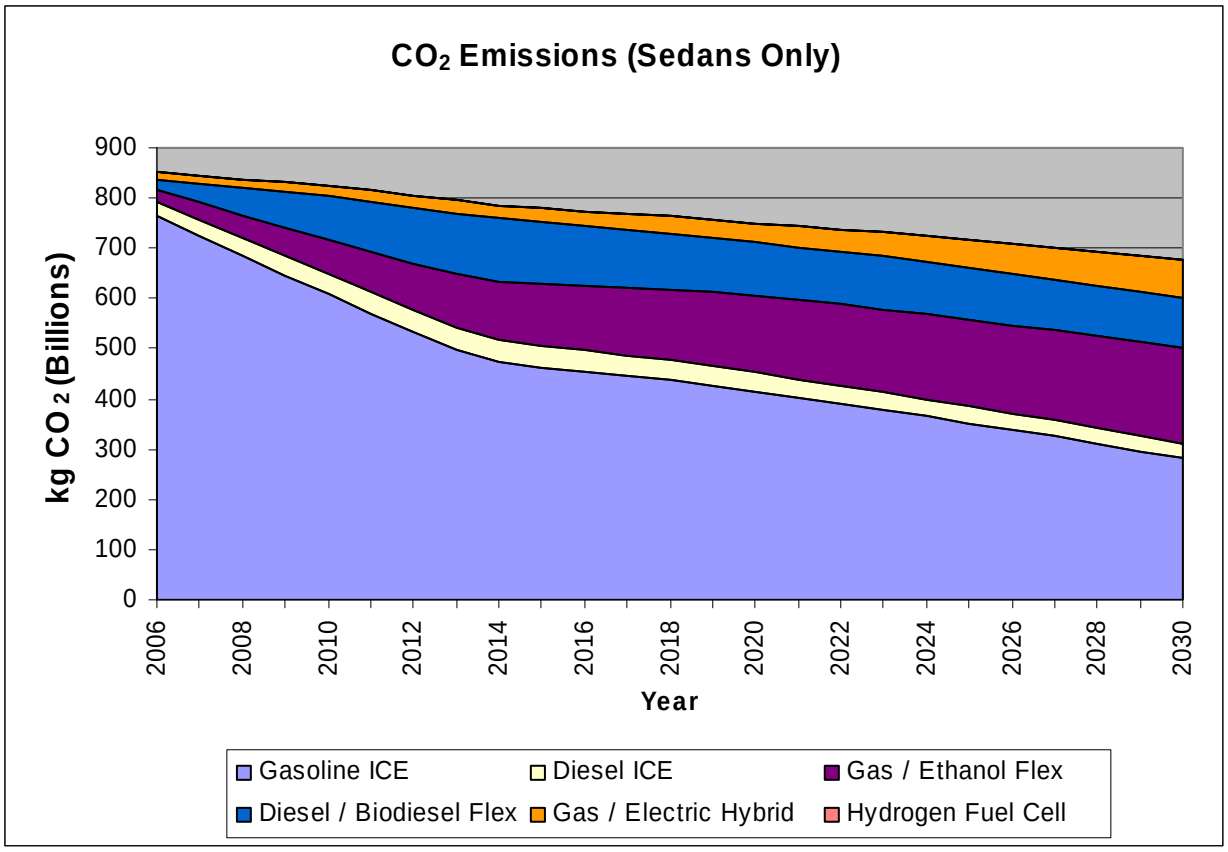
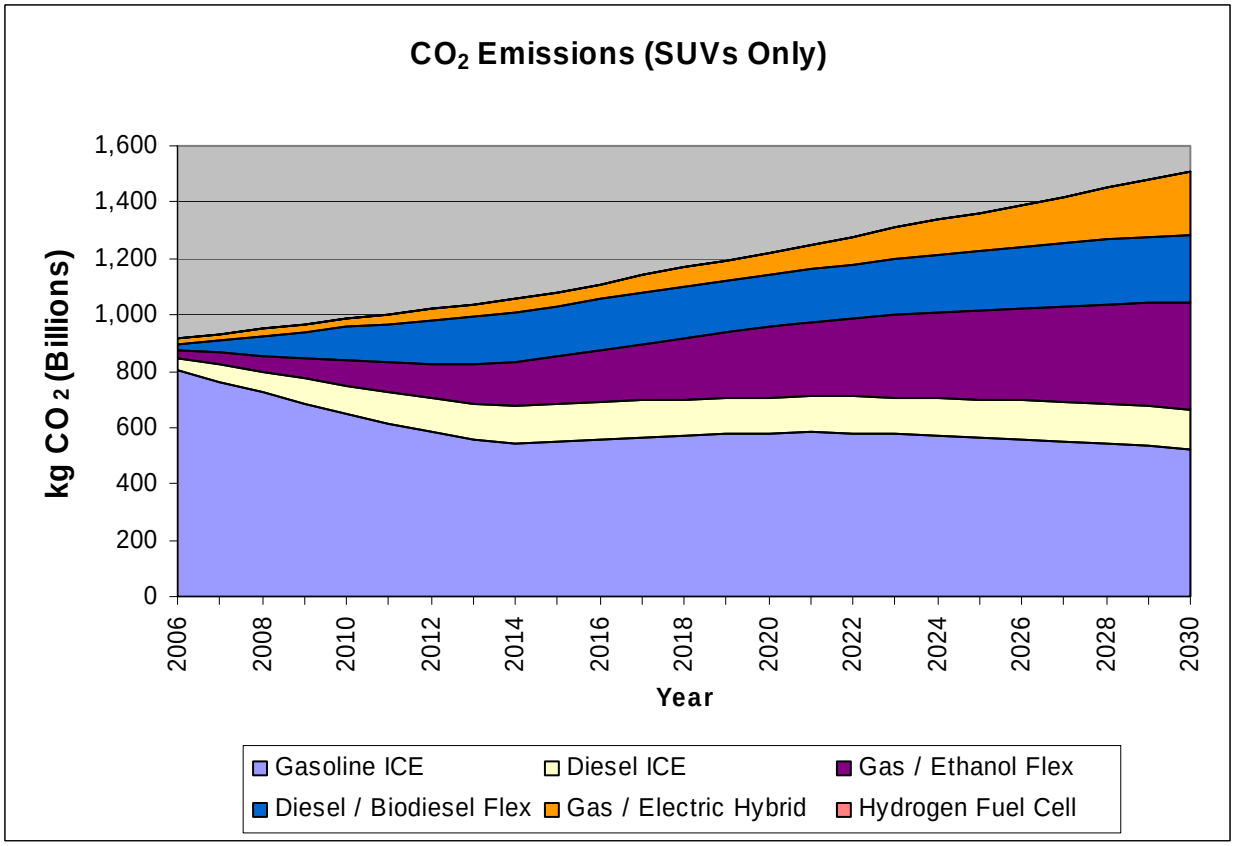
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

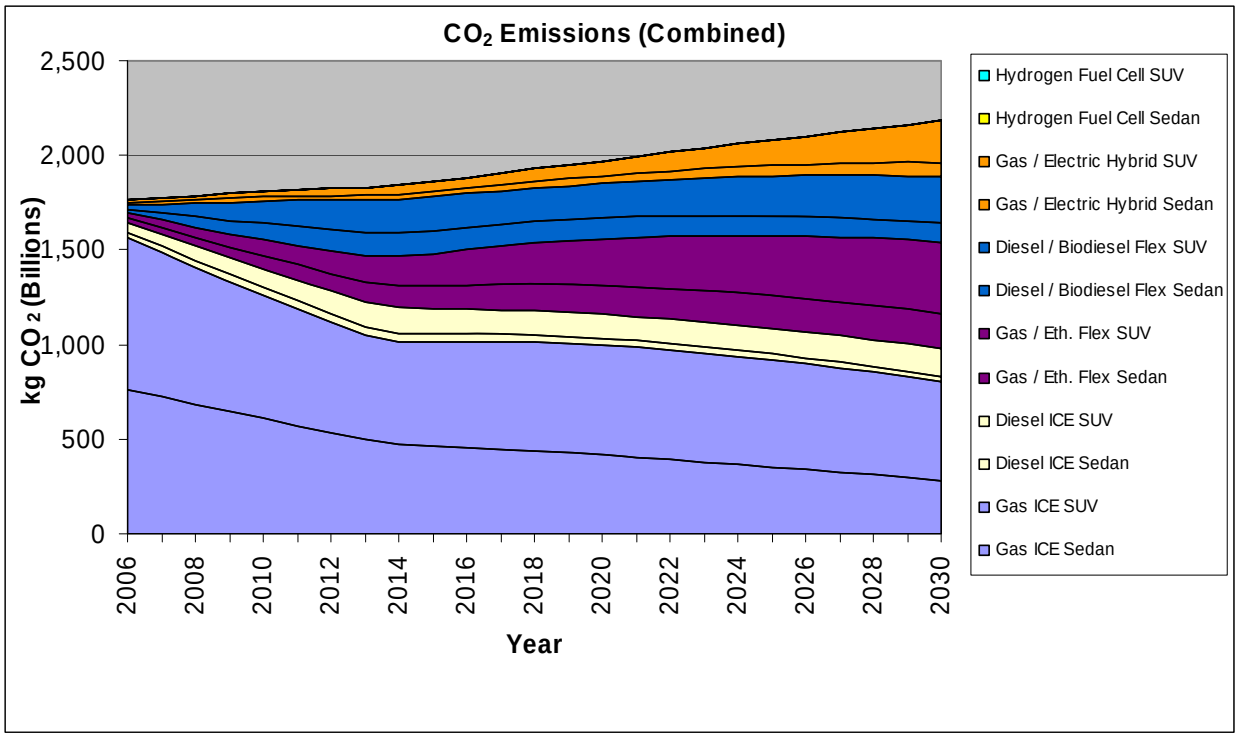


Figure 64: U.S. Alternative Scenario, Carbon Tax, Mid, Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	67	1,255
% Reduction	3.0%	2.5%

The carbon tax proves to be a steady and reasonable policy program which is capable of reducing carbon dioxide levels as compared to the baseline scenario significantly if it is applied at levels comparable to those utilized in Europe. The expected, and as predicted by the model, results of the carbon tax was to drive consumers away from conventional vehicles relying on fossil fuels due to the higher fueling costs.

The market shares lost by the conventional technologies were absorbed approximately equally by a combination of flex fuel biodiesel and ethanol vehicles and by hybrid gasoline-electric vehicles. As mentioned previously, the increased reliance on ethanol powered vehicles actually led to an increase in carbon dioxide levels from those sources, but this was offset but the significant carbon dioxide emissions reductions that were garnered by an increased reliance on biodiesel and hybrid gasoline electric technologies.

The lesson to be learned is the effectiveness of rising fuel prices in drawing consumers away from a dominant technology towards technologies that either use a different fuel or are capable of utilizing the conventional fuel more efficiently. In order to control where those consumers are driven, however, may require the application of an additional incentive to guide their choice towards a desired technology, such as coupling the carbon tax with a biodiesel subsidy or a federal tax credit for the purchase of a hybrid vehicle.

An additional lesson my be learned by the effectiveness of the various levels of the carbon tax proposed. In order to have any real level of effectiveness, the tax must be of a sufficient level to drive consumers away from conventional technologies and not just raise funds for some other purpose. The tax proposed by President Clinton would have had a negligible effect on the carbon dioxide emissions from the vehicle pool. Instead it would take a more significant carbon tax in order to have an appreciable effect, on the magnitude of a dollar per

gallon rather than cents per gallon. This level would still be considered relatively low compared to the level of taxes on gas in most European countries, yet would likely face incredible levels of opposition in then United States.

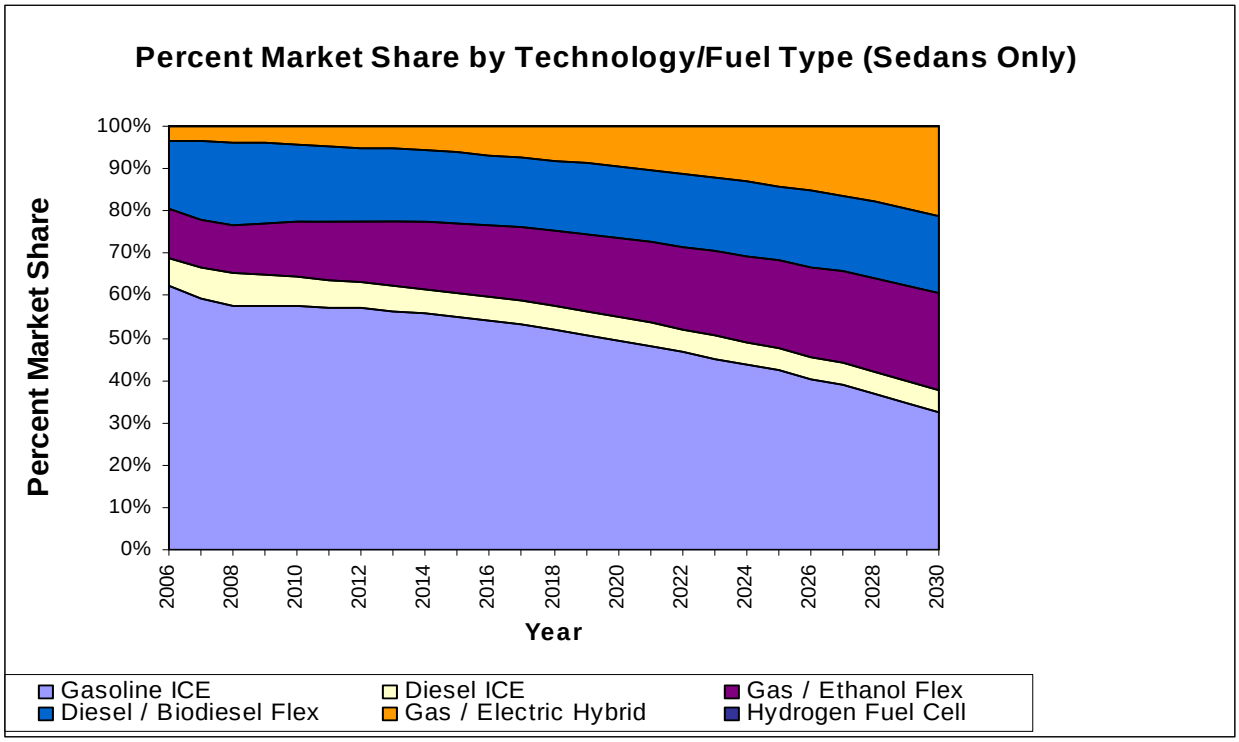
3.5.6. Alternative Fuel Subsidies

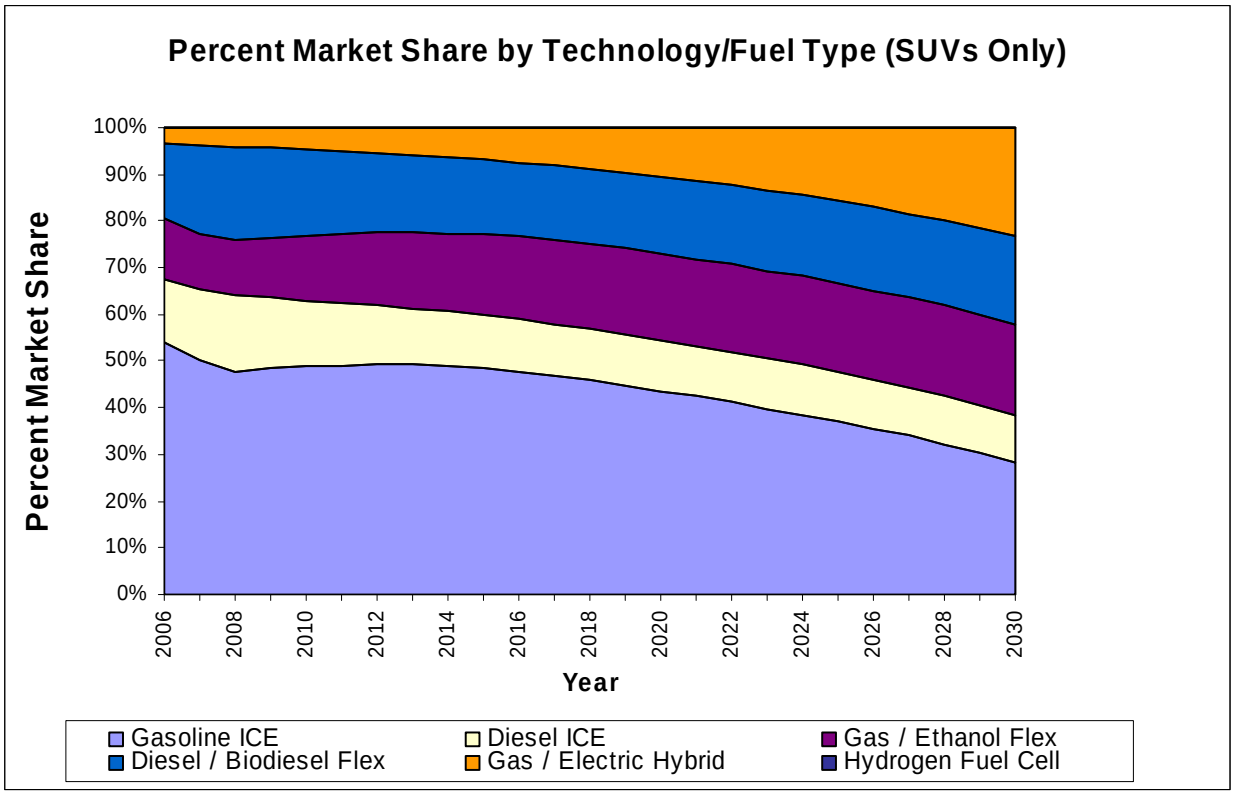
While carbon taxation has been extremely unpopular in the United States thus far, the opposite policy tool for fuel policies, incentives, has been widely utilized in the promotion of alternative biofuels such as ethanol and biodiesel. While federal incentives have been largely targeted at the acquisition of flex fuel vehicles for federal fleets and loans and tax relief for the creation of biofuel infrastructure, numerous states have implemented direct "per-gallon" subsidies to the producers or marketers of biofuels. These policies have the opposite effect of the carbon tax, effectively lowering the cost of the fuels "at-the-pump".

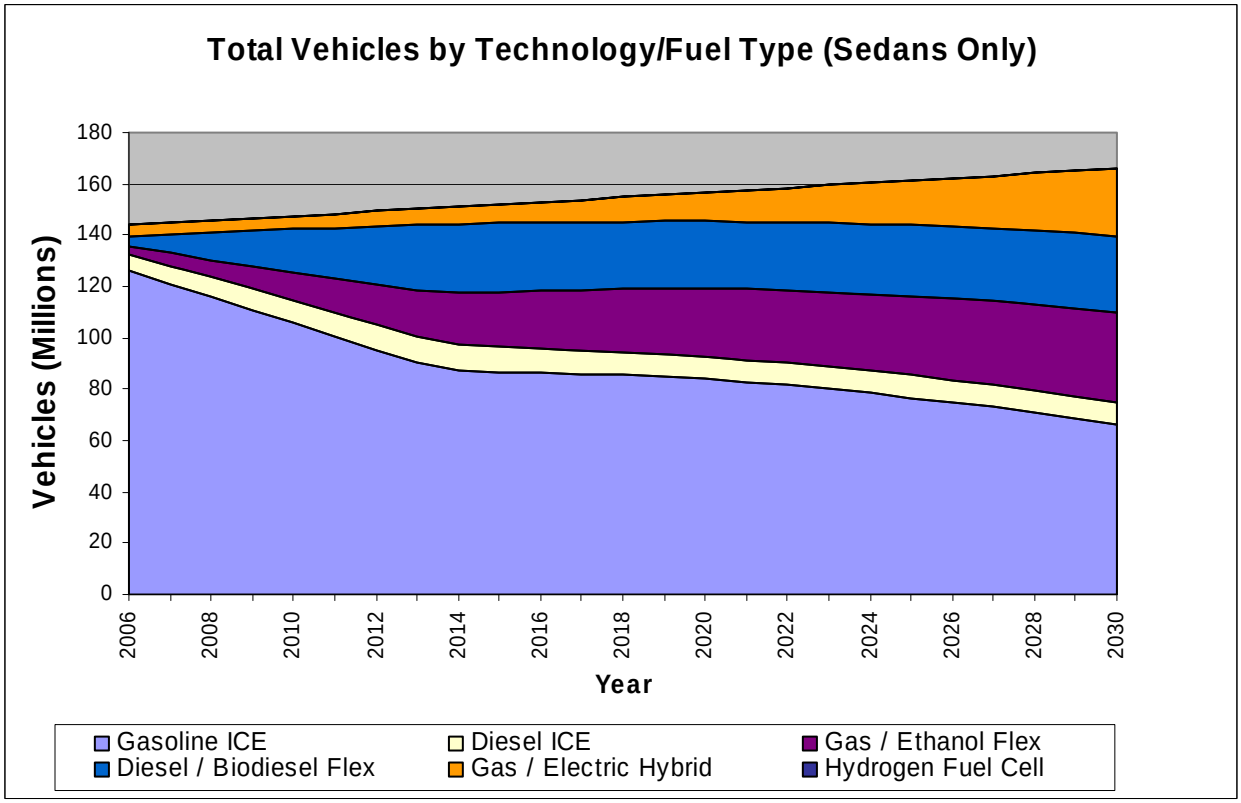
Currently 14 states offer a range of subsidies to the producers and marketers of alternative fuels. These incentives tend to be strongest in those states that have a strong agricultural industry to encourage the growth of fuel based agriculture in those areas. These incentives range from $0.05-$0.30 per gallon and are either distributed directly to the producer or applied as an income tax credit to the producer. The direct payments to the producers are more common as they allow for a more direct accounting of the cost of the production of the fuel so that a truer price may then be passed on to the consumers and marketers of these fuels. (California Energy Commission, 2004)

In this scenario, a federal fuel incentive will be applied to the cost of biodiesel and ethanol. Two sub-scenarios will be examined, one which applies the lowest level of the state incentives ($0.05) and the other that applies the highest level of state incentives ($0.030). These incentives will be applied directly to the cost of the biofuels and will apply for the duration of the projection.

Figure 65(a-g): U.S. Alternative Scenario, Alternative Fuel Subsidy, Low




Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
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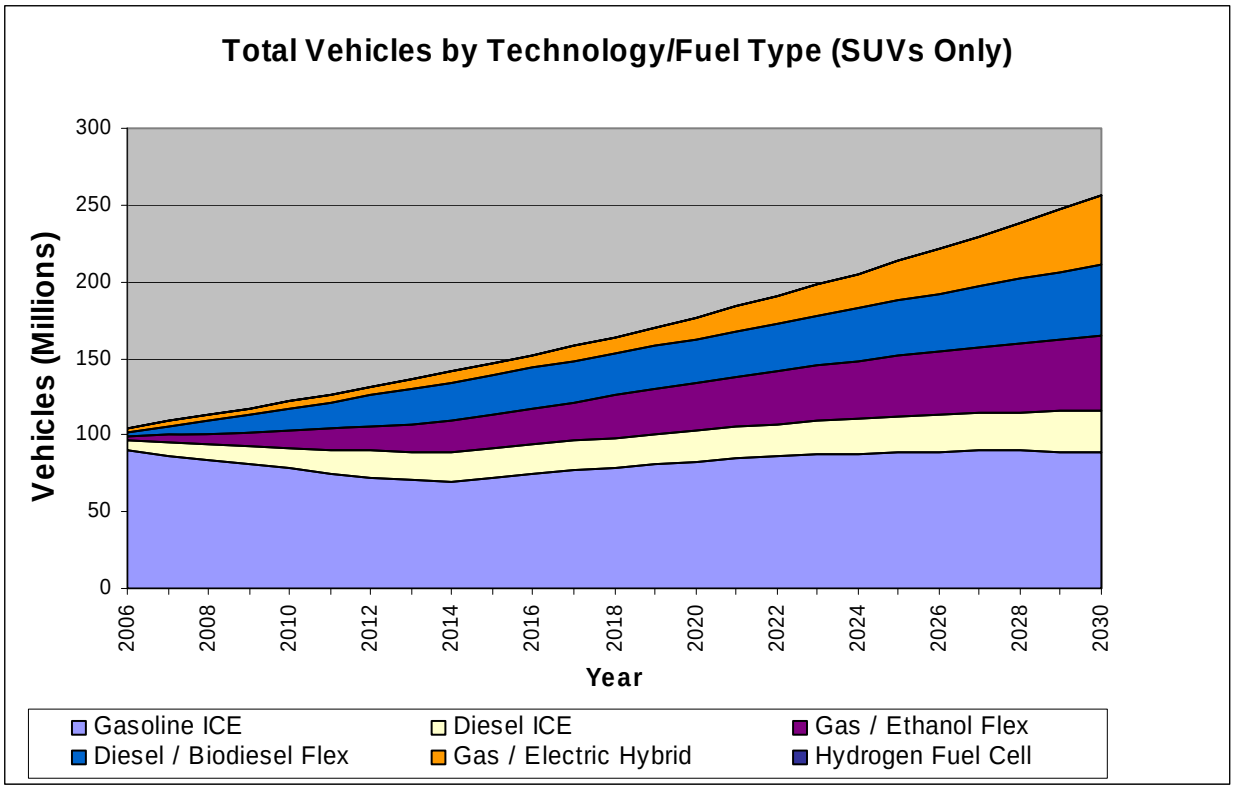
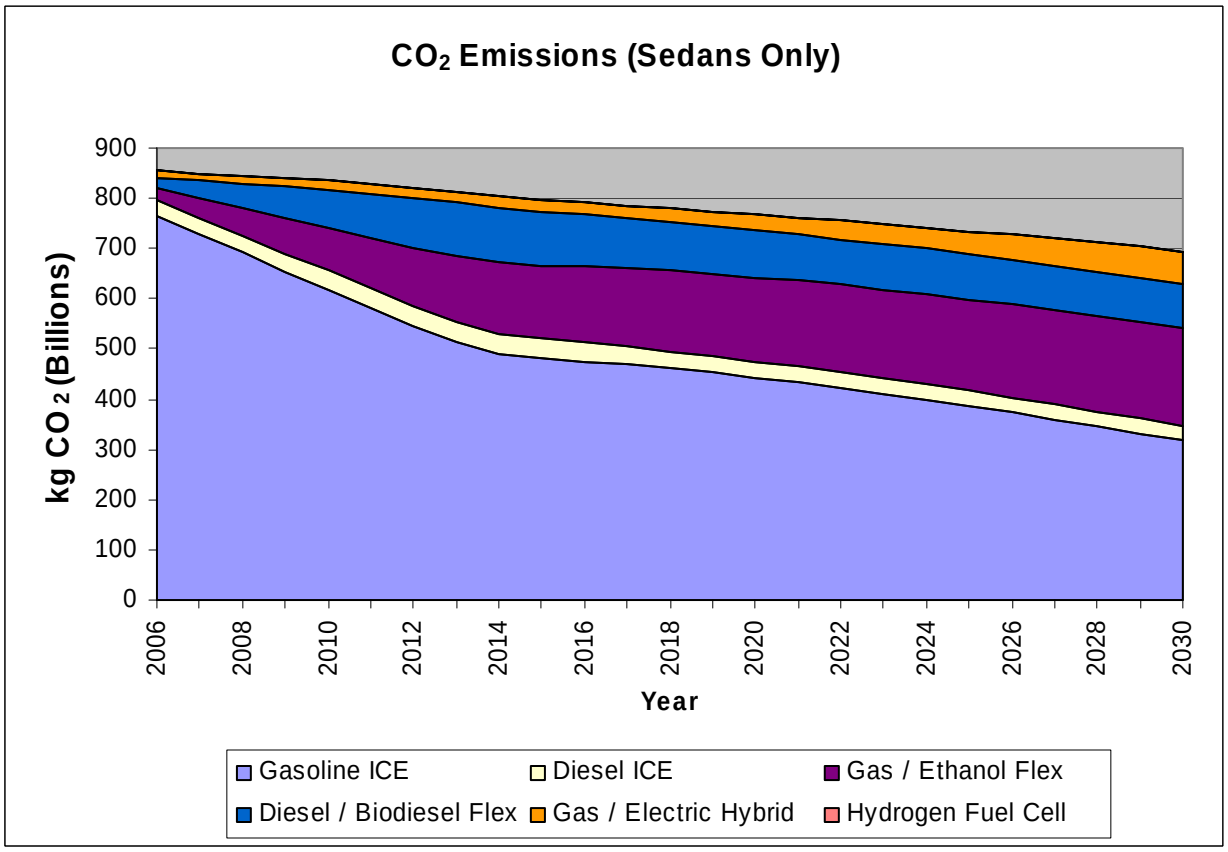
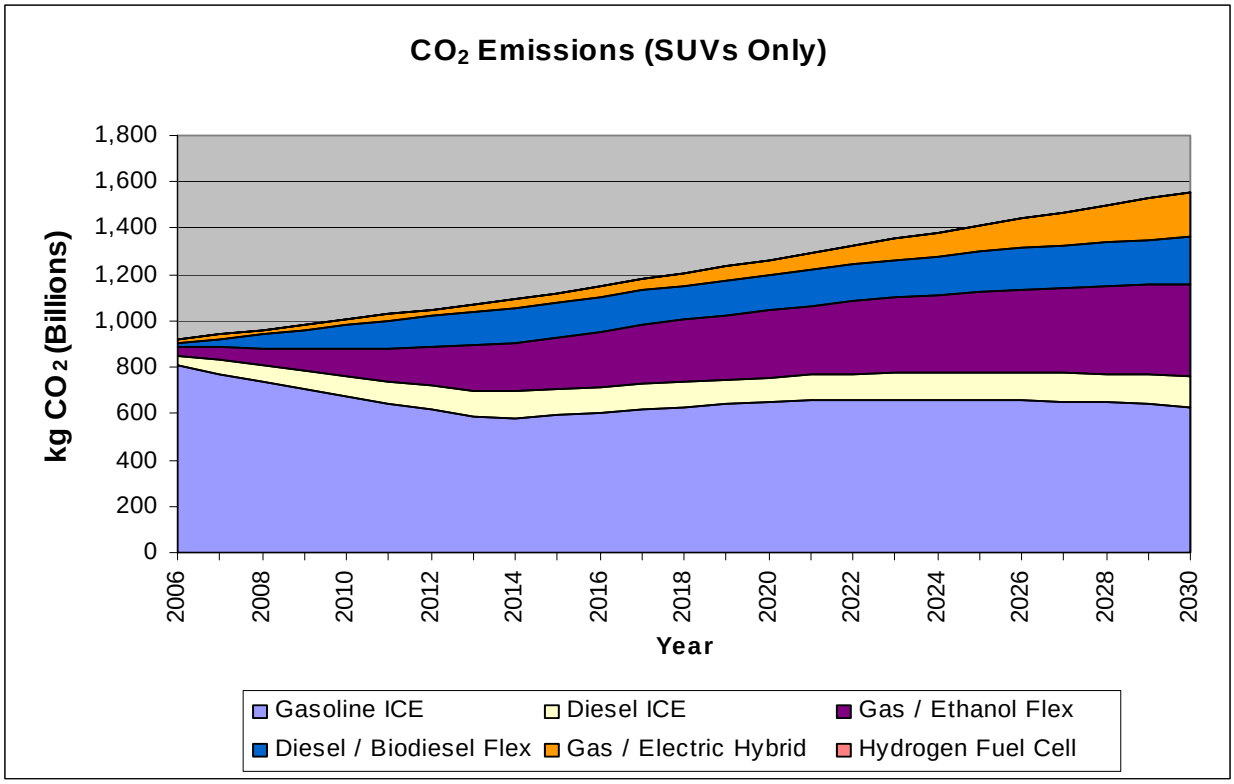
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell



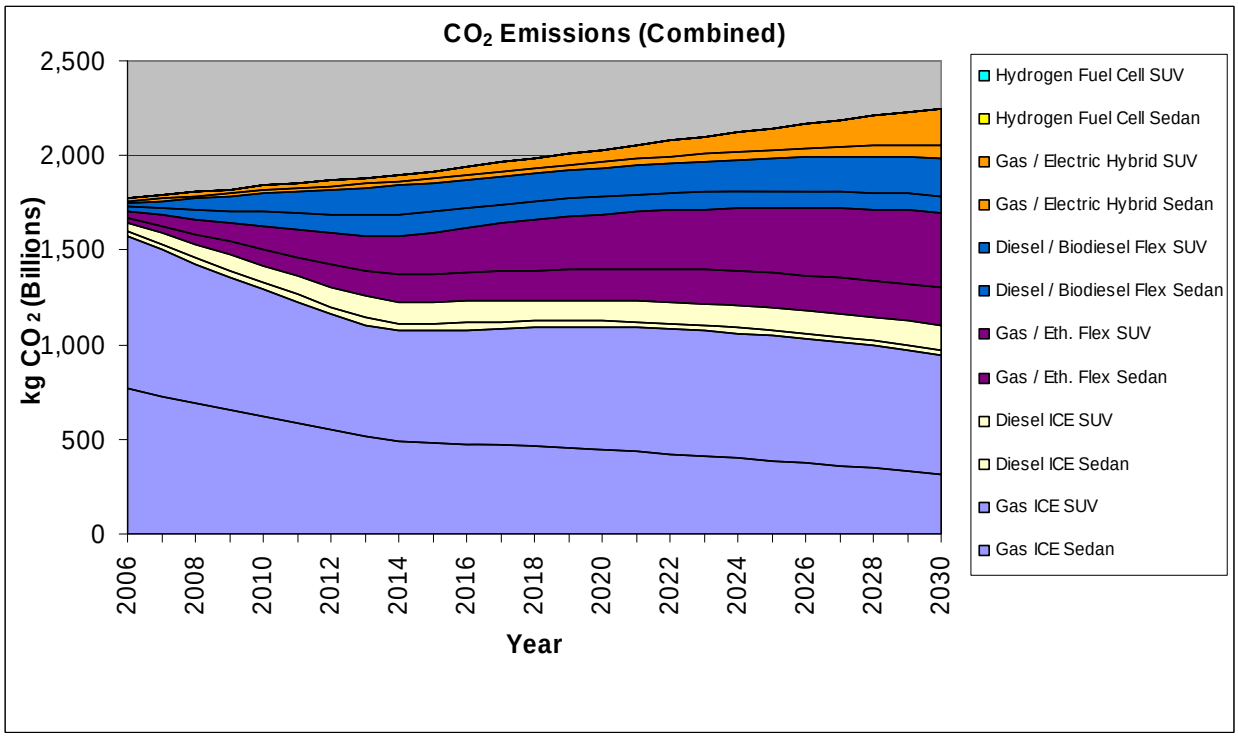
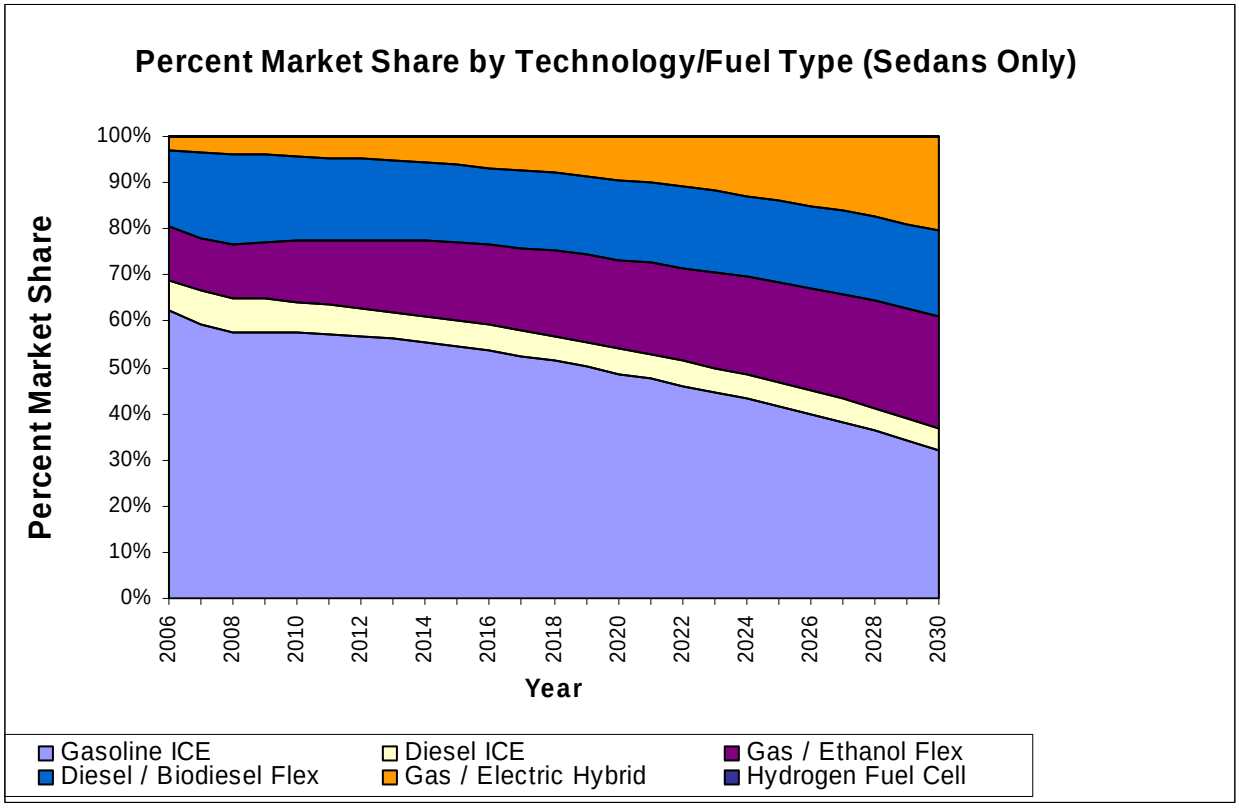
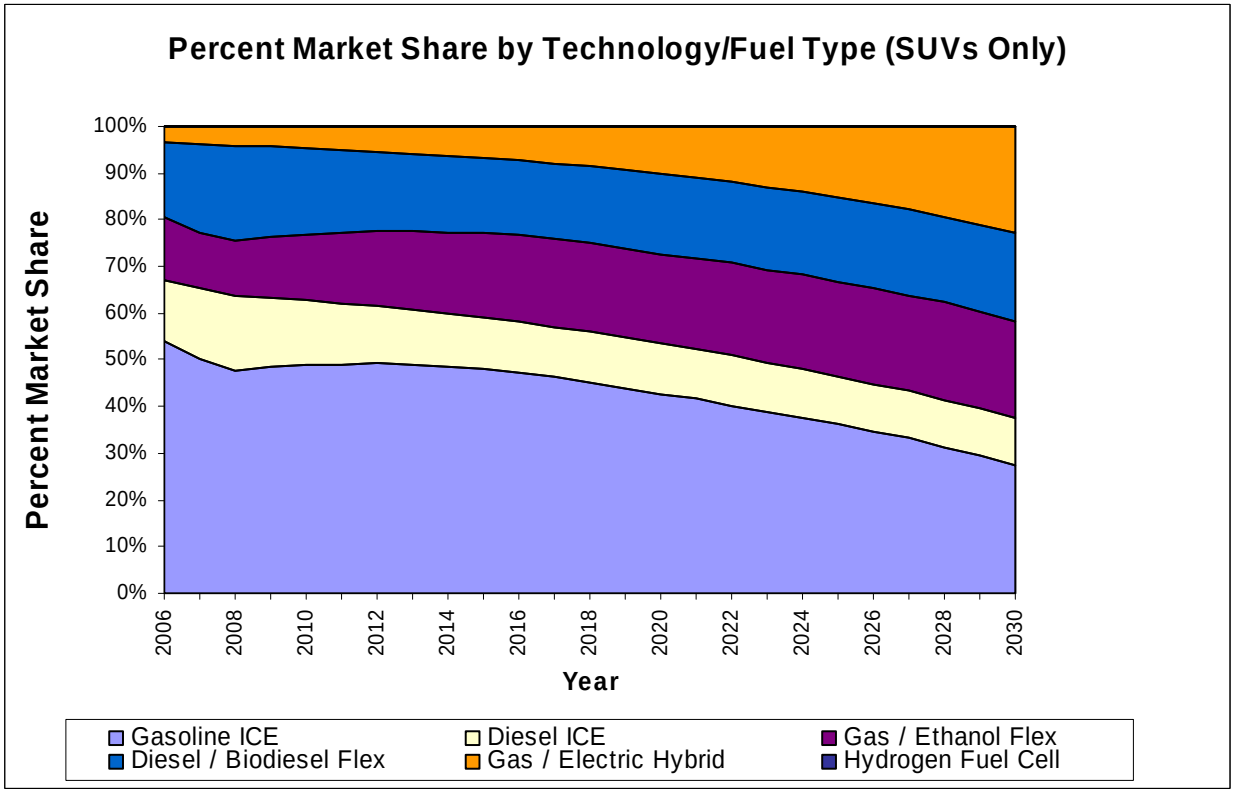


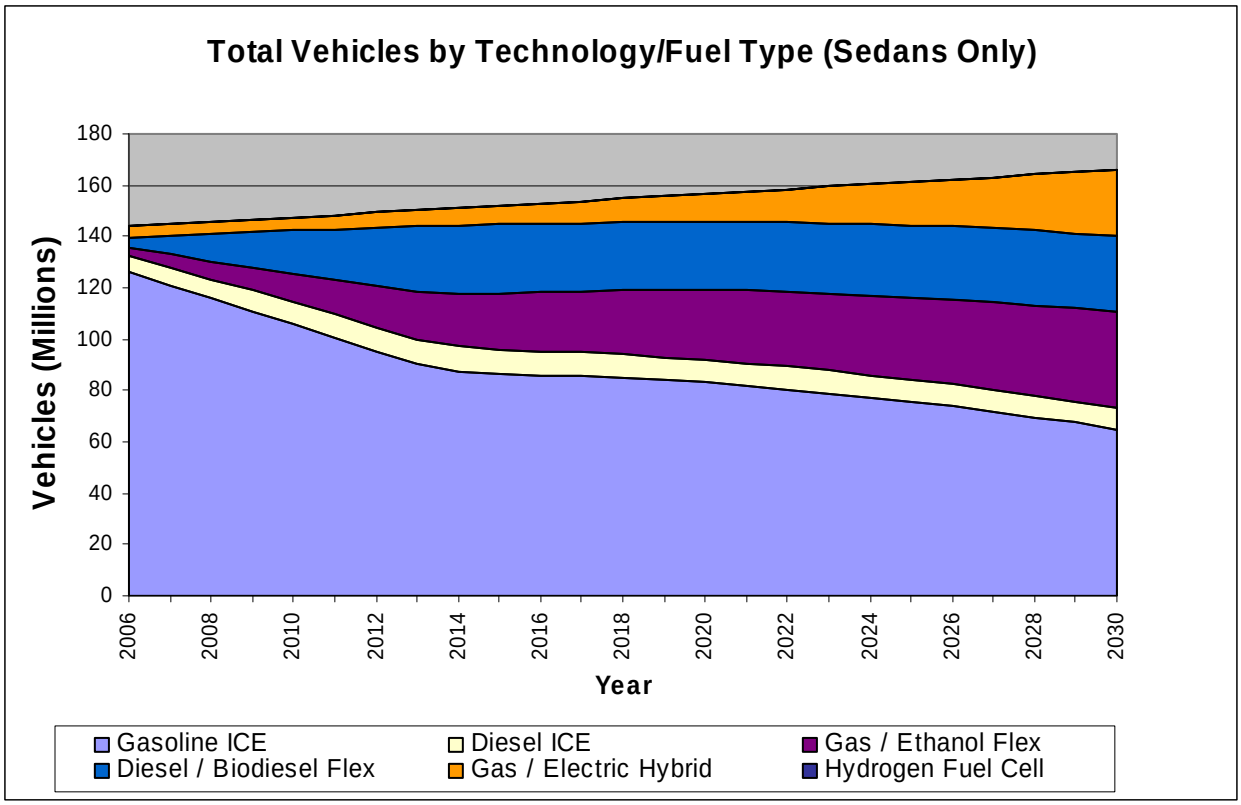
Figure 66: U.S. Alternative Scenario, Alternative Fuel Subsidy, Low, Summary Chart

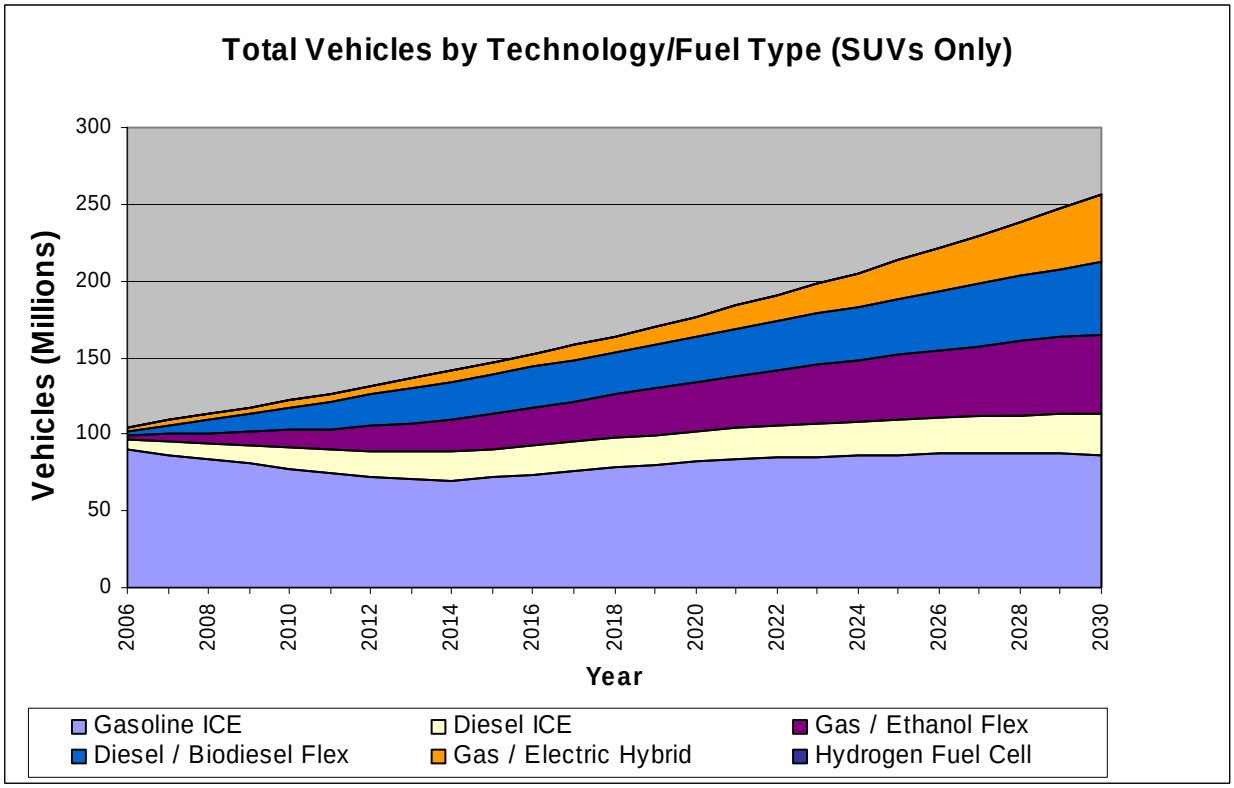
	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	-1	-15
% Reduction	-0.1%	0.0%

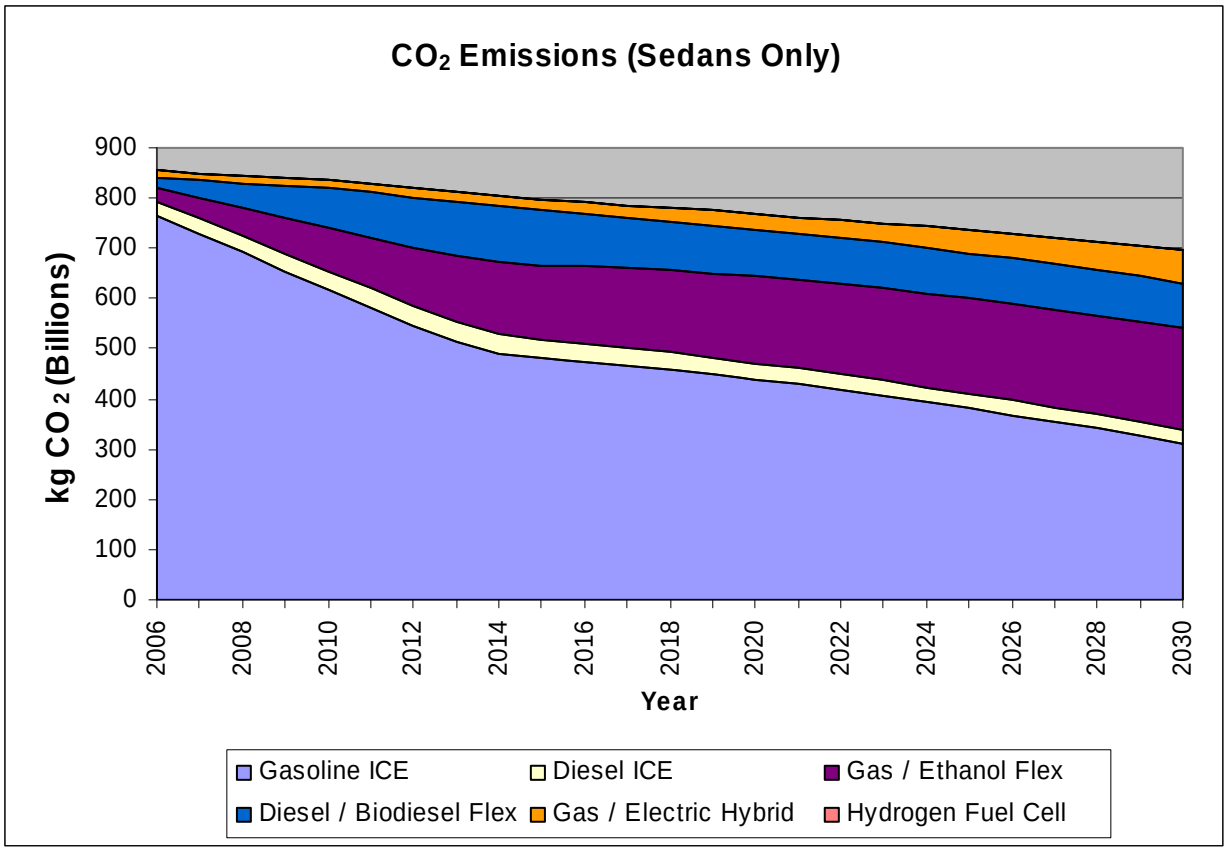
Figure 67(a-g): U.S. Alternative Scenario, Alternative Fuel Subsidy, High

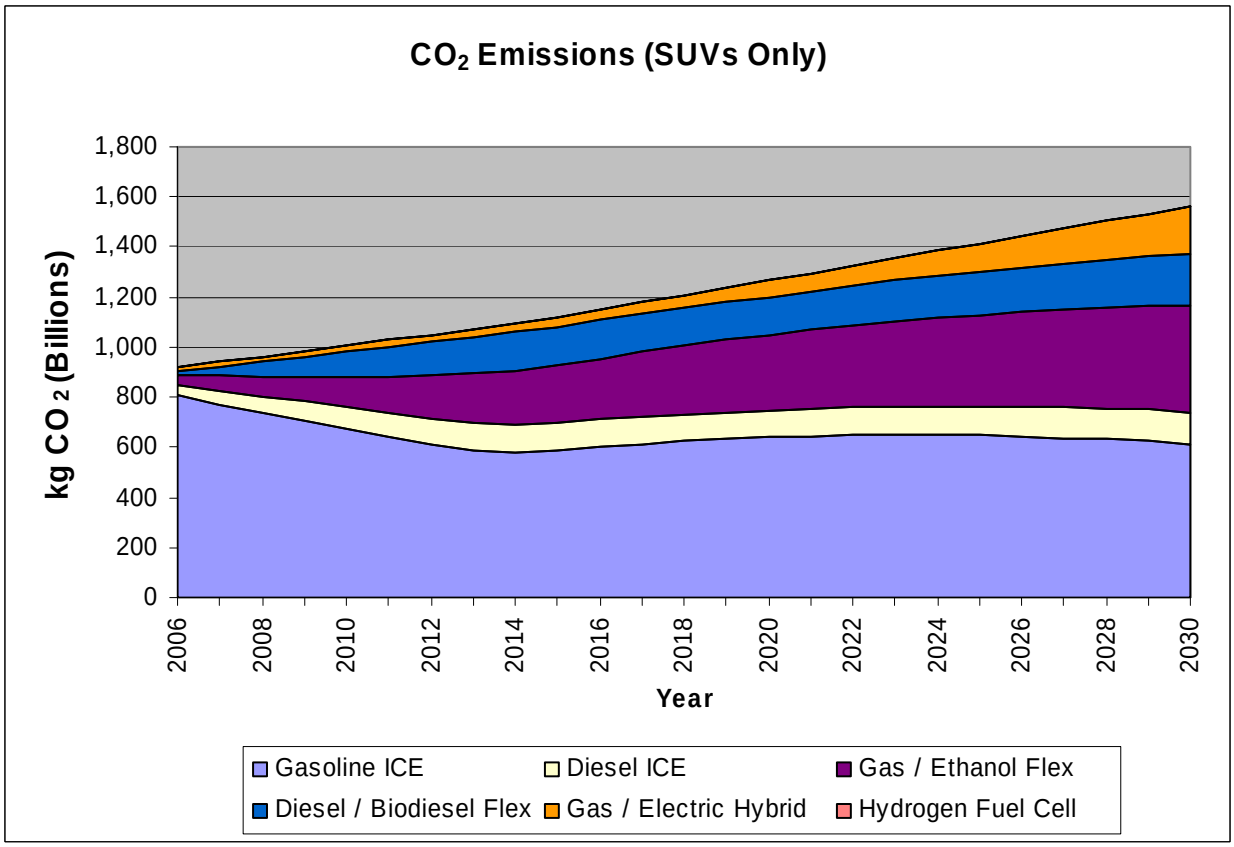





Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

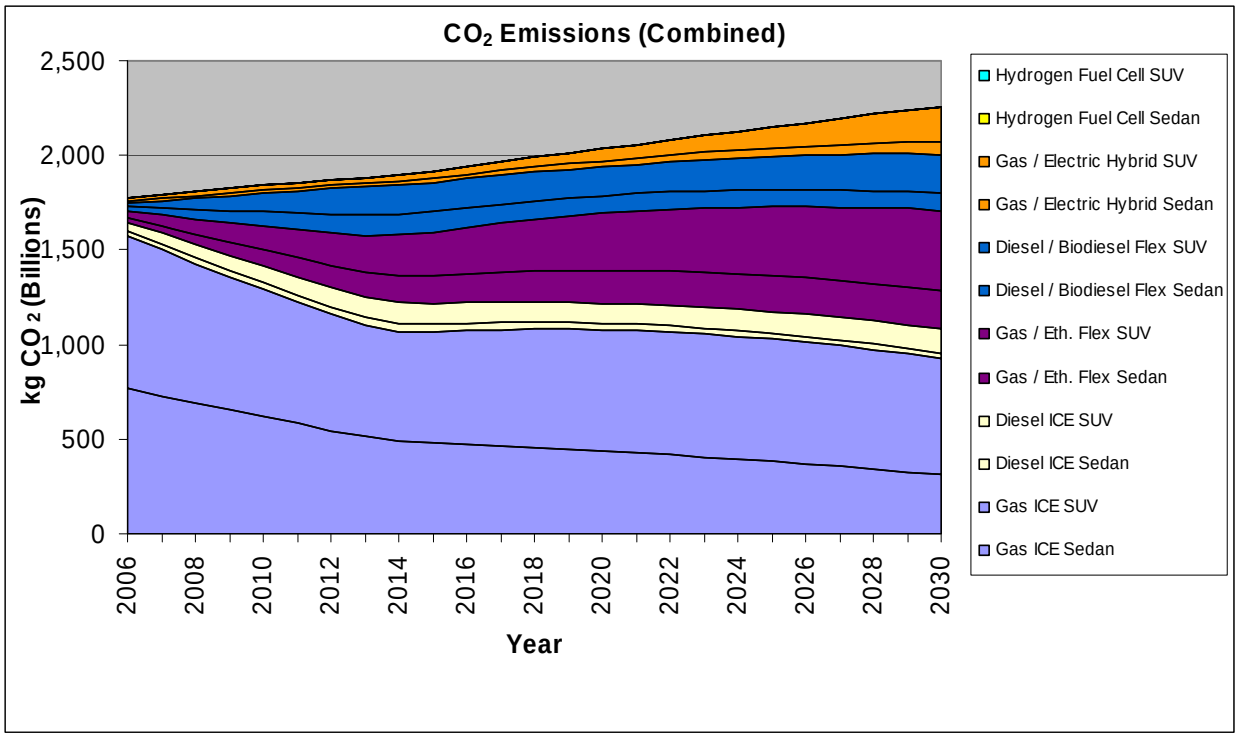


Figure 68: U.S. Alternative Scenario, Alternative Fuel Subsidy, High, Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	-9	-94
% Reduction	-0.4%	-0.2%

While the application of this policy was successful at drawing consumers away from conventional vehicle technologies towards the use of biofuels, it had the unintended result of being the only policy that led to a net increase in the level of carbon dioxide emissions as compared to the baseline scenario. While this increase was quite small (smaller in magnitude than the effects of any other policy scenario) it can only be considered a failure in terms of climate control policy.

The increase in carbon dioxide emissions is caused by the increased reliance on ethanol fueled vehicles which, as previously mentioned, run the risk of having higher carbon dioxide emissions than a conventional vehicle due to their lower fuel economies and emissions produced during the harvesting and refining of the crops to produce the fuel. The emissions gains from this sector are partially offset by emissions decreases through the increased use of biodiesel, but the ethanol technology achieves a slightly higher market penetration and cause the net increase in emissions as compared to the baseline scenario.

If carbon dioxide emissions control is the goal of a policy maker then they must be extremely careful when considering biofuels as a potential technological control strategy. The benefits of biofuels are that they are a renewable resource, can be grown domestically, and require little alteration to the existing infrastructure or vehicle technology in order to implement. Thus they may be introduced inexpensively and relatively quickly providing a short term strategy for dealing with issues of energy security and rising gasoline prices. In time, technology and practices may develop that will allow the biofuels to be produced without the release of such large amounts of carbon dioxide, but current technology causes the well-to-wheels emissions of ethanol fueled vehicles to be higher than conventional gasoline fueled vehicles. Biodiesel is

restricted to a more limited range of utility given the relative lack of support for diesel technology in the passenger vehicle fleet.

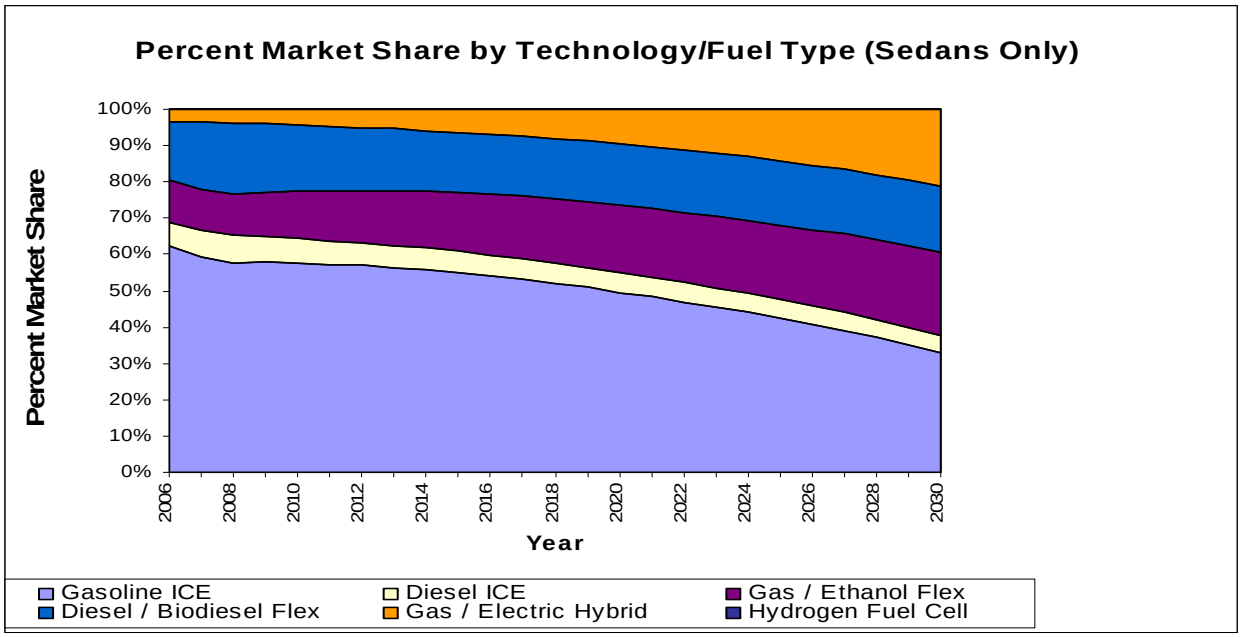
3.5.7. Decreased Annual Vehicle Miles

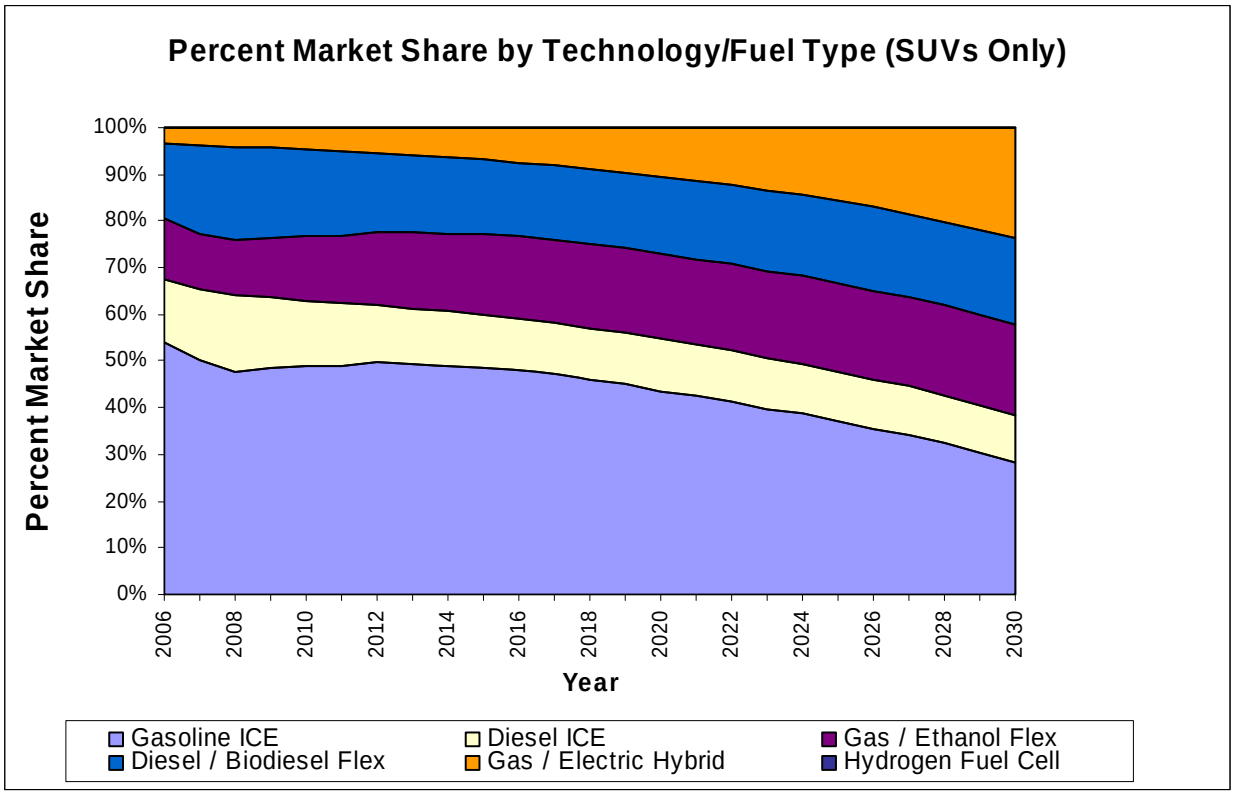
While all of the previously discussed policies have discussed a shift in vehicle technology or in fuels utilized, this scenario seeks to show the effect of a behavioral change within the model. One of the most important behavioral factors included in the model is the average number of miles traveled by each vehicle in a given year. This input has a powerful impact on the amount of emissions produced by the U.S. fleet; any percentage change in vehicle-miles-traveled (VMT) will lead to an equal percentage change in the amount of carbon dioxide emissions while leaving the market shares and number of vehicles on the road untouched. Changes in this input can represent a number of different changes in the real world such as increased carpooling, better public transportation, changes in the rural/urban demographics, increased social awareness, or many other different behavioral changes in the U.S. population.

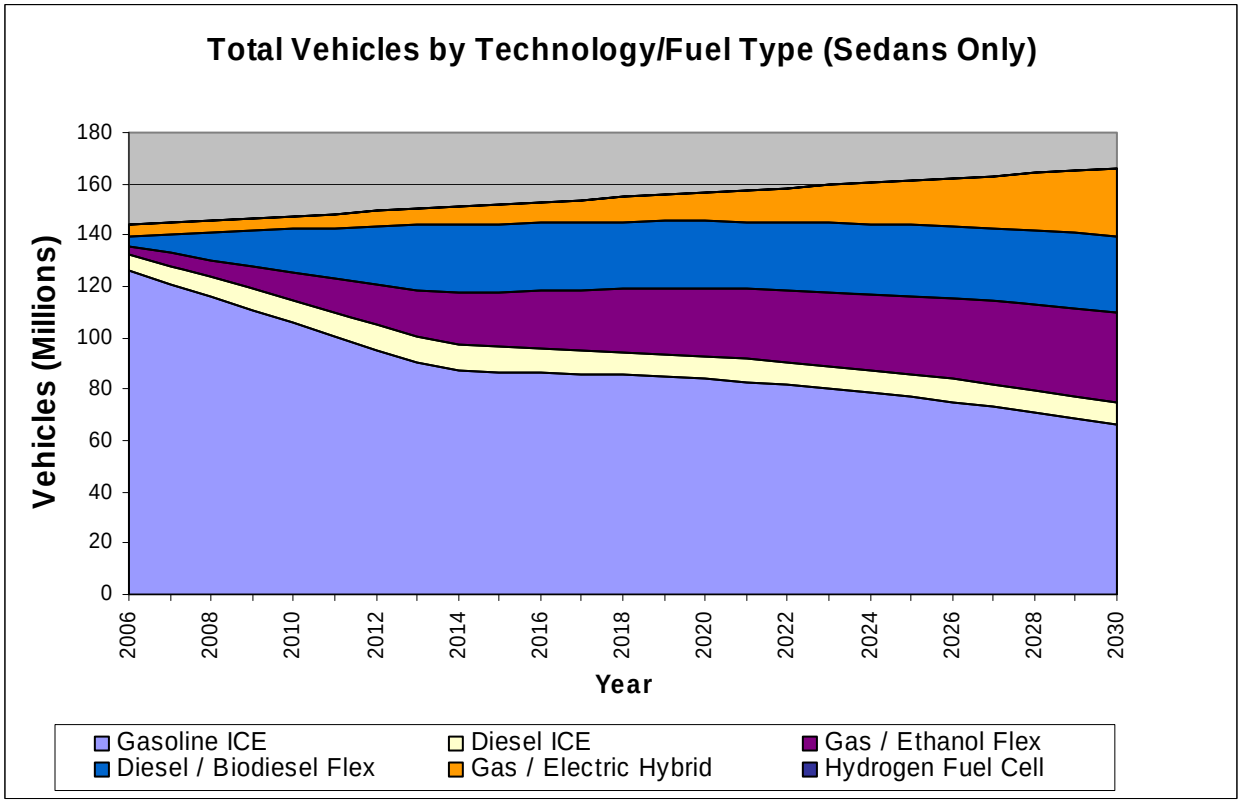
Looking specifically at the role of public transportation in reducing carbon dioxide emissions, it has been calculated that a mile traveled via public transportation emits only 43% of the carbon dioxide on average as compared to a single vehicle mile traveled. This represents a significant potential for reducing carbon dioxide emissions in the U.S. In addition to this benefit, it has also been suggested that increased development of public transportation results in more compact development patterns, which reduces the need to travel longer distances to reach a destination when vehicles are used, thus leading to an additional reduction in vehicle miles traveled, though there is substantial disagreement as to the exact measure of this effect (SAIC, 2007).

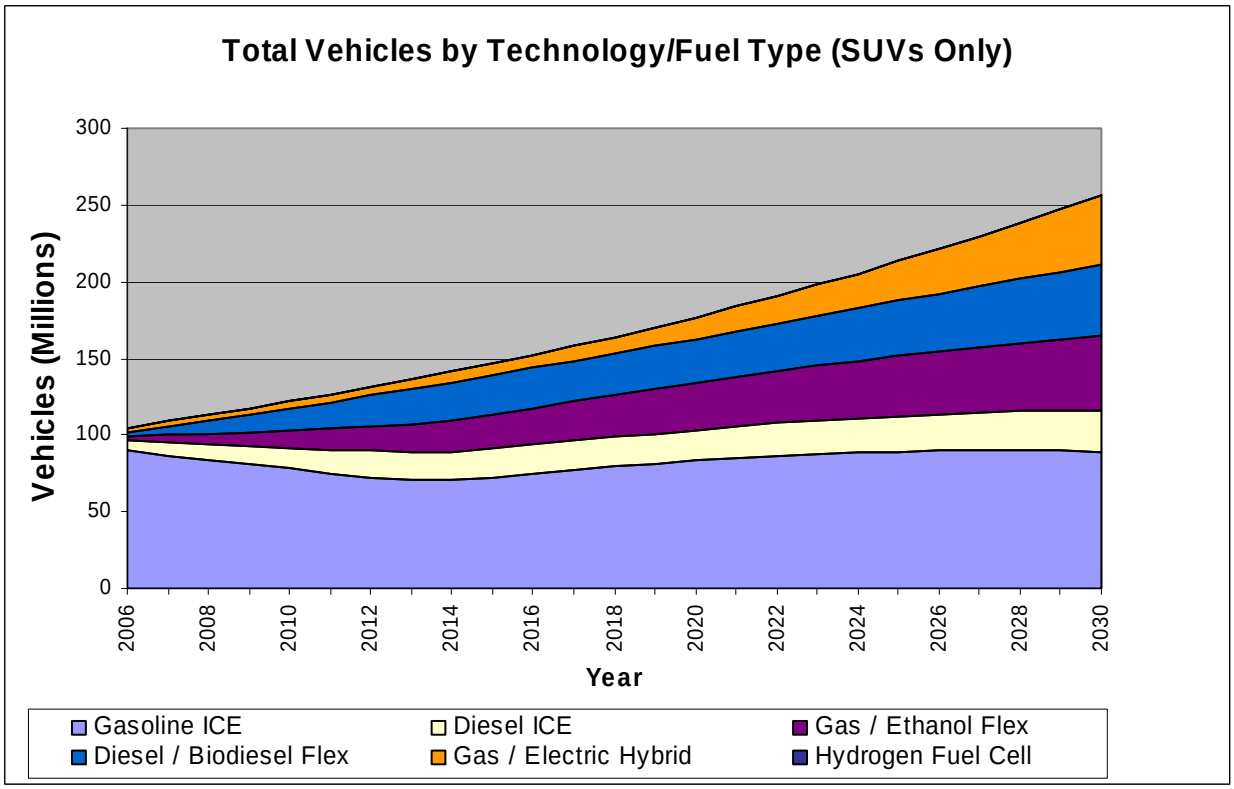
In this scenario, we will assume that an aggressive public transportation promotion and development policy has gone into effect which aims at switching 5% of all VMTs to public transit by 2010 and 20% of all VMTs to public transit by 2020. This will be enacted in the model by reducing the VMT entered into the model by a value equal to 57% (1-43%) of the percentage switching to public transportation as this will mimic the carbon dioxide reductions garnered by the switch. This equates to a reduction in VMT of 2.85% by 2010, and 11.4% by 2020.

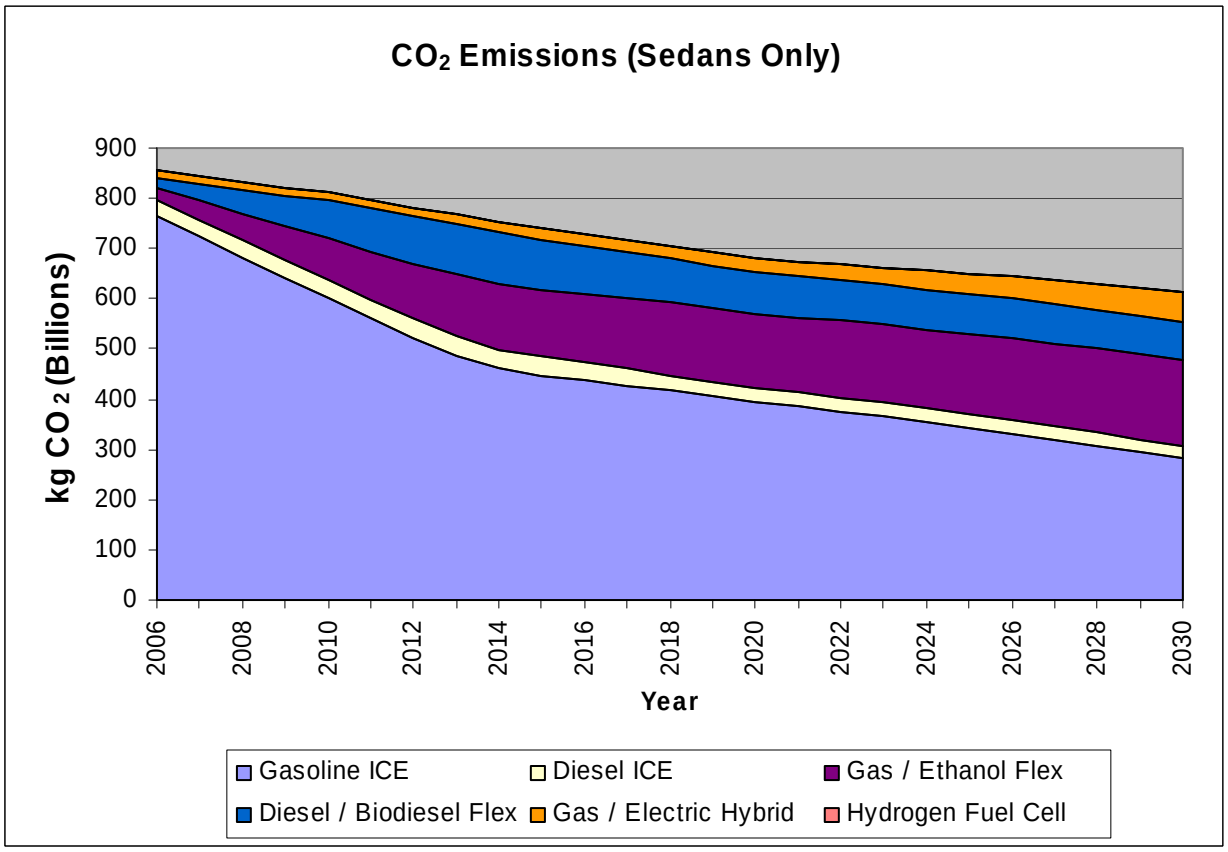
Figure 69(a-g): U.S. Alternative Scenario, Decreased Vehicle Miles

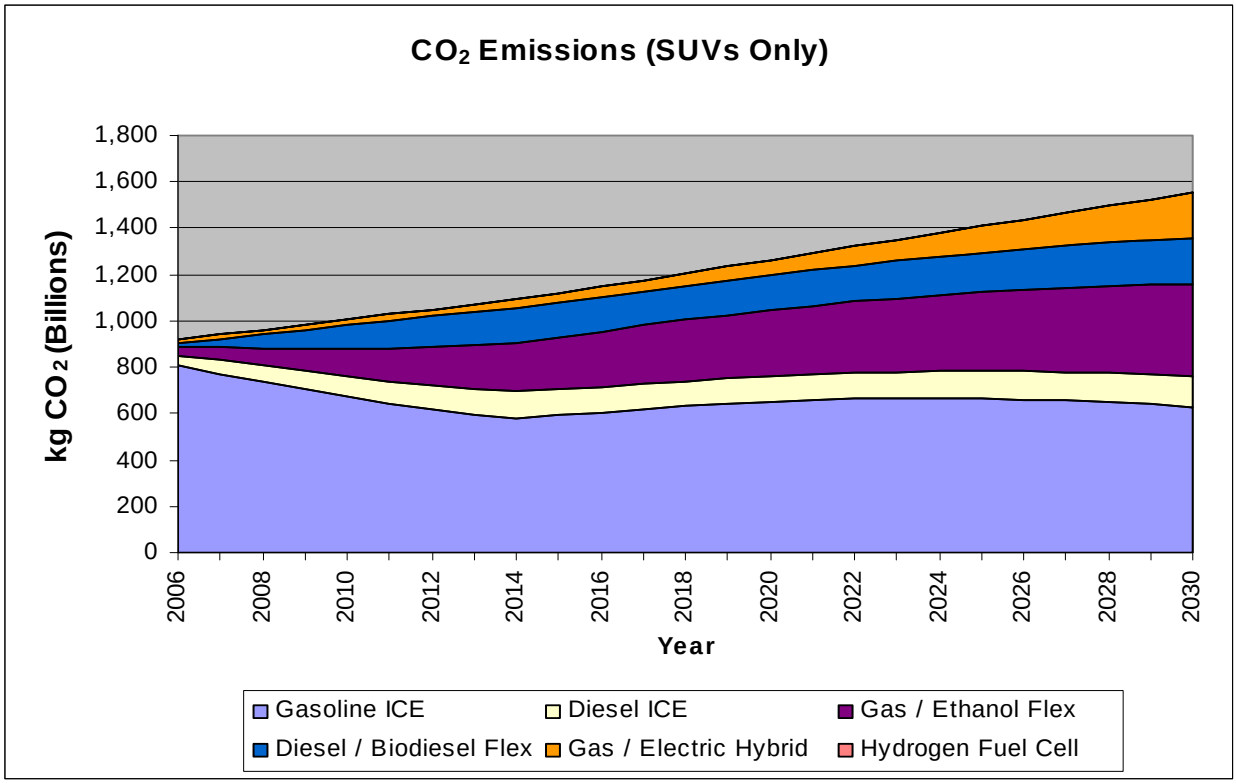



Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

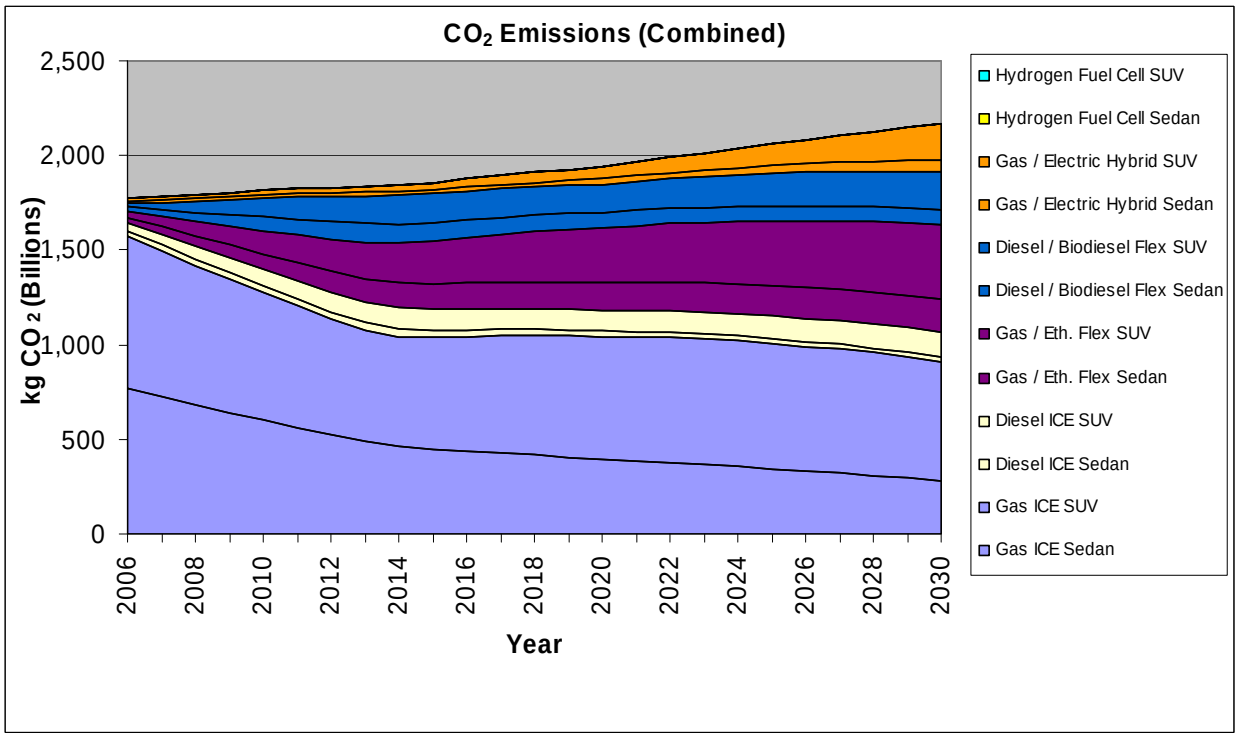

CO2 Emissions (Combined)
kg CO2 (Billions)
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan

Figure 70: U.S. Alternative Scenario, Decreased Vehicle Miles Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	79	1,488
% Reduction	3.5%	3.0%

While effective at reducing greenhouse gas emissions, the concept of reducing the number of vehicle miles traveled on average in a year is relatively difficult to enact in a real world situation. The two ways in which this could be done would be to reduce the distance that people actually travel or two share conveyances in order to improve efficiency either though carpooling or public transportation. Altering the ways in which people move around their environment, changing where they go or how often they go there, is a difficult concept to apply to reality.

