Europe's Evolving Passenger Vehicle Fleet:
Fuel Use and GHG Emissions Scenarios through 2035

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ABSTRACT

Rising transport-related greenhouse gas (GHG) emissions and a growing imbalance between diesel and gasoline fuel demand is prompting concern, including significant policy discussions, over passenger vehicles in Europe. This study developed fleet models of France, Germany, Italy and the UK to evaluate fuel use and GHG emissions trends in these countries over the next 30 years. The models were run under three hypothetical scenarios, entitled *No Change*, *Diesels Dominate*, and *Alternative Technologies Emerge*. In the *No Change* scenario the existing vehicle sales mix, emphasis on reducing fuel consumption (ERFC) and fraction of biofuels in the fuel mix was held constant at 2005 levels. In the *Diesels Dominate* scenario and *Alternative Technologies Emerge* scenarios the ERFC was raised from a historic average 50 percent to 75 percent, and the fraction of biofuels in the fuel mix was increased over time to a 10 percent energy share by 2035. The two scenarios differed in that *Diesels Dominate* assumes that the sales fraction of diesel vehicles grows to 75 percent by 2035, whereas the *Alternative Technologies Emerge* scenario assumes that a mix of alternative powertrains (e.g. gasoline turbo, hybrids and CNG) achieve a 55 percent sales share by 2035. The scenarios and fleet models were used to evaluate the feasibility of proposed new vehicle GHG emission targets, the evolution of the diesel to gasoline fuel use ratio, and the relative ability for changes in the sales mix, ERFC and biofuels share to reduce fleet-wide fuel use and GHG emissions over the next 30 years.

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1. INTRODUCTION

Over the last several years, two distinct yet related passenger vehicle issues have been raised as major concerns for the European Union. The first and most public has been the rapid growth in transport-related greenhouse gas (GHG) emissions. In 2005 the European Environmental Agency reported that the transport sector, within which passenger vehicles constitute a significant fraction of total emissions, presented one of the largest obstacles to meeting upcoming Kyoto Protocol targets (European Environmental Agency 2005). It was one of only a few sectors that had experienced a growth in GHG emissions since 1990. In fact, between 1990 and 2005, transport-related emissions increased by 26 percent while total EU-27 emissions fell by approximately 8 percent (European Environmental Agency 2008). The other major concern is a widening imbalance between the demand for diesel and gasoline fuel (CONCAWE 2007). Currently, Europe's differential consumption of diesel versus gasoline is well-matched by the US, to whom Europe exports excess gasoline in exchange for diesel. There is growing unease within Europe's refining industry, however, that this trend could become unsustainable.

European policymakers have responded to these issues in a number of ways. Beginning in July of 1998 they negotiated with the European automobile manufacturer's association to enter a voluntary commitment, promising to reduce new car carbon dioxide (CO_2) emissions to a fleet-wide average of 120 g/km by 2012 with an interim target of 140 g/km by 2008 (European Automobile Manufacturer's Association 2002). Within the voluntary agreement there was also language that suggested 95 g/km by 2020 was a reasonable engineering target. In 2007 when it did not look as if automakers were going to achieve the interim target, the European Commission proposed making the 120 g/km by 2012 a binding target. After several months of negotiation, a compromise solution was proposed. Vehicles were to achieve 130 g/km by 2012, while a variety of supplemental measures, namely biofuels, were to contribute the remaining 10 g/km required to reach a net effective 120 g/km emission level. Around this time, the European Commission introduced a proposal to require all road fuels to contain 10 percent by energy biofuels by 2020. A separate and even more stringent proposal has suggested that the GHG intensity of the road fuel mix be reduced 1 percent per year starting in 2011, such that the GHG intensity of the 2020 fuel mix is 10 percent lower than in 2010 (European Commission 2007a).

Despite a wide array of ambitious policy proposals, which to date have been focused on reducing GHG emissions, it remains unclear whether they are achievable and, if obtained, what their fleet-wide impacts would be. As such, the purpose of this research was to evaluate fuel use and GHG emissions across several prominent European countries over the next 30 years, using customized fleet models. Rather than attempting to be predictive, the models were used to illustrate the consequences of a wide range of outcomes, such as continued dieselization, the widespread adoption of alternative powertrains (e.g. hybrids), a shift toward greater emphasis on reducing fuel consumption and the introduction of biofuels at scale.

2. FLEET MODEL DEVELOPMENT

2.1 Selected European Countries

Four out of the 27 European Union (EU-27) member countries were modeled, including France, Germany, Italy and the United Kingdom (UK). These countries were chosen because, as shown in Table 1, they collectively account for over half of the EU-27's human population, passenger vehicle population and road transport-related GHG emissions. These countries are also of interest because they are each at a different phase of the trend towards dieselization in Europe. For instance, in 2005 over 2/3 of passenger vehicles registered in France were diesels, whereas only approximately 1/3 of new registrations were diesels in the UK (European Automobile Manufacturer's Association 2008).

Table 1: Human population, passenger vehicle population and road transport-related GHG emissions in 2005.

Country	Population		Vehicles		GHG Emissions	
	(10^6)	(%)	(10^6)	(%)	(10^6 tons CO_2 equiv.)	(%)
EU-27	492.0	100	214.0	100	922.6	100
France	62.8	13	30.0	14	135.2	15
Germany	82.5	17	46.1	22	153.6	17
Italy	58.6	12	35.3	16	121.5	13
United Kingdom	60.2	12	26.2	12	125.4	14
Share of EU-27	264.1	54	137.6	64	535.7	58

Source: (European Commission 2008).

2.2 Fleet Model Overview

The future passenger vehicle fuel use and GHG emissions from the four countries was analyzed using a Microsoft Excel-based fleet model. The model was initially developed in MIT's Sloan Automotive Laboratory and is depicted schematically in Figure 1. The model begins by using annual vehicle sales figures and the following scrappage equation to determine the stock of vehicles in the fleet for any given model year:

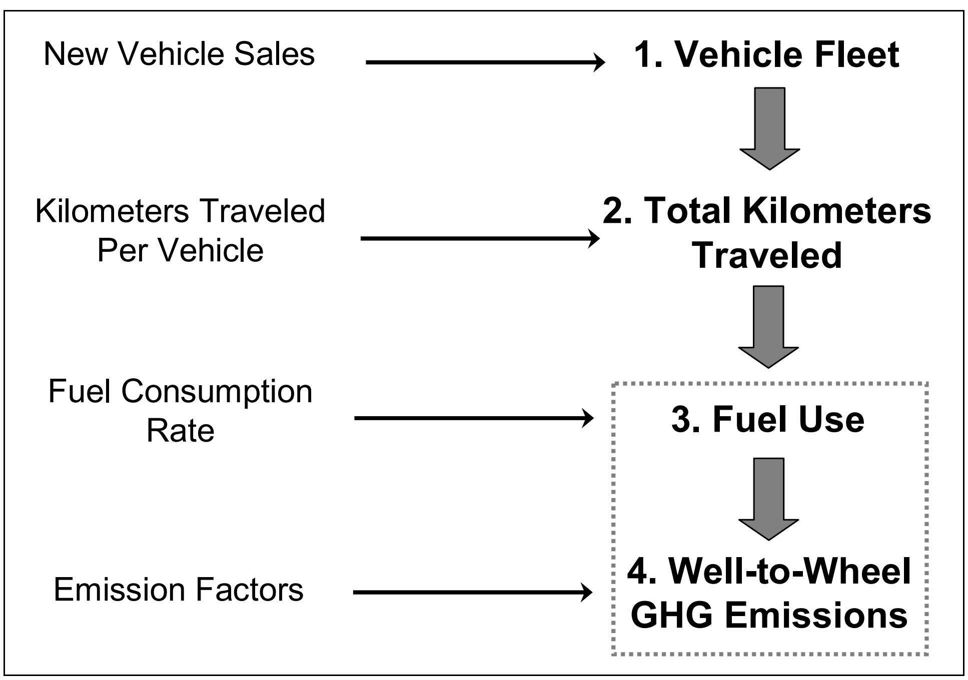
$$1 - \text{Survival Rate (t)} = \frac{1}{1 + e^{-\beta(t - t_0)}} \quad ,$$

where,

- t_0 is the median age of vehicles when they are scrapped,
- t is the present age of a given vehicle,
- and β is a parameter that expresses how quickly vehicles are retired around t_0.

The number of vehicles in the fleet from each model year is then multiplied by the number of kilometers those vehicles traveled in that year. It is assumed that the number of kilometers traveled by an average car declines linearly with age. Third, the total kilometers traveled are multiplied by the corresponding fuel consumption of vehicles from that model year to yield the total amount of fuel used by the fleet in a given year. Finally, the amount of each type of fuel consumed is multiplied by its corresponding well-to-tank and tank-to-wheel emission factor to give the total GHG emissions emitted by the fleet.

Figure 1: Fleet model schematic.



2.3 Key Assumptions

In addition to choosing an appropriate scrappage model or vehicle kilometers traveled (VKT) decline rate, several other assumptions are required to operate the fleet model. These assumptions, which are described in detail below, include the future growth rate of new vehicle sales, the fuel consumption of new vehicles and the VKT behavior of gasoline and diesel vehicles.

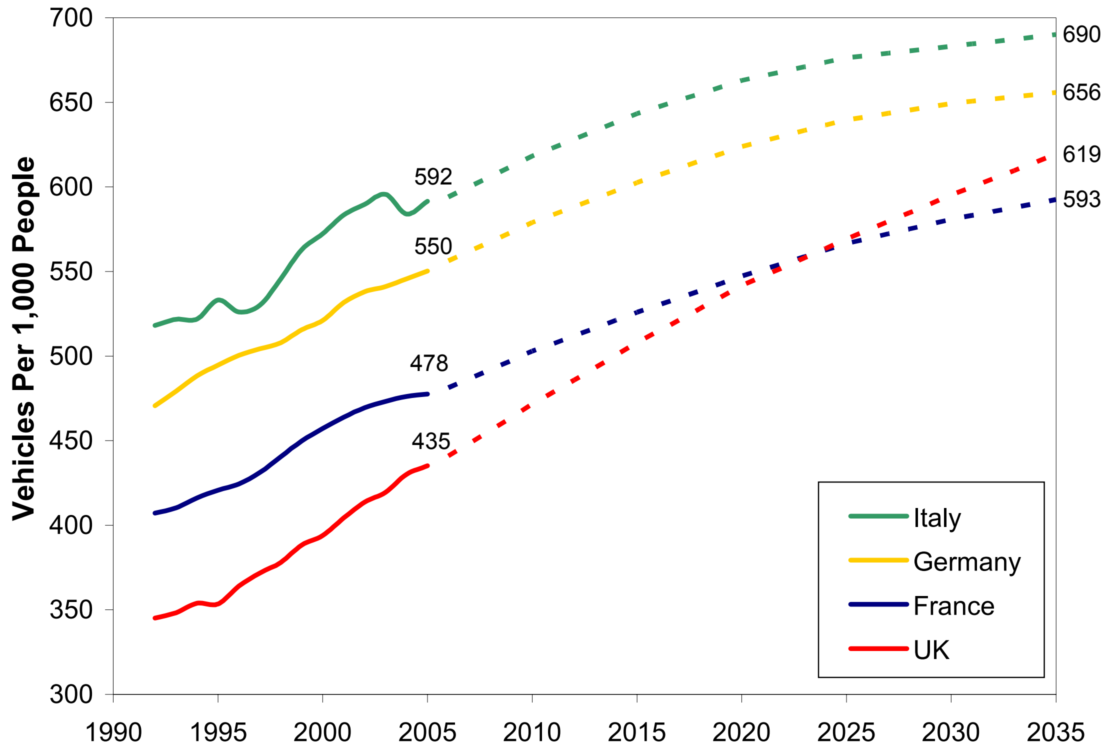
2.3.1 Timeframe (2005-2035)

A 30 year timeframe, from 2005 through 2035, was chosen over which to evaluate the results from the fleet model. The timeframe was capped at 30 years because, as will be discussed later, the authors were not confident in their ability to project improvements in vehicle performance, among other factors, beyond this time period. A shorter timeframe was ruled out because it is known that slow rates of fleet turnover imply that it can sometimes take several decades before changes in fleet fuel use and emissions are manifested.

2.3.2 Sales Growth Rate of New Vehicles

New vehicle sales growth rates were estimated using United Nations population growth rate estimates and historical motorization (i.e. vehicles per 1,000 people) trends. New sales growth rates, using a 5-year interval, were chosen such that the number of vehicles in the entire fleet would be sufficient to sustain the historical motorization trend of each country, given simultaneous changes in its human population. Figure 2 illustrates the historical motorization trend since 1990 in France, Germany, Italy and the UK. It also shows the author's estimates of future motorization, which were derived by extrapolating the motorization trend-line of each country, which as a whole increases at a declining rate. Table 2 details the estimated new sales growth rates necessary for achieving these rates of motorization, as well as the corresponding United Nations population growth rate projections.

Figure 2: Historical (solid lines) and hypothetical future (dotted-lines) motorization rates (European Commission 2008).



Source: (European Commission 2008 and United Nations 2005).

Table 2: United Nations population growth rate projections and new sales growth rate estimates.

		UN Population and New Vehicle Sales Growth Rate (%)						
		Average	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030	2030-2035
France	Pop.	-0.08	0.0	0.0	-0.1	-0.1	-0.1	-0.2
	Sales	0.33	1.5	1.0	0.5	0.0	-0.5	-0.5
Germany	Pop.	0.17	0.3	0.3	0.2	0.1	0.1	0.0
	Sales	0.83	2.5	1.5	0.5	0.5	0.0	0.0
Italy	Pop.	-0.20	0.0	-0.1	-0.2	-0.3	-0.3	-0.3
	Sales	0.50	1.5	1.0	1.0	0.0	0.0	-0.5
UK	Pop.	0.30	0.3	0.3	0.3	0.4	0.3	0.2
	Sales	1.08	1.5	1.5	1.0	1.0	1.0	0.5

Source: (United Nations 2005).

2.3.3 Vehicle Sales Mix

Several sales mix scenarios were examined, each of which included up to six different powertrain technologies: diesel, naturally-aspirated (NA) gasoline, turbocharged gasoline, gasoline hybrid, diesel hybrid and compressed natural gas (CNG). These technologies were chosen because they are either currently sold in large numbers or, in the case of diesel hybrids, because at least a few major manufacturers have announced plans to commercialize their technologies over the next several years (Les Echos 2008 and Green Car Congress 2007). Fuel cell vehicles and plug-in hybrids were not considered because the authors do not expect them to account for a significant fraction of new vehicle sales (e.g. equal to or greater than 5 percent) in Europe by 2035. This judgment is based on the fact that there are currently no announced plans to commercialize either technology in Europe, cost premiums are projected to be high, and infrastructure challenges pose additional hurdles for adoption.

The three sales mix scenarios that will be discussed are entitled *No Change*, *Diesels Dominate* and *Alternative Technologies Emerge*. They are represented quantitatively in Table 3 and described qualitatively below.

No Change

The *No Change* scenario assumes that diesel, NA gasoline, and turbo gasoline vehicles continue to be sold in the future at the same relative proportion as they were in 2005. As a simplification, the 2005 sales fractions for hybrid gasoline, hybrid diesel and CNG vehicles was assumed to be zero percent, since these vehicles captured less than one percent of new sales in each of the four markets in 2005.

Diesels Dominate

The *Diesels Dominate* scenario assumes that diesel vehicles continue to capture a larger and larger share of new sales and that by 2035 they account for 75 percent of new sales in each of the four markets. Under this scenario, the marketshare of gasoline turbo vehicles maintains its 2005 share and the growing diesel share causes a decline in the share of NA gasoline vehicles.

Table 3: Hypothetical 2035 vehicle sales mix scenarios.[1]

		2005	2035		
		Today	No Change	Diesels Dominate	Alternative Technologies Emerge
France	Diesel	69	69	75	35
	NA Gasoline	28	28	22	10
	Gasoline Turbo	3	3	3	30
	Gasoline Hybrid	0	0	0	15
	Diesel Hybrid	0	0	0	5
	CNG	0	0	0	5
Germany	Diesel	43	43	75	30
	NA Gasoline	51	51	19	15
	Gasoline Turbo	6	6	6	30
	Gasoline Hybrid	0	0	0	15
	Diesel Hybrid	0	0	0	5
	CNG	0	0	0	5
Italy	Diesel	59	59	75	35
	NA Gasoline	37	37	21	10
	Gasoline Turbo	4	4	4	30
	Gasoline Hybrid	0	0	0	15
	Diesel Hybrid	0	0	0	5
	CNG	0	0	0	5
UK	Diesel	38	38	75	25
	NA Gasoline	56	56	19	20
	Gasoline Turbo	6	6	6	30
	Gasoline Hybrid	0	0	0	15
	Diesel Hybrid	0	0	0	5
	CNG	0	0	0	5

Alternative Technologies Emerge

The *Alternative Technologies Emerge* scenario assumes that the sales share of gasoline turbo, gasoline hybrid, diesel hybrid and CNG vehicles grows significantly between 2005 and 2035, as detailed in Table 3. The assumptions that underlie this scenario are as follows:

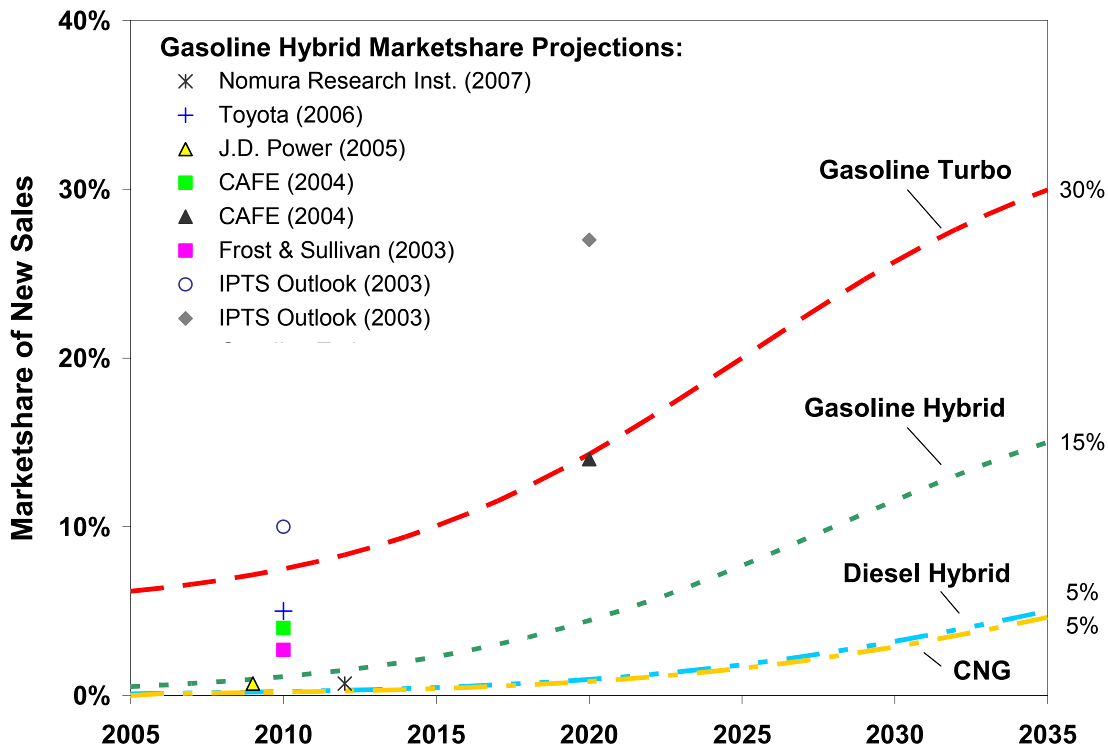
1. Due to several factors (e.g. loss of tax revenue, unsustainable gasoline/diesel refinery split, etc.), the sales fraction of diesel vehicles does not increase above its current level.

[1] While not found in the literature, separate estimates for the sales fraction of gasoline turbo vehicles in each country was estimated by subtracting 10 percent from the total gasoline sales fraction, which is the approximate 2004/2005 fraction of Western European gasoline vehicles sold with turbochargers, according to ABOUT Automotive (Beacham 2005).

2. It is assumed that the trend of gasoline turbo vehicles comprising a larger and larger fraction of total gasoline vehicle sales will continue. Similar to the rapid diffusion and high rate of market penetration observed for other subsystem technologies, such as port fuel injection and front wheel drive, this scenario projects that gasoline turbo vehicles achieve a significant fraction of all non-hybrid gasoline vehicle sales by 2035.
3. Gasoline hybrids are assumed to account for 15 percent of all new vehicles sold in 2035. While seemingly arbitrary, this target could be achieved if gasoline hybrids were able to reach 3 percent marketshare (similar to the current US hybrid sales share) by 2015 and then maintain an 8 percent compound annual growth rate until 2035, which is the same rate that diesel sales have maintained in Western Europe since 1990 (Green Car Congress 2008 and European Automobile Manufacturer's Association 2008). As shown in Figure 3, the15 percent by 2035 target is most closely aligned with the more conservative estimates found in the literature.
4. In 2035 there will be approximately 1/3 as many diesel hybrids sold as gasoline hybrids, due to the former's significantly greater cost (e.g. engine block, aftertreatment, etc.), yet only incremental fuel consumption benefit.
5. The growth in the sales share of for CNG vehicles by 2035 will be modest (e.g. 5 percent). A significantly greater marketshare is limited by several factors, including the inconvenience associated with refueling, continued demand growth for natural gas by other sectors, and infrastructure limitations. For example, CONCAWE et al. (2007) estimated that if CNG was to comprise more than 5 percent of the 2020 road fuels market, additions to the existing gas distribution network would be required.
6. Finally, it was assumed that, as the marketshare of these alternative technologies grow, gasoline hybrid, diesel hybrid and CNG sales will take equally from existing NA gasoline and diesel marketshare. Also, since turbocharging primarily involves changing subcomponents, gasoline turbo vehicle sales are assumed to take exclusively from existing NA gasoline marketshare. Just as it is not possible to know how these various alternative powertrains will fare in the marketplace with respect to one another, it is equally impossible to estimate whether they will be replacing diesel or NA gasoline technology. The decision to have the alternative technologies take equally from each incumbent was chosen to avoid deriving a more complicated, yet no more likely,

retirement scheme. The only caveat to this rule is that the marketshare of NA gasoline vehicles was never allowed to fall below 10 percent to account for the fact that, as the lowest cost powertrain option, there will always be some level of demand for conventional NA gasoline vehicles.

Figure 3: ***Alternative Technologies Emerge*** **scenario, including gasoline hybrid marketshare projections.**



Sources: (Institute for Prospective Technological Studies 2003, Frost & Sullivan 2003, Clean Air for Europe 2004, Rechtin 2005, Ciferri 2006, Nomura Research Institute 2007).

2.3.4 Vehicle Kilometers Traveled

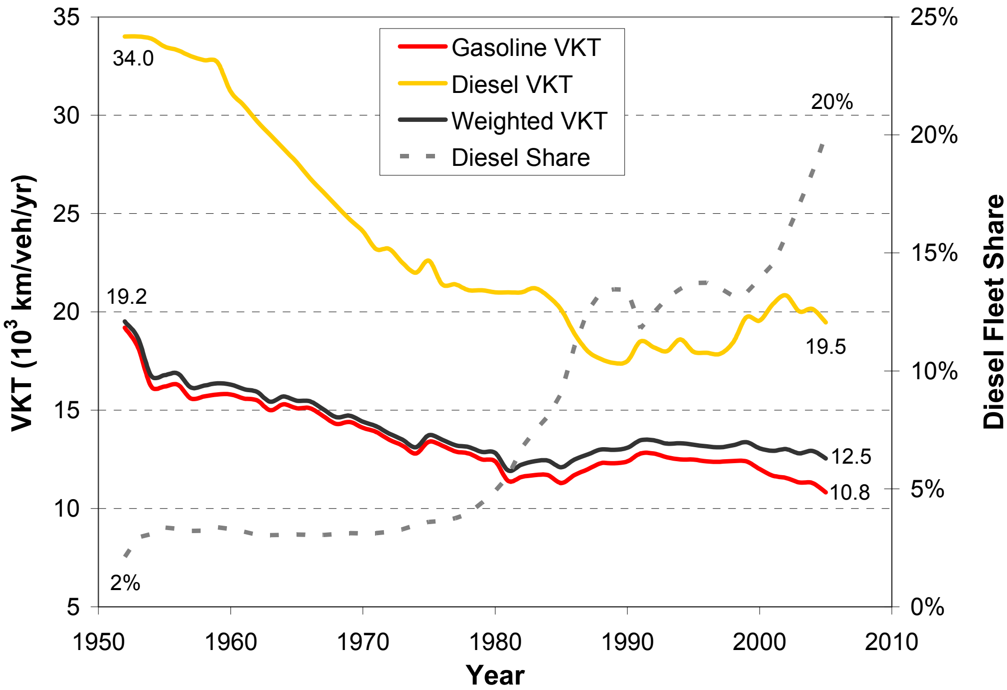
The VKT behavior of conventional, as well as newly or yet to be introduced alternative powertrain technologies, will have important repercussions on future fleet fuel use and GHG emissions. For countries like the US, where NA gasoline vehicles dominate the passenger vehicle market, the average historic VKT growth rate serves as a useful baseline estimate for future growth. The considerable presence of diesel vehicles, however, makes it more difficult to estimate the future VKT behavior of the fleet in many European markets.

As illustrated by Figure 4 and Figure 5, the historic VKT data for gasoline and diesel vehicles in Germany and France highlights several important trends.[2] Most significantly, diesel vehicles have consistently been driven further per annum than gasoline vehicles. For example, in 2005 the average diesel vehicle was driven 80 percent further in Germany and 64 percent further in France than the average gasoline vehicle in those countries. Another relevant trend is that the VKT of both gasoline and diesel vehicles has been steadily declining. A number of studies have explored the range of potential factors that are responsible for these trends, such as the preferential use of diesels by high mileage drivers (e.g. taxis), differential tax regimes on gasoline and diesel fuel, and the increasing number of multi-car families in several European countries. Schipper et al. (2002) provide a comprehensive review of the literature in this area. Despite a multitude of factors, the fundamental dynamic appears to be that the diesel VKT, as well as gasoline VKT to a lesser extent, decreases as the fraction of diesels in the fleet increases. Diesel VKT declines because, in addition to there always being a certain fraction of high mileage drivers, ordinary drivers increasingly own diesel vehicles. Conversely, as diesels continue to appeal to more and more moderate drivers, their switching away from gasoline vehicles towards diesel vehicles lowers the average gasoline VKT.

These observations informed the authors approach for modeling the future VKT behavior of gasoline and diesel vehicles, in addition to the fact that the weighted VKT in both countries has remained roughly flat over the last 30 years. Figure 6 shows the resulting VKT behavior when this methodology is applied to the *No Change* vehicle sales mix scenario for France. In this particular instance, diesel vehicles, which comprise nearly 70 percent of the fleet in 2035, are assumed to only travel approximately 25 percent further per annum than gasoline vehicles. When scenarios with alternative powertrains are modeled, it is assumed for simplicity that they exhibit the same VKT behavior as NA gasoline vehicles. The final relevant point to emphasize about VKT is that the number of kilometers traveled by a given vehicle throughout its lifetime is modeled as being linearly dependent upon its age. The older a vehicle becomes, the fewer kilometers it is assumed to travel per year. The literature suggests that approximately 5 percent is a reasonable VKT degradation rate (Greene and Rathi 1990).

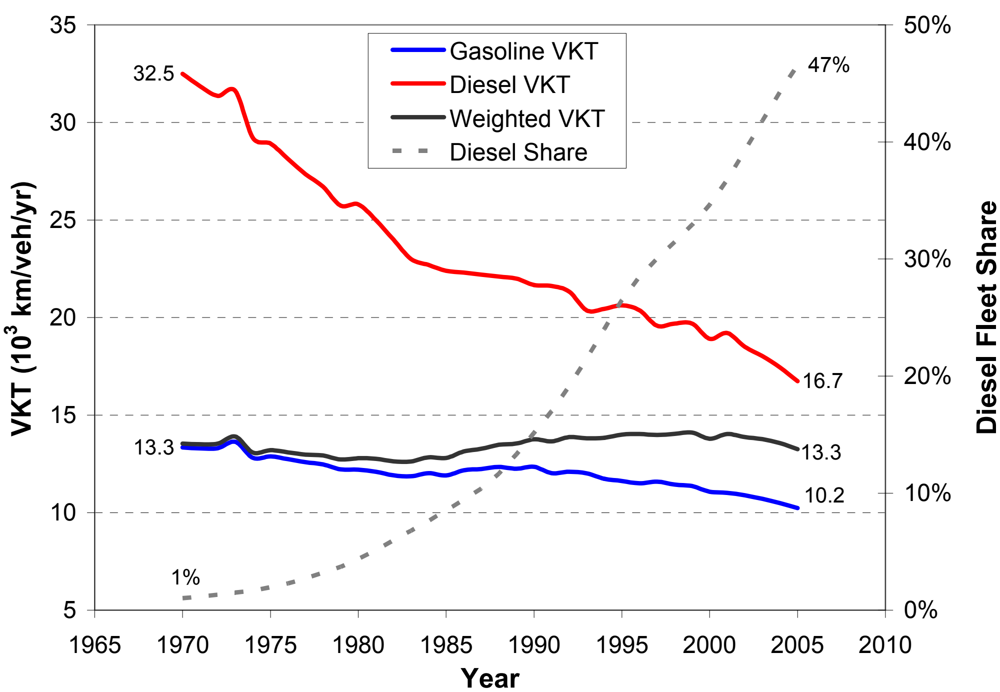
[2] Data for the United Kingdom and Italy are not shown because the authors were unable to locate up-to-date, continuous VKT data sets for these countries.

Figure 4: Historic VKT behavior and diesel fleet share in Germany.



