IMPACT OF ALTERNATIVE VEHICLE TECHNOLOGIES AND LAND USE PATTERNS ON LONG-TERM REGIONAL ON-ROAD VEHICLE EMISSIONS

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ABSTRACT

The objective of this research is to quantify the impacts of projected changes in vehicle fuels and propulsion technologies, as well as land use development patterns on regional on-road vehicle emissions over a long-term planning horizon. Roadway link-based emissions models have been developed, which utilize modal fuel use and emission rates from multiple sources. The emissions models are coupled with vehicle activity outputs derived from an integrated land use and transportation model (TRANUS) for the purpose of estimating emission inventories and assessing the potential changes in emissions that can accrue from changes in vehicle fuel, vehicle technology and land use development patterns. The results show that the complete retirement of old light-duty vehicle fleet including Tiers 0 and 1 vehicles can reduce emissions of HC, CO, and NO_x substantially. However, modest improvements in fuel economy may be offset by Vehicle Miles of Travel (VMT) growth and the associated overall average speed reductions. Compared to the suburban-type growth, herein labelled the Business-as-Usual (BAU) land use scenario without penetration of alternative vehicle technologies, the smart-growth (SG) land use model along with modest penetration of alternative vehicles into the vehicle fleet collectively can decrease emissions from on-road mobile sources by as much as 10% or more for all pollutants over a long planning horizon. This finding highlights the potential effectiveness of combined vehicle technology and land-use planning tools to reduce emissions from on-road vehicles.

Keywords: vehicle technology, land use, emissions

INTRODUCTION AND OBJECTIVES

Highway vehicles emissions are a major source of air pollution, accounting for an estimated 54% of carbon monoxide (CO), 36% of nitrogen oxides (NO_x), and 22% of volatile organic compounds (VOC) emissions in the U.S. (EPA, 2007). Emissions may be reduced through the adoption and deployment of alternative fuels and advanced vehicle technologies. These technologies, which include advanced diesel, ethanol, hybrid, compressed natural gas, electric and fuel cell vehicles may comprise 27 to 63% of new light-duty vehicle (LDV) sales by 2030 (EIA, 2007; EIA, 2009). Meanwhile, urban land use development patterns may influence the quantity and location of emissions from on-road mobile sources and thus affect air quality over a long-term planning horizon (Rodriguez et al, 2010). The objective of this research is to quantify the relative impacts of projected changes in vehicle fuels and propulsion technologies, as well as land use development patterns on regional on-road vehicle emissions of CO, hydrocarbon (HC), NO_x and carbon dioxide (CO_2) over a long-term planning horizon.

METHODOLOGY

The research team developed roadway link-based emissions models which apply modal fuel use and emission rates to various roadway facilities (e.g. freeways, arterials, local roads) as well as to speed-specific driving cycles for estimating vehicle emissions (Frey et al, 2009). Vehicle classes considered in this analysis include LDVs, heavy-duty vehicles (HDVs), and buses. Link-based tailpipe emission factors for each technology class are estimated in Frey et al, (2009) using the generalized formula:

$$EF = BER \times TECF \times HCF \times PCF \times CCF \times TCF \times SCF \qquad (1)$$

Where EF is the time-based-emission factor; BER is the basic emission rate; $TECF$ is the ambient temperature correction factors; HCF is the ambient relative humidity correction factor; PCF is the ambient pressure correction factor; CCF is the driving cycle correction factor; TCF is the technology correction factor; and SCF is the speed correction factor. In general, emission factors were found to be impacted by roadway type, link mean speed, vehicle class and technology. The detailed approach to estimating BER and the various correction factors above are described elsewhere (Frey et al, 2009).