Much of the travel being conducted is fixed in nature, a person has to travel from where there is housing to where there is employment or shopping opportunities and altering those behaviors or the physical layout of the environment would be difficult and a long term effort if even at all possible. Many public policies are aimed at facilitating a shift to public transportation with an overall goal of reducing automobile vehicle miles traveled. But even this concept is limited in the role that it can play due to the relatively fixed nature of the physical environments in which the population is traveling.

The economics of public transportation are best in areas of high density such as intra or inter city travel, or from the outlying suburbs into a major metropolitan area. Increasing public transportation for those sectors of the population that do not lay within those confine would be prohibitively expensive. And the public transportation options that could economically serve those areas has, in many cases, already been constructed. This does not mean that there is no role for this policy option in climate control, only that it is limited in the role it can play.

As can be seen, a modest increase in the use of public transportation does lead to a significant decrease in the level of carbon dioxide emissions coming from the passenger vehicle fleet. This policy tool is unlikely to be able to exceed this value, however, without incurring prohibitively high costs and, while the exact costs of even this modest scenario are uncertain due to the highly variable nature of such projects based on locations and demographics, even the economical projects would require a tremendous amount of upfront funding and take many years to complete, making this policy scenario limited in the level of its overall effect and speed with which it could be deployed.

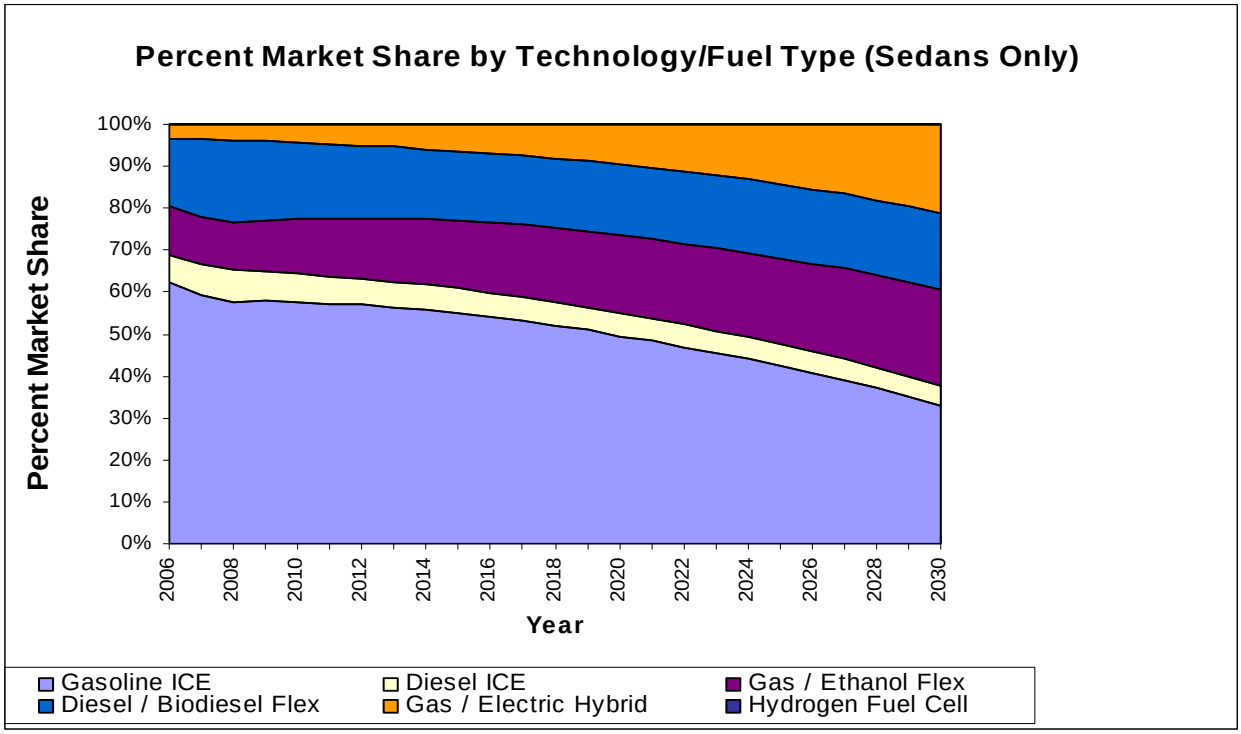
3.5.8. Shifting Consumer Preference over Vehicle Size

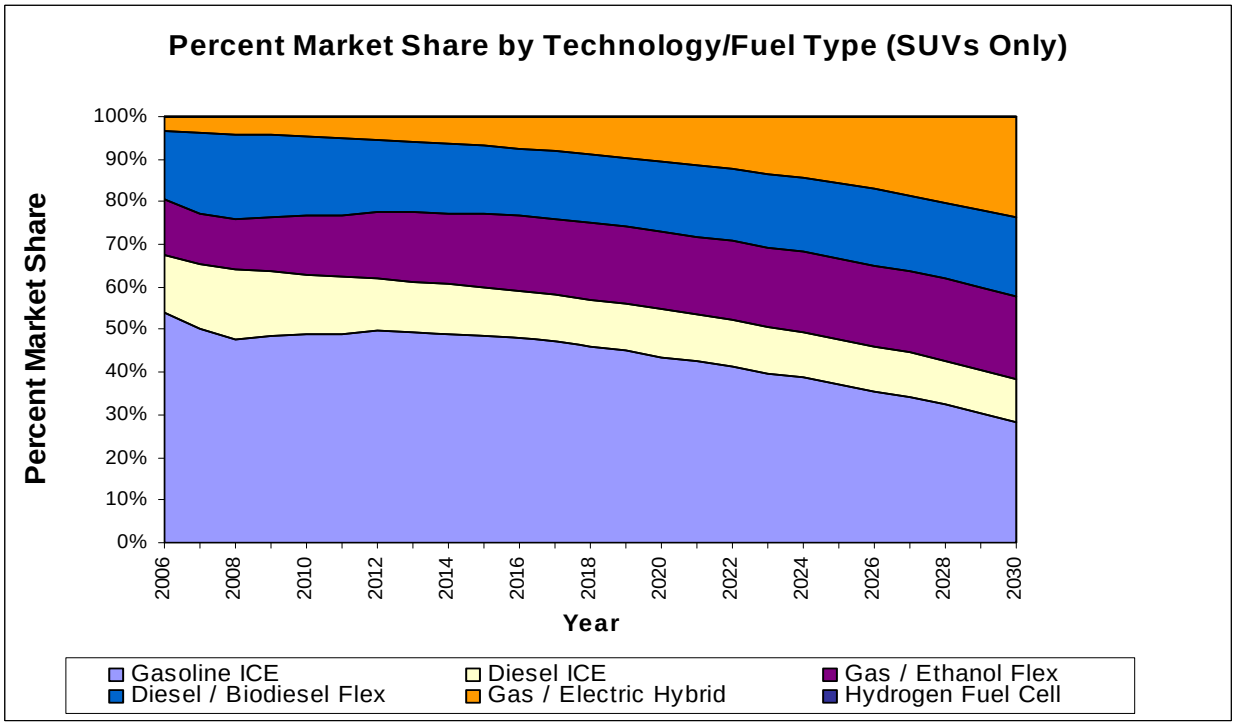
Beginning in the late 1980s and continuing into the early 2000s, consumers have shown a growing preference for larger vehicles such as SUVs as compared to the smaller more fuel efficient sedans. This has led to a tremendous rate of growth in the vehicle pool of SUVs which, in the baseline scenario, is predicted to continue into the future. In recent years however, there has been mounting evidence that consumer preferences have been shifting towards more fuel efficient vehicles. This trend can be seen in the popularity of hybrid vehicles of all types as well as the inclusion of a vehicle's MPG in most television commercials.

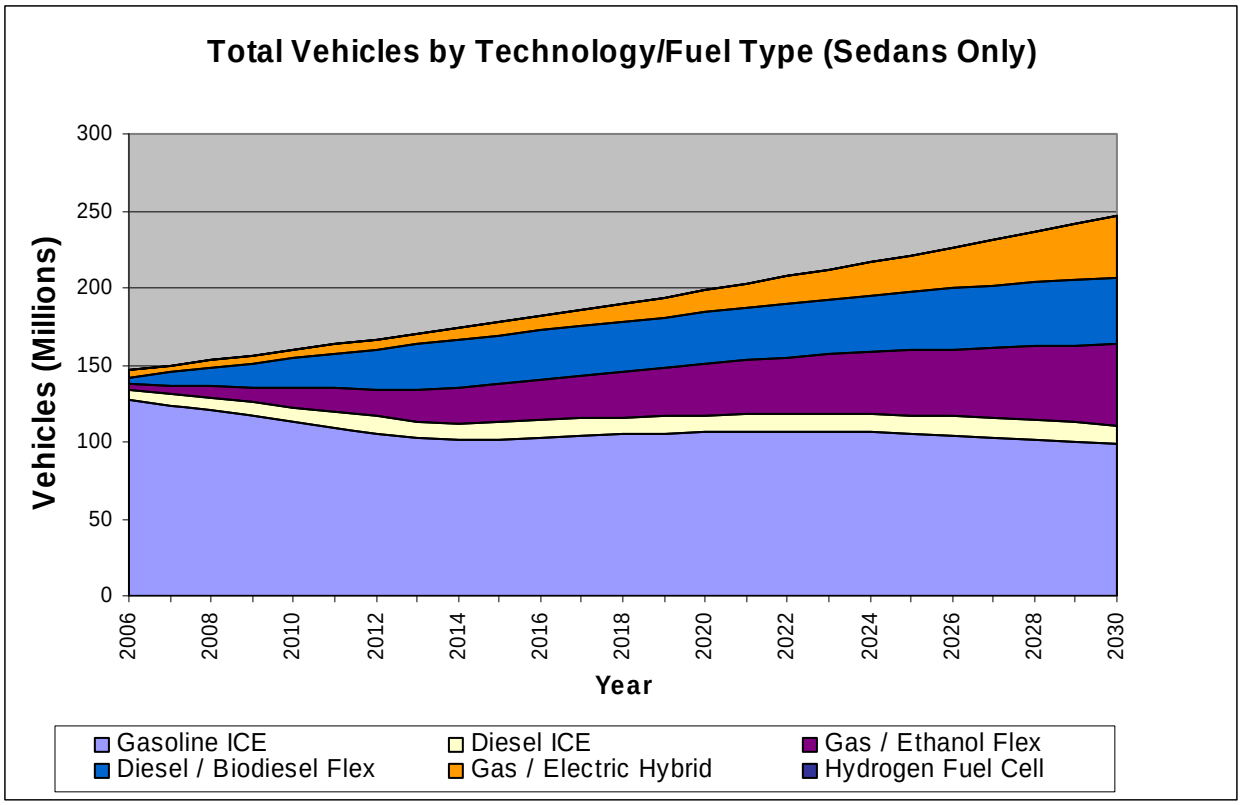
While the baseline scenario does not show this shifting consumer preference for fuel efficiency causing a decline in popularity of the SUV in favor of the sedan, there are many who believe that market shares of the vehicles will begin to shift back towards sedans and other smaller vehicles. If this shift does occur, then it will lead to a dramatic reduction in overall greenhouse gas emissions as compared to the baseline scenario. In this scenario, it is assumed that the dramatic difference in the growth rates of the SUV versus the sedan vehicle pools is reduced so that the two different pools now growth at equal rates. The average growth rate of

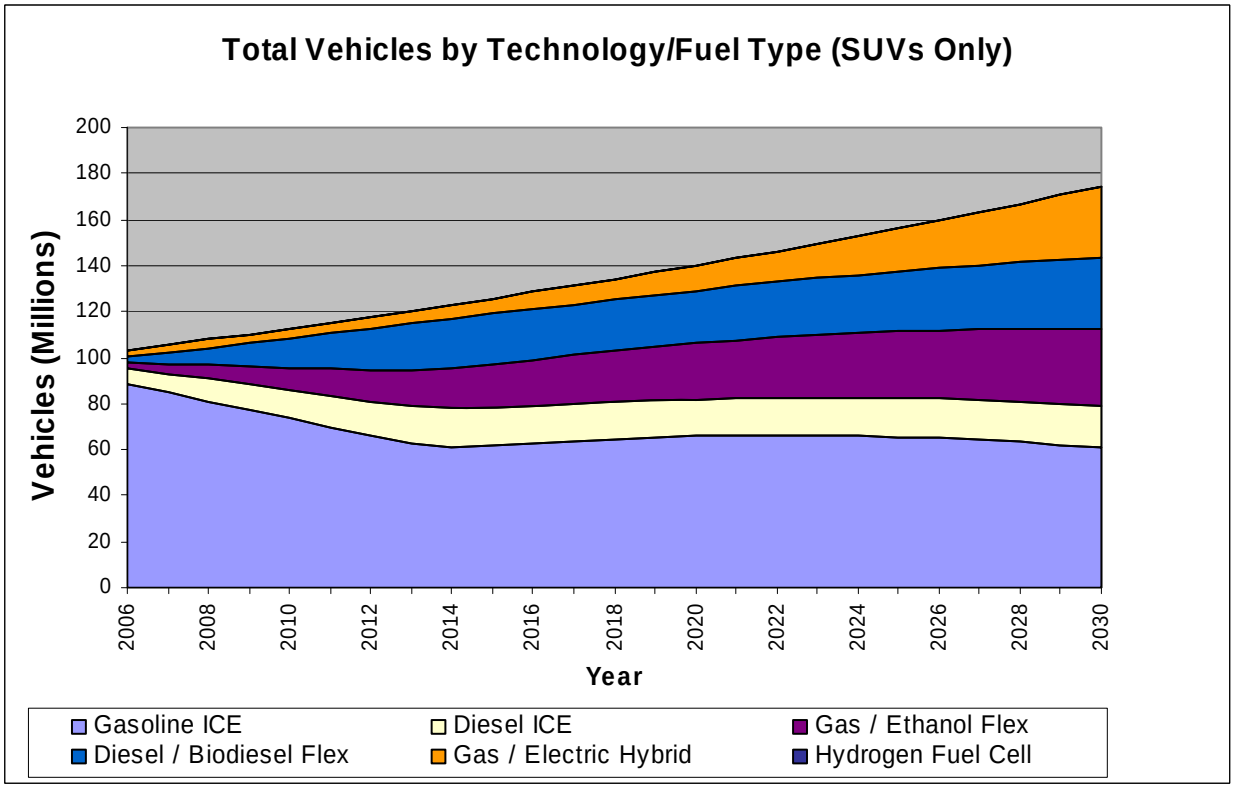
these two pools is 2.2% per year, as compared to 3.8% for SUVs and 0.6% for sedans. By averaging these two values for the duration of the study, tremendous reductions in carbon dioxide emissions can be expected, as the sedans achieve, on average, 44% higher fuel economies than SUVs.

Figure 71(a-g): U.S. Alternative Scenario, Vehicle Size Preference






Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
200
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
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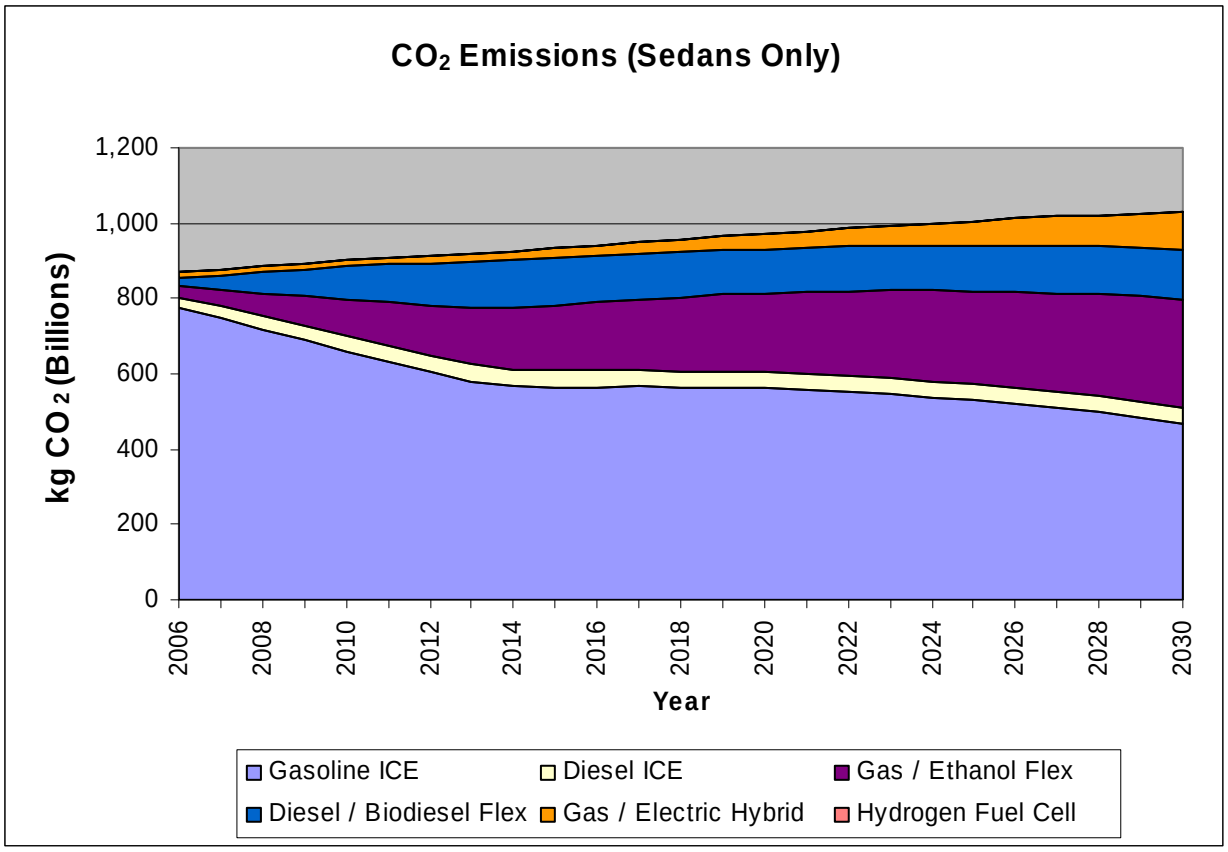
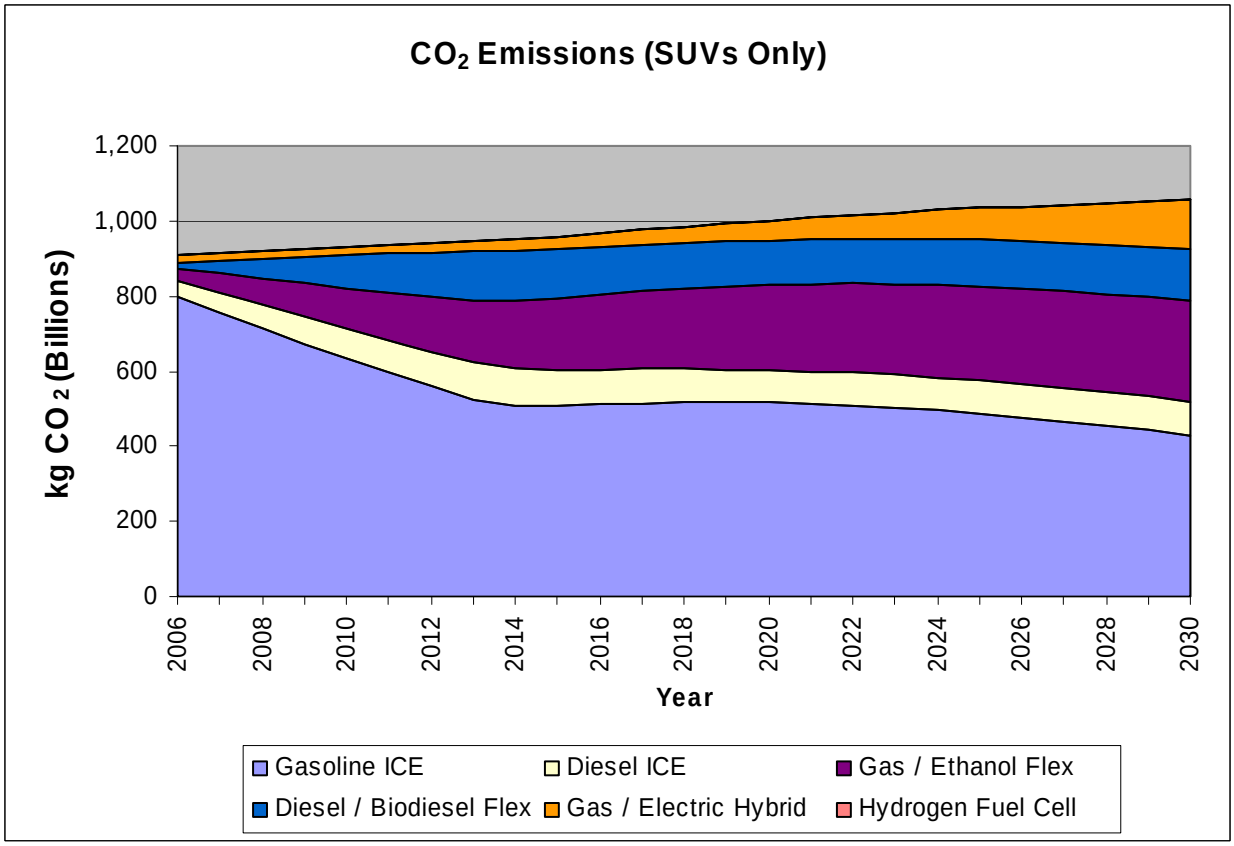
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
1,200
1,000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

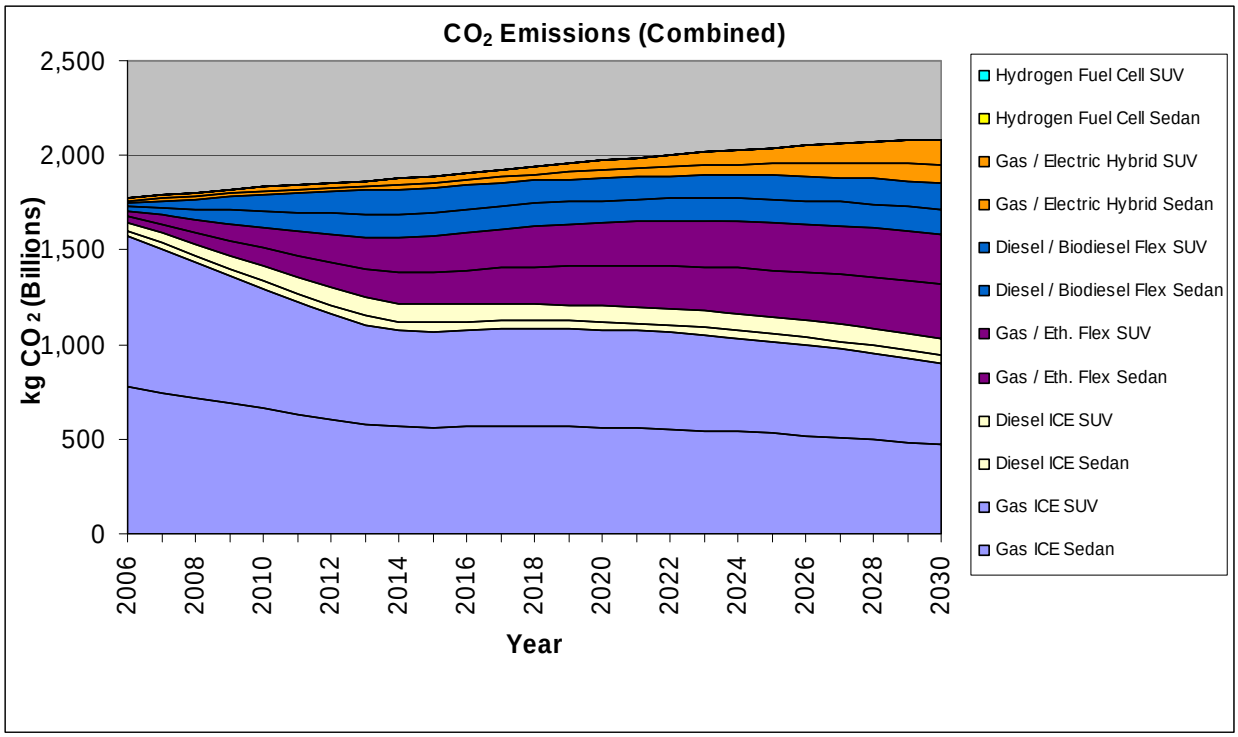


Figure 72: U.S. Alternative Scenario, Vehicle Size Preference Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	164	1,432
% Reduction	7.3%	2.9%

This scenario represents the danger that would be faced by a sustained long term affinity by the American public for sport utility vehicles. While the scenario does not shift either the absolute number of vehicles on the road, the market shares amongst the different technologies of those vehicles, the performance of the different types of vehicles, or the way in which they are driven, it represents a general shift in consumer preference from larger SUVs towards smaller, more fuel efficient sedans.

This shift leads to modest reductions in carbon dioxide emissions over the course of the projection, but the particularly interesting factor is the percentage reduction in carbon dioxide emissions seen during the 25th year of the study. In this year a 7.3% decline from the baseline scenario can be seen. This large decline in the later years of the projection shows the importance of this sort of shift in the long term effectiveness of any climate control strategy. The majority of the benefits of this consumer shift are not seen in the short term, but rather in the long term where the shift displaces a future that is primarily dominated by SUVs and replaces it with one where they play a more subdued role than they do in the baseline scenario.

Any long term climate control policy must encourage a shift towards increased levels of conservation in addition to efficiency increases and changes in technology to solve the climate change issue. In the baseline scenario, the carbon dioxide emissions increase over the course of the projection despite the fact that fuel economies are increasing and newer, alternative technologies are being adopted. This rise is caused primarily by two factors, the growing vehicle population pool (cause by human population growth) and the increasing dominance of SUV's in

the market as compared to sedans. A shift away from the culture of consumption must accompany any strategy to achieve long term carbon dioxide reductions.

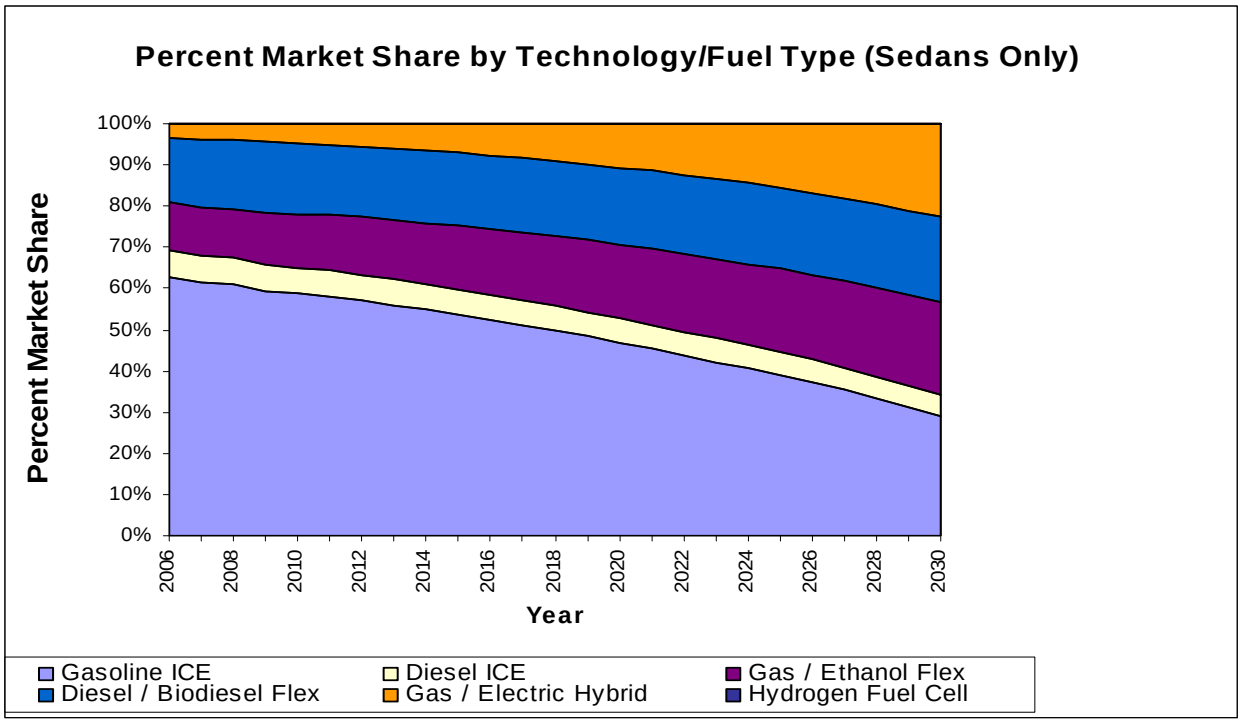
3.5.9. Increasing Price of Gasoline

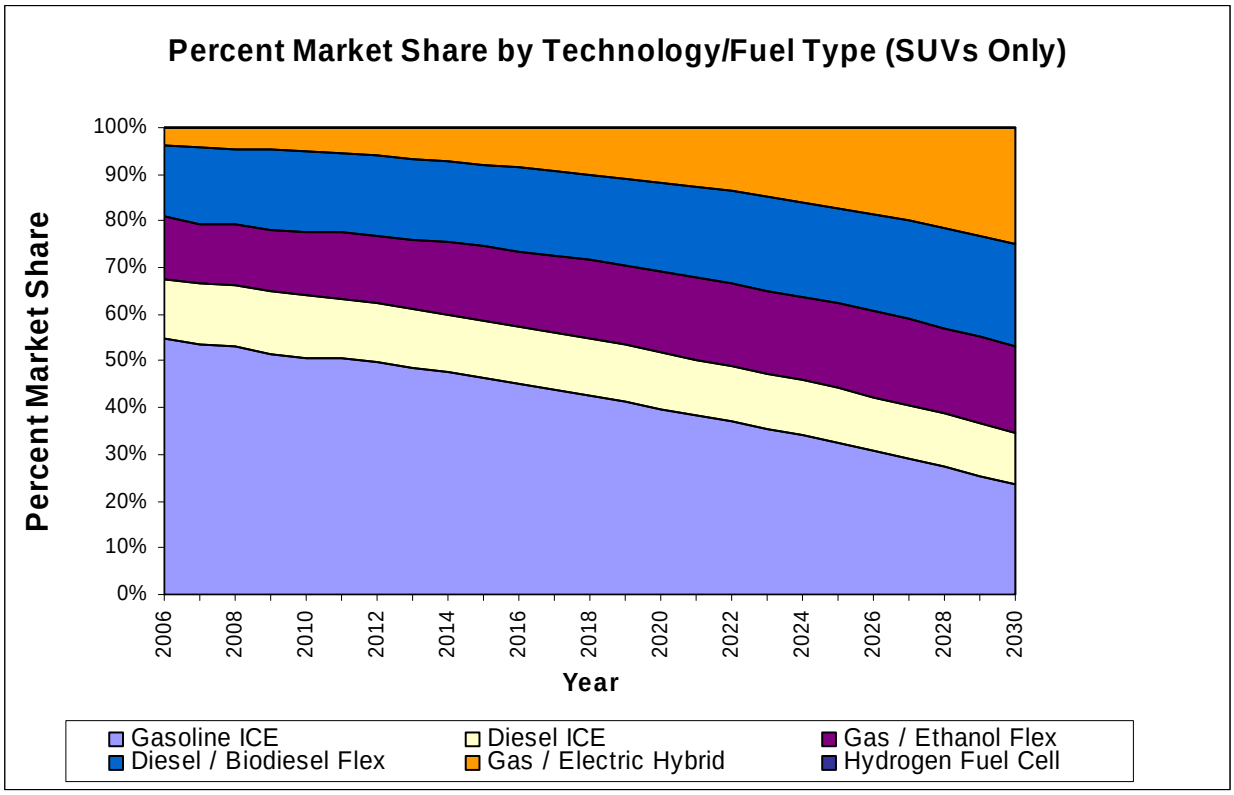
Although it is the constant focus of mainstream media and most consumers, the threat of rising gasoline prices has not made its way into the most recent government projections for the future cost of gasoline and diesel. Indeed, as mentioned earlier in this report, the EIA has consistently referred to the annual rise in gasoline prices as merely the extension of a small bump in gasoline prices before they return to their previous low levels rather than as a trend leading to the continual escalation in gasoline price.

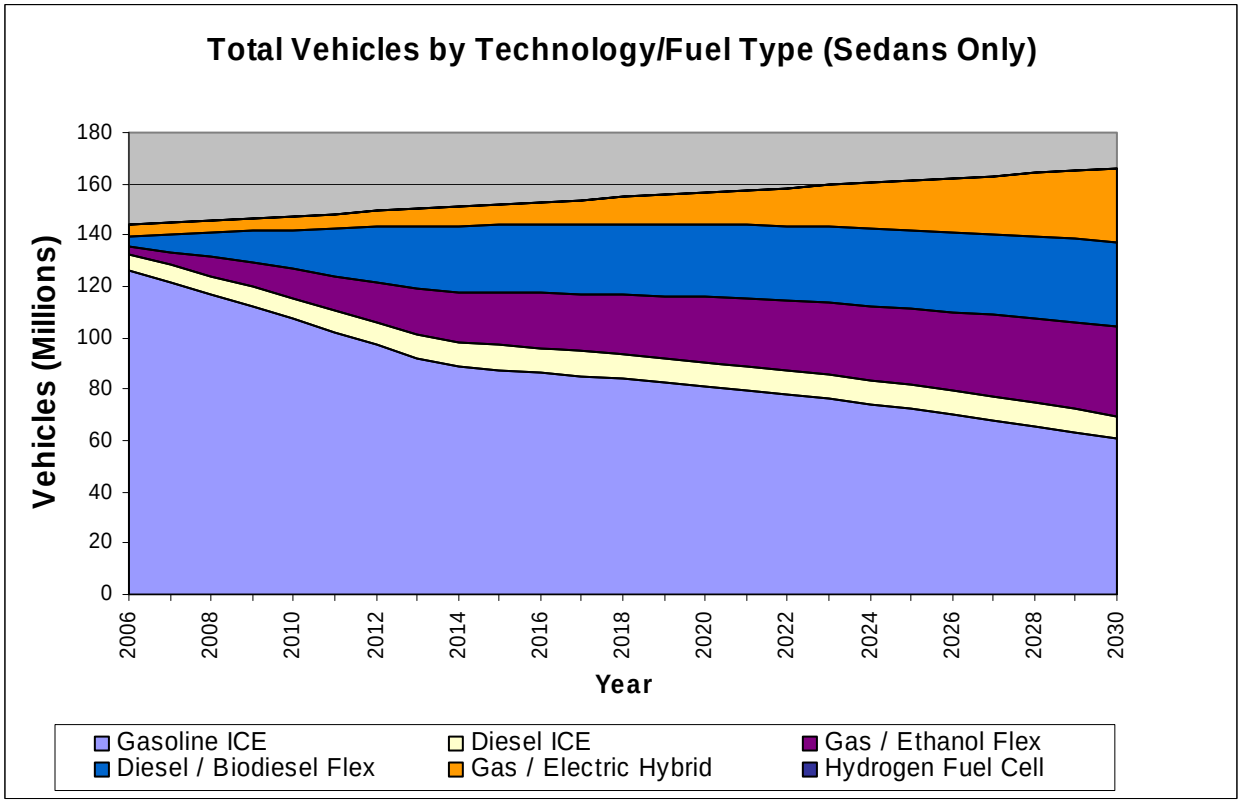
Gasoline price is an extremely important factor in determining the future market shares of alternative vehicles as fueling costs (a combination of fuel economy and fuel price) have been the second most important market share predictors after vehicle price. In our baseline scenario, where vehicle prices are largely assumed to remain static and equivalent (the exception to this being hybrid gasoline-electric vehicles and hydrogen fuel cell vehicles, both of which begin higher and drop towards equivalency with the other vehicles) fuel costs then become the primary factor in determining market share changes.

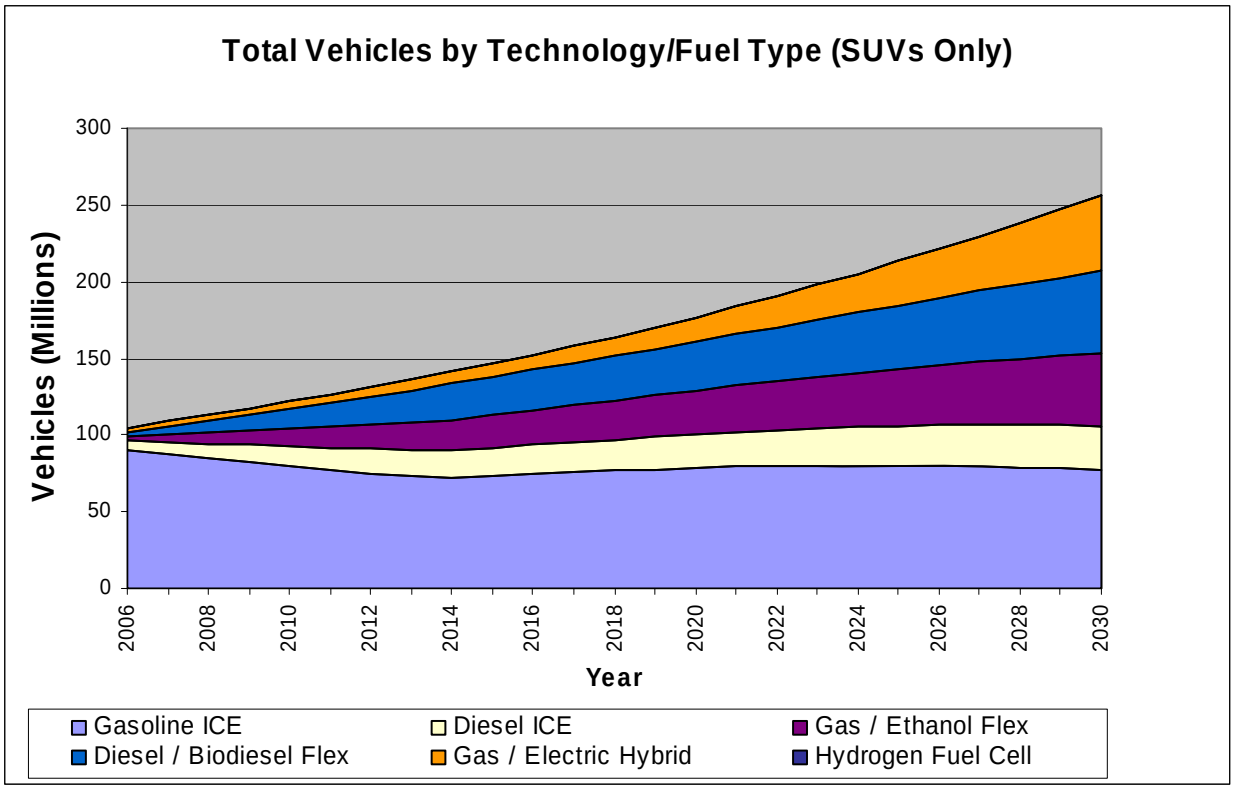
While the EIA's gasoline projection is relatively low and static, they have also made an additional projection showing the higher gasoline cost possibility, in which gasoline prices steadily rise over the course of the projection. If this gasoline cost scenario were to be applied to the model, then it would highly favor switches to alternative fuels and higher fuel efficiency vehicles such as hybrid gasoline-electric vehicles. Thus in this scenario, the EIA's higher level gasoline cost projection is applied to the baseline scenario.

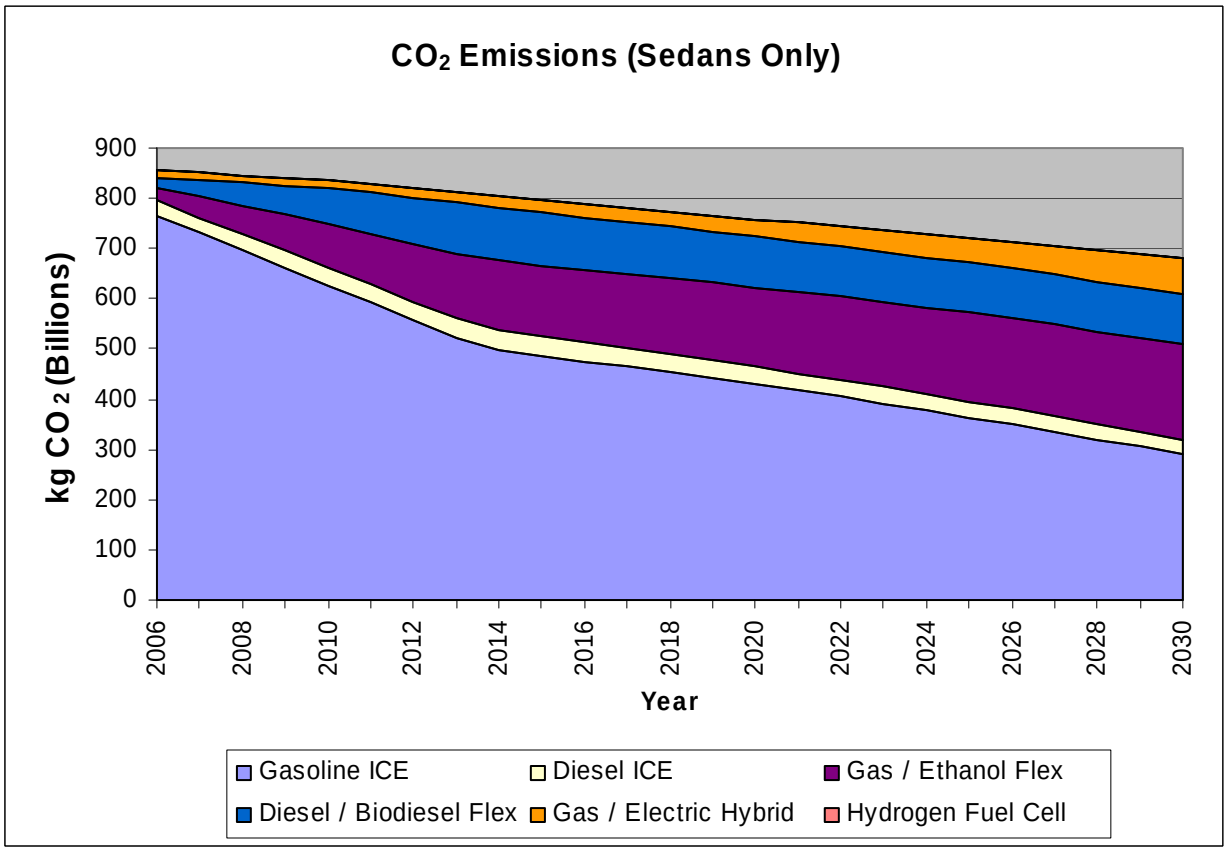
Figure 73(a-g): U.S. Alternative Scenario, Increasing Gas Price

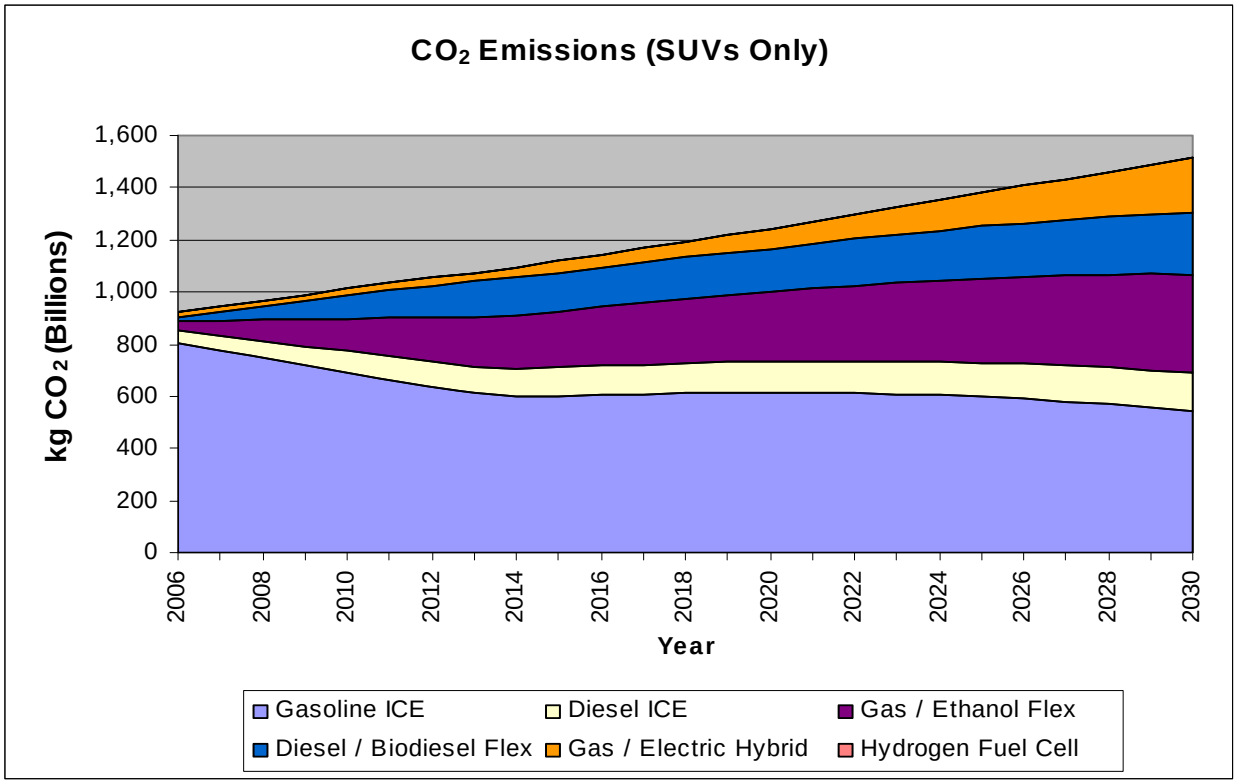



Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell



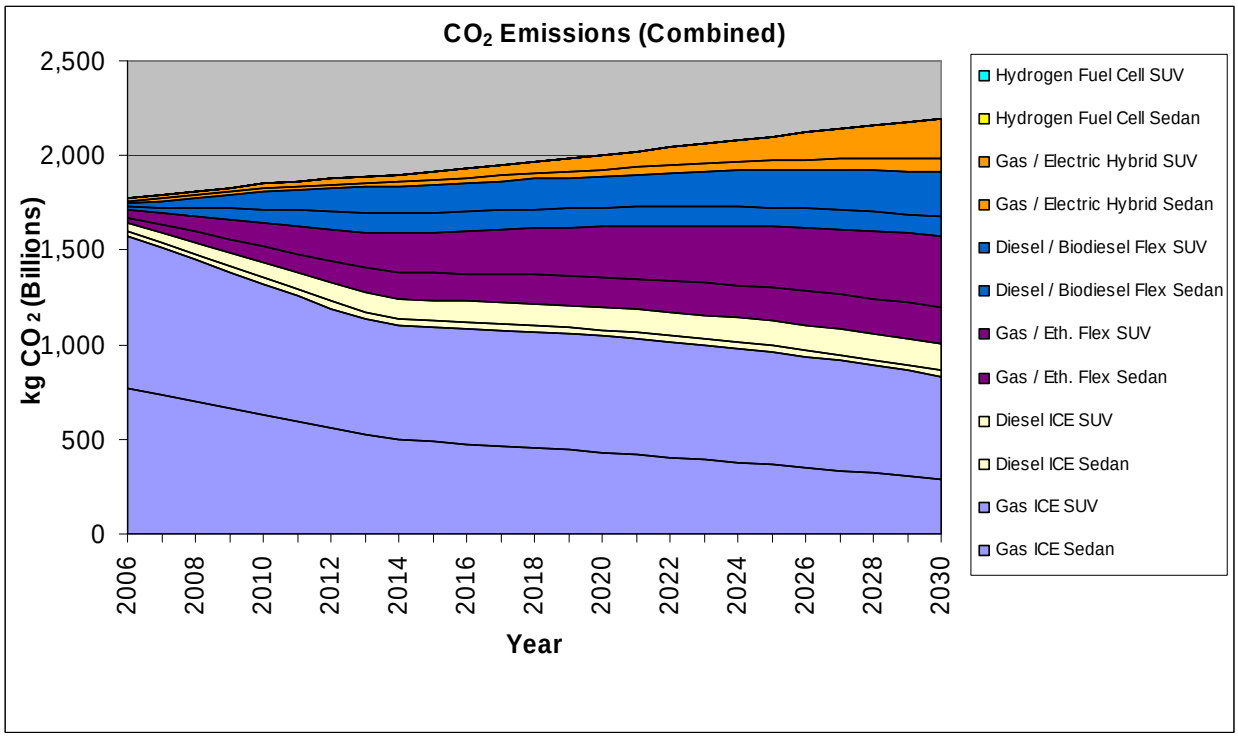


Figure 74: U.S. Alternative Scenario, Increasing Gas Price Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	53	485
% Reduction	2.4%	1.0%

The increasing cost of gasoline behaves in very much the same way as the carbon tax scenario in its effect on carbon dioxide emissions. The primary difference in this scenario is that it occurs naturally due to market forces of supply and demand rather than by legislative edict. Thus it is different in that it will not raise any tax revenue that could be applied to a variety of environmental or social causes, but also, it is not as subject to the political pressures that would oppose the introduction of any carbon tax.

The level of gasoline price increase in the naturally rising gas price scenario as compared to that used in the baseline scenario is minimal to nonexistent at first but climbs by the end of the projection to represent an increase of $1.05, a level that puts it lower than the mid-range carbon tax, but significantly higher than the lower lever carbon tax that had been proposed by President Clinton in the 1990's. What neither this, nor the carbon tax scenarios, explored is how high the price of gasoline would have to rise before it completely drove conventionally fueled vehicles out of the market entirely.

3.5.10. The Hydrogen Scenario

One of the most important results that can be garnered from the above scenarios is the complete absence of hydrogen fuel cell vehicles (HFCVs) in the projected market shares in every single scenario run. This is due to the extreme marketplace disadvantage that HFCVs have in comparison, not just to conventional vehicles, but to nearly every other alternative vehicle as well. This disadvantage is primarily in vehicle price, but extends into fuel cost, fuel availability, and make/model availability as well. Each of these factors on its own would be a nearly insurmountable market barrier to the widespread adoption of HFCVs, and together they combine to form a setting where it would be impossible to develop any sort of widespread public market for these vehicles.

Yet, hydrogen powered vehicles also represent the greatest potential for a complete shift away from fossil fuels and carbon dioxide emissions, as well as being an energy carrier with many versatile and domestically available sources. Additionally, the technology has recently garnered worldwide attention and large levels of research and development funding as well as being the focus of numerous national- and state-run demonstration programs. Thus it seems inevitable that this technology will be pursued and sought after in the market place. The question then becomes, what policy and technology changes will need to occur before hydrogen fuel cell vehicles are able to claim a significant market share and when is the soonest that this can reasonably be expected to occur?

As mentioned, there are four primary market obstacles to the adoption of HFCVs into the national fleet. They are: 1) vehicle price; 2) fuel price; 3) fuel availability; and 4) make and model availability. Each of these factors will need to be favorably influenced before HFCVs have a chance at market level competition. The first step in creating a realistic scenario was to ensure that the infrastructure necessary to support a hydrogen transportation economy was in place.

In order to accomplish this, they would have to be a sufficient amount of fuel and makes and models available. The penalties associated with fuel availability begin to rapidly decline when there is fuel availability equal to 20% the availability of gasoline today and the penalties disappear altogether when the fuel availability reaches 40%. Thus the goal for developing fueling infrastructure for a hydrogen economy should be 20-30% fuel availability. To this end, the constructed scenario has hydrogen fuel availability reach 20% by 2020, and 40% by 2025. This could be accomplished through government/corporation co-op fueling sites that are made available to the public and through a limited number of subsidized private fueling pumps at commercial stations. The fuel is assumed to come 60% from natural gas, 30% from coal, and the remained from a variety of renewable resources. The make and model availability has similar threshold limits based on the fraction of the total number of models of vehicles of each

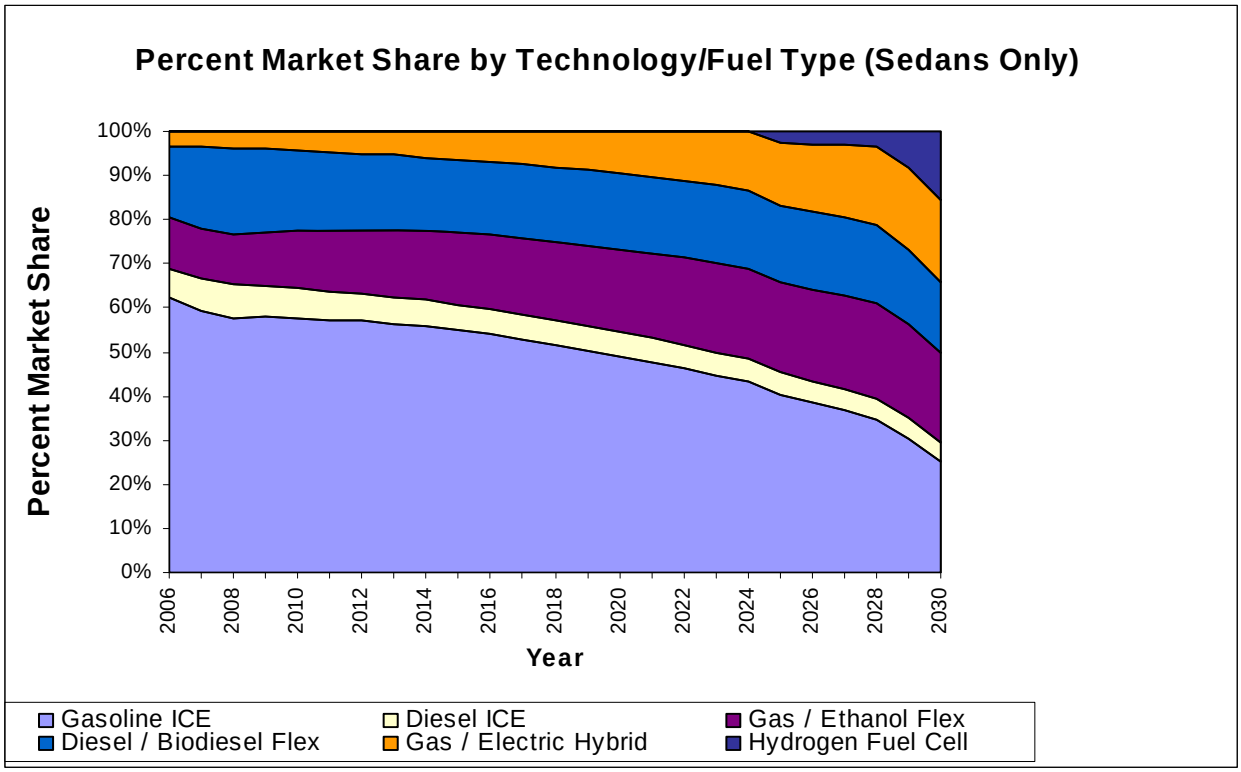
technology types are available compared to the total number of different makes and models across all technology types.

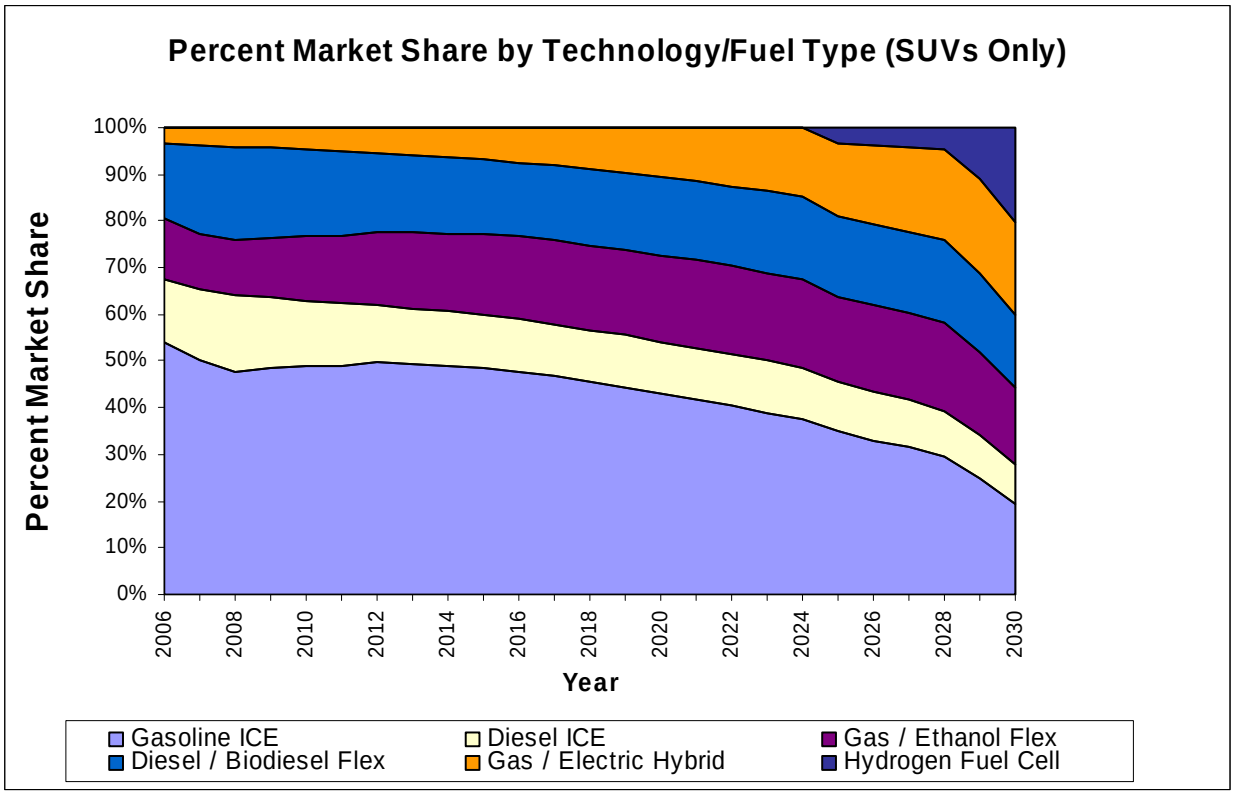
With the current settings in the original baseline scenario, the make and model penalty would be $2,750 if there were 25 makes and models available and $1,100 if 100 makes and models were available. While these numbers may seem high, a similar penalty is applied to all vehicles, so that they all end up with a similar penalty unless one technology type has a drastic advantage. As such the goal was simple to make the make and model number competitive with the other alternative vehicles. To this end a make / model number of 15 by 2020 and 30 by 2030 was chosen. Given that there are currently models appearing on the market, it seems reasonable to expect that this is an achievable number over the course of the projection.

The fuel price did not need to be altered as according to the goals set out by the DOE, which were used as the fuel costs in the baseline scenario, hydrogen will reach a cost of $2.50 by 2015. Given the far superior fuel economy of the hydrogen fuel cell vehicle, this price makes it easily competitive with any other fuel type. As such, the baseline value for the fuel cost of hydrogen was maintained.

With these infrastructure and threshold barriers set to reasonable levels that would not bar the introduction of hydrogen vehicles, the final step was to determine the level of incentive that would have to be provided to spur the purchase of hydrogen fuel cell vehicles. Due to the disparity in fuel economy between the sedans and the SUVs and due to the tremendous advantage that the fuel economy of fuel cell vehicle provides, the level of incentive required differed for the introduction of hydrogen into the sedan pool versus the SUV pool. Since the baseline fuel economies of the sedans are significantly higher than the baseline fuel economies of the SUVs, a significantly smaller incentive was needed to spur the purchase of hydrogen fuel cell SUVs.

Figure 75(a-g): U.S. Alternative Scenario, Hydrogen




Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
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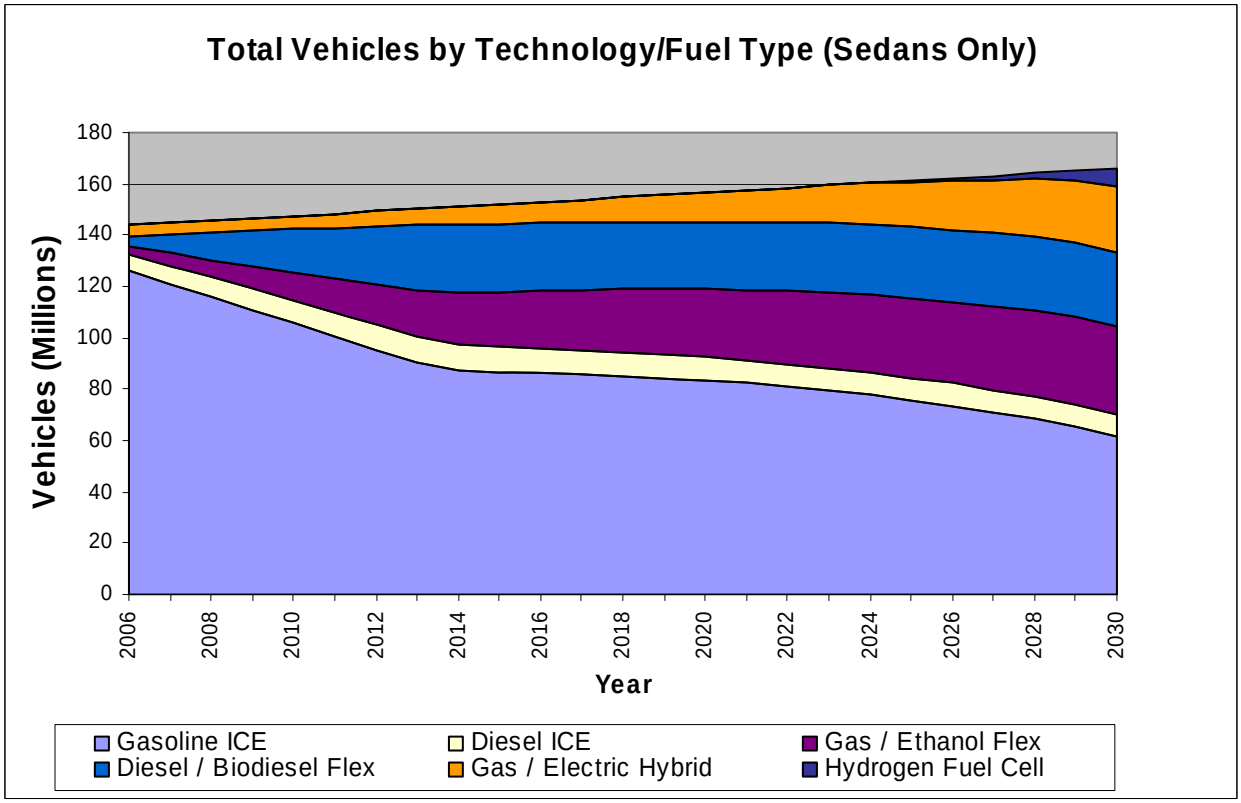
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
180
160
140
120
100
80
60
40
20
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
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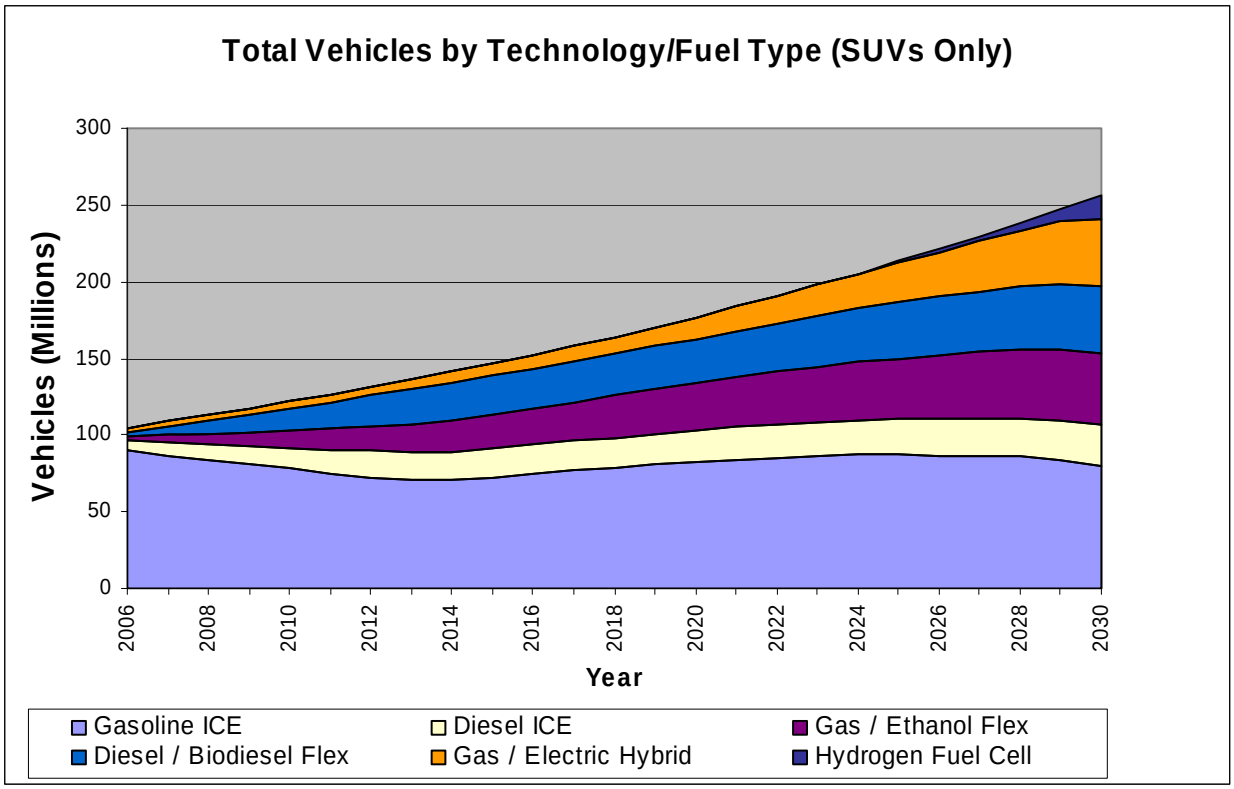
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
300
250
200
150
100
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0
2006
2008
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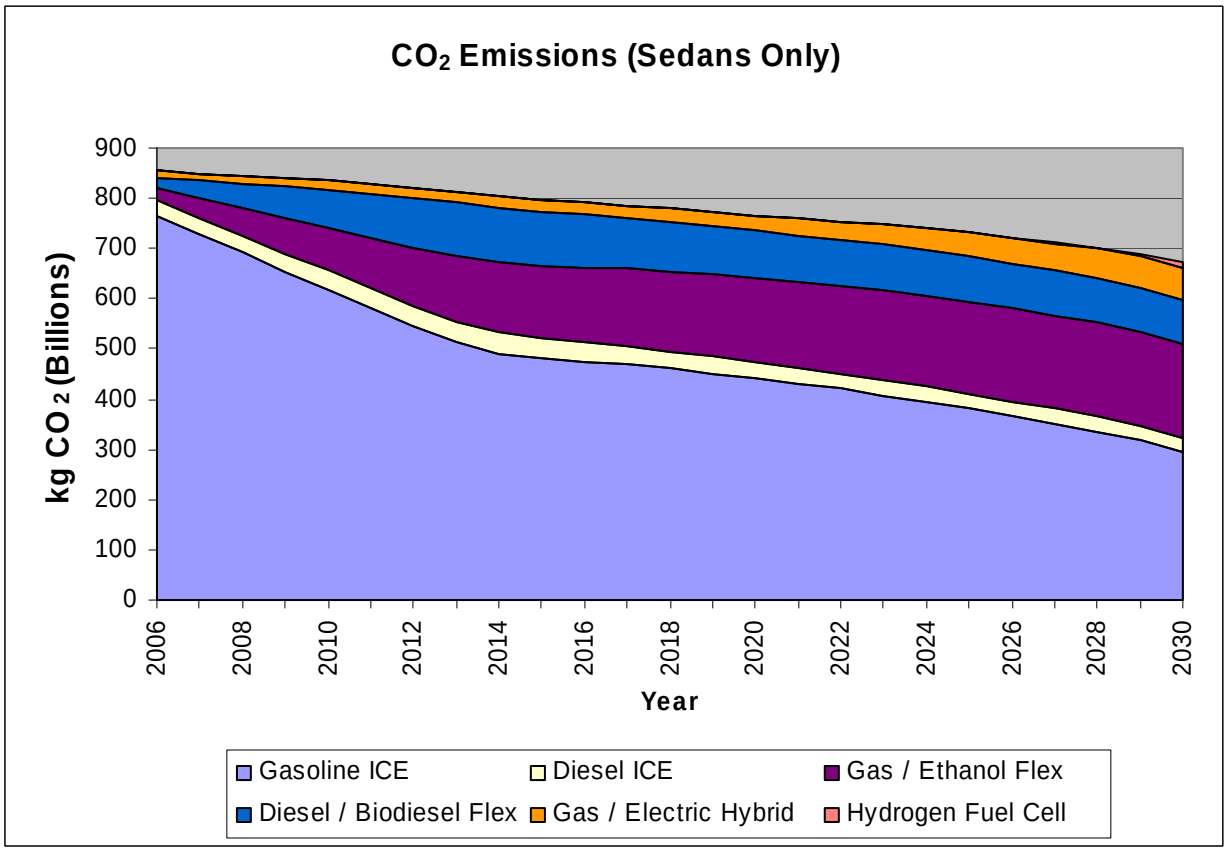
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
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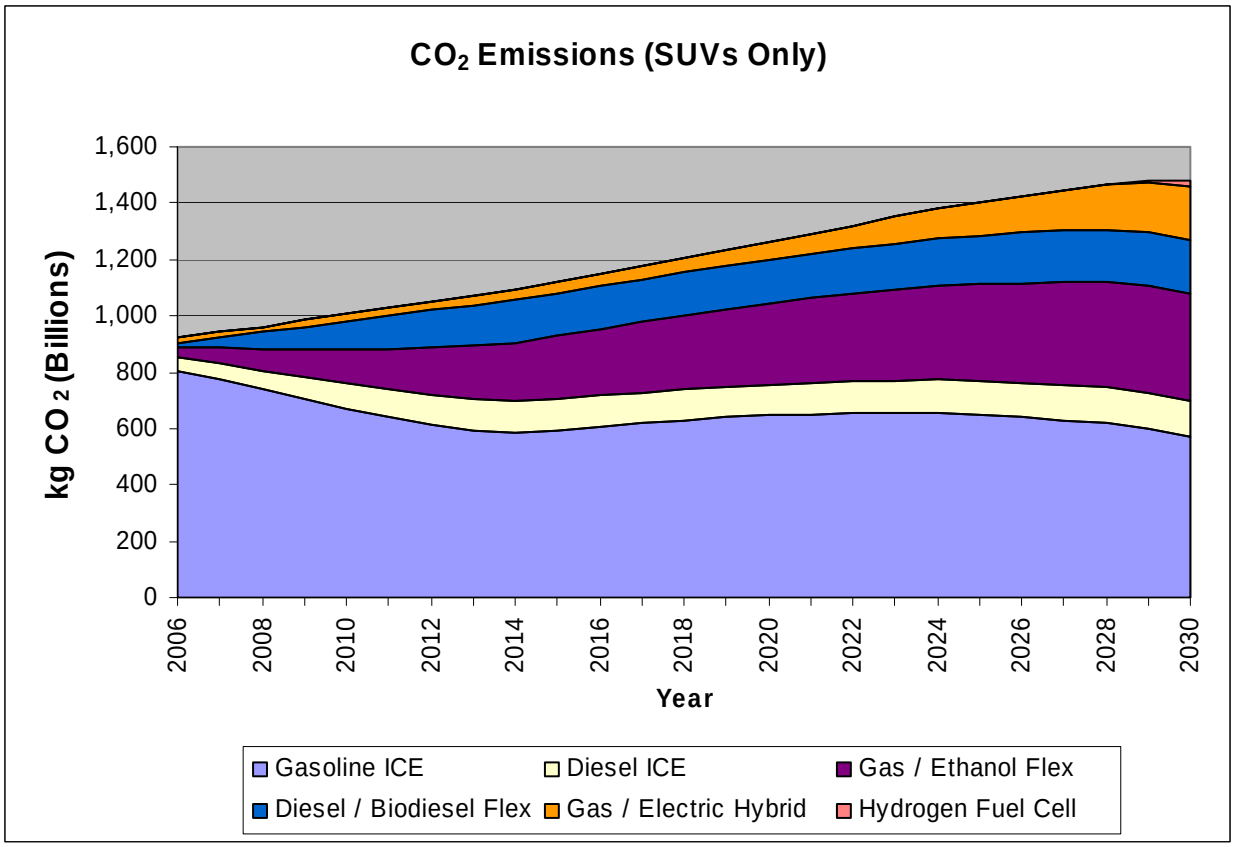
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell



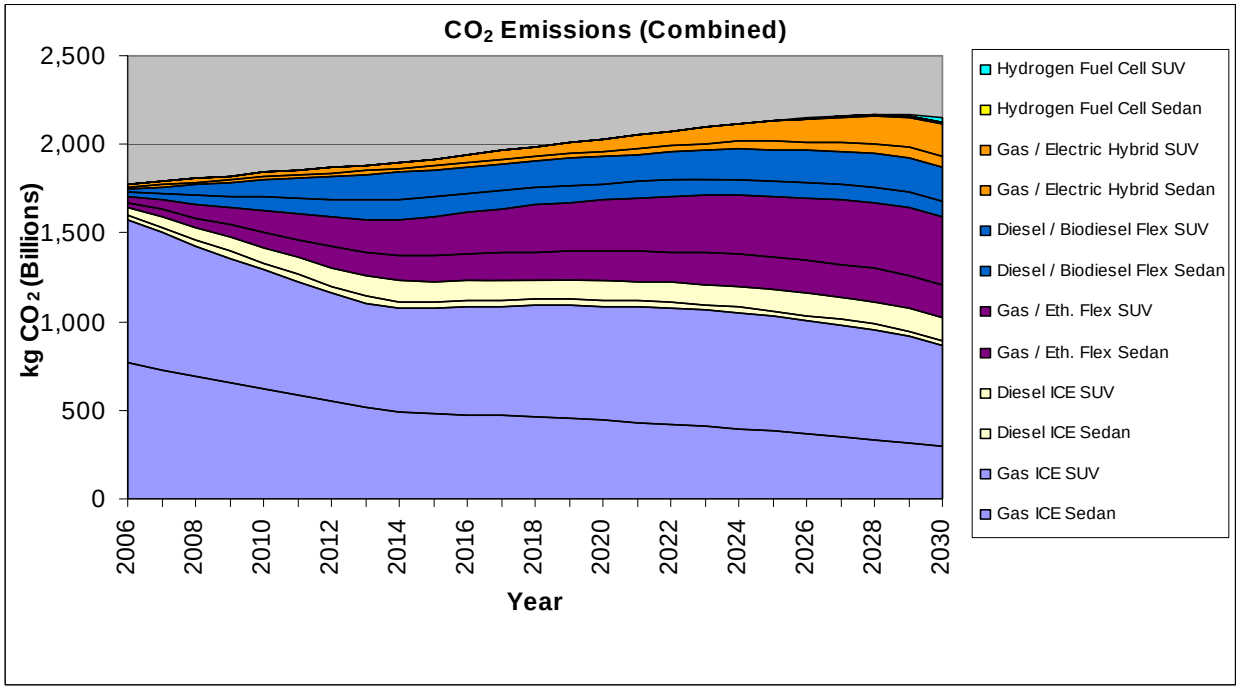


Figure 76: U.S. Alternative Scenario, Hydrogen Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	101	263
% Reduction	4.5%	0.5%

An incentive of $5,500 for sedans and $4,500 for SUVs was required in order for any significant market share of hydrogen vehicles to be acquired. This brought the purchase price of the sedans to $18,000 ($2,000 under the cost of the nearest competitor) and SUVs to $19.000 ($1,000 under the cost of the nearest competitor. This advantage was needed to overcome the obstacles that remained from a lower make and model availability, fuel availability, and the fact that they cannot run on conventional fuels as all the competitors are able.