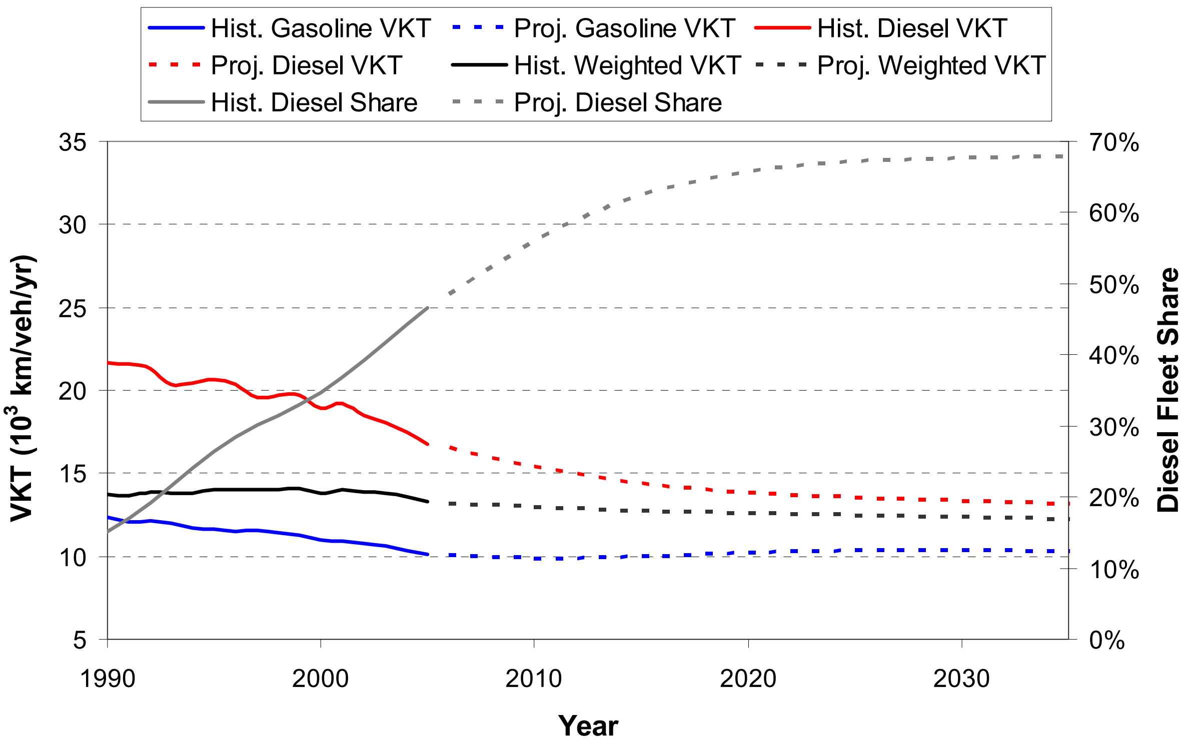
Source: (Deutscher Verkehrs-Verlag 2007).

Figure 5: Historic VKT behavior and diesel fleet share in France.



Source: (Observatoire Économique et Statistique des Transports 2007).

Figure 6: Future gasoline and diesel VKT behavior as modeled for the France *No Change* sales mix scenario.



2.3.5 Vehicle Fuel Consumption

Future Fuel Consumption at Constant Performance and Weight

Several factors were used to model the fuel consumption of future vehicles. First, it was necessary to estimate the lowest level of fuel consumption that could reasonable be achieved by each powertrain. This was defined as the rate that would be obtained if future vehicle performance (e.g. acceleration, top speed, etc.) was kept constant at today's levels.[3] Vehicle simulation models like Advisor®, in conjunction with educated estimates about the rate of improvement in a variety of parameters (e.g. coefficient of drag, tire rolling resistance, engine efficiency, hybrid control system optimization, etc.) over the next 25-30 years were used to estimate future fuel consumption. Readers are referred to studies by colleagues at MIT on the future fuel consumption of conventional and advanced powertrains for further information (Kasseris and Heywood 2007, Kromer and Heywood 2008).

[3] Even lower levels of fuel consumption could of course be achieved if previous improvements in performance are revoked. Given demonstrated customer demand for increasing levels of vehicle performance, however, lower than "constant performance" levels of fuel consumption were not modeled.

Since the above studies focused on the US market, whose passenger vehicles are larger, heavier and have higher performance than the average European vehicle, they could not be used directly to estimate the future fuel consumption of vehicles in France, Germany, Italy and the UK. Rather, the future fuel consumption for vehicles in these countries was determined by applying the relative improvement projected for the corresponding powertrain in the US to the fuel consumption of today's NA gasoline, diesel, gasoline hybrid, etc. vehicles in Europe. The fuel consumption of today's European vehicles was determined using the 2010 projections found in CONCAWE et al.'s (2007) recent well-to-wheels study.

The results of the MIT simulations for the US, the CONCAWE et al. 2010 projections for Europe, and the estimated 2035 fuel consumption for Europe are detailed in Table 4. Linearly extrapolating from today's values to the 2035 values gives a simplified and approximate estimate of the fuel consumption of each powertrain technology at any point during this period. Country-specific fuel consumption projections were then obtained by adjusting these curves slightly upward or downward until the NA gasoline and diesel values approximately matched the most recent historical New European Driving Cycle (NEDC) test fuel consumption data. The resulting future fuel consumption values, as well as historic NEDC test fuel consumption data, were adjusted upward by 10 percent to reflect the fact that "real world" fuel consumption is typically worse than test values (CONCAWE 2007). Unlike with VKT, reliable estimates of fuel consumption degradation are not available and therefore the fuel consumption of older model vehicles in the fleet model was not degraded over time.

Table 4: Future European vehicle fuel consumption levels and calculation inputs.[4]

Year	Powertrain	Fuel Consumption (l/100 km gasoline equivalent)	Relative to Today's NA Gasoline	Relative to Future NA Gasoline
MIT US Vehicle Sumulation Results:				
2005	NA Gasoline	8.8	1	
	Diesel	7.4	0.84	
	Gasoline Turbo	7.9	0.90	
	Gasoline Hybrid	5.7	0.65	
2030	NA Gasoline	5.5	0.63	1
	Diesel	4.7	0.53	0.85
	Gasoline Turbo	4.9	0.56	0.89
	Gasoline Hybrid	3.1	0.35	0.56
2010 Projections by CONCAWE et al.:				
2010	NA Gasoline	6.57	1	
	Diesel (w/ DPF)	5.48	0.83	
	Gasoline Turbo	5.9	0.90	
	Gasoline Hybrid	5.02	0.76	
	Diesel Hybrid	4.51	0.69	
	CNG (dedicated)	5.82	0.89	
Relative Improvement from US Results Applied to CONCAWE et al.'s 2010 Projections:				
2035	NA Gasoline	4.11	0.63	1
	2035 Diesel	3.48	0.53	0.85
	2035 Gasoline Turbo	3.66	0.56	0.89
	2035 Gasoline Hybrid	2.73	0.42	0.66
	2035 Diesel Hybrid	2.45	0.37	0.60
	2035 CNG (dedicated)	3.61	0.55	0.88

Sources: (CONCAWE et al. 2007, Kasseris and Heywood 2007, Kromer and Heywood 2008).

Historic Fuel Consumption, Performance and Weight Tradeoff

The second important factor for modeling future fuel consumption was estimating to what extent the efficiency improvements that accrue over time will be realized in fuel consumption reductions, as opposed to increased vehicle performance and weight. It is possible and even likely that vehicle performance and weight will increase beyond today's levels, as opposed to simply remaining constant. Detailed discussions of the tradeoff between fuel consumption,

[4] Since a diesel hybrid was not modeled in the MIT simulations, the fuel consumption of a 2035 diesel hybrid vehicle was determined using the relative improvement of the gasoline hybrid. The resulting difference between the "Relative to Today's NA Gasoline" improvement between the gasoline hybrid (42%) and diesel hybrid (37%) was proportionally similar to earlier gasoline and diesel modeling work performed at MIT, in which those values were 39% and 34%, respectively (Weiss et al. 2000). Similarly, since a dedicated CNG vehicle was not modeled in the MIT US simulations, the 2035 dedicated European CNG was determined using the relative improvement for the gasoline turbo.

performance and weight and how it has played out historically in the US and Europe are available in the literature (An and Decicco 2007, Bandivadekar et al. 2008). These studies suggest that this tradeoff can be quantified using the following simple ratio, referred to as the emphasis on reducing fuel consumption (ERFC):

$$\%ERFC = \frac{FC\ reduction\ realized}{FC\ reduction\ possible\ with\ constant\ size\ and\ performance}$$

$$or$$

$$\%ERFC = \frac{FC_{previous} - FC_{realized}}{FC_{previous} - FC_{potential}}$$

As the above equation suggests, calculating prior levels of ERFC required estimating the potential fuel consumption that today's vehicles could have achieved had their performance and weight remained constant (i.e. $FC_{potential}$). This was done using the assistance of a second parameter, called the performance-fuel economy index (PFI) (An and Decicco 2007). The PFI is an approximate measure of the rate of technology improvement and is expressed as the product of the power-to-weight ratio and fuel economy of an average vehicle in a given year. Using power, weight and fuel economy data (see Appendix A.), Figure 7 and Figure 8 show the PFI trends for gasoline and diesel vehicles over the last 11 years in France and Germany, respectively. Similar graphs for the UK and Italy for the period 1995-2001 are provided in Appendix B [5]

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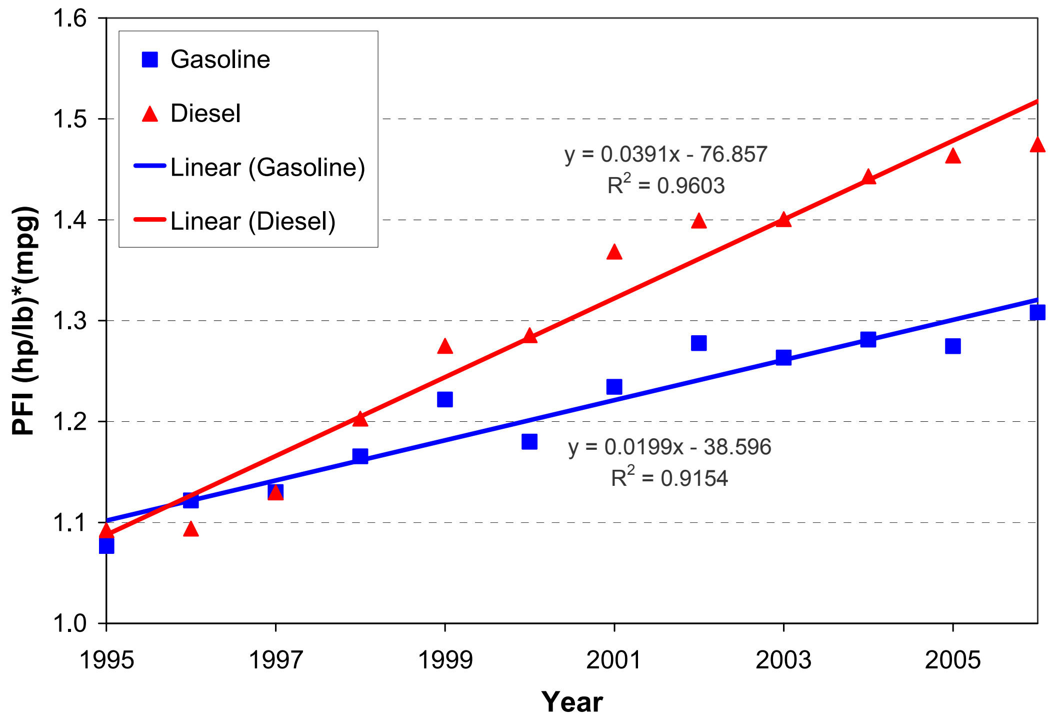
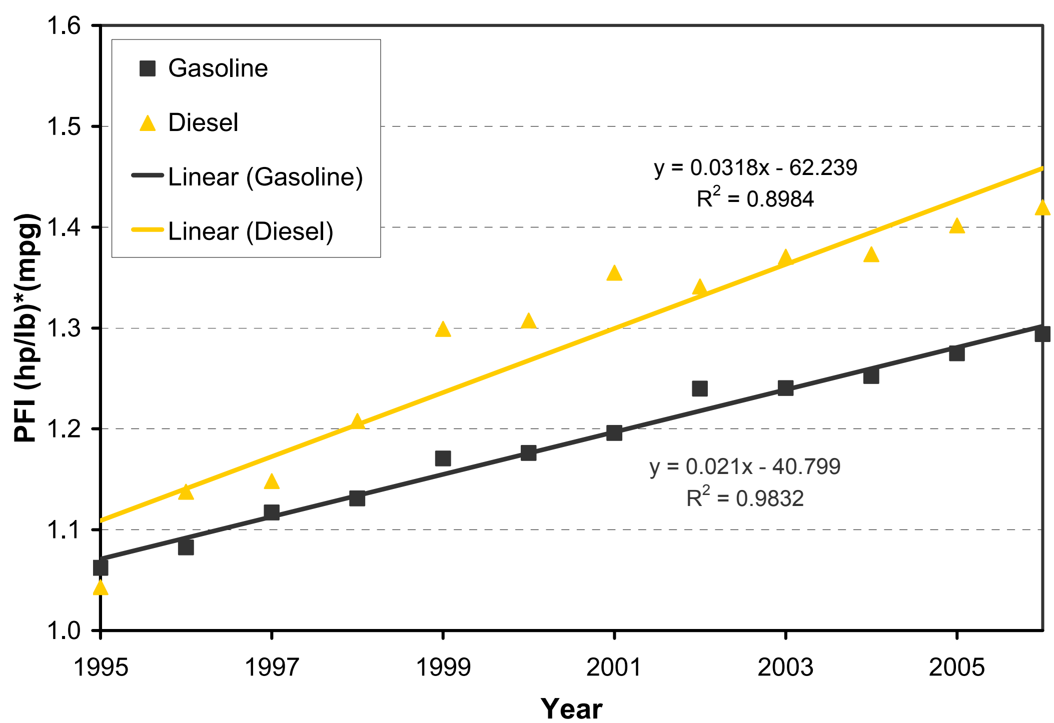
[5] Graphs for the period 1995-2006 in the UK and Italy are not shown because between 2000 and 2002 there was a change in the manner in which vehicle data was collected in these countries, impacting the continuity of information over this period.

Figure 7: The PFI for gasoline and diesel vehicles sold in France between 1995 and 2006.



Sources: (Perkins 2007 and European Commission 2007b).

Figure 8: The PFI for gasoline and diesel vehicles sold in Germany between 1995 and 2006.



Sources: (Perkins 2007 and European Commission 2007b).

Before calculating $FC_{potential}$, it is worthwhile noting that the slope of the linear fit to both the France and Germany diesel PFI data is larger than the slope of the corresponding gasoline PFI linear fit. This suggests that diesel powertrains experienced a greater increase in technology improvement than gasoline powertrains during this period. More specifically, in both countries the diesel PFI increased by a 2.8 percent compound annual growth rate, compared to 1.8 percent for gasoline PFI. A likely explanation for this observation is the shift that has occurred over the last decade from indirect injection to direct-injection, turbocharged diesel powertrains, which has resulted in significant improvements in average diesel vehicle power-to-weight ratio.

Knowing today's PFI values for gasoline and diesel vehicles in these two countries, it was possible to back calculate $FC_{potential}$ using the definition of the PFI and historic power-to-weight ratio. Table 5 shows $FC_{potential}$, as well as corresponding ERFC and specific GHG emission rates for 2006 gasoline and diesel sold in France and Germany. Table 6 displays the same information for vehicles sold in Italy and the UK in 2001. With the exception of diesel vehicles in Germany, historic ERFC values are greater than 50 percent. Also noteworthy is the 83 percent ERFC value gasoline vehicles in Italy. As a whole, this analysis suggests that greater than half of the technology or efficiency improvement that accumulated during the 1990-2006 time period was used to reduce fuel consumption. This is significantly higher than has been observed for the US, where the ERFC of gasoline vehicles over this same time period has been less than 10 percent (Bandivadekar et al. 2008). In light of this finding, it seemed reasonable to take 50 percent as a baseline estimate for the ERFC of vehicles in Europe.

Tables 5 and 6 also present realized and potential average specific GHG emission rates of new gasoline and diesel vehicles. Table 5 indicates that had 100 percent of the technology improvements that accrued since 1995 been channeled into reducing fuel consumption, Frances gasoline and diesel vehicles, as well as diesel vehicles, could potentially have achieved the 2008 interim 140 g CO_2/km target two years ahead of schedule. Additionally, Table 6 shows that both

Italy and the UK's new diesel vehicles could have possibly even met the interim target a full seven years in advance.[6]

Table 5: 2006 ERFC and GHG emission reduction values for gasoline and diesel vehicles in France and Germany, based on the 1995-2006 period.[7]

		PFI_{2006} (hp/lb•mpg)	$FC_{realized}$ (L/100km)	$FC_{potential}$ (L/100km)	$ERFC_{1995-2006}$	$GHG_{realized}$ (g CO_2/km)	$GHG_{potential}$ (g CO_2/km)
France	Gasoline	1.31	6.6	6.2	68%	151	141
	Diesel	1.47	5.5	4.9	64%	150	133
Germany	Gasoline	1.29	7.4	6.7	54%	169	154
	Diesel	1.42	6.5	5.1	22%	177	138

Table 6: 2001 ERFC and GHG emission reduction values for gasoline and diesel vehicles in Italy and the UK, based on the 1995-2001 period.

		PFI_{2001} (hp/lb•mpg)	$FC_{realized}$ (L/100km)	$FC_{potential}$ (L/100km)	$ERFC_{1995-2001}$	$GHG_{realized}$ (g CO_2/km)	$GHG_{potential}$ (g CO_2/km)
Italy	Gasoline	1.31	6.5	6.3	83%	149	144
	Diesel	1.48	5.7	5.0	61%	155	137
UK	Gasoline	1.30	7.5	7.0	52%	171	159
	Diesel	1.39	5.9	5.1	51%	161	140

As already mentioned, 50 percent was determined to be a good estimate for the baseline ERFC in the four countries examined in this study. As such, the vehicles in the *No Change* scenario were modeled assuming that the ERFC will remain at 50 percent. For the *Diesels Dominate* and *Alternative Technologies Emerge* scenarios the ERFC was increased to 75 percent to reflect a more concerted effort toward reducing fuel use and GHG emissions.

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[6] These statements are perhaps too optimistic in that they neglect the fact that continued improvements in vehicle safety, which often results in added vehicle weight, limit the ability to use all of the technology improvement to reduce fuel consumption.

[7] Realized and potential specific GHG emission rates were calculated using realized and potential fuel consumption, as well as standard tank-to-wheel energy and GHG values for gasoline and diesel fuel published in CONCAWE et al.'s 2007 Well-to-Wheel study. As such, they differ from published g/km CO_2 values, which are typically measured using a dynamometer.

2.3.6 Future Fuel Mix Scenarios

Two potential future fuel mix scenarios were evaluated. The first was a baseline scenario in which biodiesel continues to constitute approximately 2 percent of all passenger vehicle diesel fuel consumed (Emerging Markets Online 2006). The second scenario is modeled after the European Commission Directive targeting 10 percent biofuels by 2020. The second scenario, however, differs from the Directive in that it extends the deadline for compliance to 2035. This modification was made to be consistent with the vehicle fleet mix scenarios, as well as to reflect the fact that 10 percent energy is an ambitious target that may not be achieved until sometime after 2020.[8] In this latter scenario, it is assumed for simplicity that in 2035 ethanol and biodiesel will each comprise 10 percent by energy of gasoline and diesel, respectively. The limitation, of course, is that this assumption does not allow biodiesel to shoulder a larger share, say 15 percent, of 2035 diesel fuel consumption than ethanol's share of 2035 gasoline fuel consumption.

Table 7 provides the well-to-tank (WTT) and tank-to-wheels (TTW) energy and GHG emission factors used in the fleet model. Each is based on the values provided by CONCAWE et al. (2007) in their recent Well-to-Wheel study. The specific CONCAWE et al. fuel pathway is designated in parentheses. The wheat ethanol, biodiesel and natural gas pathways found in Table 7 were chosen because they represented the most likely fuel pathway and/or because their energy and emissions factors represented the median value for that fuel type. The values in Table 7 were kept constant over time to reflect the fact that, while they can be anticipated to change, reasonable estimates for how they will change are not available.

Each fuel scenario was paired with one of the three vehicle sales mix scenarios for fuel use and GHG emissions modeling purposes. The fuel use and GHG emission from the *No Change* vehicle sales mix scenario was evaluated assuming that all vehicles would be fueled by the baseline 2 percent biodiesel fuel mix. Both the *Diesels Dominate* and *Alternative Technologies Emerge* scenarios were run using the 10 percent biofuels by energy by 2035 scenario.

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[8] Achieving 10 percent by energy biofuels marketshare by 2020, assuming that ethanol and biodiesel each constitute 10 percent by energy of their respective fuel supplies, would require biodiesel supply to grow at a compound annual growth rate of over 13 percent and ethanol, which currently comprises less than 1 percent of gasoline fuel supply, to grow at an even higher rate. This does not even take into account any growth in fuel demand, which will have the effect of making the 10 percent biofuels target even more difficult to achieve.

Table 7: Well-to-tank and tank-to-wheel energy and GHG emissions from fuels.

Fuel Type (CONCAWE et al. WTW study designation)	Well-to-Tank		Tank-to-Wheels	
	Energy (MJx/MJ of fuel)	GHG (g CO_2/MJ of fuel)	Energy (MJ/L)	GHG (g CO_2/MJ of fuel)
Petroleum Gasoline (COG1)	0.14	12.50	32.20	71.00
Petroleum Diesel (COD1)	0.16	14.20	35.80	76.00
Wheat Ethanol (WTET1a)	0.89	59.20	21.20	0.00
Rapeseed-oil Methyl Ester Biodiesel (Ave: ROFA1 and ROFA2)	0.49	49.15	33.00	0.00
Natural Gas (Ave: GMCG1,GPCG1a, GPCG1b, and GRCG1)	0.23*	16.00	37*	52.80
*Natural gas WTT and TTW energy is expressed in units of MJ/m^3 at STP.				

Source: (CONCAWE et al. 2007).

2.4 Model Calibration

Before the different country models were used to simulate future fuel use and GHG emissions, they were first calibrated using historic data. This helped ensure that the characteristics of the present day fleet contained in the model corresponded closely to the actual on-road fleet in each of the four countries modeled. Three sets of historic data were calibrated to:

1. The number of gasoline and diesel vehicles in the fleet
2. The total number of kilometers traveled by each vehicle type.
3. And, the total gasoline and diesel fuel consumed.

The beta (β) variable in the retirement model and the median age of scrapped vehicles were the two parameters adjusted during calibration.

As depicted graphically in Appendix C., the individual country models were able to reproduce the historic data quite well, following an approximately two decade fleet buildup period (i.e. 1970-1990).[9] The error during the years immediately leading up to 2005 was always less than 10 percent and often only a few percent. For these reasons, it was believed that the model could be relied upon to accurately simulate the behavior of the fleet going into the future.

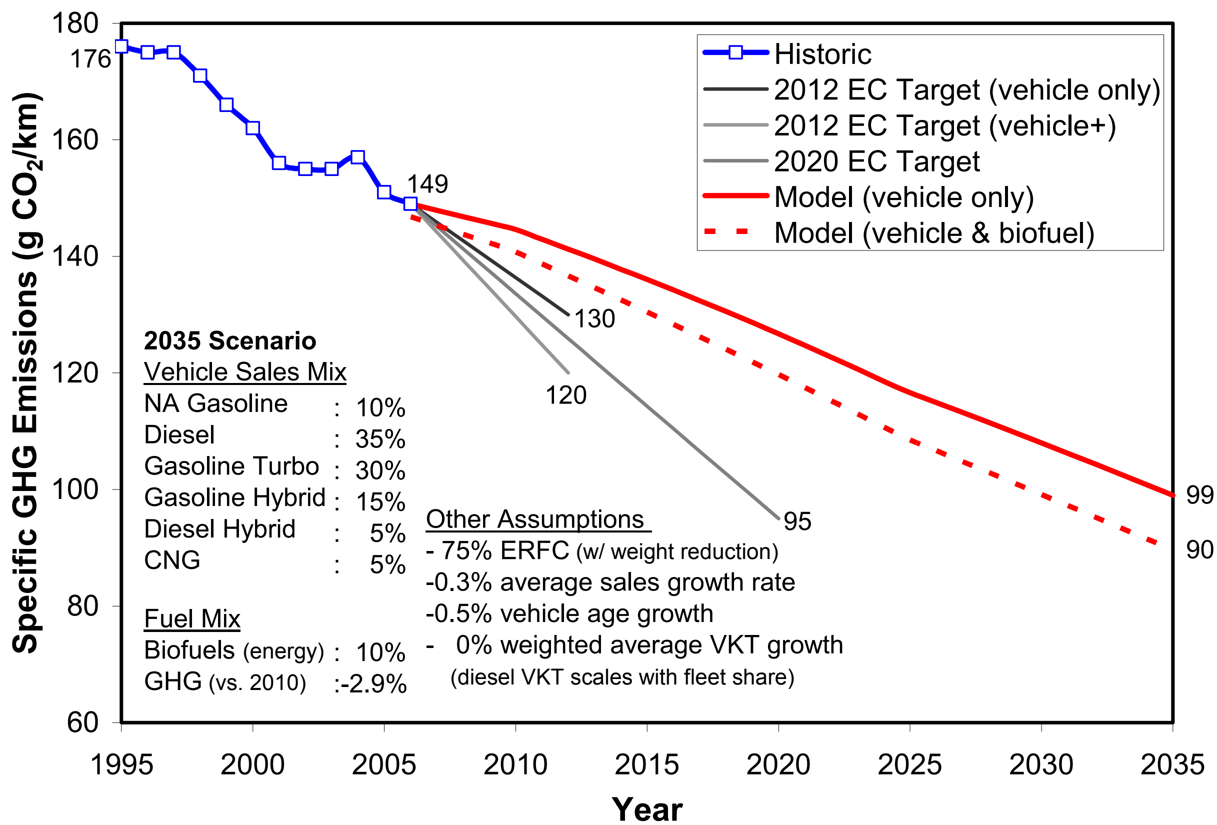
[9] The reason the model data for Germany matches the historic data starting in 1970 is because, unlike for the other countries, new sales, VKT, etc. data was available for Germany dating back to 1950, twenty years earlier.

3. RESULTS

3.1 Feasibility of Proposed CO_2/km New Vehicle GHG Emission Targets

The feasibility of achieving the proposed 2012 binding CO_2/km GHG emission targets (130 g/km and 120 g/km), as well as the hypothetical 2020 engineering target (95 g/km), was evaluated for each country under each of the three new vehicle sales scenarios. Figure 9 shows the historic trend in specific GHG emissions from the average new vehicle in France between 1995 and 2006, the linear trajectories required to meet the three targets, and the future specific GHG emissions for the *Alternative Technologies Emerge* scenario produced by the model. It suggests that, under this particular scenario, the year in which all three targets are met may be delayed by approximately a decade. For instance, when the added benefit of biofuels is included, the model suggests that the 2012 target of 120 g CO_2/km may not be met until as late as 2020.

Figure 9: Historic, proposed and modeled specific GHG emissions from new vehicles.



Source: (European Commission 2007b).

Table 8 depicts the approximate delay before each of the three targets is met in each country under each scenario. The results of this analysis are summarized below.

No Change:

- All Countries – The 95 g/km by 2020 target is not achievable before 2035.
- France and Italy – The 130 g/km by 2012 (vehicle only) target will be delayed by 10-15 years and the 120 g/km by 2012 (vehicle+) target will be delayed by 20 years.
- Germany and UK – Neither of the 2012 targets are achievable before 2035.

Diesels Dominate and Alternative Technologies Emerge:

- France and Italy – Both 2012 targets are delayed by 5-10 years and the 95 g by 2020 target is delayed by 10-15 years.
- Germany and UK – Both 2012 targets will be delayed by 10-15 years. The 95 g by 2020 target is not achievable before 2035.

Table 8: Approximate delay before the 2012 and 2020 specific GHG emissions targets are met.

Country	Scenario	Approximate Delay in Years Beyond Original Target Date		
		140 g CO_2/km by 2012 (vehicle only)	130 g CO_2/km by 2012 (vehicle+)	95 g CO_2/km by 2020 (vehicle+)
France	No Change	10-15	20	After 2035
	Diesels Dominate	5-10	10	15
	Alternative Technologies Emerge	5-10	5-10	10-15
Germany	No Change	After 2035	After 2035	After 2035
	Diesels Dominate	15	15	After 2035
	Alternative Technologies Emerge	15	15	After 2035
Italy	No Change	10	20	After 2035
	Diesels Dominate	5	5-10	10-15
	Alternative Technologies Emerge	5	5-10	10
UK	No Change	After 2035	After 2035	After 2035
	Diesels Dominate	10-15	15	After 2035
	Alternative Technologies Emerge	10-15	15	After 2035

3.2 Future Trends in Petroleum Fuel Use and GHG Emissions

3.2.1 Petroleum Fuel Use

The change in the fleet-wide consumption of petroleum gasoline and diesel fuel (i.e. excluding biofuels) between 2005 and 2035 was examined within each country and across each scenario. For example, Figure 10 depicts petroleum fuel use in France under the *Alternative Technologies Emerge* scenario by powertrain type. It shows a clear increase in the fuel that is consumed by alternative technologies at the expense of fuel consumed by diesel and NA gasoline powertrains, especially the latter. Similar petroleum fuel use graphs for each country and scenario are provided in Appendix D.

Figure 10: Petroleum fuel use in France under the *Alternative Technologies Emerge* scenario.