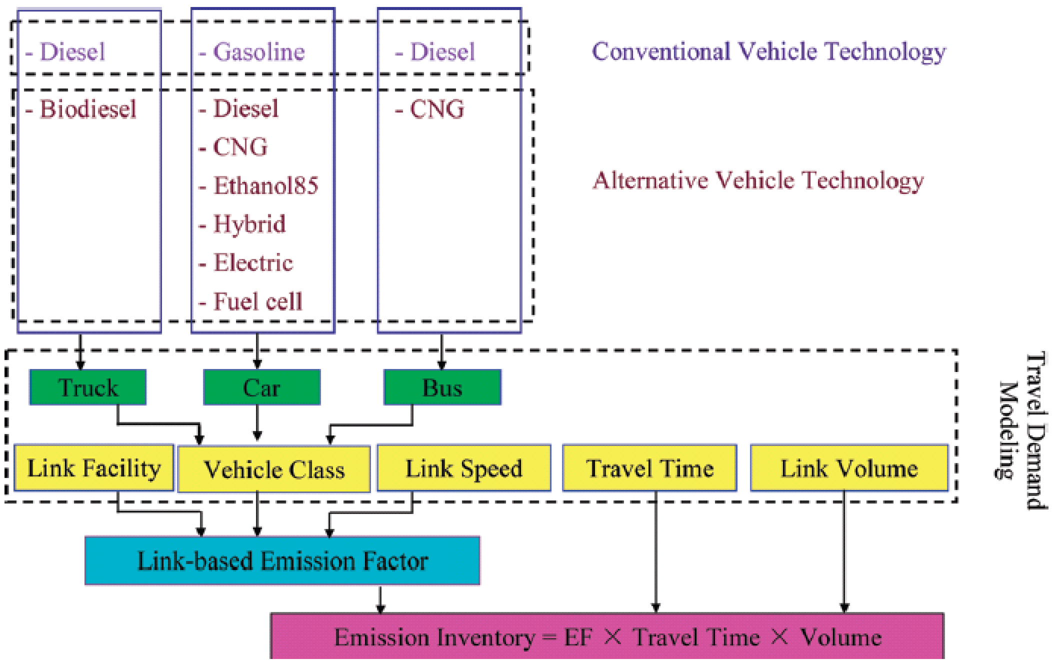

Figure 1 Overview of Regional On-Road Vehicle Emissions Modeling System (Frey et al., 2009)

In general, a mobile emission inventory is estimated as the aggregation over all network links of the product of a link-based emission factor and the vehicle activity on the link. As shown in Figure 1, the emission factors models are coupled with vehicle activity outputs derived from an integrated land use and transportation model for developing the regional on-road vehicle emission inventory. Multiple integrated scenarios are designed to assess the potential changes in emissions that can accrue from changes in vehicle fuel, vehicle technology and land use development patterns. Fuels considered in this analysis include gasoline, diesel, biodiesel, ethanol, compressed natural gas, hydrogen and electricity. The technologies considered are internal combustion engines, hybrids, fuel cell and electric. The market penetration rate for each alternative LDV technology is estimated based on the U.S. Energy Information Administration (EIA)'s new vehicle sales predictions (EIA, 2007). TRANUS, an integrated land use/transportation model, is used to simulate land markets and transportation network flows and performance at the urban and regional scales (Modelistica, 2004). Land use development patterns considered in this study are suburban-style development (or Business as Usual, BAU) and smart growth (SG), the latter characterized by a high density and transit friendly environment. The impacts on regional emissions are quantified through the specification of multiple scenarios in order to investigate their individual and collective potentials for reducing on-road vehicle emissions over a long-term planning horizon. Calendar year 2000 was selected for the baseline scenario, and year 2050 for the future scenarios, as specified in the research request for proposals. Table 1 describes vehicle fleet features in the baseline and future scenarios.

Table 1 Vehicle Fleet Features in Baseline and Future Scenarios*

Vehicle type	Fuel and technology	Market penetration by vehicle class (%)				
		Baseline (2000)	Business-as-usual (2050)		Smart growth (2050)	
			(i)	(ii)	(i)	(ii)
Cars	LDGV	100	100	73	100	73
	E85	0	0	9.9	0	9.9
	HEV	0	0	9.9	0	9.9
	LDDV	0	0	5.9	0	5.9
	CNG	0	0	1.2	0	1.2
	EV and FCV	0	0	0.1	0	0.1
Trucks	HDDT	100	100	73	100	73
	B20 Trucks	0	0	27	0	27
Buses	HDDB	100	100	73	100	73
	CNG Bus	0	0	27	0	27

* Notation: LDGV = light-duty gasoline vehicle; E85 = ethanol 85; HEV = hybrid electric vehicle; LDDV = light-duty diesel vehicle; CNG = compressed natural gas; EV= electric vehicle; FCV= fuel cell vehicle; HDDT= heavy-duty diesel trucks; B20= biodiesel 20; and HDDB = heavy-duty diesel bus.

RESULTS AND DISCUSSION

Mecklenburg County in the state of North Carolina (NC) was chosen as the study network for which a rich set of data was available for modelling purposes. The county is dominated by the city of Charlotte, the largest city in NC. In 2000 the county had 695,450 individuals residing in 235,530 households. The emission factors were estimated using Eq. (1) for each vehicle class, and the application involved emissions estimation in the morning peak hour. The modeling month was July. In addition to accounting for the impacts of local meteorological conditions such as ambient temperature, humidity and pressure, the emission models also considered local vehicle emissions inspection and maintenance programs, as well as the prevailing emission standards. Figure 2 depicts some numerical values of link-based emission factors of light-duty gasoline vehicles on arterials in the baseline scenario. In general, the average emission rate per unit time increased with link mean speed. These emission factors are then coupled with link-based vehicle activity outputs from the integrated land-use and transportation model for estimating regional on-road mobile source emissions.