Given the relatively late introduction of this technology into the vehicle pool in any significant numbers, it is not surprising that the percentage reduction of carbon dioxide emissions summed across the whole projection is relatively low. But what is interesting is the relatively high percentage reduction in the carbon emissions in the 25th year. Having only been introduced in a significant manner in the 20th year, by the 25th year hydrogen fuel cells have managed to reduce the carbon dioxide emissions by 4.5%, while only accounting for 6% of the vehicles on the road. This indicates that, given the apparent growth rate of the hydrogen fuel cell vehicles within the fleet, that they could account for a far greater reduction in carbon dioxide levels within just a few year of the end of this projection.

While this definitely seems to support the development of a hydrogen transportation sector, it is important to keep in mind that the benefits of the technology do not really begin until nearly 25 years into the future. It is quite apparent that hydrogen fuel cell vehicles can only be viewed as an extremely long term strategy for climate control and one that will take decades of planning to make come to fruition. Even with the relatively modest goals that were set forth in this scenario in terms of infrastructure development, that level of achievement will require consistent strong policies that remain stable and goal oriented over a long period of time, a task that is difficult to organize in the current political climate.

3.6 U.S. Conclusions

This array of policy scenarios shows in detail the variety of tools that are available for influencing the future of the transportation sector. While the focus was on the policies' effects on carbon dioxide emissions, these scenarios also provide insight into the effects that that policy might have on vehicle populations, fuel consumption, the economy, and energy security. From these scenarios a number of overarching lessons may be learned which could be extremely valuable in future policy making efforts.

The first lesson that must be considered is the role of biofuels in shaping the U.S. transportation sector's future. It was shown in several scenarios that modest subsidies, taxes, or incentives could easily spur a switch from the use of conventional fuels in conventional vehicles to either flex fuel vehicles or higher levels of fuel mixing in conventional vehicles. This tactic is appealing for many reasons. Due to the low level of technological change or infrastructure development that would be required, this is a policy that could be enacted in a matter of a few years rather than over the course of decades. This sort of quick action appeals greatly to a political climate that is often focused on the next election rather than the next generation.

Additionally, biofuels are produced from domestically grown crops which has the double benefit of keeping U.S. dollars in the country rather than spent on fuel imports as well as greatly increasing the nations energy security. With a substantial portion of the nation's oil being imported from politically unstable and often hostile regions, decreasing our reliance on those sources for ones that are domestically available has a great deal of appeal. Finally, the increased use of biofuels has gained high levels of support by the agricultural industry and by those states with a high level of agriculture. Thus the overall political climate and public response towards biofuels is highly favorable and faces little public opposition.

These scenarios illustrate that, despite the variety of positive factors involved in the use of biofuels, they have little positive effect on reducing GHG emissions and in some cases can actually aggravate emissions as compared to the baseline scenario. This effect is primarily

caused by the use of ethanol, which relies heavily on fossil fuels in order to be grown, harvested, and refined into a usable fuel. This is a factor that has been cited with concern previously by numerous academic studies and has been the topic of a great deal of debate. There is also the promise of cellulosic ethanol, which could potentially be produced much more efficiently and greatly reduce the amount of carbon dioxide released in the harvesting and refining process. But this technological improvement remains an uncertain hope for the future, leaving biofuels in uncertain territory in terms of their effectiveness at climate control.

A second lesson to consider is the effect of gasoline prices on the vehicle market shares. The EIA has predicted a relatively stable and low cost scenario for future gasoline prices but this claim appears to be dubious. Gas prices have been consistently rising for the past several years and the EIA projection that each passing year is simply the peak of a brief price spike has consistently been proven wrong, with each passing year instead being the next point on a gradually rising slope. But what effect could rising gas prices have on the vehicle market shares and carbon dioxide emissions?

The scenarios show that if gasoline prices rise by $0.75-$1.00, this will be sufficient to spur the departure from conventional gasoline and diesel vehicles towards alternatives. Additionally, it has been shown that if carbon taxes are applied at higher levels, such as those seen in Europe, that this departure may be accelerated significantly. What would not be sufficient to cause any significant change in the nations future carbon dioxide profile is the level of carbon tax that has been proposed in the past for this nation, which was on the level of a few cents rather than dollars.

What rising gas prices do not determine, however, is what the market shifts towards when it departs from conventional vehicles. Without a guiding force, the model predicts that the market shares are fairly evenly divided between ethanol and biodiesel flex fuel vehicles and hybrid gasoline electric vehicles. The adoption of hybrid vehicles show the greatest potential for an intermediate term strategy at dealing with rising carbon dioxide emissions. They require little to no infrastructure creation and are technologically compatible with existing social and physical structures. They also are capable of increasing fuel economy by nearly 100% which could cut fossil fuel consumption in half.

The third lesson to examine involves drawing market shares towards a particular technology, a strategy that could perhaps be used in conjunction with rising gas prices or a carbon tax. Several scenarios were run examining the use of vehicle tax credits on spurring the development of a market base for new technologies. In every case, hybrid gasoline-electric vehicles demonstrated the greatest promise. Car purchase incentives, when provided on levels consistent with what has been provided in the past show tremendous potential for spurring a market shift, especially when applied over a significant period of time, and that shift favors hybrid vehicles.

A fourth lesson is in the policy scenario that lead to the greatest amount of carbon dioxide reduction over the course of the study, and that was in the scenario in which the recently discussed federal legislation that would increase the CAFE standards for fuel economy were enacted. Even given the delay between production and adoption onto the road, this policy still led to the largest decreases in carbon dioxide emissions that were seen in any of the scenarios. This is a policy that could be enacted with little cost and represents an excellent intermediate to short term strategy towards reducing carbon dioxide emissions.

The fifth and final lesson is that technological innovation does not hold absolute sway over the control of carbon dioxide emissions. Given that technological performance and efficiency are continually increasing, it is behavioral changes and growth in consumptive patterns that are spurring the rise in carbon dioxide emissions. The policy and technology changes discussed above represent a solution to the symptoms of these behavioral patterns but do not address the actual behaviors. Two scenarios were run, showing reasonable behavioral

changes that could occur to reduce carbon dioxide emissions and both of these scenarios were competitive in effectiveness with the policy and technology scenarios we analyzed.

In reality, no single policy tool or realistic behavioral change is likely to solve the problem of rising carbon dioxide emissions. Instead, a strategy that seeks to control emissions in the short and intermediate term will have to rely on a combination of policies and incentives in order to reduce the consumption of fossil fuels, encourage the use of the most beneficial technologies, and try to limit the growing consumptive behaviors that are causing the rise to begin with. None of the scenarios on their own were able to do more that halt the growth of carbon dioxide emissions, and most were merely able to slow their growth. Given that we are currently in a situation where the amount of carbon dioxide being emitted is more than can be sustainably absorbed by the ecosystem, it is necessary to not just slow or halt the growth of carbon dioxide emissions, but to actually reverse it. Not only that, but this is a change for which many believe time is rapidly running out. A great deal of concern has arisen recently about the climate approaching a threshold of rapid disastrous change and the time to halt that change may is running out, or may have already passed.

A final scenario was run showing the potential of hydrogen fuel cell vehicles, which are often touted as the ultimate solution to the issue of climate change and energy security. Hydrogen may be obtained from a variety of domestic resources, can be created sustainably and with nearly no carbon dioxide emissions, and fuel cells themselves are highly efficient. This one technology may solve many of the core issues that trouble our current transportation economy. But adopting a hydrogen transportation economy would require massive technological development, creation of economies of scale, and the construction of considerable new infrastructure. This has led to concern over the length of time it would take to enact a hydrogen economy and the economic feasibility of enacting such a plan. The final scenario run shows a small number of modest policy options that were capable of beginning the creation of a hydrogen transportation economy by the end of the 25 year projection and which showed significant carbon dioxide emission reductions over just a few short years of the adoption of hydrogen vehicles. The barriers that face the hydrogen economy are significant, but not insurmountable, and with the proper combination of long term policies, a hydrogen transportation economy could be developed and enable the needed long term reductions in carbon dioxide emissions.

Figure 77: U.S. Alternative Scenarios Summary Chart

	Scenario	% Decrease in 25th Year	% Decrease in Aggregate
1st	Biofuel Subsidy (High)	-0.40%	-0.20%
2nd	Biofuel Subsidy (Low)	-0.10%	0.00%
3rd	Carbon Tax (Low)	0.20%	0.10%
4th	Increasing Alt. Makes/Models	0.90%	0.30%
5th	Rising Gas Price	2.40%	1.00%
6th	Vehicle Tax Credits (Low)	3.10%	1.60%
7th	Vehicle Tax Credits (Phased)	1.10%	2.00%
8th	Carbon Tax (Mid)	3.00%	2.50%
9th	Increasing Fuel Mixing	5.00%	2.90%
10th	Lower SUV Growth	7.30%	2.90%
11th	Decreased Annual VMT	3.50%	3.00%
12th	Vehicle Tax Credits (High)	7.10%	3.90%
13th	Carbon Tax (High)	6.00%	5.00%
14th	Increasing Fuel Economy	17.50%	8.10%
15th	Hydrogen	4.50%	0.50%

4. The China Scenarios

4.1. Introduction

While the western world has been the primary source of carbon dioxide emissions since the industrial revolution, many academics and politicians are growing concerned about a new source: the rapidly industrializing developing world. The developing world represents the majority of humanity in numbers, but the per capita consumption of these countries has typically been extremely low as compared to countries such as the United States, the United Kingdom, and others of the western world. But many of these nations have economies and industries that are rapidly growing and their populations' per capita consumption and related carbon dioxide emissions are growing with them. This has led to the prospect that the developing world may soon overtake the west as the largest source of carbon dioxide emissions.

Because of this, it is important to look at the trends in the transportation sector in this part of the world. China was chosen as an example because of its large population, rapid economic growth, and already significantly developed automotive market. In particular, due to the scarcity of national data, the metropolitan area of Bejing was the focus of this study due to the rapidly developing nature of the area and the comparative wealth of data on it's transportation sector as compared to other areas of China.

This section of the report seeks to mimic as closely as possible the U.S. section and thus has a similar format. A baseline scenario was created for this area of China and then this was used to run a sensitivity analysis as well as to gauge the effect of the alternative scenarios that were run. *No structural changes were needed to be made to the model in order to run this set of scenarios.* The alternative scenarios run were chosen to be as close as possible to the U.S. scenarios in order to ease comparison, but some of the U.S. scenarios represented situations that could not occur in the Chinese political climate and, also, there were some scenarios run in the Chinese set that only made sense to be run in this particular setting and thus are not included in the U.S. policy scenarios.

4.2. The China Baseline Scenario

The baseline scenario for China represents a set of conditions that would be most likely to happen if no major policy, social or technological changes are made in the next 25 years. The scenario best reflects historical trends, with a projection into the future. Major inputs are the same as the United States scenario, including fuel costs, fuel mixing, vehicle efficiencies, vehicle prices, fuel availability and make/model availability.

Other variables such as vehicle ownership, technology market share, transport modes and patterns are considered in order to better represent the Chinese situation. As with the United States scenario, no major policy, social or technological changes are assumed under the baseline scenario and technology types that are not expected to be used at a significant level in the near future were excluded, thus leaving the following technologies to be considered: (1) conventional gasoline internal combustion engine (ICE); (2) conventional diesel ICE; (3) flex fuel gasoline-ethanol ICE; (4) flex fuel diesel-biodiesel ICE; (5) hybrid gasoline-electric; and (6) hydrogen fuel cell.

4.2.1. Fuel Costs

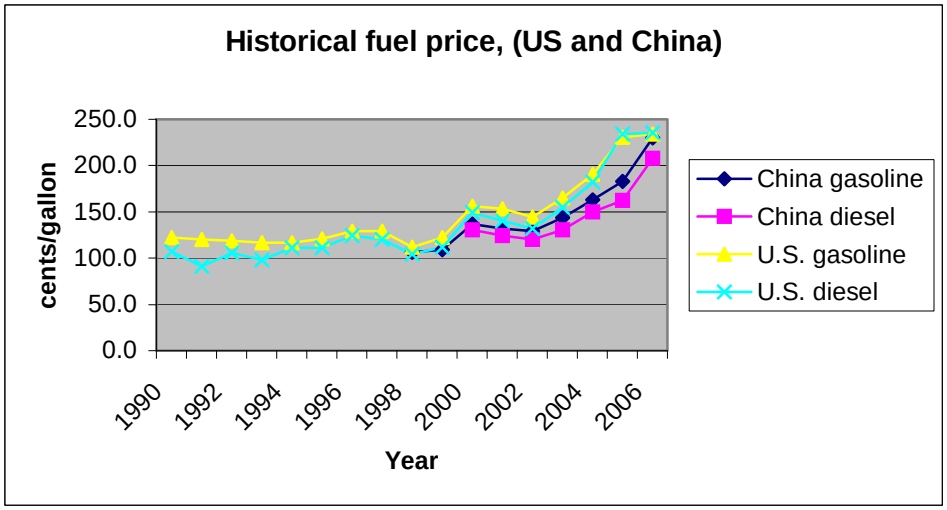
It is very difficult to forecast fuel prices in China, as the pricing does not reflect market demand and supply and is tightly controlled by the government. On one hand, central government would like to keep up with the international oil market, but on the other hand, the

government would also like to maintain a relatively stable environment for domestic economy development by maintaining low oil prices. With soaring oil prices in recent years, it becomes more and more difficult to reconcile these two principles. Oil prices in China are largely lagging behind international oil market. Although the government has recently increased prices more frequently, retailing oil prices in China had been lower than international crude oil prices for a long time (Wang, 2006). On the other side, a series of oil shortage, especially diesel shortage were happening in 2005 and 2006, partly due to low profits of retailers (Chinareviewnews, 2005, 2006)

Various reforming methodologies on pricing have been proposed and discussed, but it is not clear at this moment which one will be adopted. The most recent approach is "guided by the market but controlled by the government". The National Development and Reform Commission (NDRC) sets up a retailing price based on weighted average retailing prices in Singapore, Rotterdam and New York in the previous month, plus taxes and other fees. Once the price varies more than 8%, NDRC sets up a new price (Zhu, 2006). Retail oil prices could be in the range of ±8% of the guiding price (NDRC, 2005, 2006). The large lag-behind of pricing time has resulted in a lag of retail oil prices, as well as oil shortages on the market. As there is no clear direction on future pricing reform, making projections on oil prices in China especially difficult.

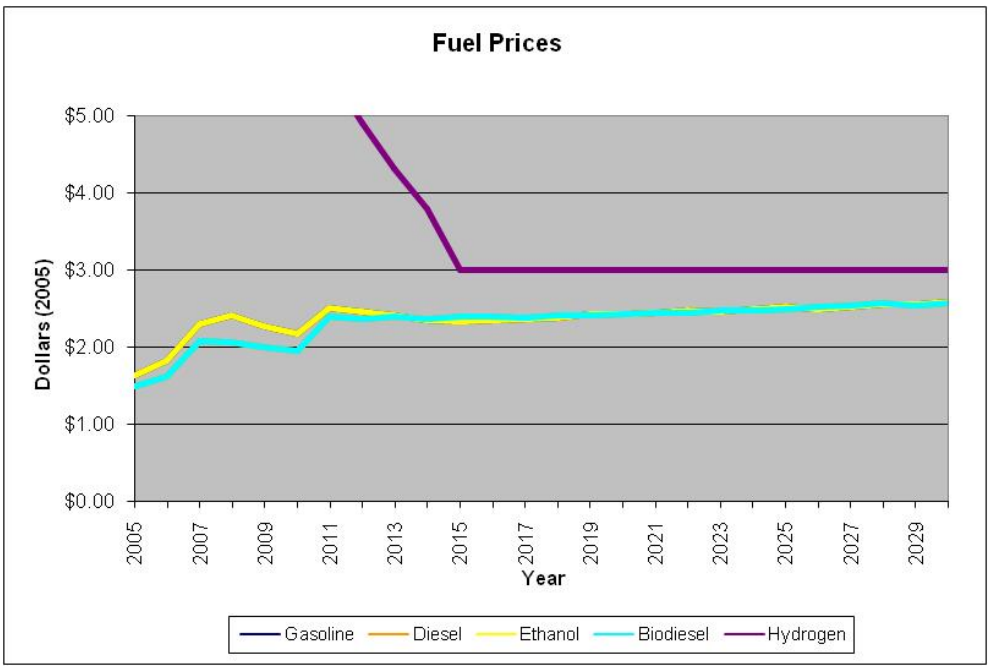
Figure 78 shows historical fuel prices in China and in the United States. Because of heavy subsidies, fuel prices in both countries remain relatively low. As shown in Figure 78, historical fuel prices in China were very close to those of the United States. Therefore in this study, we would refer to fuel price projections for the United States.

Figure 78: Historic U.S. and Chinese Fuel Prices



Data Source: DOE, 2006. Sina, 2007. Bank of China, 2007.

Fuel taxation has been discussed for a few years but is not in operation yet. It is, however, a stated policy in the 11th-FiveYear Plan (2006-2010). In this study we assume that by the year 2010, gasoline prices in both countries will be at the same level. And considering that China's fuel reserves are lower than those of the United States, in the future, China's gasoline prices will be 20% higher than that of the United States. The Chinese Renewable Energy Law has stated that there is no additional cost for alternative fuels at gas stations; therefore we assume any blended biodiesel or blended ethanol will have the same prices as diesel or gasoline. In addition, currently, the price of LPG is based on the price of gasoline, setting at a ratio of 0.83-0.92 of gasoline price. In this study, we use the median value --- 0.875 as the calculation basis, and set this ratio constant over the time.

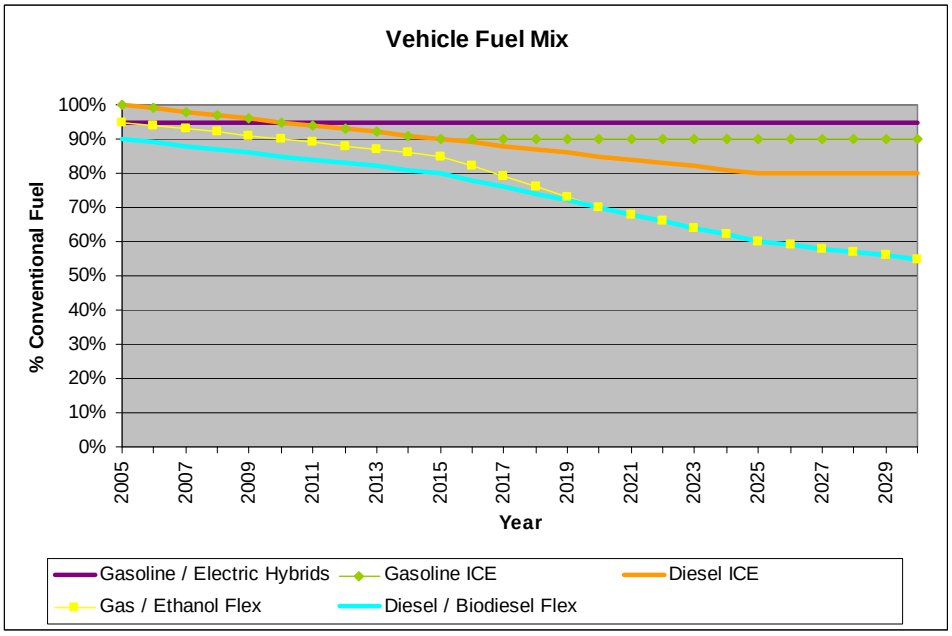


Data Source: EIA, 2006. NDRC, 2005 and 2006.

4.2.2. Fuel Mixing

Ethanol-blended gasoline (with a 10% concentration) has been demonstrated in several provinces (CCICED, 2006). Biodiesel development for transportation use is also in process. However, one must consider that China needs to feed a population five times larger than that of the United States, with a slightly smaller land area. As land is primarily used for agricultural purposes, a serious constraint has been put on domestic biofuel development in China. For that reason, we assume that biodiesel and ethanol development in China will be five years behind of the U.S. case.

Figure 79: Chinese Baseline, Blend of Bio vs. Petro Fuels Being Utilized in ICE's



4.2.3. Vehicle Efficiencies

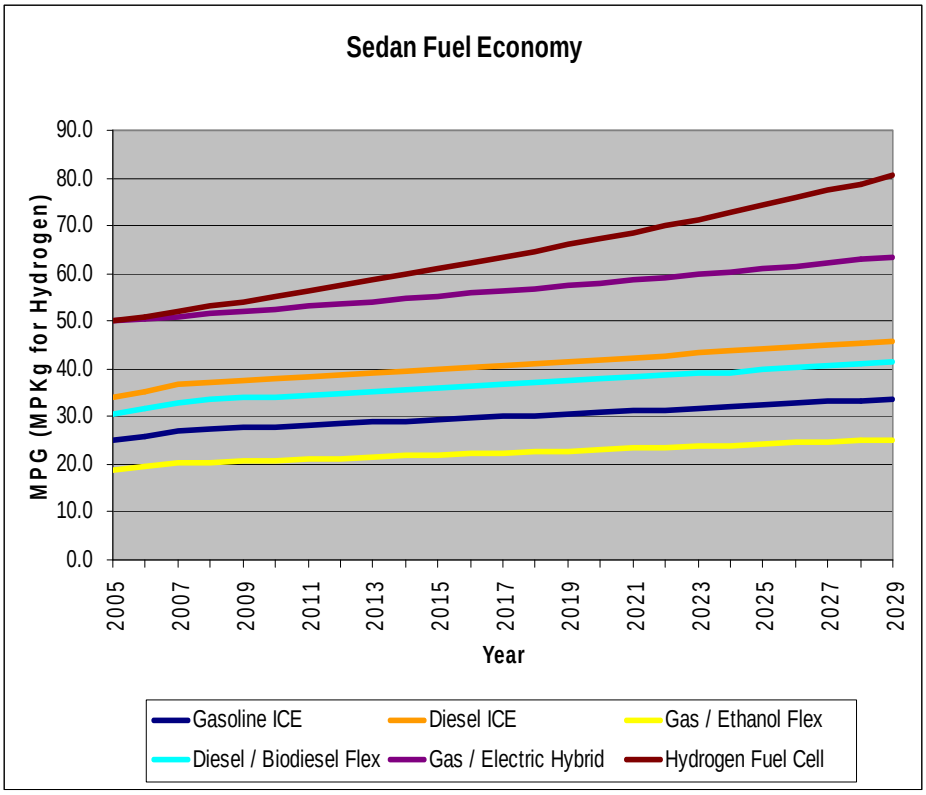
China has introduced energy conservation plans and increased public awareness of energy conservation. The 11th Five-Year Plan has restated and strengthened this -commitment to improved energy efficiency. Premier Wen Jiabao has announced that China will build an energy-saving society and implement state policies to promote efficient technological processes and encourage sustainable consumption through economic restructuring (Xinhuanet, 2004).

Fuel Consumption Regulations for Passenger Vehicles were issued on September 20th 2004, and the implementation of fuel economy limited values were undertaken in July 1st 2005, and the implementation of more stringent fuel economy standards will come in January 2008. The standards are based on the classes of vehicle weight, and impose restrictions on the maximum fuel consumption within each vehicle class.

The gross vehicle weight in China is 24% lighter than that of U.S. averagely, and engine displacement and engine power is 57% and 50% smaller than those of U.S. respectively (CCICED, 2006: 68). According to USA Today (2007), a midsize sedan weights 3,487 pounds, and a midsize SUV weights 4,259 pounds in the US. Therefore, roughly a midsize sedan weights 2650 pounds and a mid-size SUV weights 3237 pounds in China. According to the vehicle weight, we chose a corresponding MPG for conventional gasoline internal combustion engine: 25 mpg for sedans and 20.8 mpg for SUVs. Our result conforms to the 9.5 liters per 100 km stated by Ng and Schipper (2005).

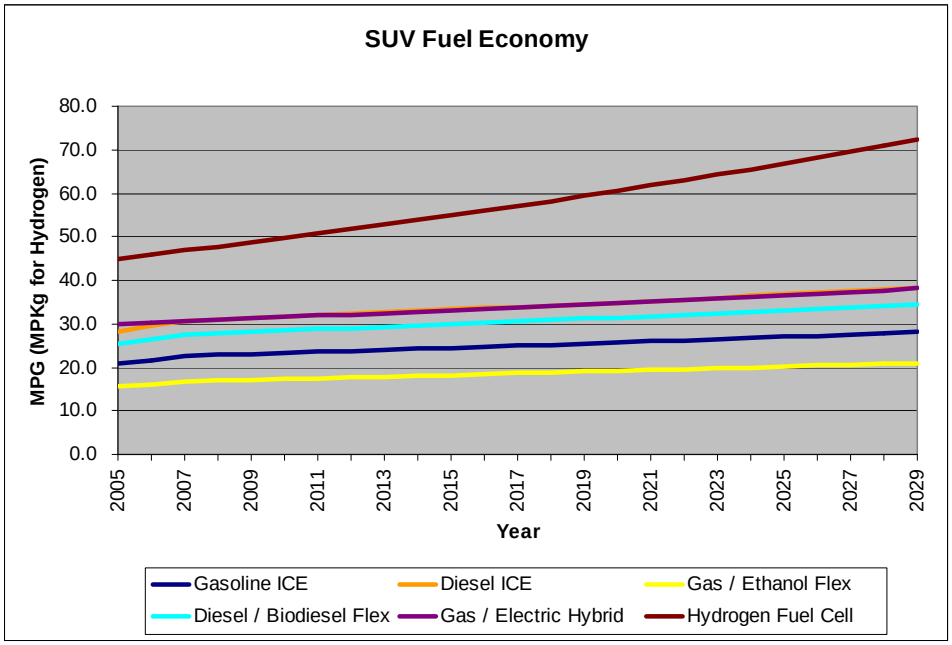
Further more, it is estimated that the full implementation of the standards will result in an improvement of 15% of vehicle fuel economy for new passenger vehicles by 2008 (CCICED, 2006). After that, we assume there is 1% growth every year.

Figure 80: Chinese Baseline, Sedan Fuel Economy



Data Source: CCICED, 2006.

Figure 81: Chinese Baseline, SUV Fuel Economy

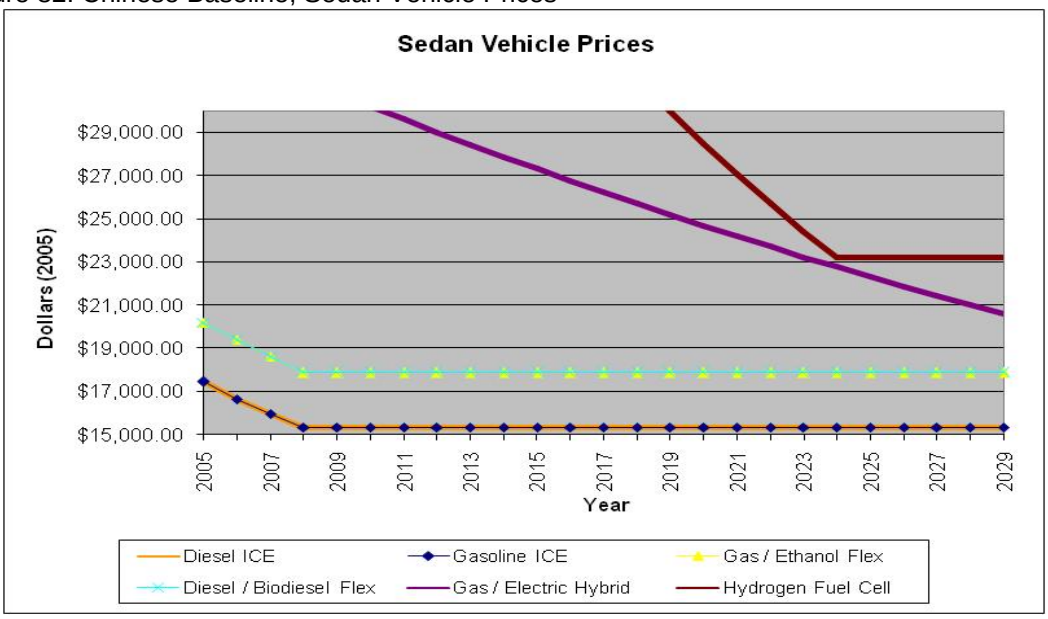


Data Source: CCICED, 2006.

4.2.4. Vehicle prices

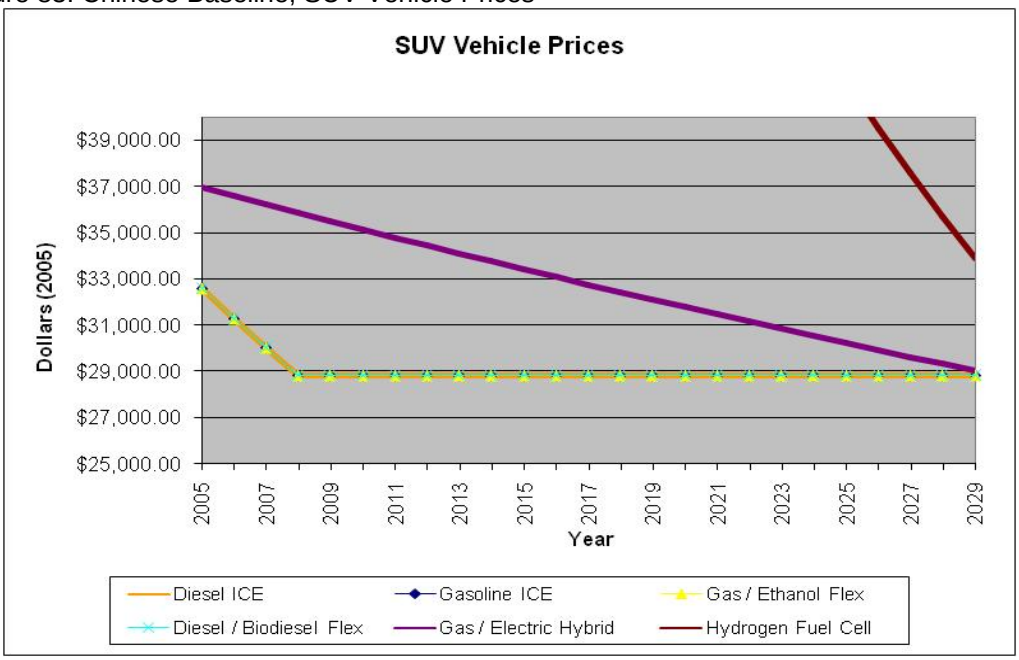
Passenger vehicle prices have been decreasing in recent years. Experts estimate that the prices will continually decrease by 4-5% in the future 3-5 years and then would stay stable (Sina, 2003 & 2004; Liu, 2003; JRJ, 2004). Underlining reasons include increasing production capacity, reducing unit cost, rationalizing pricing, and decreasing tariffs for imported vehicles, among others. We will assume a 4% price reduction would continue into year 2008, and then stay at the same level.

Figure 82: Chinese Baseline, Sedan Vehicle Prices



Source: Sina 2003 & 2004. Liu, 2003; JRJ, 2004.

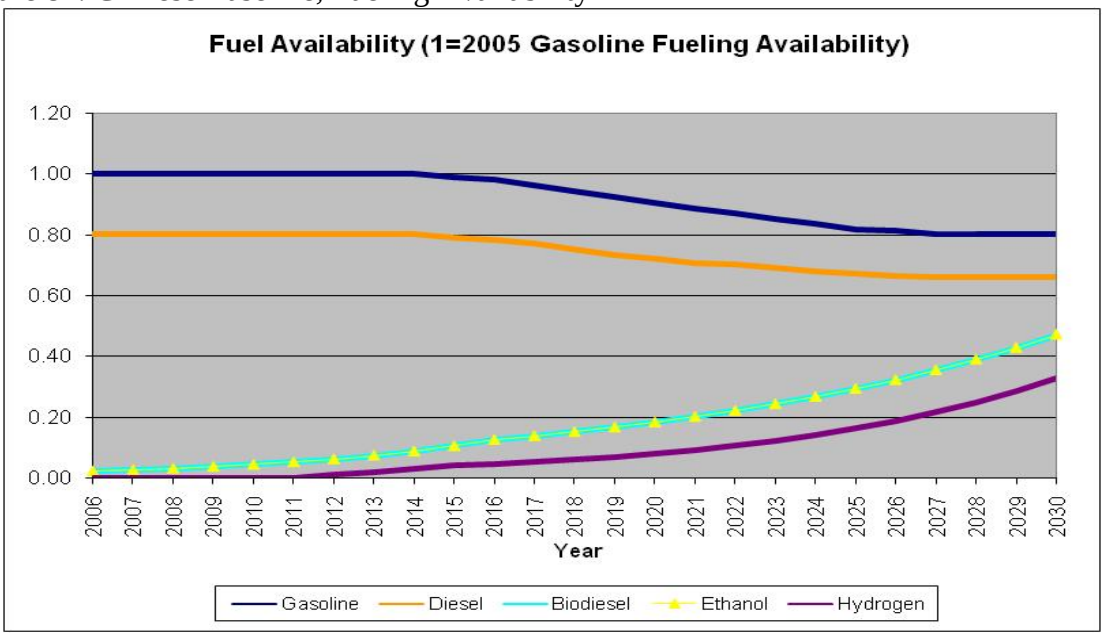
Figure 83: Chinese Baseline, SUV Vehicle Prices



4.2.5. Fueling Availability

Gasoline and diesel are two dominating fuels for transportation, and will continue to be so in the foreseeable future. Initial availability value for gasoline is set at 100% and that for diesel is set at 80%. The values will remain the same of the first 10 years, and then decrease at 2% every year. Initial values for ethanol and biodiesel are set at 2%. There were 62 LPG stations and 24 CNG stations in the city of Beijing (Qinghua University, 2004). Most vehicles which run on LPG and CNG are buses and restructured taxies, and they are not considered for the baseline scenario. Initial availability for hydrogen is 0%, but is expected to grow rapidly.

Figure 84: Chinese Baseline, Fueling Availability



4.2.6. Make/Model Availability

Currently there are 273 makes and models available for sedans in Chinese market, including 269 conventional gasoline vehicles, 3 diesel vehicles and 1 hybrid vehicle. For SUVs, there are 192 makes and models available, including 181 conventional gasoline SUVs, and 11 diesel SUVs. Available makes and models for conventional vehicles gradually decrease as number of makes and models of alternative fuel vehicles and alternative vehicles slowly increase.

Figure 85: Chinese Baseline, Sedan Make/Model Availability

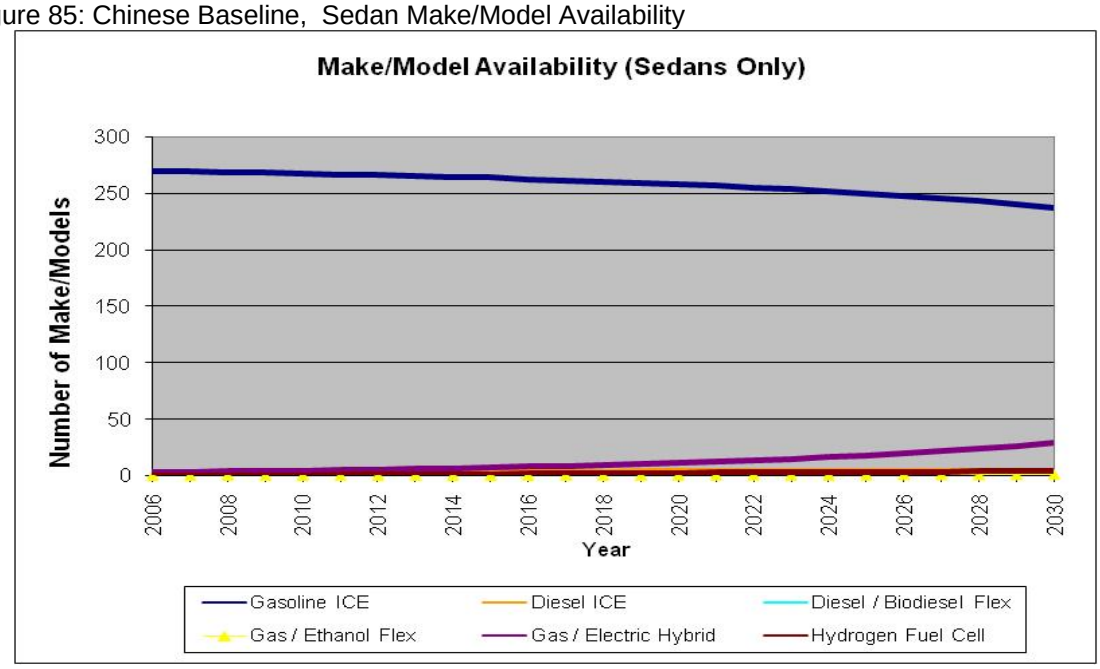
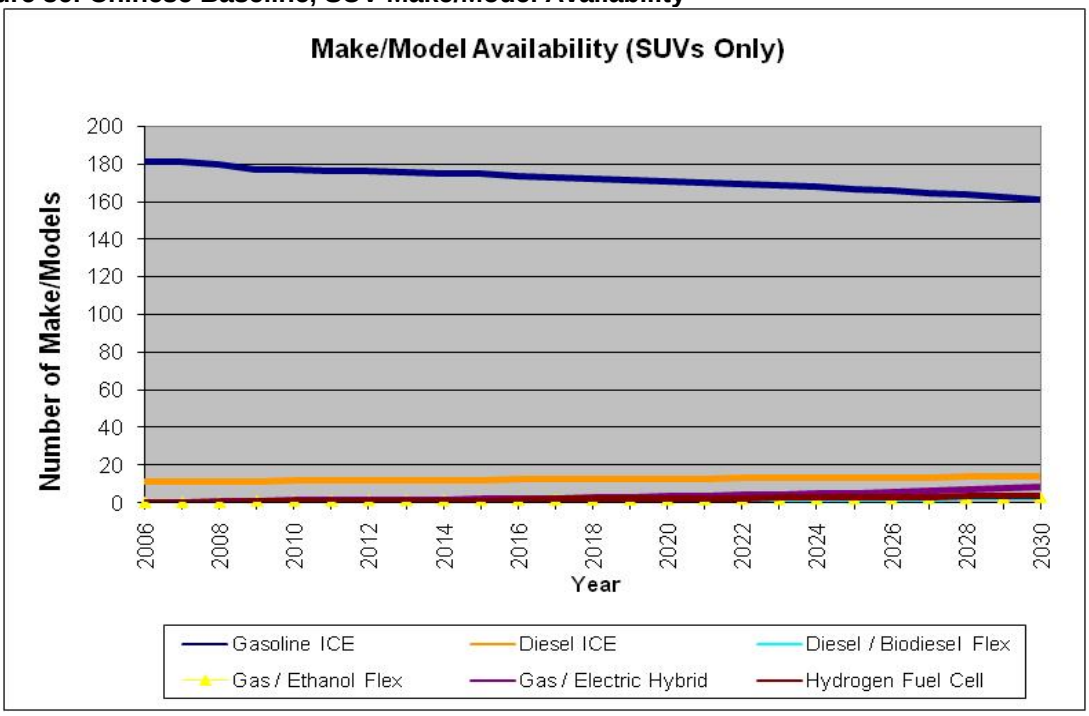


Figure 86: Chinese Baseline, SUV Make/Model Availability



4.3. China Baseline Scenario Results

The following section describes CarCarbon results for the baseline scenario study for China. Shown as future energy, emissions, and vehicle populations, the scenario results represent a business-as-usual pathway for various policy scenarios.

4.3.1. Number of Vehicles

As in the U.S. case, CarCarbon predictions of vehicle quantity are shown in two ways. The first is expressed in percentage market share by technology/fuel type for each year, as shown in Figures 87 and 88. The second is expressed in total number of vehicles of each technology on the road, which includes not only newly purchased vehicles in that year, but also all the vehicles that were purchased in all previous years that have yet to be retired, broken down by technology type, as shown in Figures 89, 90, and 91.

Figure 87: Chinese Baseline, Sedan Market Share

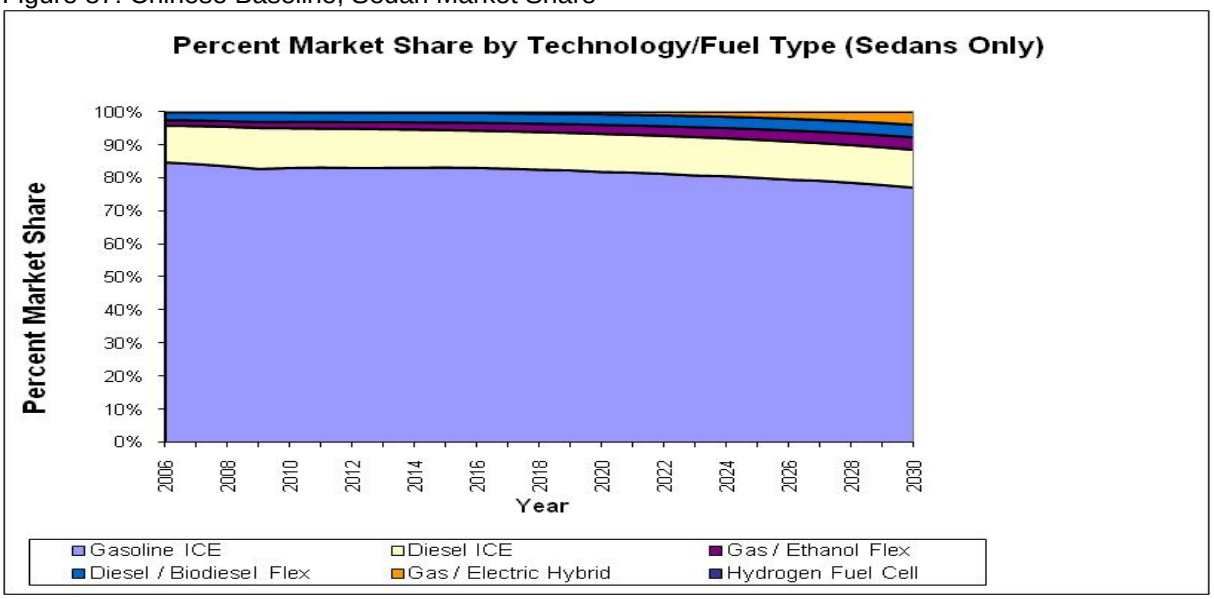
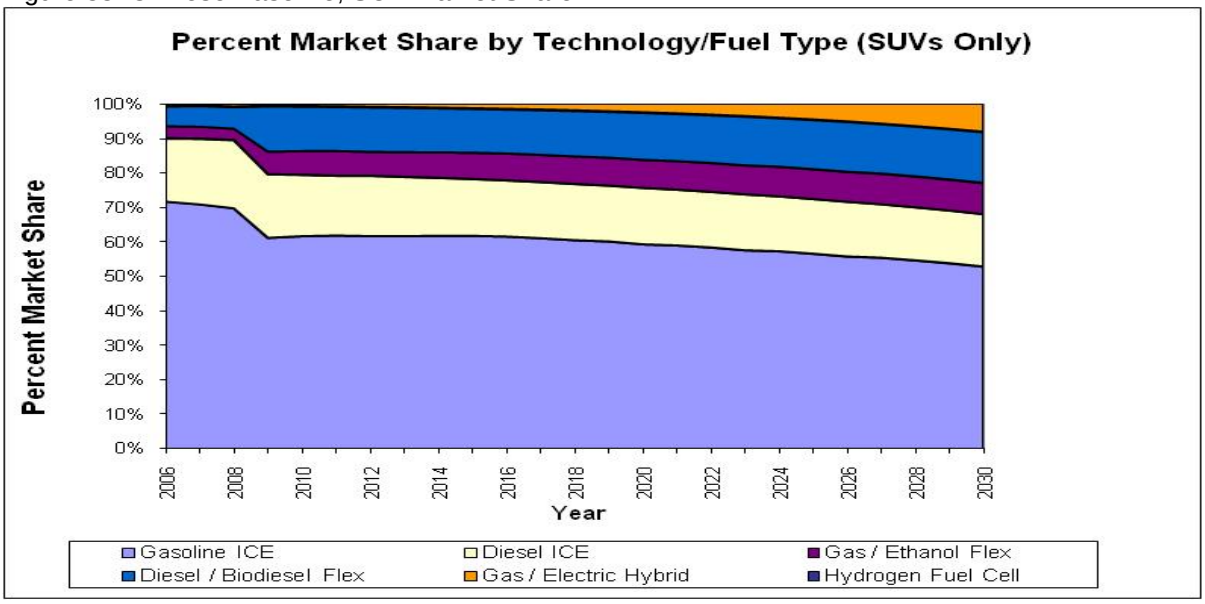


Figure 88: Chinese Baseline, SUV Market Share



As shown in above figures (Figures 87 and 88), there is a steady decrease in conventional gas ICEs and diesel ICEs in the market place. Flex fuel vehicles, both gas/ethanol flex and diesel/biodiesel flex, increase slightly over time. Gas/electric hybrid is the fastest growing class among these technologies.

As with the baseline scenario of the United States, there is a rapid drop of market share of conventional ICEs in year 4. That is because fuel costs for China baseline are based on the U.S. case -- EIA projections that gas prices will drop from their peak and then level out, therefore similar patterns are observed. The drop of conventional SUVs is more obvious than conventional sedans because SUVs are more energy-consuming and more sensitive to fuel prices.

The total number of on-road vehicles, both sedans and SUVs, increase rapidly over the period. Although the market share of conventional ICEs exhibits immediate decrease, this does not translate to an immediate decrease in total numbers of on-road conventional vehicles. The total number of conventional vehicles increases much faster than flex vehicles and hybrid vehicles. Conventional vehicles are and will continue to be the dominant vehicles driven on the road. The number of flex vehicles and hybrid vehicles grow continuously through this period while hydrogen fuel cell vehicles do not have penetration in the market.

Figure 89: Chinese Baseline, Sedans By Technology Type

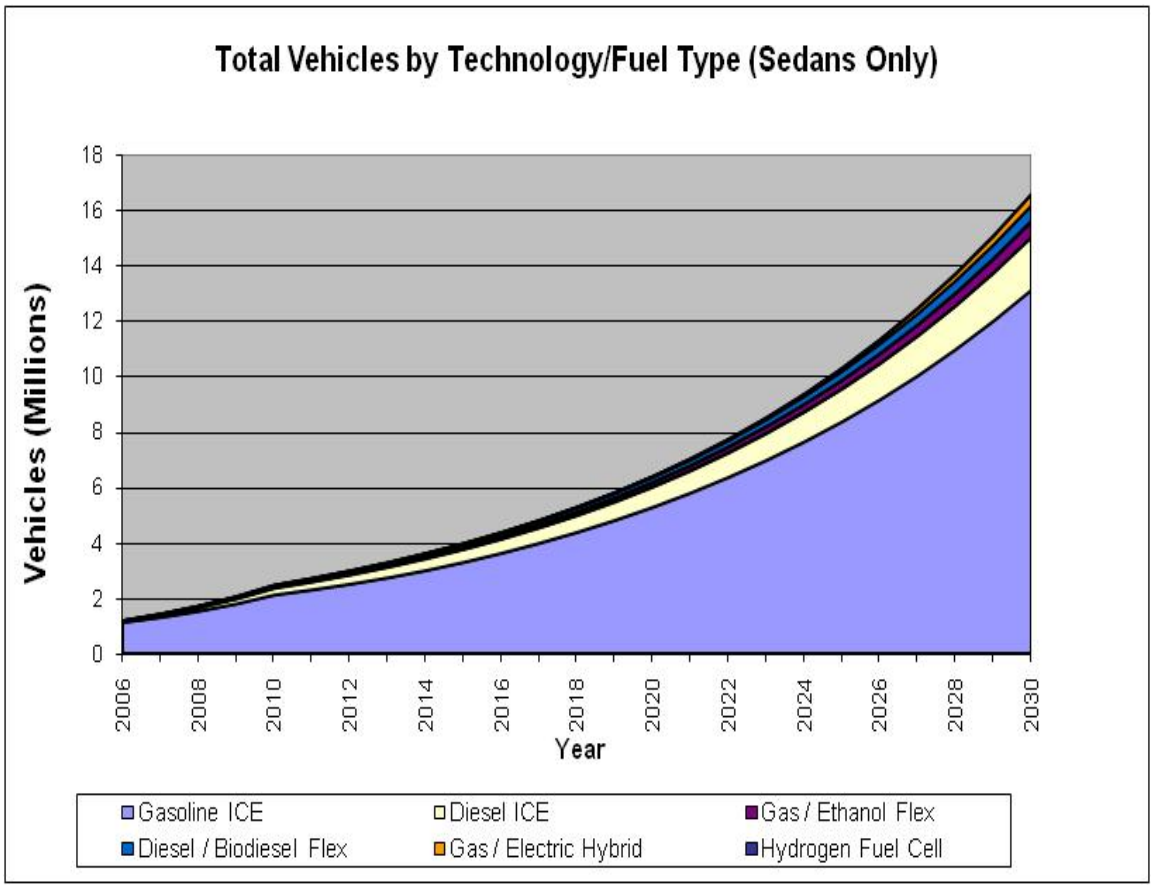


Figure 90: Chinese Baseline, SUVs by Technology Type

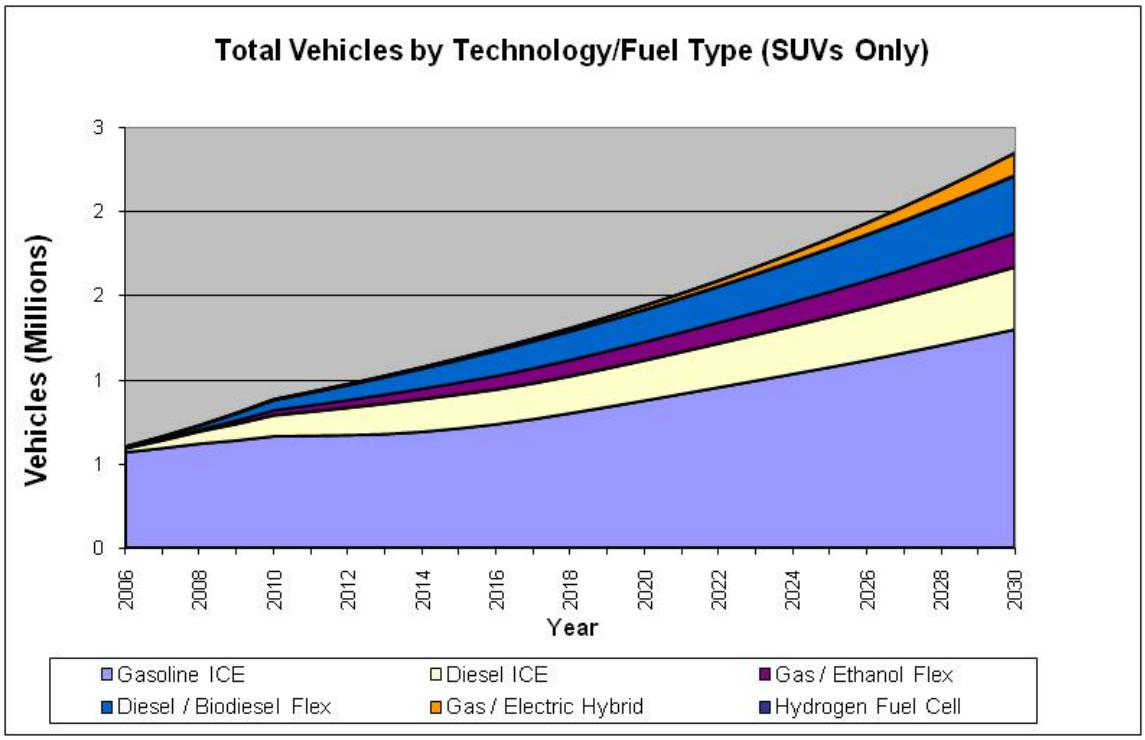
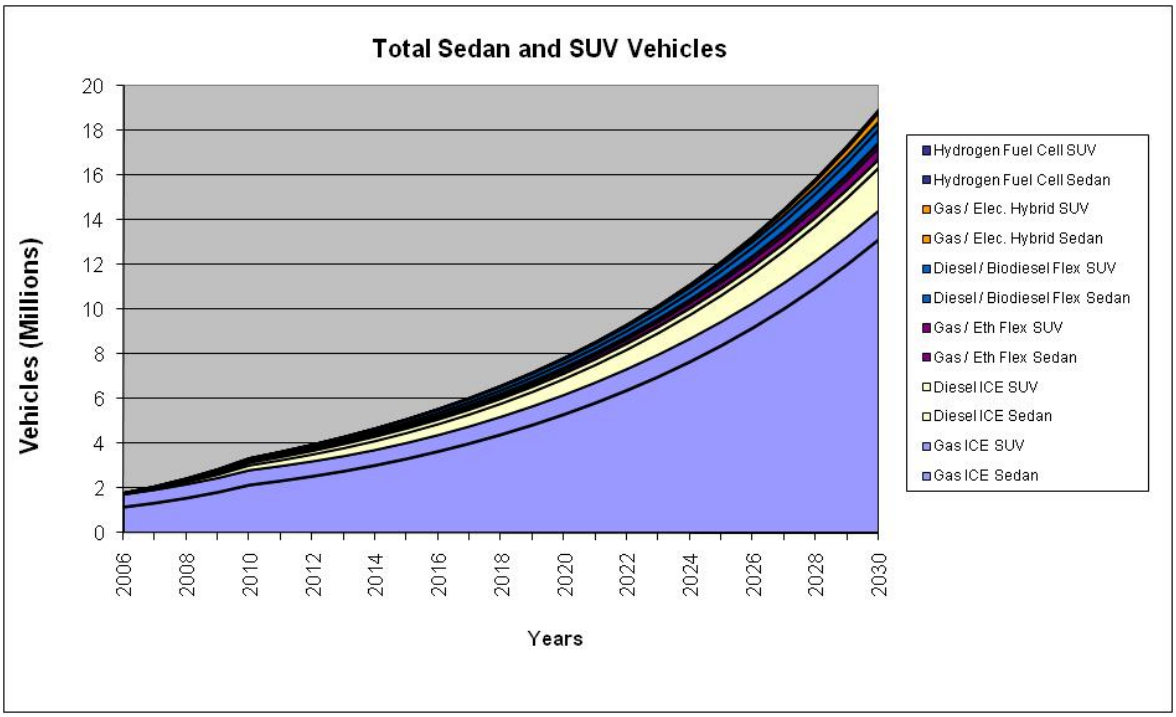


Figure 91: Chinese Baseline, All Vehicles by Technology Type



4.3.2. Energy Consumed by Vehicle Type

The total amount of energy consumed by different technology types is another important output of CarCarbon model. For better comparison, energy consumption is expressed in terms

of BTUs. As time goes, energy consumption continuously increases. Conventional gasoline is still the dominating fuel. For sedans, because of the rapid growth of vehicles, conventional gasoline increases most rapidly.

Coping with decrease of market share of conventional SUVs, conventional fuel consumption by SUVs remains relatively stable in the beginning and start to increase as total SUV numbers on the road grow. Gasoline consumption of conventional SUVs does not increase as much as sedans. Obviously, consumption of ethanol, biodiesel and hybrid in SUVs are obviously larger than those of sedans.

These figures imply that overall vehicle numbers overcome the choices over fuel types, finally leading to the rapid increase of energy consumption.

Figure 92: Chinese Baseline, Sedan Energy Consumption

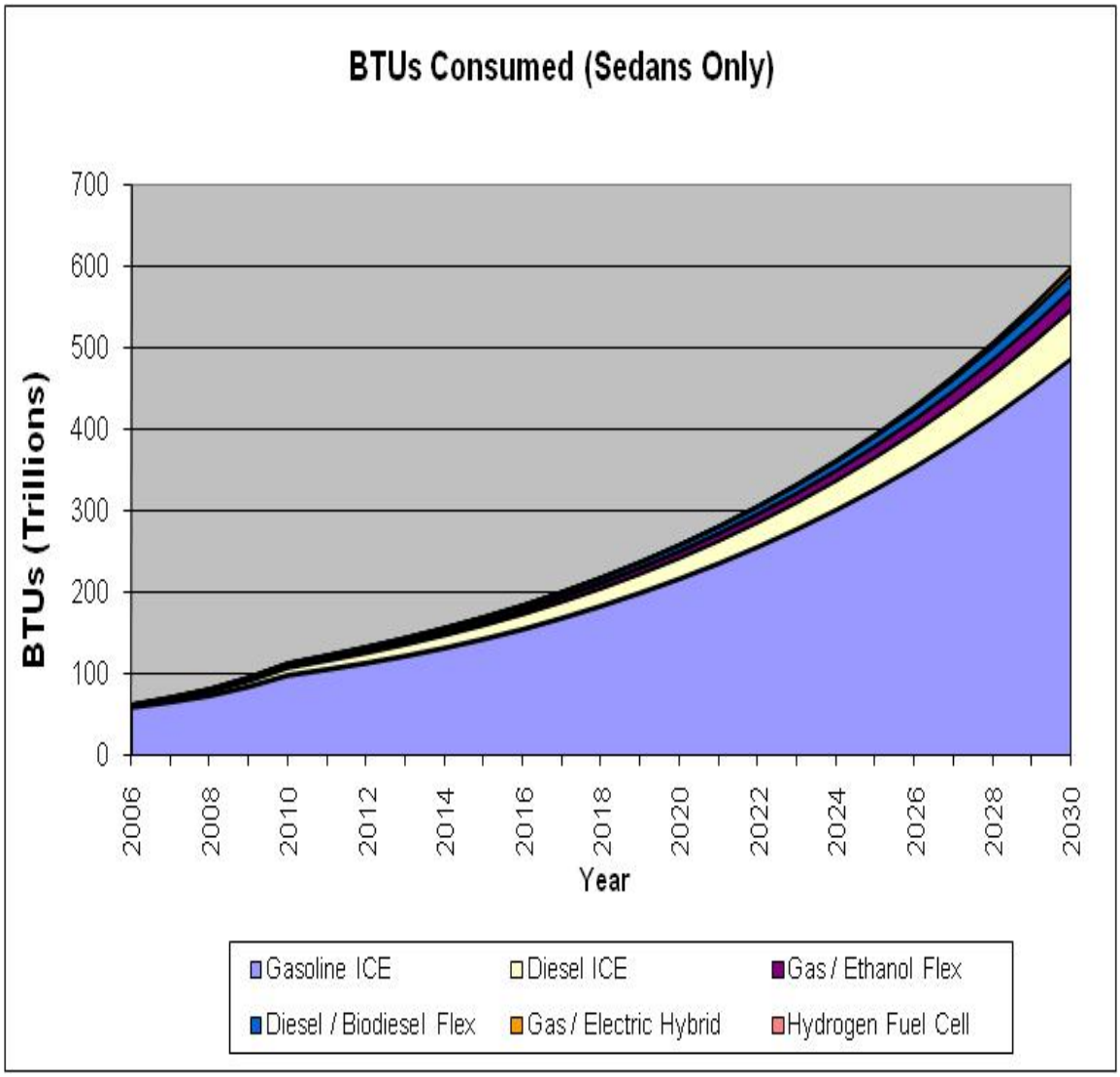


Figure 93: Chinese Baseline, SUV Energy Consumption

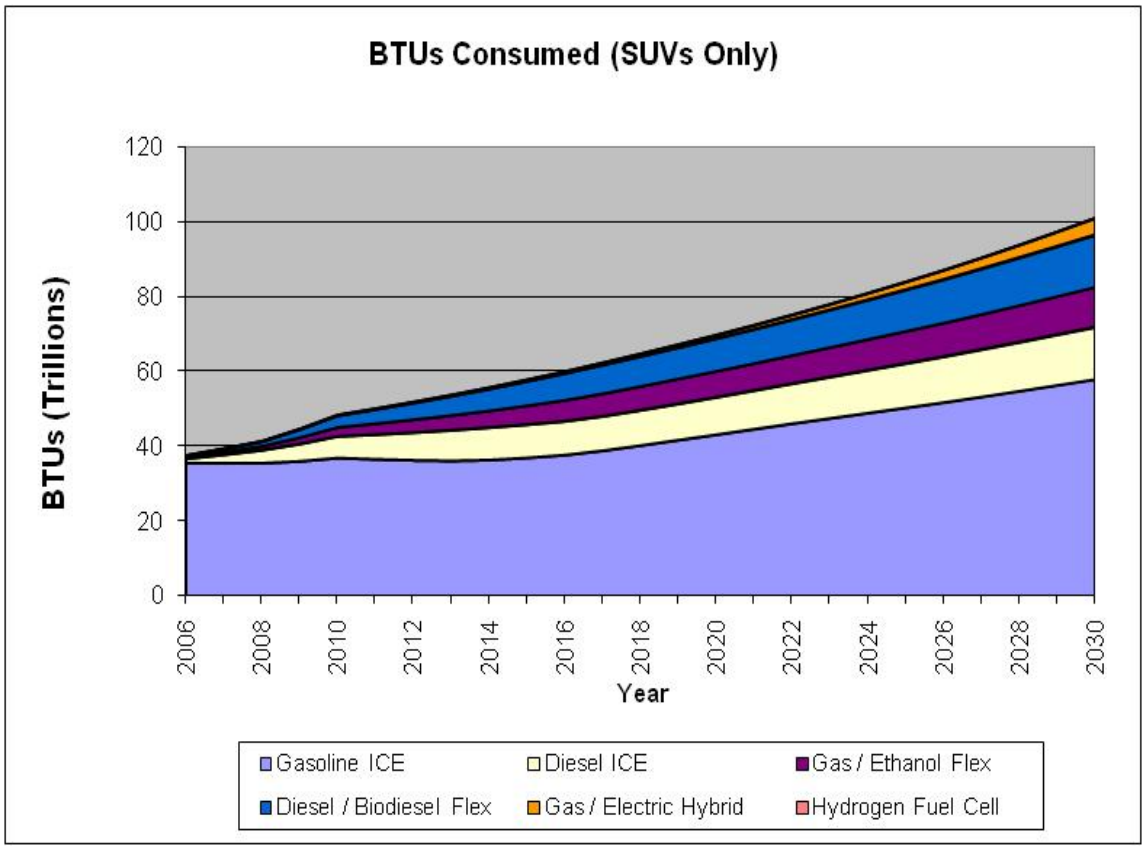
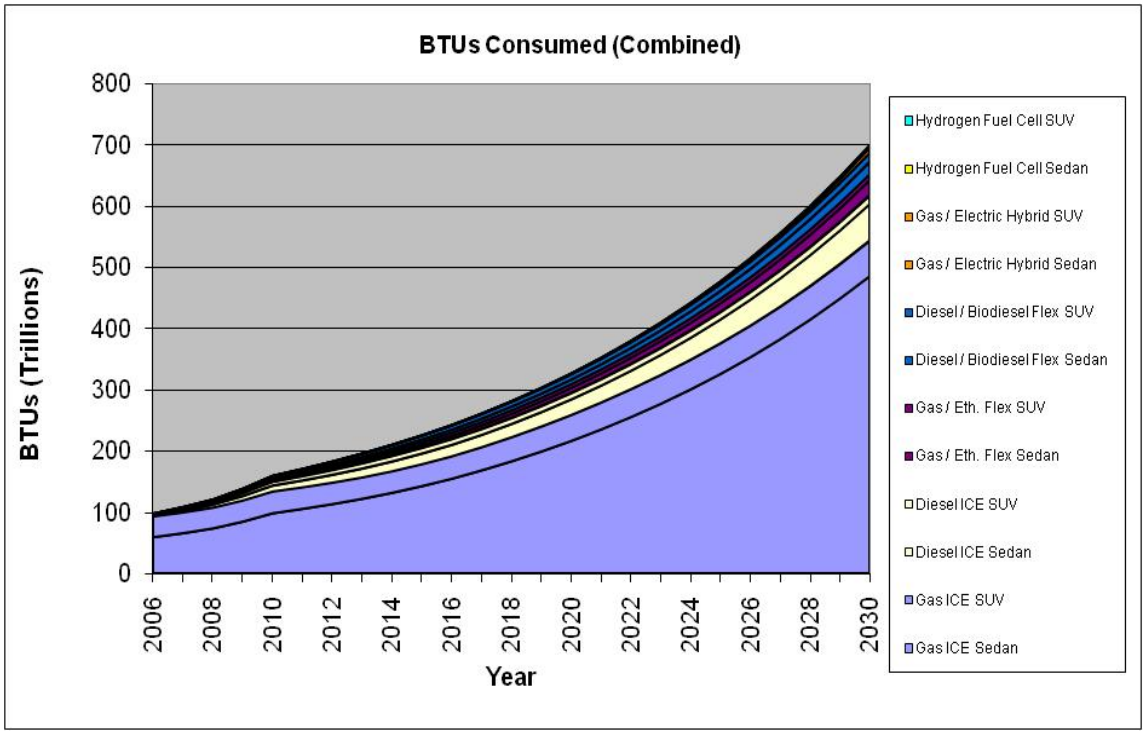


Figure 94: Chinese Baseline, All Vehicle Energy Consumption



4.3.3. Energy Consumed by Fuel Type

Figures 95, 96, and 97 show energy consumption by each fuel type, in terms of gallons of fuel consumed. As a result of rapid growth in passenger vehicle ownerships, conventional gasoline is the category that increases most rapidly. Among that, sedan gasoline consumption increases much faster than SUV gasoline consumption. Other fuels, diesel, biodiesel, ethanol and hybrid are also continuously increasing over the period.

Figure 95: Chinese Baseline, Gallons of Gasoline Equivalent Consumed by Sedans

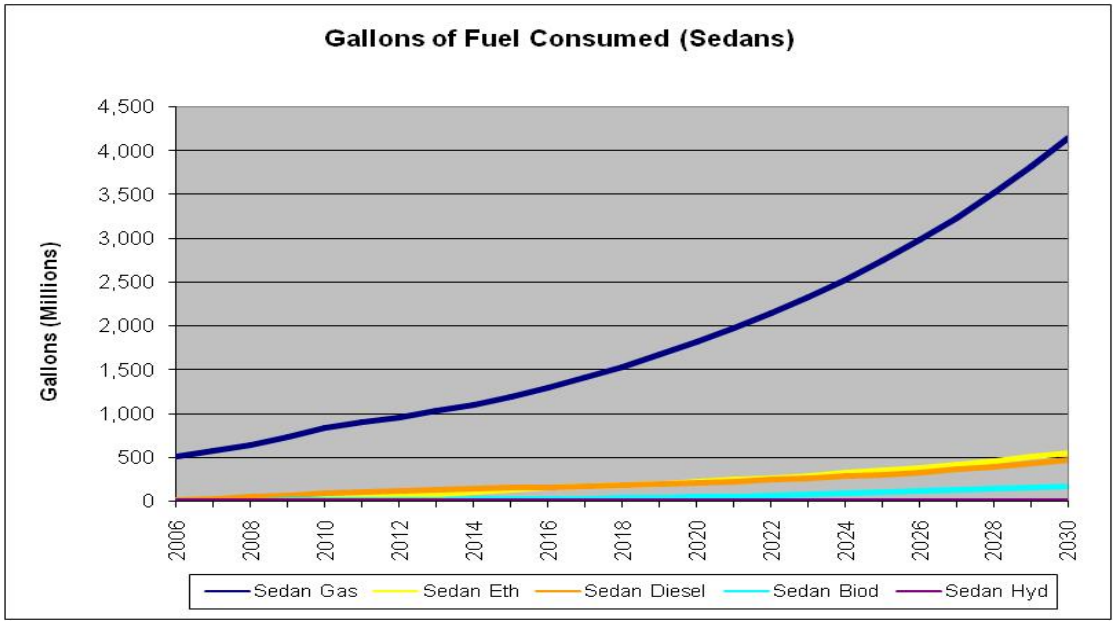
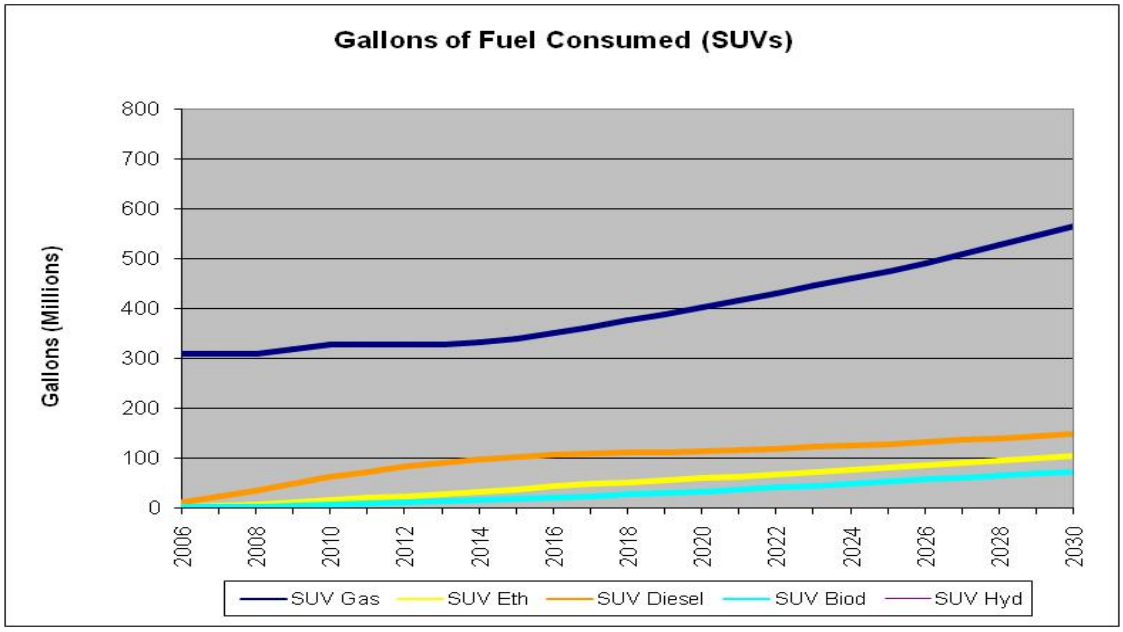


Figure 96: Chinese Baseline, Gallons of Gasoline Equivalent Consumed by SUVs



4.3.4. CO_2 Emissions

Corresponding to the rapid increase in vehicle ownership is the rapid increase of CO_2 emissions. The pattern of CO_2 emissions increase matches the pattern of energy consumption. Conventional gasoline is the primary source of CO_2 emissions, and it will remain to be so in the 25 years. As more SUVs switch to alternative fuels, CO_2 emissions from conventional gasoline SUVs remain relatively stable. As with energy consumption, increased numbers of vehicles offset the fuel choices that lead to the overall increase of emissions.

Figure 97: Chinese Baseline, Sedan CO_2 Emissions

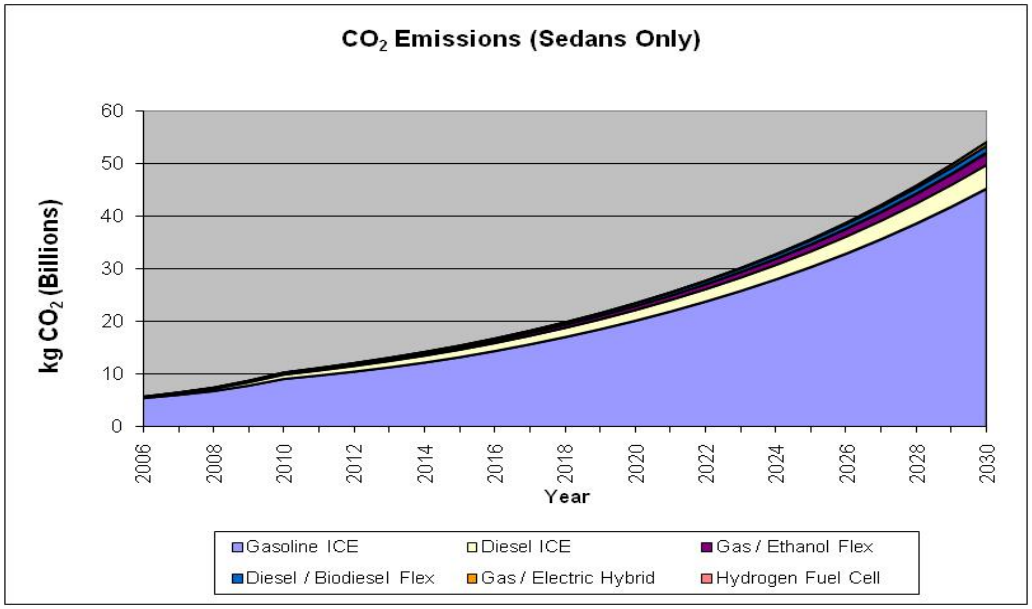


Figure 98: Chinese Baseline, SUV CO_2 Emissions

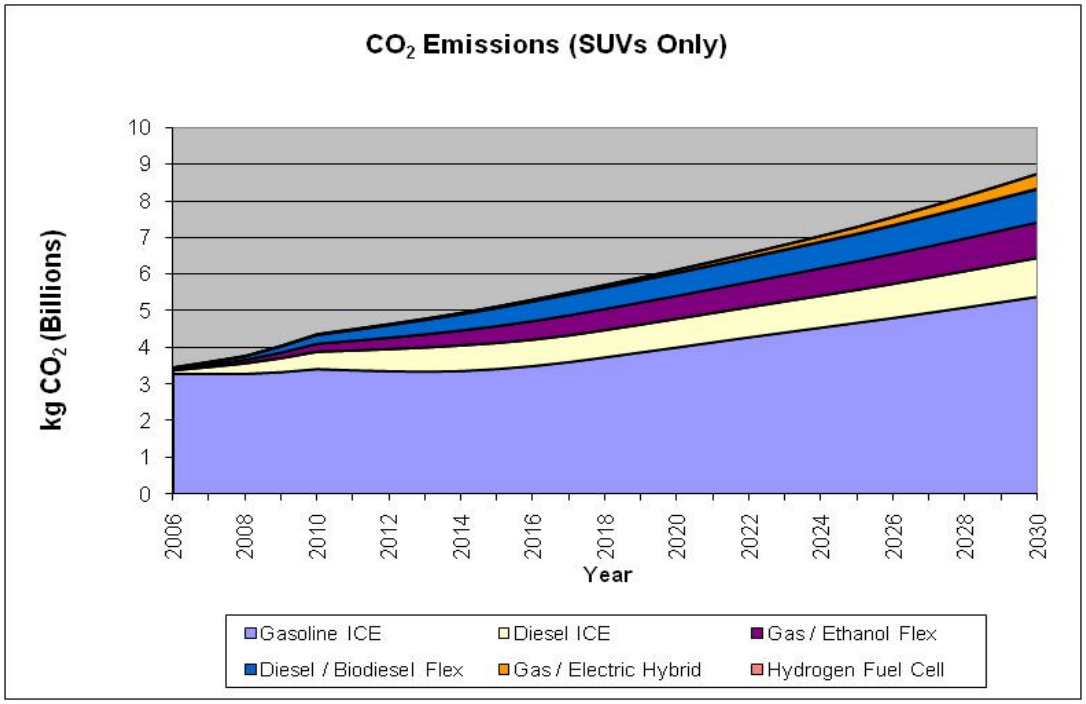
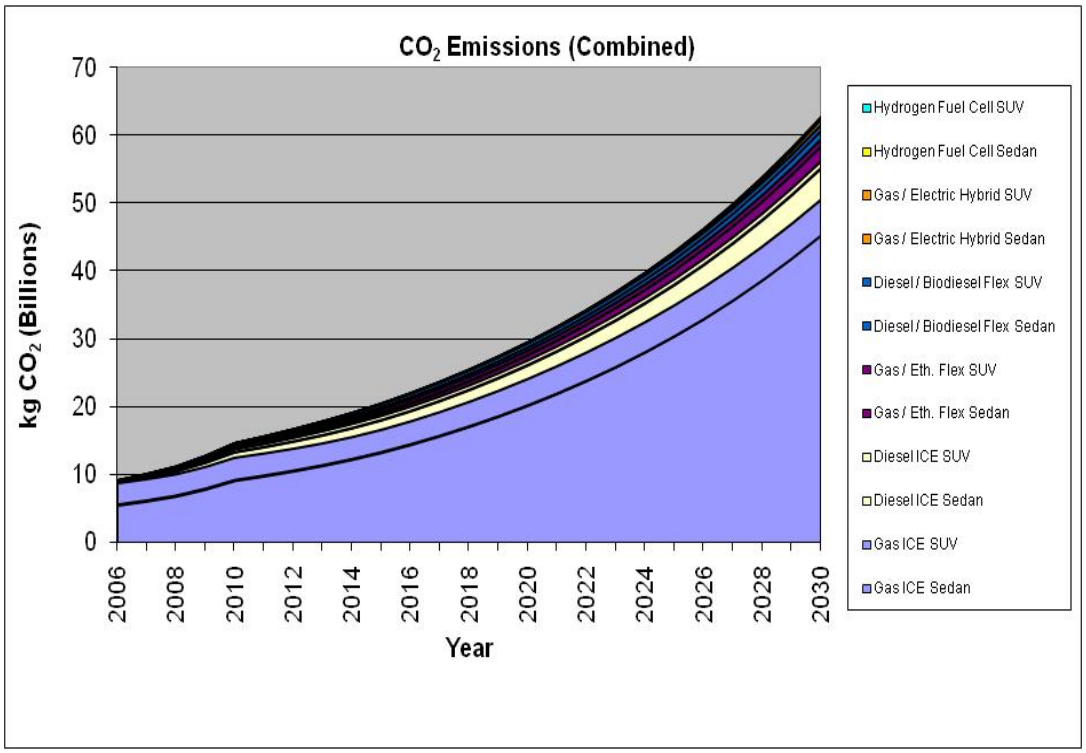


Figure 99: Chinese Baseline, All Vehicle CO_2 Emissions



4.3.5. Normalized Emissions

The CarCarbon model breaks down carbon dioxide emissions per vehicle. With efficiency improvement, there is a steady decrease of per vehicle emission rates. Comparing with the overall CO_2 emissions in section 2.4, it is clear that efficiency improvements alone are not enough to cut transportation CO_2 emissions. Other policies should be adopted if effective emission reduction is desired in the future.