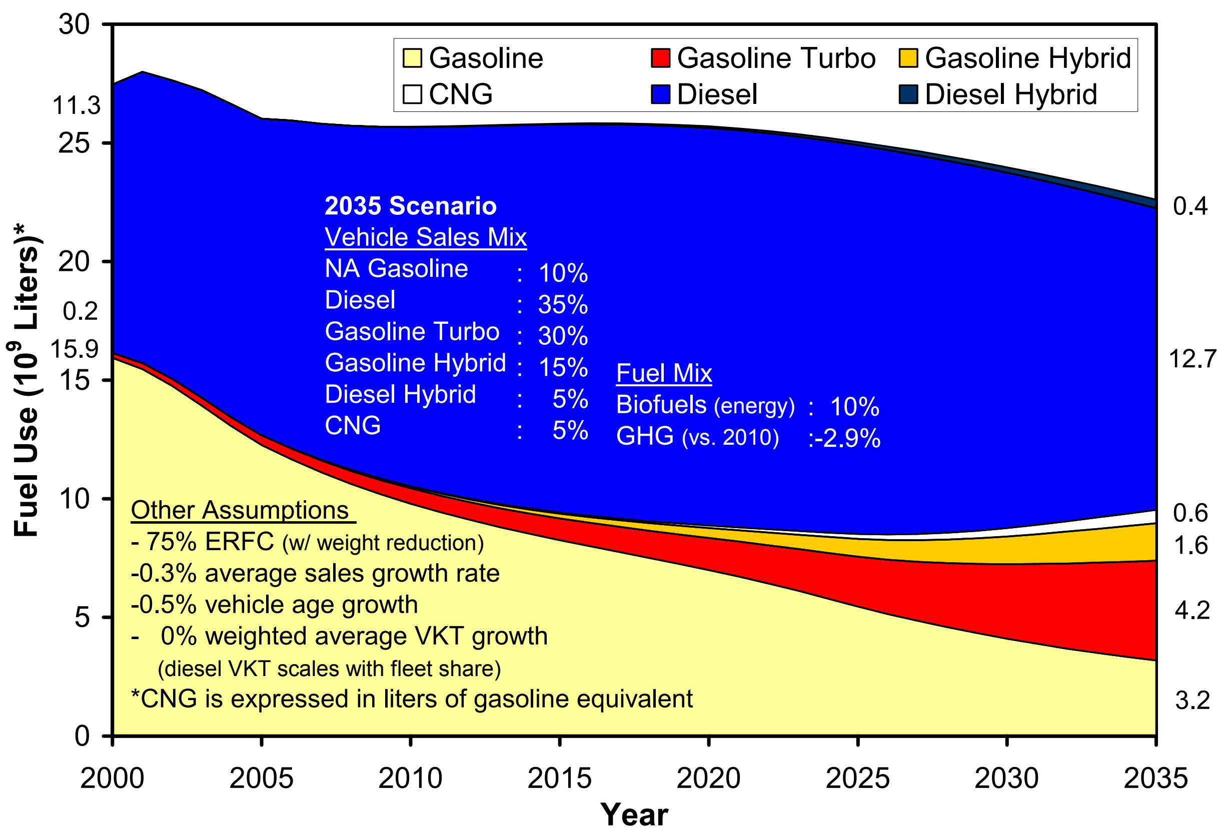


Table 9 distills some of the information contained in Figure 10 and the graphs in Appendix D., namely the total gasoline and diesel fuel use in 2005 and 2035. An analysis of these graphs and Table 9 leads to the following conclusions:

1. Under the *No Change* scenario, total petroleum fuel use (expressed in gasoline equivalent) remains relatively constant in France and Germany between 2005 and 2035 (approx. -5%), declines significantly in Italy (approx. -20%), and grows measurably in the UK (approx. +13%).
2. The *Diesels Dominate* and *Alternative Technologies Emerge* scenarios produce similar reductions in total fuel use with the latter yielding marginally greater reductions in most countries. The approximate relative reduction in total fuel use for each country was as follows: Italy (35%), Germany (30%), France (20%) and UK (10%). This ordering is consistent with the average new sales growth rates detailed in Table 2.
3. The *Diesels Dominate* scenario results in greater than 50 percent reductions in gasoline fuel use. Reductions ranging from 30 to 50 percent in gasoline fuel use are achieved under the *Alternative Technologies Emerge* scenario.
4. Somewhat obviously, in both the *No Change* and *Diesels Dominate* scenarios, diesel fuel use increases the most in the UK (66-120%) and Germany (30-56%), where the current fraction of new vehicles sold that are diesels is significantly less than in either France or Italy.
5. For France, Germany and Italy, the *Alternative Technologies Emerge* scenario could be viewed as an effective strategy for moderating or even slightly curbing growth in diesel fuel use. Growth in diesel fuel use in the UK appears to be unavoidable, regardless of the scenario.

Table 9: Petroleum Gasoline and Diesel Fuel Use in 2005 and 2035.

Country	Scenario	Fuel Use 2005 Gasoline (10^9 liters)	Fuel Use 2005 Diesel (10^9 liters)	Fuel Use 2005 Total* (10^9 liters)	Fuel Use 2035 Gasoline (10^9 liters)	Fuel Use 2035 Diesel (10^9 liters)	Fuel Use 2035 Total* (10^9 liters)	Percent Change Gasoline (%)	Percent Change Diesel (%)	Percent Change Total (%)
France	No Change	12.7	13.1	27.3	8.2	16.4	26.4	-35	25	-3
	Diesels Dominate				5.9	14.5	22.0	-54	11	-19
	Alternative Technologies Emerge				8.1	11.8	21.2	-36	-10	-22
Germany	No Change	32.6	11.5	45.4	25.9	15.0	42.6	-21	30	-6
	Diesels Dominate				12.3	17.9	32.2	-62	56	-29
	Alternative Technologies Emerge				20.3	11.3	32.9	-38	-2	-28
Italy	No Change	19.7	10.5	31.4	10.5	13.1	25.1	-47	25	-20
	Diesels Dominate				6.0	12.6	20.0	-70	20	-36
	Alternative Technologies Emerge				8.8	9.8	19.7	-55	-7	-37
UK	No Change	24.3	8.3	33.5	22.4	13.8	37.7	-8	66	13
	Diesels Dominate				9.6	18.3	29.9	-60	120	-11
	Alternative Technologies Emerge				17.6	10.1	28.8	-28	22	-14

*Total fuel use is expressed in 10^9 liters of gasoline equivalent.

3.2.2 Diesel to Gasoline Fuel Use Ratio

An alternative way of analyzing petroleum-derived gasoline and diesel fuel use is to consider the ratio in which they are consumed. This is a particularly relevant metric for European fuel refiners, who are concerned about a growing imbalance between diesel and gasoline fuel demand. Figure 11 illustrates the potential trajectories (each corresponding to one of the three scenarios) that the fuel use ratio in France could follow. Appendix E. contains similar graphs for Germany, Italy and the UK.

Table 10 provides the fuel use ratio in 2005 and 2035, the year in which the peak fuel use ratio is obtained and the relative change in the ratio during the 30 year period. The following general findings can be drawn from an analysis of Table 9, Figure 11 and Appendix E:

1. The diesel to gasoline fuel use ratio is projected to increase between 2005 and 2035 in each country under all scenarios. Except for only one instance, this increase was always greater than 50 percent and sometimes several hundred percent.

2. Under the *No Change* scenario in each country, it takes approximately 10 years before the fuel use ratio reaches equilibrium.
3. Under the *Diesels Dominate* scenario, the rate of growth in the fuel use ratio increases at a declining rate for France and Italy, the two countries that begin with a relatively high fraction of diesels in their 2005 fleets. In contrast, the rate of growth in the fuel use ratio increases at an increasing rate for Germany and the UK, the two countries that begin with a relatively low fraction of diesels in their 2005 fleets.
4. Under the *Alternative Technologies Emerge* scenario, the fuel use ratio curves for France and Italy peak in approximately 2025 and 2030, respectively, before starting to decline. In Germany and the UK the same scenario causes a leveling off in the fuel use ratio after approximately 10 years, similar in effect to the *No Change* scenario.

Figure 11: Diesel to gasoline fuel use ratio in France.

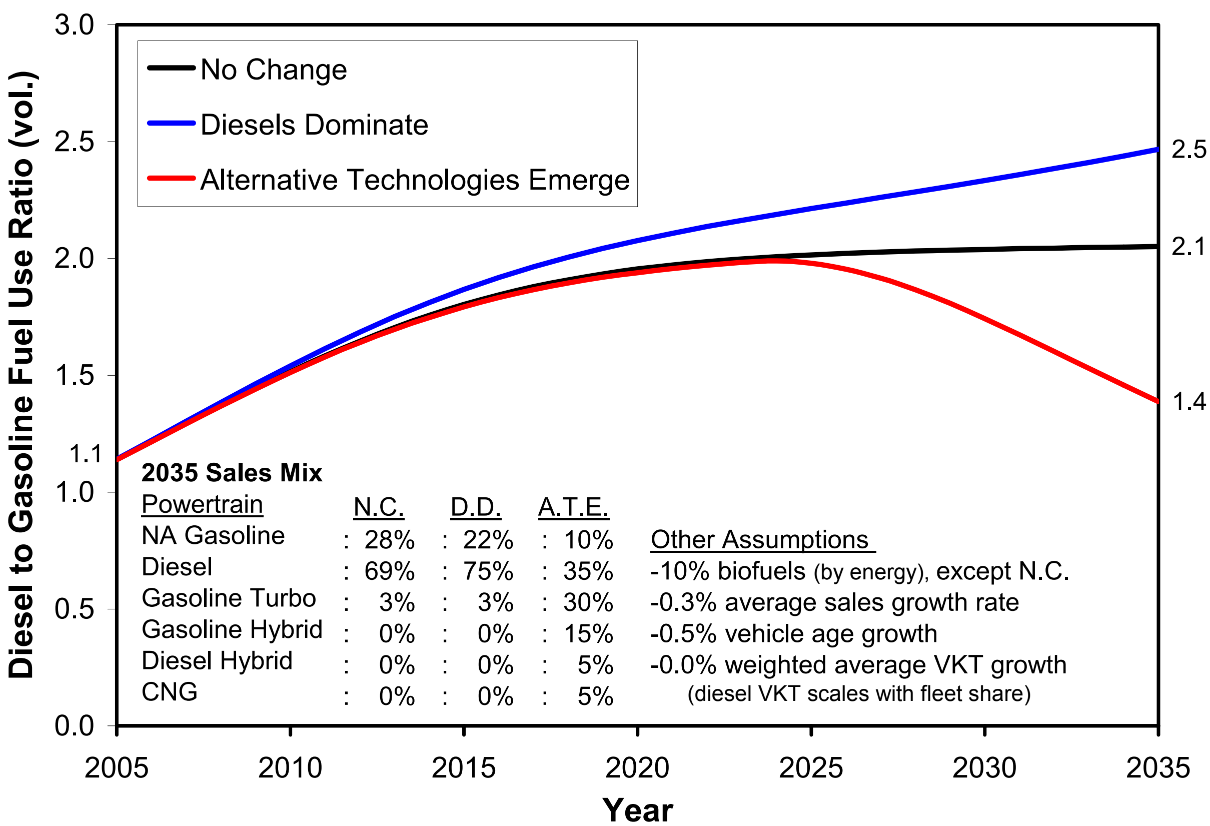


Table 10: Diesel to gasoline fuel use ratio in 2005 and 2035, year of peak fuel use ratio and relative change in fuel use ratio.

Country	Scenario	Fuel Use Ratio			
		2005	2035	Peak	Change
		(—)	(—)	(year)	(%)
France	No Change	1.1	2.1	2035	91
	Diesels Dominate		2.5	2035	127
	Alternative Technologies Emerge		1.4	2024	27
Germany	No Change	0.4	0.6	2035	50
	Diesels Dominate		1.5	2035	275
	Alternative Technologies Emerge		0.6	2023	50
Italy	No Change	0.5	1.3	2035	160
	Diesels Dominate		2.1	2035	320
	Alternative Technologies Emerge		1.1	2029	120
UK	No Change	0.3	0.6	2035	100
	Diesels Dominate		1.9	2035	533
	Alternative Technologies Emerge		0.6	2024	100

3.2.3 Well-to-Wheels GHG Emissions

Figure 12 compares the 2005 fleet-wide well-to-wheels (WTW) emissions in each country to the resulting emissions under each scenario in 2035. Similarly, Table 11 quantifies these results in terms of the percentage change in well-to-tank (WTT), tank-to-wheel (TTW) and total emissions. Several findings can be drawn from these results, the first two of which echo findings from the analysis of total fuel use.

1. Under the *No Change* scenario, WTW GHG emissions remain relatively constant in France and Germany between 2005 and 2035 (approx. -5%), declines significantly in Italy (approx. -20%), and grows measurably in the UK (approx. +14%).
2. The *Diesels Dominate* and *Alternative Technologies Emerge* scenarios produce similar reductions in WTW GHG emissions with the latter yielding marginally greater reductions in most countries. The approximate relative reduction in WTW GHG emissions for each country was as follows: Italy (30-35%), Germany (25%), France (15%) and UK (5-10%).

These reductions are each approximately 5 percent lower than corresponding reductions in total fuel use discussed earlier.

3. The reductions in total WTW GHG emissions is driven primarily by reductions in TTW emissions, which is because TTW emissions account for the large majority of total emissions (80-85%). Reductions in TTW emissions are driven by two factors: (a) the average vehicle achieving lower and lower levels of fuel consumption, thanks to greater ERFC and better technology (e.g. turbocharging, hybrids, etc.); and 10 percent of fuel energy coming from biofuels, whose TTW emissions are treated as zero.

Figure 12: Well-to-wheels GHG emissions for each country and scenario.

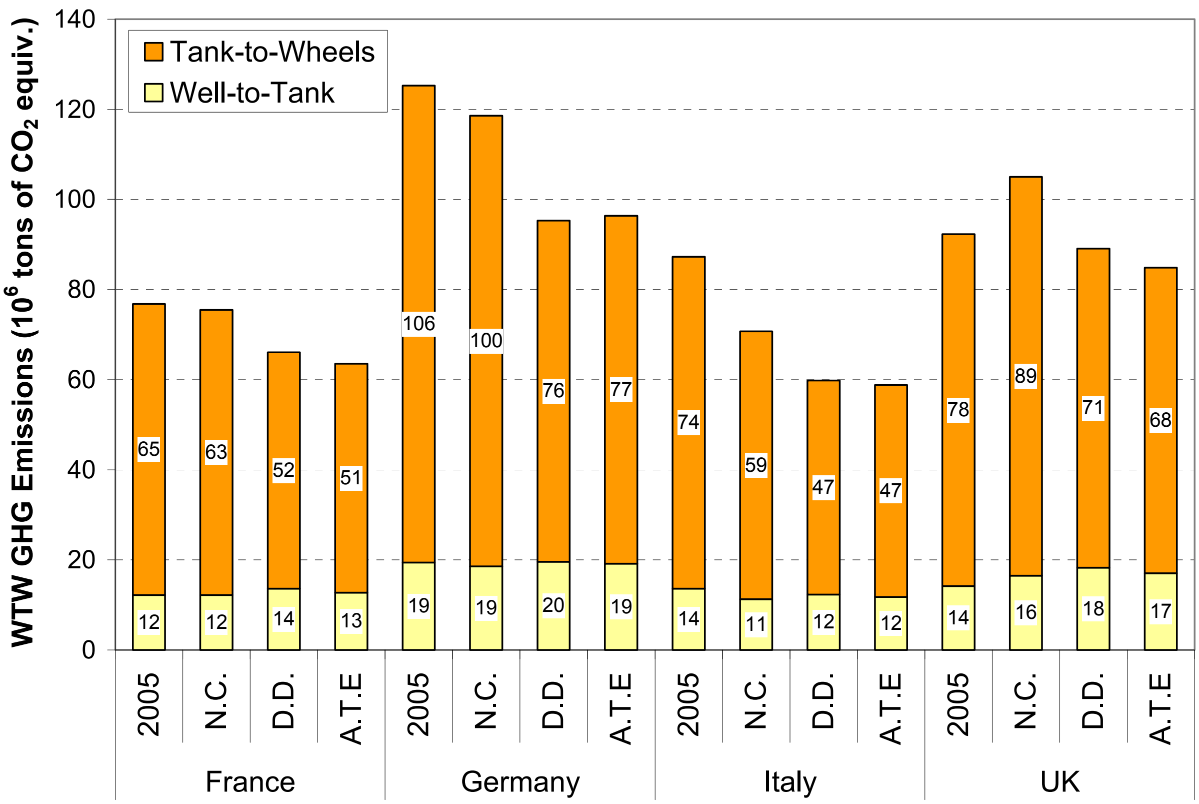


Table 11: The percentage change in well-to-tank, tank-to-wheels and total well-to-wheels GHG emissions.

(Values shaded in grey denote instances of increased emissions.)

Country	Scenario	Percent Change (%)		
		WTT	TTW	Total
France	No Change	0	-2	-2
	Diesels Dominate	12	-19	-14
	Alternative Technologies Emerge	5	-21	-17
Germany	No Change	-4	-6	-5
	Diesels Dominate	1	-28	-24
	Alternative Technologies Emerge	-1	-27	-23
Italy	No Change	-17	-19	-19
	Diesels Dominate	-10	-36	-32
	Alternative Technologies Emerge	-14	-36	-33
UK	No Change	16	13	14
	Diesels Dominate	28	-9	-4
	Alternative Technologies Emerge	20	-13	-8

3.3 Fuel Use and GHG Emission Reduction Potential of Greater ERFC, Alternative Powertrains and Biofuels

When compared to the *No Change* scenario, the *Diesels Dominate* and *Alternative Technologies Emerge* scenarios differ in three ways: (a) they simulate the effect of increasing the ERFC from 50 to 75 percent during the 2005-2035 time period; (b) they explore the impact of altering the types of vehicles in the fleet; and (c), they examine the influence of introducing a greater fraction of biofuels into the fuel mix. Up until now, this analysis has considered the combined effect of these three changes. While it is not possible to analyze the relative impact of each measure individually (since all three are correlated to each other), the following sections compare the additive impact that each has on total fuel use and GHG emissions.

3.3.1 Petroleum Fuel Use Reduction Potential

Figure 13 and Figure 14 depict the fuel use reduction potential of the *Diesels Dominate* and *Alternative Technologies Emerge* scenarios, respectively, in France. Each wedge in these graphs should be interpreted as the reduction in fuel use obtained by introducing an added measure. For example, the blue wedge in Figure 13 shows the fuel use reduction that could be achieved by transitioning from a *No Change* sales mix to the *Diesels Dominate* vehicle sales mix. The red wedge shows the benefit of increasing the ERFC to 75 percent, while maintaining the *Diesels Dominate* vehicle sales mix, and so on. Appendix F. contains similar fuel use reduction graphs for Germany, Italy and the UK. Table 12 summarizes Figures 13 and 14, as well as the graphs in Appendix F., by quantifying the additive fuel use reduction that greater ERFC, an altered vehicle mix, and biofuels contribute in each country. This analysis reveals the following results:

1. Similar to fleet model-based analyses of the US passenger vehicle market, increasing the ERFC is shown to have a significant impact on 2035 fuel use (Sperling and Cannon 2007). The reduction attributable to transitioning from 50 to 75 percent ERFC across all countries is approximately 8 percent.
2. Given that it constitutes 10 percent by energy of all fuel consumed in 2035, biofuels were also shown to have a large effect on petroleum-based fuel use. The reduction for all countries and each scenario was approximately 8 to 9 percent.
3. *Diesels Dominate*:
    a. France – given that approximately 70 percent of new vehicles sold in France are already diesels, there was very little impact from increasing their market share by an additional 5 percent by 2035 to 75 percent.
    b. Germany – increasing the diesel sales share to 75 percent by 2035 had an effect that was equivalent to freezing the 2005 sales shares and simply increasing the ERFC to 75 percent.
    c. Italy and UK – increasing the diesel sales share to 75 percent by 2035 accomplishes approximately half of the reduction that would be achieved by increasing the ERFC to 75 percent and freezing the 2005 sales share.
4. Similar to the results obtained from the US fleet modeling study, the impact of introducing alternative technologies is relatively small and takes several decades to manifest. Specifically, the fuel use reduction in 2035 attributable to introducing

alternative technologies ranged between approximately 2.5 and 5 percent. The following factors help explain why the impact from alternative technologies is smaller than one might expect:

a. Although the combined 2035 new sales marketshare of non-conventional or alternative powertrains (e.g. NA gasoline and diesel) in each country is over 50 percent, their share of the total fleet is significantly lower.
b. When an alternative powertrain is introduced into the fleet they are taking the place of what would otherwise have been a NA gasoline or diesel vehicle. In the latter case, the relative fuel consumption improvement on a vehicle basis is not as large as occurs when that vehicle takes the place of a NA gasoline vehicle only.
c. The advantage from introducing alternative powertrains becomes smaller the higher the ERFC. For example, the fuel consumption of 2035 NA gasoline and gasoline hybrid vehicles in France, assuming 50 percent ERFC, is estimated at 5.34 and 3.55 L/100km, an absolute difference of 1.79 L/100km. When the ERFC is increased to 75 percent the absolute difference becomes 1.58 L/100km (i.e. 4.72 minus 3.14 L/100km).
d. In countries with low or negative new sales growth rates, the youngest vehicles account for a smaller and smaller fraction of the entire fleet. Thus, if those vehicles are alternative powertrains with low fuel consumption their impact will be smaller than it would otherwise have been if the size of the fleet was growing. For example, compare the size of the wedges in the fuel use reduction graph for Italy with the graph of the UK in Appendix F.

Figure 13: The fuel use reduction potential of the *Diesels Dominate* scenario in France.

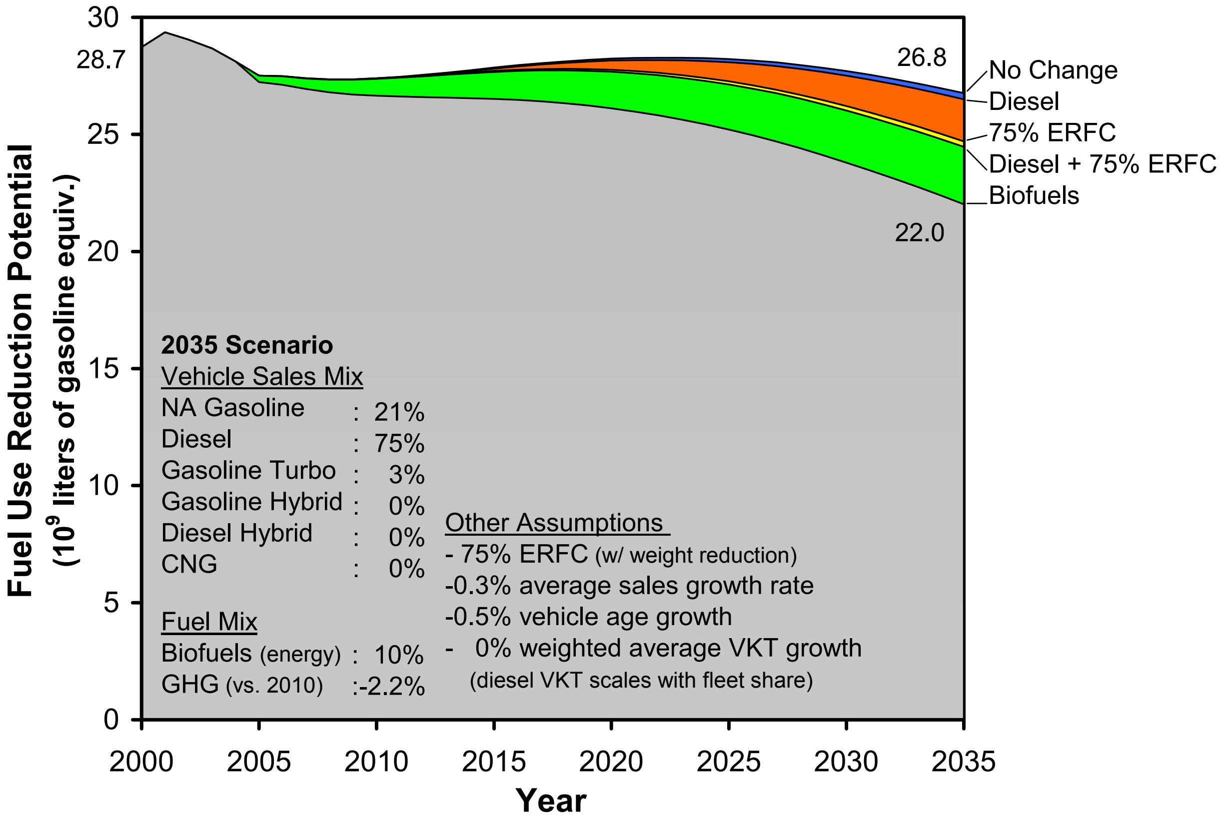


Figure 14: The fuel use reduction potential of the *Alternative Technologies Emerge* scenario in France.

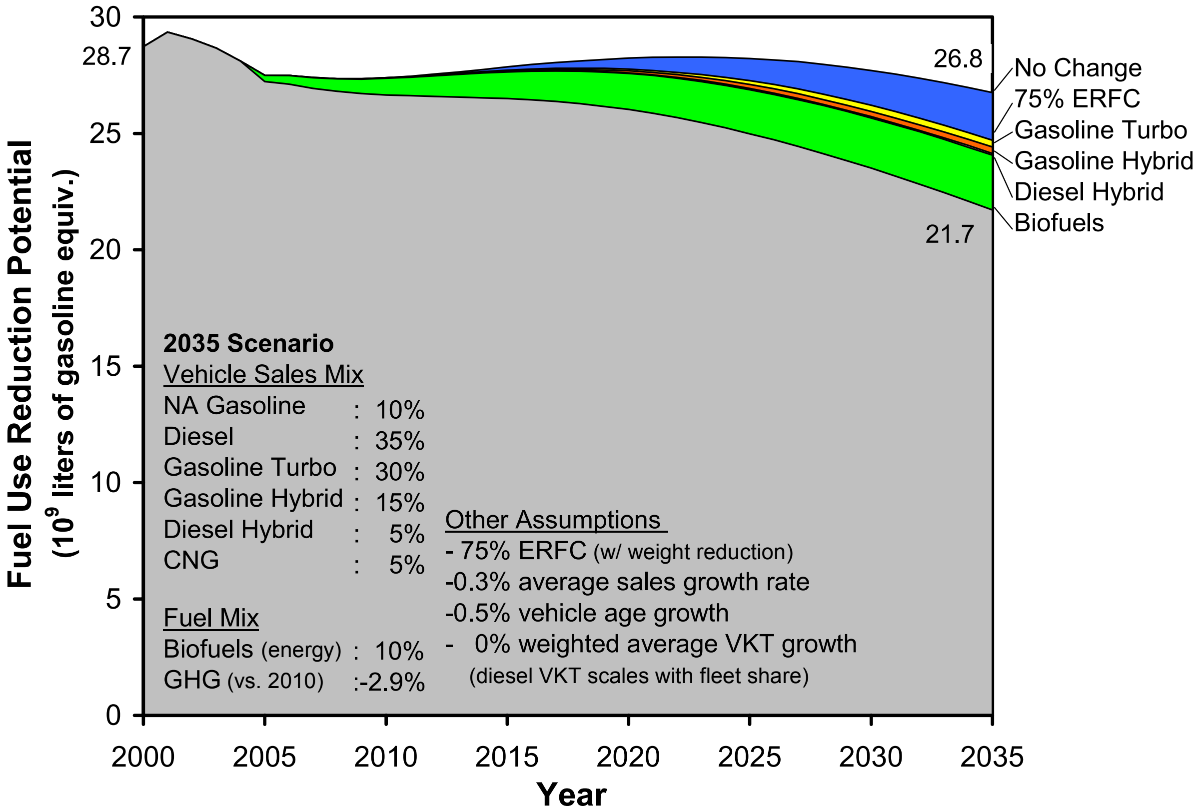


Table 12: The additive fuel use reduction from greater ERFC, an altered vehicle mix and biofuels.

Country	Scenario	Additive Fuel Use Reduction (%)		
		75% ERFC (vs. No Change)	+Vehicles	+Biofuels
France	Diesels Dominate	7.8	0.7	9.3
	Alternative Technologies Emerge		2.6	8.6
Germany	Diesels Dominate	8.4	8.4	8.2
	Alternative Technologies Emerge		4.2	8.4
Italy	Diesels Dominate	8.3	4.0	8.7
	Alternative Technologies Emerge		3.2	8.3
UK	Diesels Dominate	8.4	4.2	8.7
	Alternative Technologies Emerge		5.0	8.4

3.3.2 WTW GHG Reduction Potential

Figure 15, Figure 16 and Table 13, along with the graphs in Appendix G. depict the WTW GHG reduction potential of the *Diesels Dominate* and *Alternative Technologies Emerge* scenarios. An analysis of this data yields many of the same results as were discussed with regard to fuel use reduction potential. The only significant difference is that the contribution from biofuels is significantly lower, 4-5.5 percent as opposed to 8-9 percent. This is, of course, because replacing one liter of gasoline with wheat ethanol only reduces WTW GHG emissions by 30 percent and replacing one liter of diesel with biodiesel only reduces WTW GHG emissions by 45 percent, as per Table 7.

Figure 15: The WTW GHG reduction potential of the *Diesels Dominate* scenario in France.

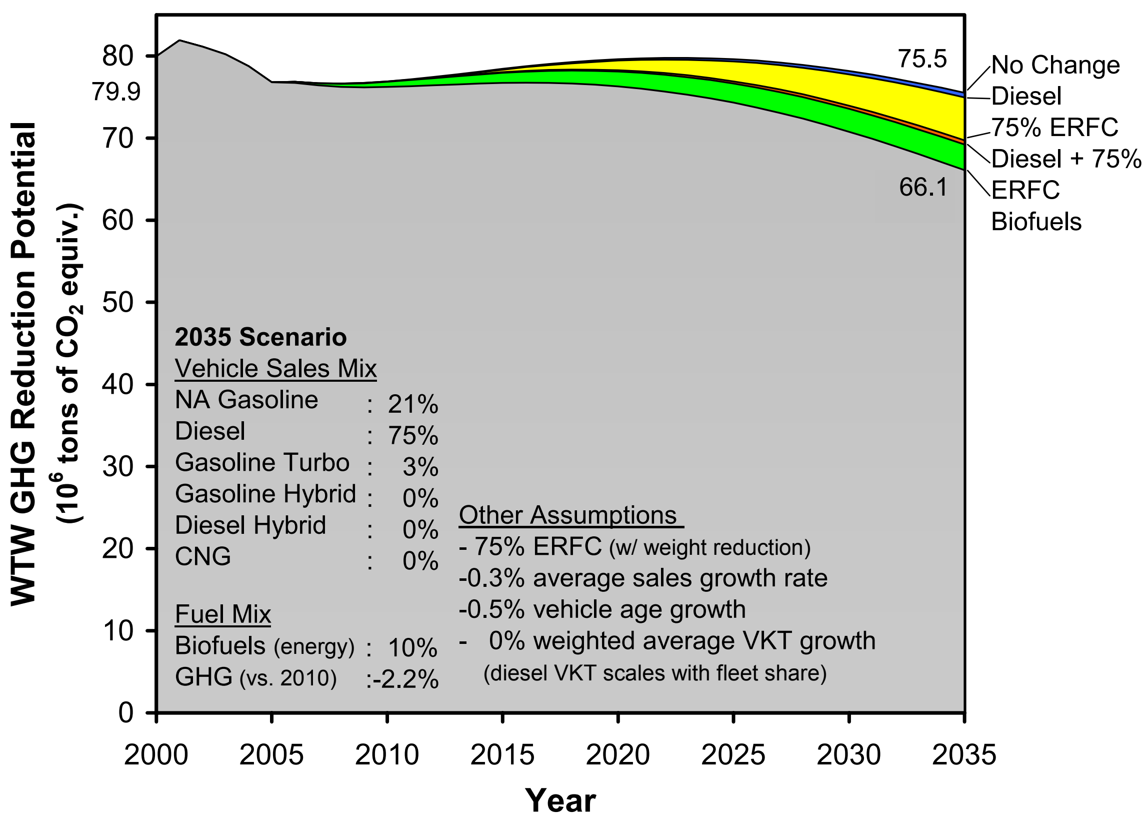


Figure 16: The WTW GHG reduction potential of the *Alternative Technologies Emerge* scenario in France.