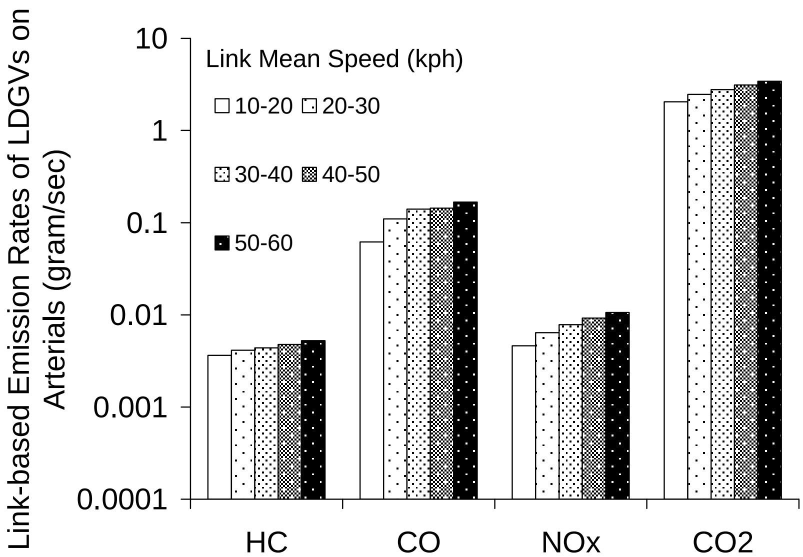

Figure 2 Examples of Emission Factors for Light-duty Gasoline Vehicles (LDGVs) in Baseline Scenario

Two future regional development scenarios were considered: the first reflects the typical suburban sprawl growth pattern also called BAU while the second represents a controlled growth pattern called SG with features such as higher-development density and a more walkable urban form. Detailed attributes of each of the two land use patterns can be viewed elsewhere (Rodriguez et al, 2010). Vehicle activity data are summarized in Table 2 for the baseline and future scenarios, respectively. Compared to the baseline scenario, the total vehicle miles traveled (VMT) increased significantly by 97.5% for the BAU scenario and by 86.7% for the SG scenario. Neither future scenario included any significant capacity additions, so the VMT effects are confined to natural demand growth. The total VMT for the SG scenario are 5.5% less than that those for the BAU scenario. The overall average network speeds are 42 mph, 33mph and 35mph for the baseline, BAU and SG scenarios, respectively. Compared to the baseline the average network speed decreases by 21% for the BAU scenario and by 17% for the SG scenario because the significant increases in the total VMT are associated with both future scenarios. These results demonstrate the benefits of SG land use pattern in reducing VMT and improving the level of service.

Table 2 Vehicle Miles Travel in Test Network: Baseline and Future Land-Use Scenarios

Roadway Type	Baseline Scenario	Future Scenario	
		Business-as-Usual	Smart Growth
Freeways	649, 860	1,232,060	1,337,910
Arterials	1,470,760	2,930,120	2,640,750
Local roads	254,750	527,300	440,140
Ramps	65,260	130,400	136,900
Bus rapid transit	0	0	250
Light-rail	0	350	1,220
Commuter-rail	0	80	320
Entire network	2,440,640	4,820,310	4,557,480

Table 3 summarizes the total regional vehicle running tailpipe emissions (plus rail stack emissions when applicable) for a weekday morning peak hour for the baseline and future scenarios. Compared to the baseline scenario, all future scenarios achieve significant reductions in HC, CO and NO_x emissions by 59 to 87% partly because of the assumption of complete retirement of old Tier 0 and Tier 1 vehicles in the future. However, CO_2 emissions in all future scenarios significantly increase, compared to the baseline scenario. It thus appears that the modest improvements in fuel economy are completely offset by significant VMT increases and the associated network speed reductions.

Table 3 Estimated Total Network Vehicle Running Emissions: Weekday Morning Peak Hour (tons)

Scenario			Total emissions (tons)			
Model Year	Land use Pattern	Alternative vehicle Technologies	HC	CO	NO_x	CO_2
2000	Baseline	No	1.23	39.0	4.36	995
2050	Business-as-usual	No	0.26	16.0	0.63	1700
	Business-as-usual	Yes	0.25	14.2	0.60	1640
2050	Smart-growth	No	0.24	15.0	0.60	1580
	Smart-growth	Yes	0.23	13.3	0.57	1530

As illustrated in Table 4, the modest market penetration of alternative vehicle technologies may help reduce emissions for a given land use pattern. This finding is similar to what the researchers found while modeling a nearby network in the Research Triangle Region (Frey et al, 2009). For a given penetration rate of alternative vehicles, comparisons of total emissions for all pollutants between the BAU and SG scenarios show the smart-growth land use pattern may further help reduce emissions. The combined impacts of changes in land use patterns and alternative vehicle technologies are pronounced, leading to emission reductions of 10% or more for all pollutants.