Figure 100: Chinese Baseline, CO_2 Emissions Per Year Per Sedan

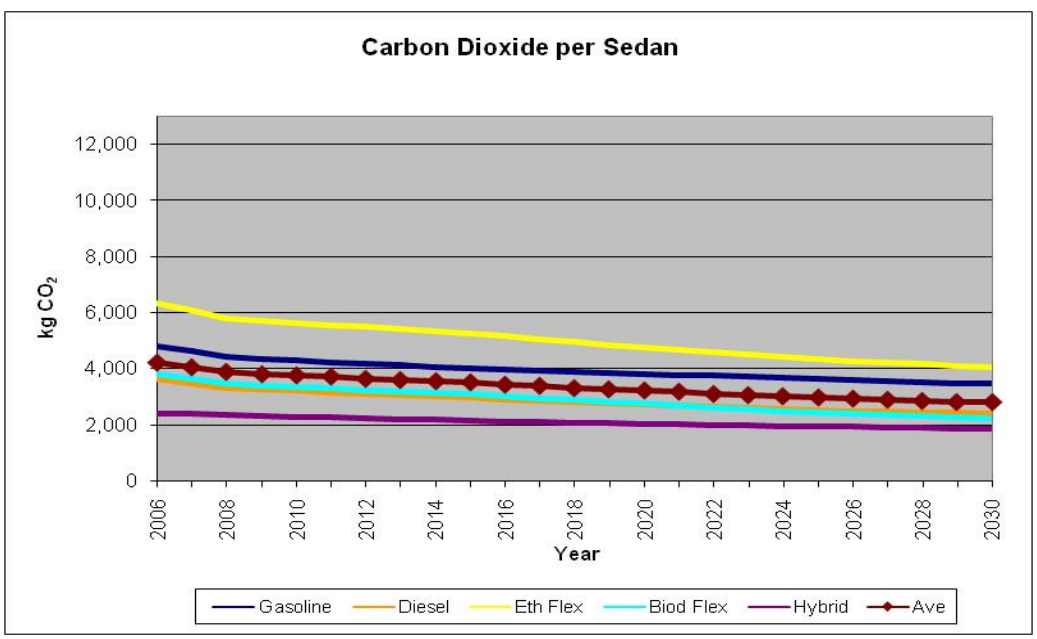
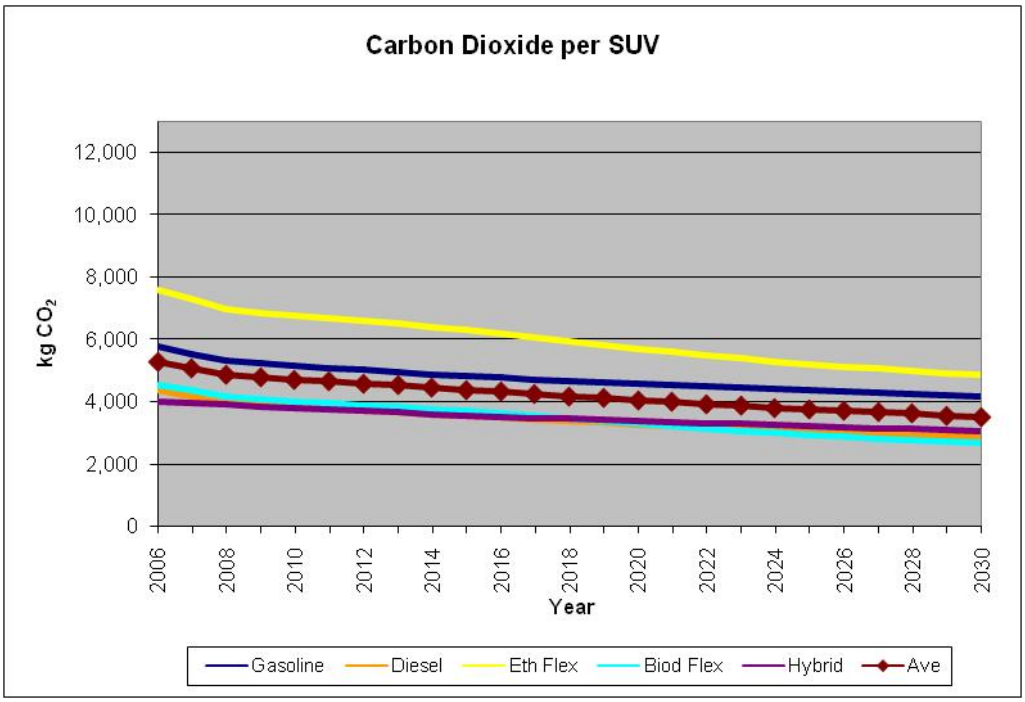


Figure 101: Chinese Baseline, CO_2 Emissions Per Year Per SUV



4.4. China Sensitivity Analysis

Methodologically the Chinese sensitivity analysis was conducted in the same fashion as the U.S. sensitivity analysis, with the same variables focused on for the same reasons. This makes the differences in the results between the two particularly interesting as any change in the importance or effect of changes to the variables will be completely caused by differences in the basic inputs of the baseline scenario, thus highlighting the fact that the model is sensitive to different variables based on the inputs of the baseline scenario, and not just sensitive to variables based on the mechanics of the model.

While there were differences in the sensitivity analyses of the two different scenarios, there were also similarities. In particular is the negligible effect that was garnered from alterations to fuel availability. Once again, this is due to the fact that small changes to the fuel availability have little to no effect when they occur at the extremes of either high availability or low availability. Instead, an effect only occurs in the transitional period between 10% and 40% availability. Even in these circumstances, significant changes only occur during the shift between 20% and 30% when this variable is at its most volatile. As in the U.S. sensitivity analysis, neither ethanol nor gasoline, the two fuels examined in this sensitivity analysis traverse this range due to the + or – 10% change to their values.

	Gasoline ICEs	**Ethanol Flex Fuel**	**Gas-Electric Hybrids**
1st	Fuel Economy	Vehicle Price	Fuel Price
2nd	Vehicle Price	Fuel Economy	Vehicle Price
3rd	Fuel Price	Fuel Price	Fuel Economy
4th	Make/Model	Make/Model	Make/Model
5th	Fuel Availability	Fuel Availability	Fuel Availability

The number of gasoline vehicles on the road, just like in the U.S. baseline scenario is very clearly most strongly affected by the vehicle price of these vehicles. But also similarly to the U.S. case, the carbon dioxide emissions are not most strongly affected by vehicle price by the fuel economy of these vehicles. This makes a lot of common sense based on the fact that the primary competitor for gasoline, especially in China compared to the U.S. is ethanol, which has little to no carbon dioxide benefits as compared to gasoline ICEs. This while a vehicle price change may drive consumers away from gasoline ICEs, the effect on emissions is secondary as compared to a change in the fuel economy. The fuel economy change in gasoline ICEs has the greatest impact of any of the variables on carbon dioxide because of the large number of gasoline ICEs on the road. They so dominate the market that a percent increase in fuel economy roughly equates to an equivalent decrease in emissions.

The other variables were similar in magnitude to the changes caused in the U.S. scenario though the exact order of the sensitivity of the variables was altered slightly. For the most part, these variables were relatively close in sensitivity in the U.S. sensitivity analysis and remained so in the China sensitivity analysis, and their change in ranking was due to minute changes in magnitude rather than vastly different trends. Generally, however, make/model availability proved to be more important in the China sensitivity analysis than in the U.S. sensitivity analysis.

Figure 102: Chinese Sensitivity Analysis, % Change in Vehicles From Gasoline

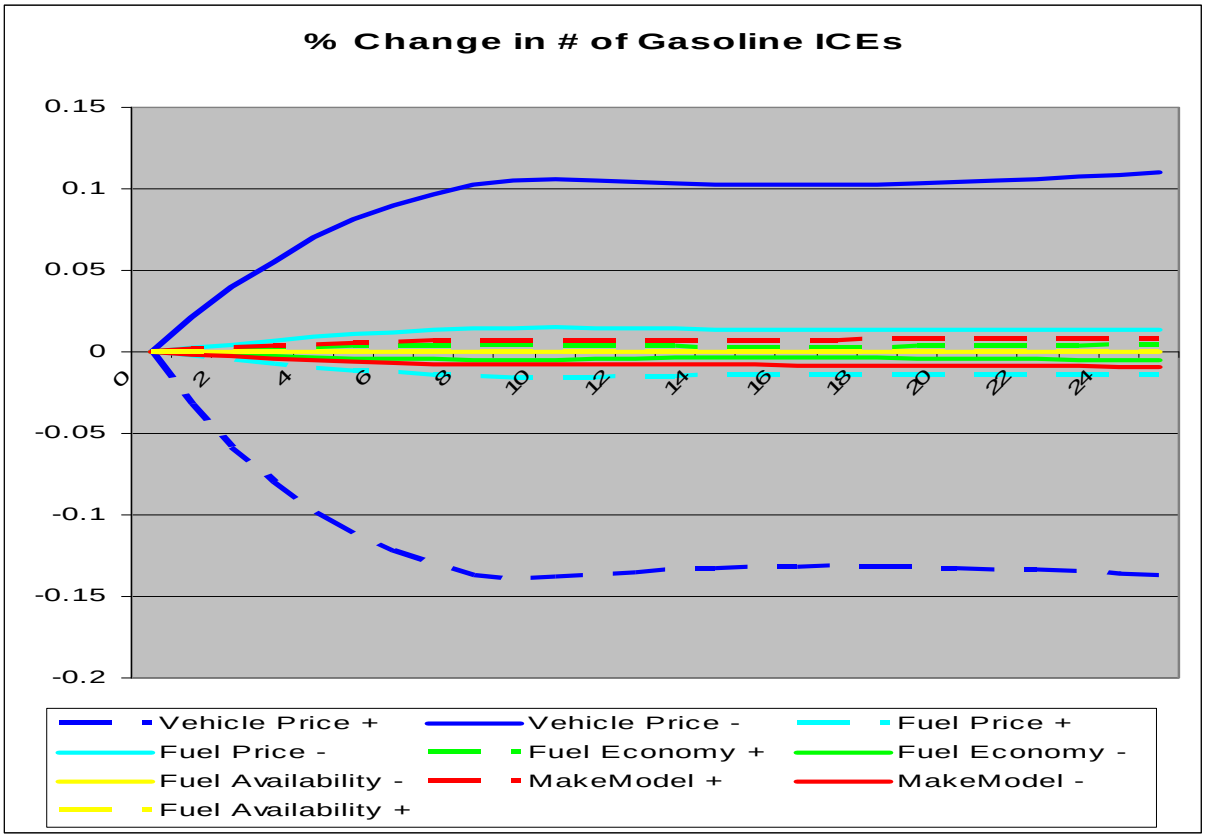
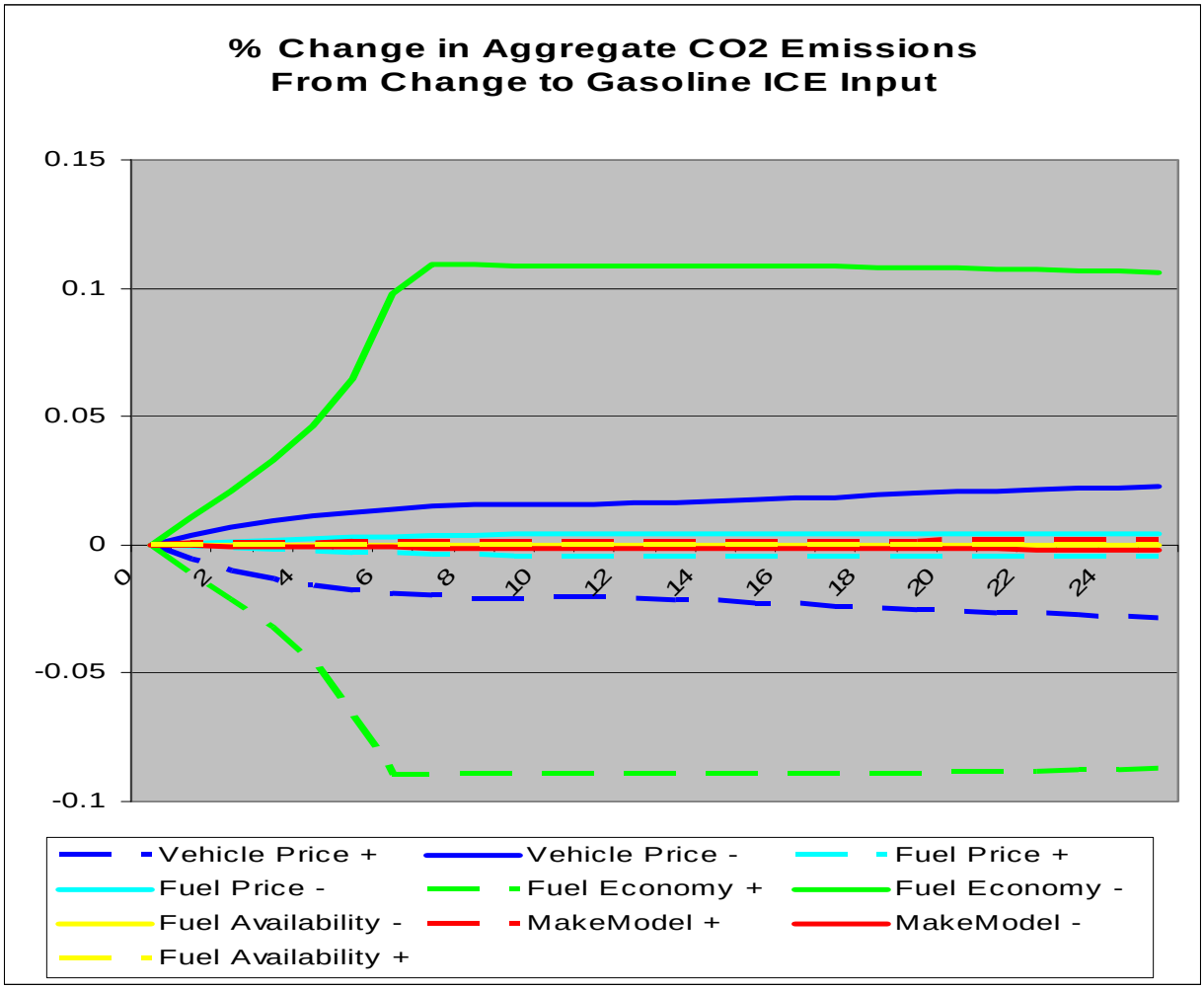


Figure 103: Chinese Sensitivity Analysis, % Change in CO_2 From Gasoline



The ethanol flex vehicle section of the sensitivity analysis was the most similar in nature to the U.S. sensitivity analysis, with only a minor change in the effect of make/model availability and fuel price on the number of ethanol flex fuel vehicles on the road. The effects of the sensitivity analysis on carbon dioxide emissions through changes to ethanol inputs was extremely similar to the effects in the U.S. sensitivity analysis and the order of importance of the variables was exactly the same.

As in almost all of sensitivity analysis results, vehicle price had by far the most impact on both the number of vehicles and the level of carbon dioxide emissions. This was followed by fuel economy, which had a moderate level of impact, and then fuel price and make/model availability, both of which had low levels of impact. As in all of the other results, fuel availability had negligible impact. Fuel economy and vehicle price are certainly the variables to focus on in any change that is made to ethanol flex fuel vehicles.

Figure 104: Chinese Sensitivity Analysis, % Change in Vehicles From Ethanol

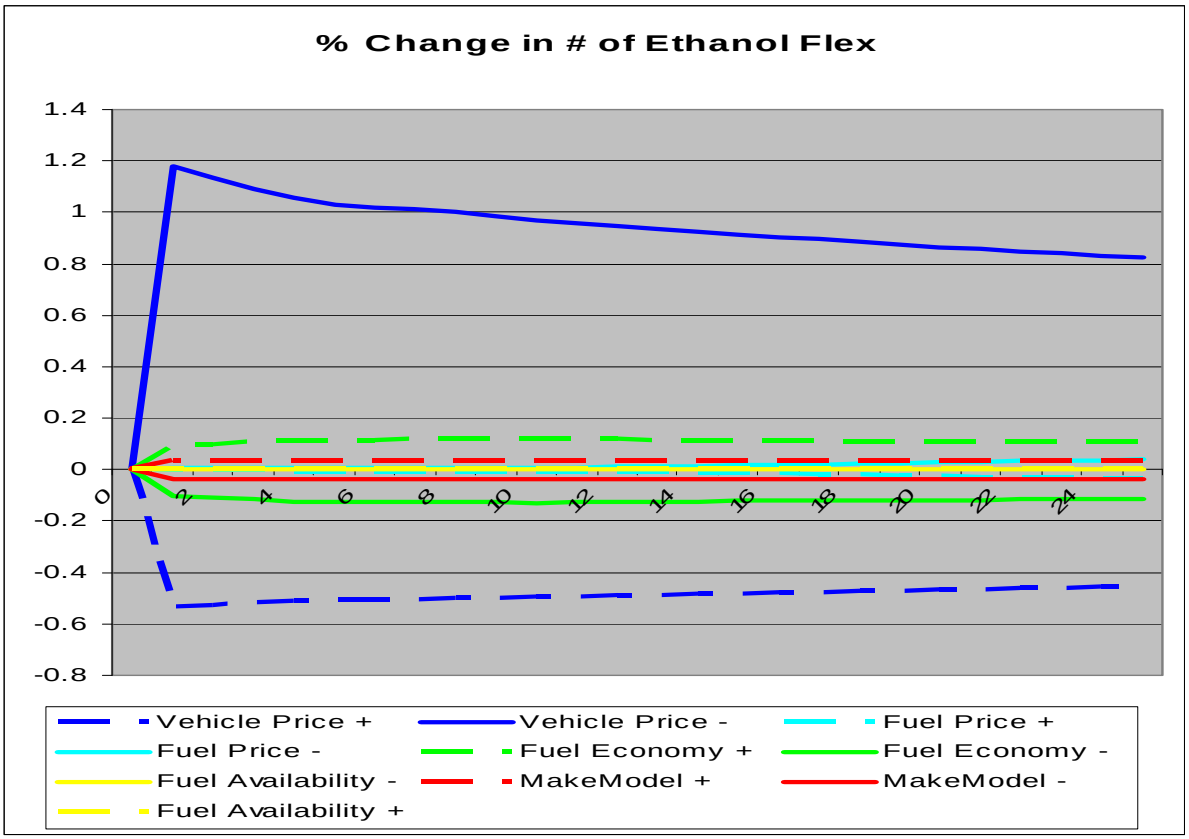
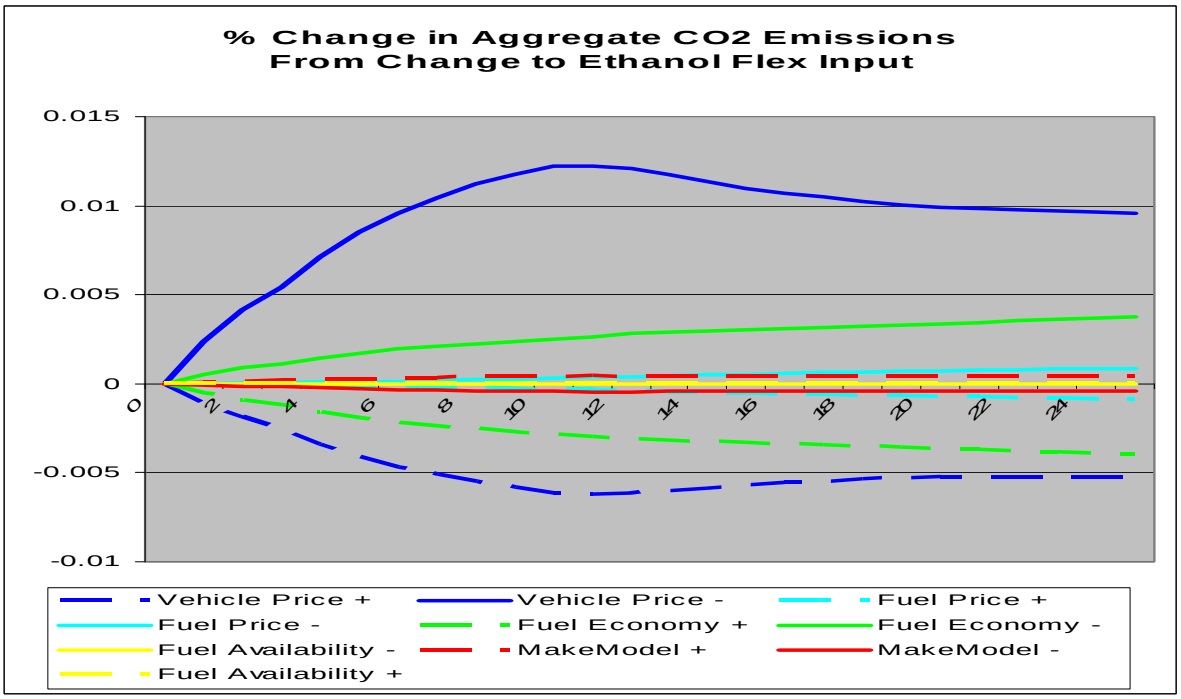


Figure 105: Chinese Sensitivity Analysis, % Change in CO_2 From Ethanol



Once again the results from the China sensitivity analysis for hybrid gasoline-electric vehicles were similar to the results of the U.S. sensitivity analysis in the corresponding section. The primary difference occurs in the effect of the variables on carbon dioxide emissions. In the China sensitivity analysis fuel price is the most important factor in determining carbon dioxide emissions, while in the U.S. scenario, the vehicle price is more important. This discrepancy is due to the retention of a large number of hybrid gasoline-electric vehicles due to a lower gasoline price in the China scenario, which leads to a far higher level of emissions than if they had converted to ethanol or hybrid vehicles.

Vehicle price regains dominance in the latter years of the projection however, showing the high level of sensitivity that the China scenario has to this variable. Nearly the exact year that the vehicle price of the hybrids is equivalent to the vehicle price of the gasoline ICEs shows a tremendous leap in the adoption of the technology. This carries through to the end of the projection where the early growth in hybrids leads to a dramatic decline in carbon dioxide emissions.

Figure 106: Chinese Sensitivity Analysis, % Change in Vehicles From Hybrids

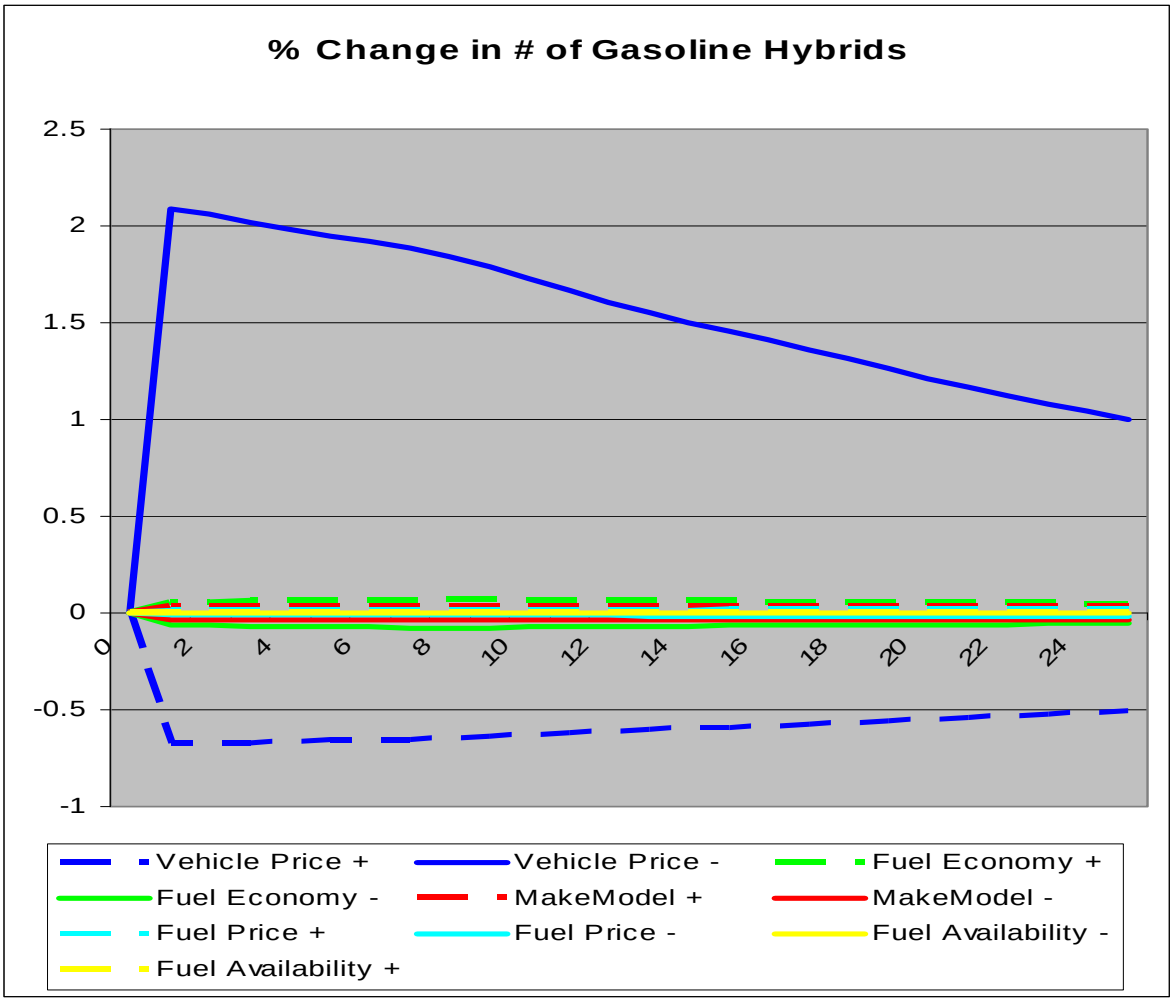
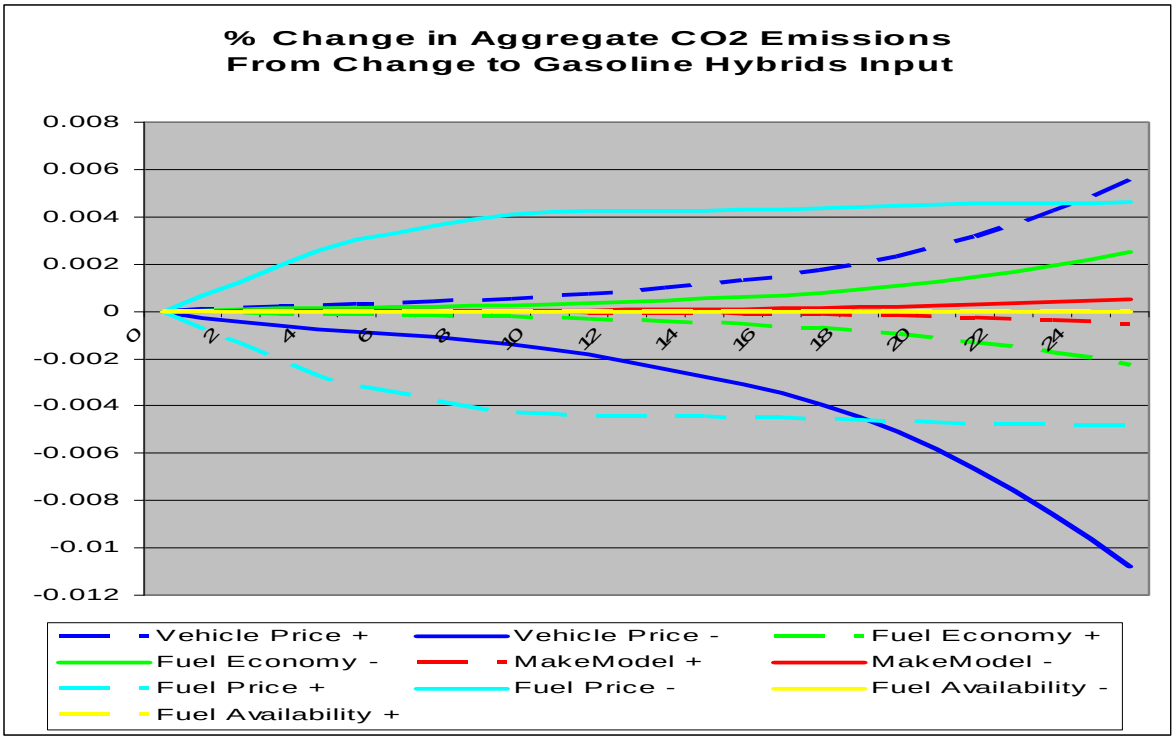


Figure 107: Chinese Sensitivity Analysis, % Change in CO_2 From Hybrids



4.5. China Policy Scenarios

There are many opportunities for energy savings and emissions reduction in urban transportation systems. But, these opportunities come hand-in-hand with complex difficulties. There is a huge potential for savings because room for improvement exists in various aspects, such as institutional, regulatory, planning, technical, operational, and financial sectors. Various factors could have an impact on China's transport energy consumption and therefore emissions in the future. The macro-level economy, population growth, transport mode, development of mass transit systems, auto-industry development, fuel economy, fuel prices and individual preferences are among the important influencing variables. Improvement on one or several sectors could benefit transportation efficiency and the urban environment, which will directly or indirectly improve energy efficiency and energy savings.

Many domestic and international lessons and experiences could be consulted for future policy formulation. Additionally, both domestic and international experiences show that better management on demand and supply, and better structural change on urban transportation could effectively improve urban transportation efficiency (Wu, 2005). Effective strategies include economic constraints on private vehicle use, fuel taxation, emission taxation, parking fees, peaking hour charges, development of bus rapid transit, integrated transportation system, and railway development (Wu, 2005). Based on historical conditions and possible development trends in the future, this section discusses several policy scenarios. CarCarbon is used to analyze these scenarios and resulting impacts on energy consumption and emission reduction.

Policy factors that might influence transport energy use include: national energy development strategies; regional planning and urban transportation planning; transportation mode and patterns; environmental protection (i.e.: emission standards would impact on

alternative fuels development and fuel efficiency); fuel efficiency (mandatory or voluntary), and other corresponding financial policies (i.e., fuel taxation).

4.5.1. Increasing Fuel Economy

One effective strategy for transport energy conservation is to increase the fuel economy of vehicles (NDRC, 2004). International experiences have showed that mandatory fuel economy standards are the most effective method to encourage auto manufacturers to apply advanced technologies and thus to improve vehicle fuel efficiency levels. For example, the fuel efficiency of passengers have been doubled since the enactment of CAFE in the United States fuel economy standards for gasoline and diesel light duty passenger and freight vehicles in Japan has resulted in a 16% improve than in 1995 (CCICED, 2006). China has issued weight-based fuel economy standards in 2004, which require the auto industry to produce more fuel efficient vehicles, including cleaner advanced vehicles or alternative-fuel vehicle technologies.

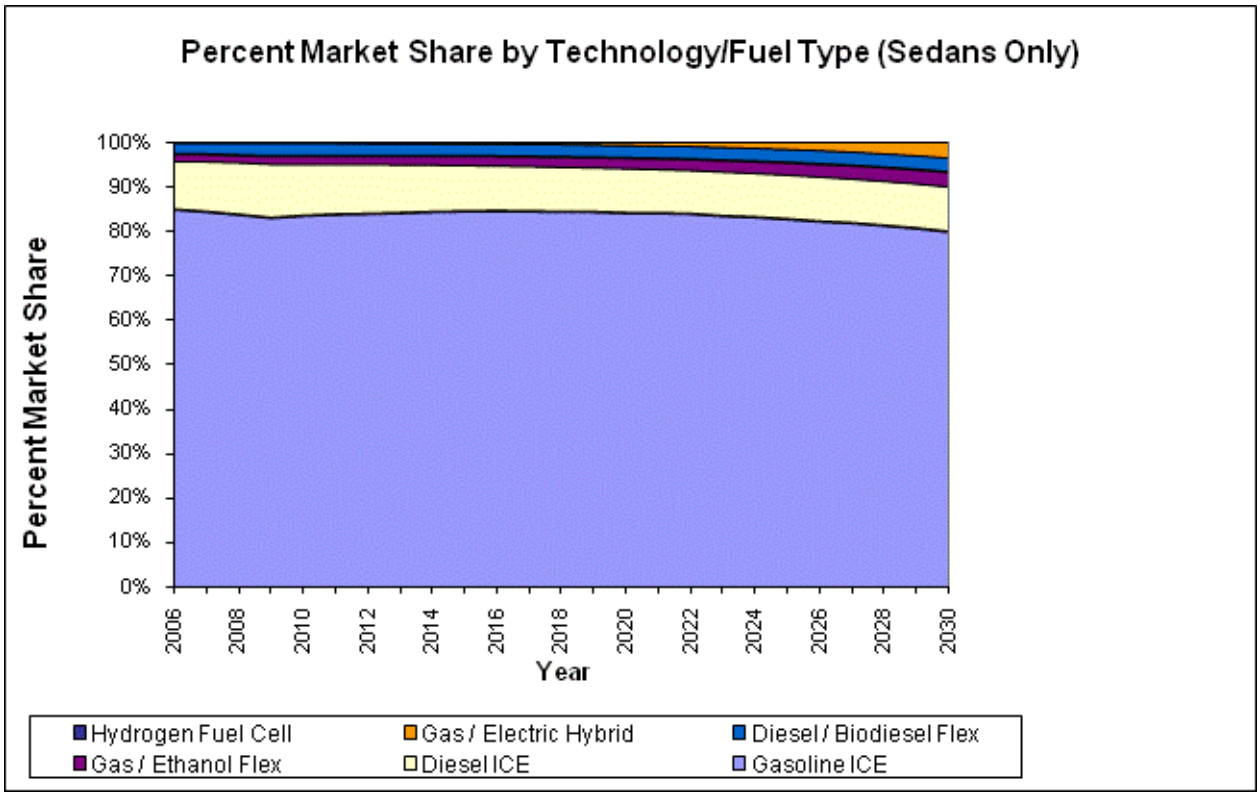
Currently the growing group of middle-class households is the major purchase power of private vehicles and the major focus is on smaller, affordable, and therefore efficient vehicles. Numerous press reports in 2005 suggest a shift toward smaller, less expensive models (WRI, 2005). It is estimated that the full implementation of the standards will result in an improvement of 15% of vehicle fuel economy for new passenger vehicles by 2008 (CCICED, 2006). As a result of the standards, China can save 85 million tons of oil by 2030, which is equivalent to 56 million cars' oil consumption in a year (CCICED, 2006).

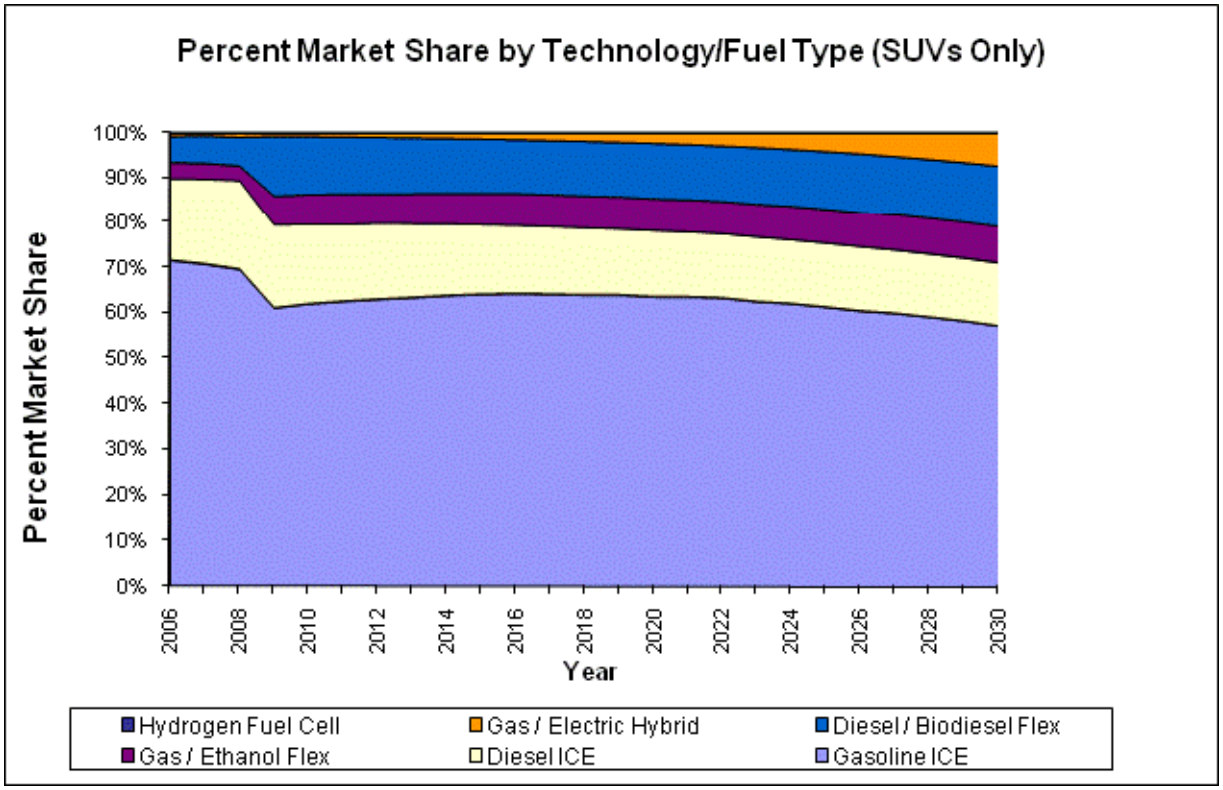
In reality, a shift toward lighter cars could lead to higher fuel economy of the vehicle pool. However, since the fuel economy standards are based on vehicle weight, there is no incentive for vehicle manufacturers to pursue better fuel economy for the whole fleet. The standards itself could not prevent large penetration of heavy and fuel intensive vehicles on the market. Furthermore, the prominent share of large imported cars and SUVs in the sales mix over the past five years may contribute to high average vehicle weight.

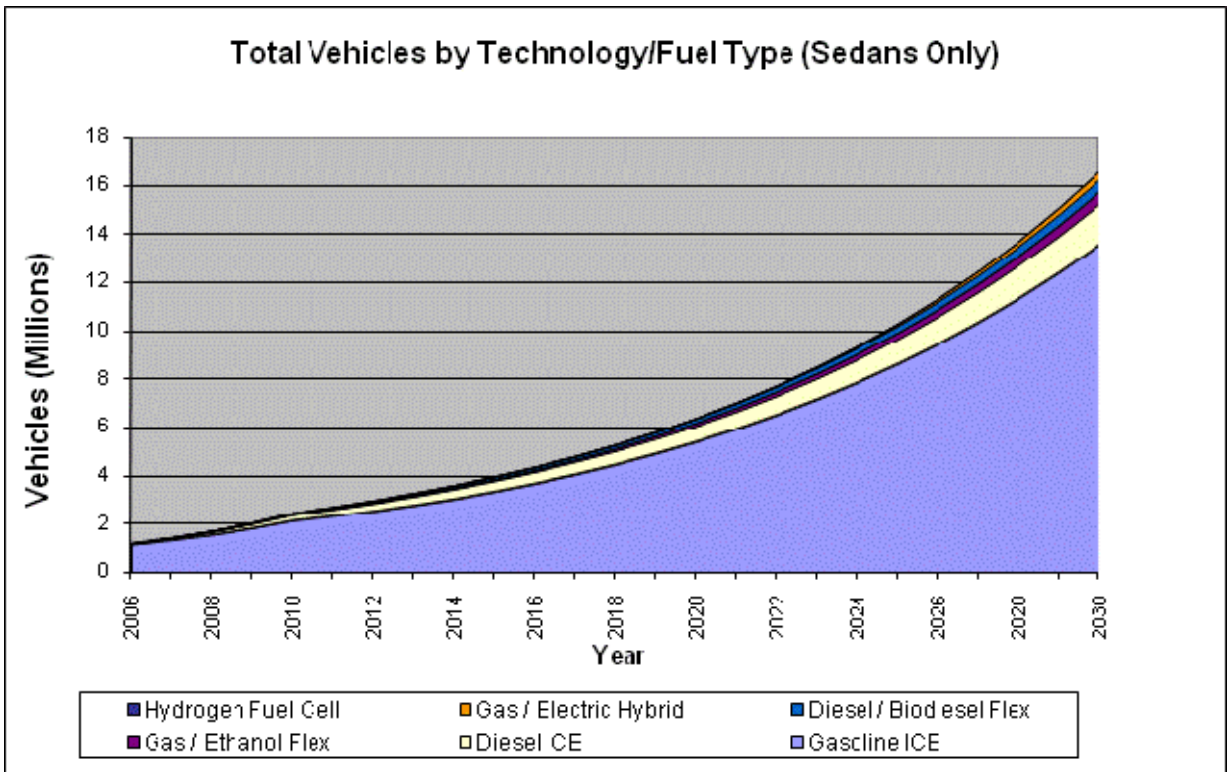
Historical experiences in many other countries show that the weight and engine size of new vehicles tends to increase as incomes rise. Considering the specific situation of China, future uncertainties regarding consumer preferences and vehicle weights exist. If China goes with the trend as other countries, it could largely compromise the accomplishment of fuel economy standards. Therefore it would be an area that might be addressed in future polices intending to conserve energy. In addition, since an implementation mechanism for the standards is not available, governmental agencies should make it an urgent task to develop such an implementation mechanism as well as supporting policies, laws, regulations, and incentives to ensure that the products of enterprises will meet the required standards (CCICED, 2006).

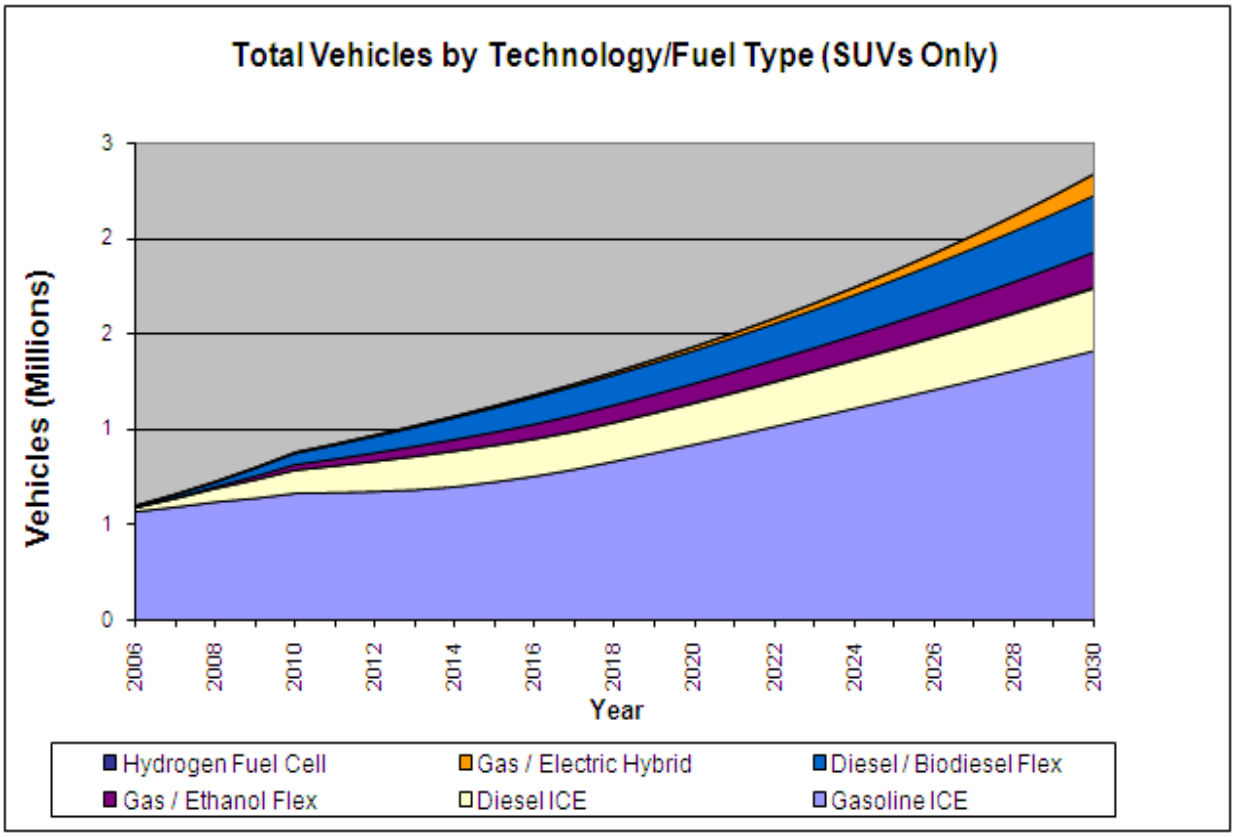
For the time being, China has already issued and implemented the first and second phase of fuel economy standards, but the system should be much stricter to reflect China's urgent desire to reduce transport energy consumption. CCICED (2006) suggest that based on transportation development and technical feasibility, the vehicles to be produced in 2015 in China are expected to reach the same level as in Europe in the same period; that is, the fuel consumption per 100 kilometer will be halved of the level of current Chinese vehicles. That translate to that, the fuel consumption of light-duty vehicles to be made in 2008 should be reduced by 15% to 7.5L/100km; a further reduction of 25% by 2012 to 5.6L/100km (the European requirement in 2008); and about 4.8L/100km should be developed to catch with Europe and Japan in around 2016 (CCICED, 2006).

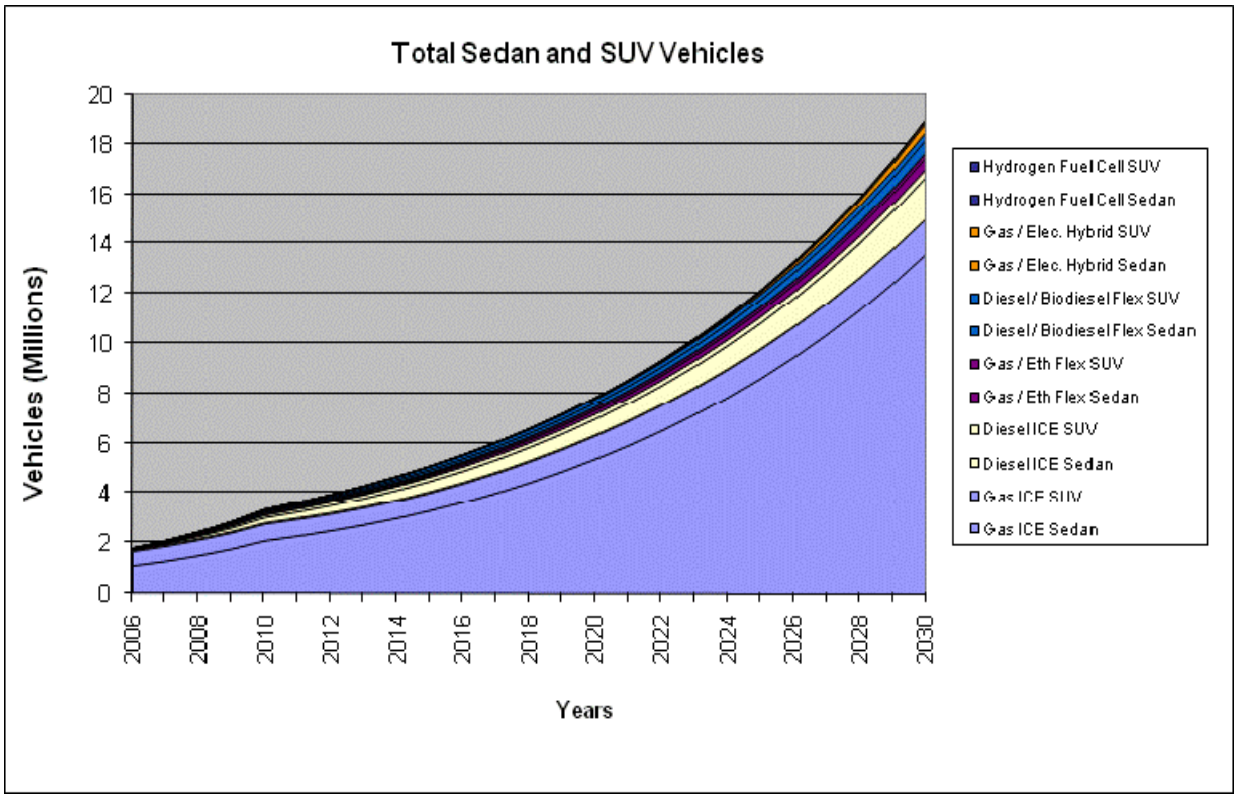
Figure 108(a-j): Chinese Alternative Scenario, Increasing Fuel Economy

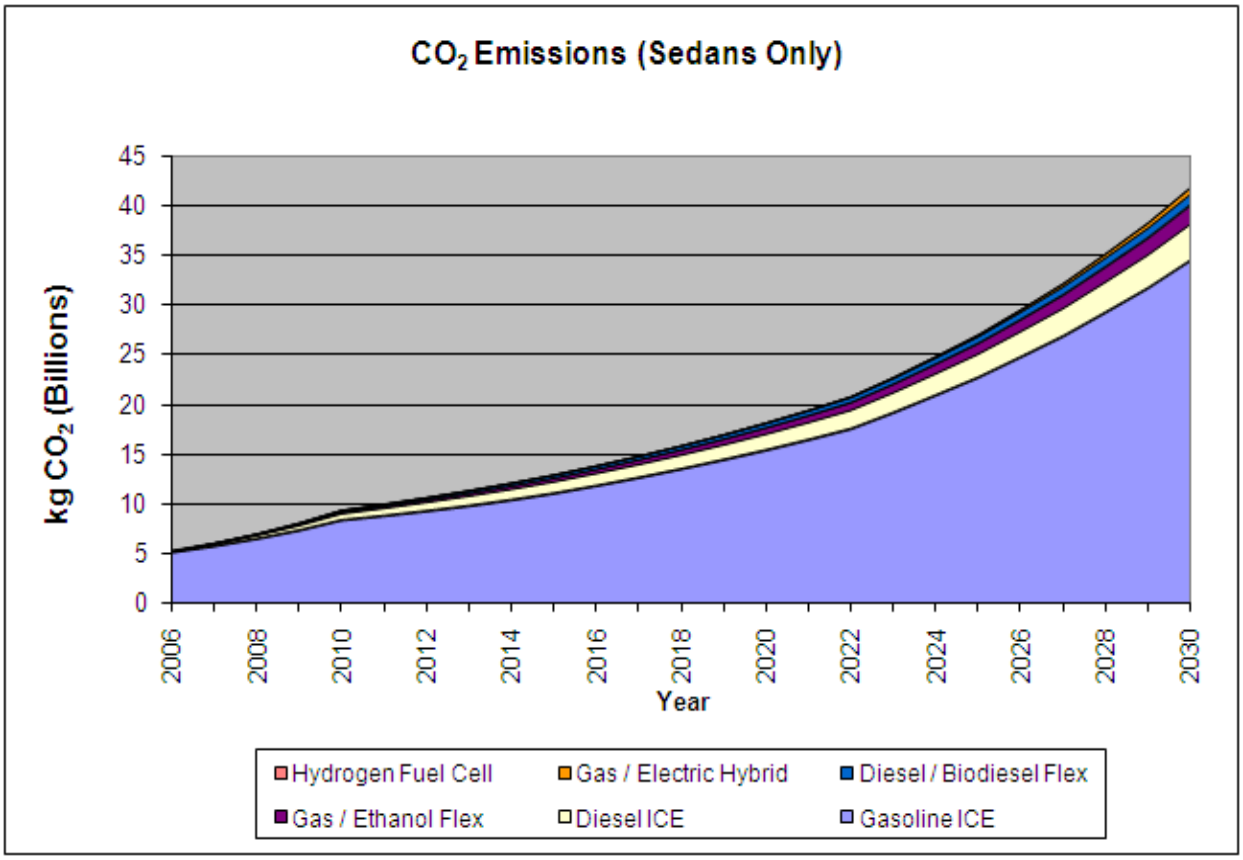


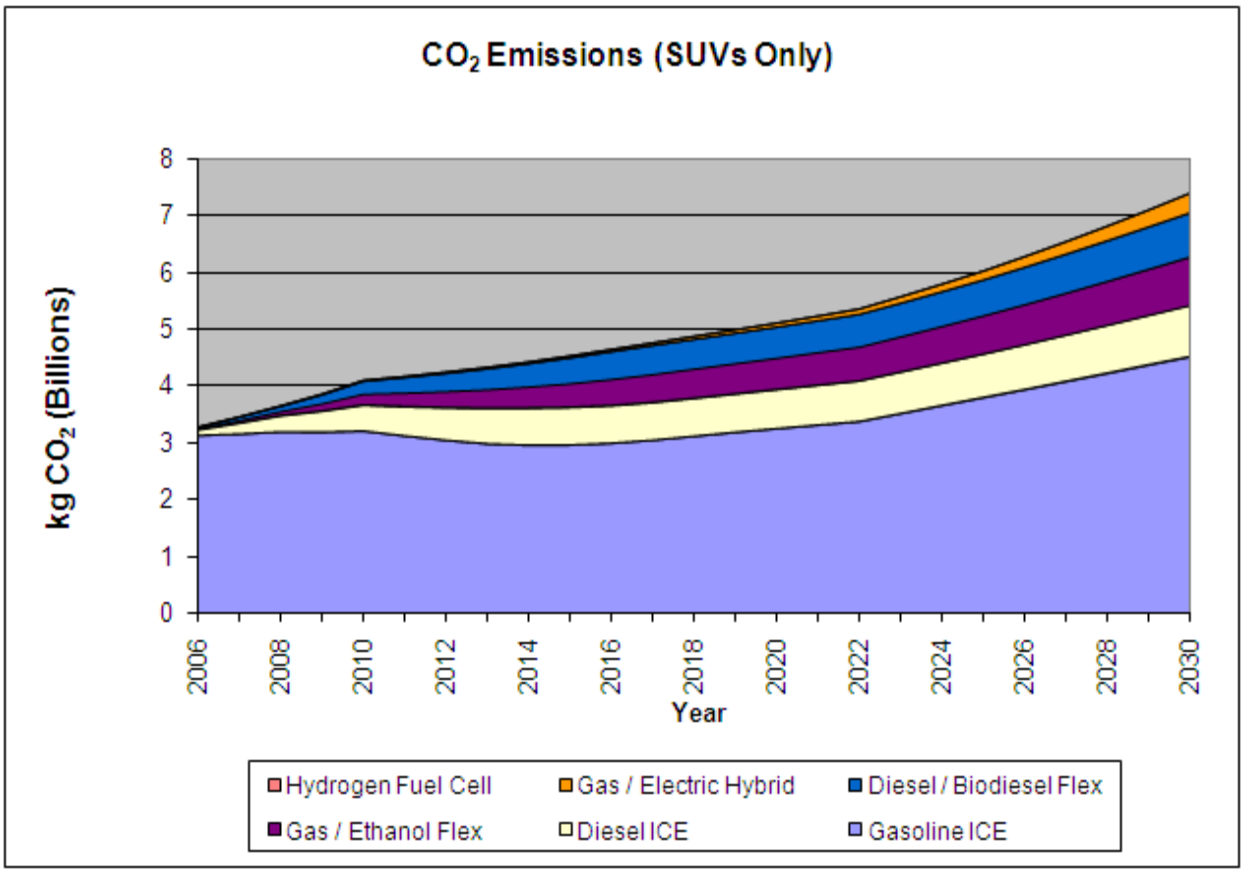


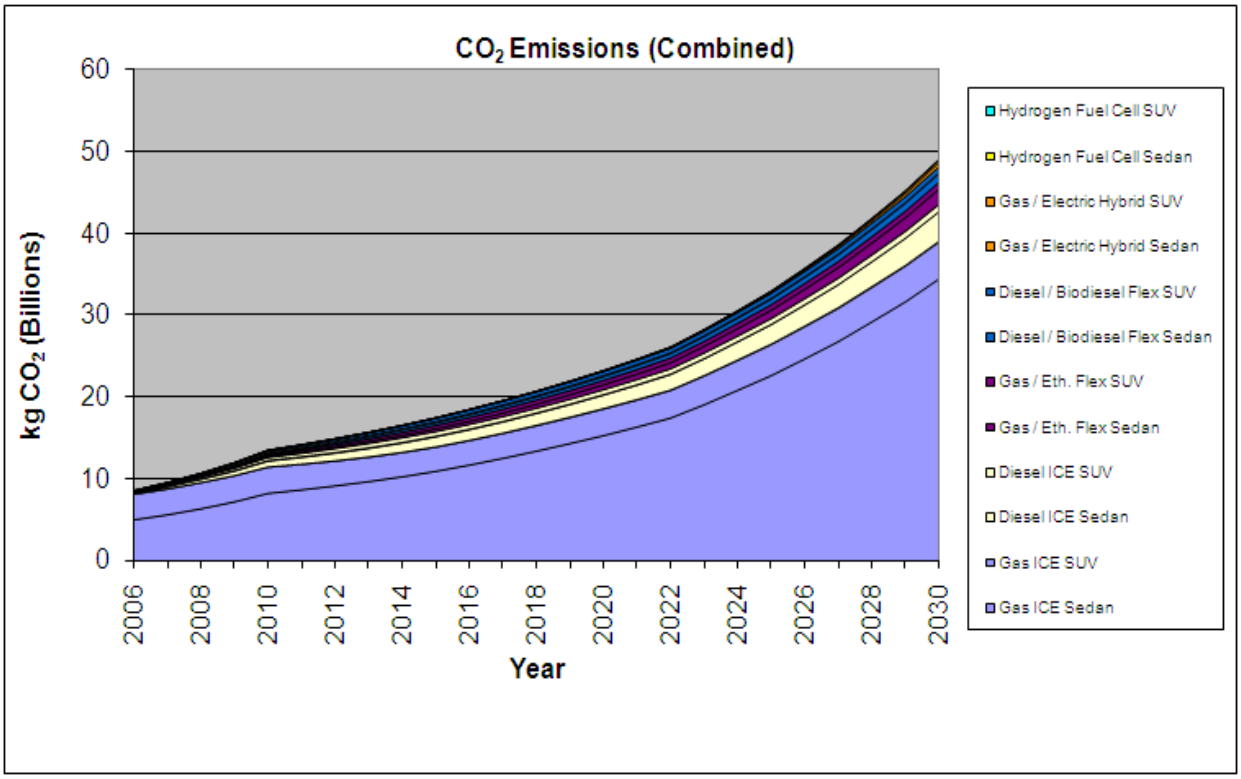

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
18
16
14
12
10
8
6
4
2
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell
Gas / Electric Hybrid
Diesel / Biodiesel Flex
Gas / Ethanol Flex
Diesel ICE
Gasoline ICE

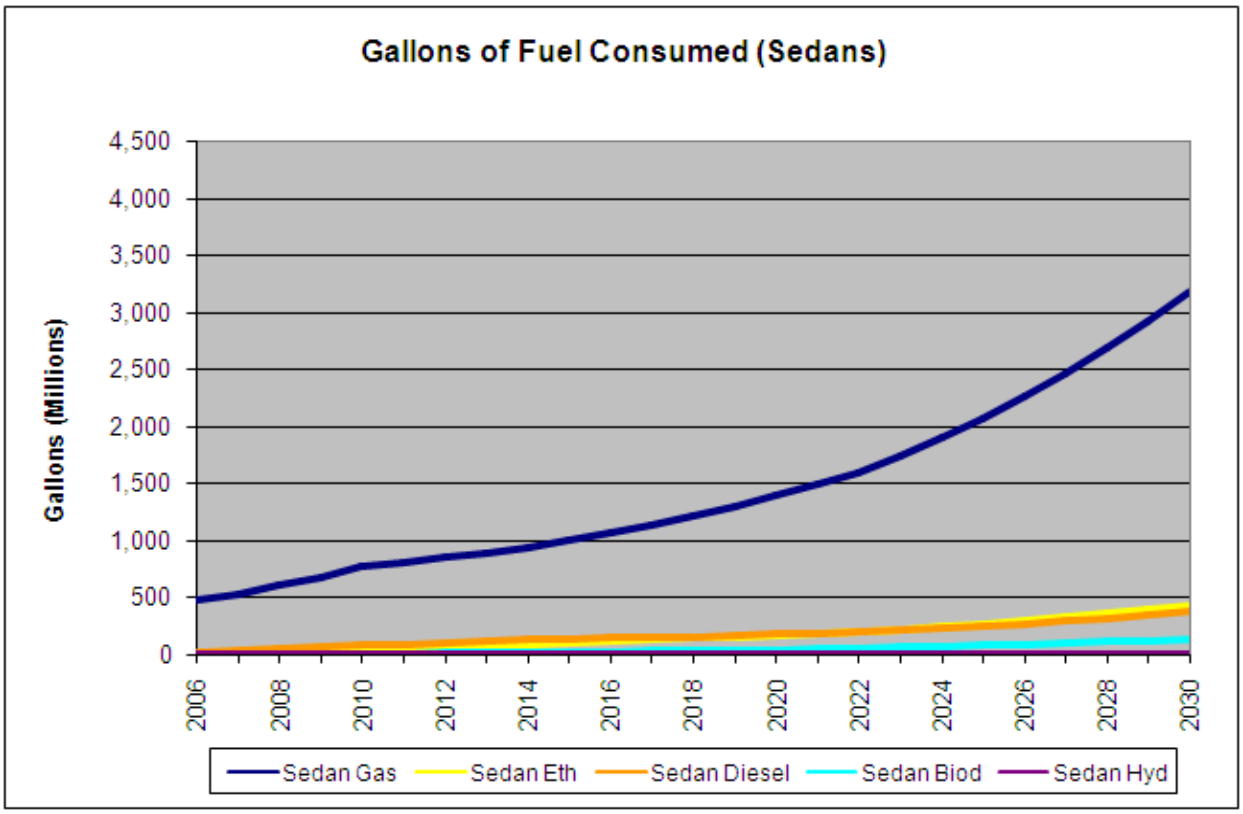

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
3
2
2
1
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell
Gas / Electric Hybrid
Diesel / Biodiesel Flex
Gas / Ethanol Flex
Diesel ICE
Gasoline ICE

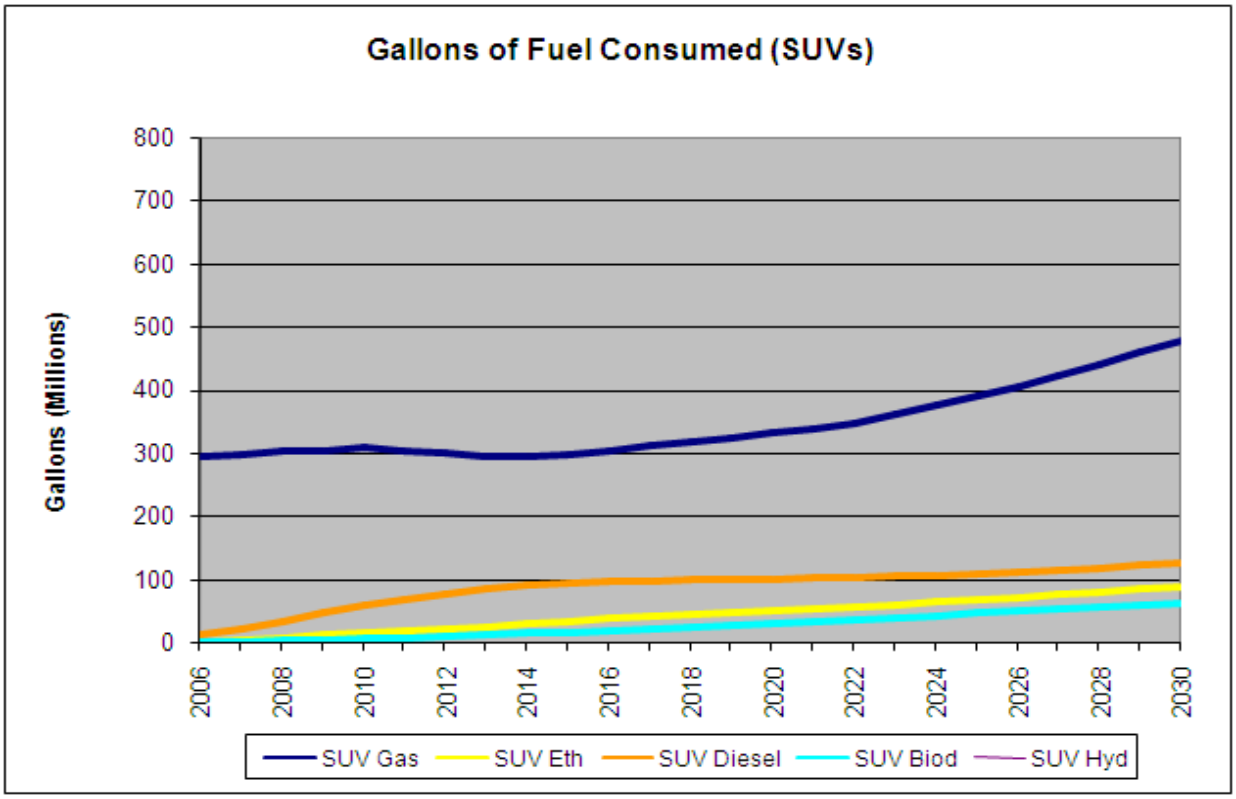

Total Sedan and SUV Vehicles
Vehicles (Millions)
0
2
4
6
8
10
12
14
16
18
20
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Years
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Elec. Hybrid SUV
Gas / Elec. Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth Flex SUV
Gas / Eth Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


CO_2 Emissions (Sedans Only)
kg CO_2 (Billions)
0
5
10
15
20
25
30
35
40
45
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell
Gas / Electric Hybrid
Diesel / Biodiesel Flex
Gas / Ethanol Flex
Diesel ICE
Gasoline ICE


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
0
1
2
3
4
5
6
7
8
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell
Gas / Electric Hybrid
Diesel / Biodiesel Flex
Gas / Ethanol Flex
Diesel ICE
Gasoline ICE


CO2 Emissions (Combined)
kg CO2 (Billions)
0
10
20
30
40
50
60
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


Gallons of Fuel Consumed (Sedans)
Gallons (Millions)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd


Gallons of Fuel Consumed (SUVs)
Gallons (Millions)
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
SUV Gas
SUV Eth
SUV Diesel
SUV Biod
SUV Hyd

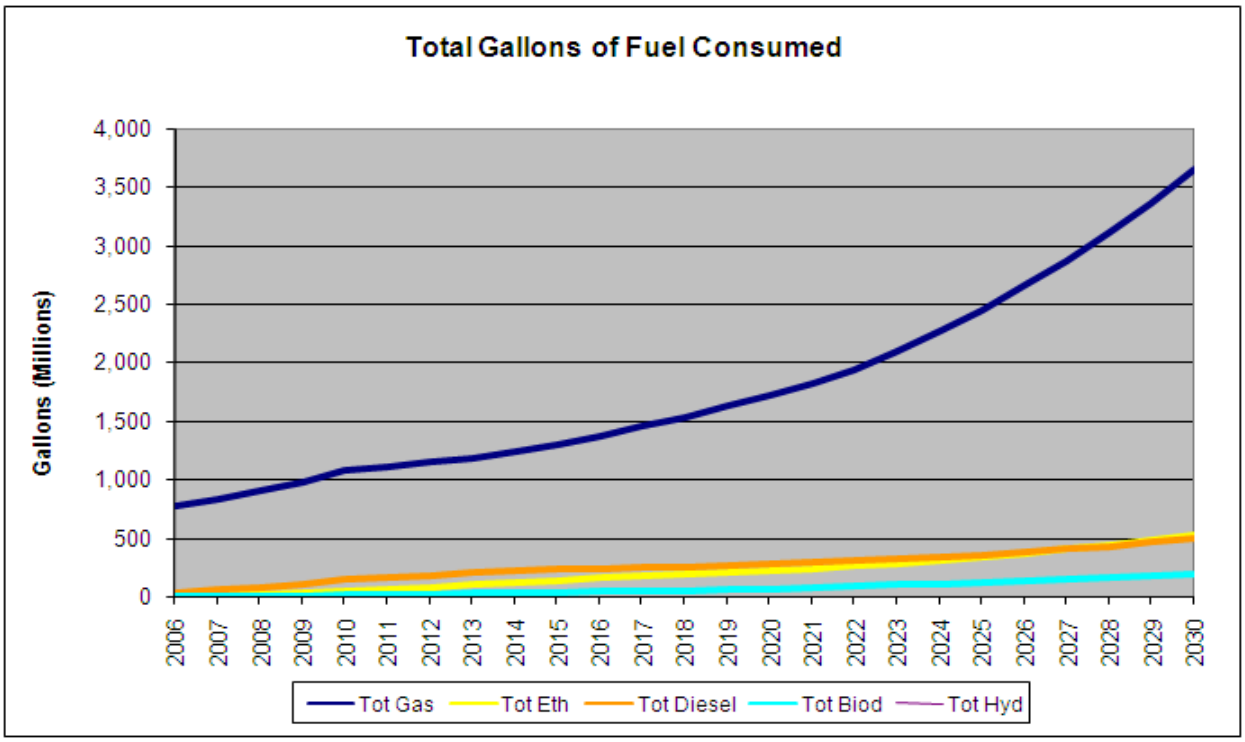


Figure 109: Chinese Alternative Scenario, Increasing Fuel Economy Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	13	142
% Reduction	21.76%	19.37%

CarCarbon results show that large increase of fuel economy has a significant impact on emission reduction. A 50% increase of fuel economy by 2015 resulted in a 21.76% reduction of CO_2 emissions in Year 2030 and a 19.37% reduction over the whole period. However, this reduction is due to purely technology improvement, which does not impact much on the penetration of alternative fuels and alternative vehicles, and the rapid growth of vehicle numbers. As can be seen from above graphs, although there is a sizable reduction compare to the baseline scenario, the increase of CO_2 emissions in the 25 years is still significant. Unless combined with other policy strategies, China's transport emission would continuously growing at a high rate.

4.5.2. Vehicle Technology Improvement

Vehicle technology plays a central role in emission reduction and vehicle energy efficiency improvement. In 2001, the Ministry of International Trade and Industry in Japan laid down the 2010 vision of vehicle technology development, which covers battery-powered electric vehicle (BPEV), hybrid-electric vehicle (HEV), fuel cell electric vehicle (FCEV), compressed natural gas vehicle (CNGV) and liquid petroleum gas vehicle (LPGV) (CCICED, 2006). In addition to investment in R&D, financial incentives were used to promote the target. During 1997 and 2001, the number of BPEVs and HEVs sold were 26,000 and 155,000 respectively.

Advanced technologies have huge potentials of energy saving and environmental protection. The national government has determined to carry out programs of research and

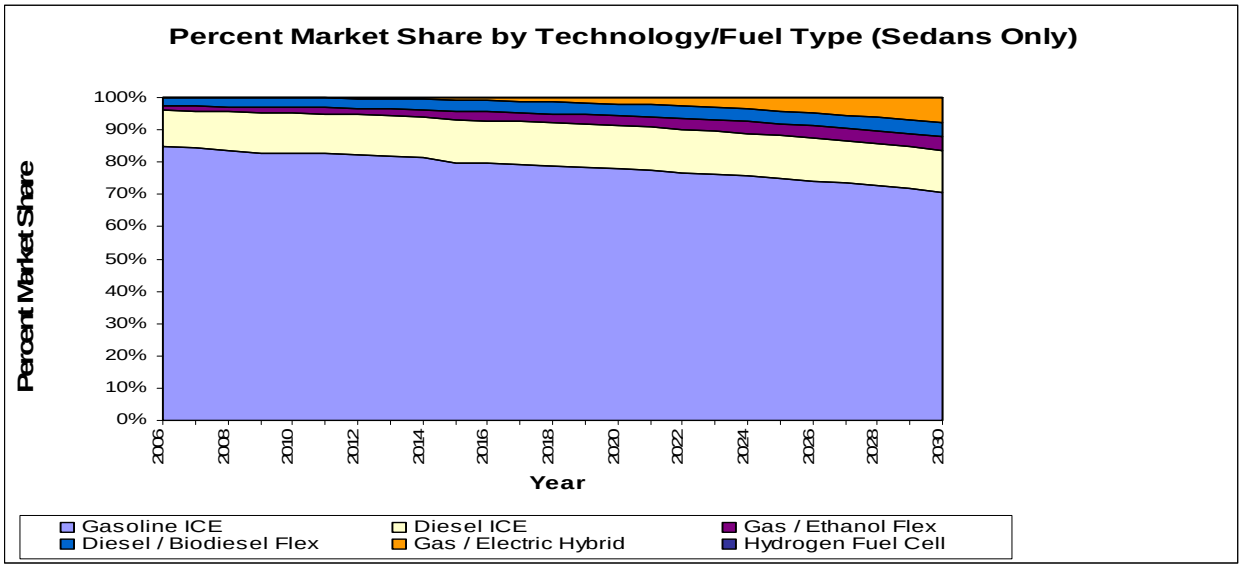
development of environmental friendly, efficient transportation technologies. But at present, there is no support for industrialization and commercialization of advanced vehicle technologies in the national policy (CCICED, 2006).

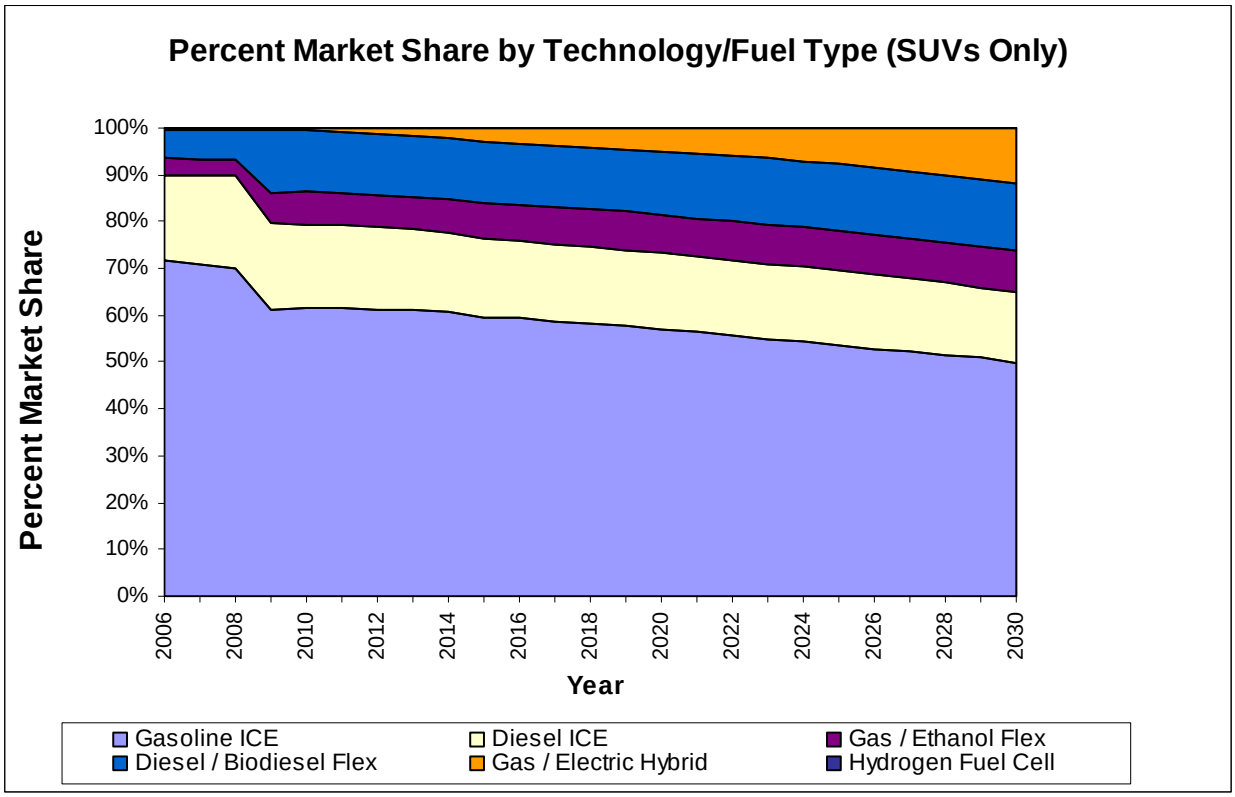
A later scenario will address hydrogen fuel cell technology, which is a technology under development in many countries. This scenario, however, addresses gasoline hybrid-electric vehicle (HEV) technology, which has been demonstrated, developed, and applied in a vast array of countries. Despite its international growth, HEV technology has not been paid enough attention in China. Only a handful of hybrid vehicle models are available on the market. Toyota has started building its Prius hybrid sedans in China with a Chinese partner. The Government of China has the option to continue attracting and encouraging such joint efforts, and to increase the diversity of advanced vehicle technologies in China. Therefore in the near future, the focus of advanced technology development in China should be industrialization and commercialization of HEVs. The country should make full use of the policies to promote the demonstration, production, and the use of hybrid electric technologies. Such policies should encourage auto manufacturers to establish new vehicle assembly lines for HEV production.