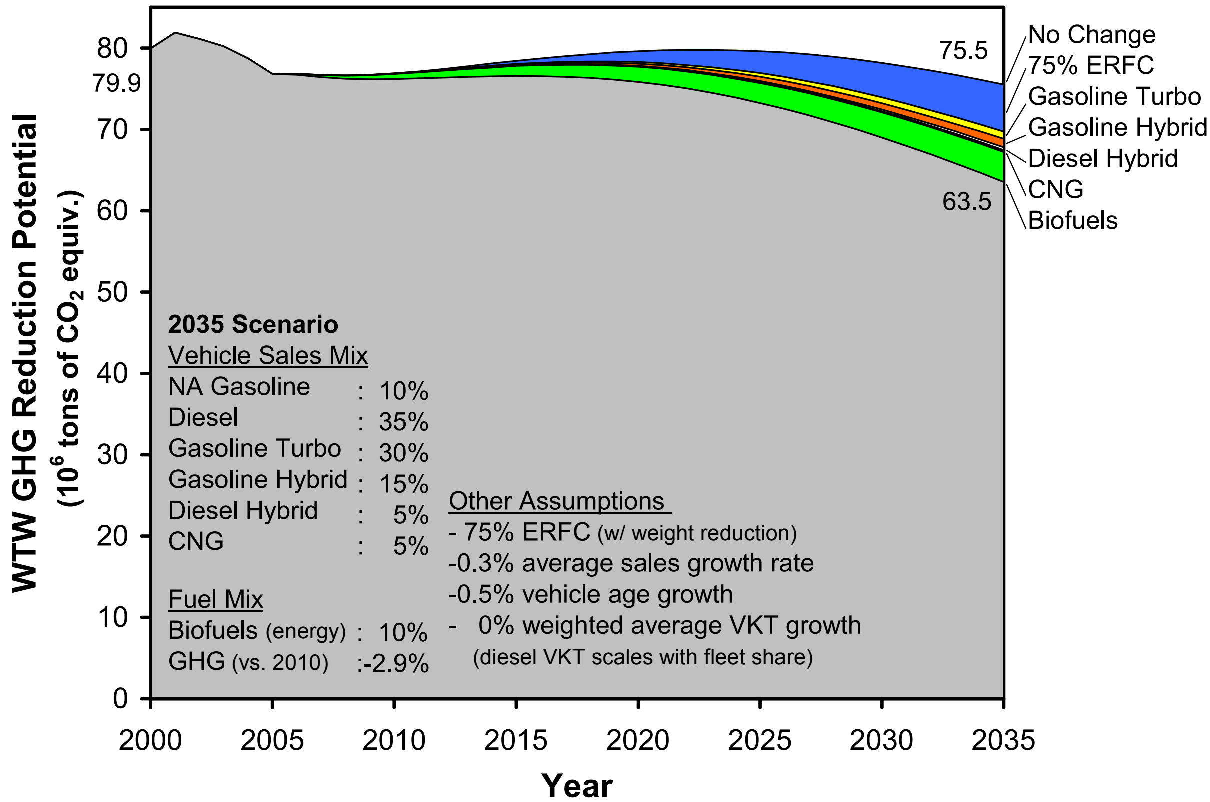


Table 13: The additive WTW GHG reduction from greater ERFC, an altered vehicle mix and biofuels.

Country	Scenario	Additive GHG Emission Reduction (%)		
		75% ERFC (vs. No Change)	+Vehicles	+Biofuels
France	Diesels Dominate	7.7	0.7	4.1
	Alternative Technologies Emerge		3.3	4.9
Germany	Diesels Dominate	8.3	7.1	4.2
	Alternative Technologies Emerge		4.8	5.6
Italy	Diesels Dominate	8.1	3.3	4.1
	Alternative Technologies Emerge		3.7	5.0
UK	Diesels Dominate	8.4	2.5	4.3
	Alternative Technologies Emerge		5.4	5.3

4. CONCLUSIONS

Feasibility of Vehicle CO_2/km Target Deadlines

This analysis suggests that under a *No Change* scenario there could be significant delays (10-20 years if not longer) before proposed 2012 and 2020 CO_2/km targets are met. Even under the *Diesels Dominate* and *Alternative Technologies Emerge* scenarios there may still be delays, ranging from approximately 5 to 15 years, depending upon the country.

Petroleum Fuel Use and GHG Emissions

Under the *No Change* scenario, total petroleum fuel use and GHG emissions remain relatively constant in France and Germany between 2005 and 2035 (approx. -5%), decline significantly in Italy (approx. -20%), and grow measurably in the UK (approx. +15%). The *Diesels Dominate* and *Alternative Technologies Emerge* scenarios produce similar reductions in total fuel use and GHG emissions. The approximate relative reduction in total fuel use and GHG emissions in each country was: Italy (35% and 30%), Germany (30% and 25%), France (20% and 15%) and the UK (10% and 5%). This ranking is consistent with the ranking of countries by average new sales growth rate, based on UN population projections.

Petroleum Fuel Use Ratio

The diesel to gasoline fuel use ratio will continue to increase for at least the next 10 years, regardless of the future scenario, reflecting the time it takes to turn over the vehicle fleet. This increase is particularly pronounced under the *Diesels Dominate* scenario. Under the *No Change* scenario in all countries, as well as the *Alternative Technologies Emerge* scenario in Germany and the UK, the fuel use ratio increases for approximately 10 years before leveling off at a fixed ratio. Under the *Alternative Technologies Emerge* scenario in France and Italy the fuel use ratio peaks at around 2025 and 2030, respectively, before starting to decline. While a declining fuel use ratio in these countries would help restore the fuel demand imbalance, it could also be problematic to petroleum refiners' abilities to properly stage capacity additions.

The Reduction Potential from Greater ERFC, an Altered Vehicle Mix and Biofuels

Greater ERFC and the introduction of 10 percent by energy biofuels both had a large and similar impact on the potential to reduce petroleum-based fuel use below *No Change* consumption levels. Somewhat surprisingly, the introduction of advanced powertrains under the *Alternative Technologies Emerge* scenario resulted in only minor reductions in fuel use by 2035. The combination of several factors helps explain this apparent discrepancy: (a) when new technologies are first introduced it takes time for their fleet share to catch up to their sales share; (b) the relative benefit of an alternative powertrain could be lower if it takes the place of a diesel vehicle instead of a NA gasoline vehicle; (c) the advantage from introducing alternative powertrains becomes smaller the higher the ERFC; and (d) in countries with low or negative new sales growth rates, the youngest vehicles account for a smaller and smaller fraction of the entire fleet.

The fuel use reduction potential associated with the continued growth in diesel sales share was less consistent across countries. In France, the existing sales share is so close to 75 percent that there was very little difference between the two results. In Germany, 75 percent diesels had a similar effect to simply increasing the ERFC to 75 percent. In Italy and the UK, 75 percent diesels had half the benefit of 75 percent ERFC. The findings were similar when it came to the GHG emission reduction potential of these three options, except that the benefit from biofuels was only half as great.

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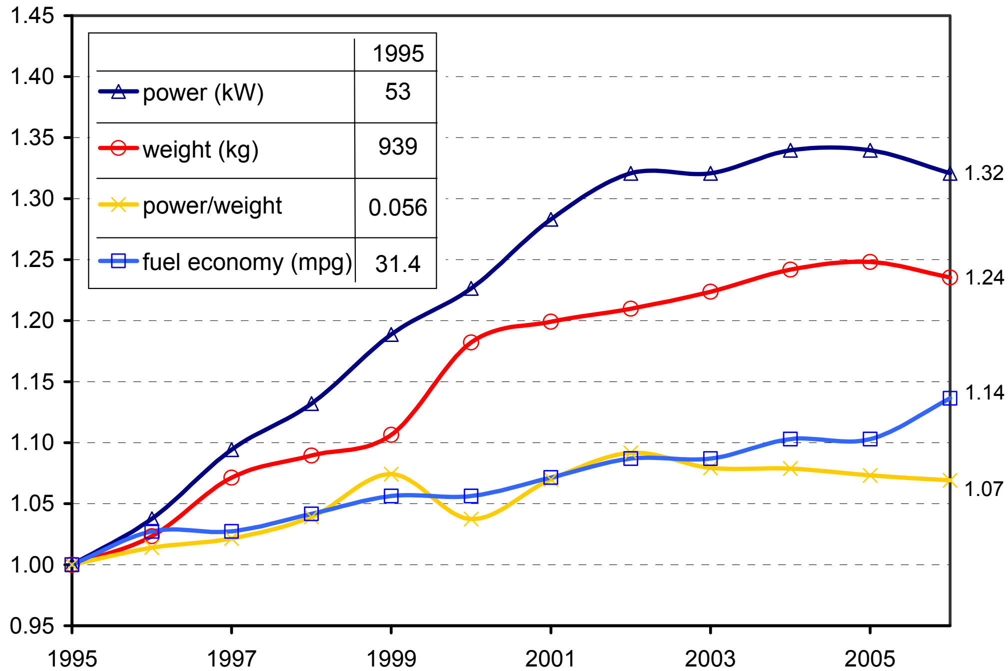
APPENDICES

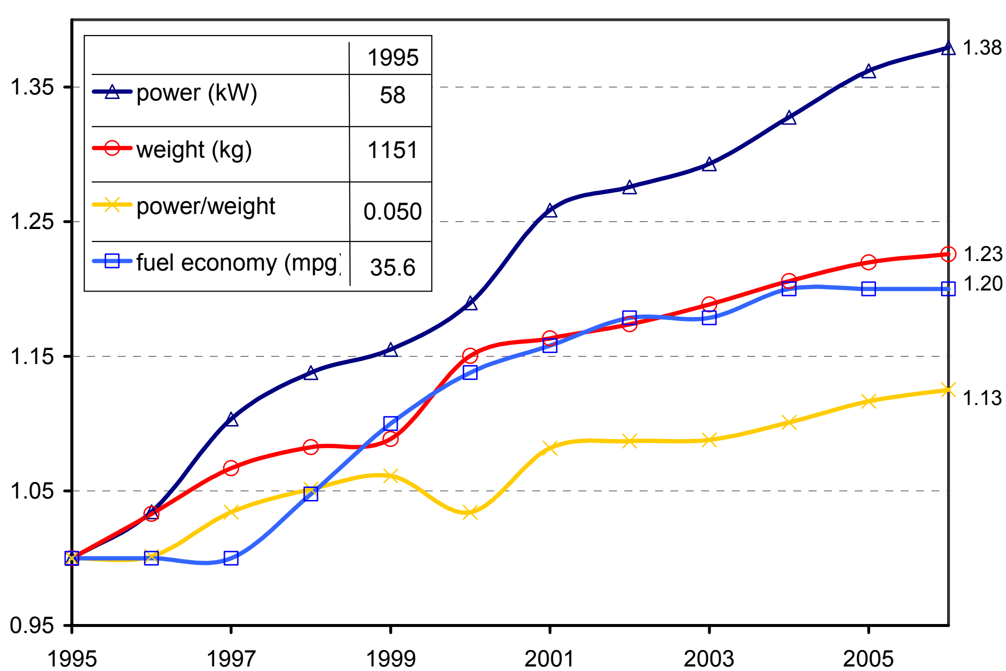
A. Normalized Power, Weight and Fuel Economy Data

Sources: (Perkins 2007 and European Commission 2007b).

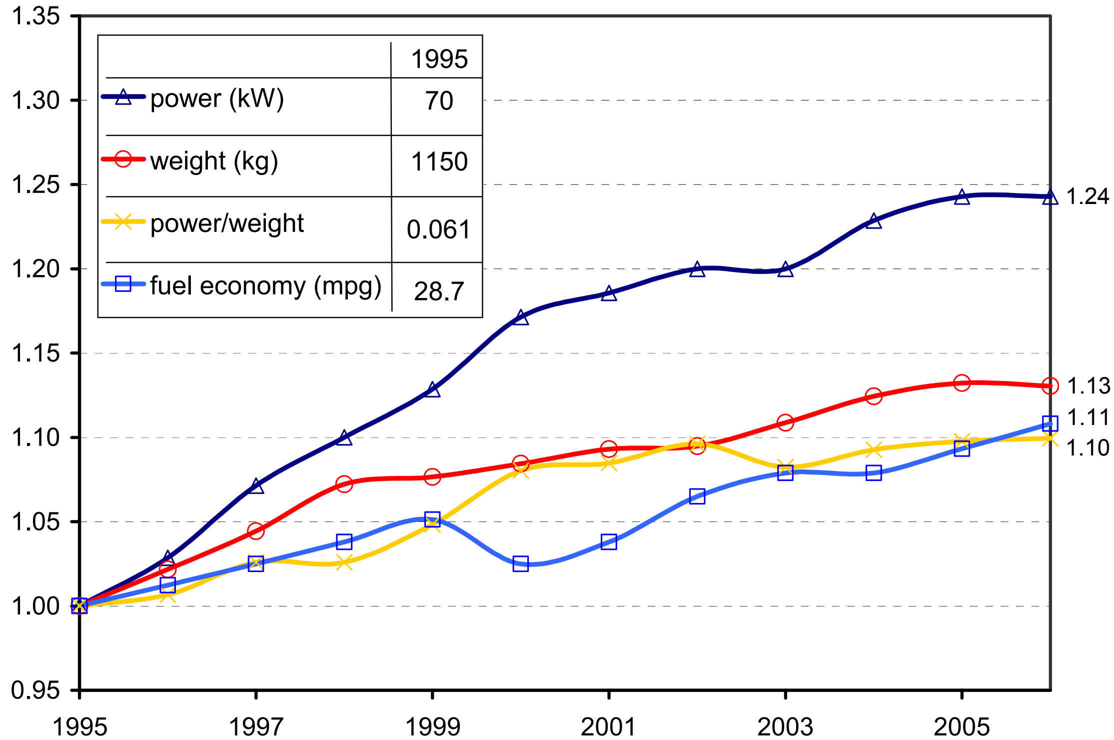
France (Gasoline)



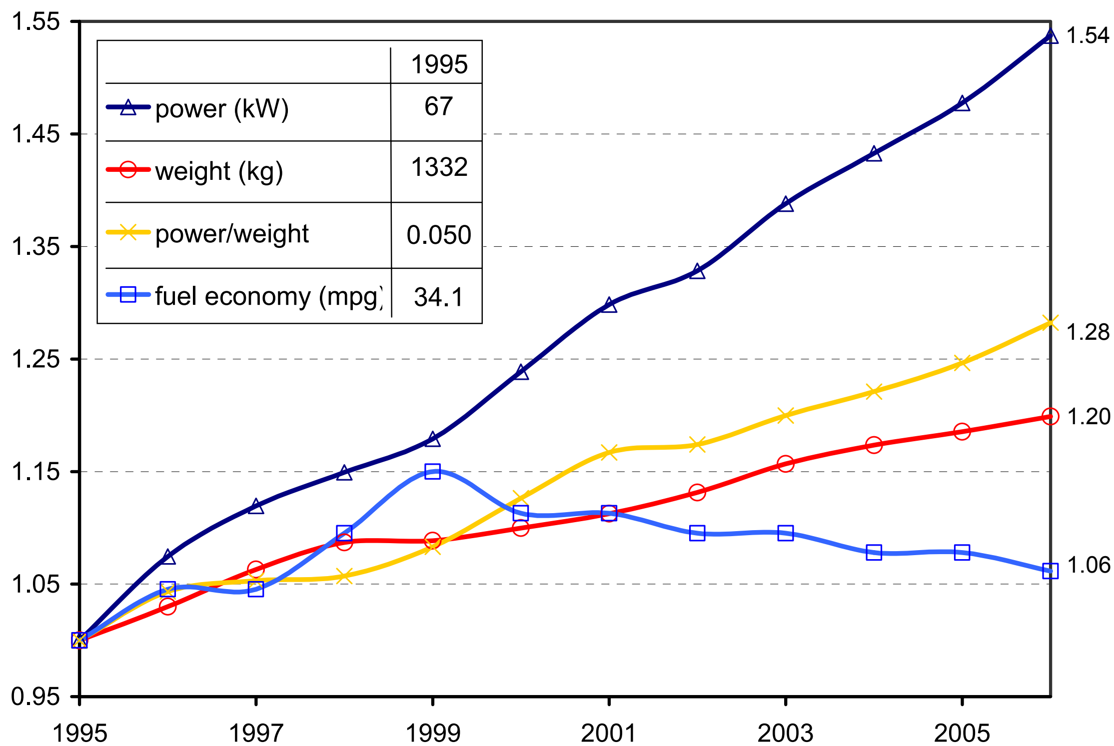
France (Diesel)



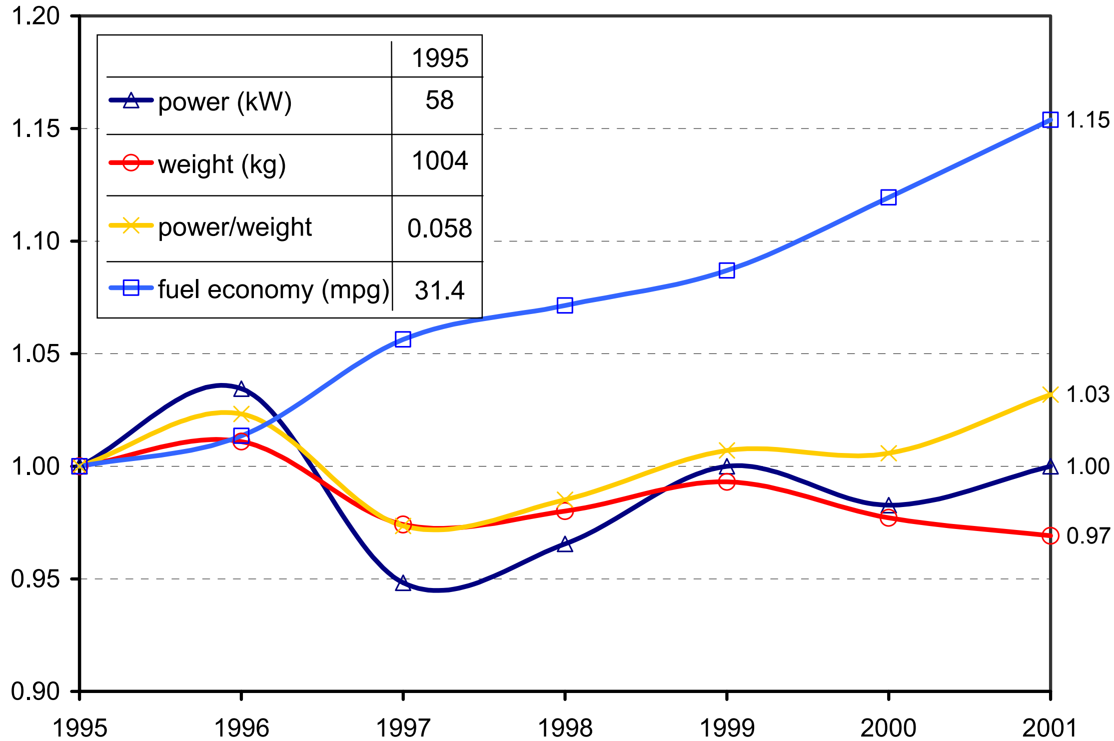
Germany (Gasoline)



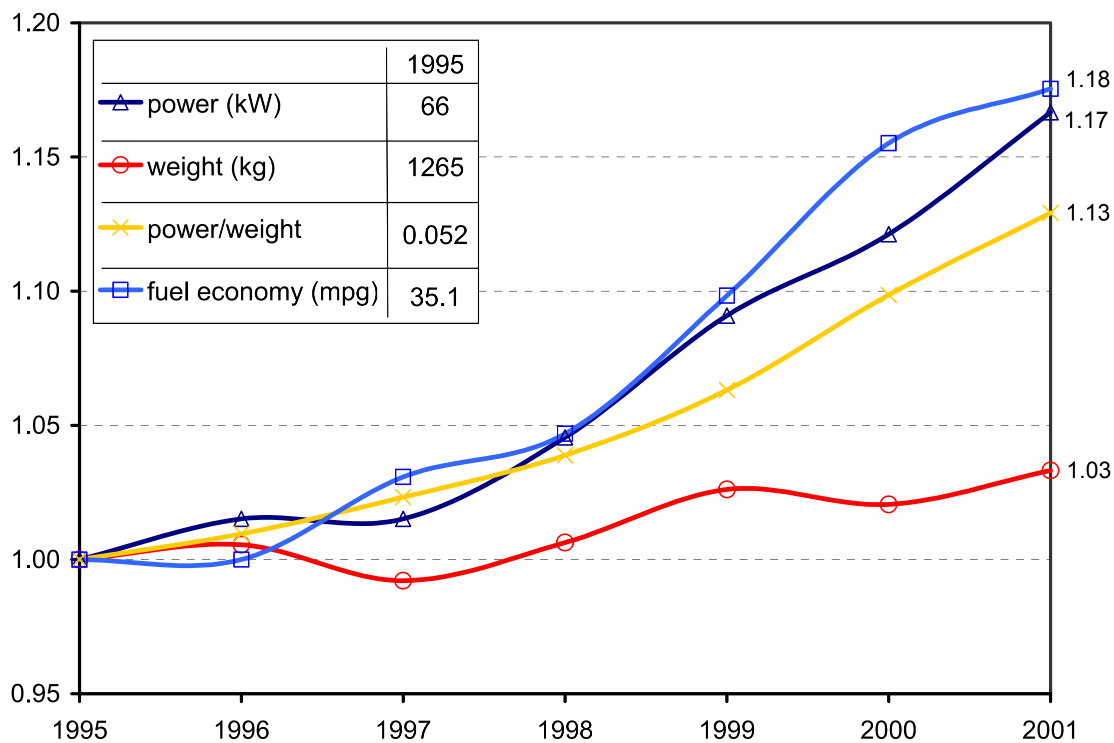
Germany (Diesel)



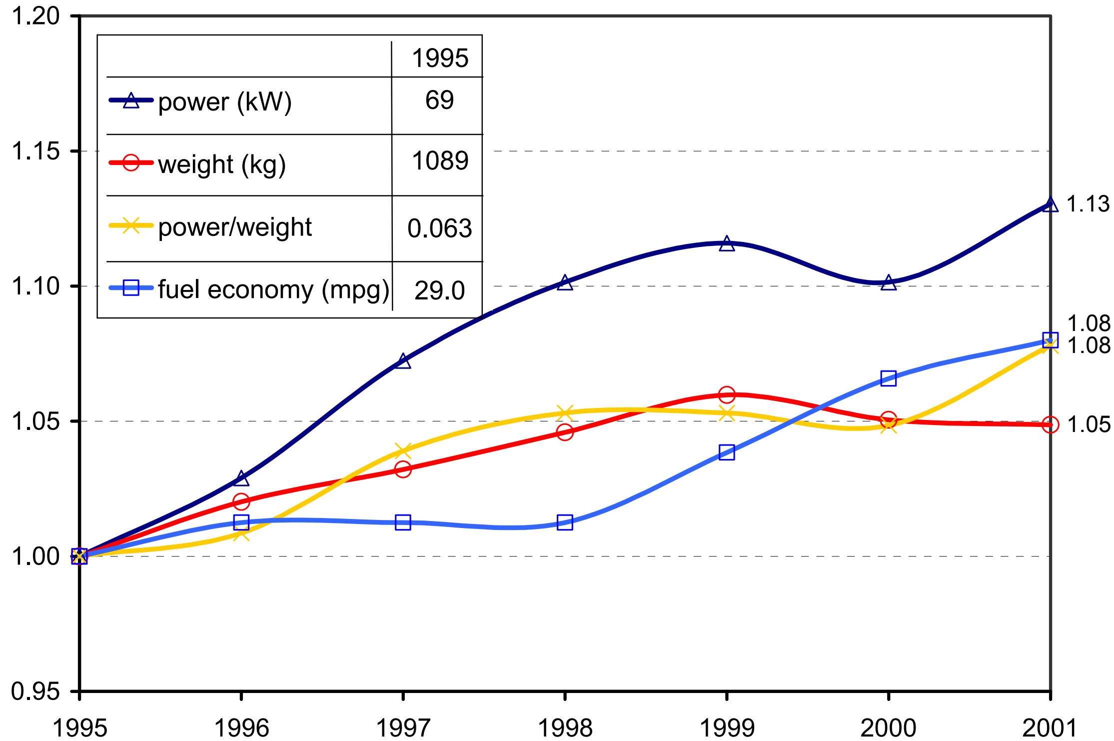
Italy (Gasoline)



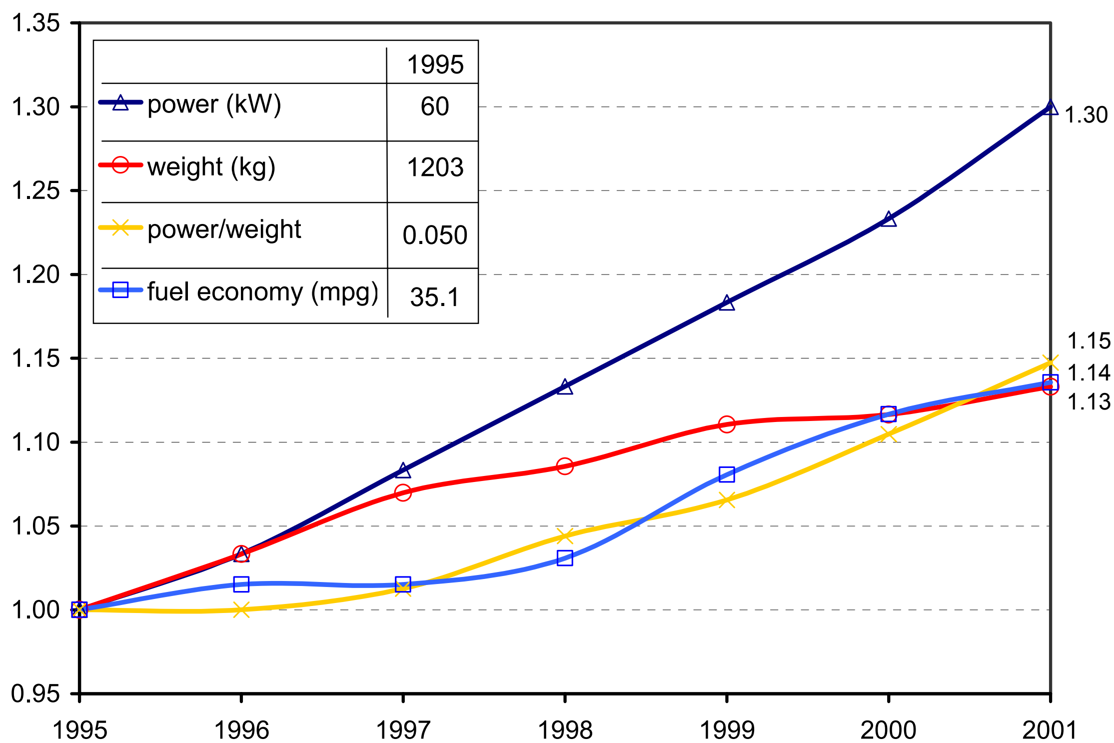
Italy (Diesel)



UK (Gasoline)

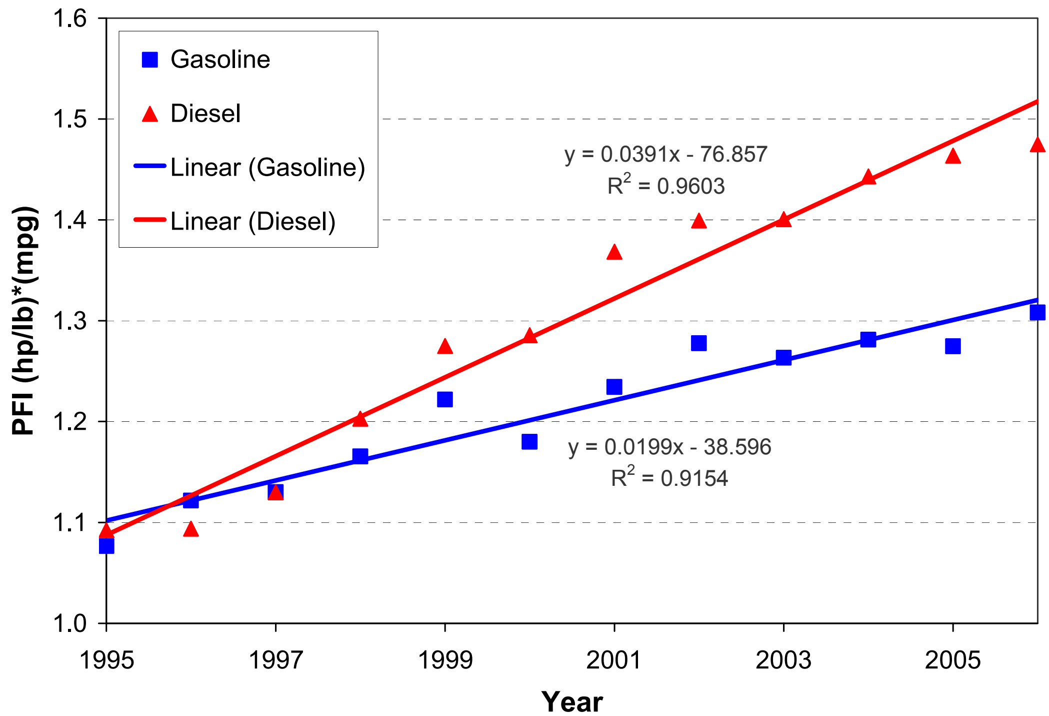


UK (Diesel)