Table 4 Relative Individual and Collective Impacts of Land Use and Vehicle Technologies on Total Network Vehicle Running Tailpipe HC Emissions

Vehicle technology penetration rate		Relative emission change (%)	
		Land-use pattern	
Conventional (%)	Alternative (%)	Business-as-usual	Smart growth
100	0	Benchmark	-7.8
73	27	-6.0	-11.6

Due to the uncertainty in alternative technology penetration rates, regional total emissions were calculated for the full range of market penetrations from zero to one hundred percent. As exemplified in Figure 3, for a given land-use pattern, regional emissions from LDV fleet linearly decrease as the total fraction of alternative vehicle technologies increases. With full market penetration under the BAU land-use pattern, emissions reductions of light-duty vehicle fleet relative to the BAU scenario with zero penetration of alternative vehicle technologies would be on the order of 29% for HC, 43% for CO, 26% for NO*x*, and 18% for CO_2. In contrast, and as shown in Figure 3, the collective effect of alternative vehicle technologies and the SG land-use pattern on emission reductions becomes more pronounced. These results imply that increasing the share of alternative technologies and changing the land-use patterns may be effective to reduce regional vehicle emissions.

CONCLUSIONS

The emissions modeling system presented in this paper demonstrates the feasibility of accounting for changes in vehicle technology, land use and travel behavior and quantify their environmental impacts over a long-term analysis horizon. Analytical comparisons of regional emission results carried out for multiple scenarios show that on-road vehicle emissions are correlated with urban growth, land use patterns, and advances in vehicle technology. Promoting the penetration of alternative fuels and vehicle technologies and increasing transit investments along with the promotion of higher-density and more walkable urban communities could collectively produce pronounced environmental benefits in reducing on-road mobile source emissions and improving urban air quality.

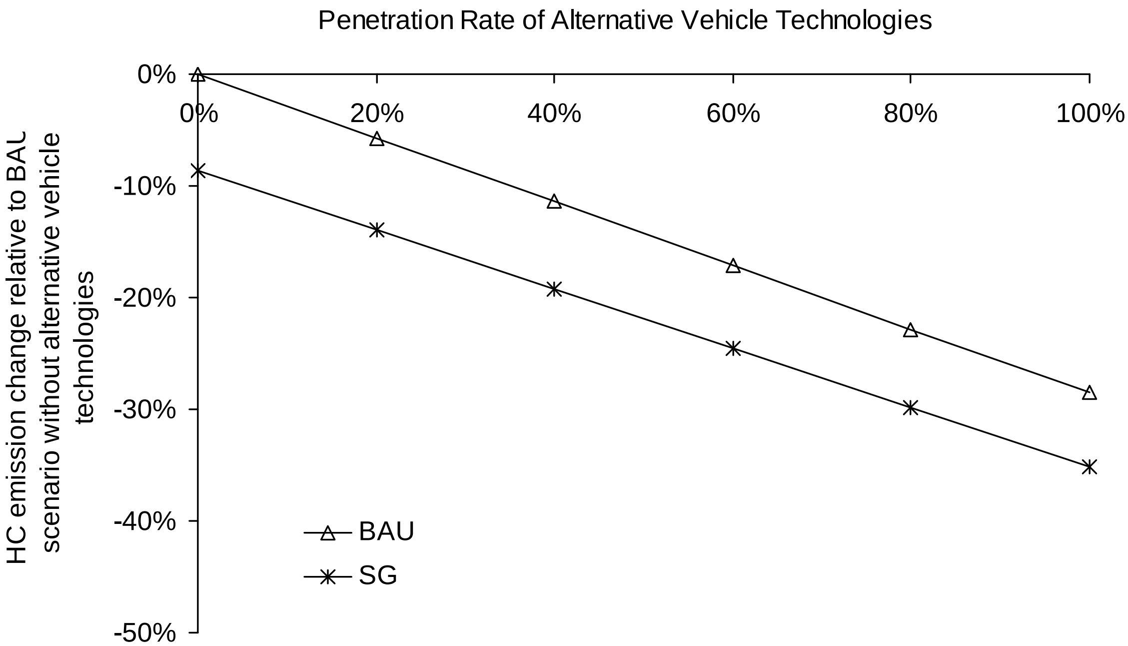

Figure 3 Sensitivity of HC Emissions from Light-duty Vehicle Fleet to Total Penetration Rate of Alternative Vehicle Technologies

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