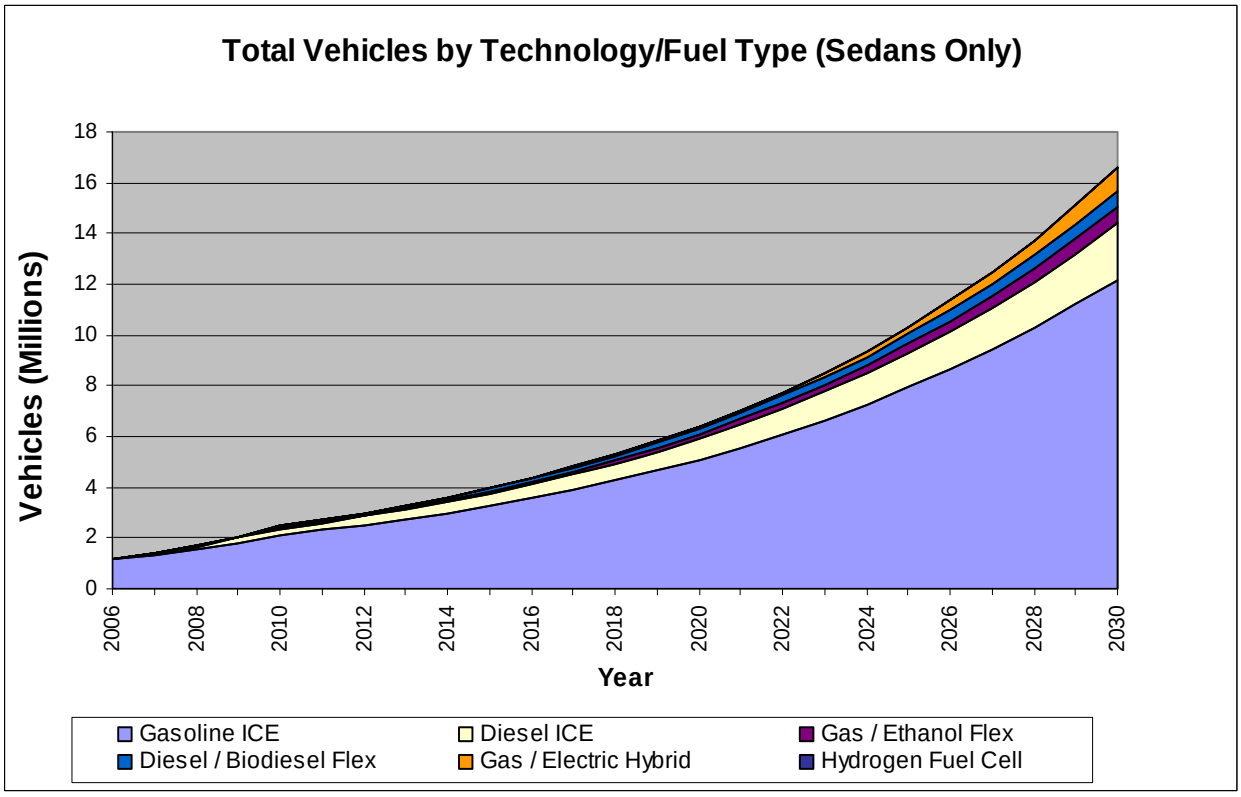
The hybrid technology might have a huge impact on energy conservation and emission reduction in the Chinese transport sector. Some large cities such as Shanghai proposed to realize 10% of market penetration of HEVs by 2010 (CCICED, 2006). In the mid- and long-term technology development plans, the Chinese government decides to increase the market penetration of HEVs to 40% ~ 50% of new vehicle market by 2020. It is predicted that the number of HEVs will be 3 million in China by then with government's strong policy and economic support. This will result in 2.1 million tons of oil saved in 2020 (CCICED, 2006).

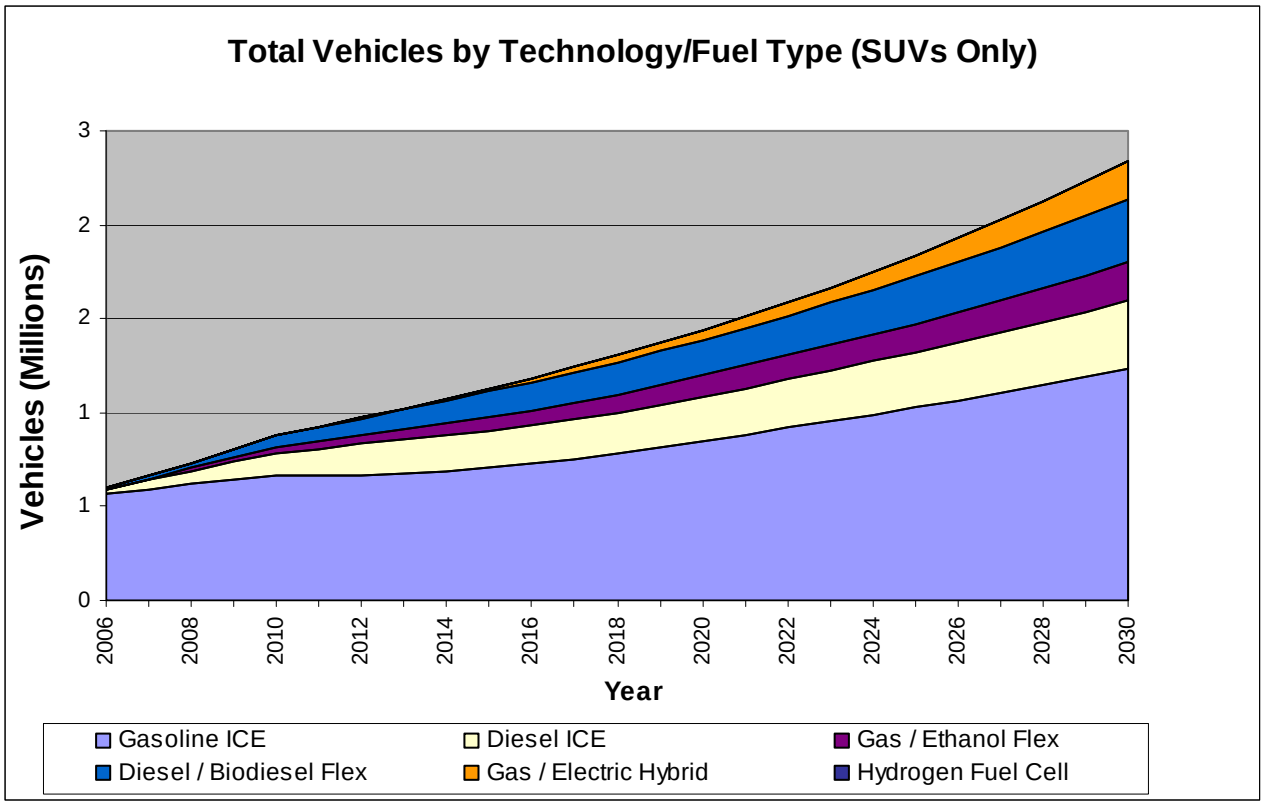
Successful development of HEV will require diverse and effective input including fundamental research, and fiscal incentives for manufacturers and consumers. As we will have a separate policy scenario on incentives for end users, here we will only consider manufacturer-side improvements, which translate into higher make and model availability in CarCarbon. Under this scenario, the make and model availability of sedan HEVs increases 50% annually for the first 10 years of the simulation, then increases 1% annually for the remainder of the simulation. The availability of SUV HEVs increases 80% annually for the first 10 years, then increases 1% annually for the remainder of the simulation. Furthermore, for both sedans and SUVs, the number of biodiesel-hybrids and ethanol-hybrids is double that which was available under the baseline (however, the availability of these vehicle types is still quite low).

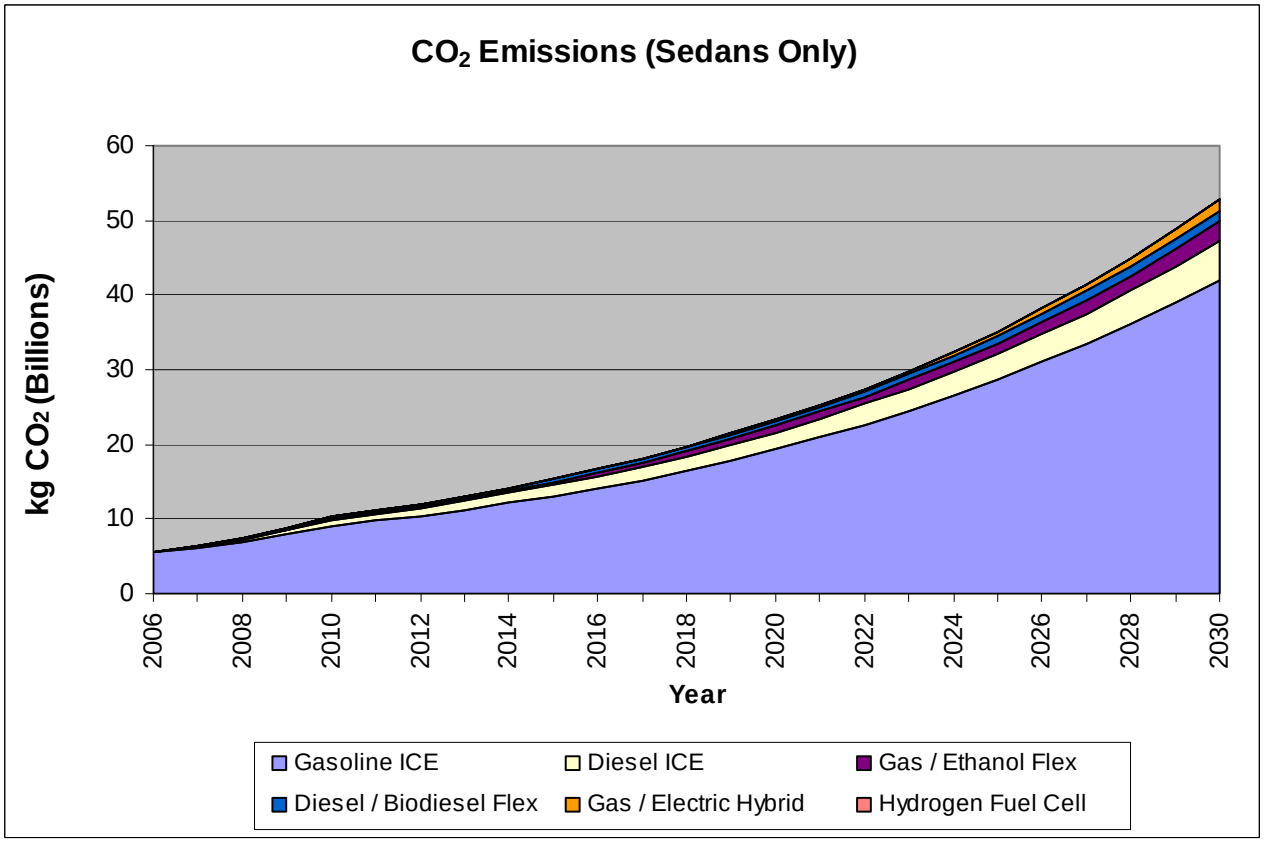
Figure 110(a-j): Chinese Alternative Scenario, Vehicle Technology Improvement

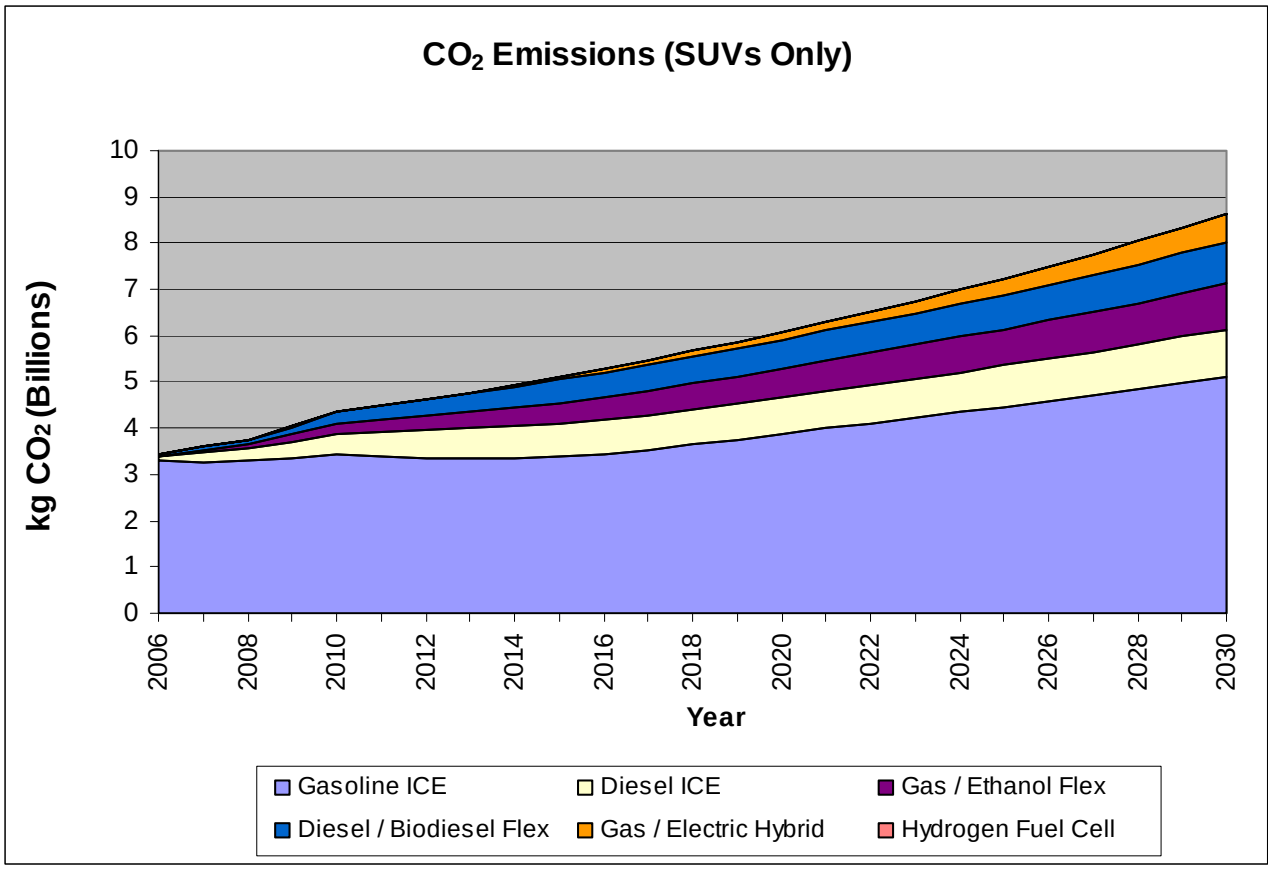


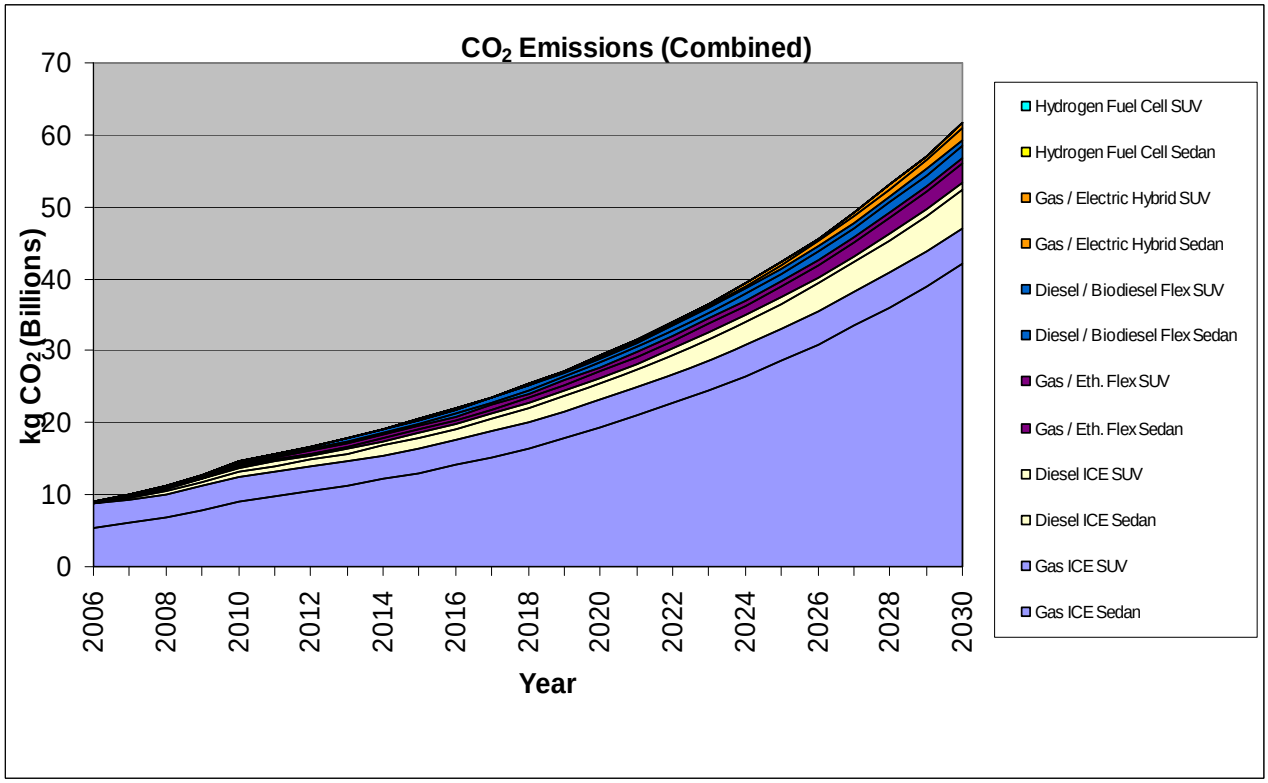

Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

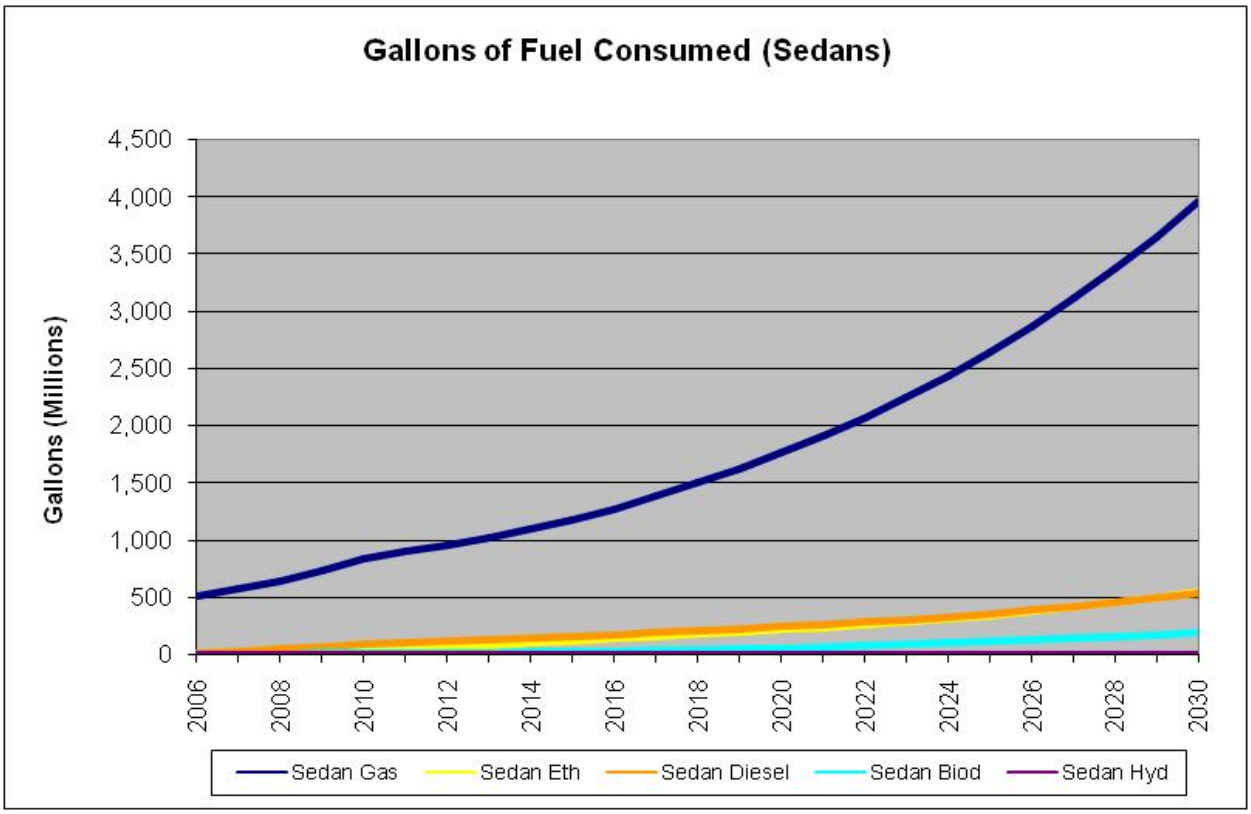

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
18
16
14
12
10
8
6
4
2
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

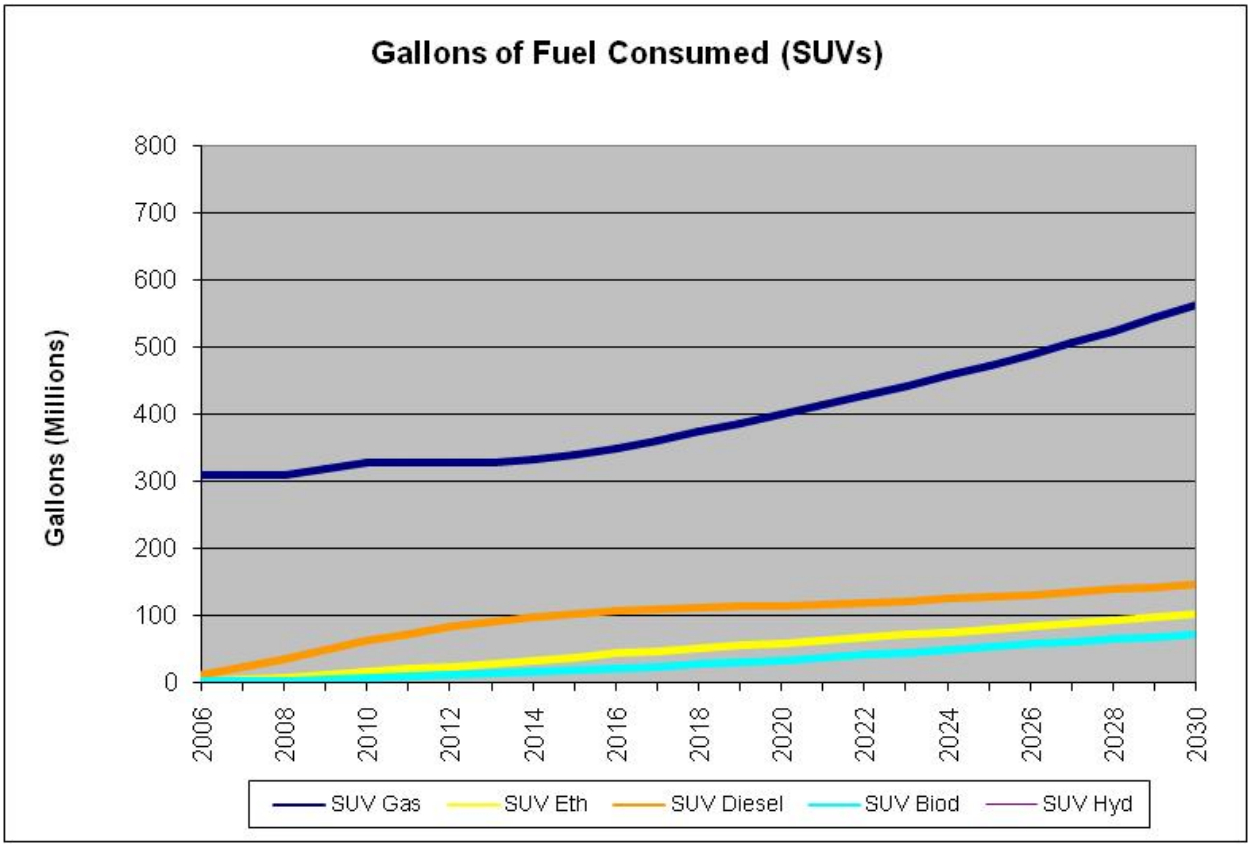

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
3
2
2
1
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
0
1
2
3
4
5
6
7
8
9
10
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Combined)
kg CO2 (Billions)
0
10
20
30
40
50
60
70
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


Gallons of Fuel Consumed (Sedans)
Gallons (Millions)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd


Gallons of Fuel Consumed (SUVs)
Gallons (Millions)
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
SUV Gas
SUV Eth
SUV Diesel
SUV Biod
SUV Hyd

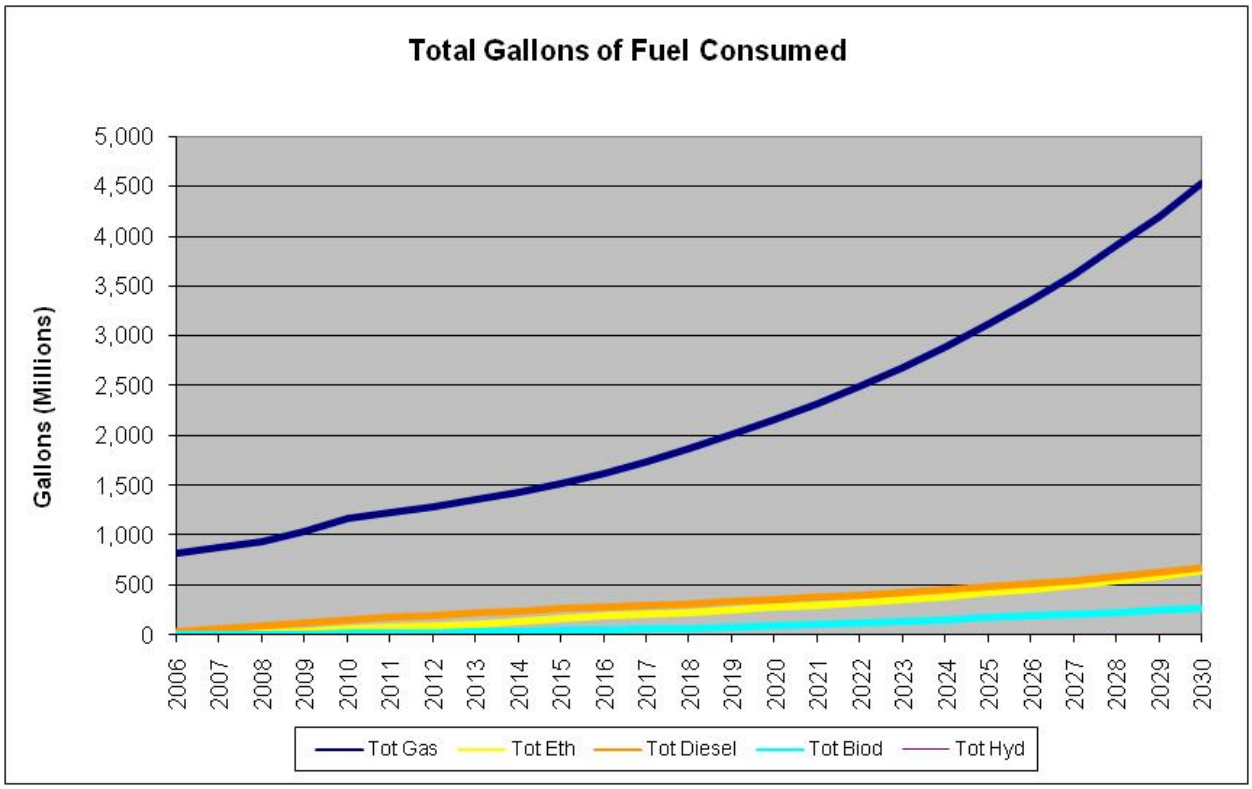


Figure 111: Chinese Alternative Scenario, Vehicle Technology Improvement Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	1.225	7.83
% Reduction	1.95%	1.07%

As seen in the graphs and table above, the relatively modest increase in made/model availability of hybrid electric vehicles as witnessed in this scenario, does not have a substantial impact on reducing emissions over time. In fact, by the 25th year, there is only a 2% decrease in carbon emissions, accounting for an aggregate reduction of only 1%. The reason for the limited emissions reductions results of this scenario is simply due to the fact that HEVs do not become the dominating vehicle type. Indeed, conventional gasoline vehicles remain the market leader in terms of number of vehicle stock.

On the other hand, while a 1-2% decrease in carbon emissions may seem low, if this decrease is taken in combination with a wider portfolio of policy options aimed at reducing carbon emissions, then it may prove to be highly effective. In other words, if the HEV approach is just one of ten, for example, similar approaches, then the aggregate reduction in carbon emissions could be on the order of 10-20%.

4.5.4. Development of Alternative Fuels

The United States has issued a series of policies to develop alternative fuel vehicles, such as the Clean Air Amendment Act, Energy Policy Act, Strategy Plan of GNGVs, and the Ethanol Development Plan. In order to promote alternative fuels, the U.S. has provided various incentives to encourage R&D and market incentives. The government has invested funds to research automotive technology fueled with soy-based diesel, which has promoted the

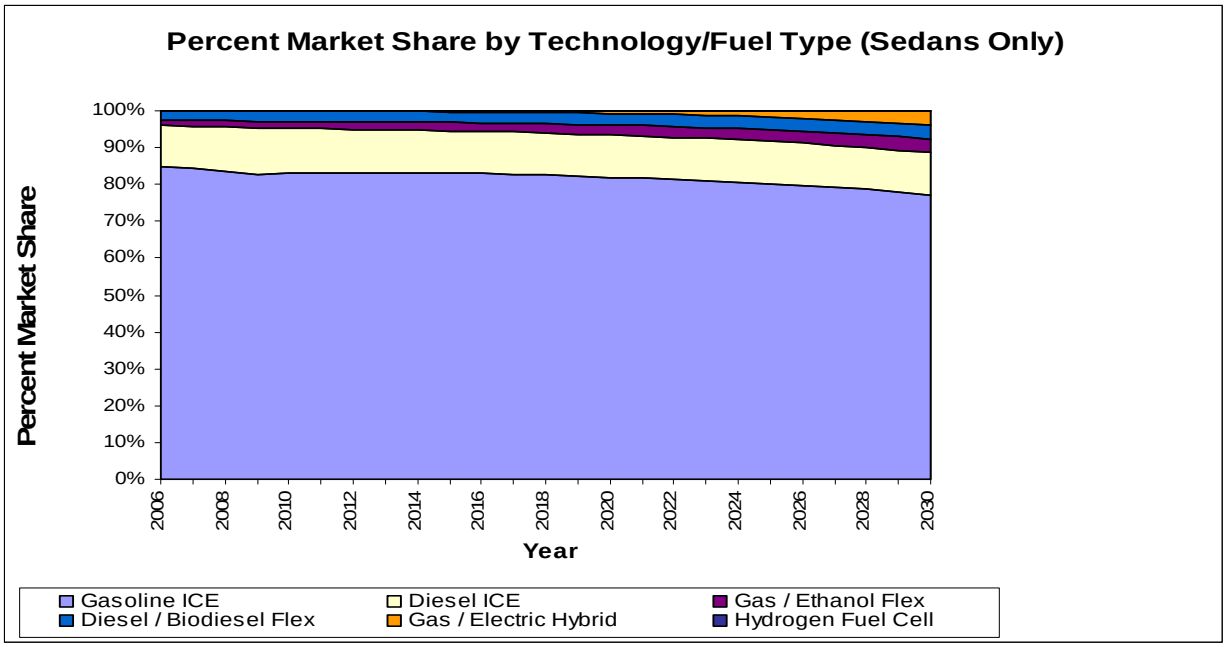
application of biodiesel in the transportation sector. Elsewhere, Brazil has promoted application of ethanol fuel since 1975, and E22 and E95 have been widely used in the whole country. As of 2006, the consumption of ethanol fuel accounts for 40% of the personal automotive fuel in Brazil (CCICED, 2006). In addition, the United States, Europe and Japan all have strict automobile emission regulations, which indirectly promote advanced technologies and clean fuels. Financial incentives for consumers are a very effective approach to promote alternative fuel development. But as the Chinese Renewable Energy Law regulate that same market prices for conventional fuels and biofuels and we will have incentives in a later scenario, here in this scenario we will only focus on development of alternative fuels from the supply side.

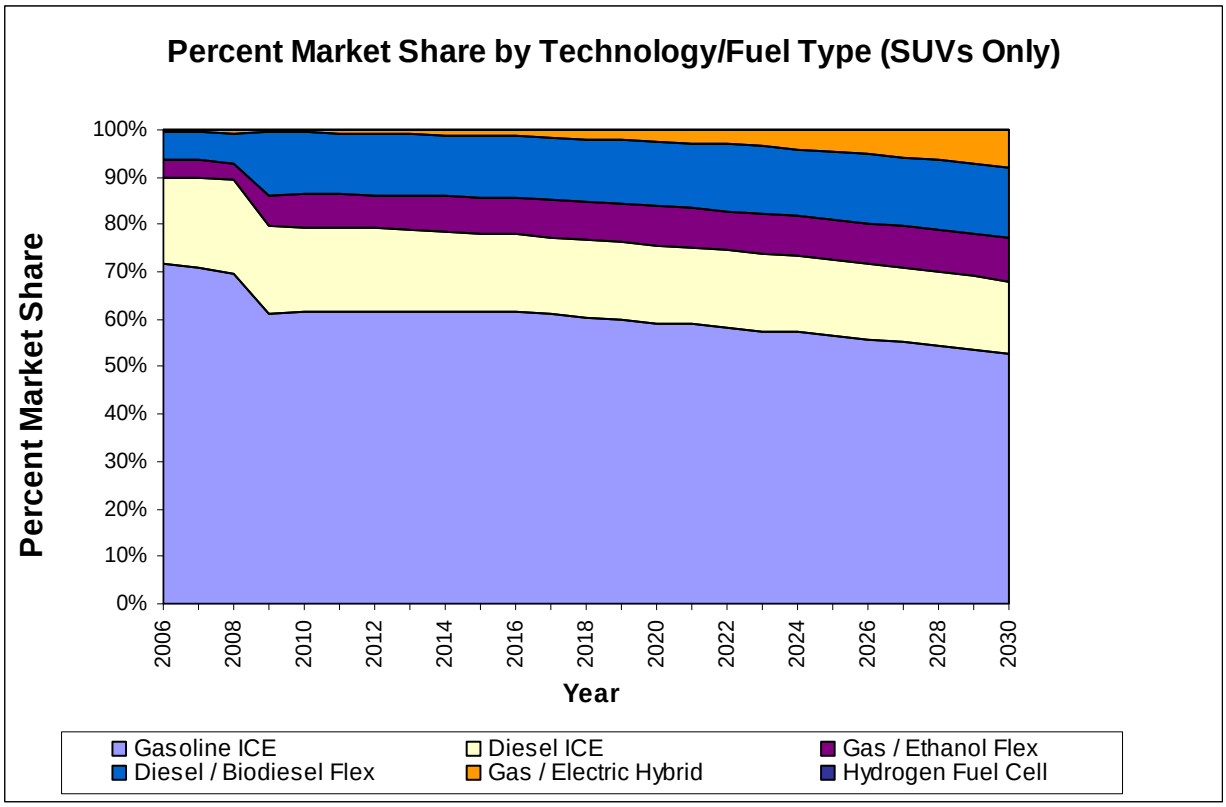
Currently, gasoline and diesel are two dominating transportation fuels in China. CNG and LPG have been used for buses and taxies in some cities. In provinces such as Jilin and Henan, 10% ethanol has been added to regular gasoline for powering vehicles (Wu, 2005). With development of science and technology, transportation fuel would be more and more diverse and environmental friendly.

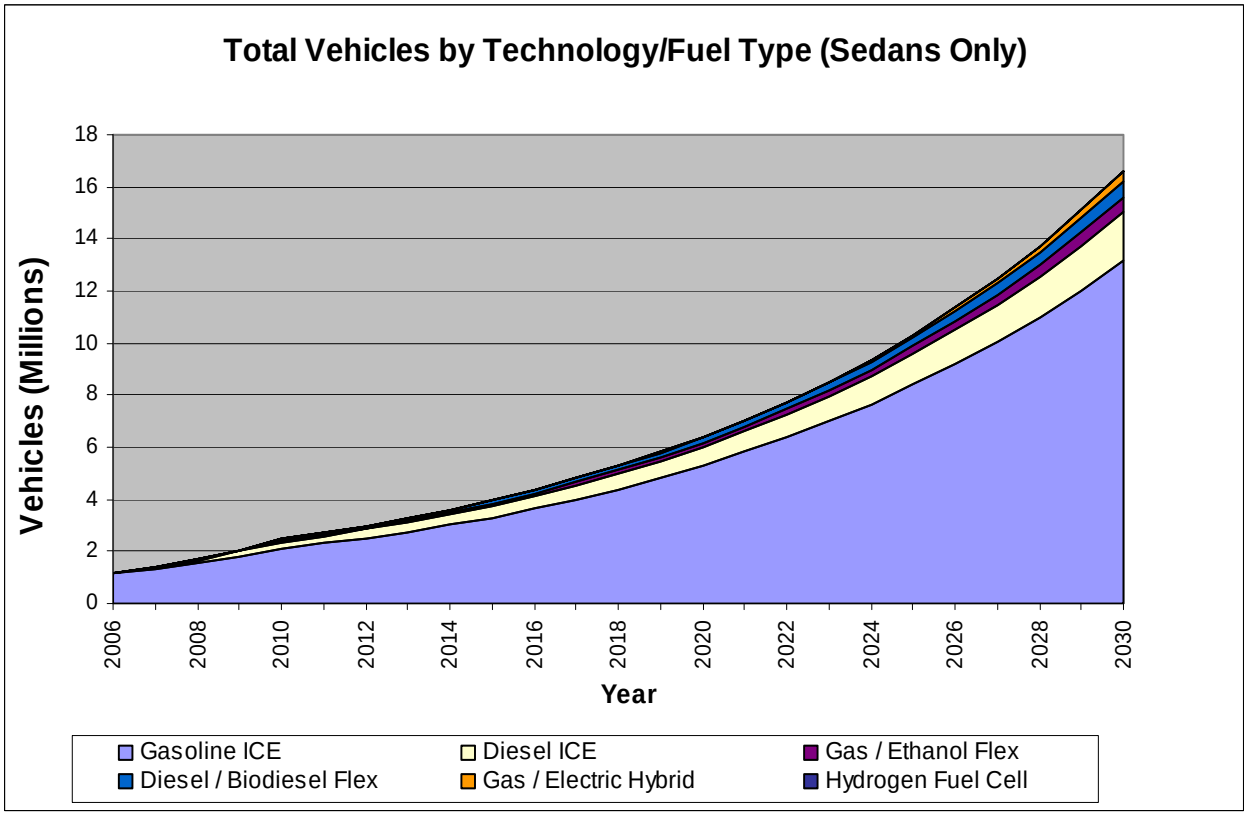
Policy strategies to promote alternative fuels include research and development, and establishment of relevant product standards and more strict emission standards. In the near term, production technology and energy efficiency technology of clean alternative fuels should be the central focus of policies; the technologies which can reduce carbon emissions might be the target in the long term. On the other hand, even if pollution control levels of Chinese vehicles will reach the level of EU IV standards around 2010 from the latest requirement of State Environmental Protection Administration, it will still be 5~8 years behind that of developed countries (CCICED, 2006). It is likely not possible that China will catch up to the standards imposed in developed countries until 2015 or later. This is due to the fact that although the government encourages alternative fuel development, infrastructure construction on fueling stations is lacking and many cities do not have a clear vision of future development Therefore if long term and sustainable alternative fuel development is desired, there should be effective policies to address infrastructure construction.

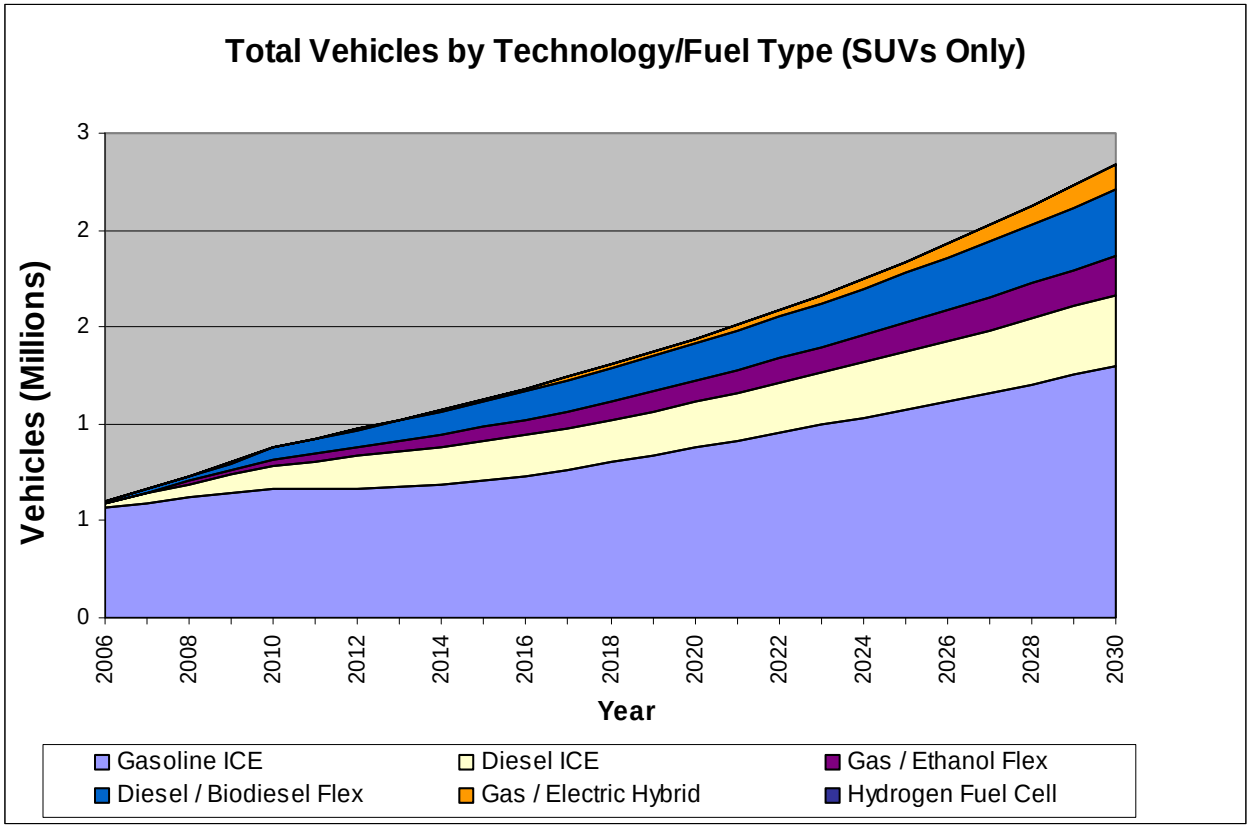
In CarCarbon, these policy strategies could be interpreted as an increase of fuel mixing and fuel availability. We assume fuel mixing is equivalent to the baseline scenario of the United States, and fuel availability for biodiesel and ethanol increase by 10% over the US baseline.

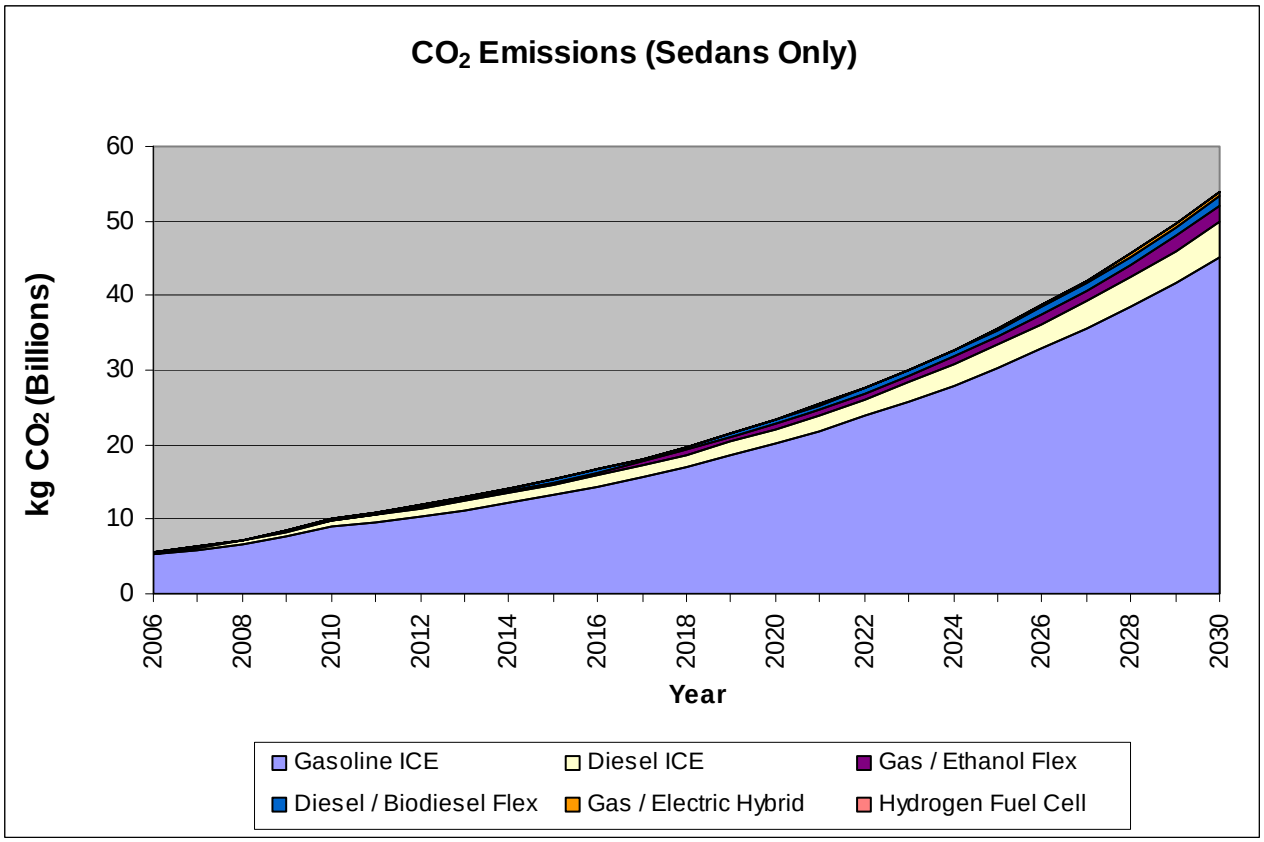
Figure 112(a-j): Chinese Alternative Scenario, Alternative Fuels Development

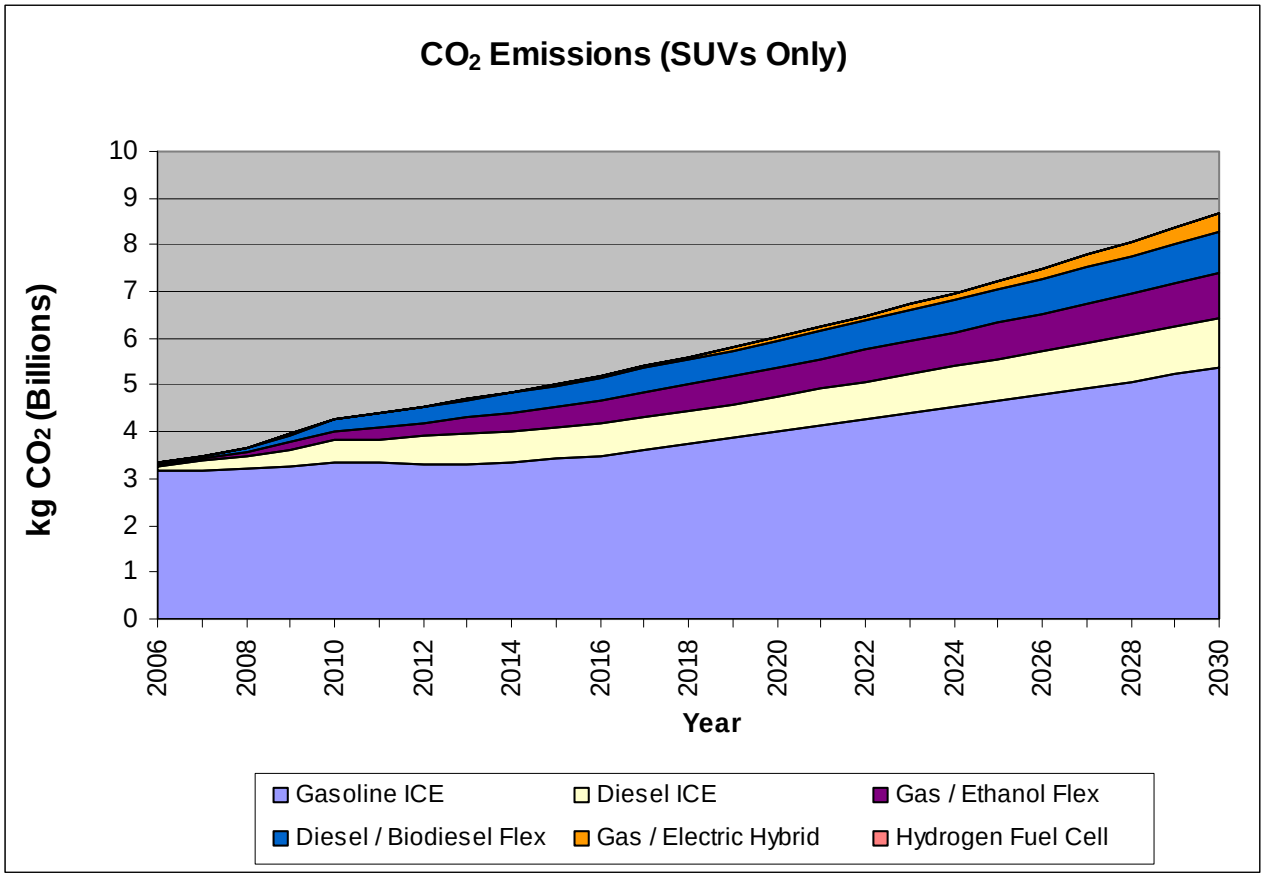


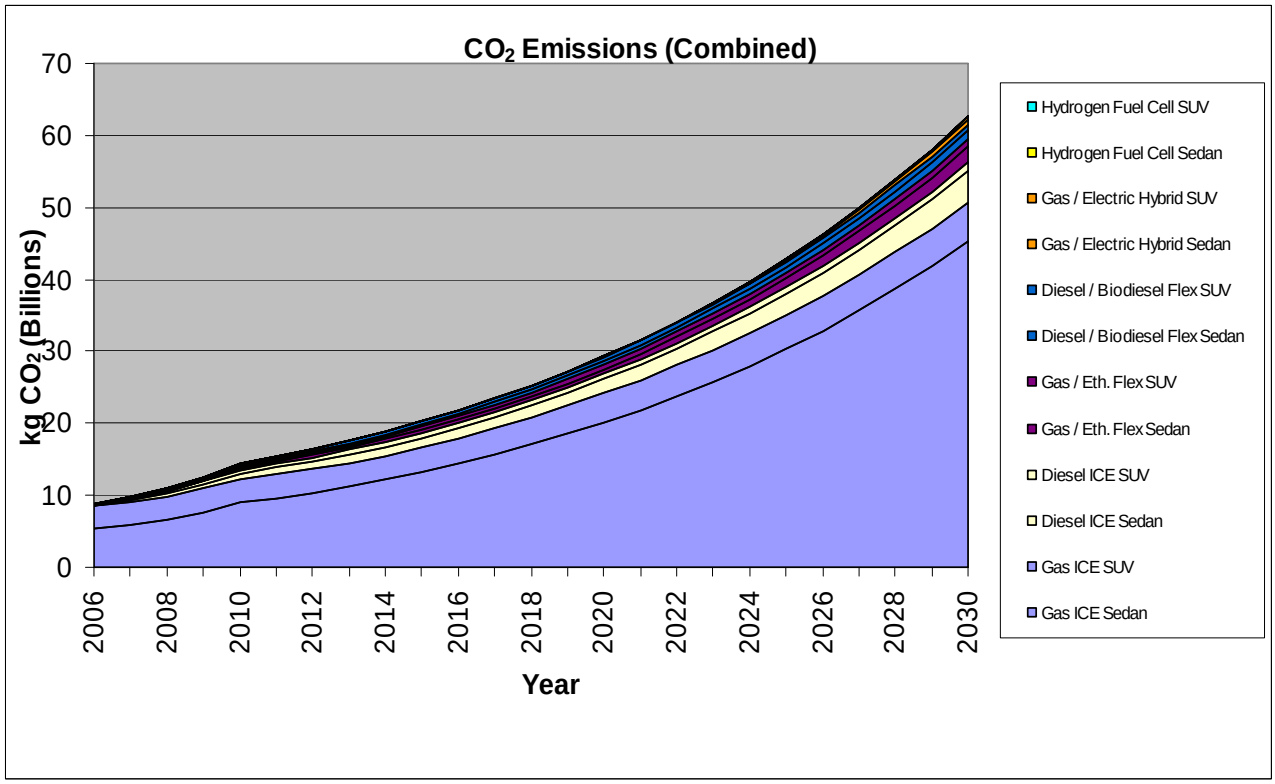

Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

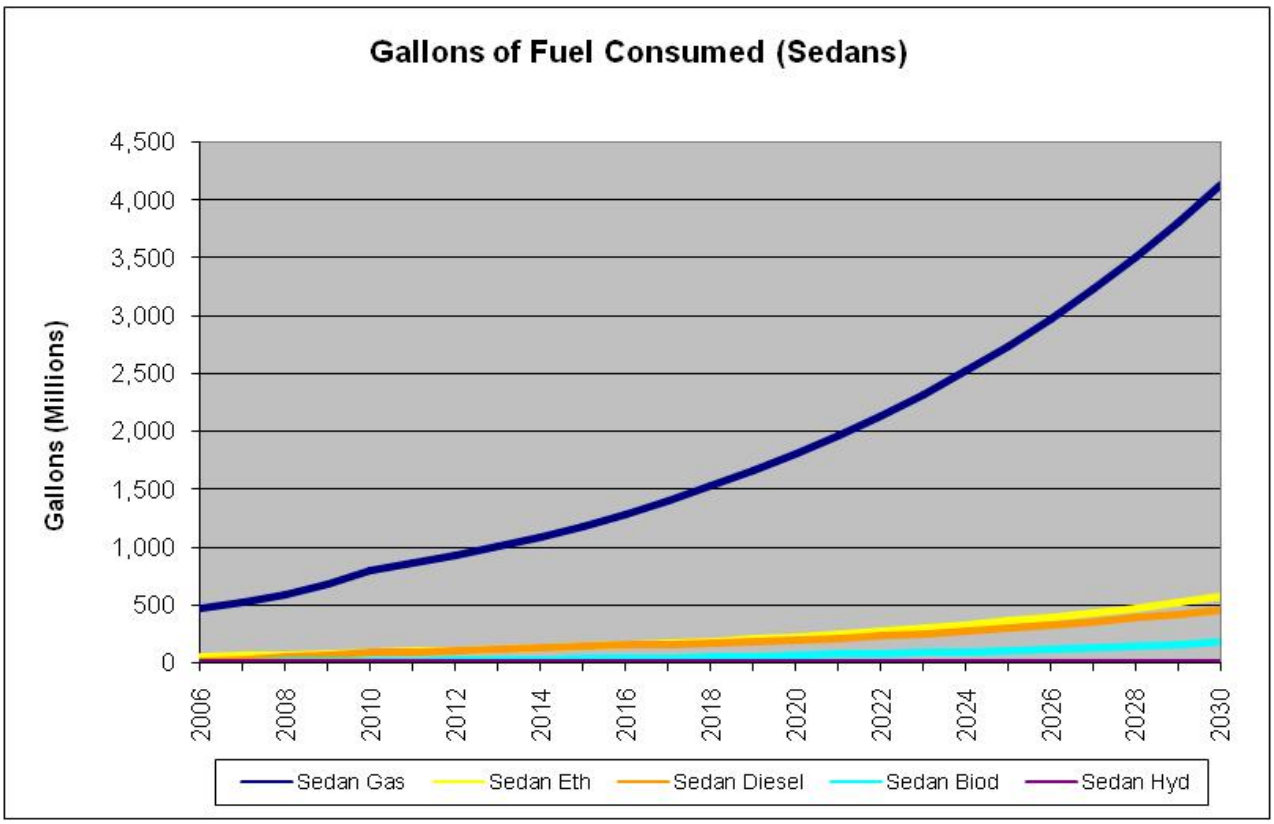

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
18
16
14
12
10
8
6
4
2
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

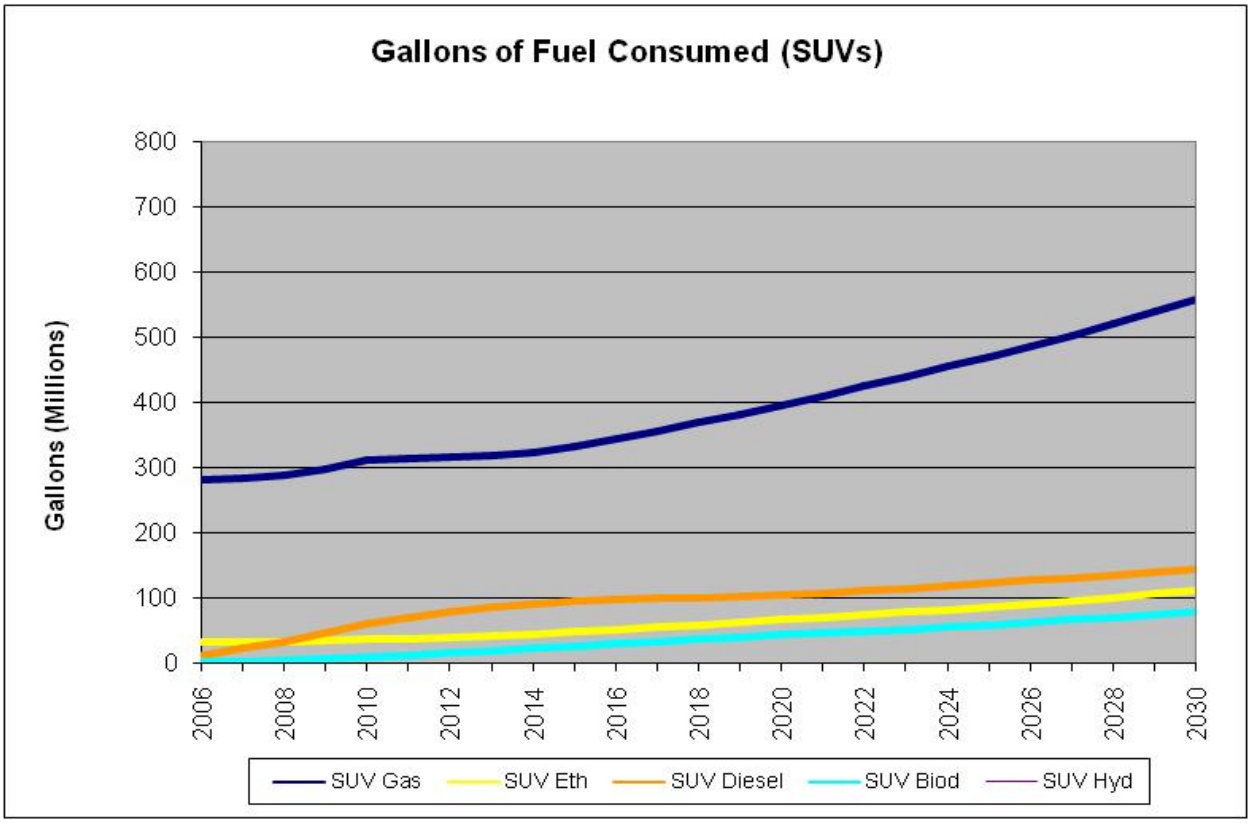

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
3
2
2
1
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
0
1
2
3
4
5
6
7
8
9
10
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Combined)
kg CO2 (Billions)
0
10
20
30
40
50
60
70
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


Gallons of Fuel Consumed (Sedans)
Gallons (Millions)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd


Gallons of Fuel Consumed (SUVs)
Gallons (Millions)
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
SUV Gas
SUV Eth
SUV Diesel
SUV Biod
SUV Hyd

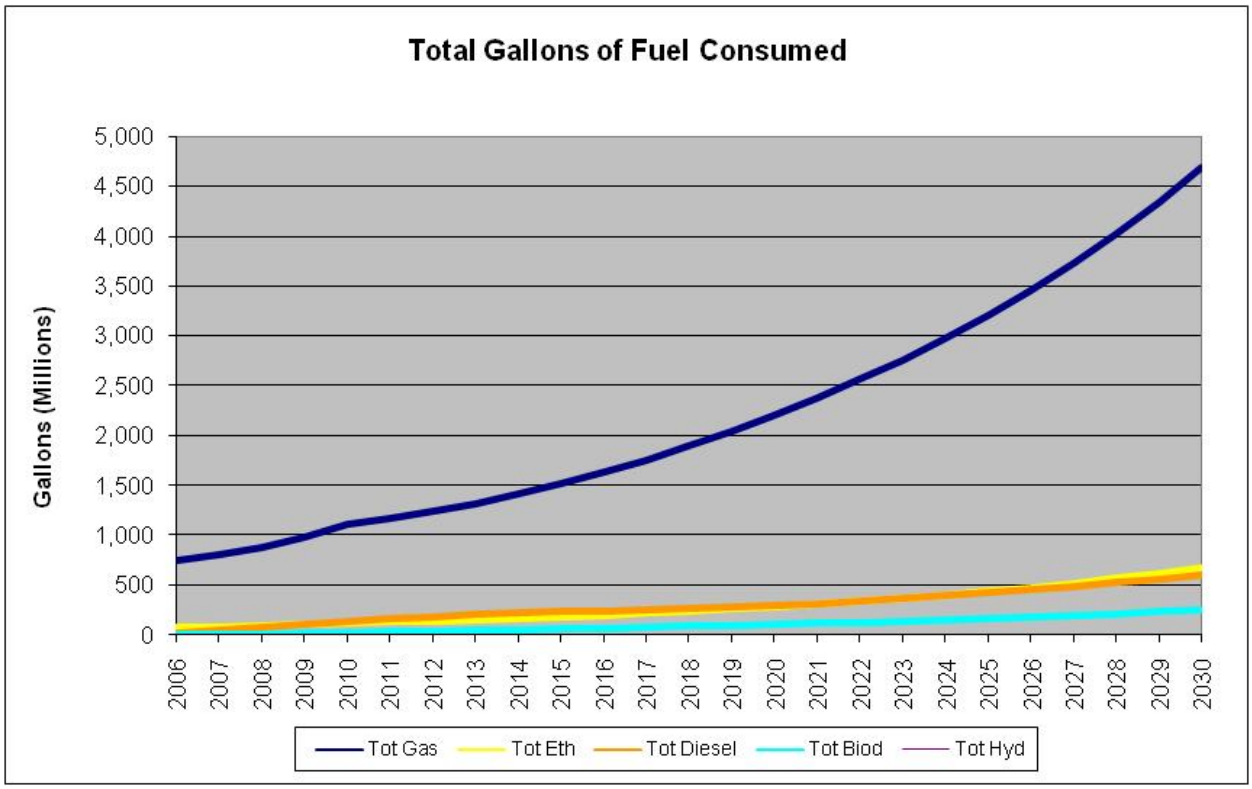


Figure 113: Chinese Alternative Scenario, Alternative Fuels Development Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	0.15	4.84
% Reduction	0.24%	0.66%

As seen in the graphs and table above, the abovementioned changes in fuel mixing and fuel availability have minimal changes on carbon dioxide emissions. Indeed, by the 25th year of the simulation, there is only a 0.24% reduction in annual carbon dioxide emissions, accounting for only a 0.66% aggregate reduction. The reason for the limited impact of this scenario is that although there is a 10% increase in the availability if ethanol and biodiesel, these fuel still have a very limited availability compared to that of gasoline. Whereas gasoline's availably is 1.0 and 0.8 at year 1 and 25 respectively, the relative availability of ethanol and biodiesel is 0.1 and 0.6 for the same years.

As with the *Vehicle Technology Improvement* scenario, the policies proposed in this scenario would still be effective if they were incorporated into a wider portfolio of policy options. In such a situation, these small incremental gains may sum to yield a larger, more effective gain.

4.5.5. Fuel Taxation

Price of fuels is one crucial factor in a consumer's decision whether to choose an energy efficient model. Thus fuel taxation is one important policy for leveraging fuel consumption. Various countries have adopted fuel taxation for incentives of energy savings. As an important influencing factor, fuel taxation has clear impact on adjustment of energy conservation and VMT. For example, gasoline taxation in the U.S. is 0.1 US$ per liter, for diesel is 0.12 US$ per

liter. While in European countries, fuel taxation is usually more than 0.3 US$ per liter, with the highest taxation in U.K. for gasoline the tax rate is 0.73 US$ per liter, for diesel the tax rate is 0.77 US$ per liter (Wu, 2005). Fuel price in European countries and Japan is 2~3 time that in U.S. due to the high fuel tax, which stimulate the consumers to buy the vehicles with high fuel economy and reduce their driving mileage.

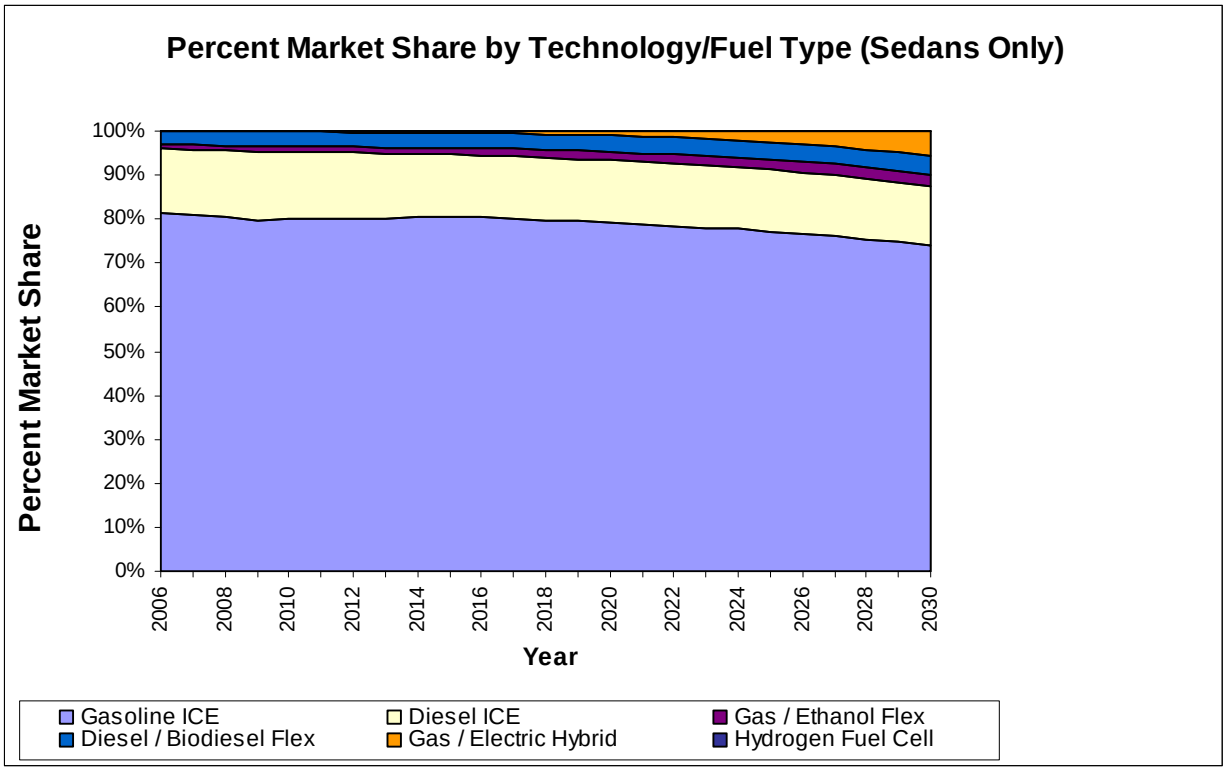
It is worth noting that China's private vehicle ownership rates are far less than most developed countries, but on the other side, large amounts of government/company vehicles are major contributors in the vehicle pool. Government/company vehicles are not as sensitive to fuel prices (thus fuel taxation) as private vehicles (there is no comprehensive study on this yet). This special situation needs to be take into full consideration when formulating fuel taxation polices.

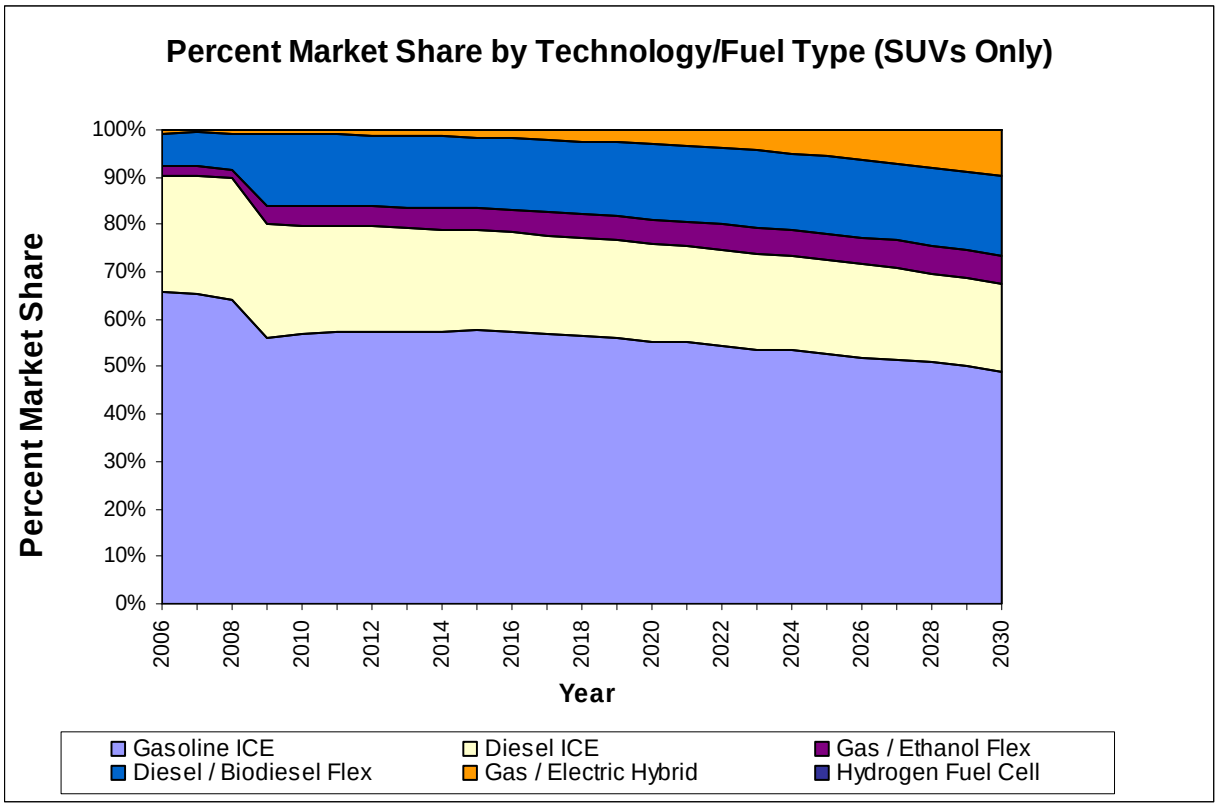
Fuel taxation has been discussed for years in China but is virtually nonexistent at present. China uses road fees to collect capital for infrastructure construction. As road fees are fixed numbers and are not related to the use of vehicle, they does not have impact on transport energy use and related emissions.

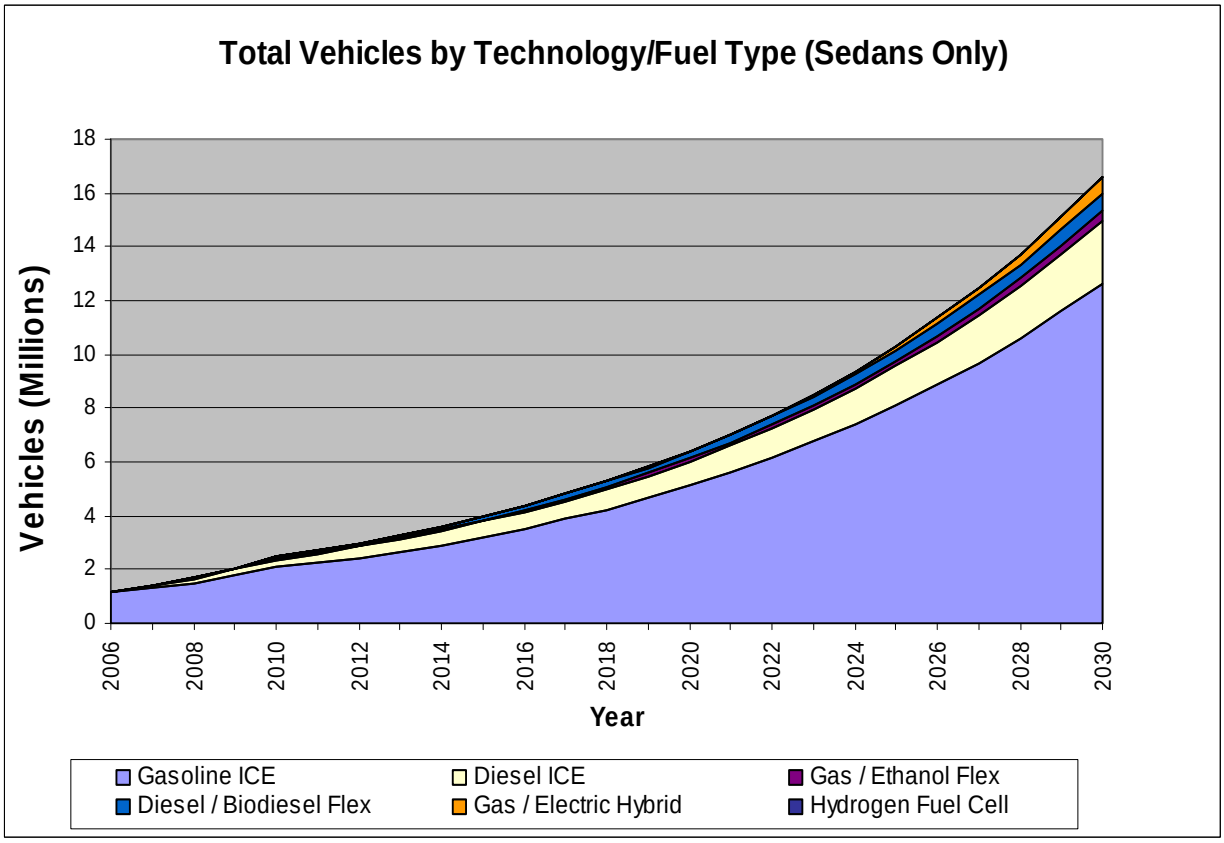
It is claimed that during the 11th five-year plan period (2006-2010), taxation would be imposed on fuels. The level of fuel taxes imposed should be enough to abate vehicle emissions and serve as revenue for transport infrastructure and maintenance purposes (Carruthers, 2002). Fuel prices should include taxes to reflect the perceived externalities and risks of foreign oil imports, and fees to reflect the environmental damage related to fuel quality (WRI, 2005). The latter was the goal of fuel taxation reform in Sweden in the late 1980s and early 1990s, as taxes rose on more polluting fuels but fell on cleaner fuels (IEA, 2000).

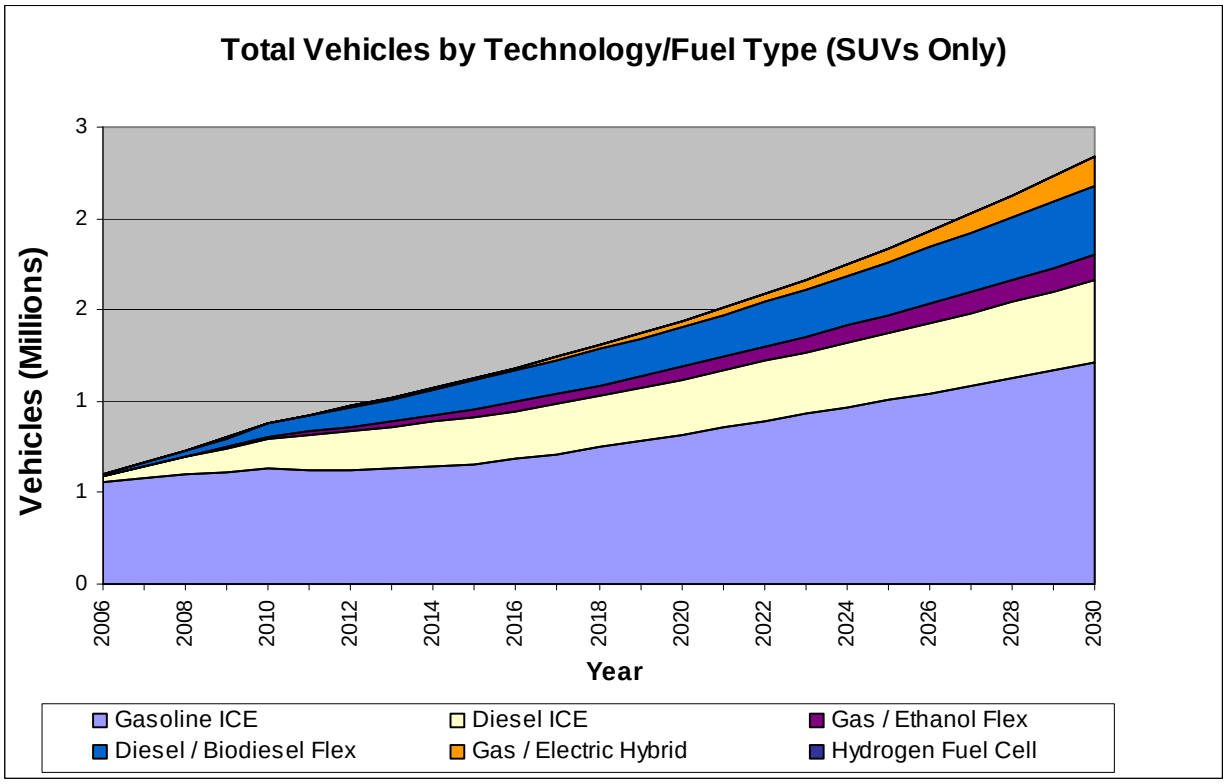
In this scenario, we assume that a Japanese equivalent level tax rate (approximately $0.70 per liter, about $2.66 per gallon) is added to conventional gasoline and diesel on the Chinese market.