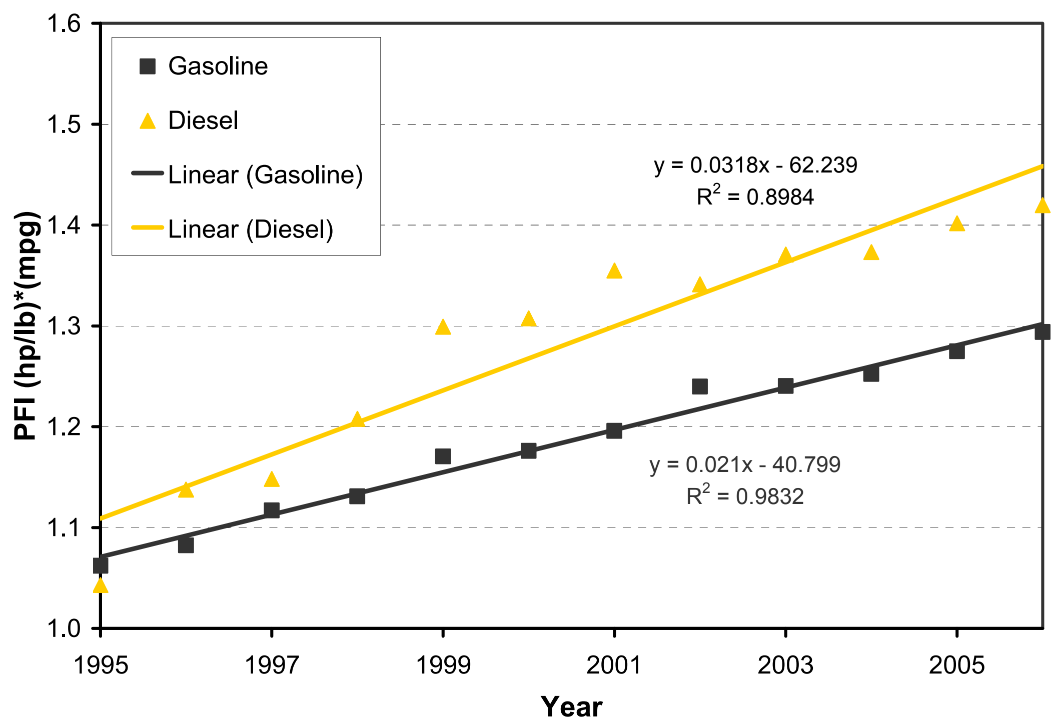


B. Historic Fuel Consumption, Performance and Weight Tradeoff
Sources: (Perkins 2007 and European Commission 2007b).

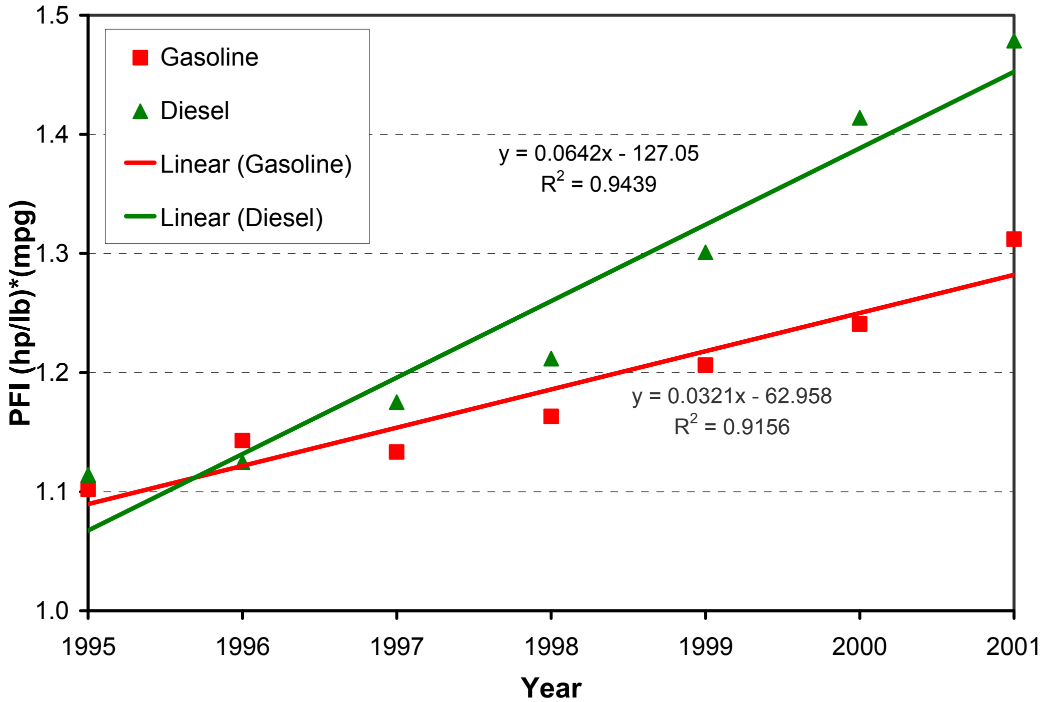
France



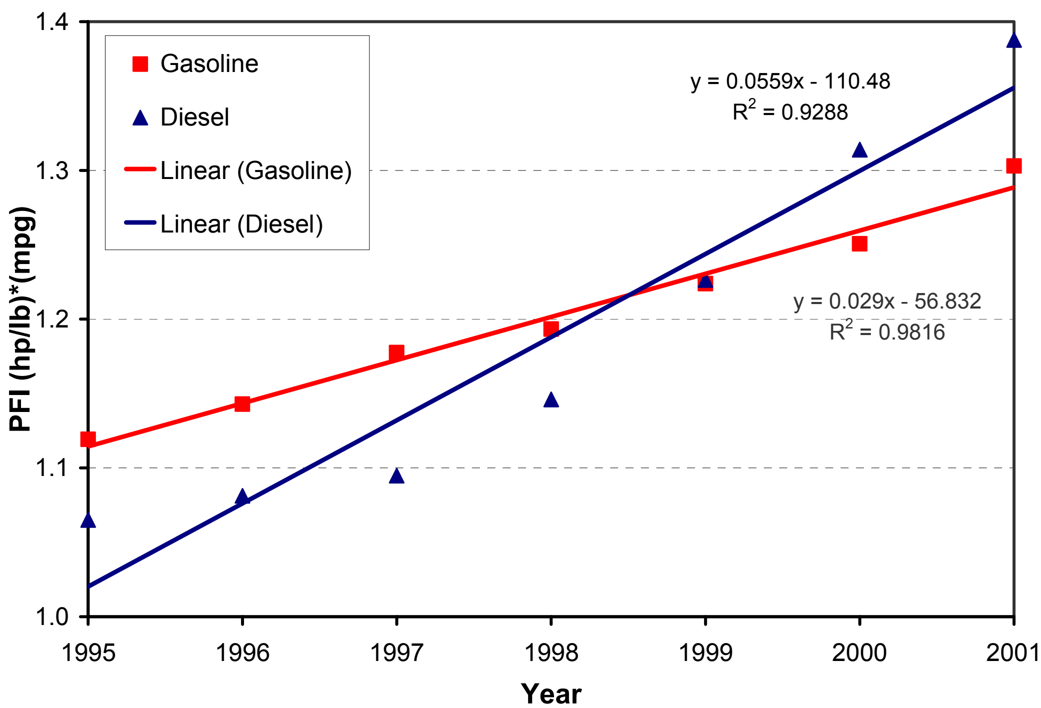
Germany



Italy

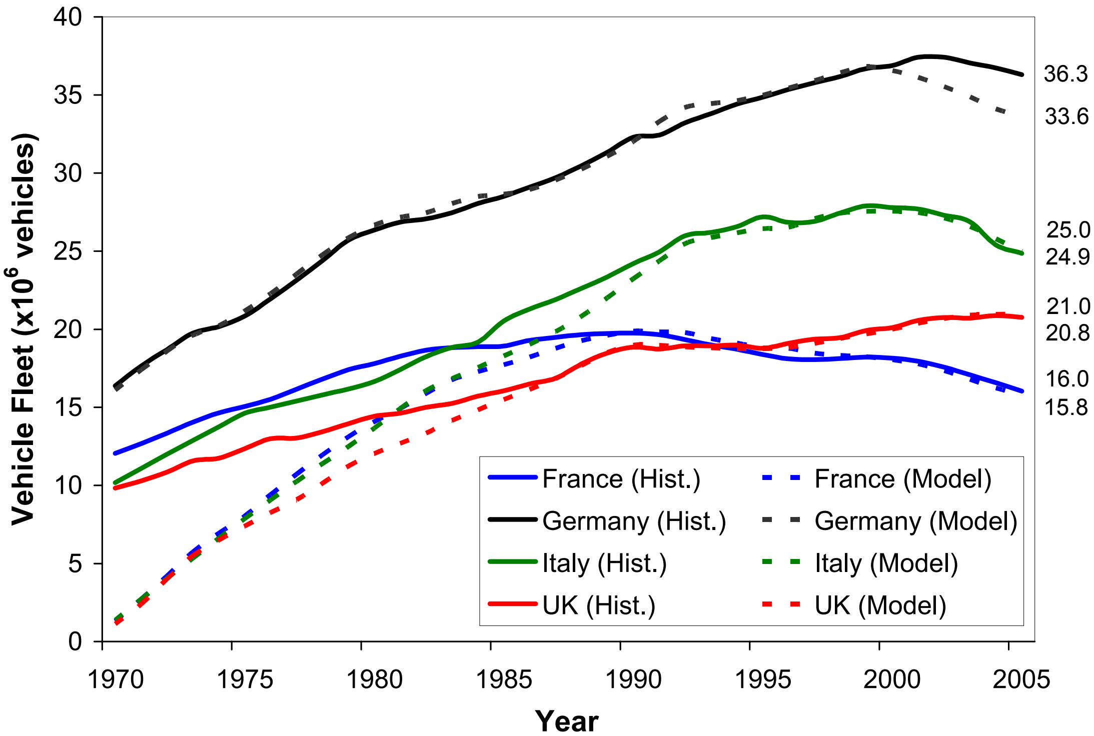

1.5
1.4
1.3
1.2
1.1
1.0
PFI (hp/lb)*(mpg)
Gasoline
Diesel
Linear (Gasoline)
Linear (Diesel)
y = 0.0642x - 127.05
R2 = 0.9439
y = 0.0321x - 62.958
R2 = 0.9156
1995
1996
1997
1998
1999
2000
2001
Year

UK

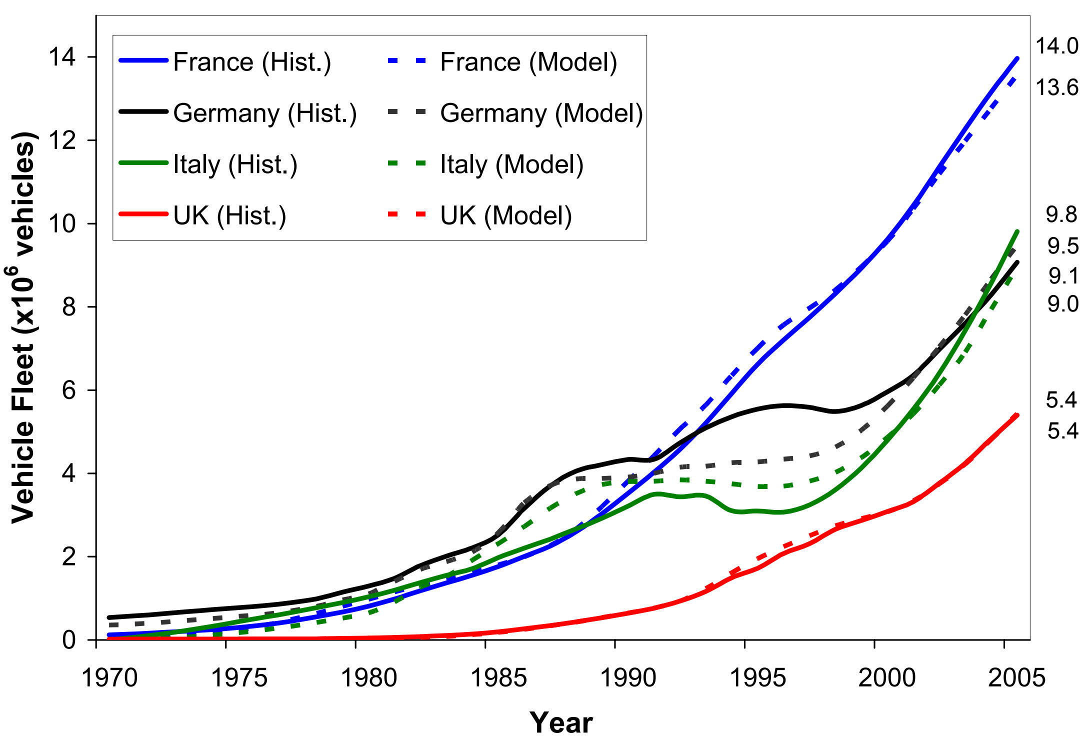

1.4
1.3
1.2
1.1
1.0
PFI (hp/lb)*(mpg)
Gasoline
Diesel
Linear (Gasoline)
Linear (Diesel)
y = 0.0559x - 110.48
R2 = 0.9288
y = 0.029x - 56.832
R2 = 0.9816
1995
1996
1997
1998
1999
2000
2001
Year

C. Calibration to Historic Data

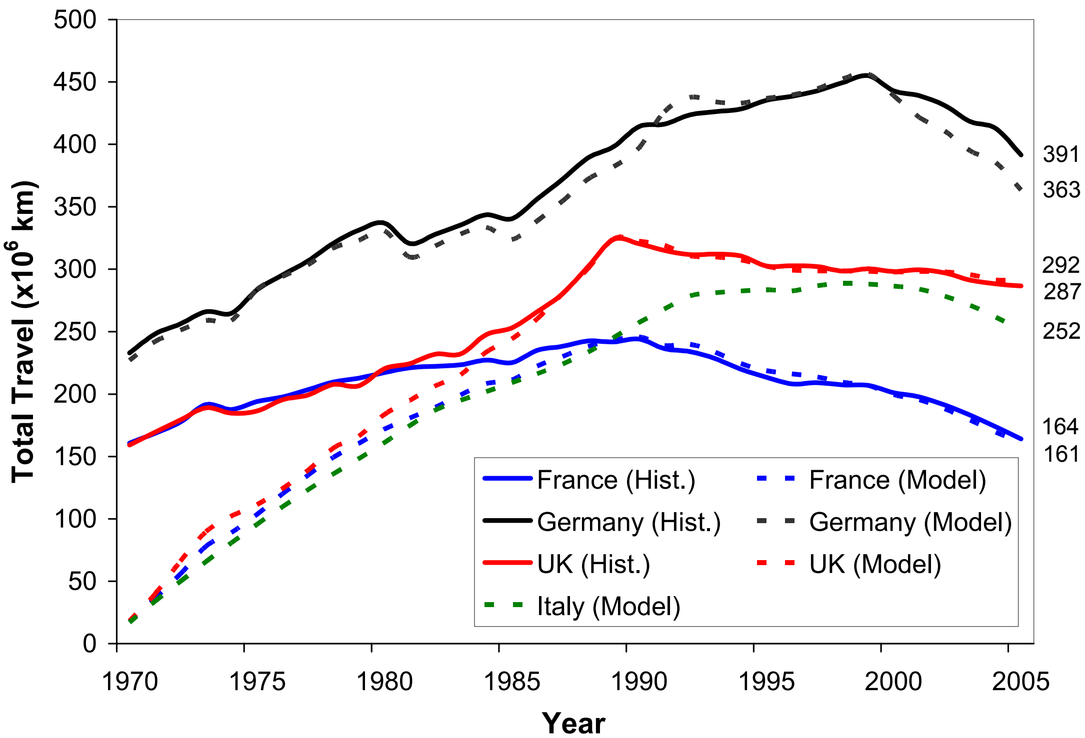
Vehicle Fleet (Gasoline)



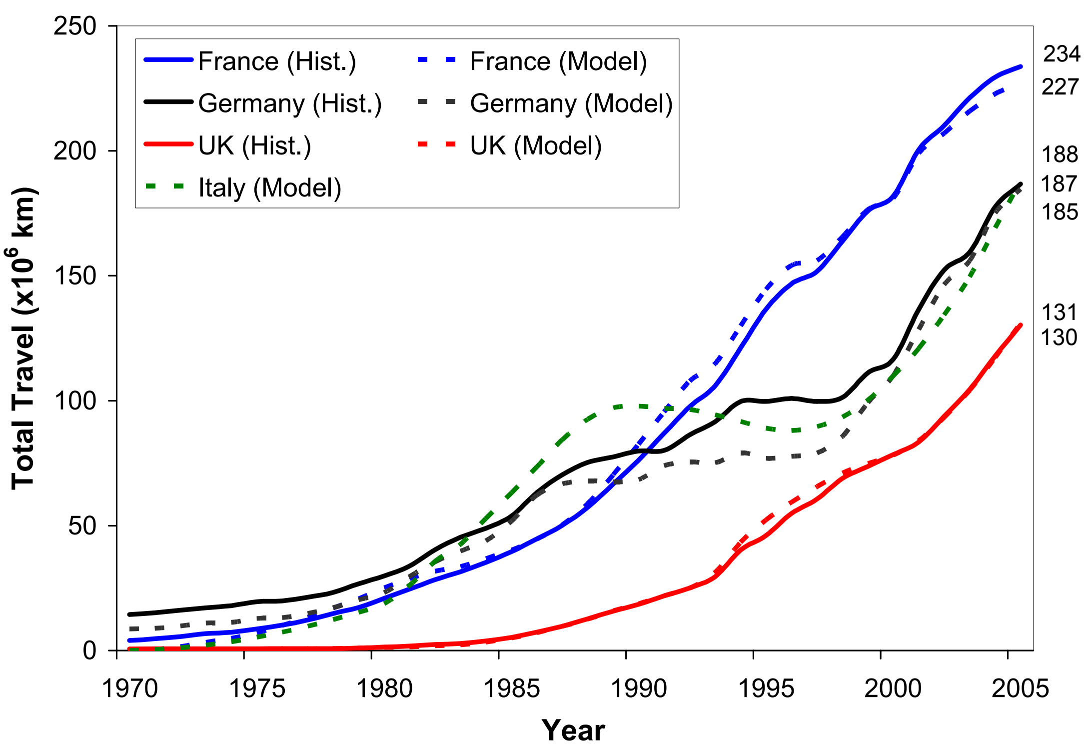
Vehicle Fleet (Diesel)



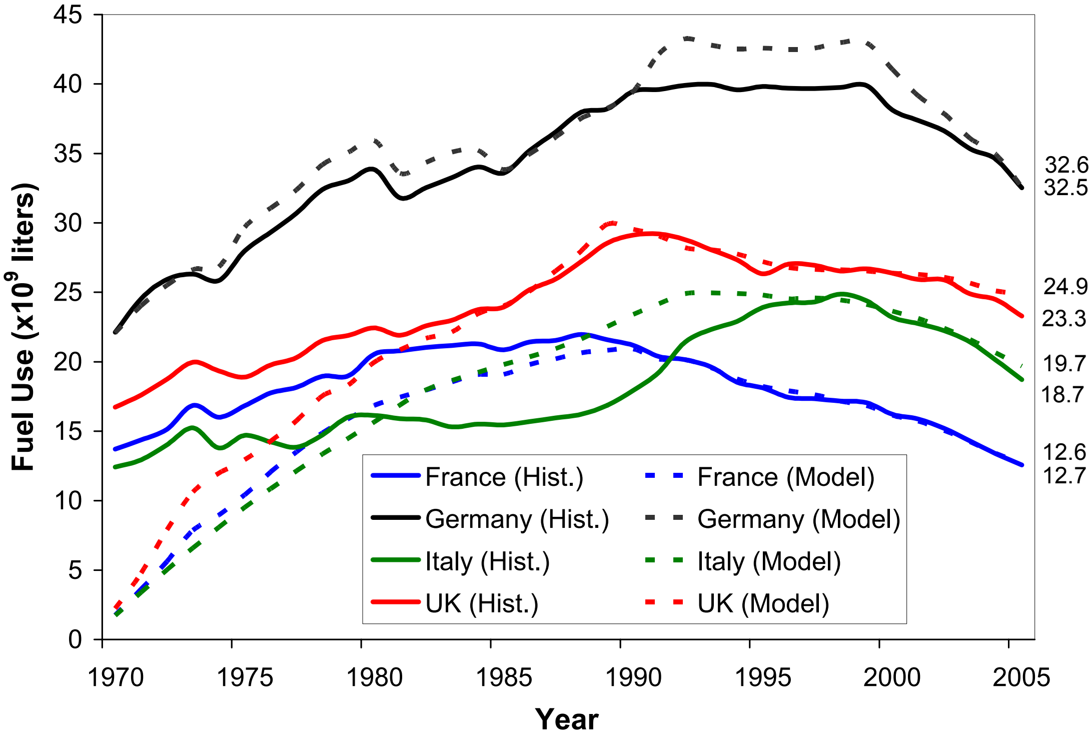
Total Traveled (Gasoline)



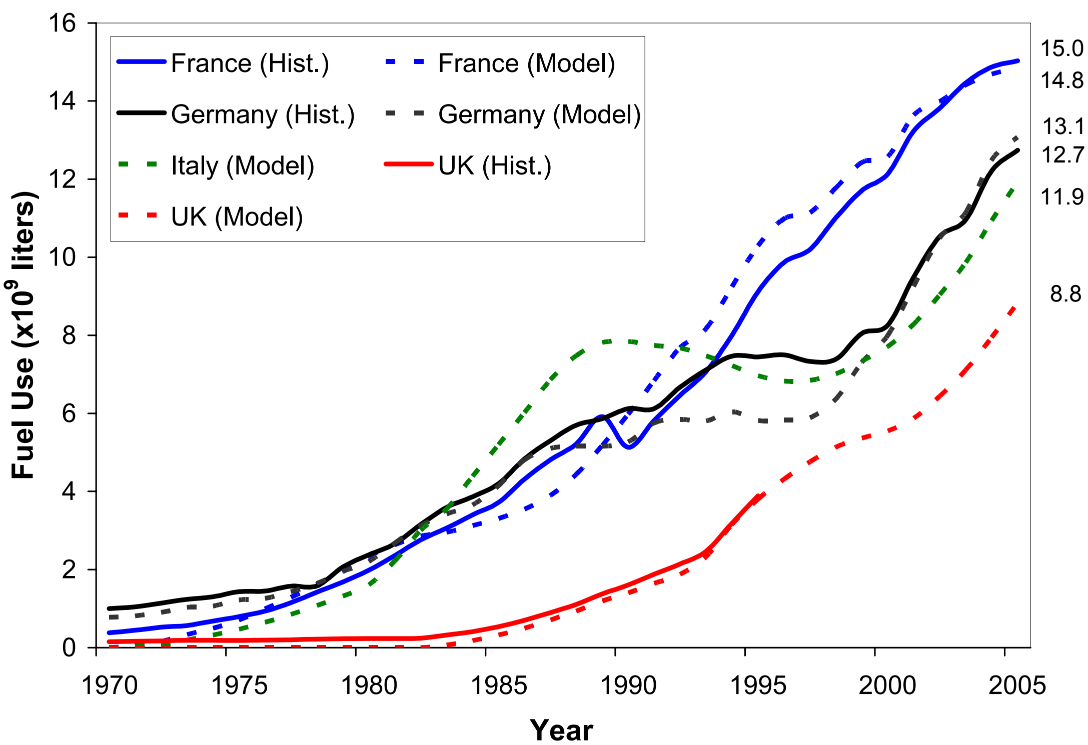
Total Travel (Diesel)



Fuel Use (Gasoline)

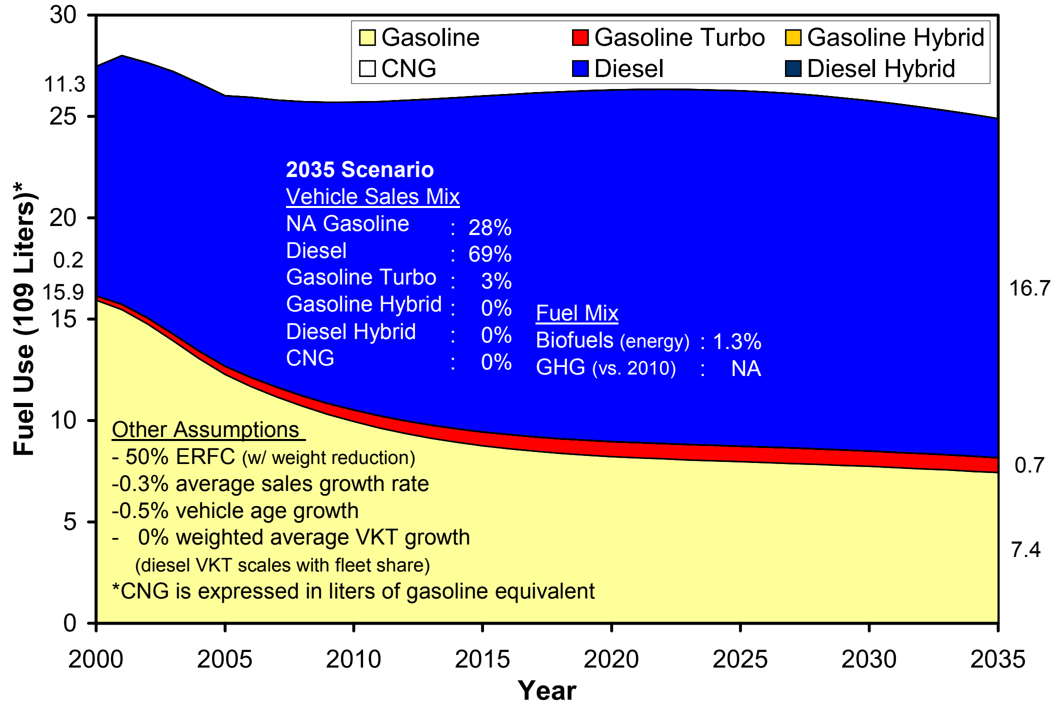


Fuel Use (Diesel)

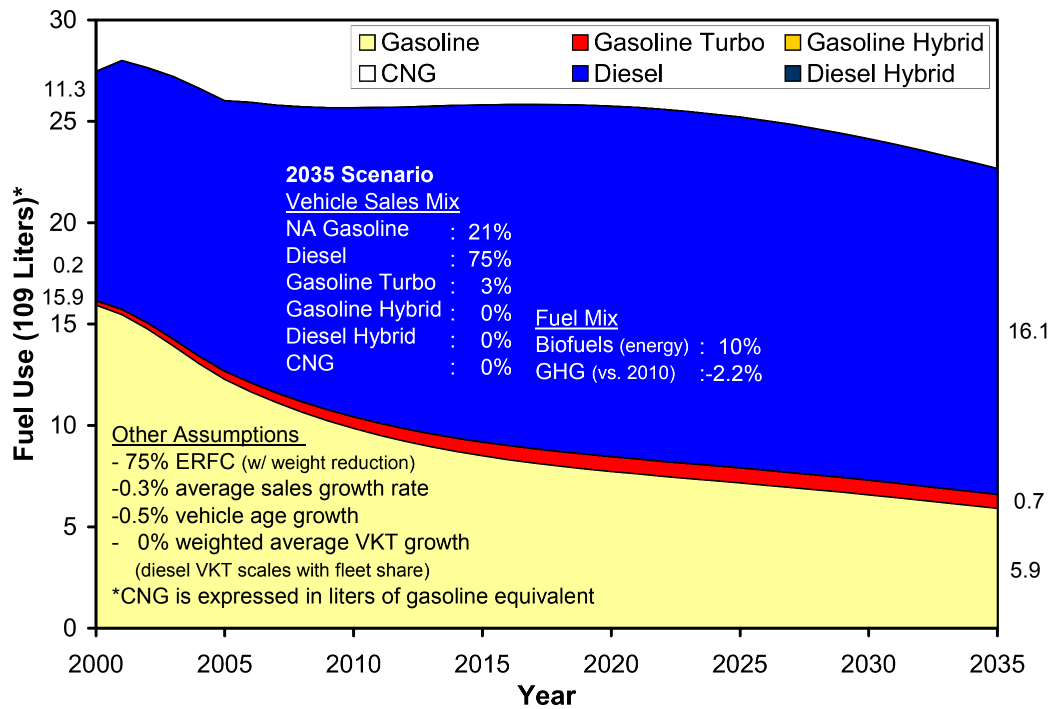


D. Petroleum Fuel Use

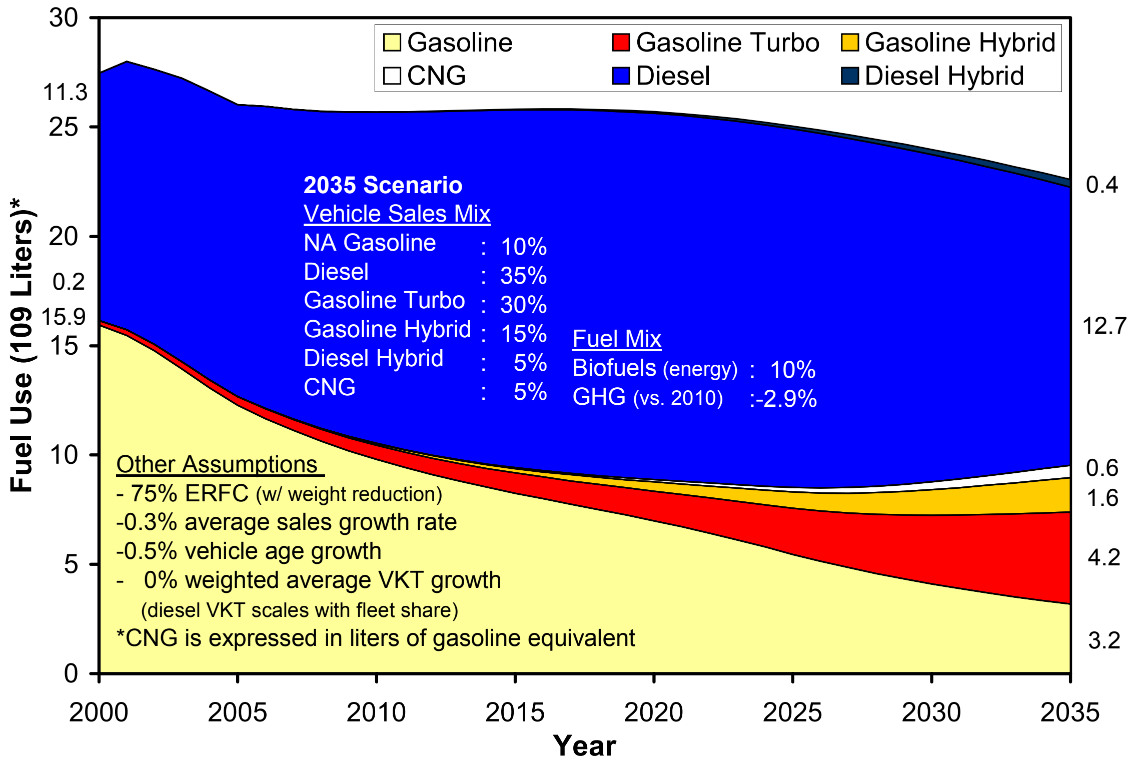
France: *No Change*



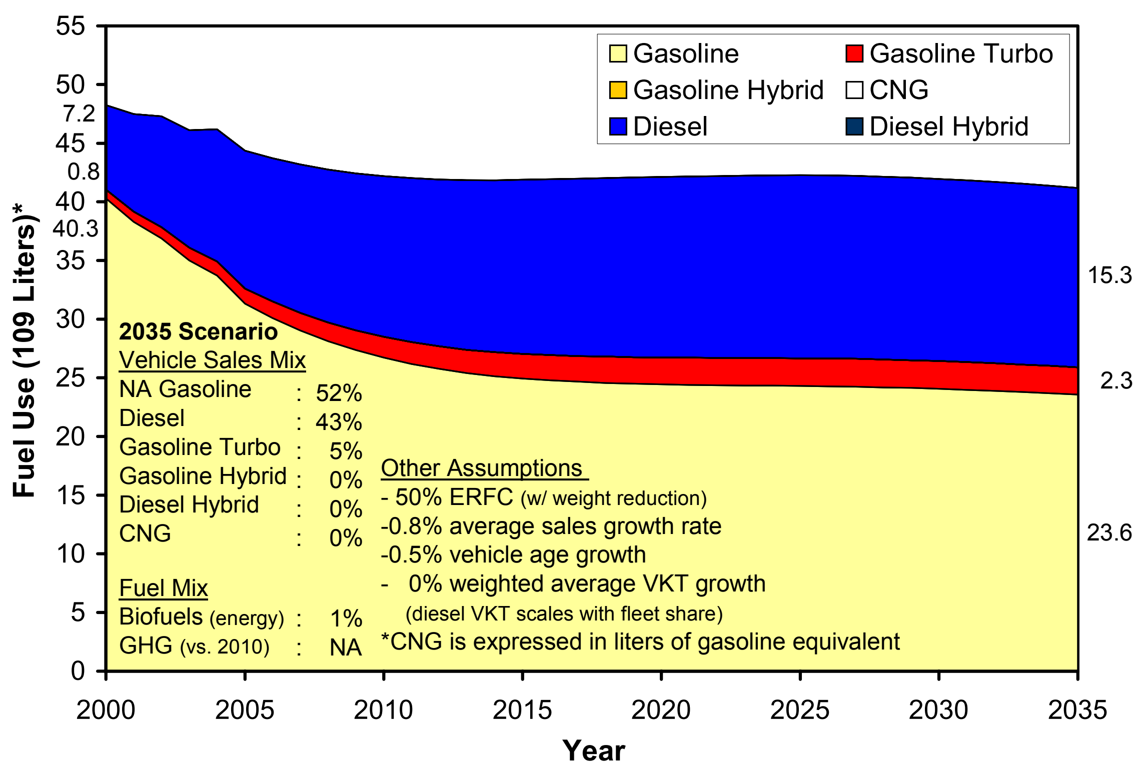
France: *Diesels Dominate*



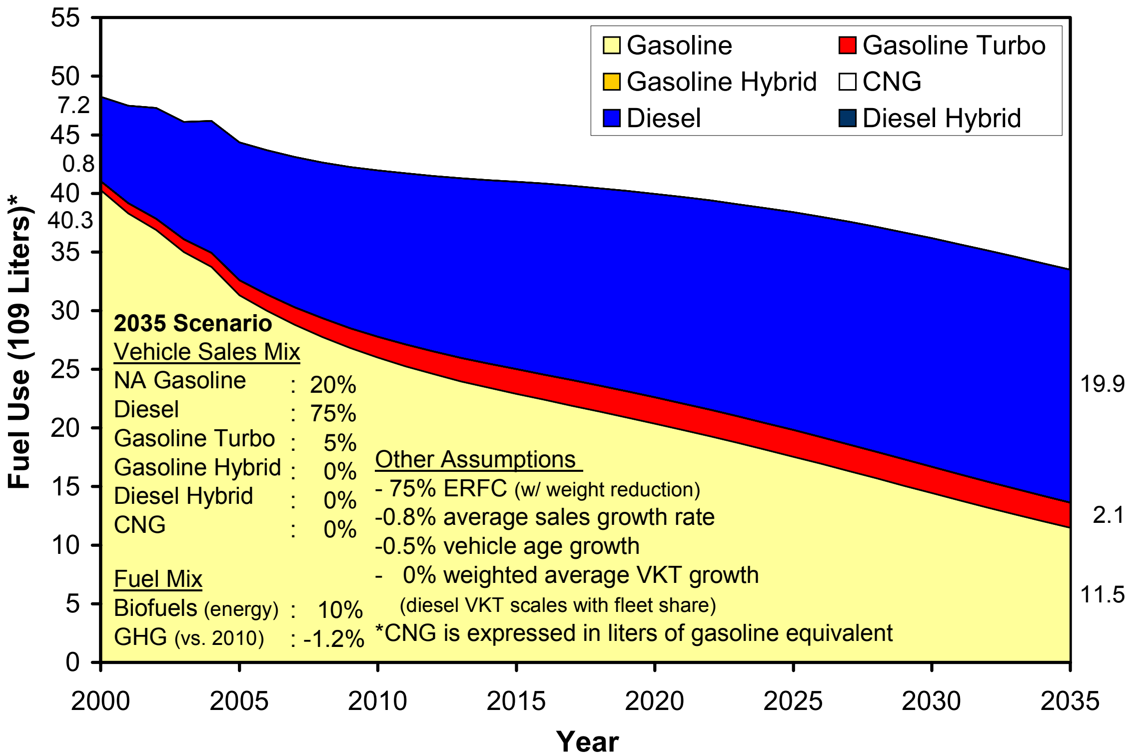
France: *Alternative Technologies Emerge*



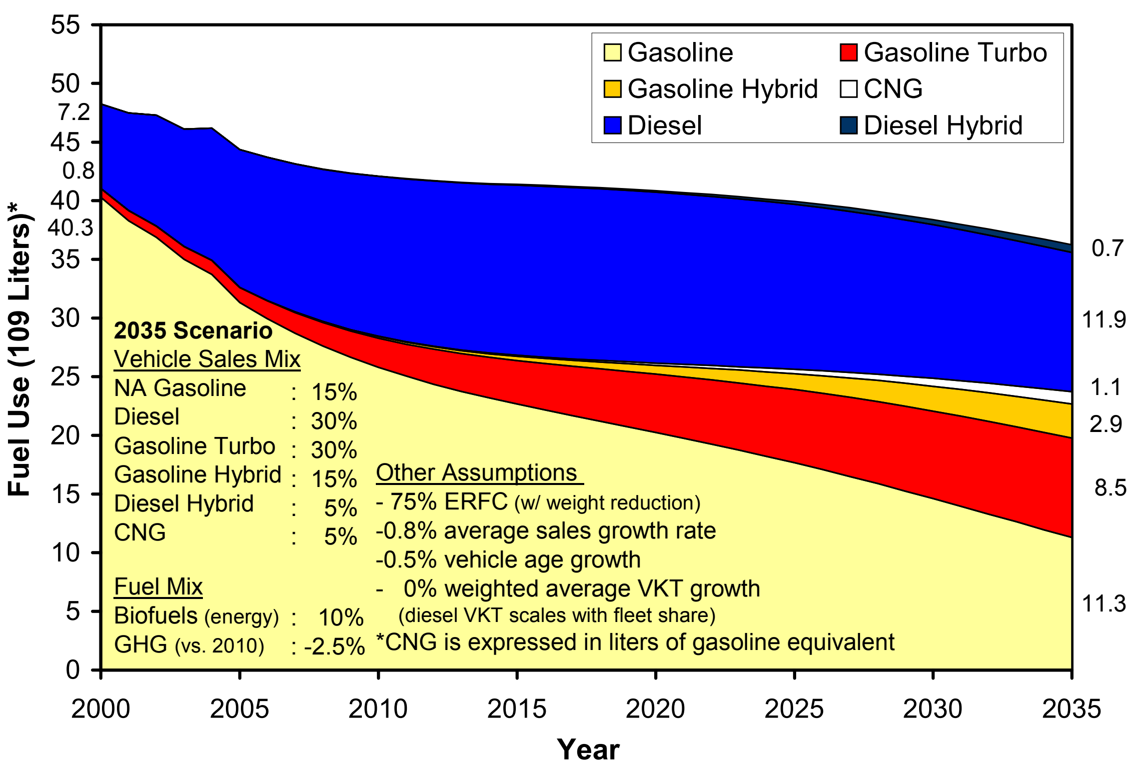
Germany: *No Change*



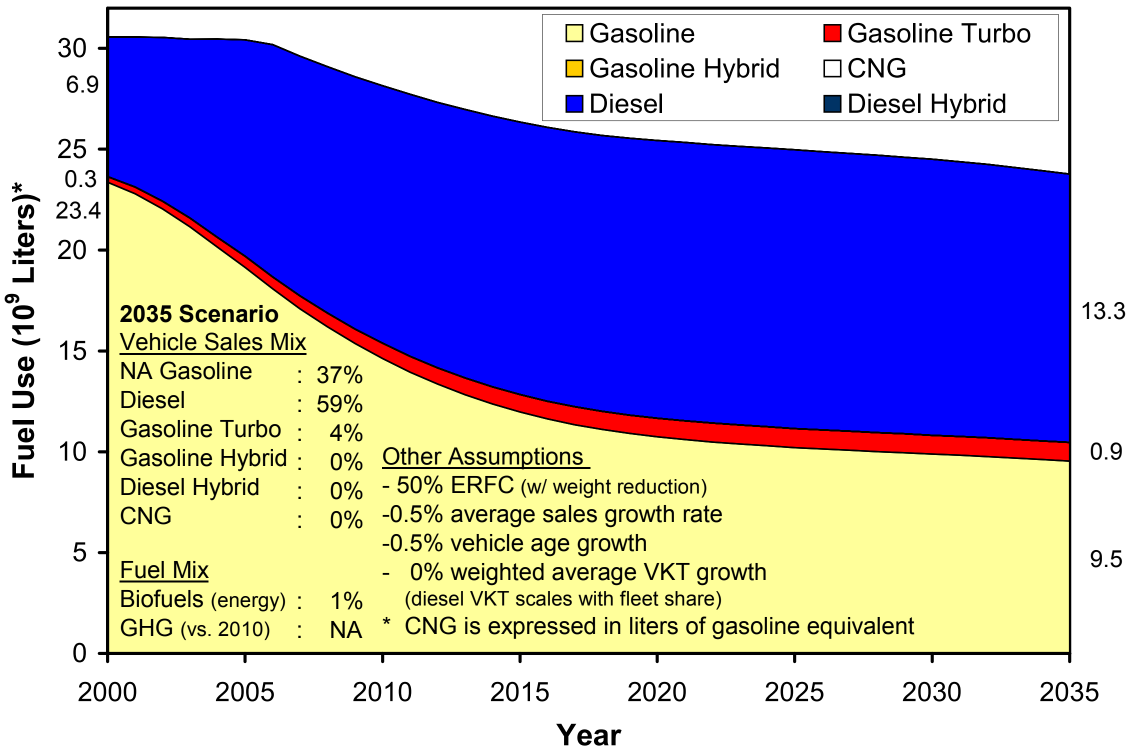
Germany: *Diesels Dominate*



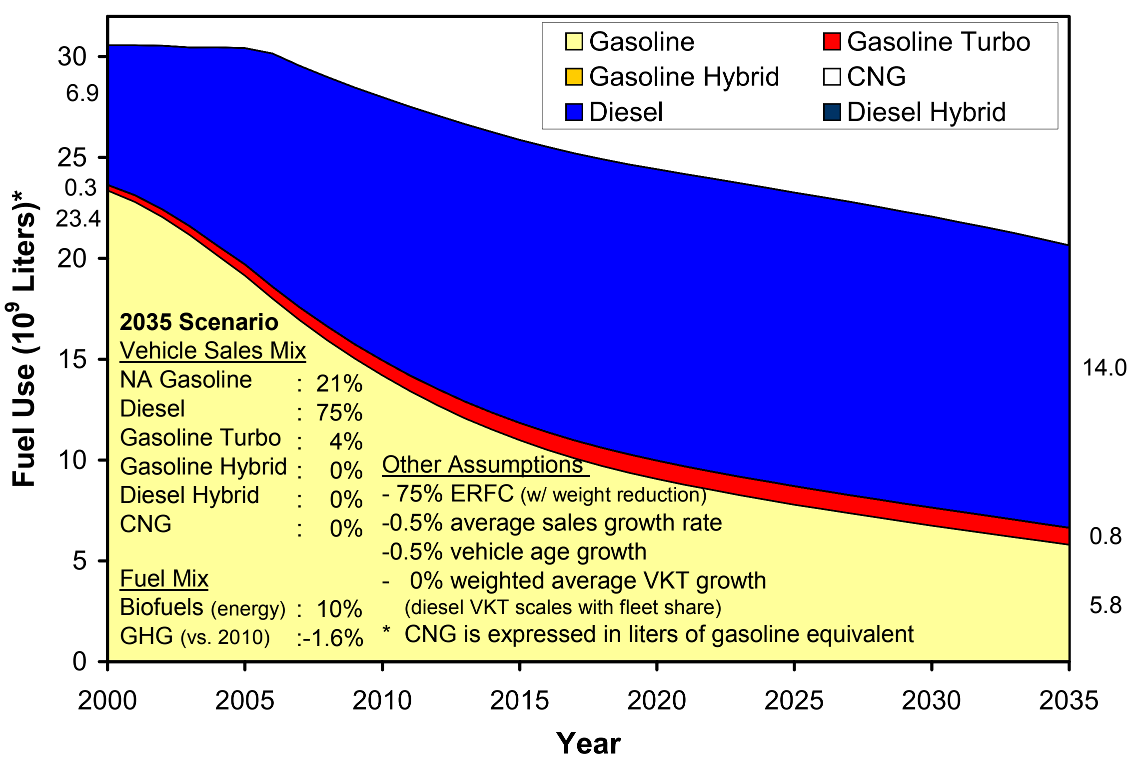
Germany: *Alternative Technologies Emerge*



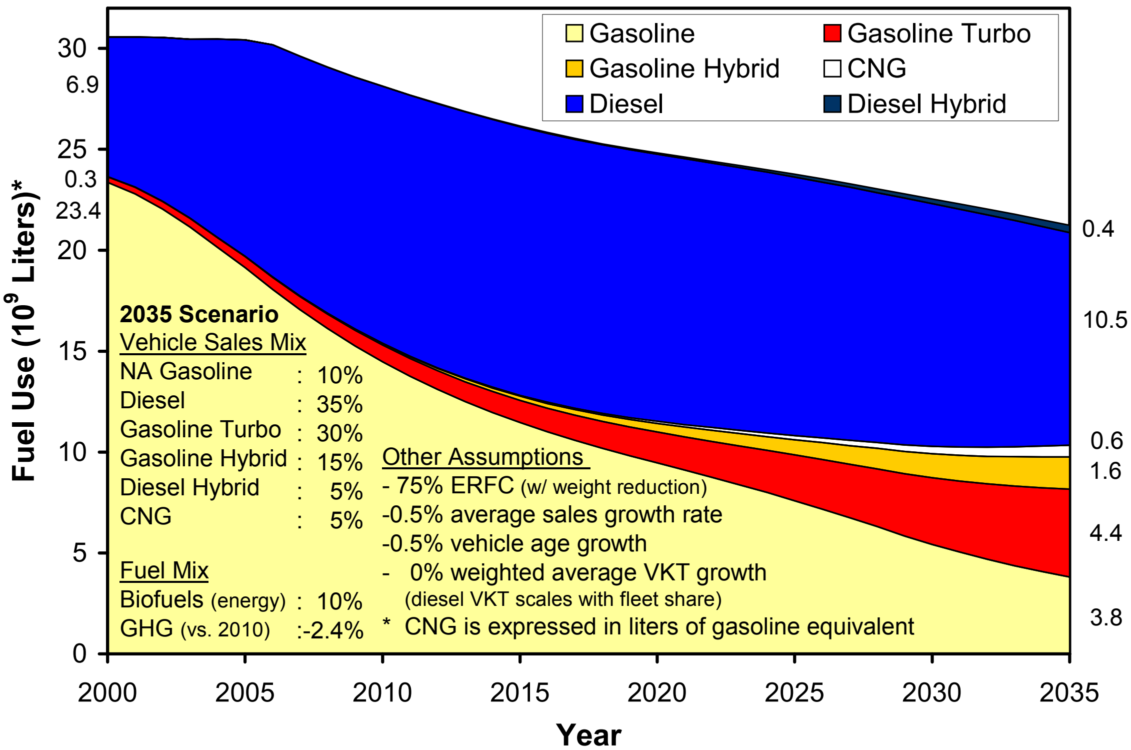
Italy: *No Change*



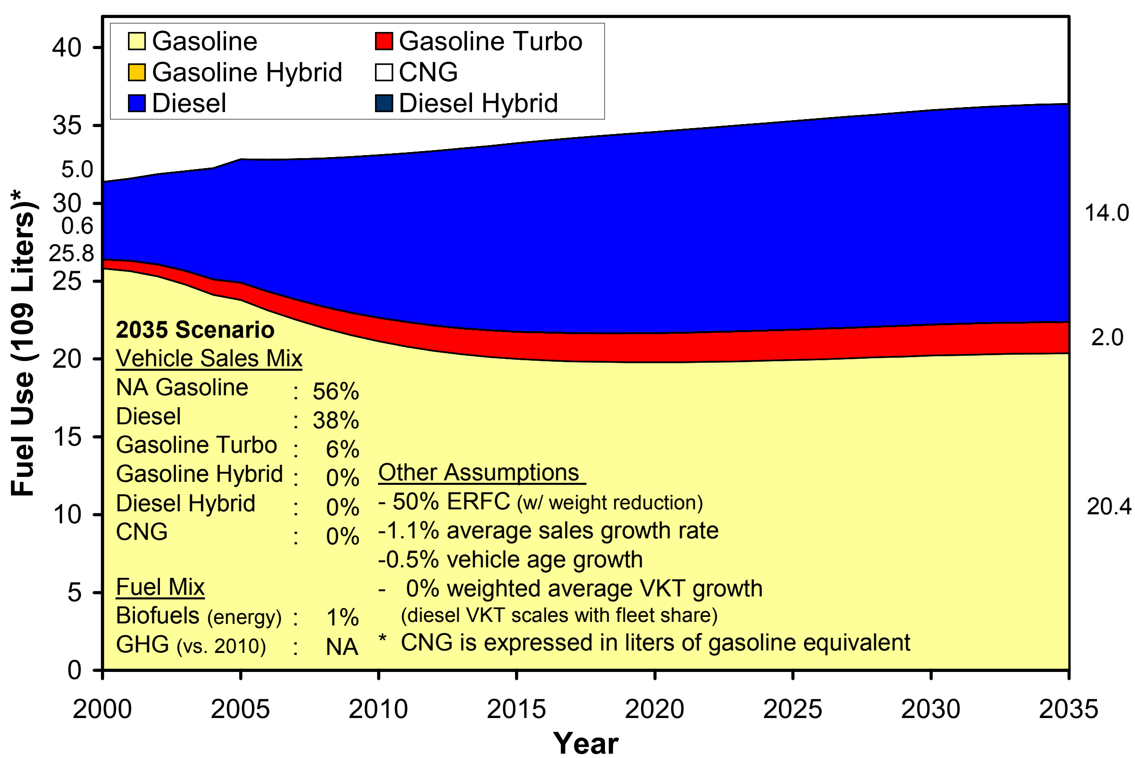
Italy: *Diesels Dominate*



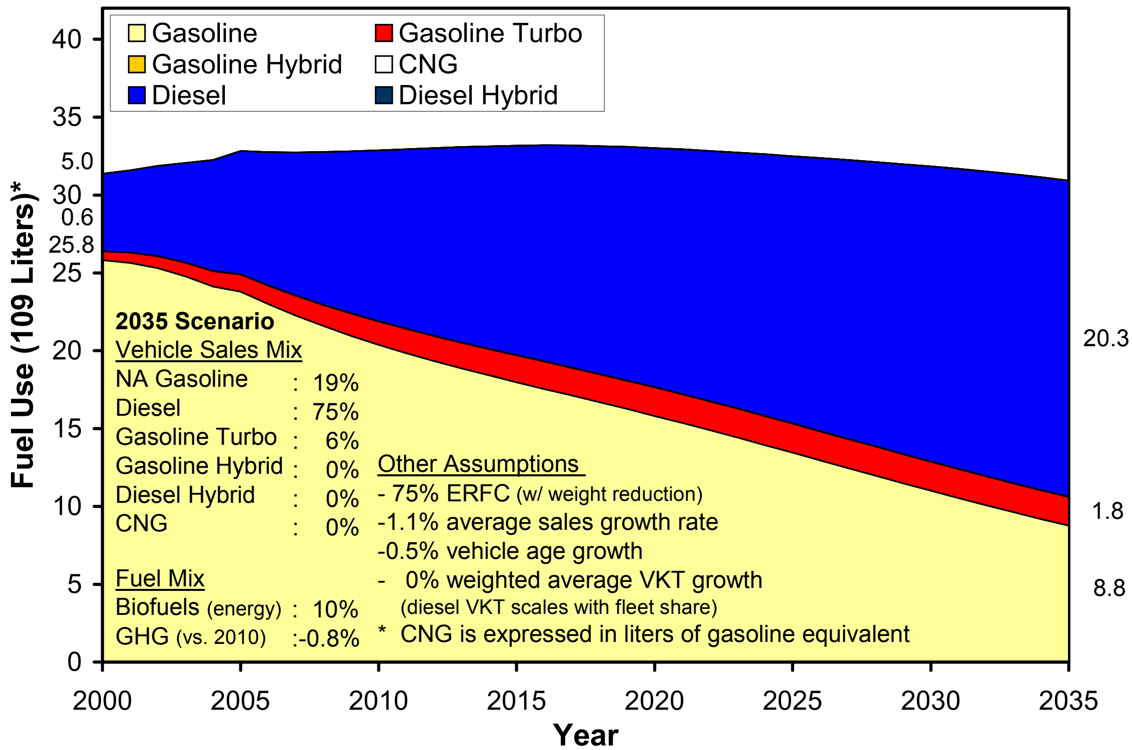
Italy: *Alternative Technologies Emerge*