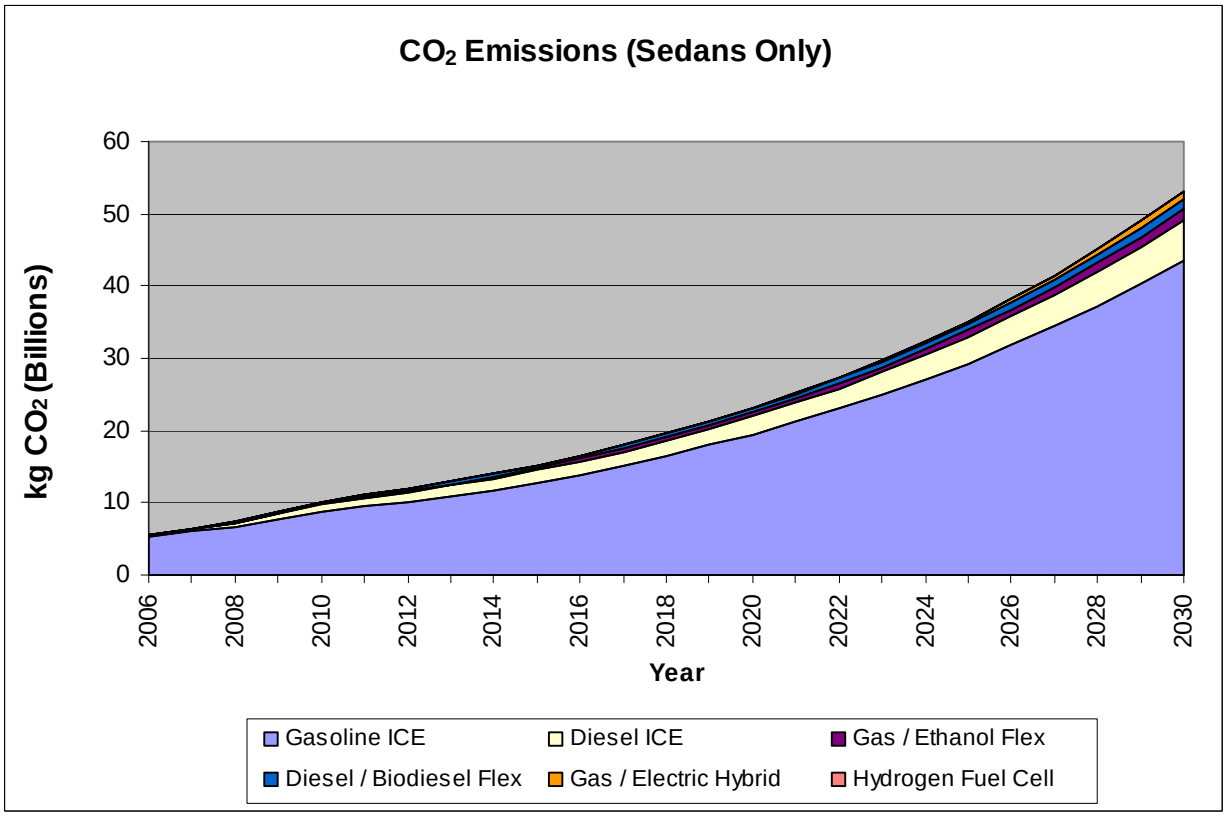
Figure 114(a-j): Chinese Alternative Scenario, Fuel Taxation

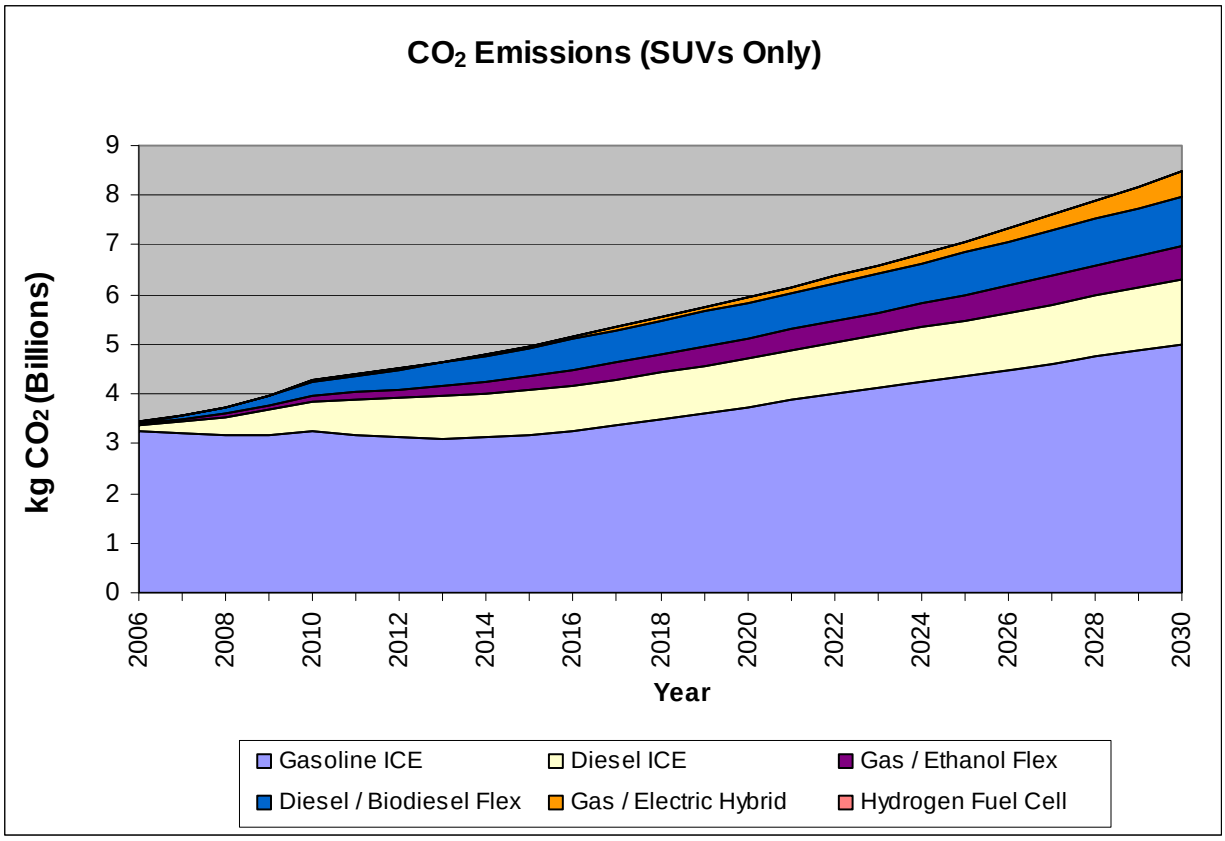


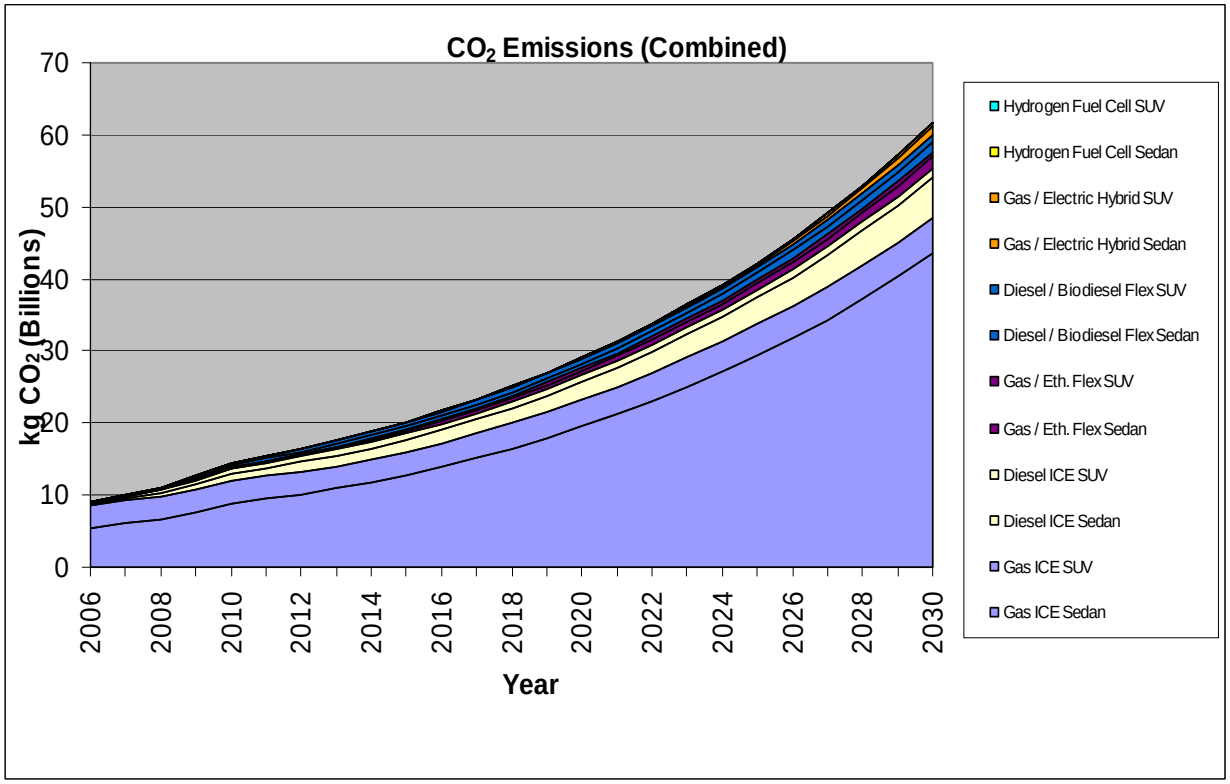

Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

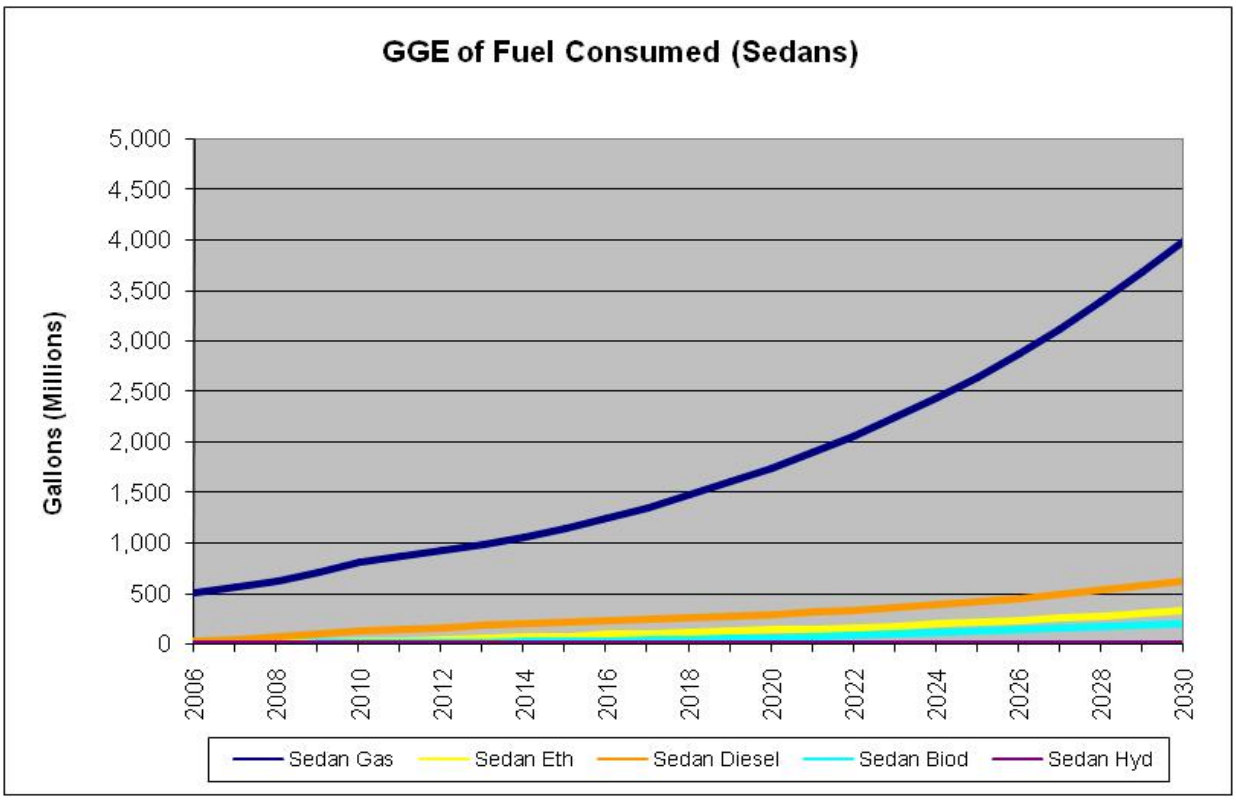

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
18
16
14
12
10
8
6
4
2
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

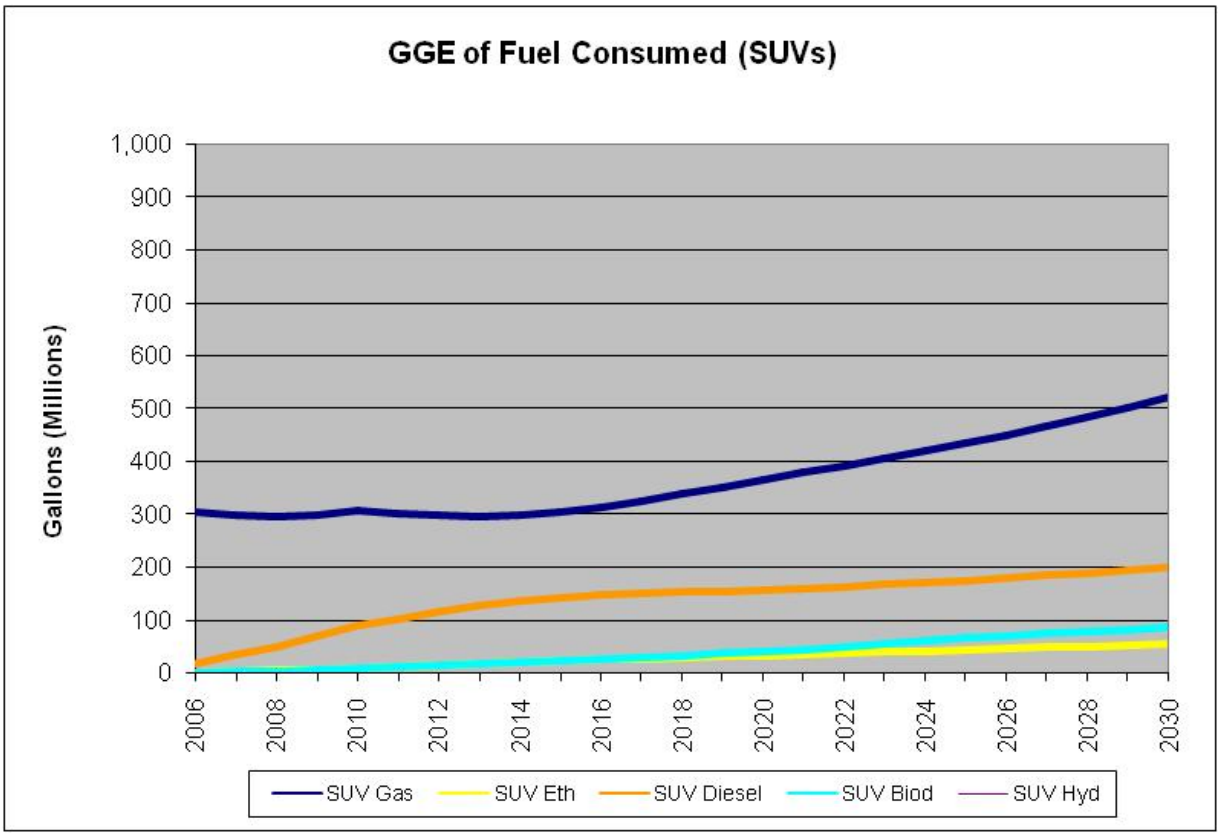

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
3
2
2
1
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
0
1
2
3
4
5
6
7
8
9
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Combined)
kg CO2 (Billions)
0
10
20
30
40
50
60
70
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


GGE of Fuel Consumed (Sedans)
Gallons (Millions)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd


GGE of Fuel Consumed (SUVs)
Gallons (Millions)
1,000
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
SUV Gas
SUV Eth
SUV Diesel
SUV Biod
SUV Hyd

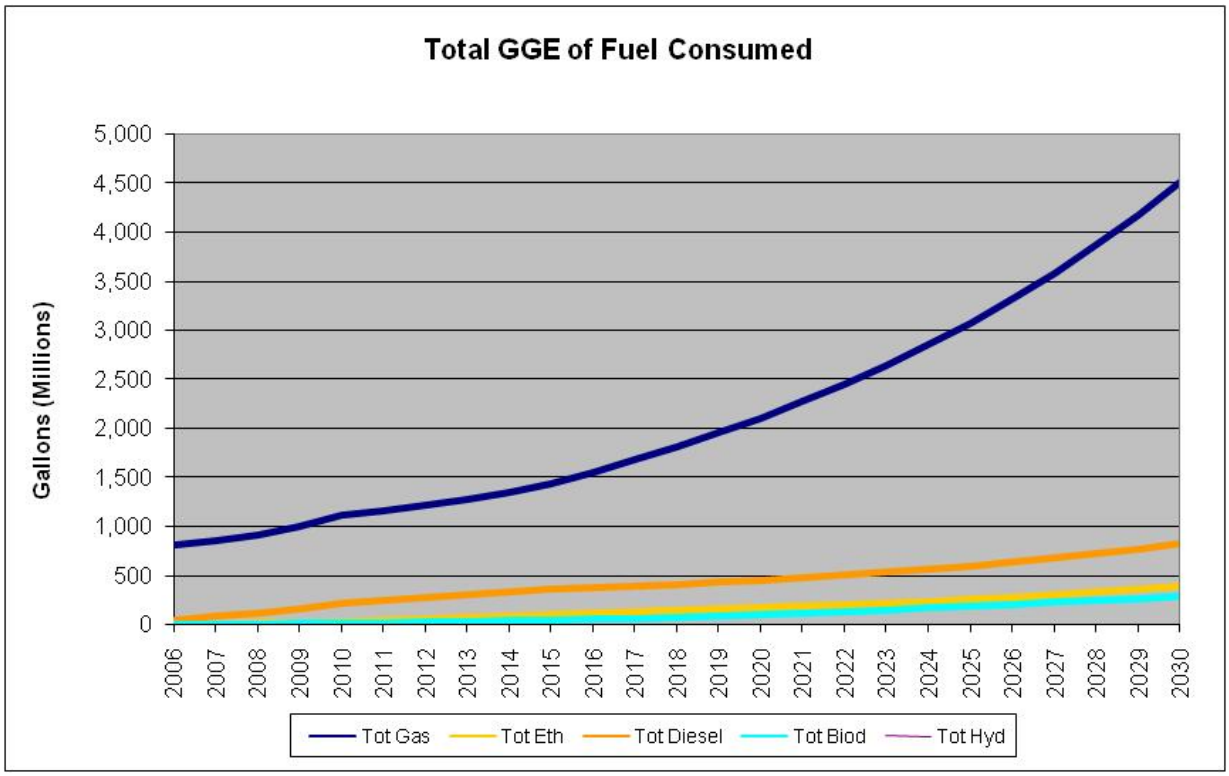


Figure 115: Chinese Alternative Scenario, Fuel Taxation Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	1.15	11.64
% Reduction	1.83%	1.59%

As seen in the graphs and table above, levying a $2.66 USD tax on gasoline and diesel fuels has the impact of reducing carbon dioxide emissions by 1.83% in the 25th year, accounting for an aggregate emissions reduction of 1.59% over the 25-year period. Gasoline vehicles remain the dominant vehicle type despite the increased fuel price.

It is worth noting that in comparison to the previously discussed gasoline hybrid-electric scenario this scenario has a lower percent reduction in carbon emissions during the 25th year, but a considerably higher emissions reduction over the sum of the 25 year period. Thus, this policy is more effective in the short-run and causes shifts (albeit minor) almost immediately.

Again, as previously mentioned, although a 1.6% aggregate reduction in carbon dioxide emissions may seem unsubstantial, in combination with a wider portfolio of policy options, this policy may be quite effective. Multiple policies which yield a 1-2% reduction can be “stacked” and yield a much greater net impact.

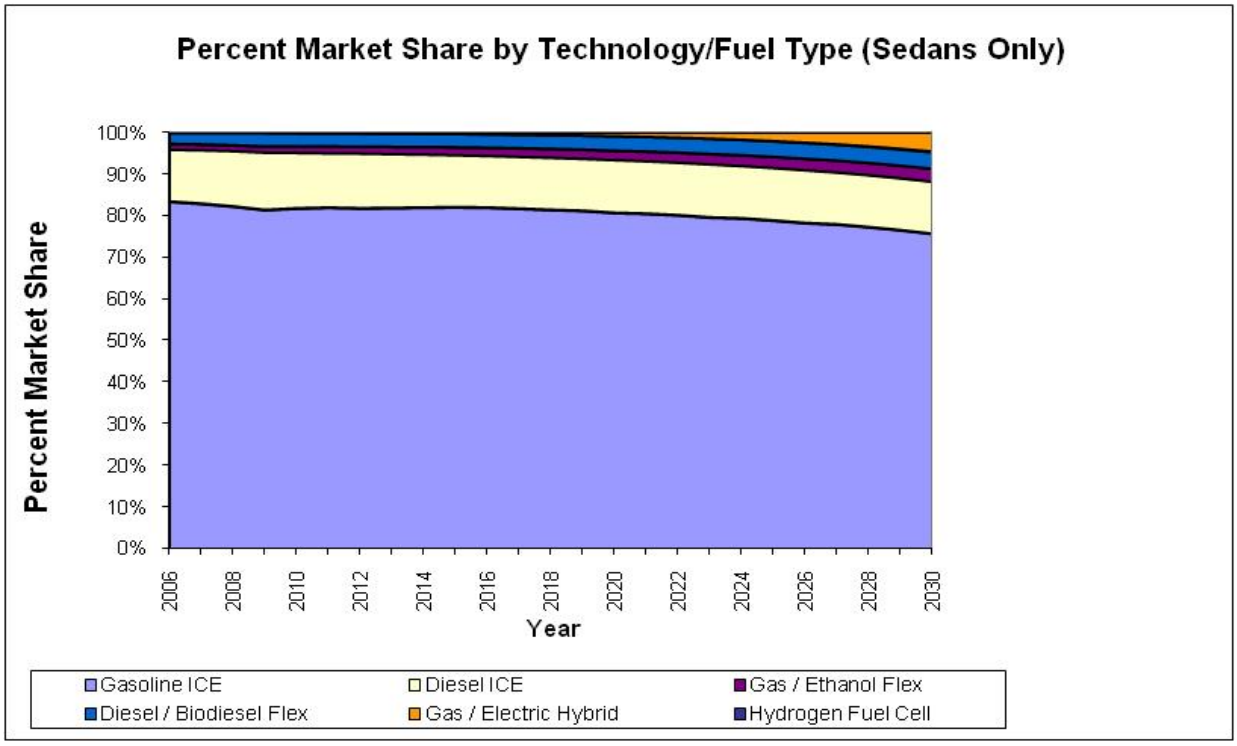
4.5.6. Carbon Taxation

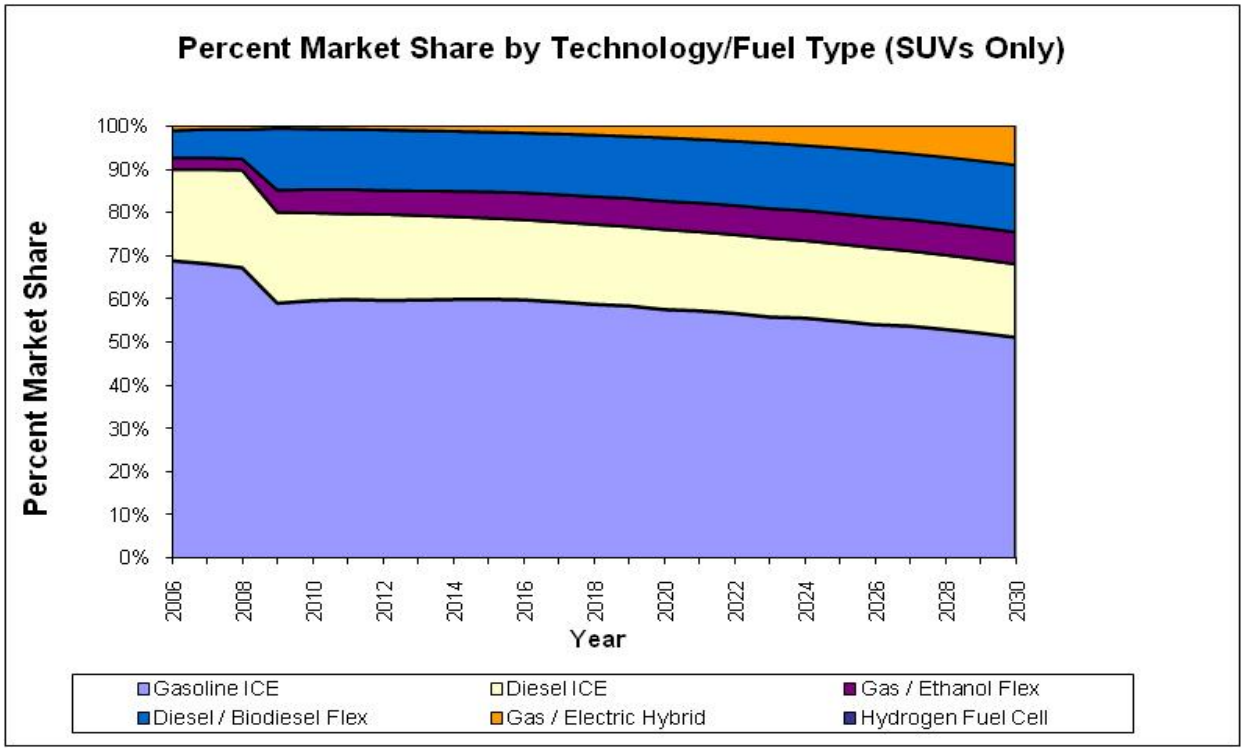
Beside direct taxation on fuels, some countries also impose carbon emission taxes and environment-based fuel taxes. Some European countries such as Sweden have either adopted or are in consideration of carbon emission taxation of fossil fuel consumption sectors such as transportation (Wu, 2005).

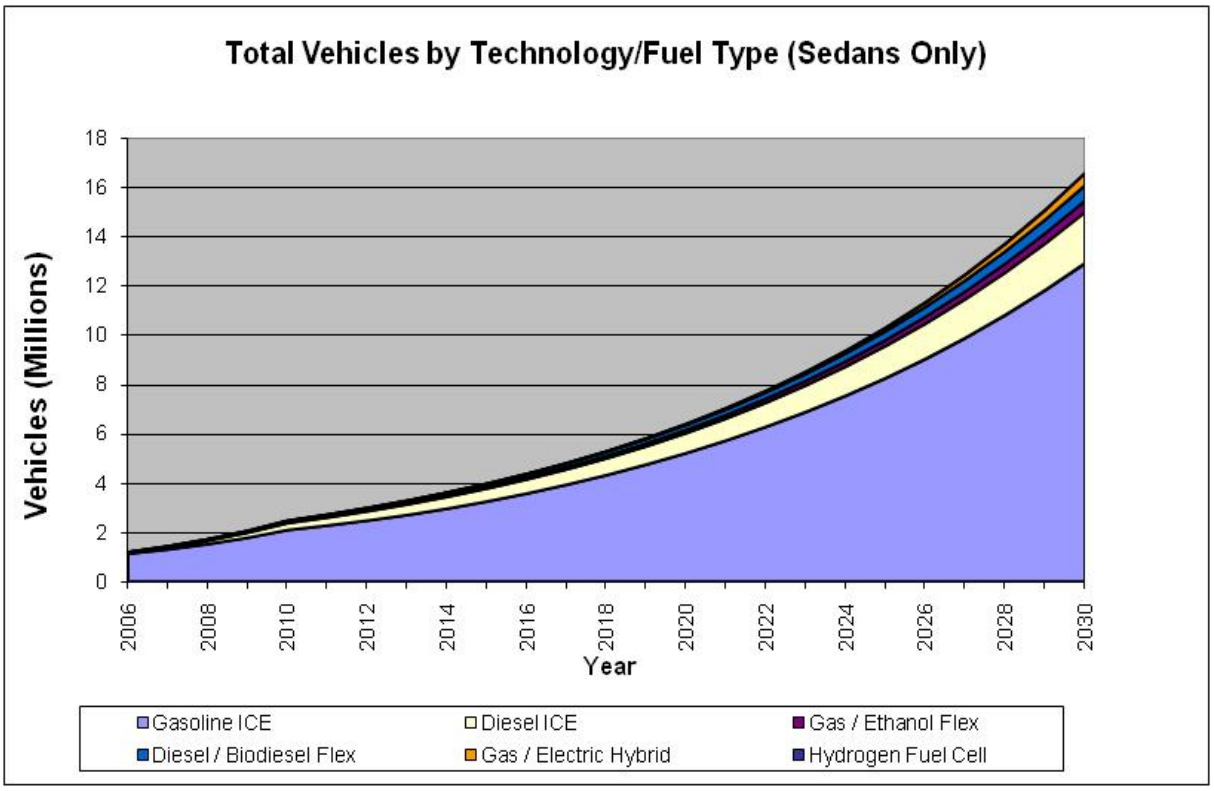
Compared to concerns over energy security, reduction of greenhouse gases is not the top priority in China. However, as the world’s second largest emitter and with ever-growing emissions, China is facing serious pressures both domestically and internationally. Soon the

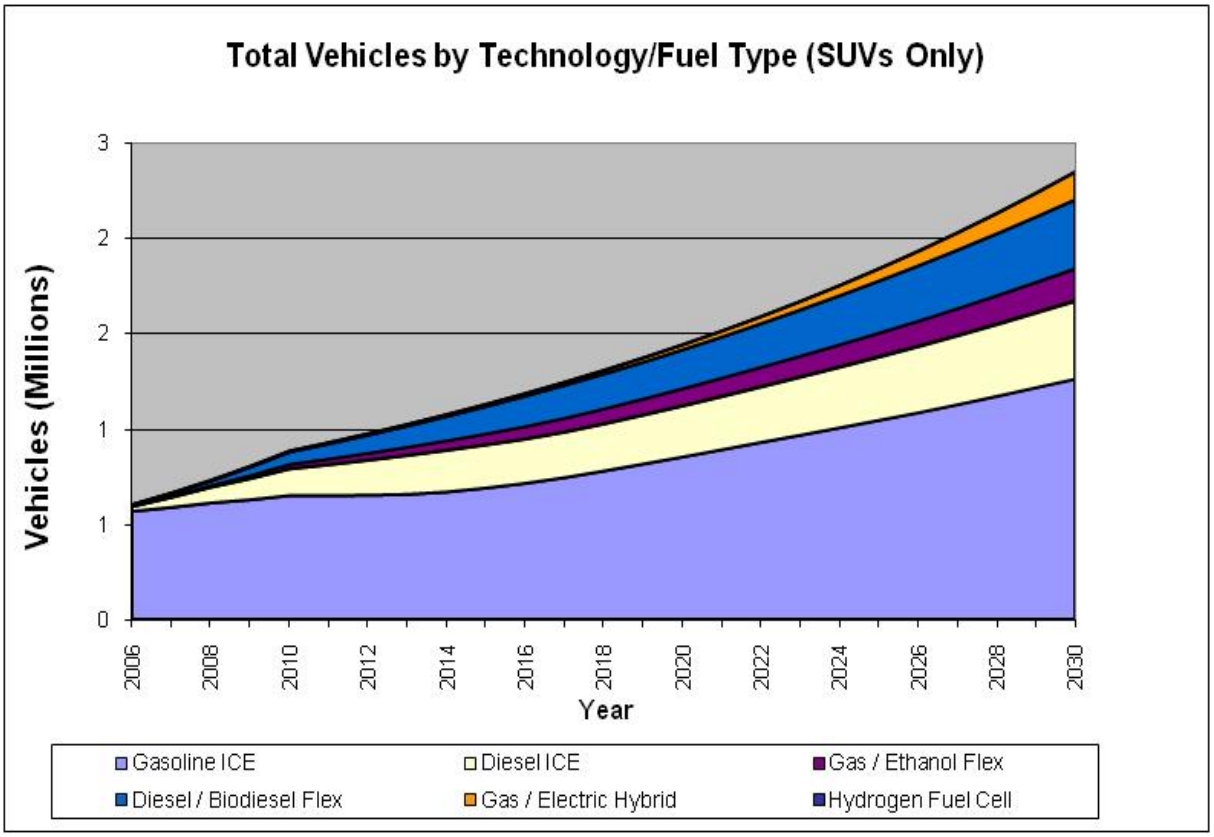
country has to confront the challenge of cut its emissions. In this policy scenario we will adopt a Japanese rate of $1.29/gallon as carbon tax (see detailed description in Section 3.5.5 – US policy scenarios)

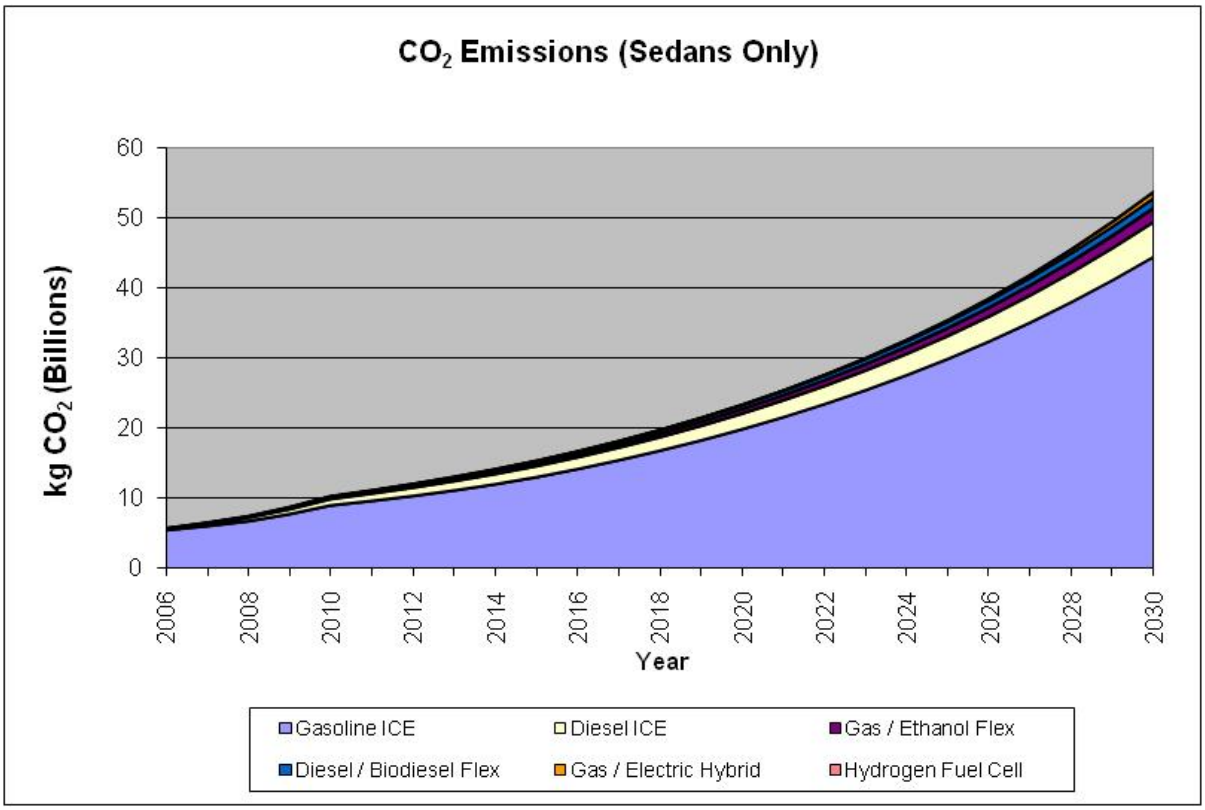
Figure 116(a-j): Chinese Alternative Scenario, Carbon Taxation

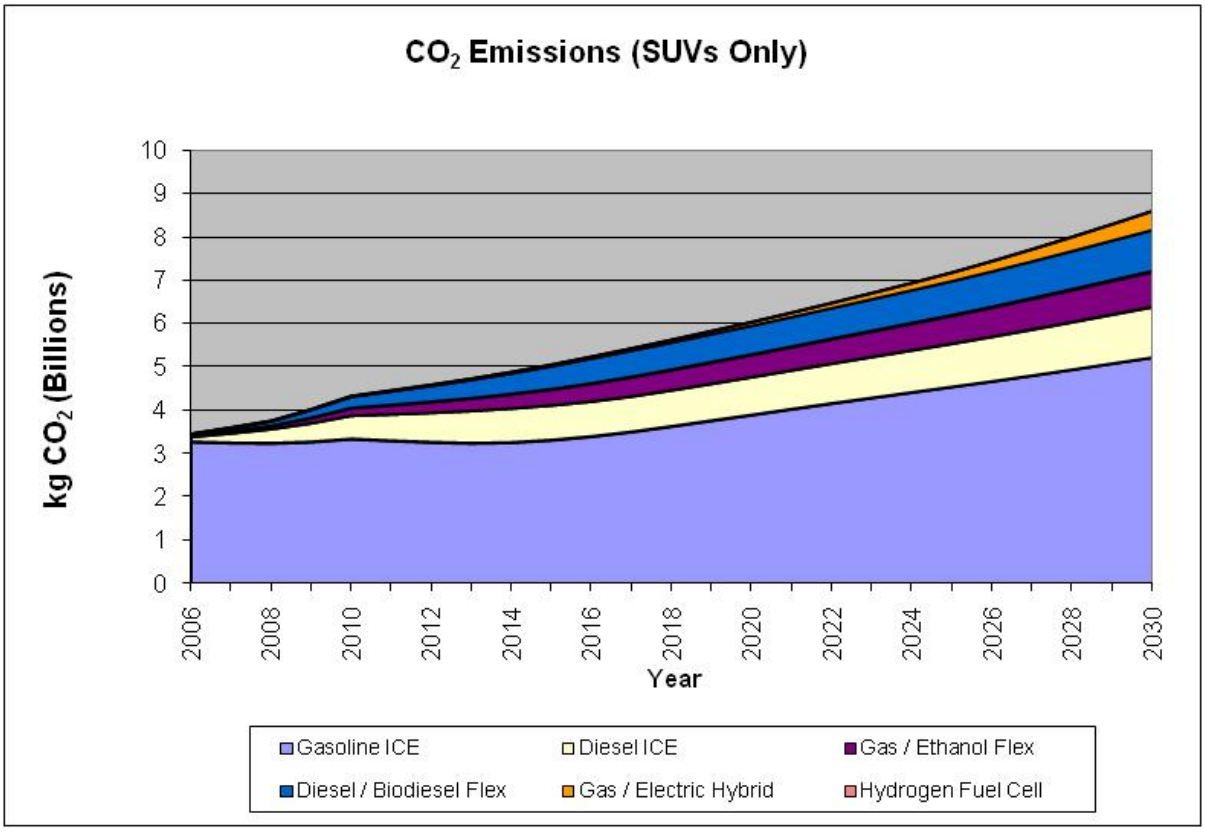


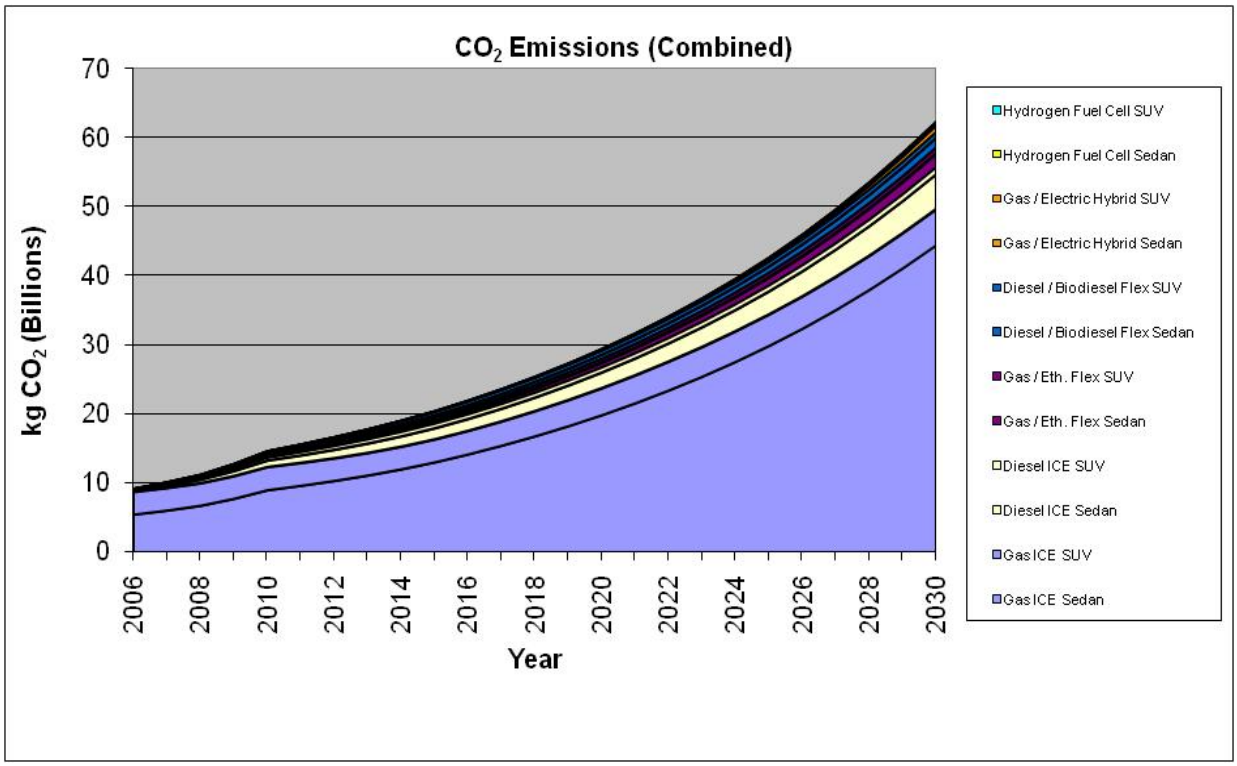


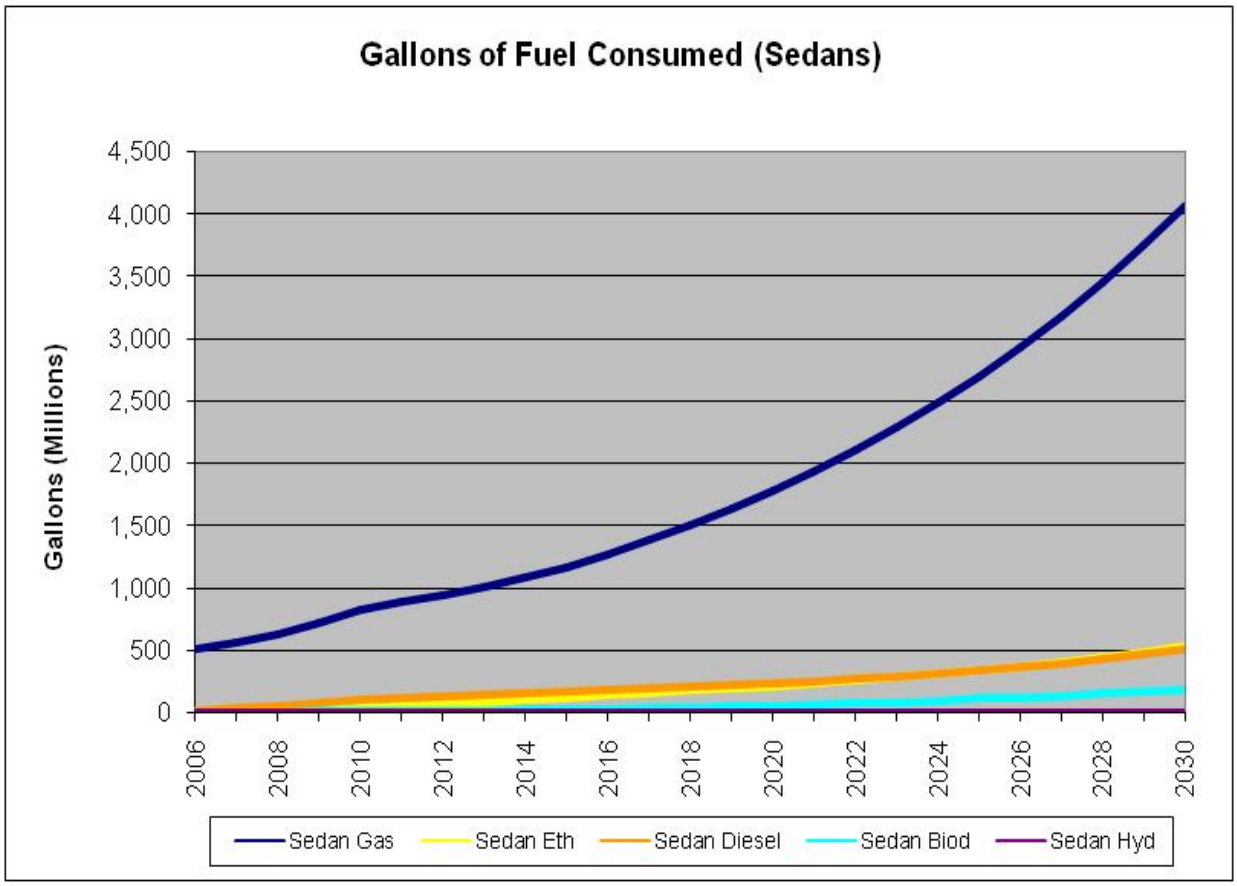

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
0
2
4
6
8
10
12
14
16
18
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

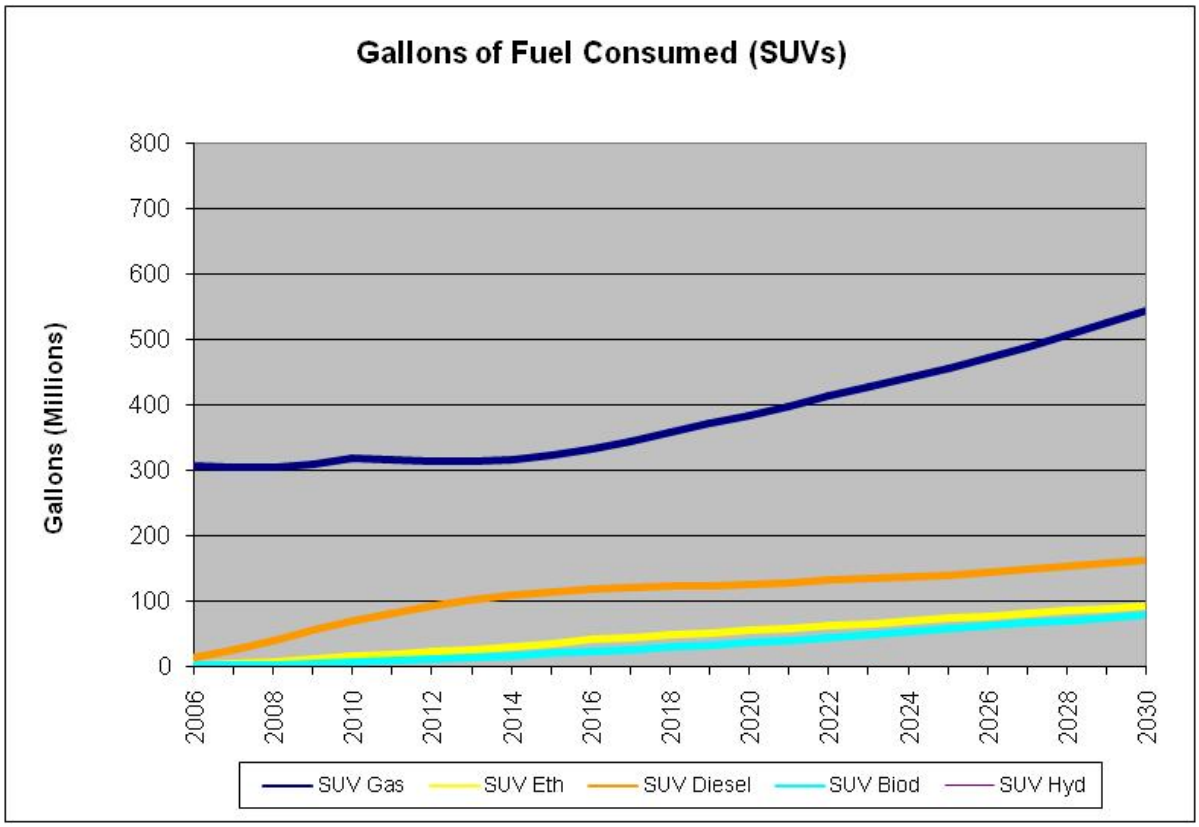

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
0
1
1
2
2
3
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
10
9
8
7
6
5
4
3
2
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Combined)
kg CO2 (Billions)
70
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


Gallons of Fuel Consumed (Sedans)
Gallons (Millions)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd


Gallons of Fuel Consumed (SUVs)
Gallons (Millions)
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
SUV Gas
SUV Eth
SUV Diesel
SUV Biod
SUV Hyd

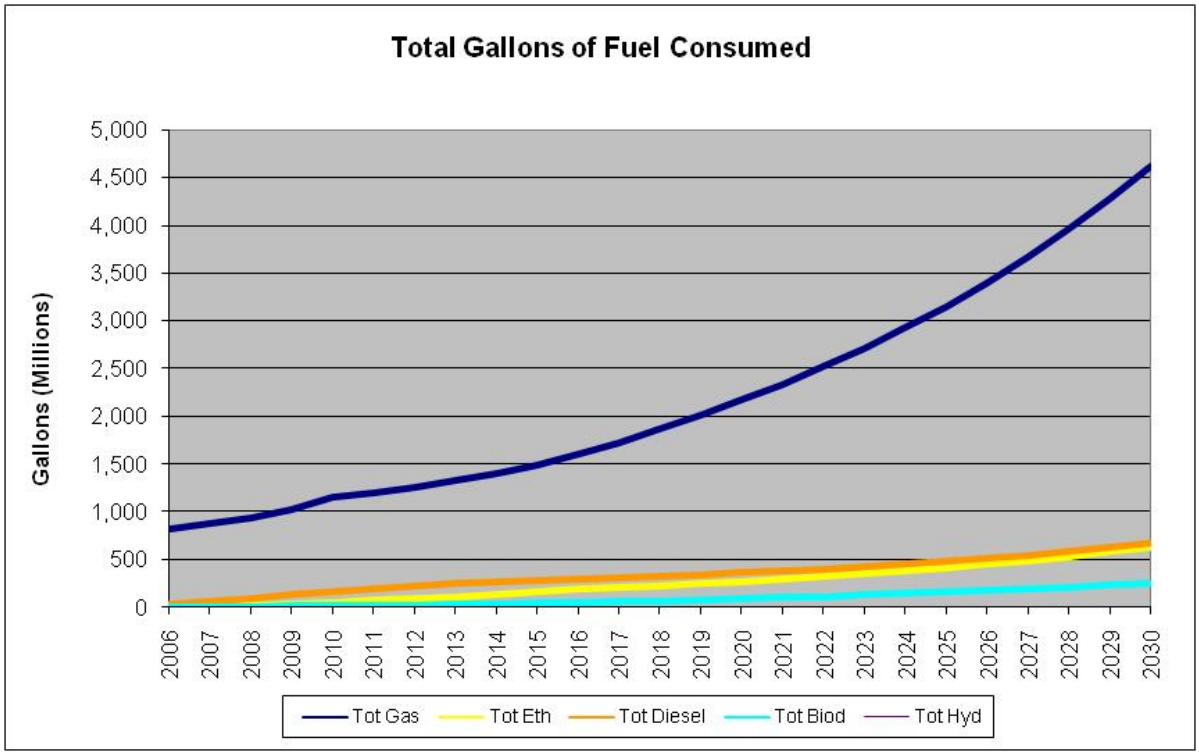

Total Gallons of Fuel Consumed
Gallons (Millions)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Tot Gas
Tot Eth
Tot Diesel
Tot Biod
Tot Hyd

Figure 117: Chinese Alternative Scenario, Carbon Taxation Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	0.55	5.35
% Reduction	0.87%	0.73%

Imposition of carbon taxation is an effective way of CO_2 emission reduction. With the tax, reduced emission in Year 2030 alone reaches 0.55 million metric tons, while aggregate emissions during this period amounted to 5.35 million metric tons.

However, when look at the percentage reduction, we found that the number is relatively low – both are less one. This illustrates that the effect of carbon taxation imposition has been overridden by the rapid growing vehicle numbers. Unless useful strategies been taken to limit vehicle usage, carbon taxation alone could not really cut emission to a desired stage.

4.5.7. Motor Vehicle Taxation

Motor vehicle taxation takes various forms in different countries. It has been implemented in many developed and developing countries. Vehicle taxation may be a good source of revenue, encourage shift to other transport modes, or, if imposed properly, may encourage shift to more efficient and less polluting vehicle types.

Taxation on vehicles is usually one-time taxation at the time of purchase, including sales tax, value-added tax, purchase tax, property tax, registration tax and other consumption taxes. Some of these are imposed as a certain percentage of the vehicle price; some are depending up on characterizations such as engine size, capacity, fuel economy and emissions etc. Among those countries with high vehicle taxation, Singapore, Denmark and Japan are typical examples. According to Singapore's auto quota system, taxation on a new vehicle would be 2-3 times as much as the vehicle price (Wu, 2005). Singapore has imposed a heavy vehicle ownership tax that causes considerably smaller vehicles ownership in the country. For example, consumer needs to spend 77,000 Singapore dollars to buy a Toyota Corolla, which original costs 20,000 Singapore dollars (CCICED, 2006).

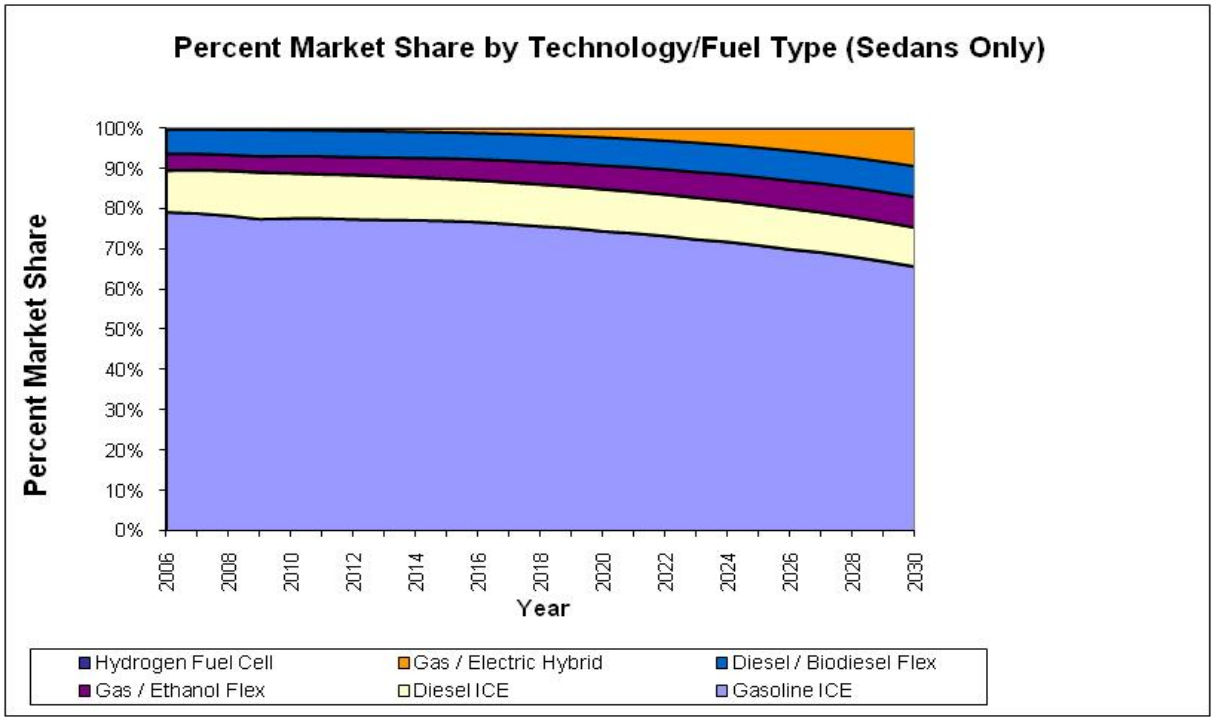
Some countries offer a differentiated system to encourage new, clean and high energy efficient vehicles, as applied in Sweden and Germany, offers incentives for vehicle owners to switch to low emission vehicles (Breithaupt, 2002). For example, end users in Denmark are allowed to pay 16.7% less tax if their fuel consumption for 100 km is between 2.5 ~4 liters (Wu, 2005). If buying high emission vehicles, end users need to pay green property tax. In Japan, less purchase tax would be paid if buying clean alternative fuel vehicles; 25% ~ 75% fees need to be paid if compatible with emission standards (Wu, 2005). Furthermore, Japan started allowances for alternative fuel vehicles and electric vehicles. Vehicle manufacturers may also be encouraged to develop less polluting vehicles that could be preferred by consumers due to lower taxation (Schwaab and Thielmann, 2002).

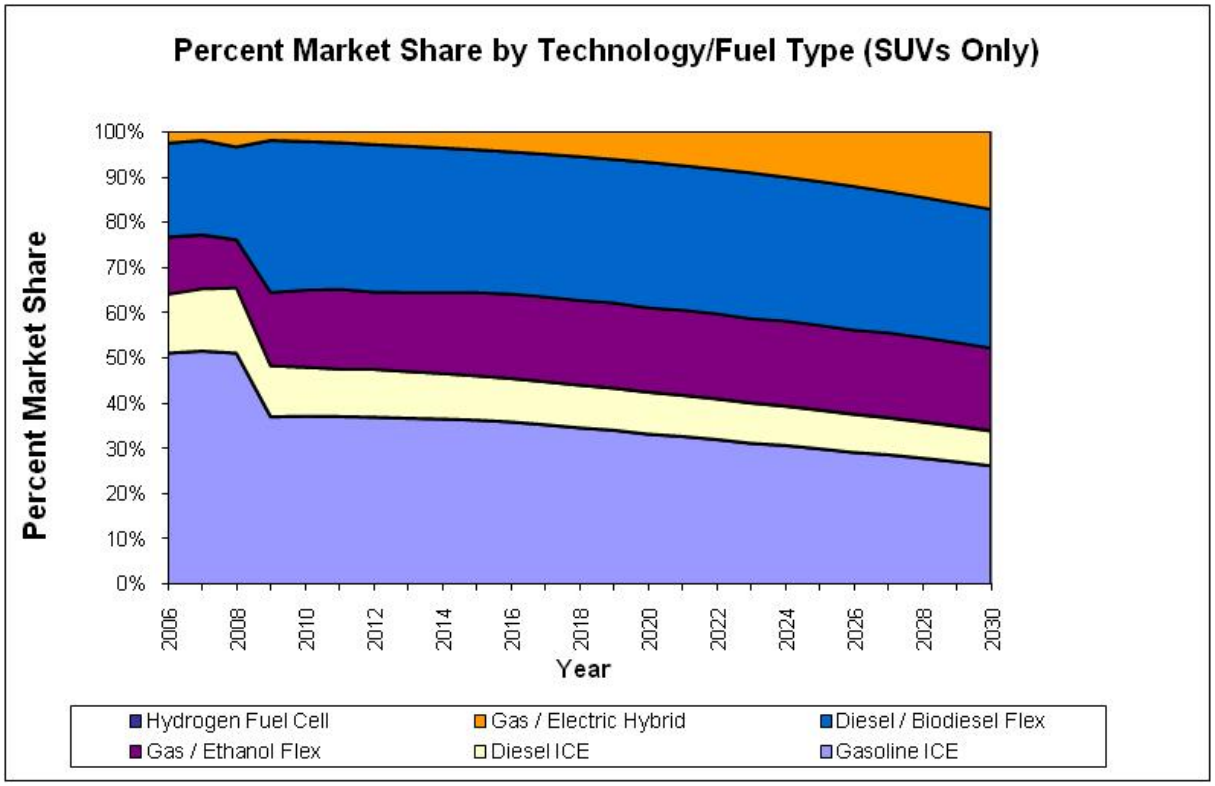
Current taxes applicable to motor vehicles in China include value added (VAT, 17%), excise (5%), vehicle acquisition (10%), and vehicle usage taxes (60 ~ 320 RMB per year) (Huang, 2005). No fiscal and taxation policies and measures to promote the low oil consumption, environmental protection vehicles except 30% of excise tax reduction to passenger cars which reach the Europe II limits standard, which has significant encouraged switch to cleaner vehicles (Wu, 2005; Huang, 2005). The successful experience tells that China could establish a vehicle tax system to promote clean, fuel efficient vehicle development.

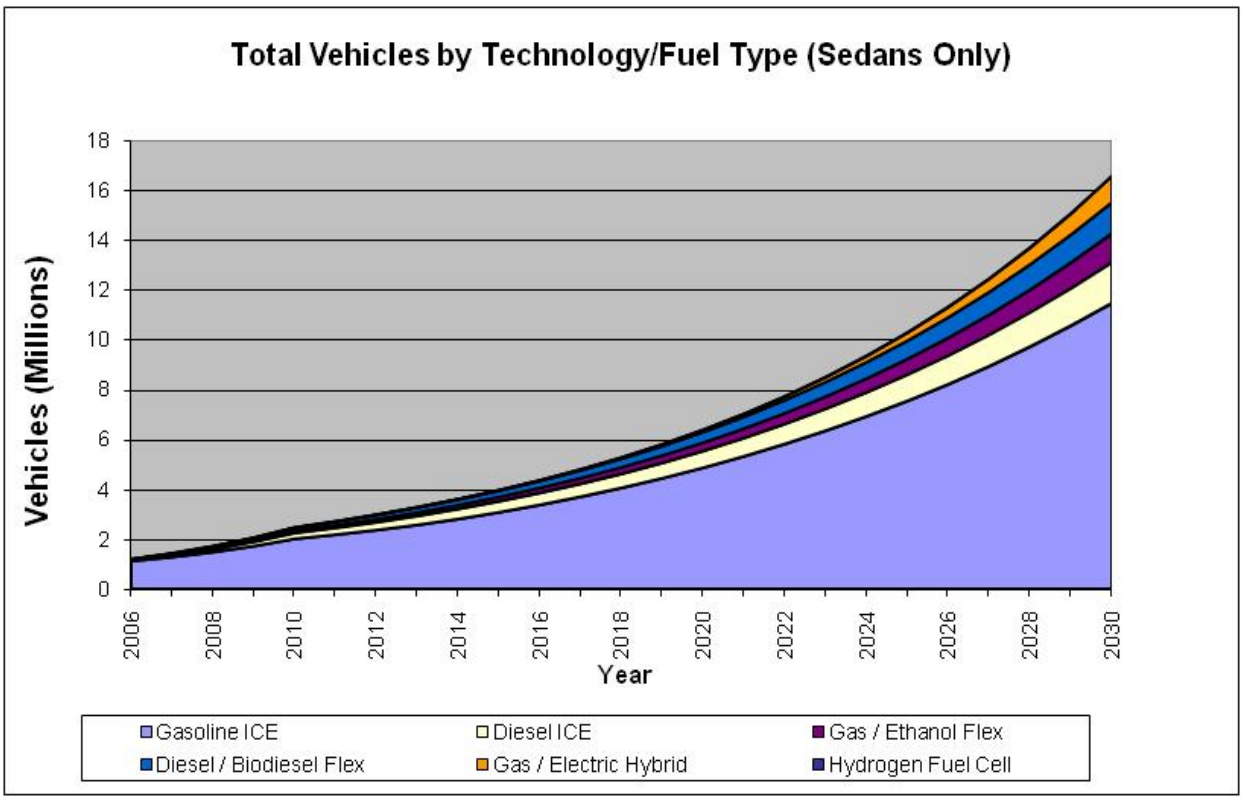
Unlike other taxation options, vehicle taxation does not contribute to variable costs of transportation and therefore is unlikely to influence vehicle miles traveled or other driving habits. But consumers are sensitive to tax rate because the vehicle tax is levied at the period of purchase stage (Huang, 2005). It is proposed to reduce 50% of vehicle acquisition rate to

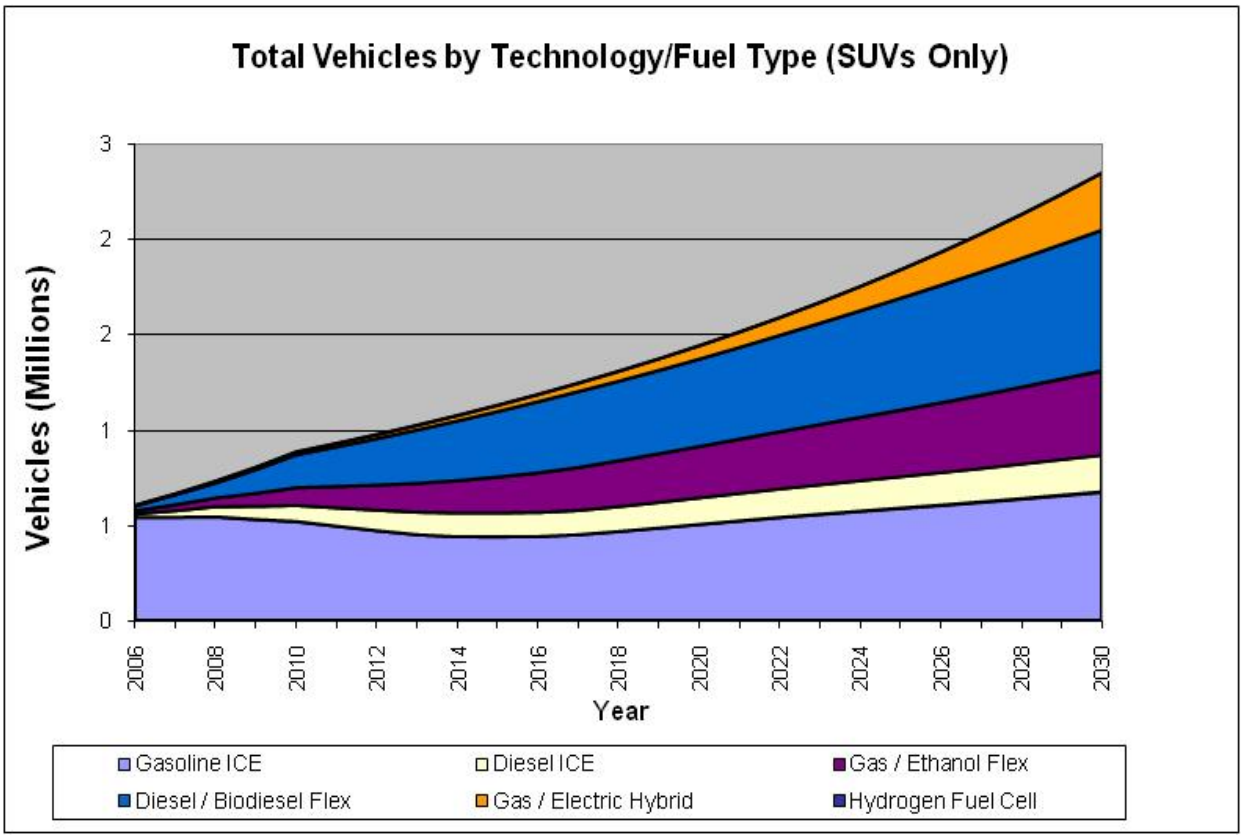
vehicles which meet national standards and referring to American's gas-guzzler tax to punish additional 50% of vehicles that could not meet the standards. Additionally, it is suggested to reduce 50% vehicle-purchase tax for alternative vehicles such as hybrids and fuel cells (Huang, 2005).