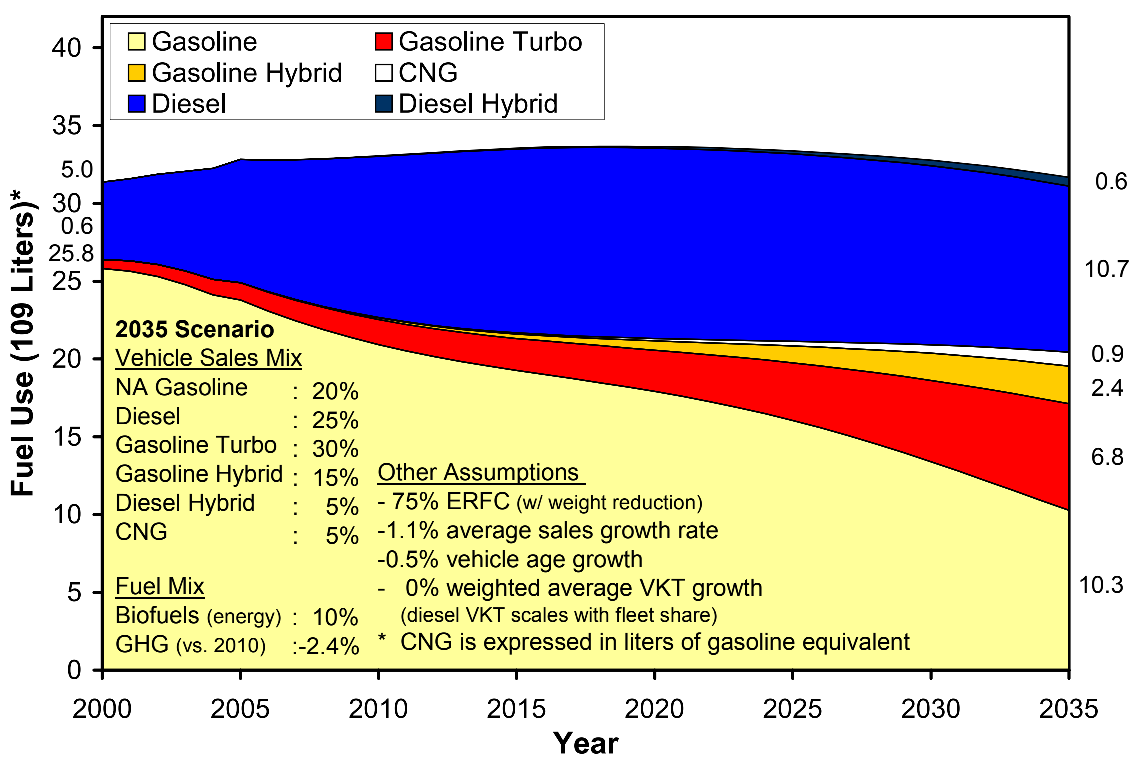
UK: *No Change*



UK: *Diesels Dominate*

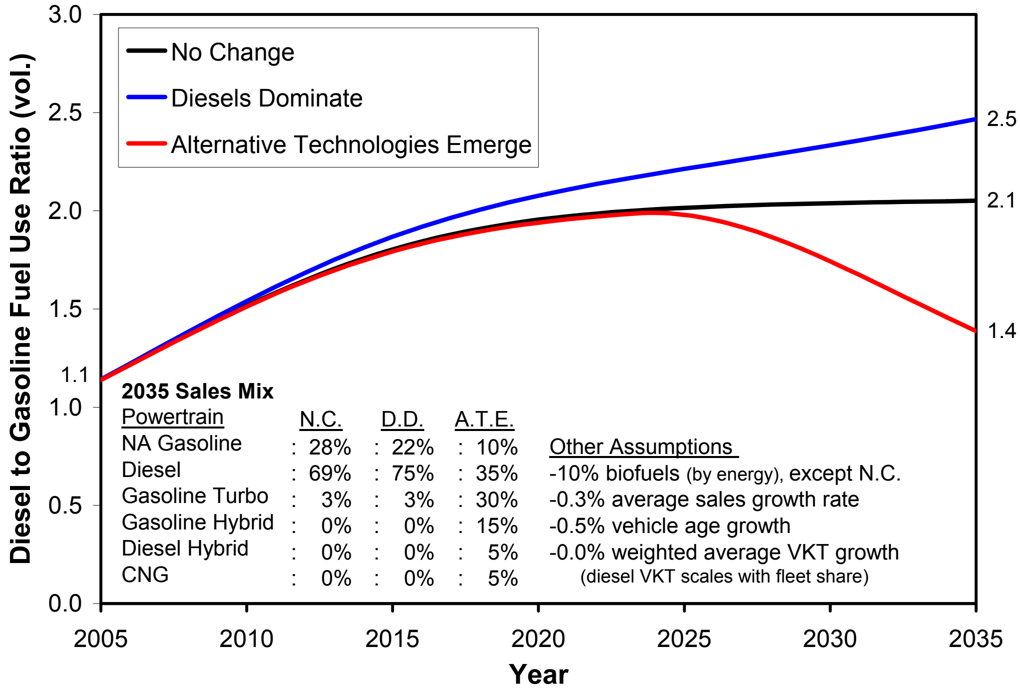


UK: *Alternative Technologies Emerge*

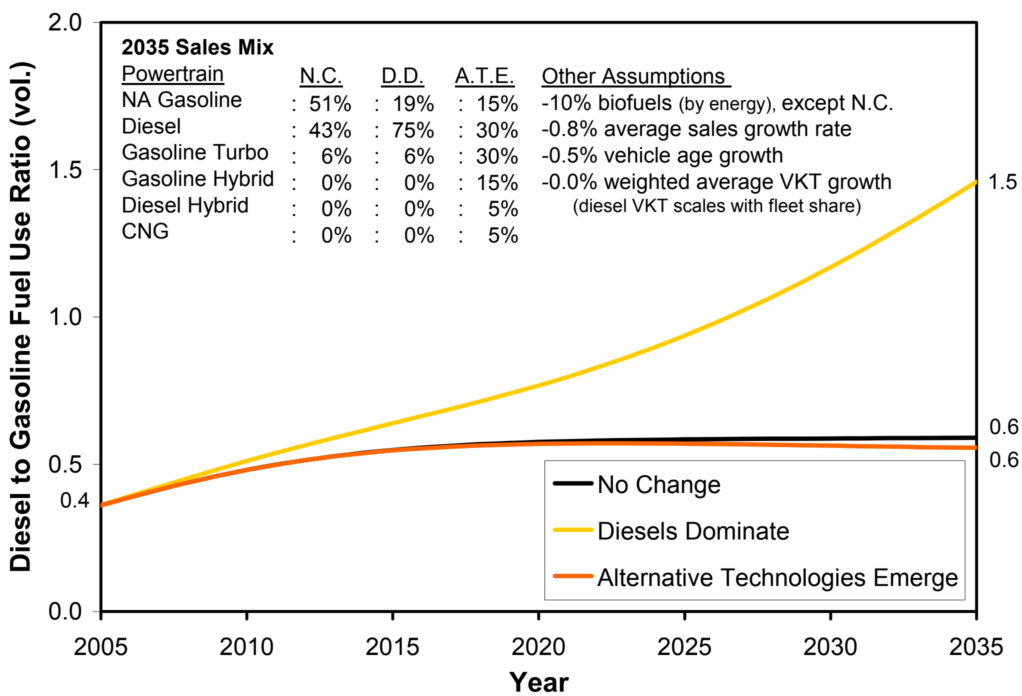


E. Diesel to Gasoline Fuel Use Ratio

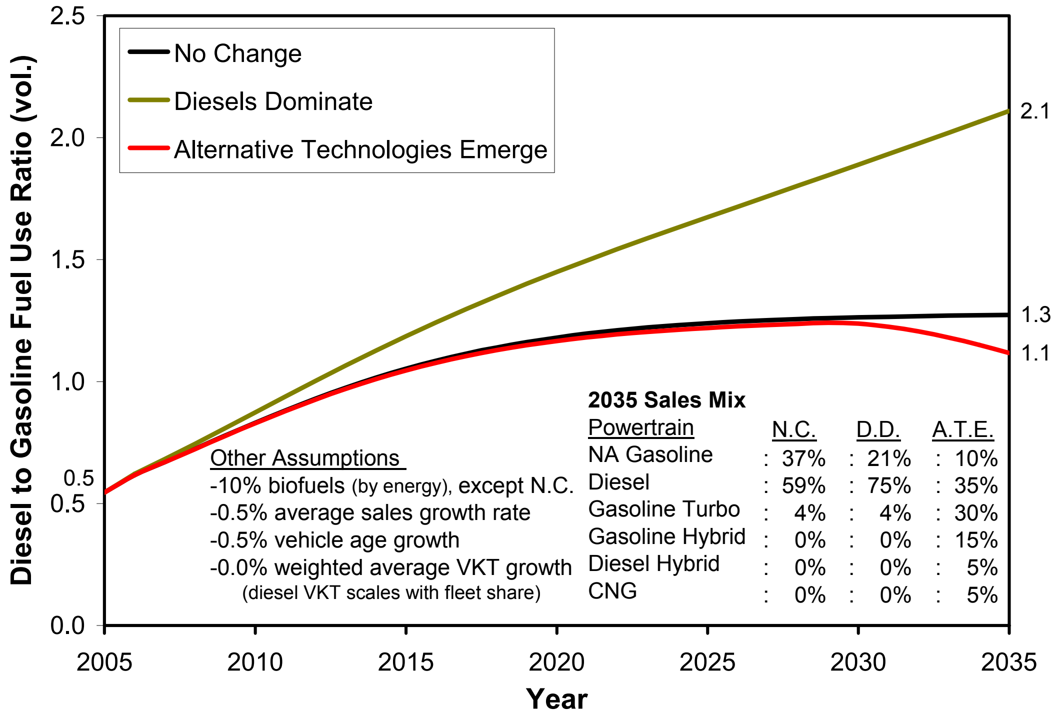
France



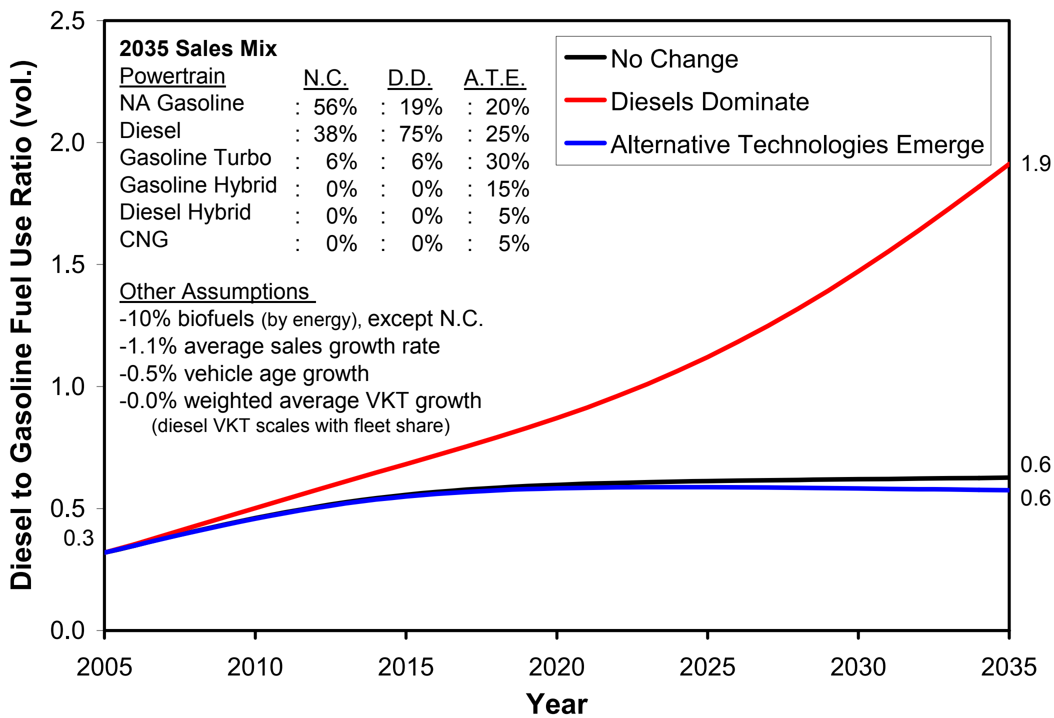
Germany



Italy

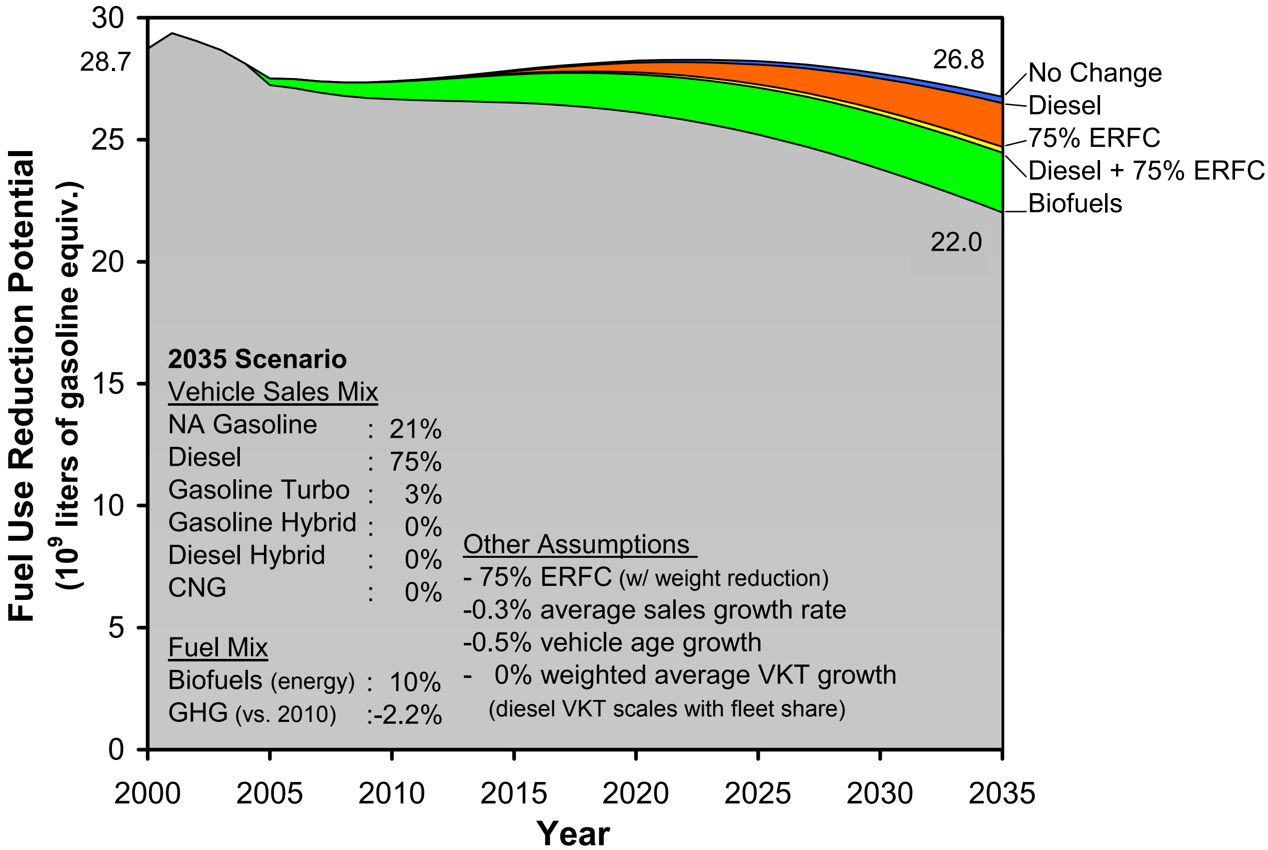

No Change
Diesels Dominate
Alternative Technologies Emerge
2.1
1.3
1.1
0.5
2035 Sales Mix
Powertrain N.C. D.D. A.T.E.
NA Gasoline : 37% : 21% : 10%
Diesel : 59% : 75% : 35%
Gasoline Turbo : 4% : 4% : 30%
Gasoline Hybrid : 0% : 0% : 15%
Diesel Hybrid : 0% : 0% : 5%
CNG : 0% : 0% : 5%
Other Assumptions
-10% biofuels (by energy), except N.C.
-0.5% average sales growth rate
-0.5% vehicle age growth
-0.0% weighted average VKT growth
(diesel VKT scales with fleet share)
Diesel to Gasoline Fuel Use Ratio (vol.)
0.0
0.5
1.0
1.5
2.0
2.5
2005
2010
2015
2020
2025
2030
2035
Year

UK

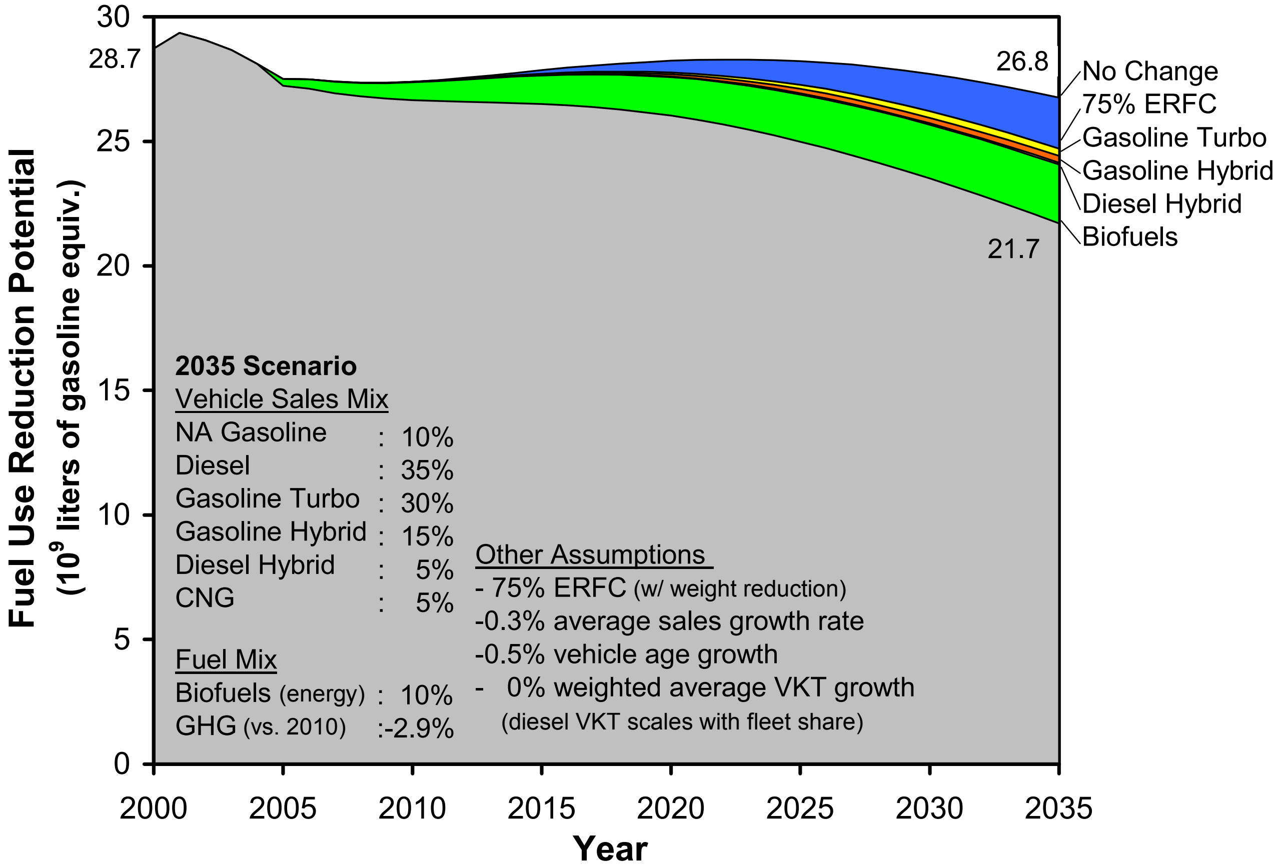

2035 Sales Mix
Powertrain N.C. D.D. A.T.E.
NA Gasoline : 56% : 19% : 20%
Diesel : 38% : 75% : 25%
Gasoline Turbo : 6% : 6% : 30%
Gasoline Hybrid : 0% : 0% : 15%
Diesel Hybrid : 0% : 0% : 5%
CNG : 0% : 0% : 5%
Other Assumptions
-10% biofuels (by energy), except N.C.
-1.1% average sales growth rate
-0.5% vehicle age growth
-0.0% weighted average VKT growth
(diesel VKT scales with fleet share)
No Change
Diesels Dominate
Alternative Technologies Emerge
1.9
0.6
0.6
0.3
Diesel to Gasoline Fuel Use Ratio (vol.)
0.0
0.5
1.0
1.5
2.0
2.5
2005
2010
2015
2020
2025
2030
2035
Year

F. Petroleum Fuel Use Reduction Potential

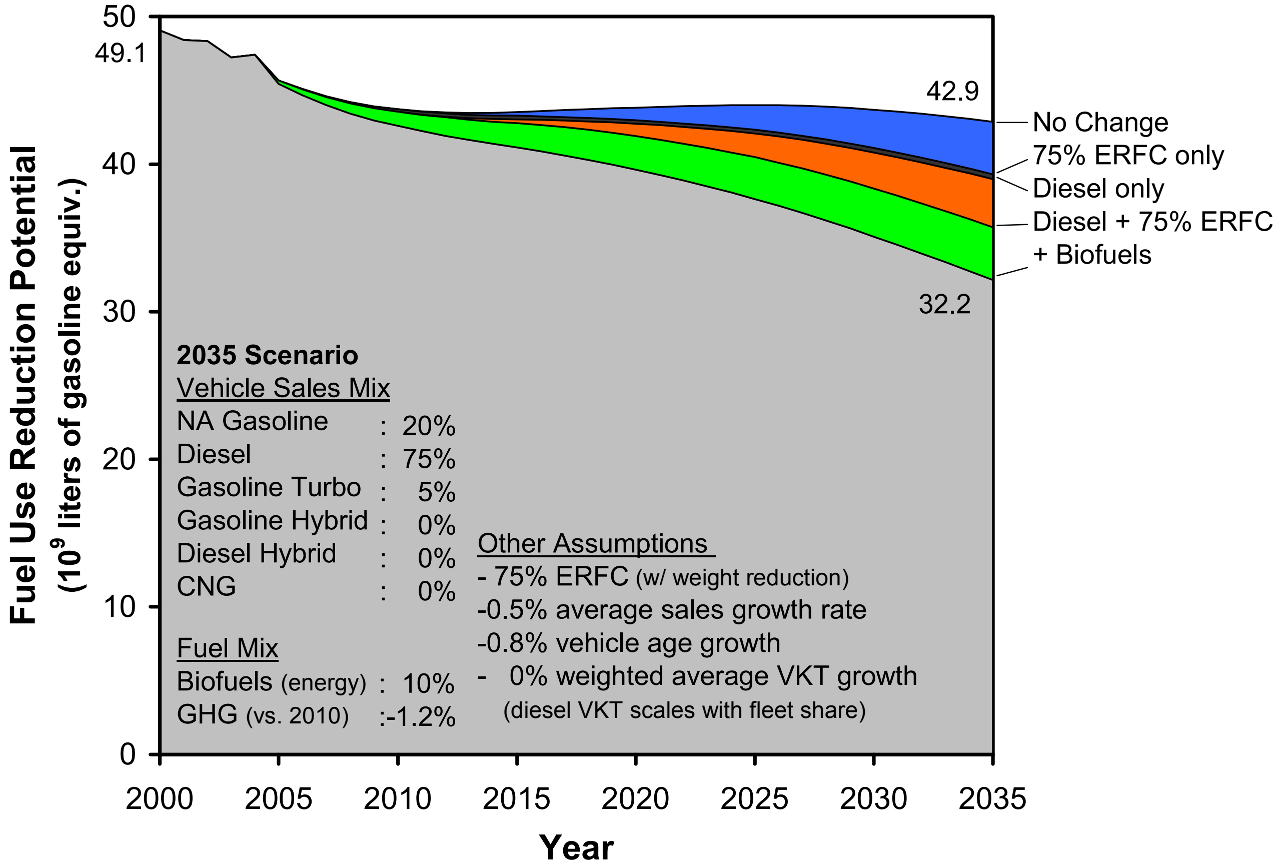
France: *Diesels Dominate*



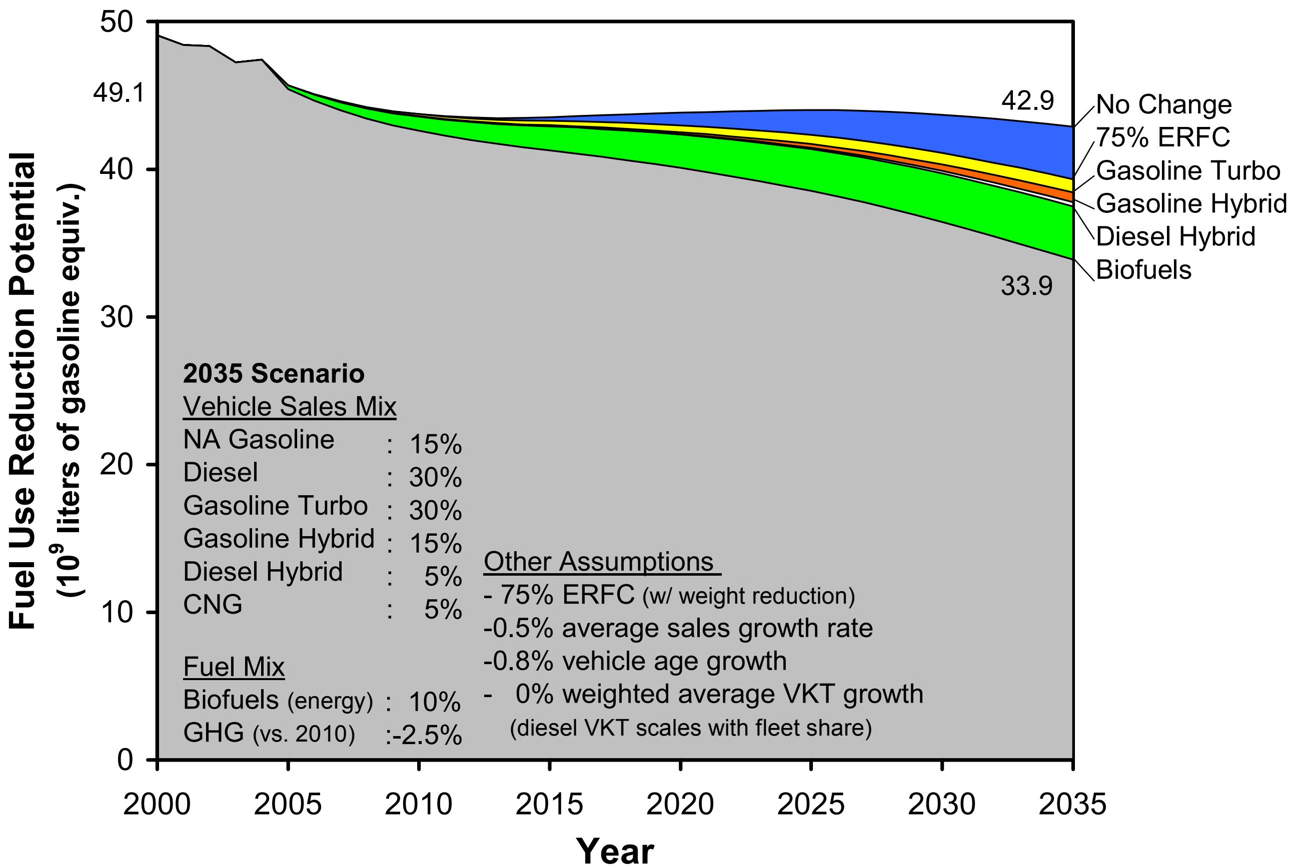
France: *Alternative Technologies Emerge*



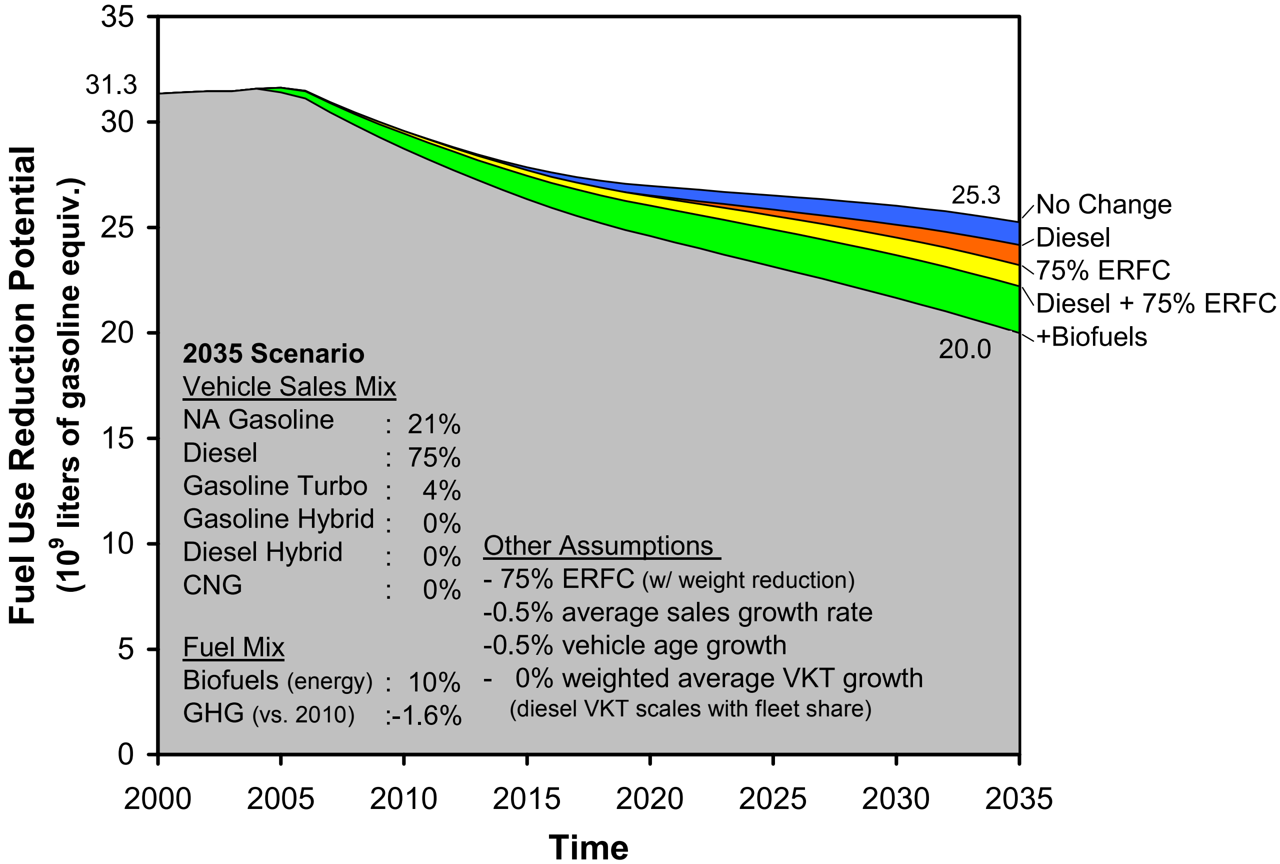
Germany: *Diesels Dominate*



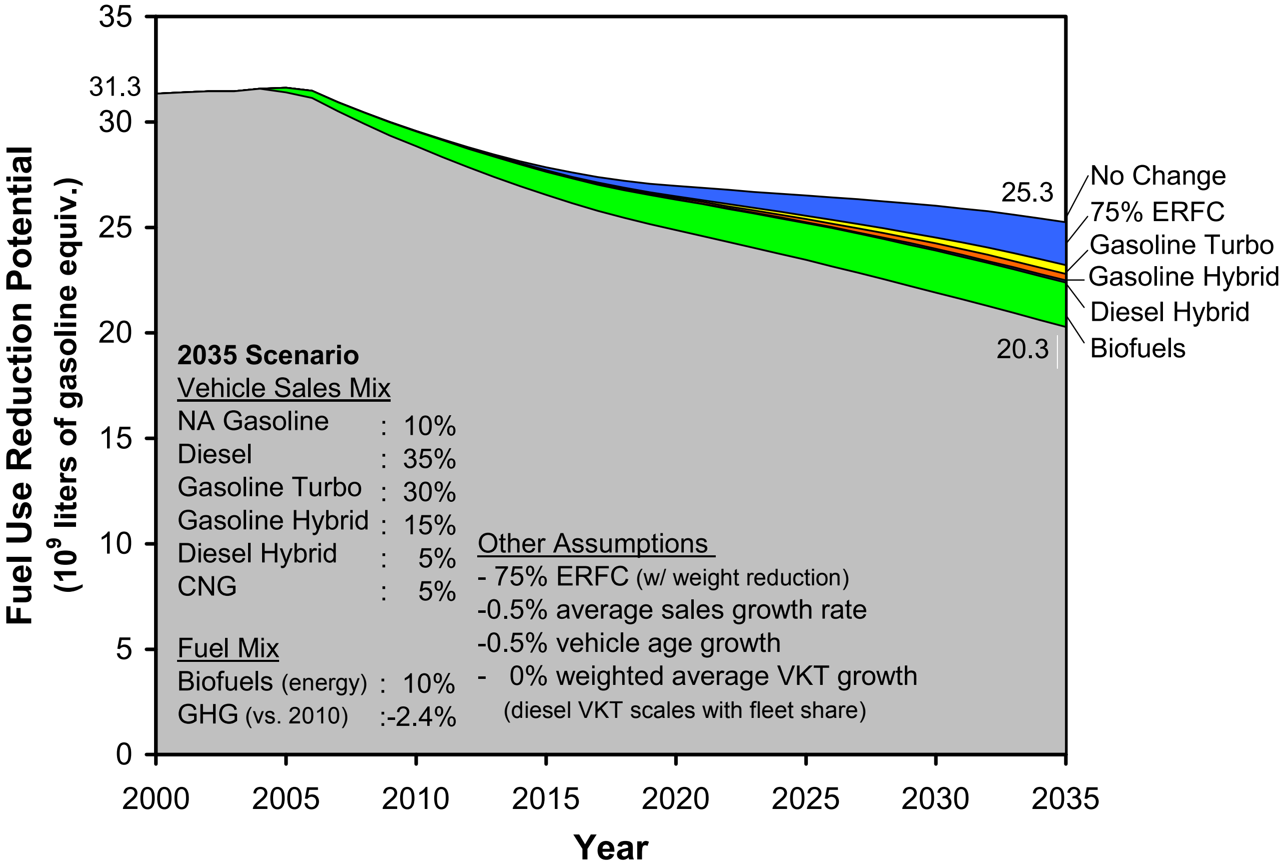
Germany: *Alternative Technologies Emerge*