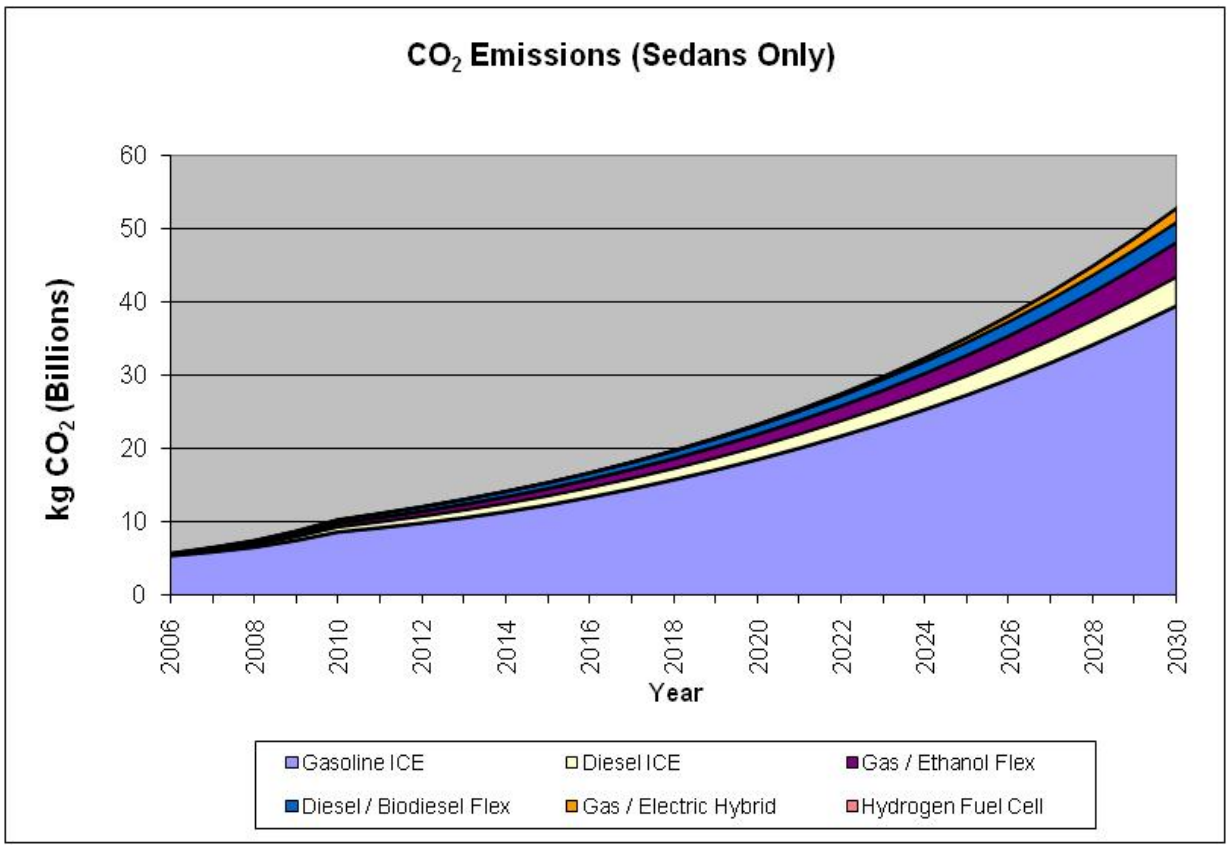
Figure 118(a-j): Chinese Alternative Scenario, Motor Vehicle Taxation

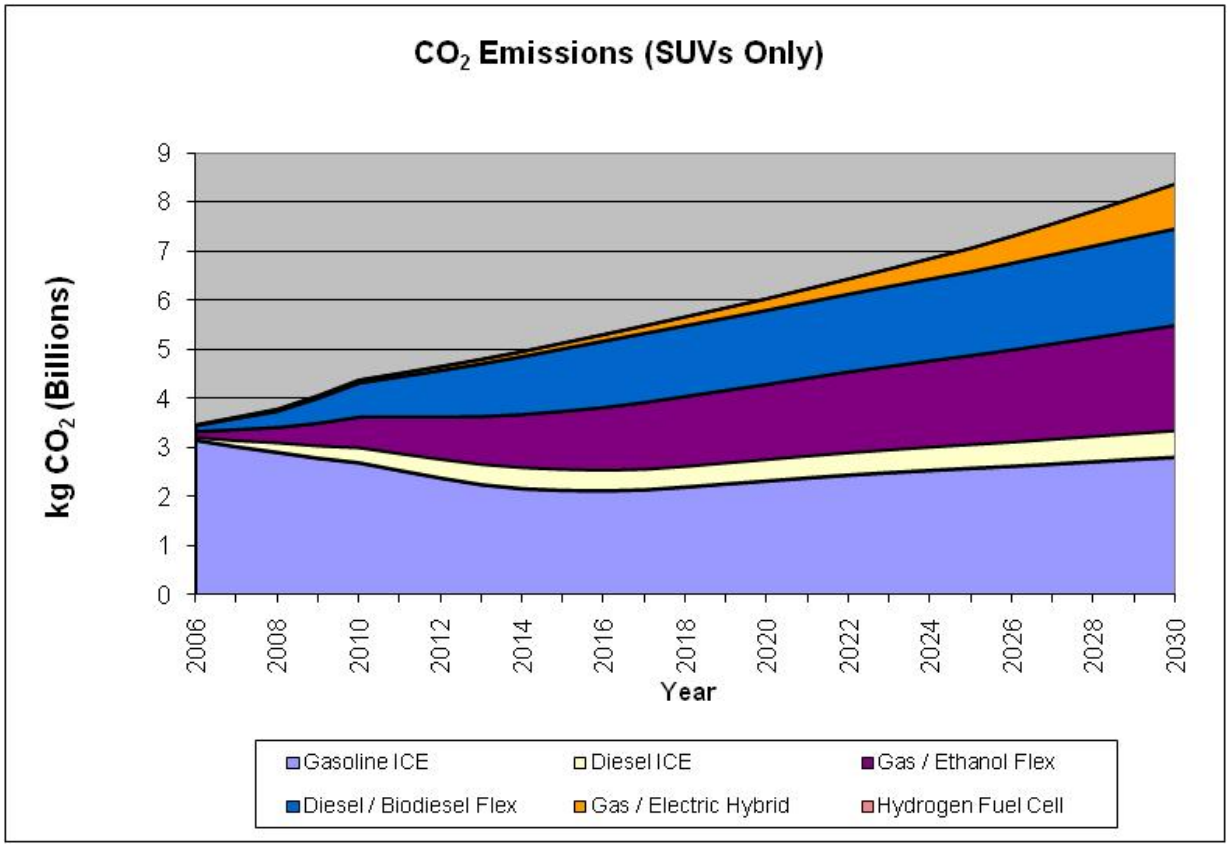


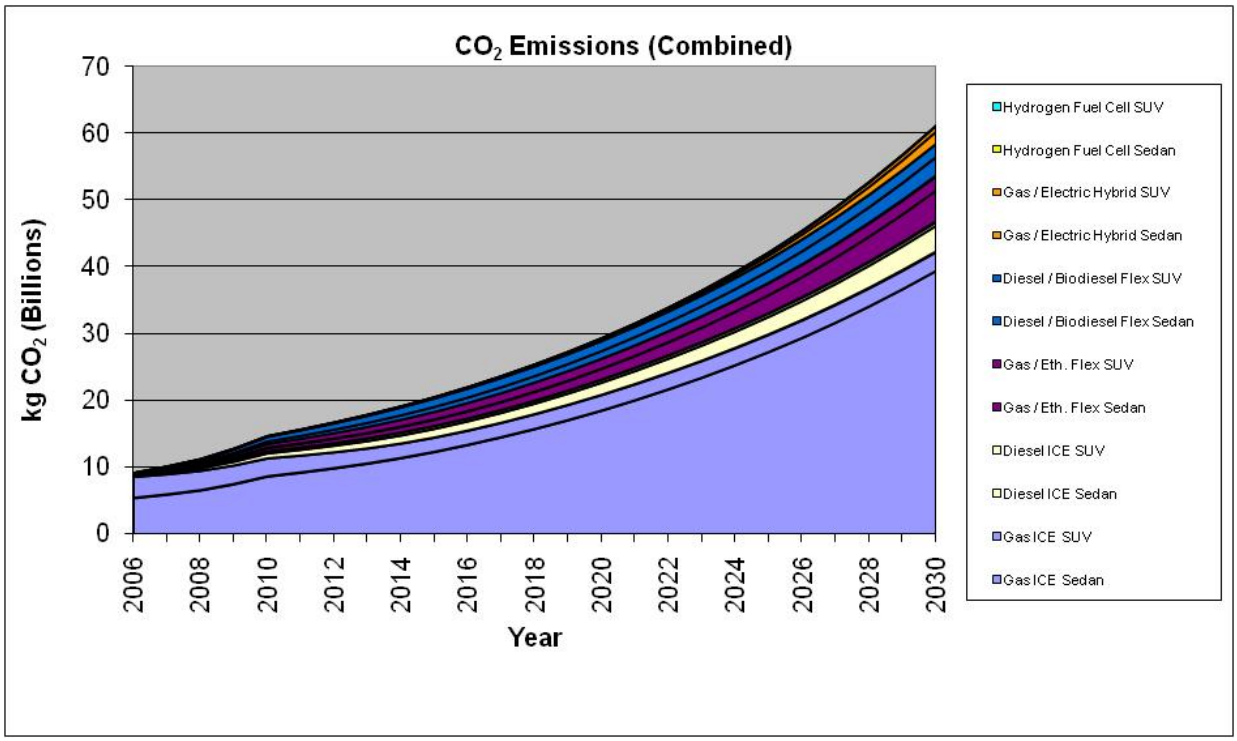


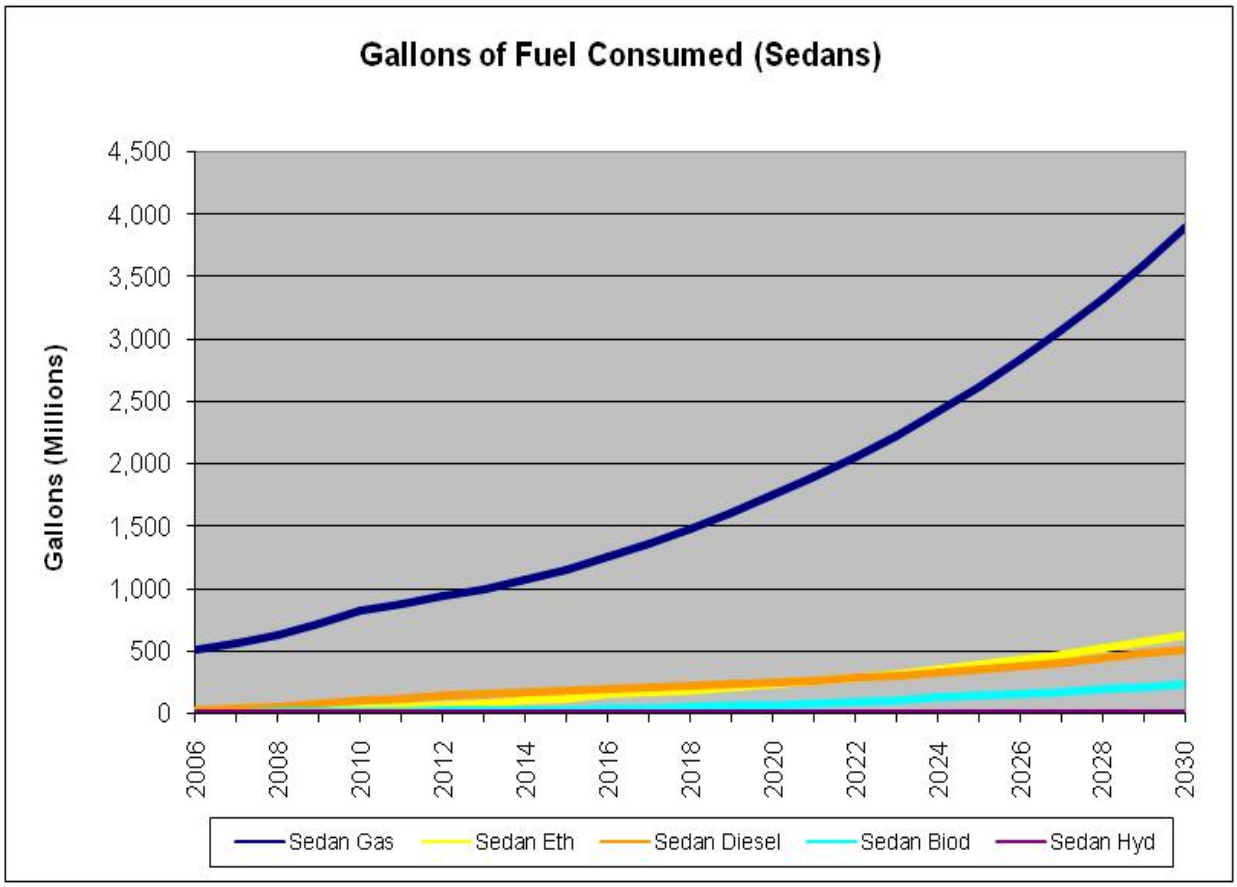

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
0
2
4
6
8
10
12
14
16
18
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

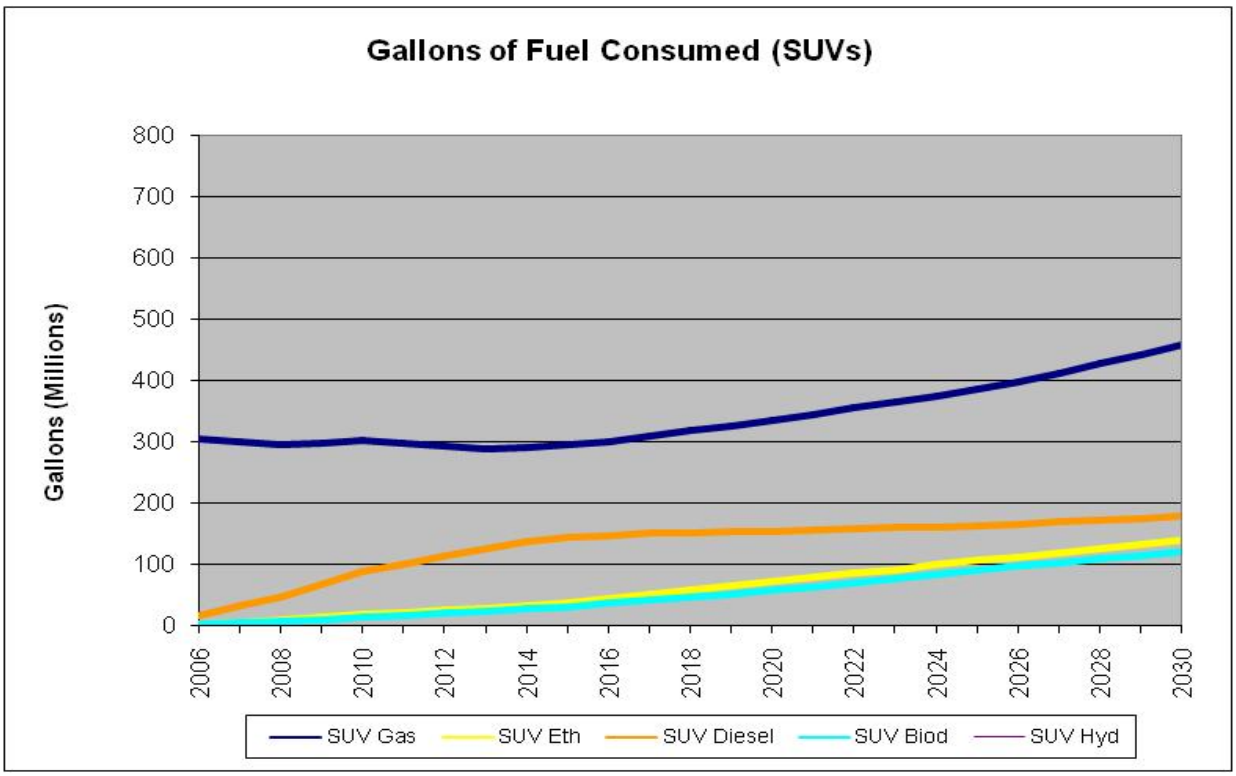

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
0
1
1
2
2
3
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
9
8
7
6
5
4
3
2
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Combined)
kg CO2 (Billions)
70
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


Gallons of Fuel Consumed (Sedans)
Gallons (Millions)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd



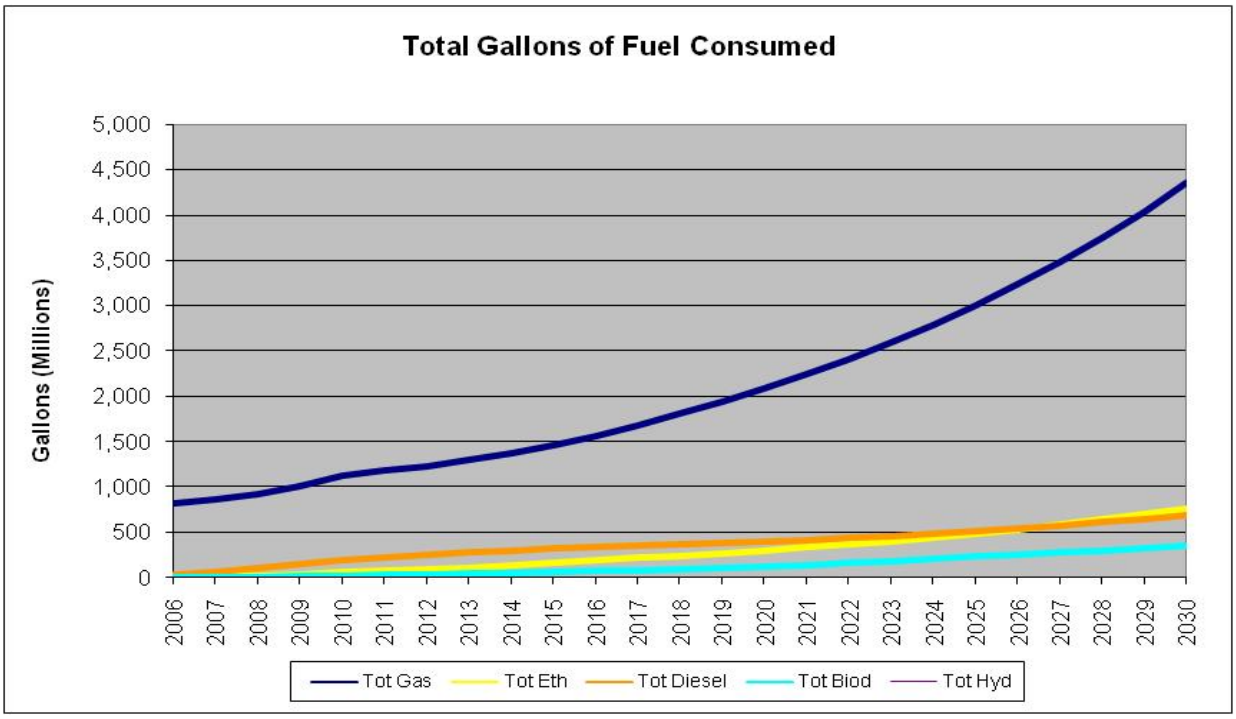


Figure 119: Chinese Alternative Scenario, Motor Vehicle Taxation Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	1.6	8.88
% Reduction	2.54%	1.21%

As seen in the graphs and table above imposing vehicle taxes will reduce the carbon dioxide emissions marginally. By the 25th year of simulation there is a 2.54% reduction in annual carbon dioxide emissions accounting for a 1.21% aggregate reduction.

This limited effect of the vehicle taxation is due to the fact that the taxation will reduce the number of polluting vehicles coming on road- after the taxation is actually implemented. However the vehicles which are already on road and are not clean and will not retire for many years will continue emitting the CO_2.

It is also necessary to ensure that the taxes on polluting vehicles actually encourage the customers to shift to cleaner and more efficient vehicles. So the reduction in CO_2 emissions also depends on the effectiveness of the policies to promote efficient and clean vehicles.

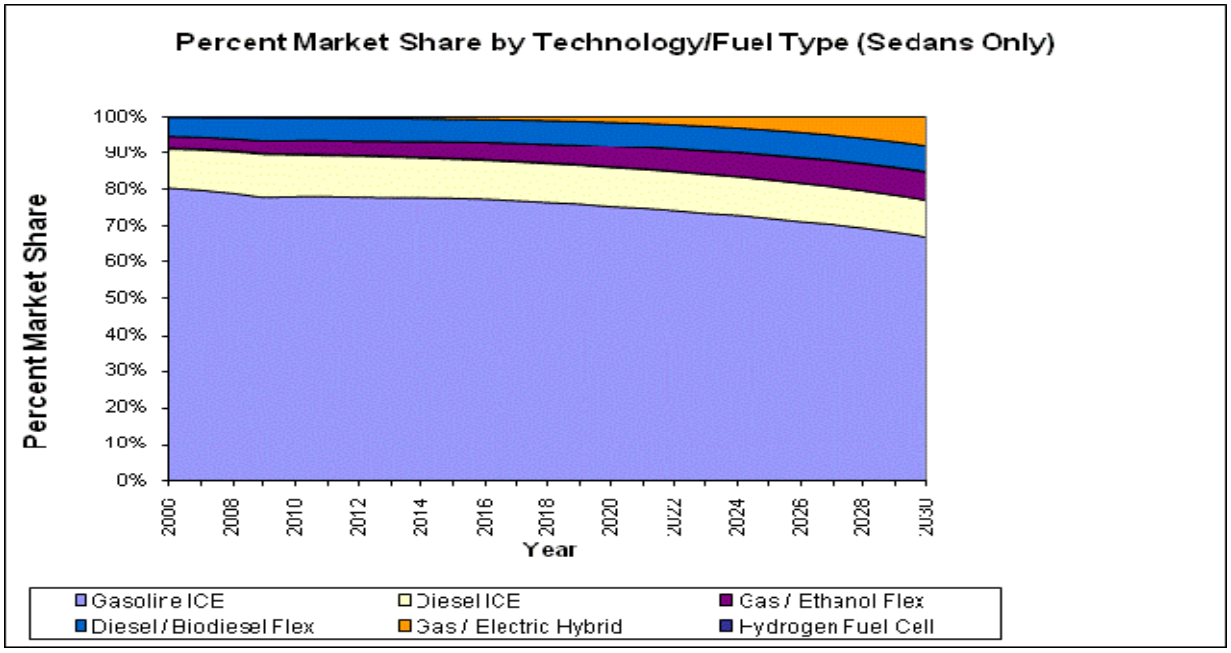
Again when this policy is considered as one of the numerous policy options to promote clean vehicles and to discourage the polluting ones, then the small incremental gains will sum up to yield a larger more effective gain.

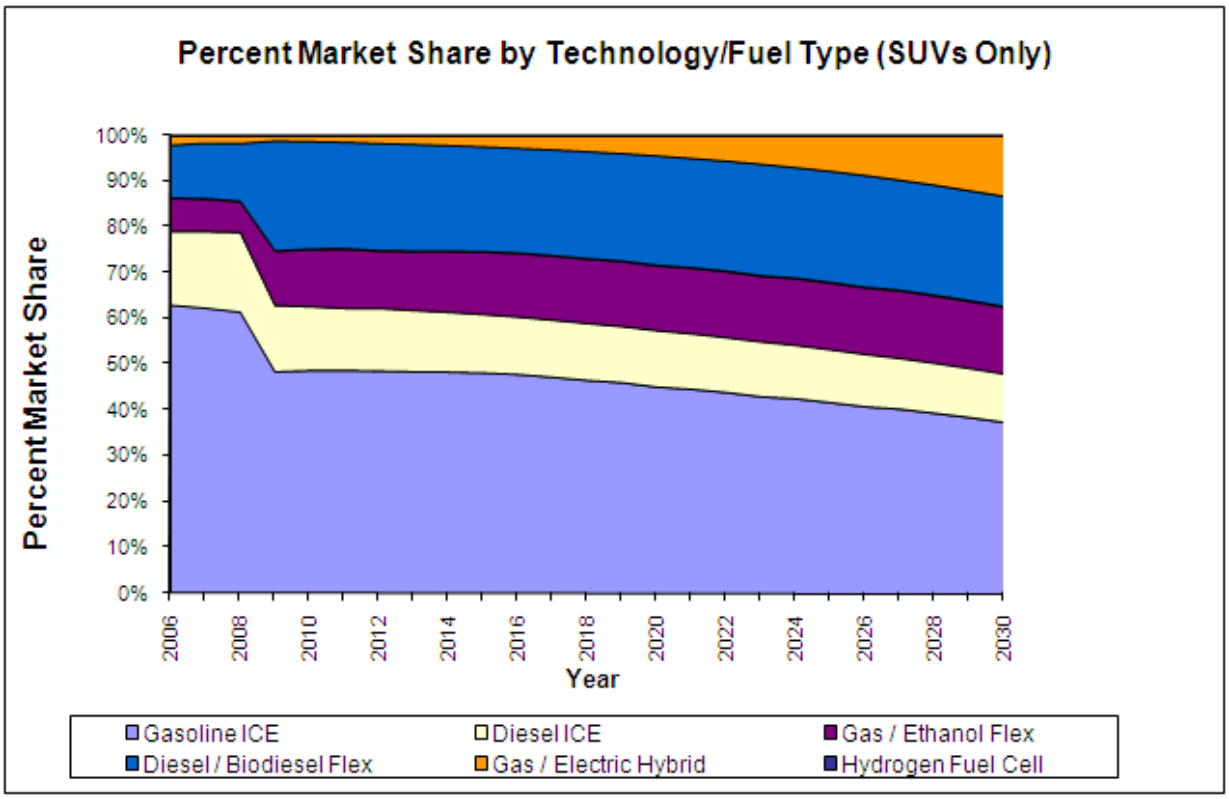
4.5.8. Vehicle License Plate Fee

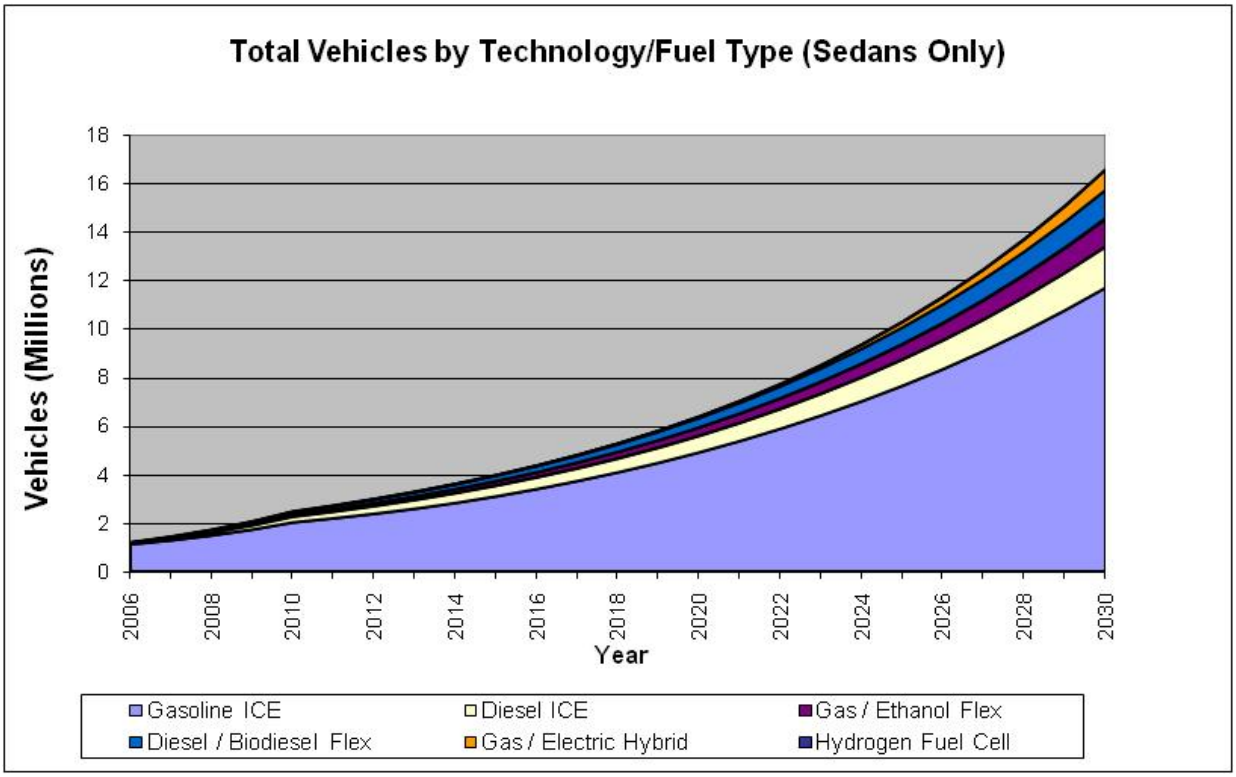
Vehicle license plate fee is a fee the owner pays when registers the vehicle. The fee rate varies from one place to another. It could be relatively high in some cases to discourage private vehicle ownerships. For example, the city of Shanghai has imposed a license plate fee, as high as 40,000 RMB (equivalent to 5333 US dollars) (Zhongguo Paizhao Wang, 2007), comparing to only hundreds of RMBs in adjacent areas. As a result, many vehicle owners in Shanghai turn to nearby provinces – Jiangsu and Zhejiang -- for vehicle registration. What they would face when driving in Shanghai is a higher road fee and restricted entrance to certain roads and bridges during specific time periods.

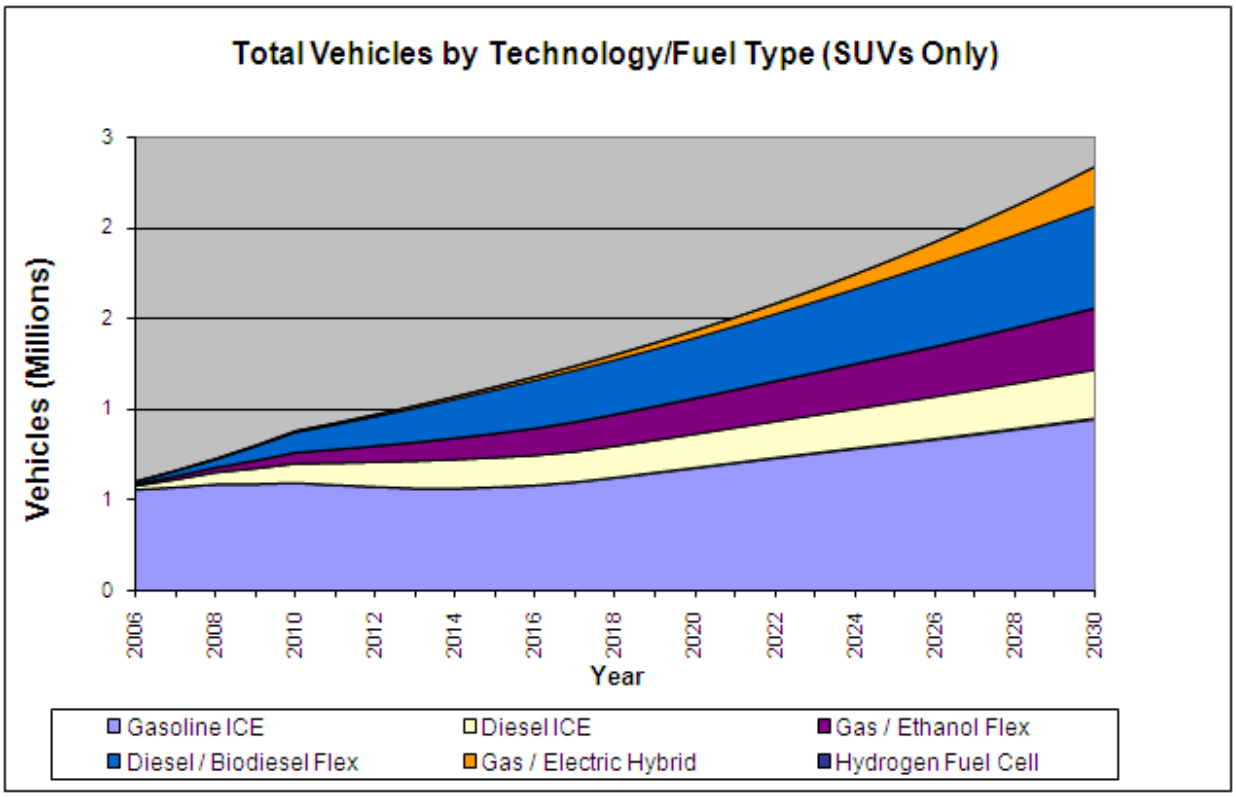
The city of Beijing does have road pricing system to prevent non-Beijing vehicles enter certain roads during peak hours. But currently there is no extra license plate fee, and it is unlikely to be imposed in the near future (ChinaNews, 2007). However, this could be a scenario through which we will analyze the impact of imposition of vehicle plate fee on transport energy consumption and emission reduction. In addition, just like the *Vehicle Taxation* scenario, we propose to differentiate the vehicle plate fee for different type of technologies: 50% less for alternative fuels and vehicles.

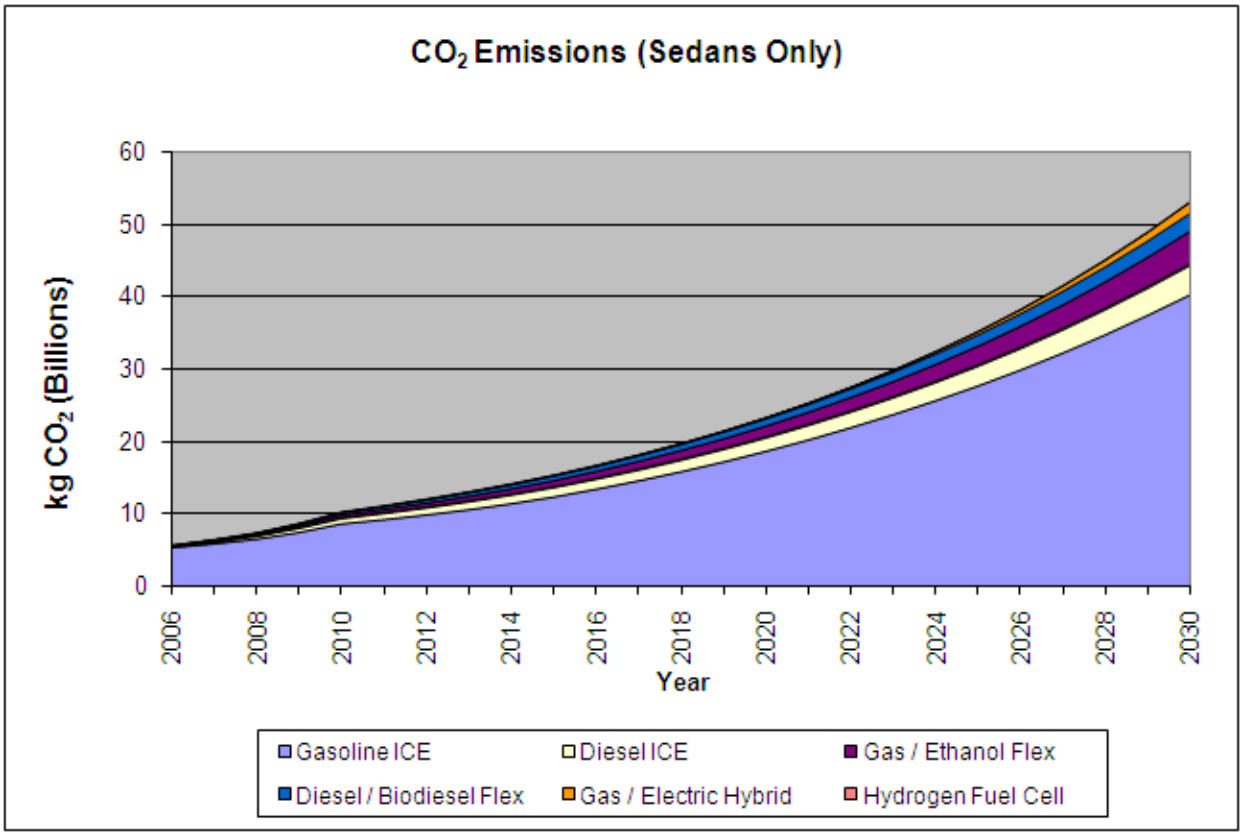
Figure 120(a-j): Chinese Alternative Scenario, Vehicle License Plate Fee

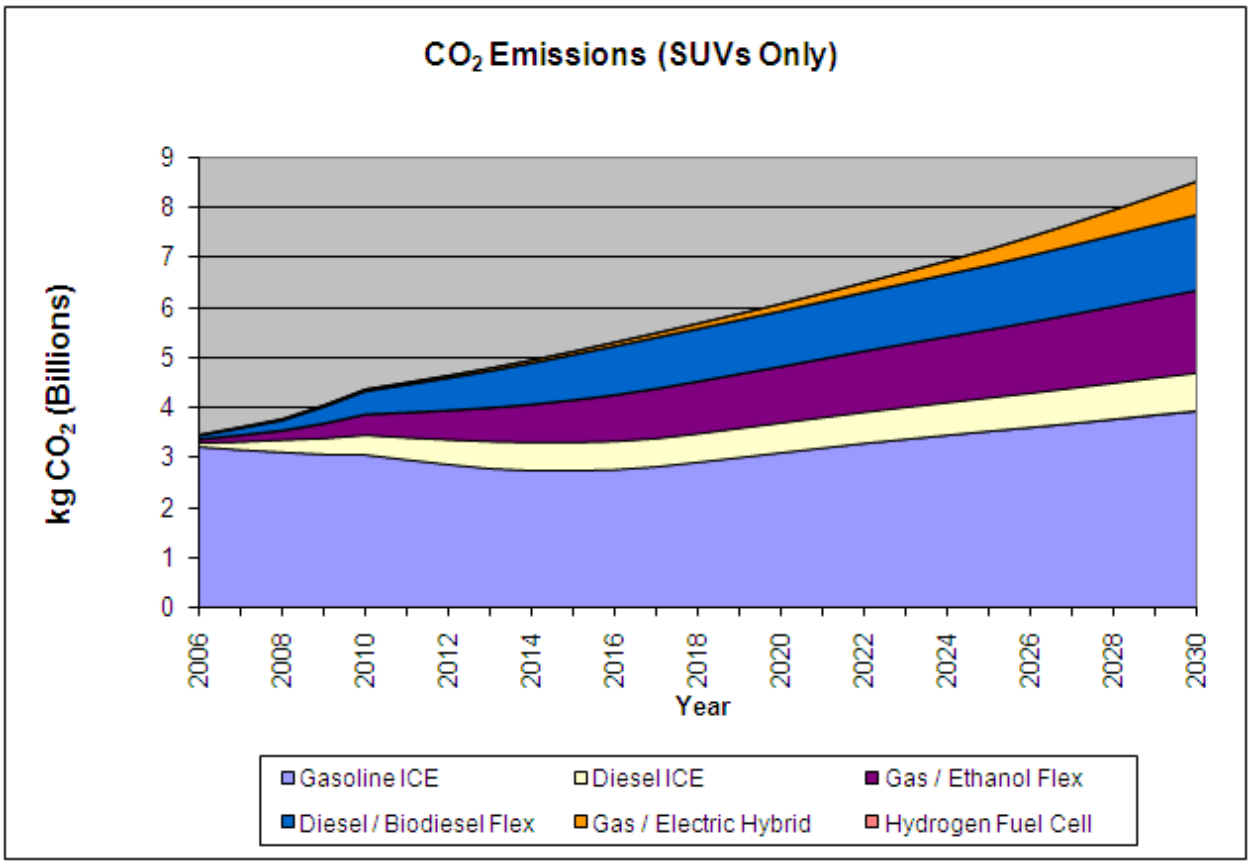


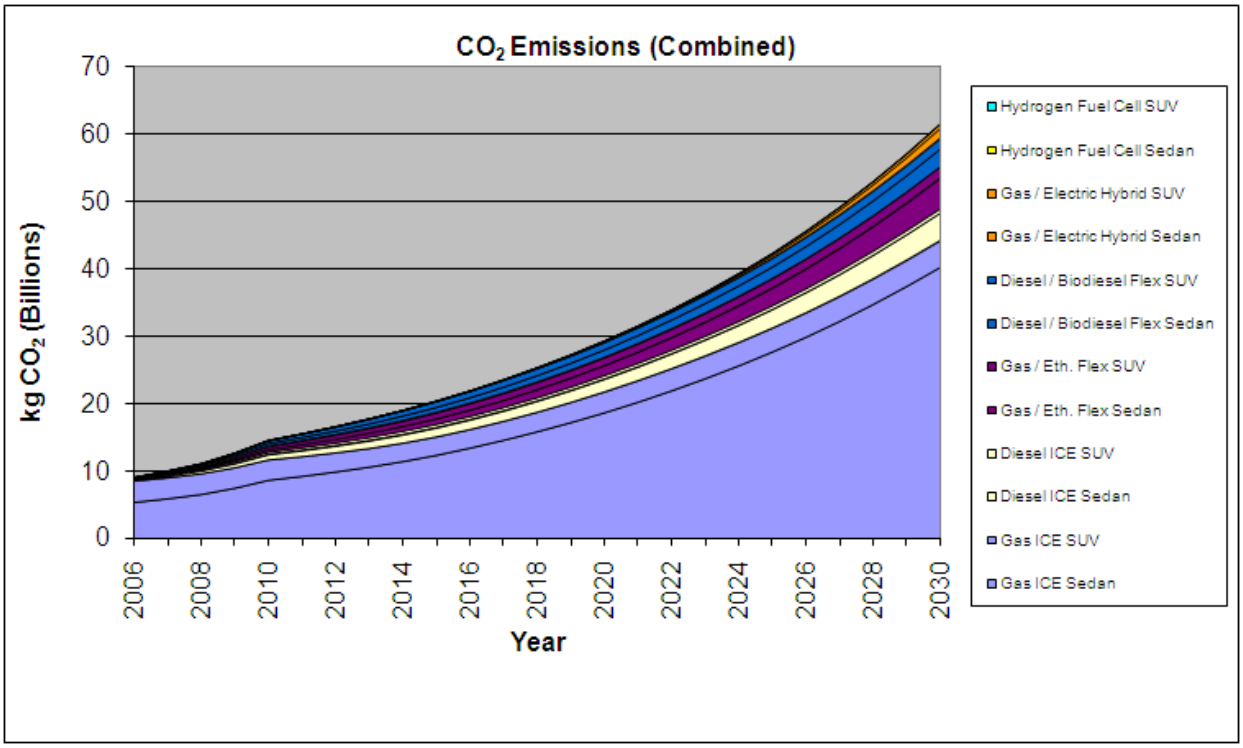

Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

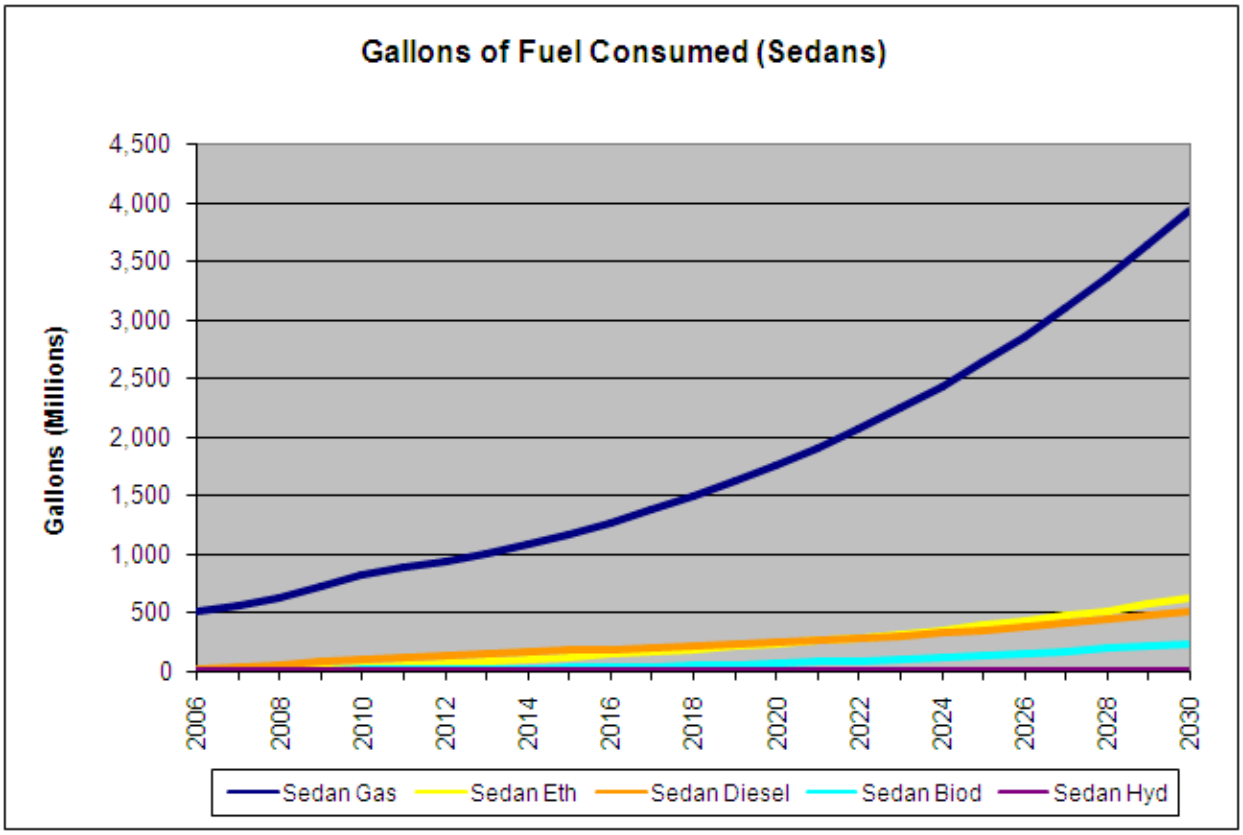

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
18
16
14
12
10
8
6
4
2
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

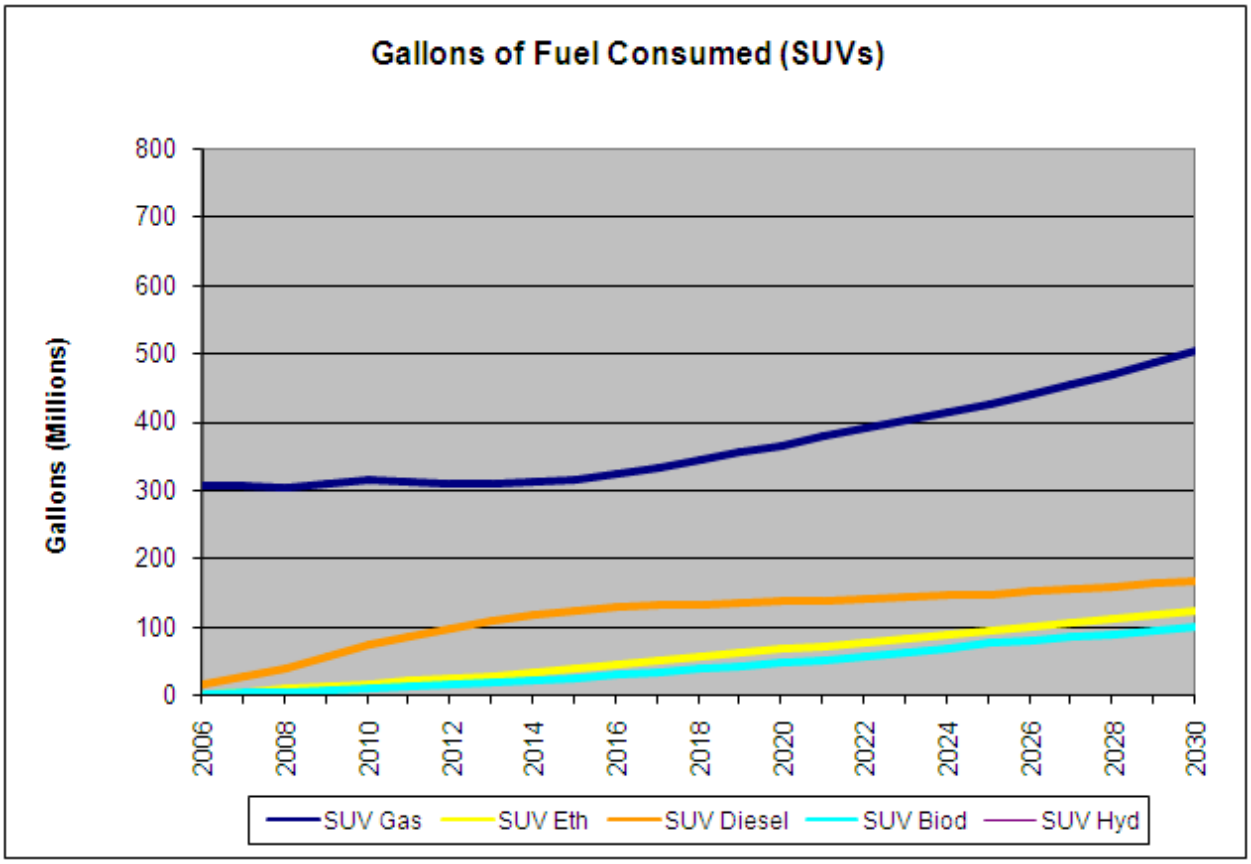

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
3
2
2
1
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO_2 Emissions (Sedans Only)
kg CO_2 (Billions)
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
0
1
2
3
4
5
6
7
8
9
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Combined)
kg CO2 (Billions)
0
10
20
30
40
50
60
70
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


Gallons of Fuel Consumed (Sedans)
Gallons (Millions)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd


Gallons of Fuel Consumed (SUVs)
Gallons (Millions)
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
SUV Gas
SUV Eth
SUV Diesel
SUV Biod
SUV Hyd

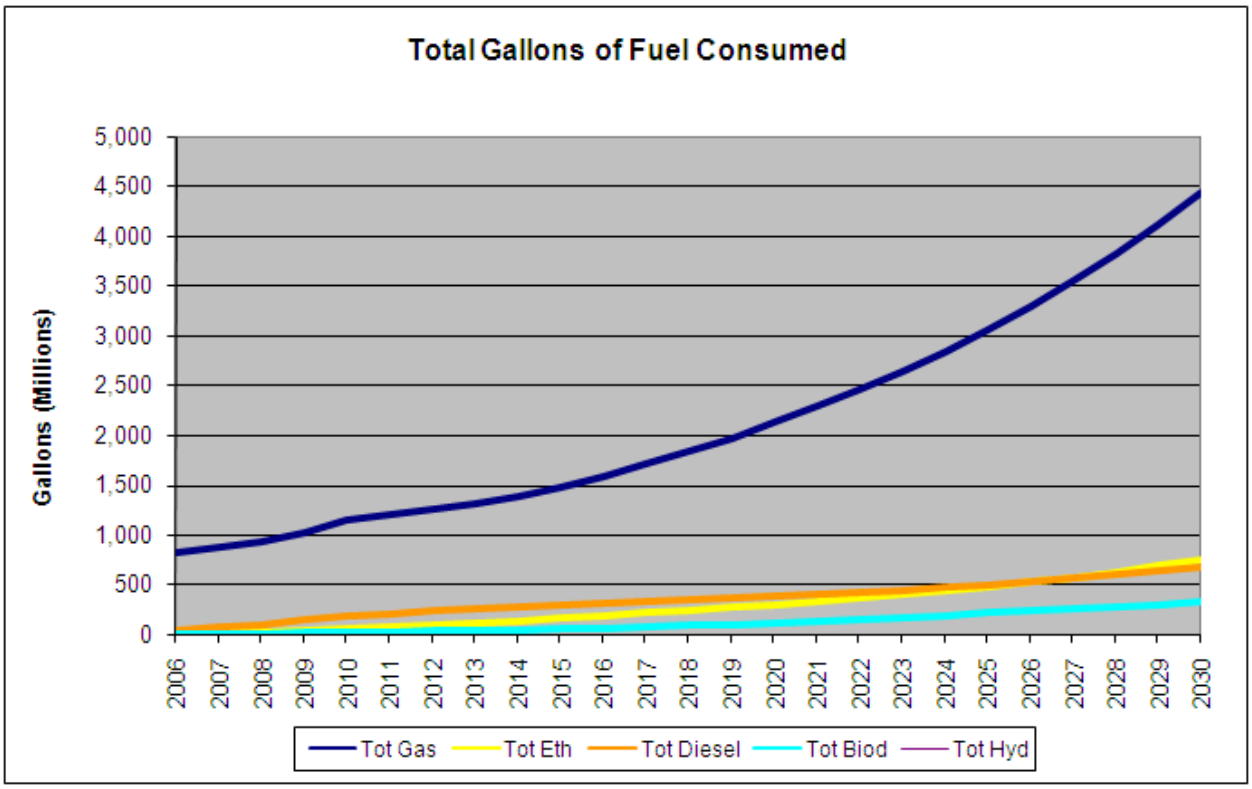


Figure 121: Chinese Alternative Scenario, License Plate Fee Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	1.10	5.54
% Reduction	1.74%	0.76%

Above graphs and table show that imposition of heavy and differentiate license plate fee does have impact on emission reduction but the amount is not impressive. In fact, license plate fee would result in 1.74% reduction in Year 2030 and 0.76% in the 25 years.

As different fee rates are applied to different technologies, the imposition of license plate fee have influence over people's purchasing preference over technologies. However, as the overall vehicle number still goes up at a remarkable rate, slightly increased market share of clean vehicles failed to influence much on the overall emissions. Other policy strategies need to be adopted if significant emission reduction is desired.

4.5.9. Reducing VMT

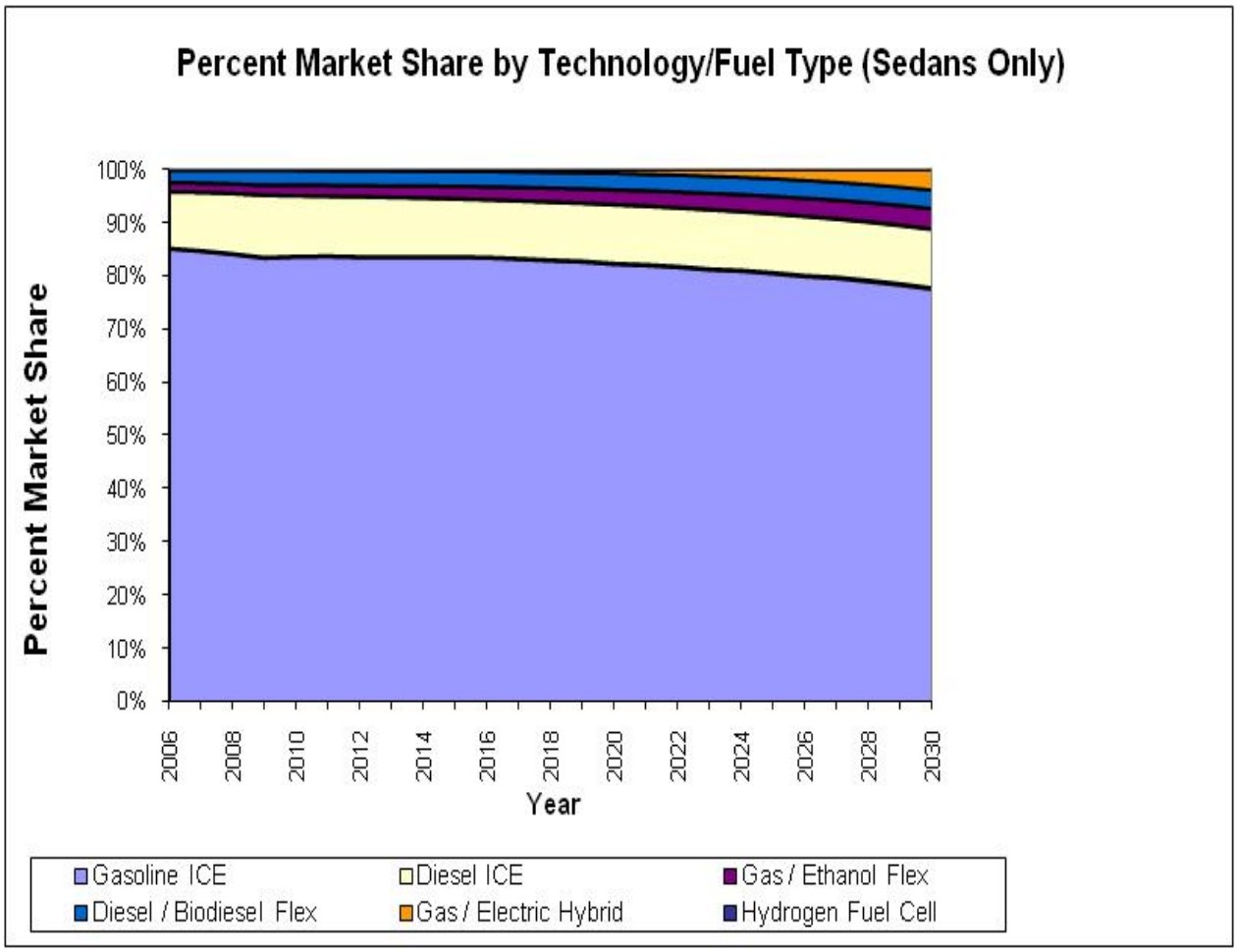
Increasing vehicle operation fee is another effective way to limit vehicle usage, and therefore transport energy consumption. Road pricing is a demand side management through which drivers pay directly for utilizing public services (WRI, 2005). Road pricing takes the forms of toll roads, toll bridges, and congestion pricing systems, whereby drivers are charged when entering specific zones during certain time periods. Experience from London shows that the imposition of a £5 fee on bringing a car into a well-defined zone during business hours led to 15 percent fewer cars entering that zone (WRI, 2005). Singapore has also achieved similar results (Menon, 2000).

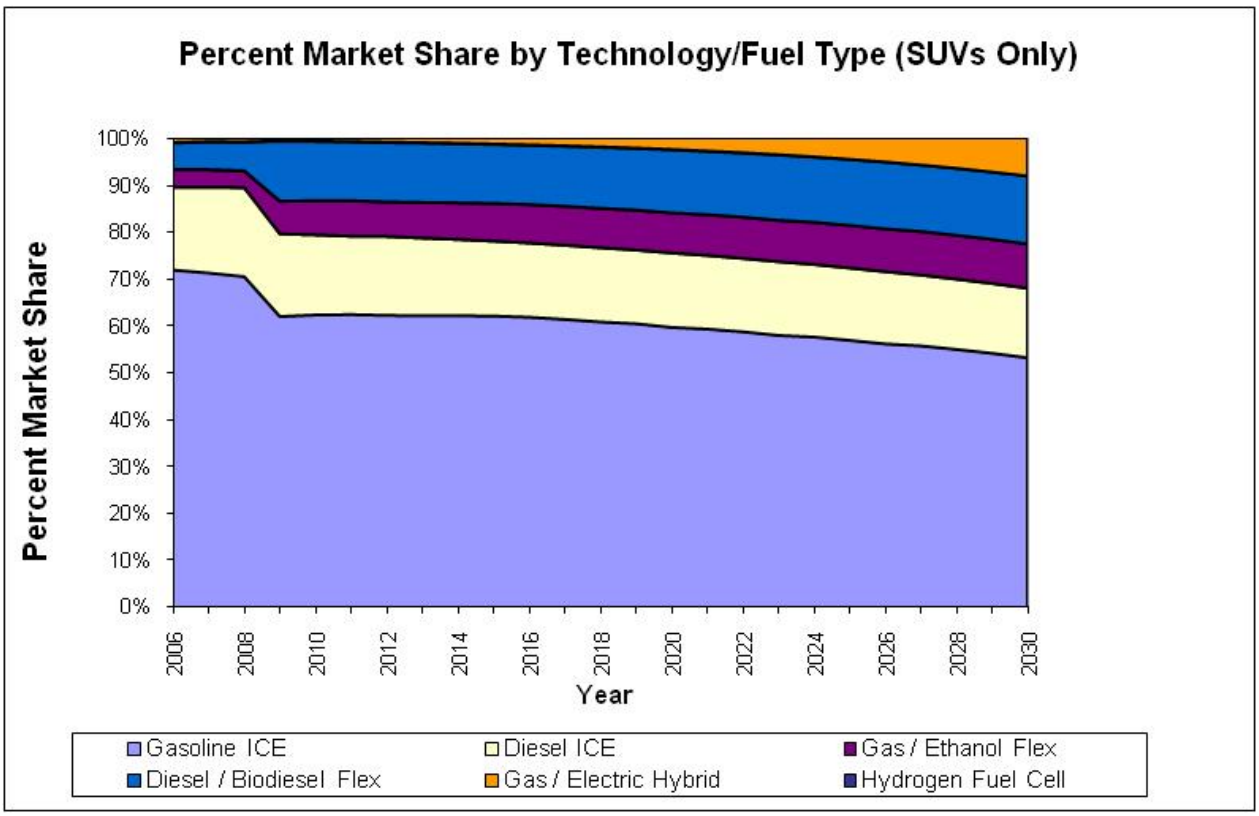
Traffic congestion is a serious problem in urban transportation. For example, CCICED (2006) estimated that the lowest speed in the city of Beijing is 10km per hour. Shanghai Academy of Environmental Sciences (2005) also observed that the vehicle speed in the inner area of Shanghai is as low as 10 km. Clearly, charging a fee to use scarce road space is an important approach for Chinese cities.

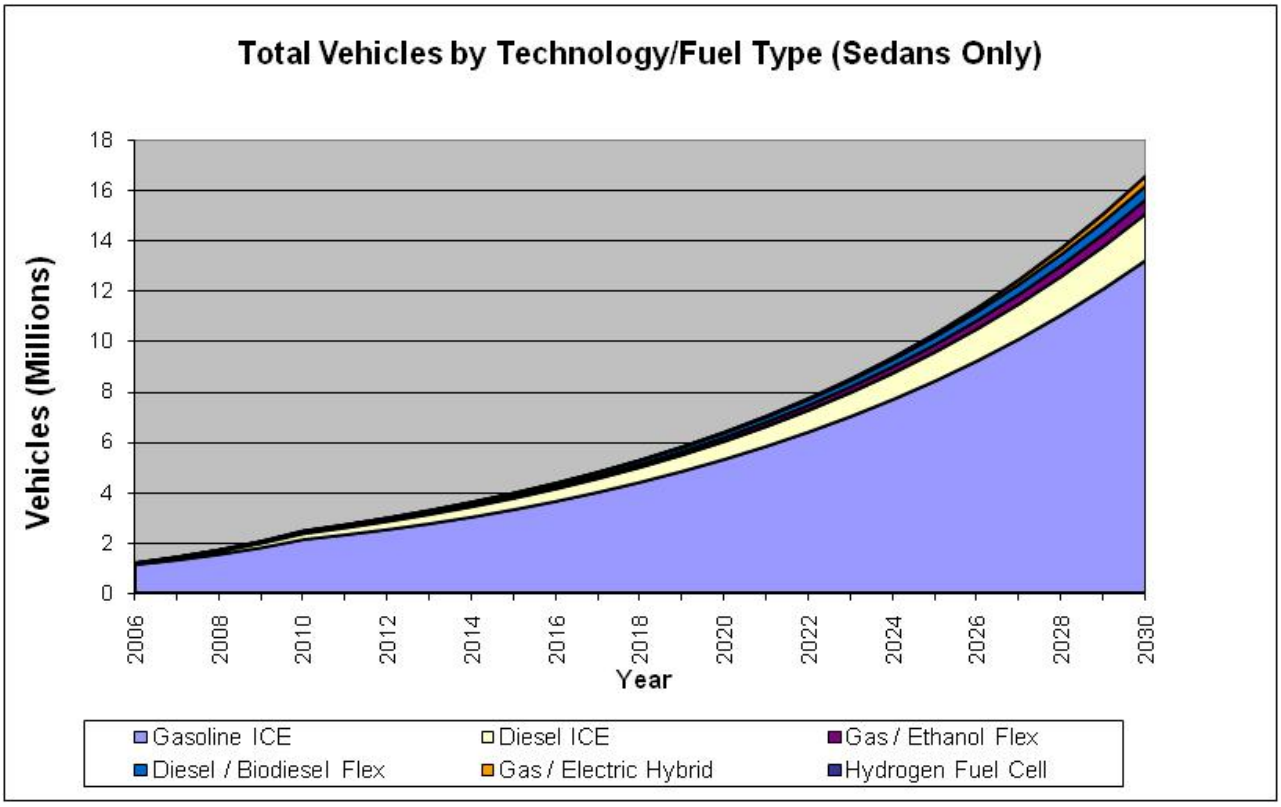
Additionally, rapidly increased on-road vehicle numbers and scarce land availability have put pressure on limited parking spaces. For instance, in Shanghai, the ratio of parking spaces to vehicle ownership is around 60%, while most world cities have the ratio near 100% (Shanghai Academy of Environmental Sciences, 2005). Poor management on land use has caused illegal parking on the streets or residential communities, which may lead to traffic congestion and accidents (Shanghai Academy of Environmental Sciences, 2005). An effective management on parking system is thus desired. Furthermore, parking charges is another option to increase operational costs of passenger vehicles, thus making private car use less appealing. It may reduce the mileages driven and encourage switch to public transportation.

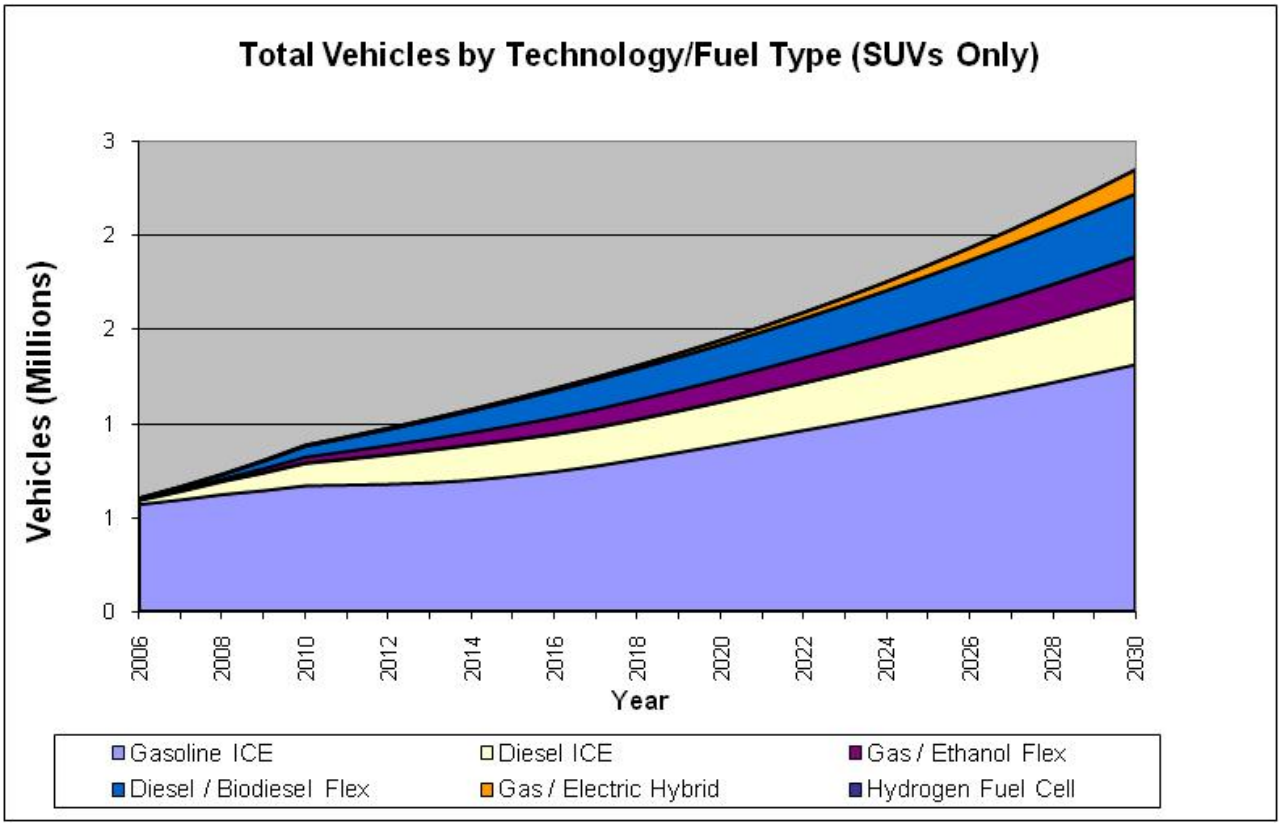
In this scenario, we assume that effective road pricing and parking management system is adopted in Beijing, which increases operation cost by $100 per year, and reduces the vehicle miles traveled by 15%.

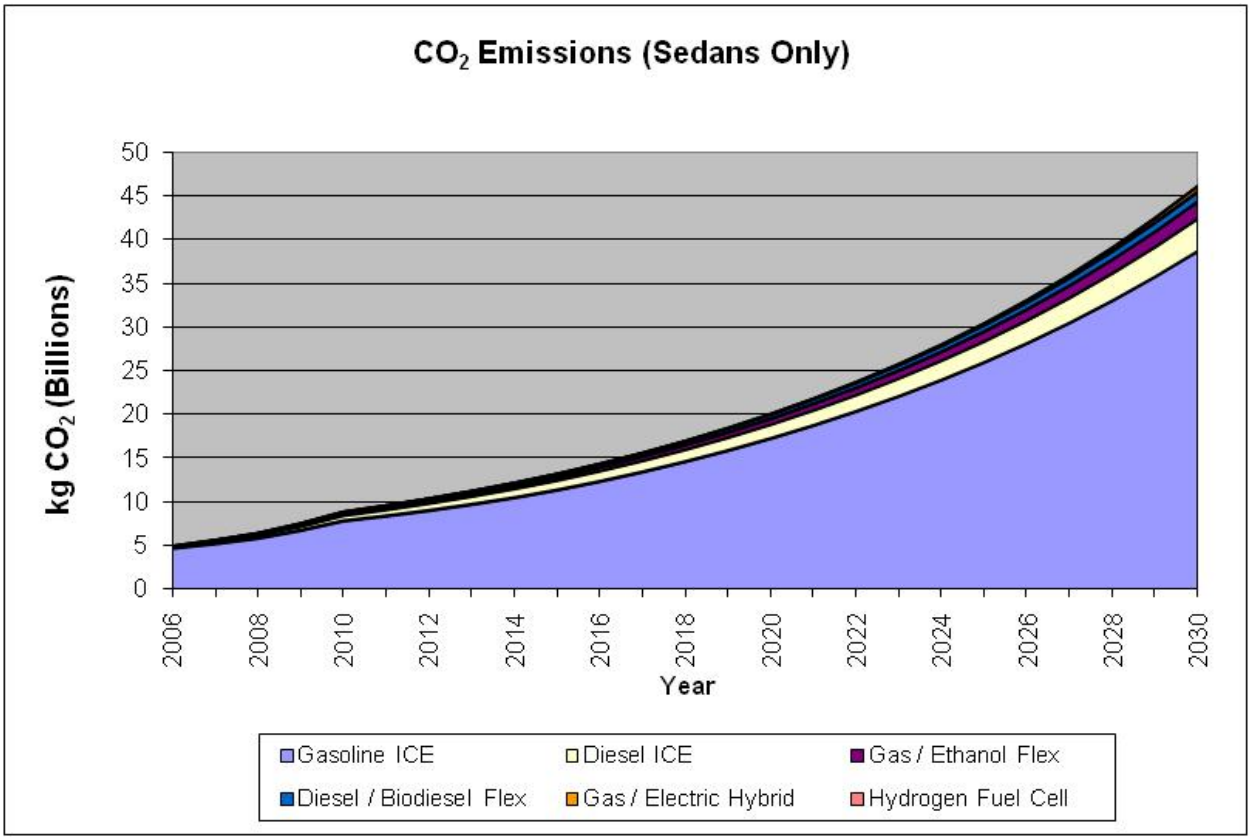
Figure 122(a-j): Chinese Alternative Scenario, Reducing VMT

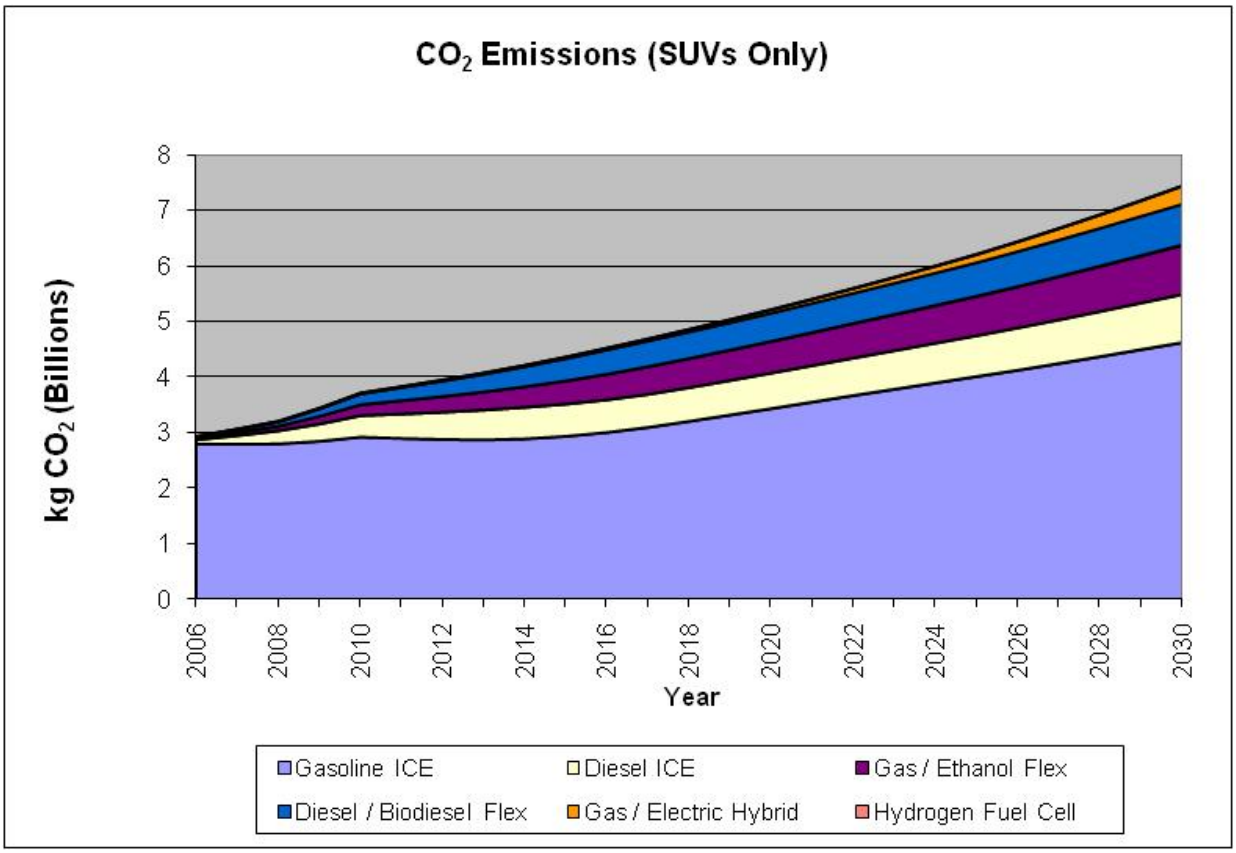


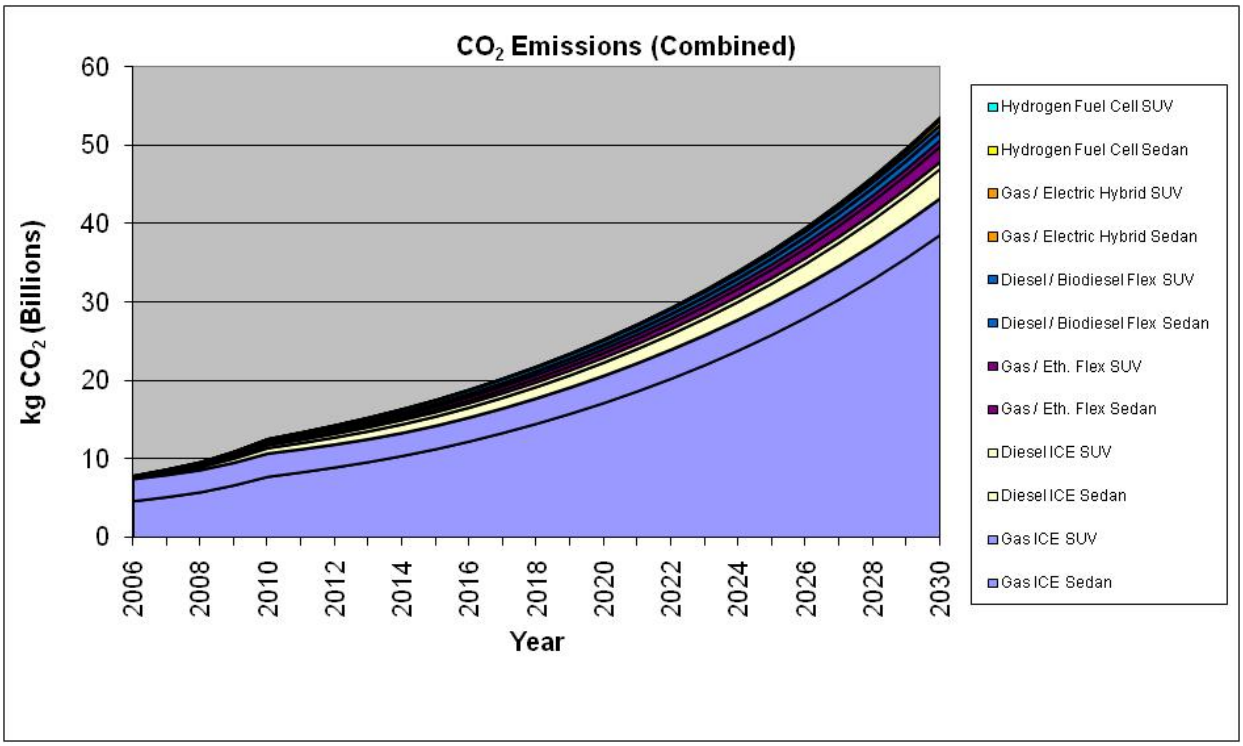

Percent Market Share by Technology/Fuel Type (SUVs Only)
Percent Market Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

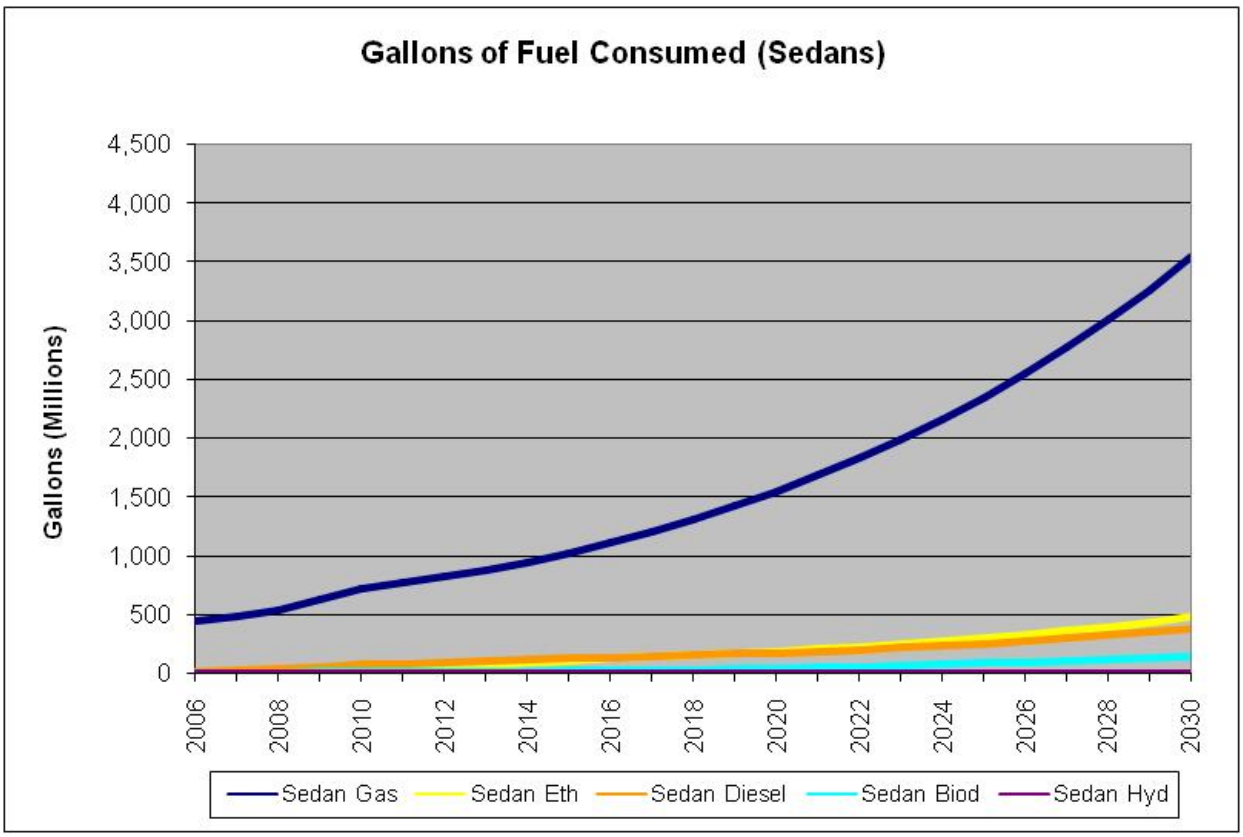

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
18
16
14
12
10
8
6
4
2
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

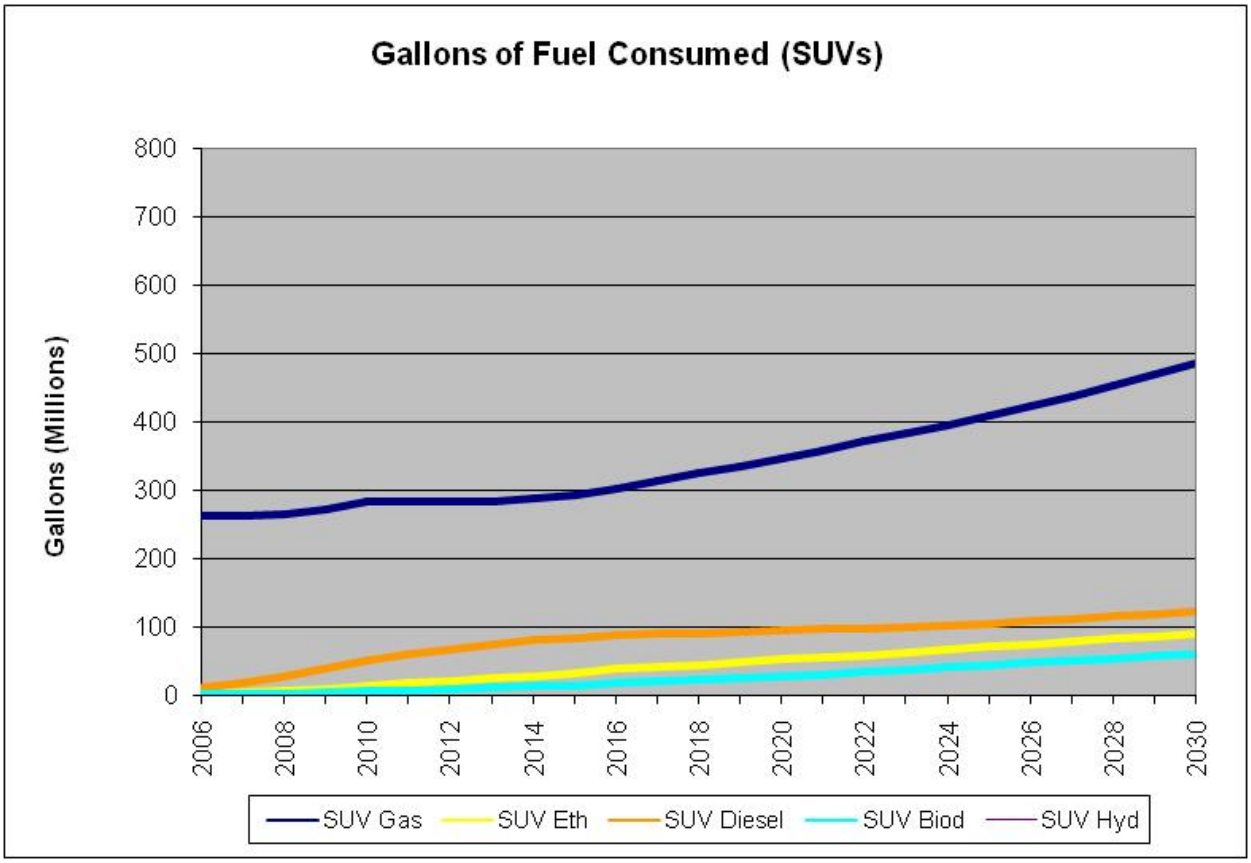

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
3
2
2
1
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
50
45
40
35
30
25
20
15
10
5
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
0
1
2
3
4
5
6
7
8
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Combined)
kg CO2 (Billions)
0
10
20
30
40
50
60
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


Gallons of Fuel Consumed (Sedans)
Gallons (Millions)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd


Gallons of Fuel Consumed (SUVs)
Gallons (Millions)
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
SUV Gas
SUV Eth
SUV Diesel
SUV Biod
SUV Hyd

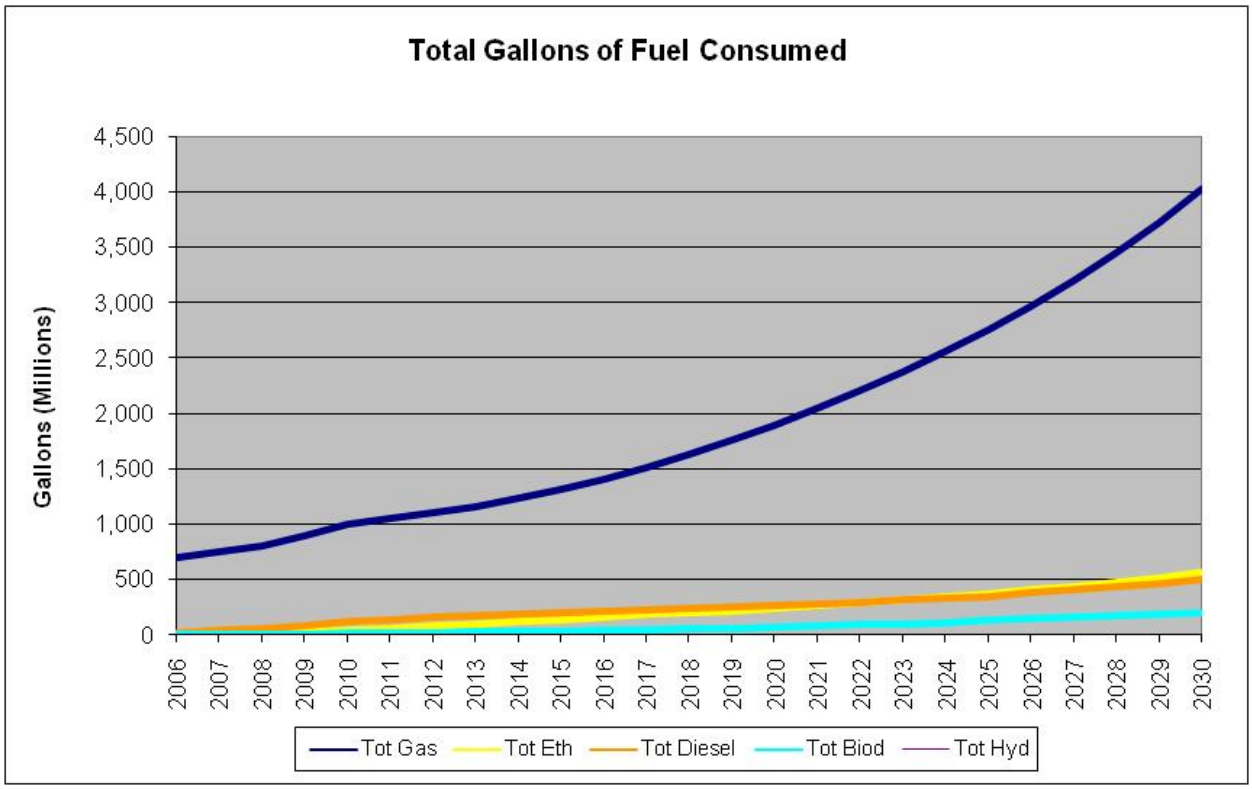


Figure 123: Chinese Alternative Scenario, Reduced VMT Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	9.28	108.52
% Reduction	14.78%	14.81%

As seen in the graphs and table above effective parking management system will reduce the carbon dioxide emissions significantly. By the 25th year of simulation there is a 14.8% reduction in annual carbon dioxide emissions accounting for a 14.81% aggregate reduction. This significant reduction in carbon dioxide emissions is because proper parking management has a direct impact on the number of miles driven and as indicated by studies, a 15% reduction in miles driven can be achieved. Since the umber of miles driven is reduced across the entire spectrum of vehicles – including the existing less efficient vehicles and the new efficient vehicles, this has a net effect of conservation of energy too. This significant decrease in carbon dioxide emissions when considered in combination with other policy actions to reduce the carbon dioxide emissions will lead to substantial reductions.