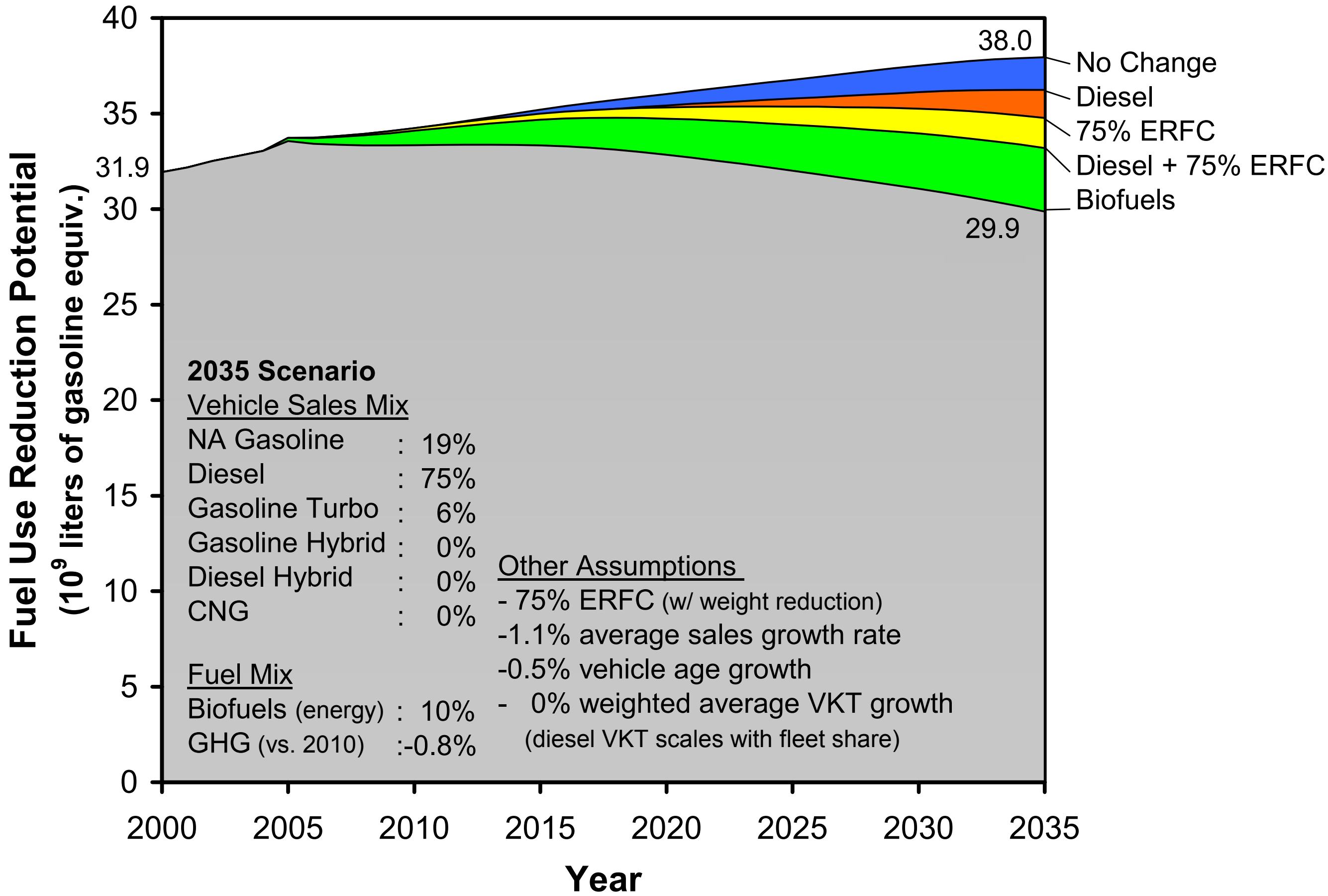
Italy: *Diesels Dominate*



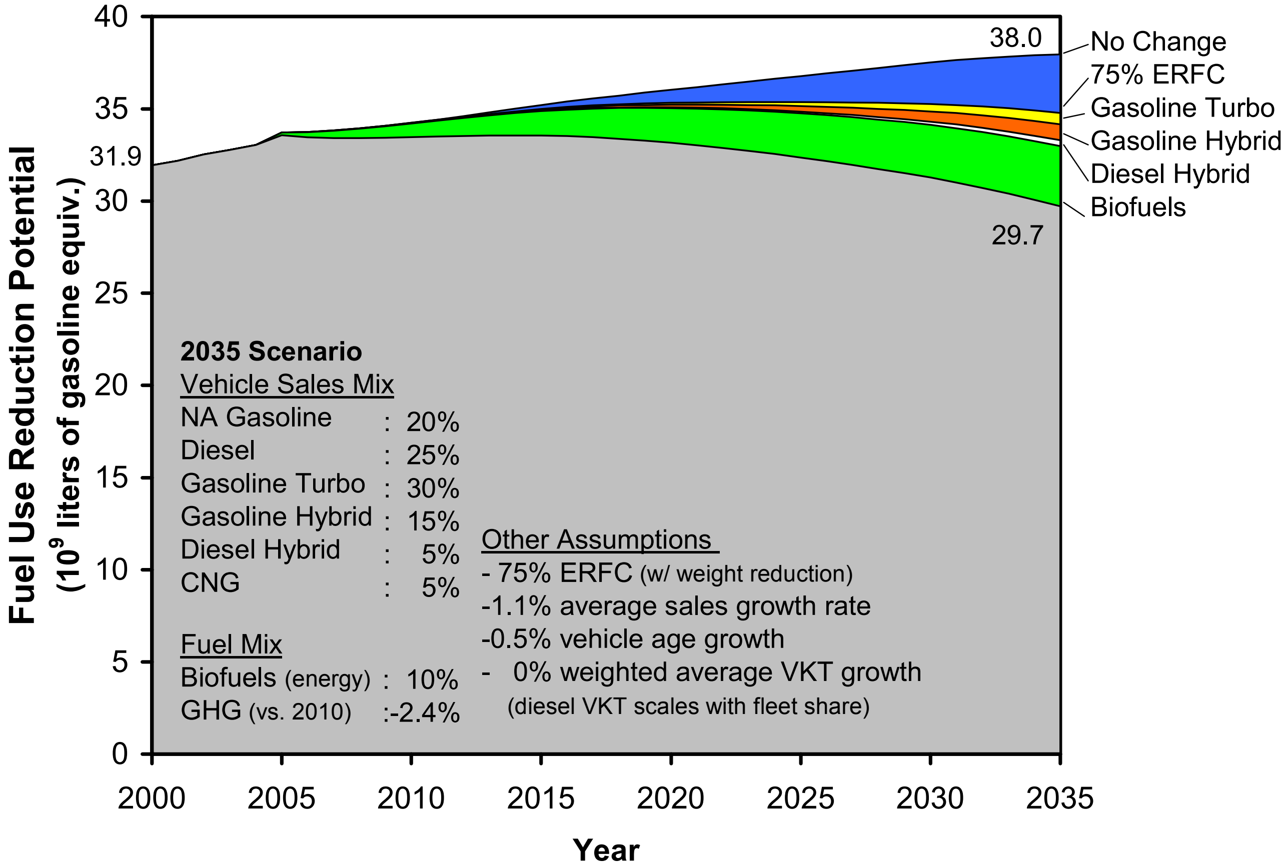
Italy: *Alternative Technologies Emerge*



UK: *Diesels Dominate*

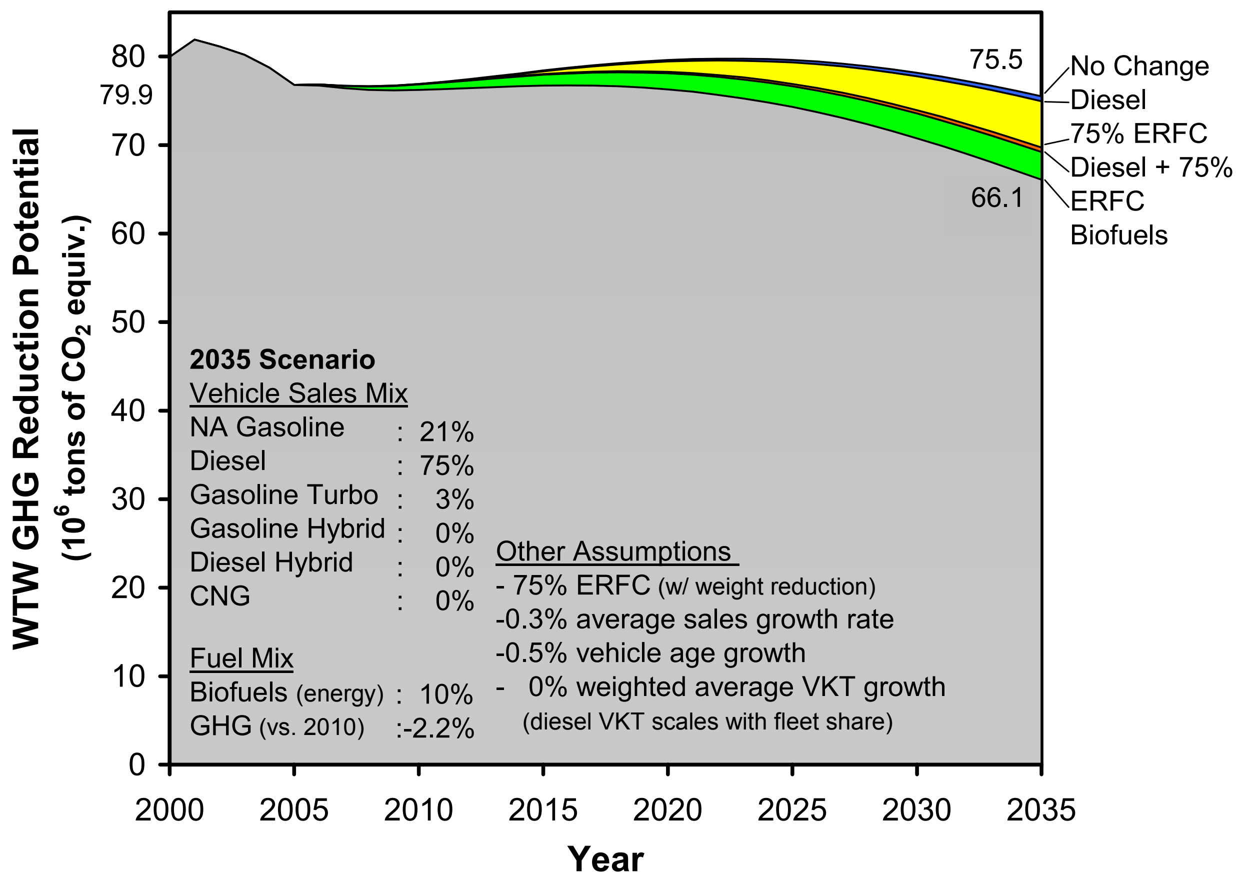


UK: *Alternative Technologies Emerge*

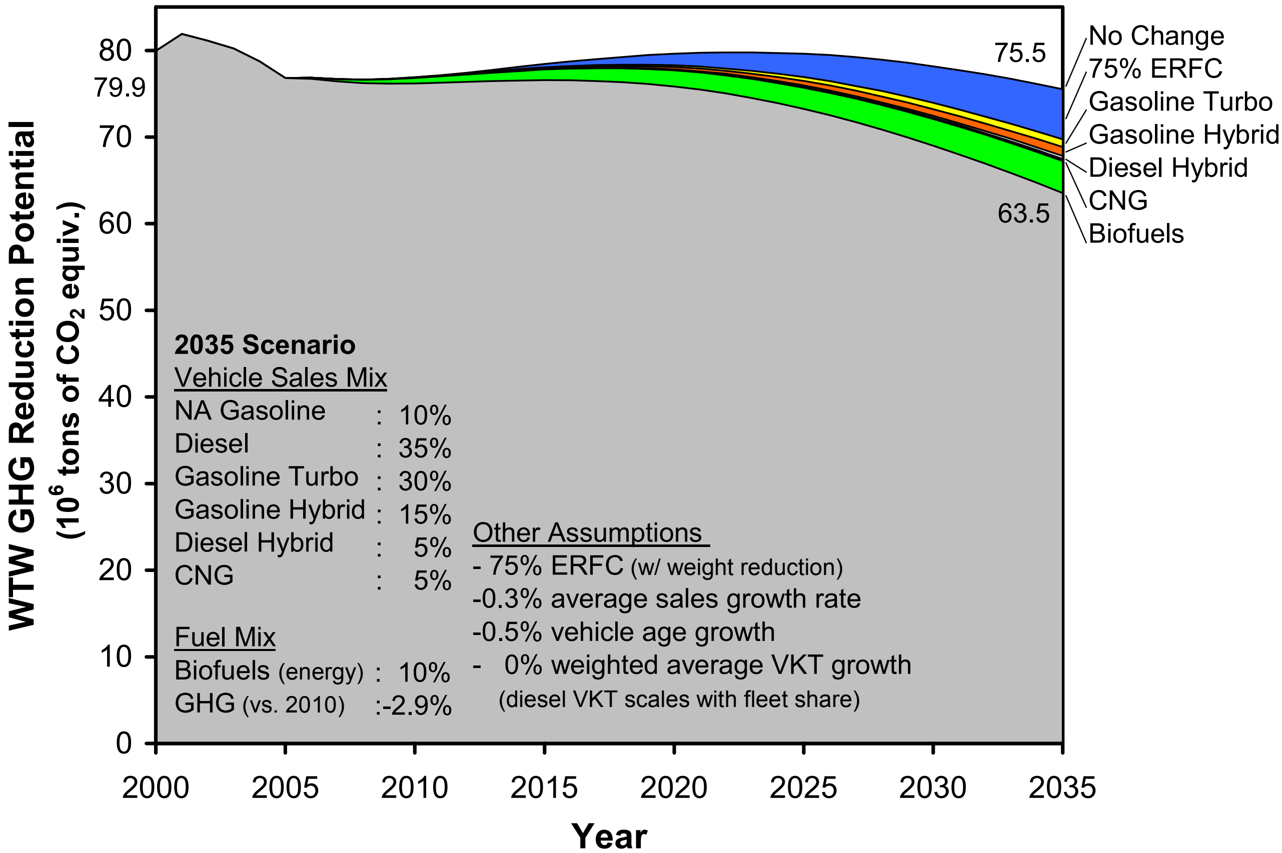


G. WTW GHG Emission Reduction Potential

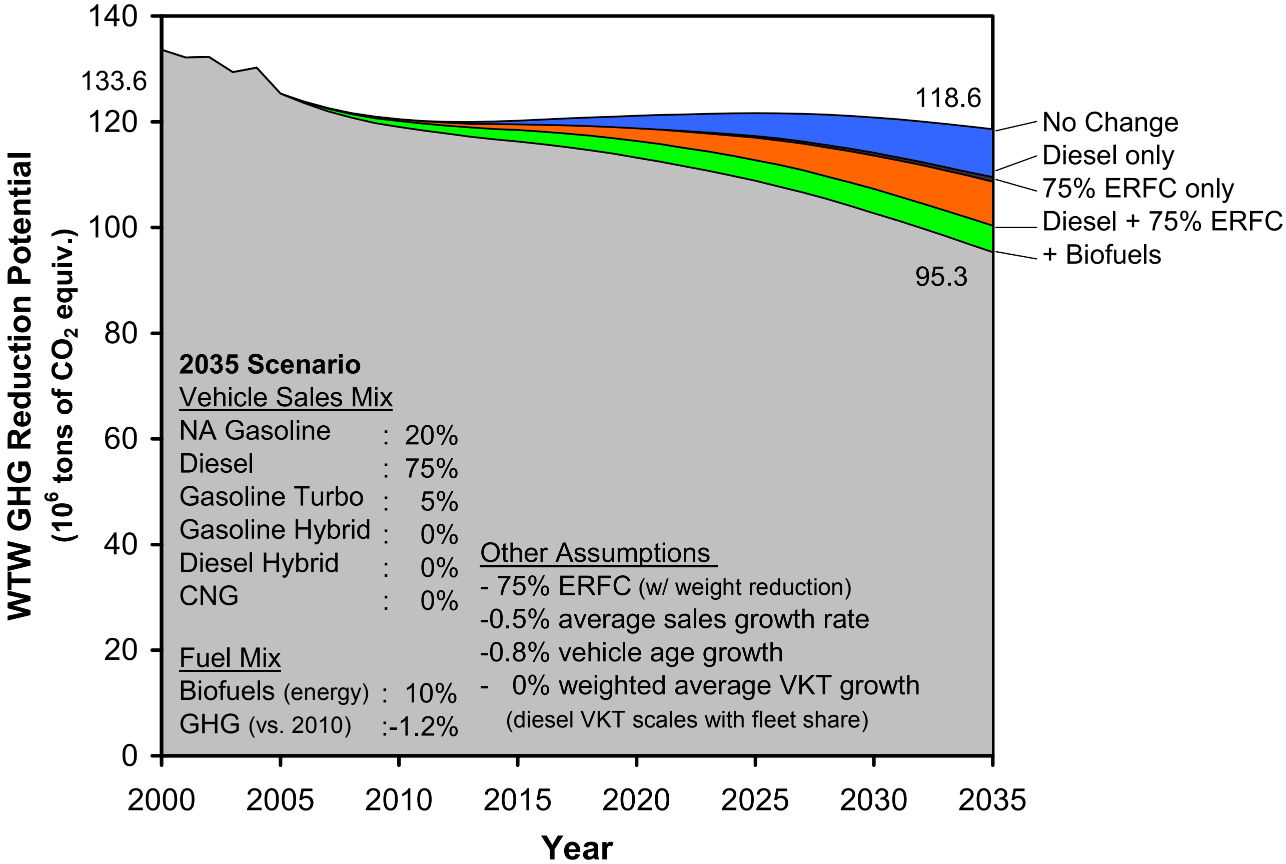
France: *Diesels Dominate*



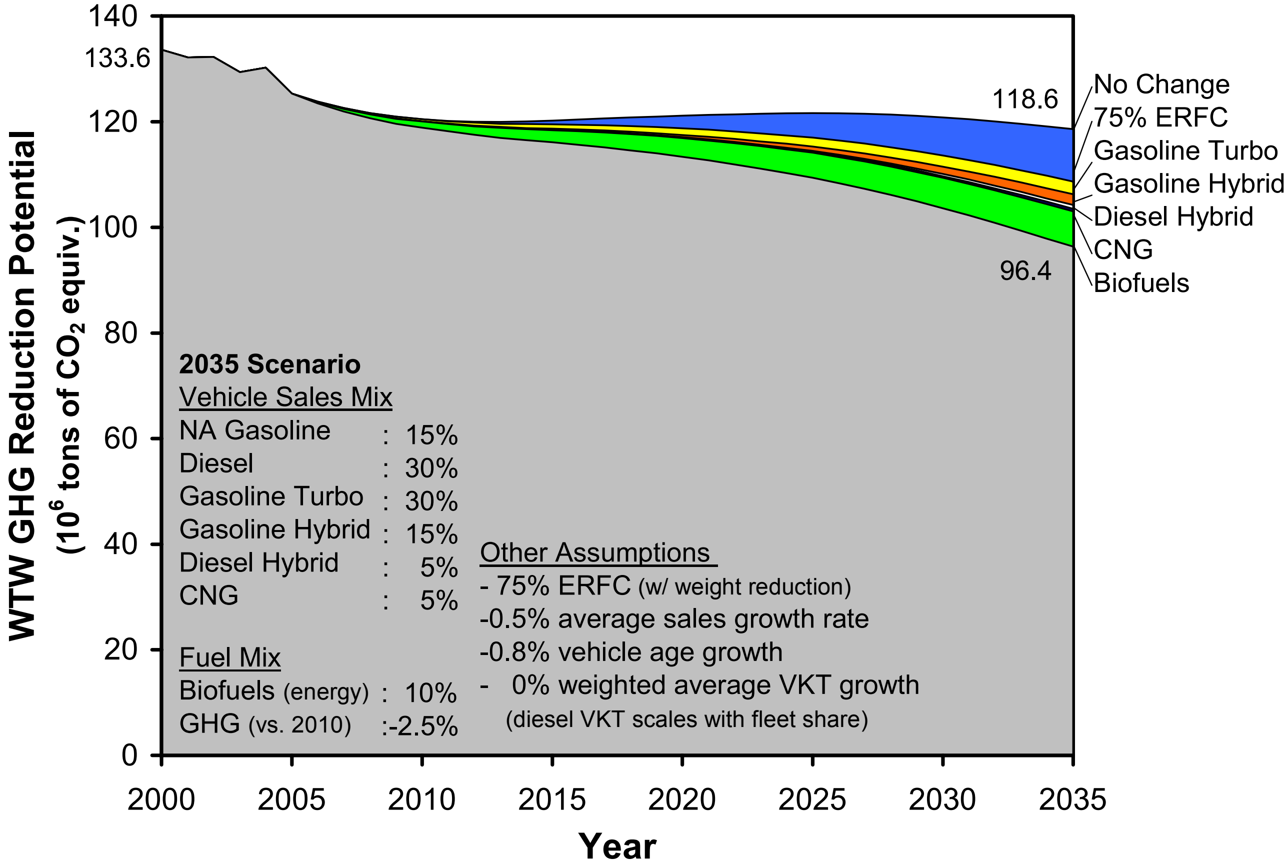
France: *Alternative Technologies Emerge*



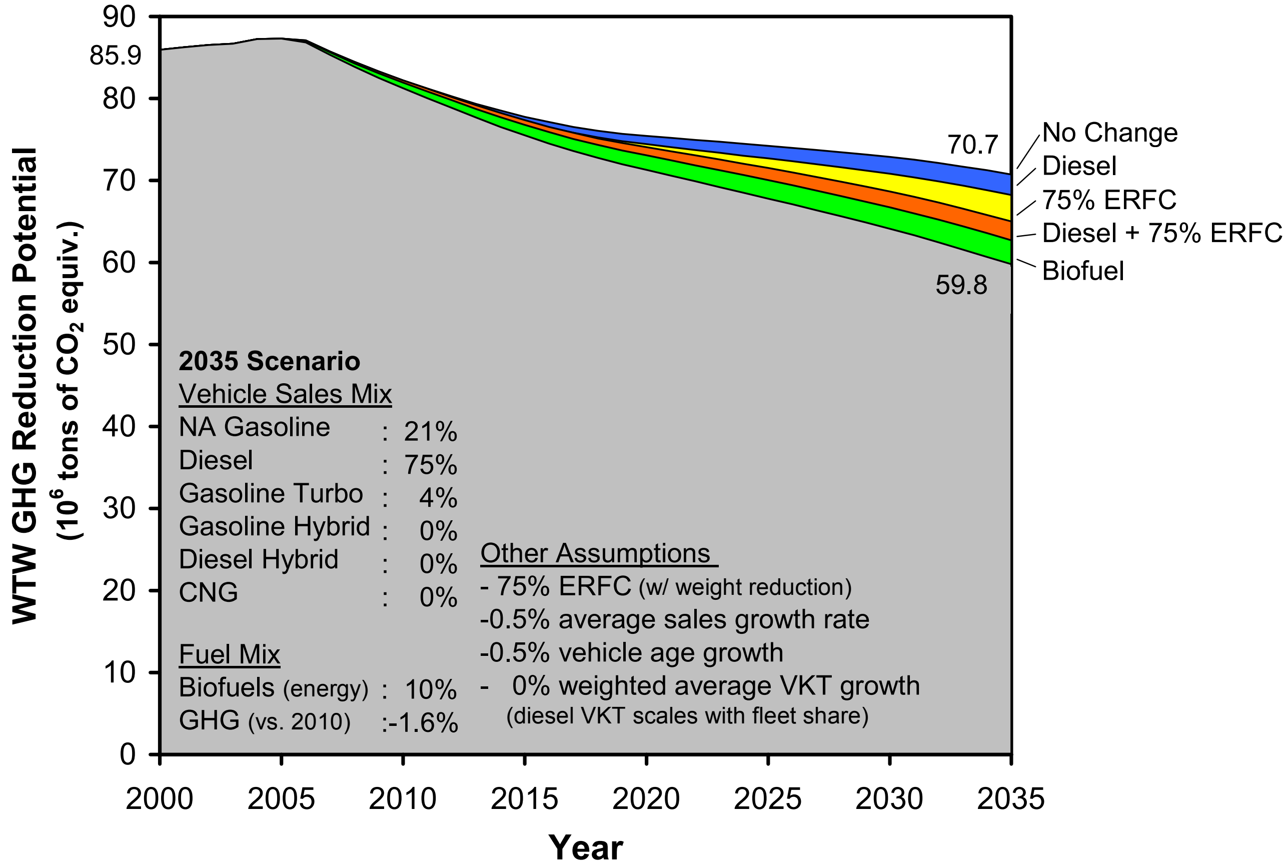
Germany: *Diesels Dominate*



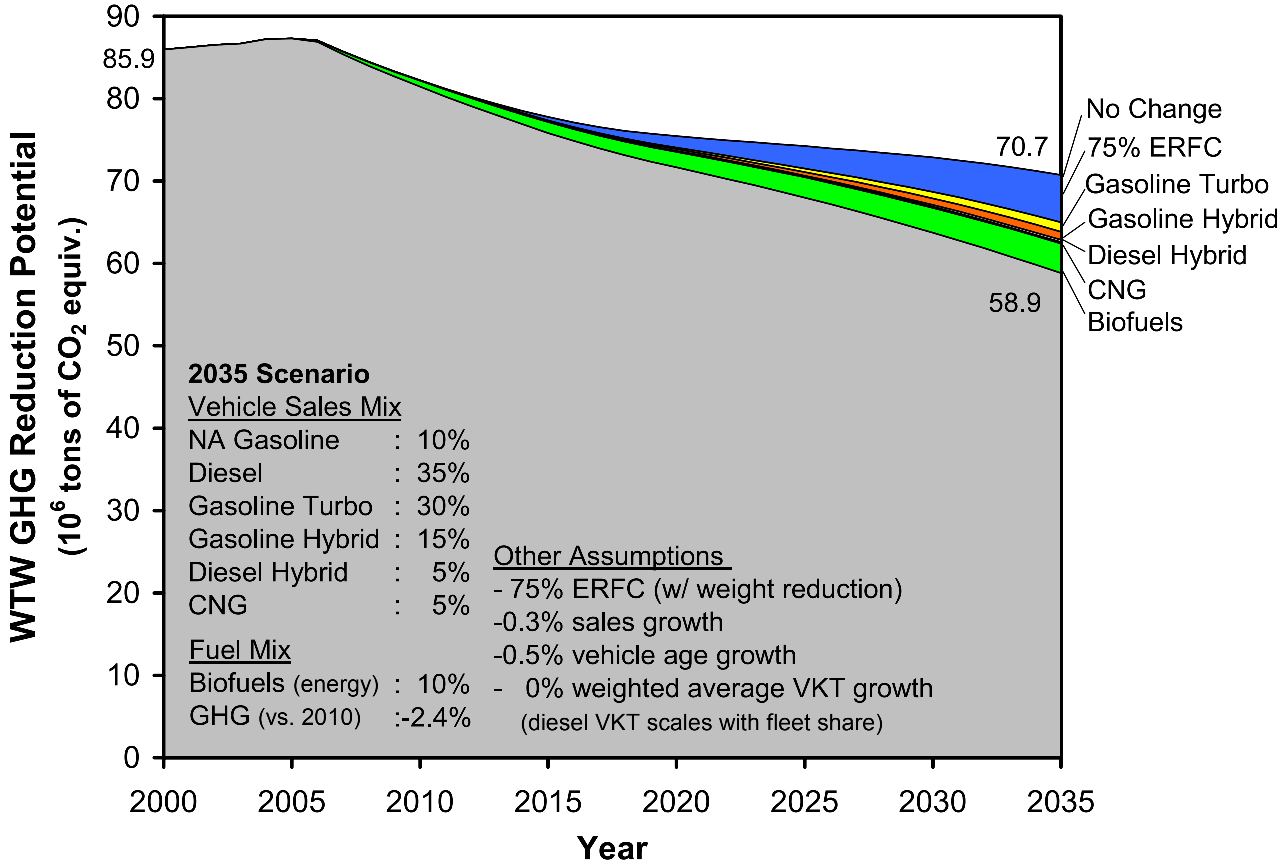
Germany: *Alternative Technologies Emerge*



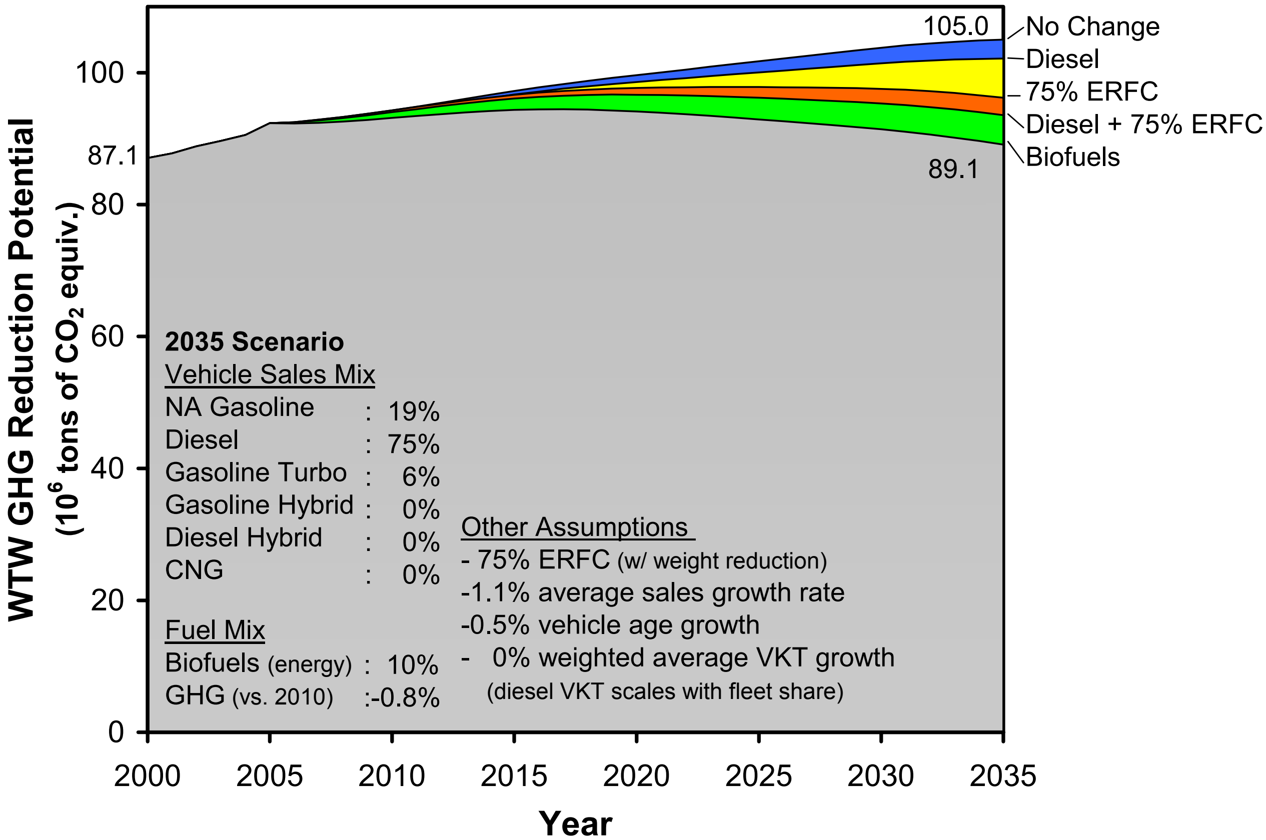
Italy: *Diesels Dominate*



Italy: *Alternative Technologies Emerge*



<u>UK: *Diesels Dominate*</u>



UK: *Alternative Technologies Emerge*