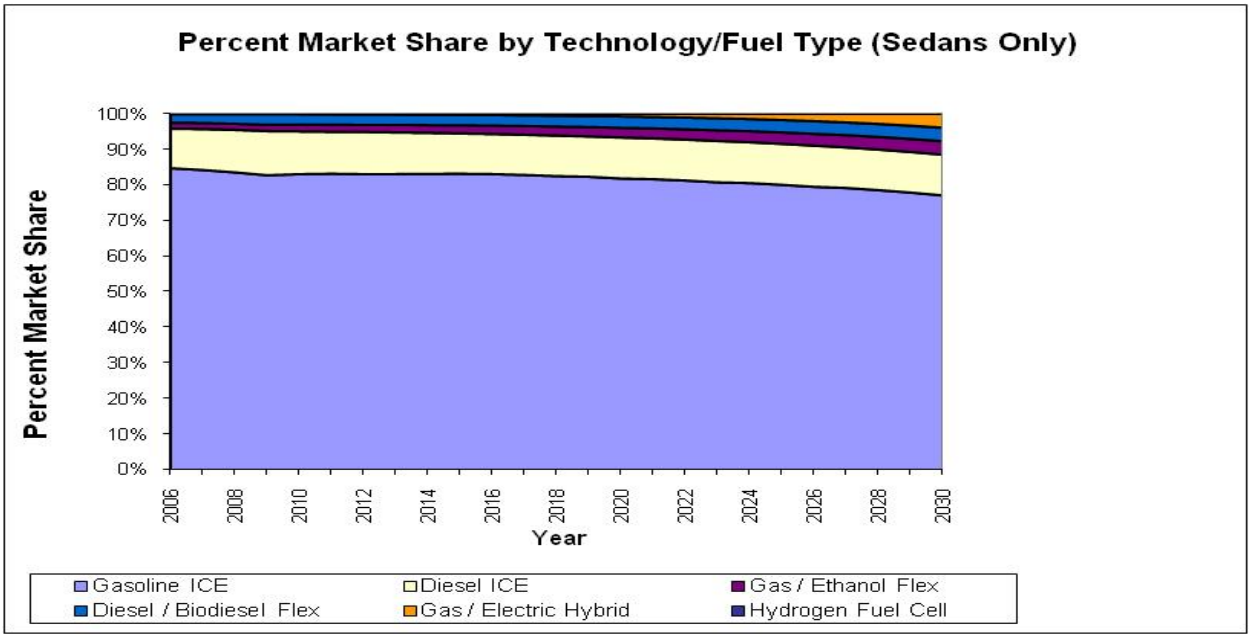
4.5.10. Slowing Vehicle Growth Rate

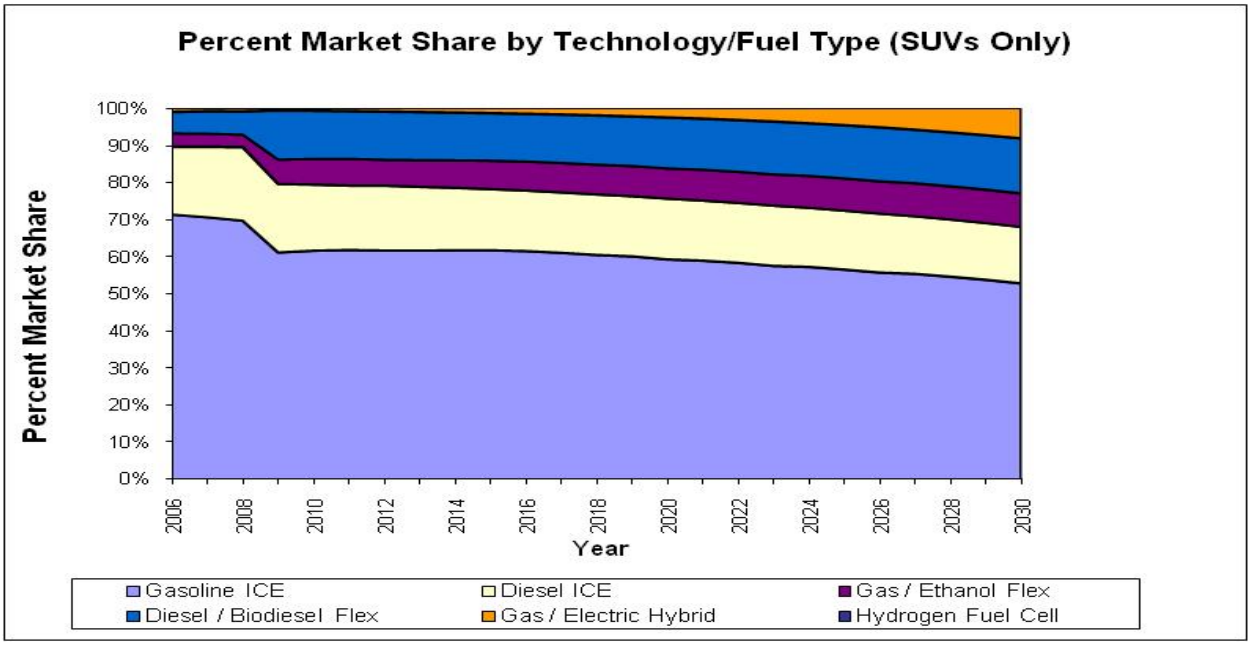
China's vehicle growth, especially private passenger vehicle growth, has been remarkable for the past two decades. Privately owned vehicles, especially passenger vehicles, is the category that has increased most. The total number of civil vehicles has been growing at an average rate of 10% annually for the past 15 years, compared to 22% for private vehicles and 30% for private passenger cars (NBSC, 2005). From 1992 to 2004, China's private motor vehicles increased by 1156%, growing from 1.18 million to 14.8 million (NBSC, 2005).

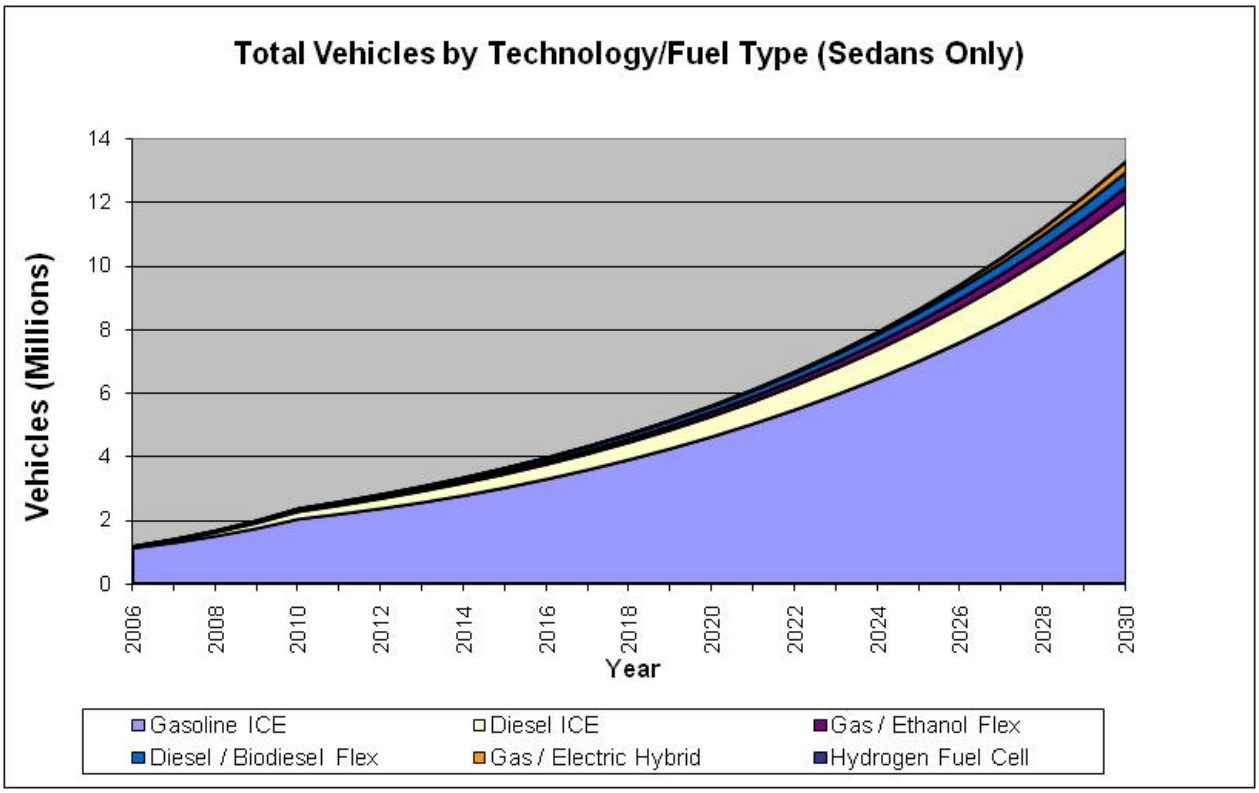
Researchers have estimated future vehicle ownerships in China using the car/GDP ratio (Kobos etc., 2003; WRI, 2005; Qinghua University, 2005) and concluded that vehicle ownership is expected to rise continuously.

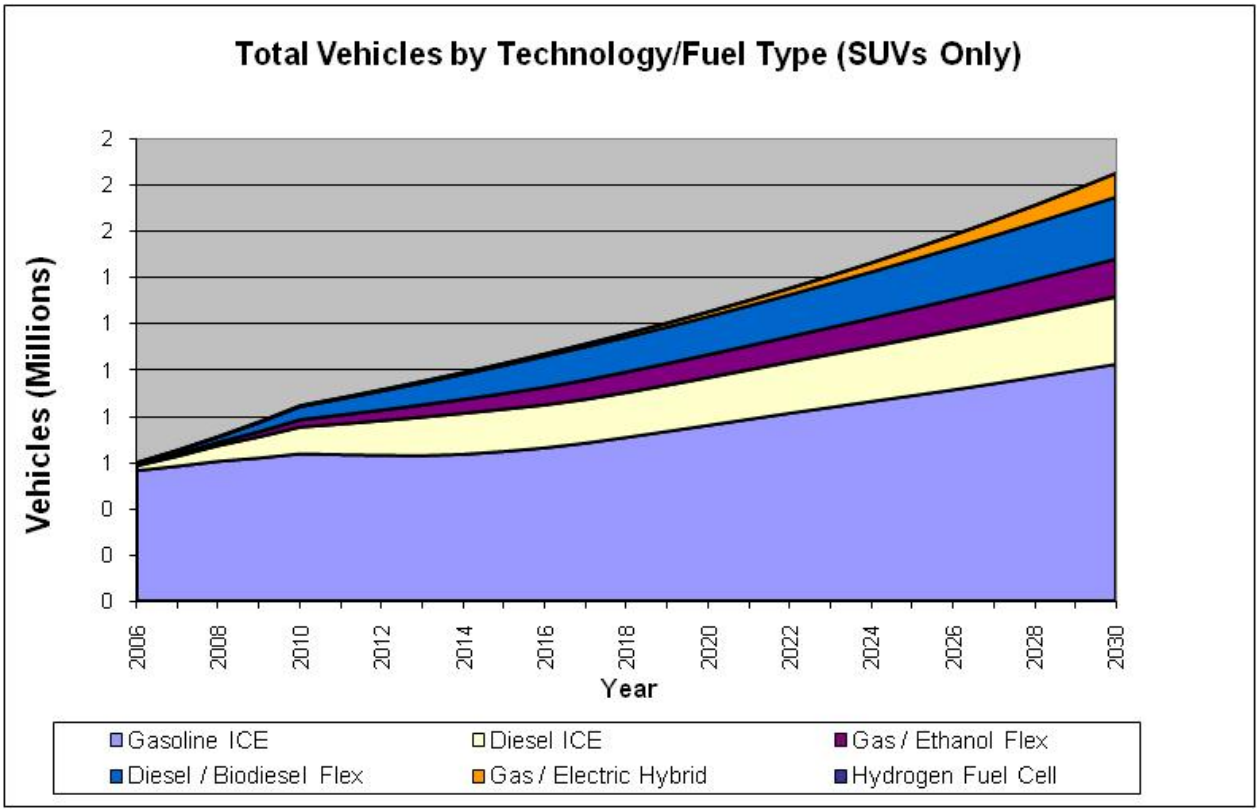
China has realized the challenges coming with motorization and is making efforts to build a sustainable transport sector. Integrated public transportation has been regarded as the development priority (NDRC, 2004; MOST, 2005). Considering the severe constraint on spaces in Chinese cities, it is possible that in the future the growth of vehicle ownerships will be slowing down. In this scenario, we assume that by the end of the 25 year period, private passenger vehicle ownerships will be 20% less than the baseline scenario.

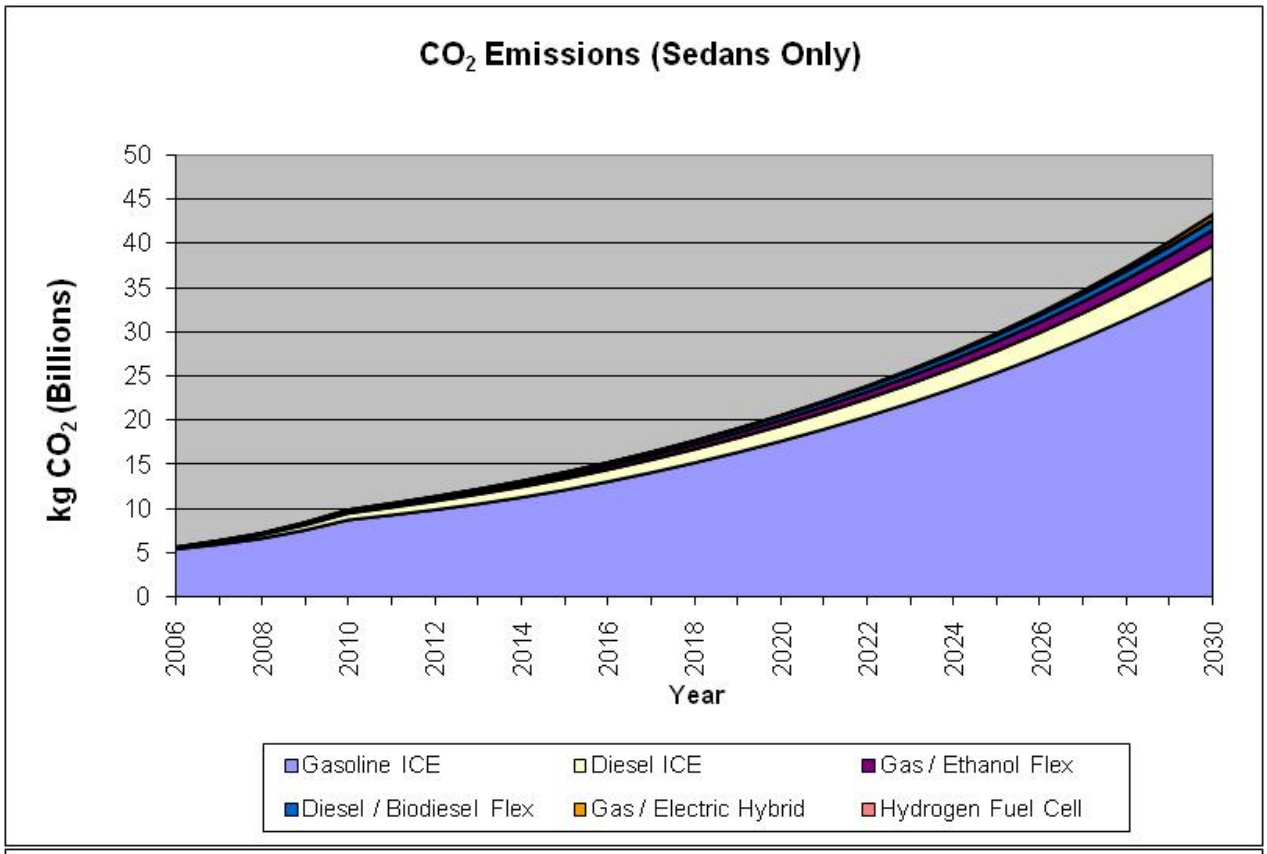
Figure 124(a-j): Chinese Alternative Scenario, Slowing Growth Rate

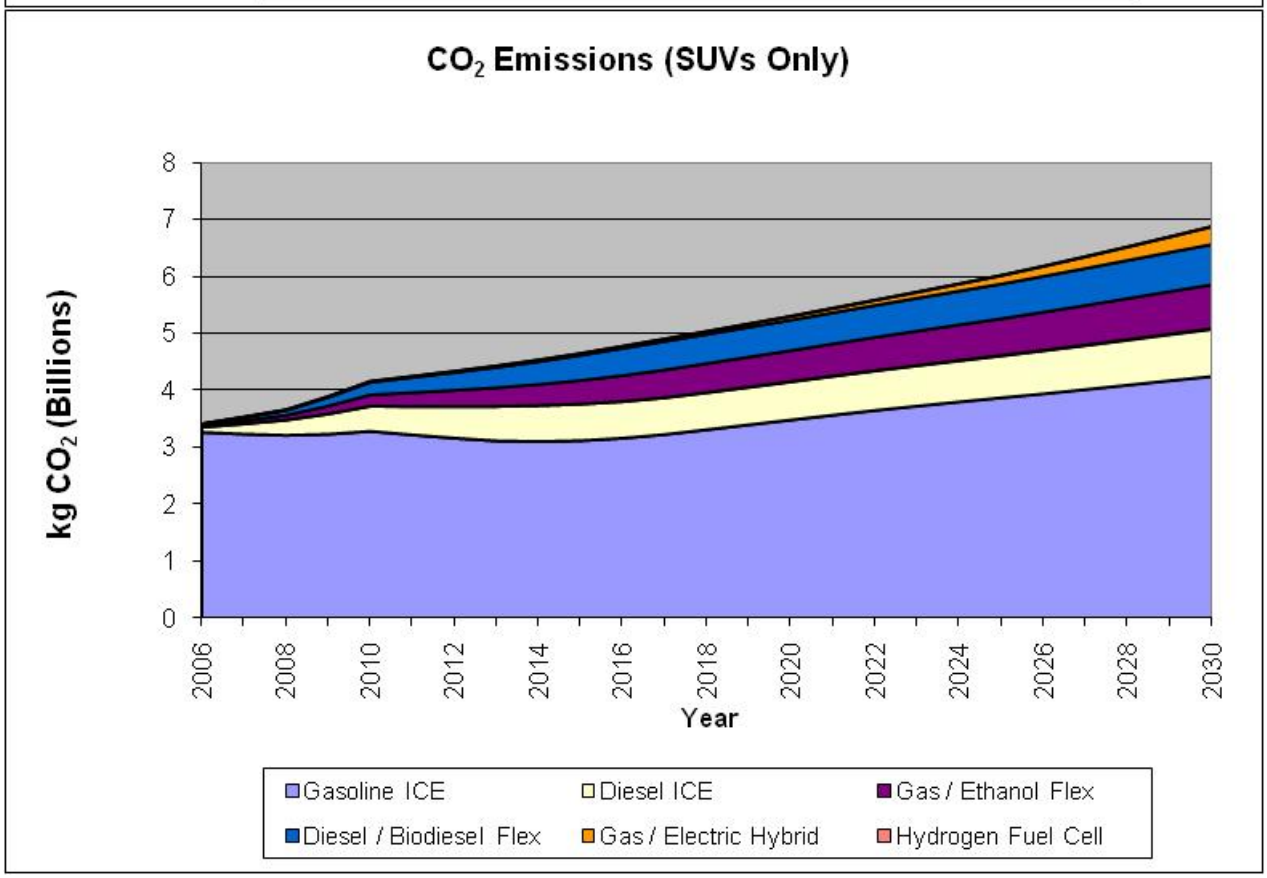


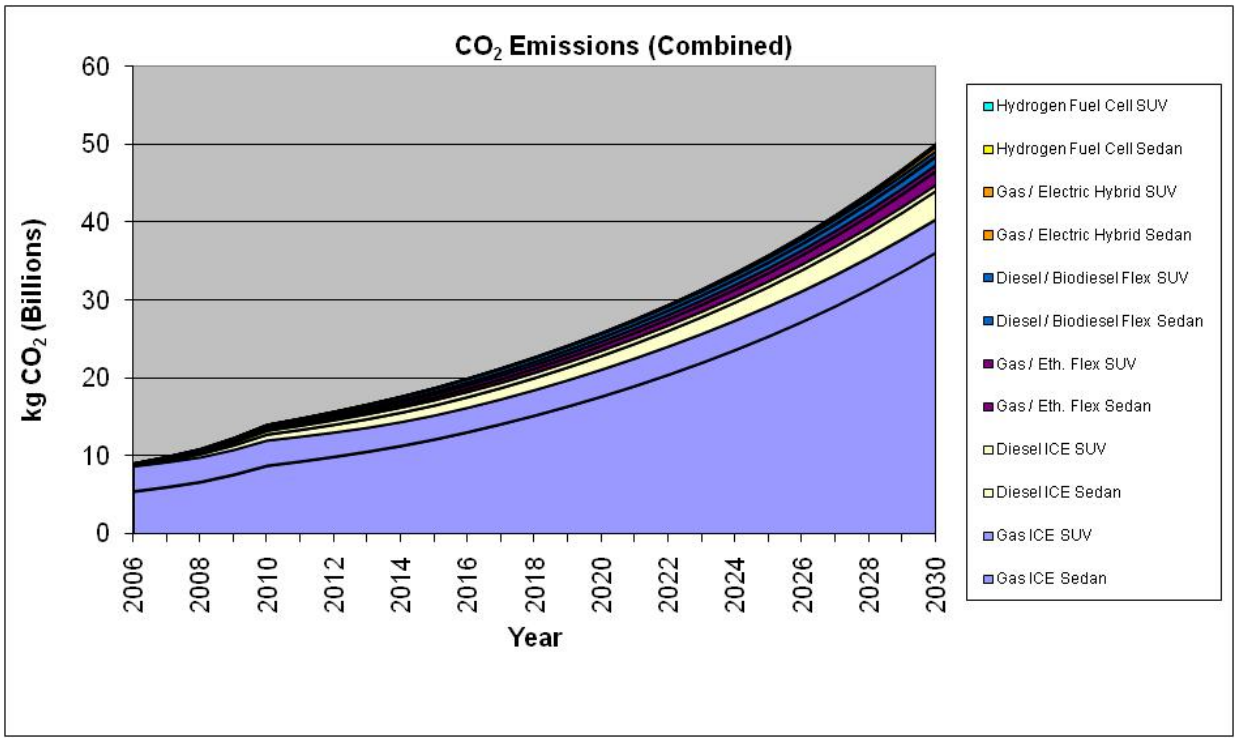


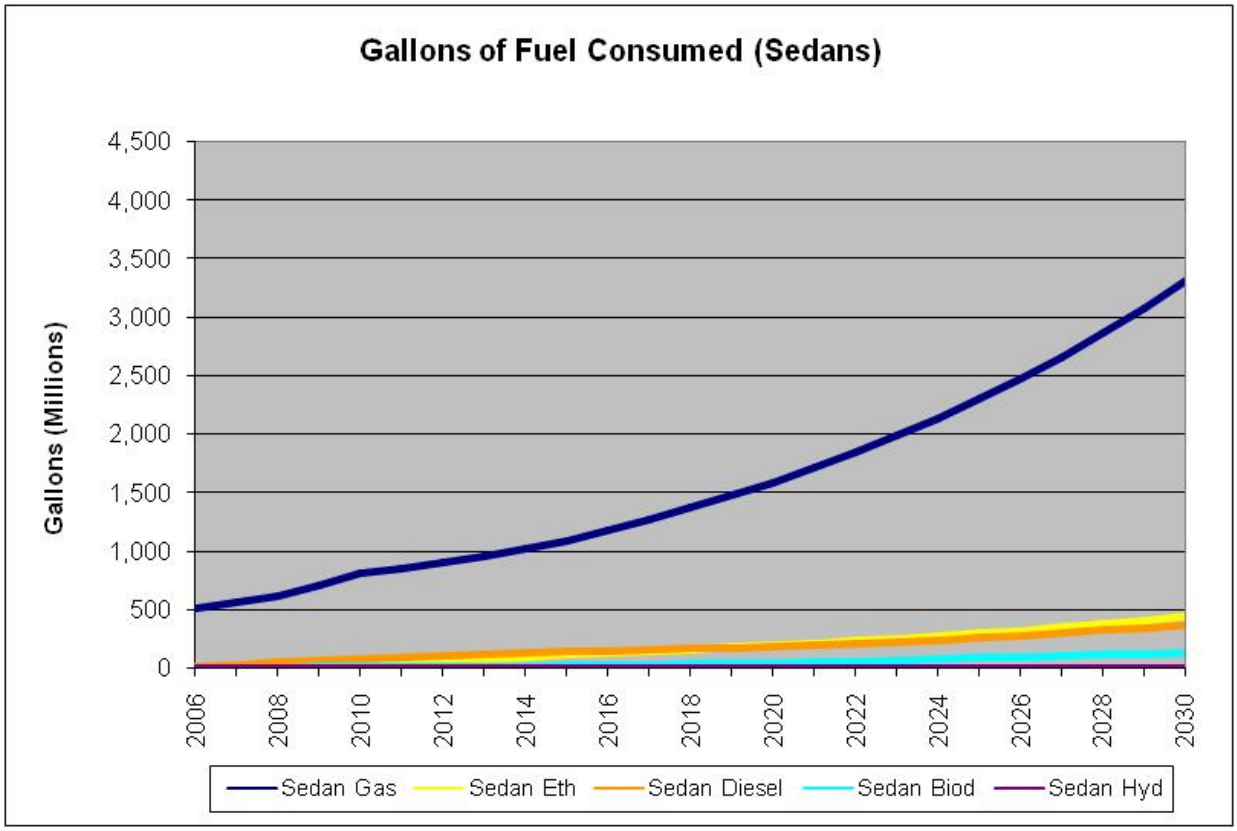

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
14
12
10
8
6
4
2
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

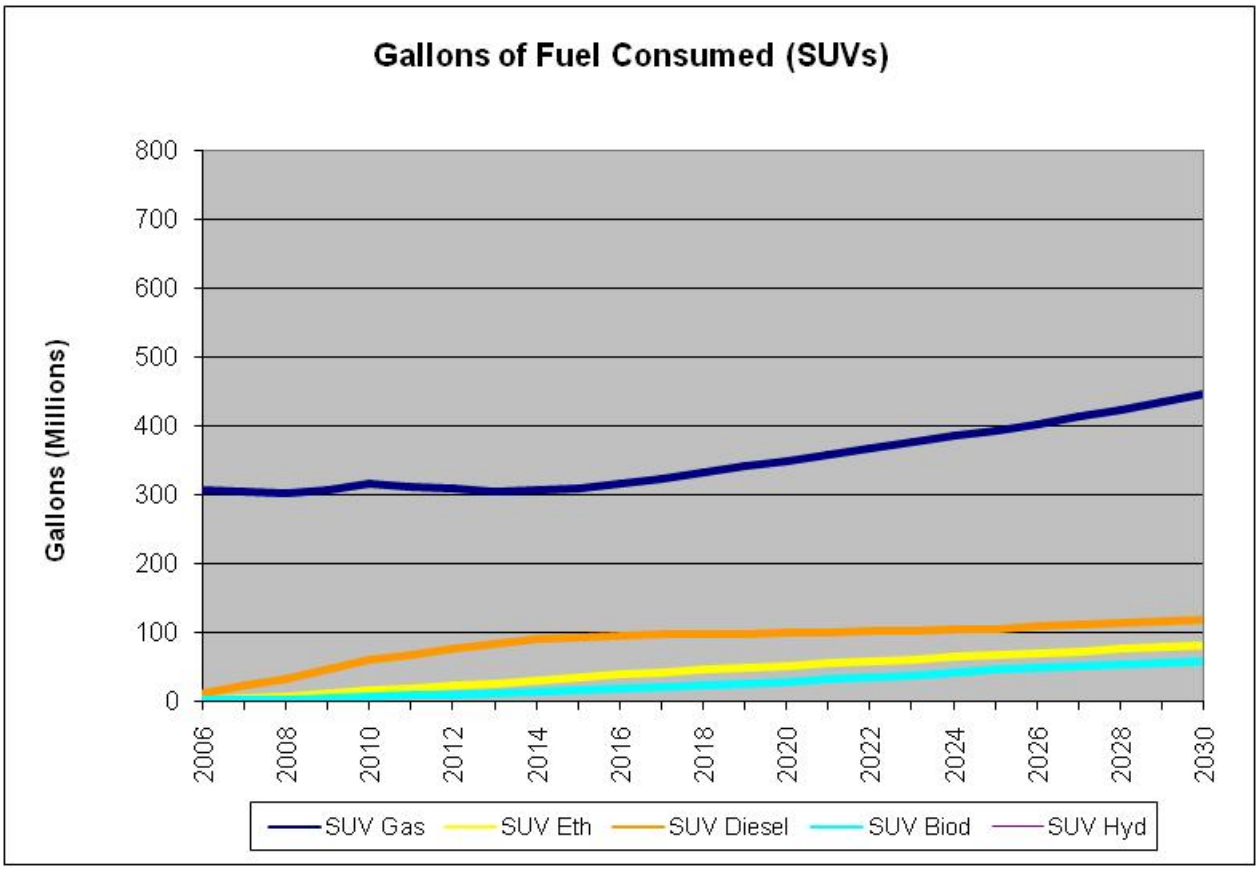

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
2
2
2
1
1
1
1
1
0
0
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
50
45
40
35
30
25
20
15
10
5
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
8
7
6
5
4
3
2
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Combined)
kg CO2 (Billions)
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


Gallons of Fuel Consumed (Sedans)
Gallons (Millions)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd


Gallons of Fuel Consumed (SUVs)
Gallons (Millions)
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
SUV Gas
SUV Eth
SUV Diesel
SUV Biod
SUV Hyd

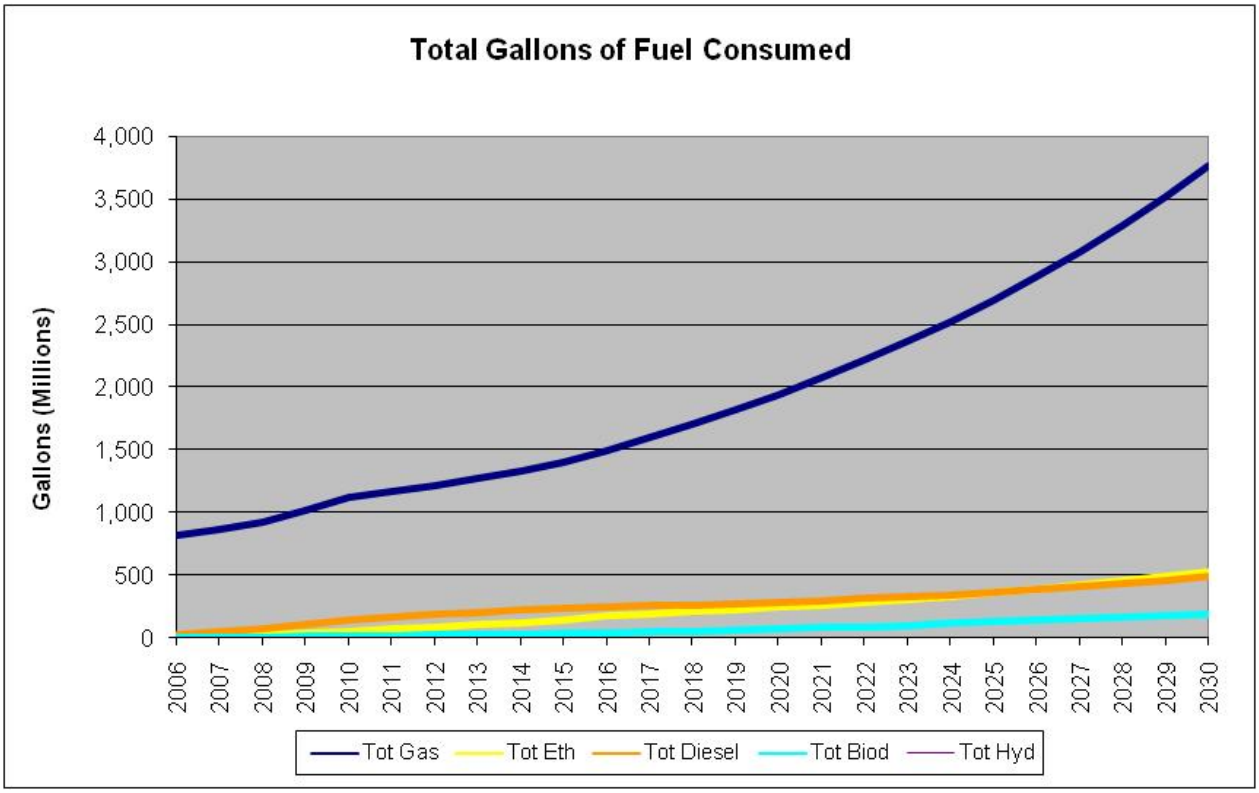

Total Gallons of Fuel Consumed
Gallons (Millions)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Tot Gas
Tot Eth
Tot Diesel
Tot Biod
Tot Hyd

Figure 125: Chinese Alternative Scenario, Slowing Growth Rate Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	12.72	101.25
% Reduction	20.24%	13.82%

CarCarbon simulation results illustrate that reducing of vehicle numbers does have a significant reduction in terms of CO_2 emissions. A 20% less of vehicle number by the end of 25 year period resulted in a 20.24% less emission in Year 2030 and a 13.82% less emission within 25 years. However, slowing the vehicle growth rate does not have any effect on the market percentage of technology types and vehicle miles traveled. If reduction benefit could be obtained from the latter two categories, a more substantial emission reduction could be achieved.

4.5.11. Hydrogen Scenario

According to domestic and international studies, it is estimated that the large-scale commercialization of cars with fuel cell will happen around the year of 2020, and the ultimate hydrogen economy will be realized between 2040 and 2050 (US DOE, 2002; European Commission, 2003; Toshiaki ABE, 2003; Wang and Ouyang, 2007). Officials and planners in China envision a situation in which China can “leapfrog” into the hydrogen economy. Indeed, it has been agued that a goal of hydrogen vehicles entering the marketplace in the 2015-2020 time frame in China is possible (MOST, 2004)

The Ministry of Science and Technology (2004) has envisioned three phases by which to transition to the hydrogen economy in China. The first phase (up to 2020) involves substantial research, development and demonstration work with strong government support and international collaborations. Public transportation, particularly in urban areas, is the vanguard of the hydrogen economy in China (MOST, 2004). In the second phase (2020-2050), there is increased use of hydrogen, primarily for public transportation, but also for personal vehicles and electric power applications. Hydrogen makes up about 1% of the overall energy market. The public will begin to gain access to economically competitive fuel cell vehicles in 2030. After 2050, hydrogen energy becomes competitive with other forms of energy, is generally accepted by the public, and is used to the extent China’s hydrogen infrastructure co-exists with conventional and other sustainable energy systems.

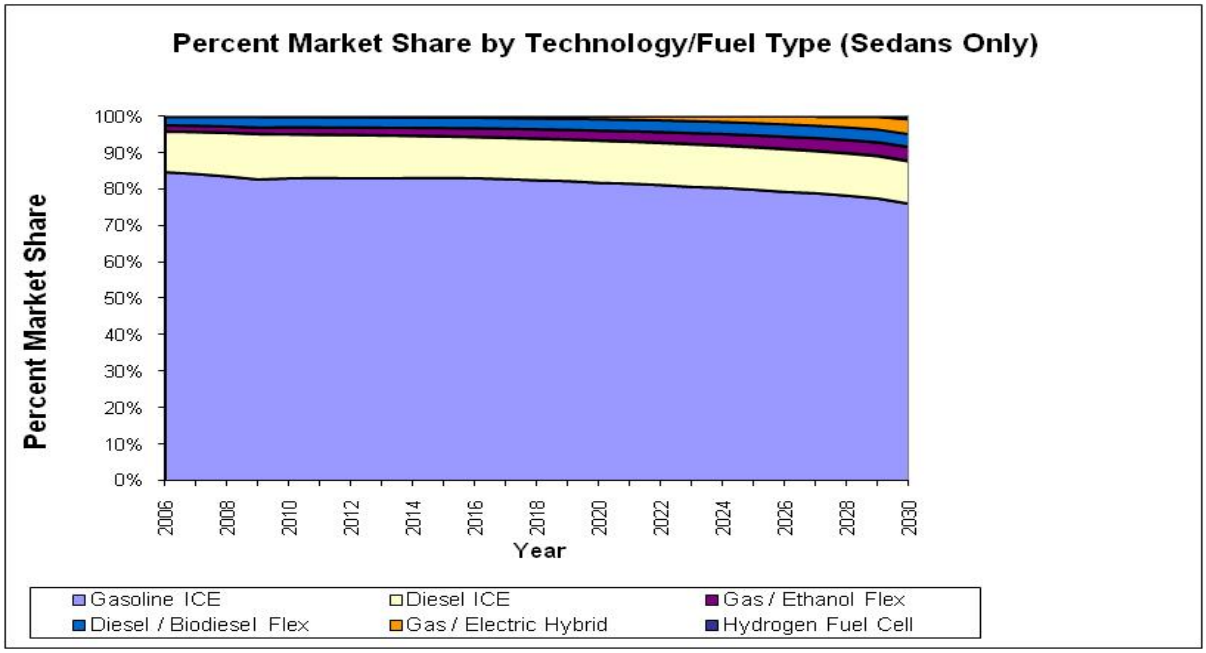
In the near term, hydrogen will be locally produced. After 2020, limited pipeline systems will augment local production to fuel clusters of hydrogen stations, extending the reach of hydrogen to a wider area. In the 2030-2050 time frame, hydrogen stations and regional pipelines will spread across China, particularly around cities that have high demand for hydrogen due to public transit use (MOST, 2004). The 8 million ton hydrogen production annually today in China could satisfy the energy demand of 6.6 million fuel cell cars (Wang and Ouyang, 2007).

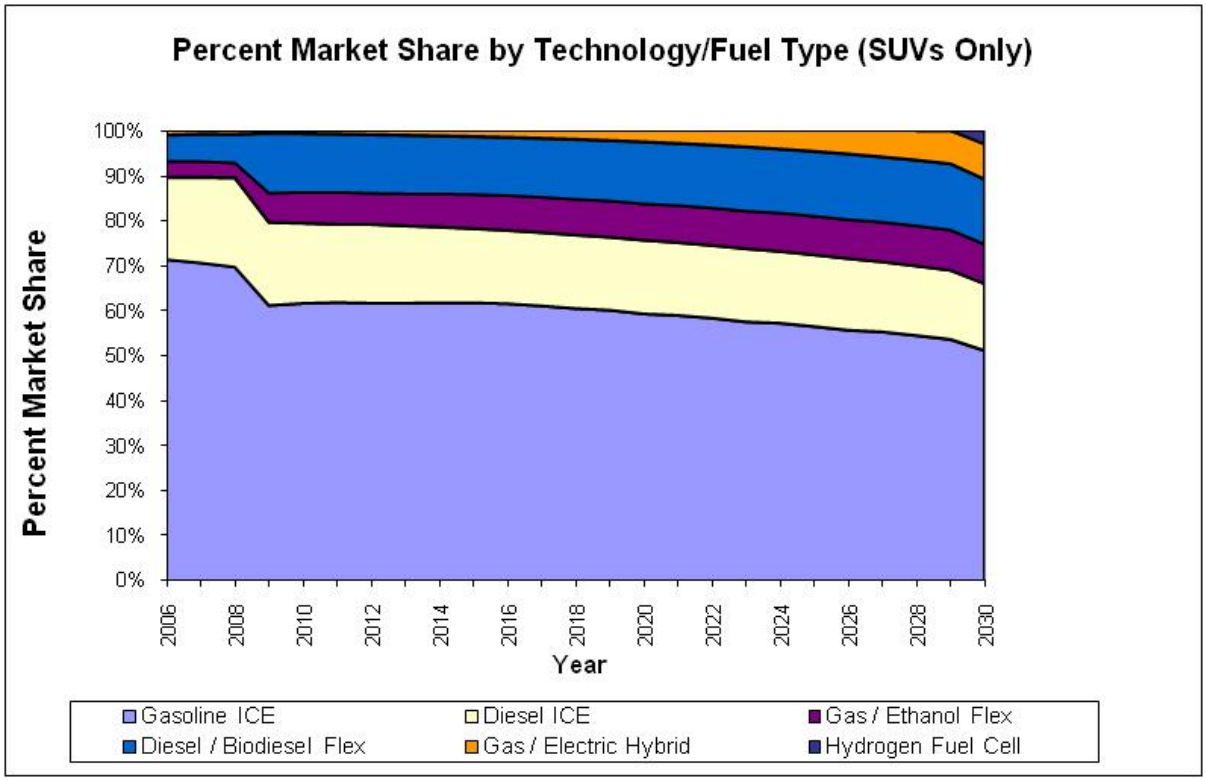
Hydrogen development faces a classic “chicken and egg” dilemma. Many people believe that the weak infrastructure construction equipped China with advantages for next generation vehicle development. This kind of advantage does not exist in industrial countries, therefore provide a better environment for R&D of new vehicles (MOST, 2004; Zhu, 2005; Wang and Ouyang, 2007). China has the advantage of being able to select from the latest technologies to jump over the technology gap (Gan, 2003).

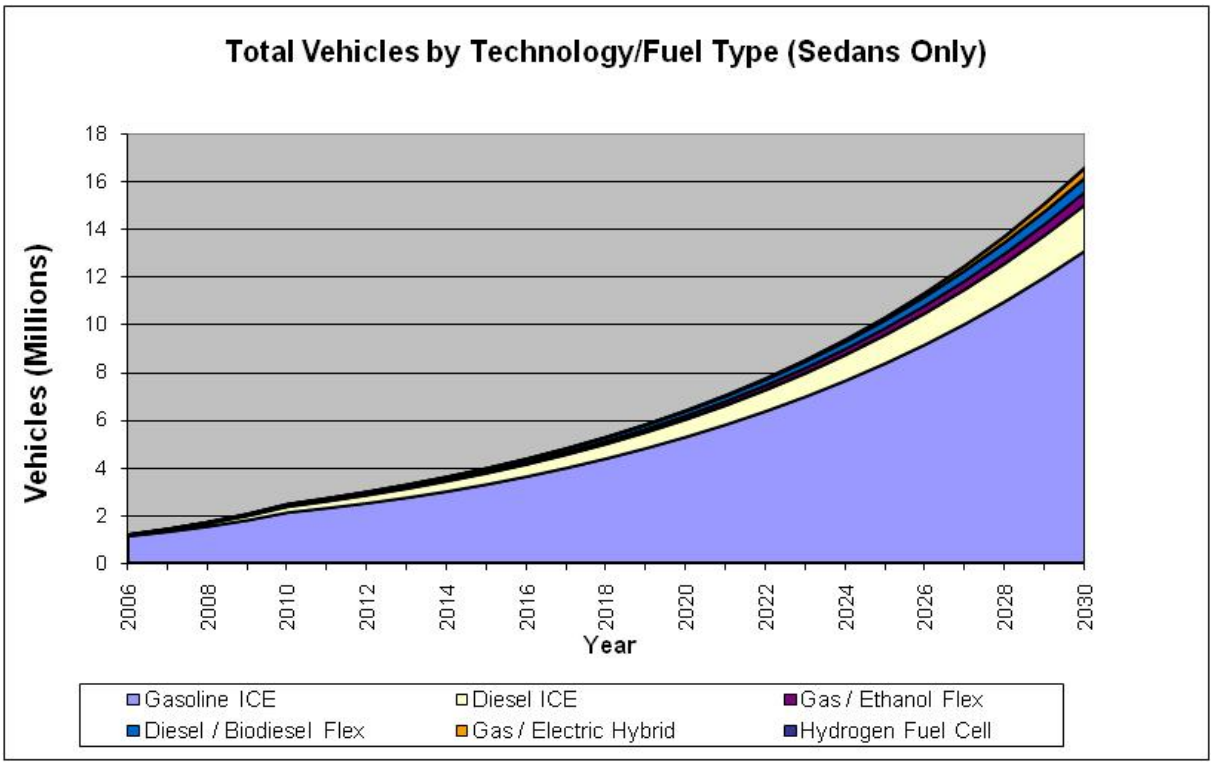
However, in order to achieve the above mentioned goals, a set of comprehensive policy strategies have to be taken to encourage research, development, demonstration of hydrogen vehicles, thus driving down the costs and making more makes and models available. According to the fuel cell passenger car testing results carried out by Chinese researcher (Wan, 2004; Wan, 2006), the fuel consumption is 0.95 kg hydrogen which is 3.51 of petrol equivalent for 100

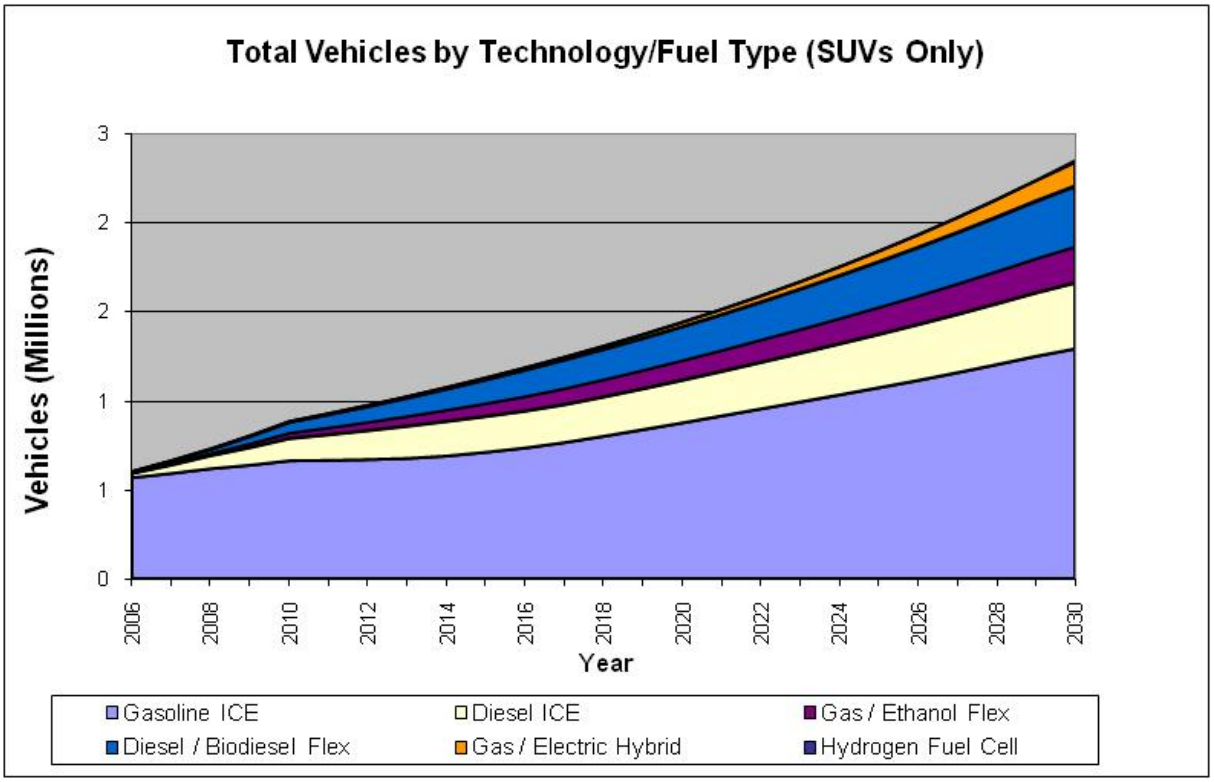
km. The efficiency could be higher as the theoretical fuel economy of hydrogen is high. With regard to fuel cell vehicle marketing, we expect that public transportation would be the major source of hydrogen consumption in the next 25 years. Financial incentives need to be used for promoting private passenger vehicles run on hydrogen. On the other side, infrastructure construction of hydrogen filling stations gradually starts to take off, by the year 2020 there would be a significant share of hydrogen stations.

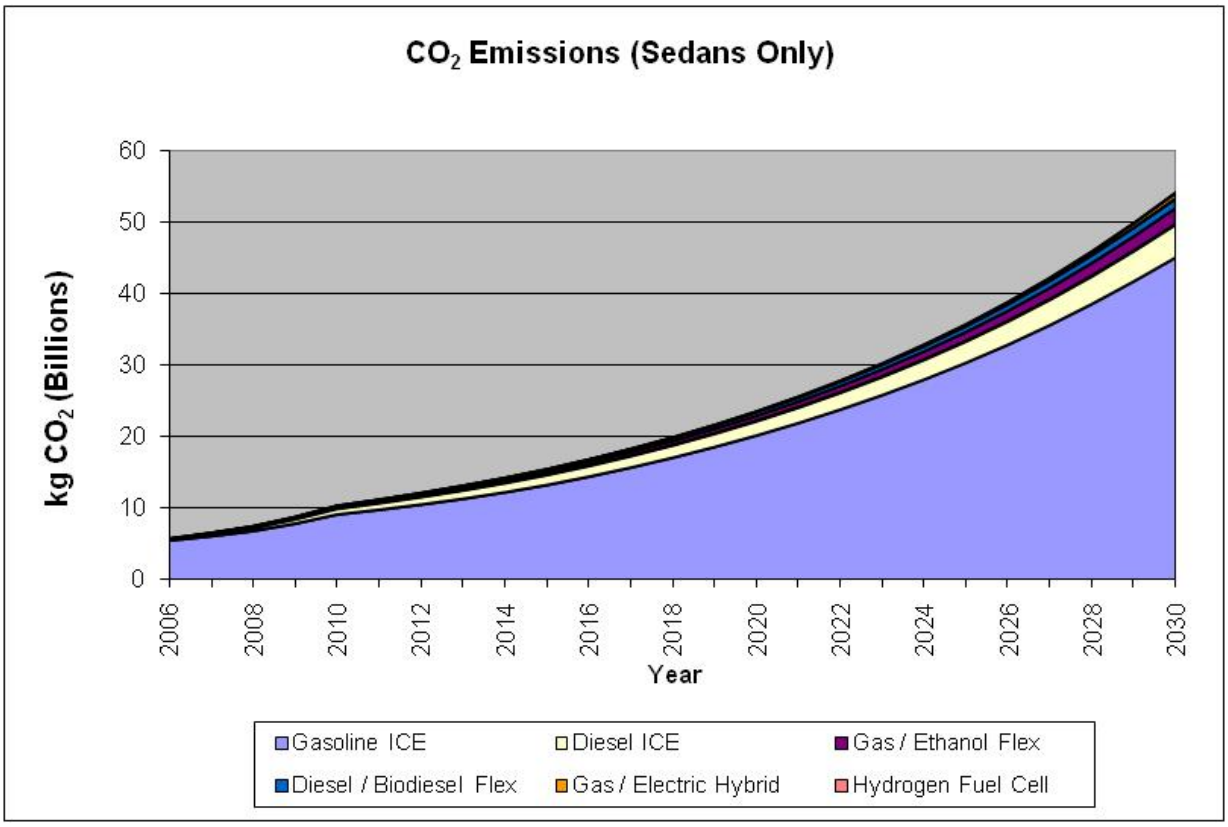
Figure 126(a-j): Chinese Alternative Scenario, Hydrogen

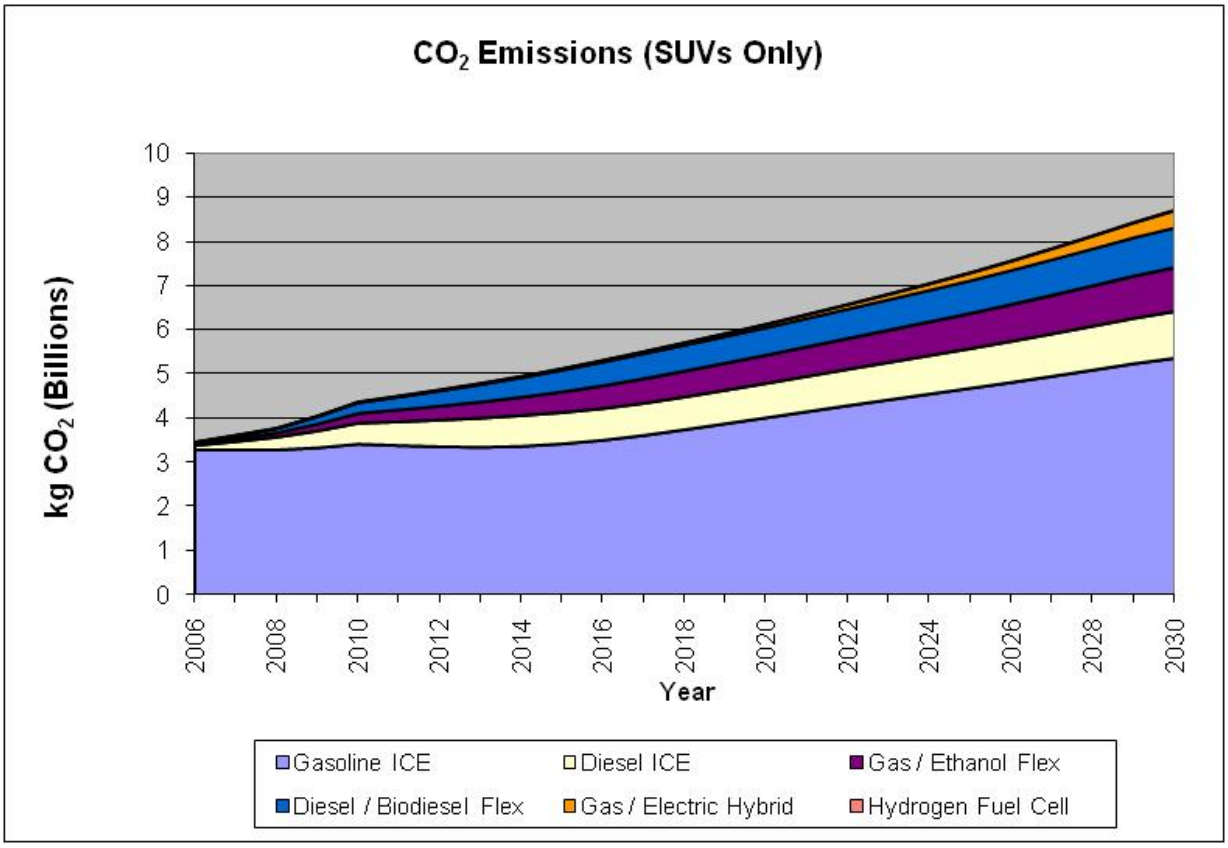


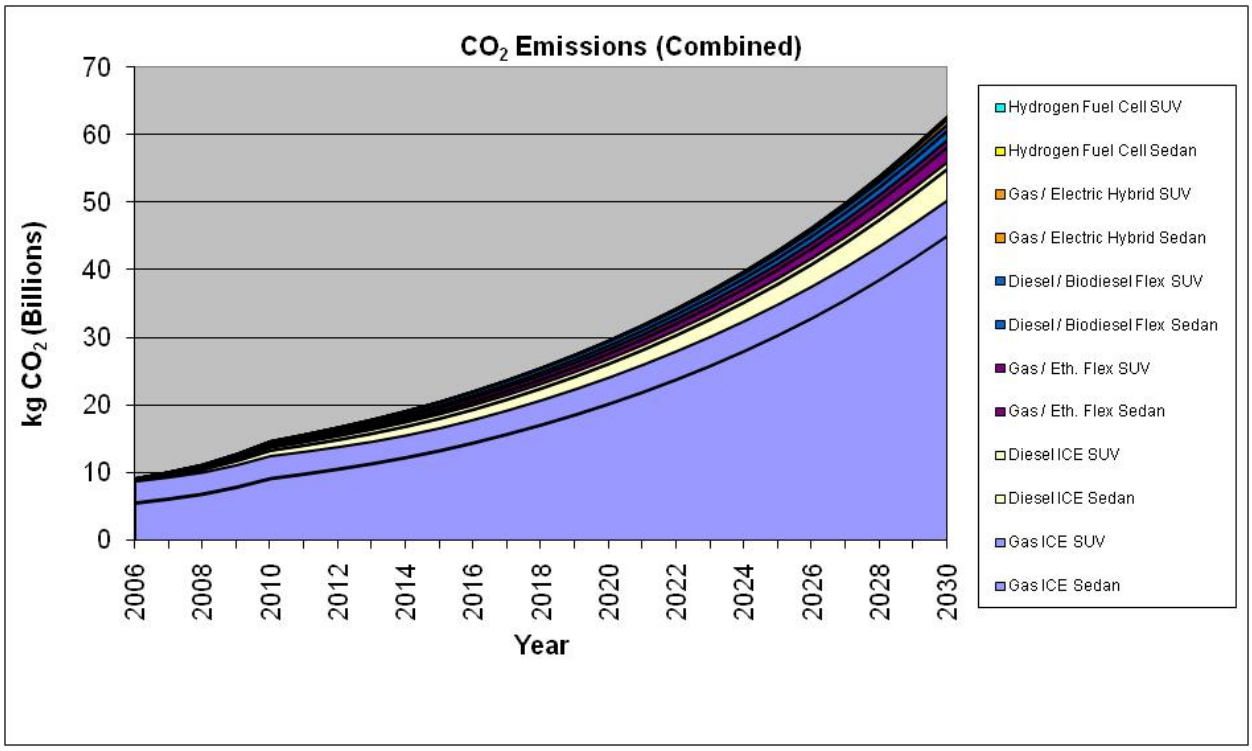


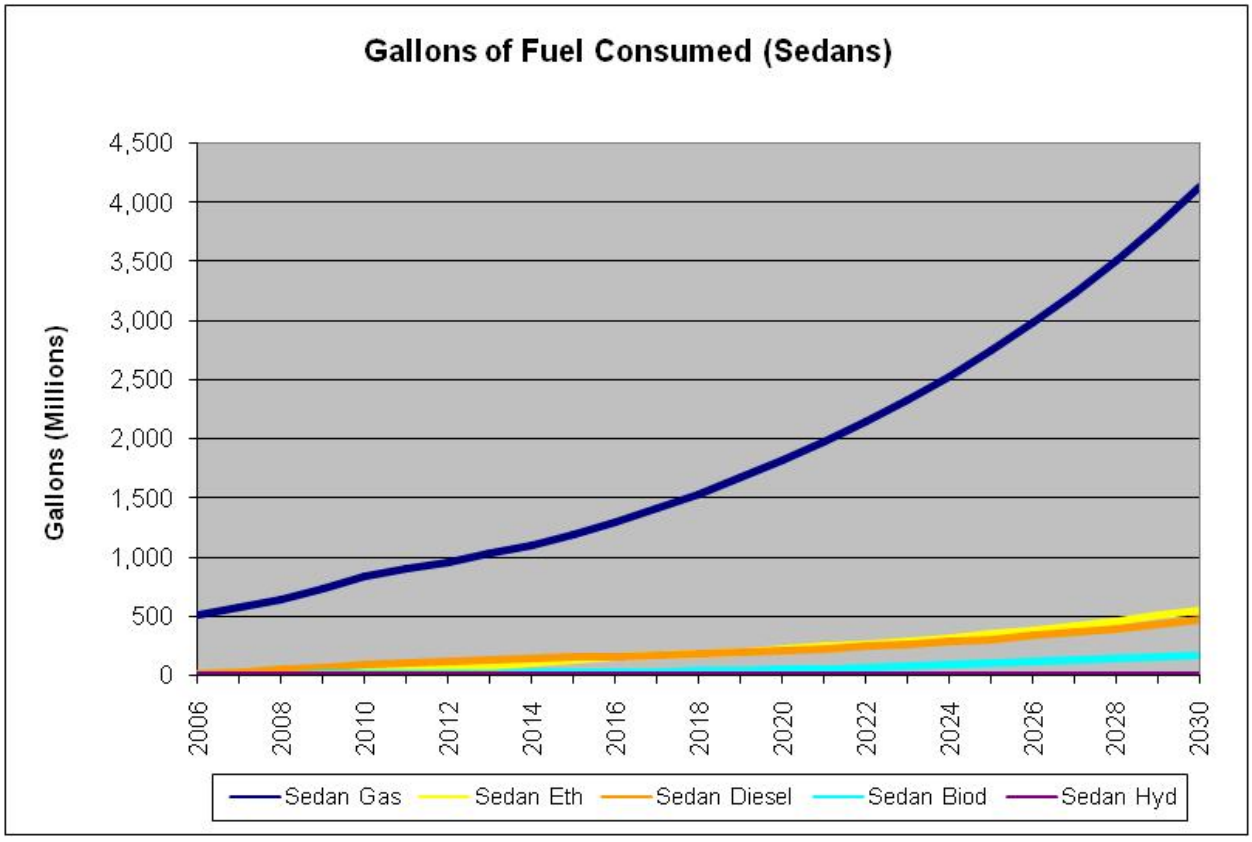

Total Vehicles by Technology/Fuel Type (Sedans Only)
Vehicles (Millions)
0
2
4
6
8
10
12
14
16
18
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell

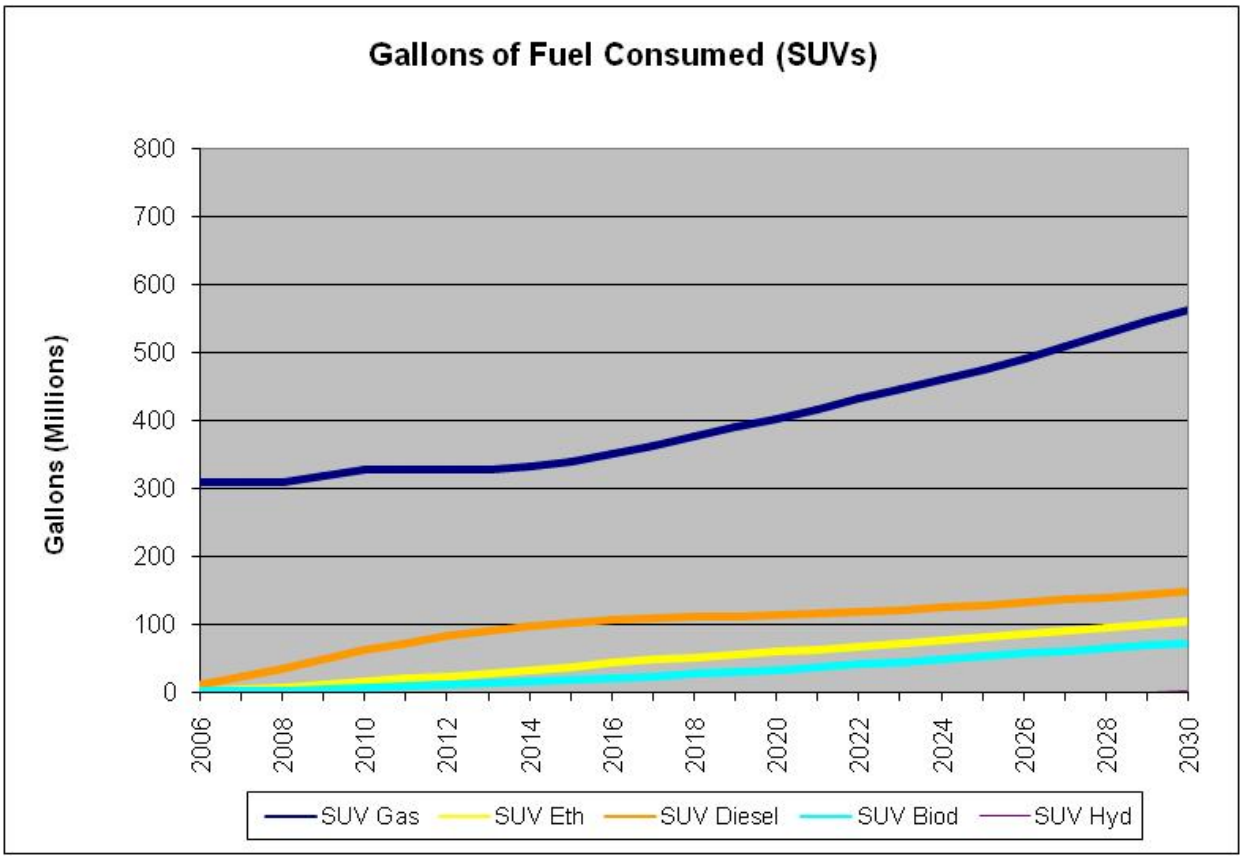

Total Vehicles by Technology/Fuel Type (SUVs Only)
Vehicles (Millions)
0
1
1
2
2
3
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Sedans Only)
kg CO2 (Billions)
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (SUVs Only)
kg CO2 (Billions)
10
9
8
7
6
5
4
3
2
1
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Gasoline ICE
Diesel ICE
Gas / Ethanol Flex
Diesel / Biodiesel Flex
Gas / Electric Hybrid
Hydrogen Fuel Cell


CO2 Emissions (Combined)
kg CO2 (Billions)
70
60
50
40
30
20
10
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Year
Hydrogen Fuel Cell SUV
Hydrogen Fuel Cell Sedan
Gas / Electric Hybrid SUV
Gas / Electric Hybrid Sedan
Diesel / Biodiesel Flex SUV
Diesel / Biodiesel Flex Sedan
Gas / Eth. Flex SUV
Gas / Eth. Flex Sedan
Diesel ICE SUV
Diesel ICE Sedan
Gas ICE SUV
Gas ICE Sedan


Gallons of Fuel Consumed (Sedans)
Gallons (Millions)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Sedan Gas
Sedan Eth
Sedan Diesel
Sedan Biod
Sedan Hyd


Gallons of Fuel Consumed (SUVs)
Gallons (Millions)
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
SUV Gas
SUV Eth
SUV Diesel
SUV Biod
SUV Hyd

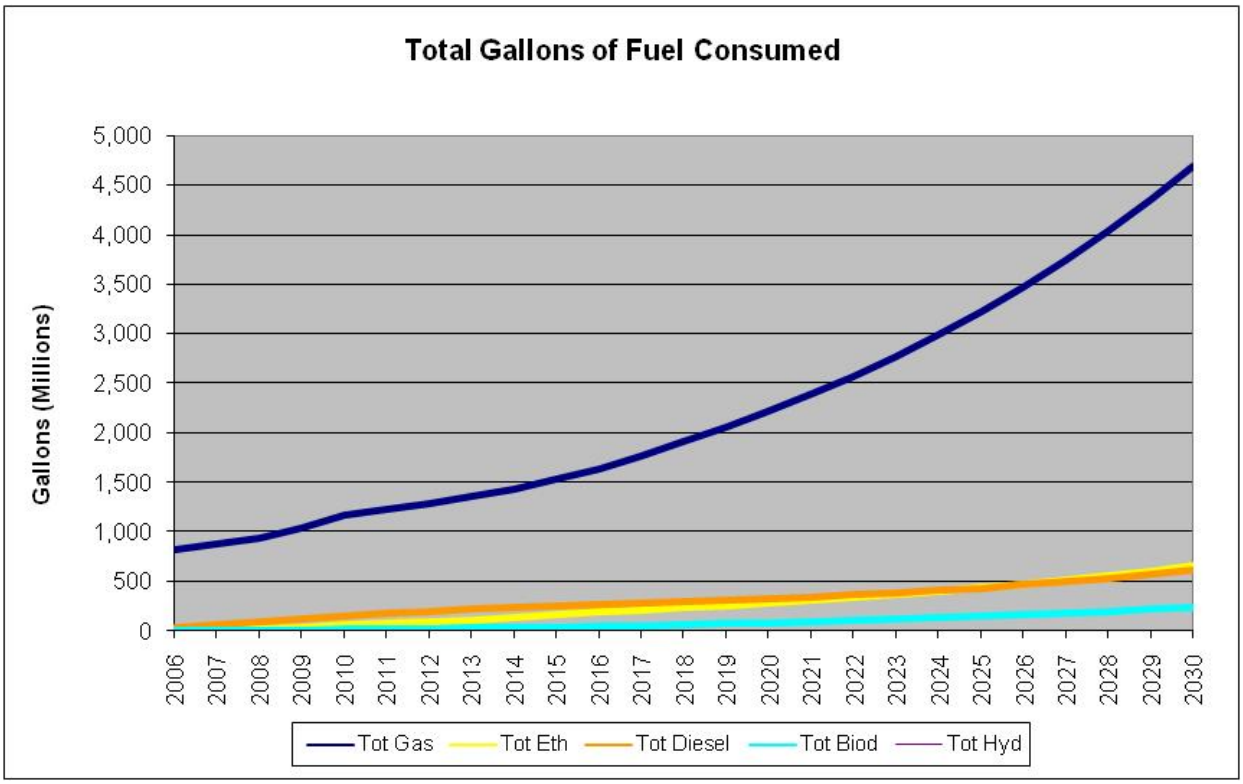

Total Gallons of Fuel Consumed
Gallons (Millions)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Tot Gas
Tot Eth
Tot Diesel
Tot Biod
Tot Hyd

Figure 127: Chinese Alternative Scenario, Hydrogen Summary Chart

	Year 2030 Emissions	Aggregate Emissions
Amount Reduced (Million Metric Tons)	0.11	0.21
% Reduction	0.18%	0.03%

As can be seen, the percentage of emission reductions in this scenario is very low. It is not a surprising result as the market share of hydrogen vehicles is relatively low. But compare to the arrogate emission reduction (0.03%), the slightly higher reduction percentage (0.18%) in the last year shows that the technology is promising in terms of cutting emissions. This is especially true when consider the tiny market share of hydrogen vehicle in year 29 and 30.

Model results also suggest that the polices adopted in this scenario are not enough for a transition to hydrogen economy in next 25 years. Consistent and strong support on research, manufacturing, marketing and infrastructure construction is needed for a better transition.

4.6 China Conclusions

Figure 128 summarizes the CarCarbon simulations of all of the China policy scenarios. All the proposed scenarios have influence of transport CO_2 emissions. As shown, a large increase of fuel economy achieves the highest reduction (21.76% in Year 2030 and 19.37% overall), followed by the scenario that reduce vehicle ownerships by 20% in Year 2030 (20.24% in Year 2030 and 13.82% overall). Reducing VMT also has significant impact on emission reduction, a 15% lower VMT resulted in 14.78% less emission in Year 2030, and 14.81% less emission over the 25 years.

Figure 128: Summary Chart of Chinese Scenario Results

	Scenarios	% decrease in 25th year	% Decrease in Aggregate
1st	Increasing fuel economy	21.76%	19.37%
2nd	Vehicle technology development	1.95%	1.07%
3rd	Alternative fuel development	0.24%	0.66%
4th	Fuel taxation	1.83%	1.59%
5th	Carbon taxation	0.87%	0.73%
6th	Vehicle taxation	2.54%	1.21%
7th	License plate fee	1.74%	0.76%
8th	Reducing VMT	14.78%	14.81%
9th	Slowing vehile growth rate	20.24%	13.82%
10th	Hydrogen	0.18%	0.03%

The hydrogen scenario we proposed only lead to a slight emission reduction benefit: 0.18% in the last year and 0.03% over the 25 years. Fuel taxation and carbon taxation both increase the cost of fuels, thus lead to slight reduction of emissions. The same effect can be seen as vehicle possession fee (vehicle taxation and license plate fee) increases, availability of makes and models grows (through vehicle technology development), and share of alternative fuels in fuel mix gets larger (through alternative fuel development).

In CarCarbon simulations, these policy scenarios run independent of each other. The figures show that single policy action is not enough for cutting CO_2 emissions, which suggests that in reality, a set of policy strategies should be taken together for reducing emissions, switching to alternatives and finally transit to hydrogen economy.

5. Conclusions

While an in-depth comparison between the China and U.S. scenarios was not possible at this date, a number of important conclusions may be drawn from these two studies, both on their own and through casual comparison. The primary pieces of data to be gathered from this study may be divided into three categories: 1) What effects the greatest level of change in vehicle populations?; 2) What effects the greatest level of change in carbon dioxide emissions?; and, 3) Under what conditions will a hydrogen economy be able to develop in the next 25 to 30 years?

In terms of effecting a change in the vehicle populations, by far the greatest impact was felt, in both sets of scenarios, by those policies and technological changes which caused a drop or rise in either fuel price or vehicle price. Effective, realistic policies demonstrating this effect included: alternative vehicle tax credits; carbon taxes on fuels; and subsidies to alternative fuels. An important point which must be made is that it would seem that these policies would work best in tandem, with both a carrot and a stick policy. One would act to drive the market share away from the undesired technology while the other would draw the consumers towards the most beneficial alternative technology. Without the carrot policy, the market share that leaves the dominant technology tends to be absorbed into several different technologies or into those that may have undesired effects such as into hybrid vehicles if the desired effect is maximum reduction in reliance on fossil fuel import or into ethanol flex vehicles if the desired effect is maximum reduction in carbon dioxide emissions.

Additionally, on their own, the impact of the carrot policies are far less substantial than the impact on the stick policies. Thus the greatest effect could be garnered by a combination of the two types of policy. Economically this makes sense as well. As the stick policies would tend to generate revenue through the application of taxes or fees while the carrot policies would tend to require income, such as incentives and subsidies. Thus, paired together properly, they could have a net zero impact on the economy creating as little upheaval as possible.

The effects on the carbon dioxide levels can be split into two general categories. Observing the final year of the policy instead of the aggregate effect on the course of the projection may lead to differing conclusions. Indeed, some policies may yield a high level of impact in the last few years of the study while others may achieve a high level of impact early in the study but only a moderate impact in the end, and others may accomplish both. This set of effects can divide the policies into their near and long term effects. Some of the policies only yield effects in the short term, others only in the long term, and some few affect both equally. None of these types of policies are unwanted or unneeded. Climate change is a problem that needs to be considered on the long term, yet also the time allotted for making change before dramatic irreversible effects occur is quickly running out. Therefore, an effect climate change strategy will effect change in both the near and long terms.

Thus, policies such as slowly shifting the consumer preference towards smaller sedans instead of SUVs and encouraging the growth of a hydrogen economy, which might not have the greatest impact on carbon dioxide emissions in the near term, have tremendous potential for long term benefits and an eventual sustainable transport sector. Additionally, policies such as, increasing fuel economy for gasoline ICEs, phased incentives for hybrid gasoline-electric vehicles, and carbon taxes on fossil fuel will yield long term scenarios that closely resemble the baseline scenario, but are by far the most effective at yielding the short term results that are necessary to avoid dramatic consequences from climate change in the coming century.

The final data to be gathered from this study is the level of effort that it will take in order to successfully develop a hydrogen transportation economy in the next 25 to 30 years. While there are many strategies that will reduce levels of emissions or at least slow there growth,

there are very few possibilities for reducing carbon dioxide emissions from the transport sector to near zero in the near, intermediate, or long terms. It is also difficult to find an policy or technology option that, once it has achieved a substantial reduction in carbon dioxide emissions will be able to maintain a low level of carbon dioxide in the long term in the face of growing populations, growing per capita vehicle ownership, and rising annual vehicle miles traveled in the developing world. The hydrogen transportation economy is one of the few options that could achieve this and the only one which seems socially, technologically, and economically reasonable at this point in time.

Yet at the same time, hydrogen faces a number of barriers and challenges, many of which translate into low consumer acceptance. Primarily, these are vehicle price, fuel price, fuel availability, and make and model availability. Of all of these, vehicle price and fuel availability are the most daunting. Yet, it was found that through a modest series of incentives and policies, hydrogen can be made successful in the time frame of the study. According to the baseline scenario, fuel prices are expected to drop over the next 15 years to levels that are reasonable compared to other fuels, thus it was not a barrier that needed to be dealt with.

Fuel availability and make model availability are both barriers, but they do not represent variables that need to be brought in line with the conventional vehicle and fuels or the other alternatives, instead they only need to be brought to a sufficient threshold level, at which point market forces could take over, and these levels were relatively low. In areas such as California, these are barriers that are already being overcome and there are many real world examples of how this may be successfully accomplished.

This leaves the final obstacle of vehicle price. Fuel cell vehicle prices are expected to drop, but not at such a rate that they will be within a reasonable level of conventional vehicle or other alternative vehicle prices. Thus, in order to make them competitive, an incentive, such as a tax credit, would have to be offered. The level of this incentive was questionable however, as, if it would need to be too high, it would be unreasonable to consider implementing.

Through experimentation, the level of the incentive needed to promote fuel cell vehicles in the U.S. was found to be $4,500-$5,500 per vehicle, a level which is reasonable when compared to the incentives offered recently from hybrid gasoline electric vehicles. As those incentives were scaled according to the vehicles reduction in emissions, the hydrogen fuel cell vehicles, which achieve a far greater reduction in emissions than hybrids even when the source of the hydrogen is fossil in origin due to their very high fuel economy, could reasonably expect to receive a higher incentive than that which was offered for the Toyota Prius ($3,150). Thus the level of the incentive needed was found to be within a level of reasonability and the other barrier variables, while daunting, have been proven to be surmountable.

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