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# **Abating Greenhouse Gas Emissions through Cash-for-Clunker Programs**

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## **ABSTRACT**

Policymakers use incentive-based vehicle scrappage or "Cash-for-Clunker" programs to pursue a range of social and economic goals such as decreasing vehicular emissions, preventing vehicle abandonment, lowering consumer spending on gasoline, and stimulating new vehicle sales.

However, there are no programs aimed solely at greenhouse gas (GHG) reduction. This study discusses design considerations for such a program. We evaluate past and present programs to show how regulatory elements in vehicle scrappage programs can be adjusted to maximize GHG savings. We show how fuel-economy based eligibility requirements are preferable to age-based requirements and how financial incentives can be properly aligned to balance program cost and participation rate. Finally, we present a program framework that, at minimum, ensures a Cash-for-Clunkers program offsets GHG emissions attributable to vehicle manufacturing and end-of-life disposal with use-phase emissions reductions.

## INTRODUCTION

Abating transportation-related greenhouse gas (GHG) emissions is a major challenge to today's environmental regulators. In 2007, the U.S. Transportation Sector accounted for 28% of domestic GHG emissions, measured in units of carbon dioxide equivalent (CO<sub>2</sub>e) emissions, a 29% increase from 1990 (1,2). With over 254 million vehicles registered in the U.S. in 2008 (3), small changes in the fleet makeup can have large effects on aggregate CO<sub>2</sub>e emissions. One regulatory approach for changing the fleet makeup is through a vehicle scrappage program, which increases the vehicle turnover rate by incentivizing vehicle retirement. When these programs require the purchase of a replacement vehicle they are commonly known as "Cash-for-Clunker" or "Cash-for-Replacement" programs. In early 2009 U.S. Congress began discussing a Cash-for-Clunkers program to reach two simultaneous goals: stimulate the auto industry and reduce GHG emissions. Legislation was eventually passed that emphasizes stimulating new auto sales, rather than reducing emissions. In the future, however, there may be a need to design and implement vehicle scrappage programs that exclusively target GHG emissions. To help inform the decisions of future policymakers, we will discuss the topic using examples from both domestic and international, and past and present programs.

The specific requirements in Cash-for-Clunker programs can vary greatly. However, there are regulatory elements common to all programs including: 1) retired vehicle eligibility, 2) length of program, 3) monetary incentive, and 4) replacement vehicle eligibility. This paper discusses how to adjust these four elements in a GHG emissions reduction program while also ensuring a moderate participation rate and abatement cost.

## BACKGROUND

Vehicle scrappage programs gained popularity in the 1990s when state and regional organizations sought to reduce transportation-related criteria pollutant emissions (Table 1). These programs offered small incentives (under \$1,000), had limited number of participants (less than 1,000 vehicles per year), and targeted the oldest vehicles in the fleet (4). Several studies show that the oldest vehicles in the fleet account for a large proportion of fleetwide criteria pollutant emissions (5,6,7,8). In 2009 vehicle scrappage programs again gained popularity as national governments sought ways to assist their struggling auto industries. These recent programs are characterized by large participation rates (100,000-1,400,000 vehicles), large incentives (\$1,400-\$4,500 per vehicle), and a required vehicle replacement (9).

**TABLE 1 Examples of Stated Goals in Past Programs**

<b>Program Location</b>	<b>Stated Goal of Program</b>	<b>Duration</b>
Sweden	Reduce vehicle abandonment and reduce GHG emissions	1976 - present
U.S.: Los Angeles Region	Reduce criteria pollutant emissions	1990, 1993
Greece	Reduce criteria pollutant emissions	1991 - 1993
U.S.: Delaware	Reduce criteria pollutant emissions	1992
U.S.: Illinois	Reduce criteria pollutant emissions	1993
Hungary: Budapest	Reduce criteria pollutant emissions	1993 - present
Denmark	Reduce criteria pollutant emissions	1994 - 1995
France	Reduce criteria pollutant emissions	1994 - 1995

Ireland	Reduce criteria pollutant emissions	1995 - 1997
Norway	Reduce criteria pollutant emissions	1996
Canada: Vancouver	Reduce criteria pollutant emissions	1996 - present
Italy	Reduce criteria pollutant emissions	1997
Germany	Stimulate auto industry	2009 - present
United Kingdom	Reduce criteria pollutant emissions and stimulate auto industry	2009 - present
U.S.: Texas	Reduce criteria pollutant emissions	2009 - present
Austria	Stimulate auto industry	2009 - present
Germany	Stimulate auto industry	2009 - present
France	Stimulate auto industry and reduce GHG emissions	2009 - present
Italy	Stimulate auto industry and reduce GHG emissions	2009 - present
Portugal	Stimulate auto industry and reduce GHG emissions	2009 - present
Romania	Stimulate auto industry	2009 - present
Spain	Stimulate auto industry and reduce GHG emissions	2009 - present
Luxembourg	Stimulate auto industry and reduce GHG emissions	2009 - present
Cyprus	Stimulate auto industry and reduce GHG emissions	2009 - present
Slovakia	Stimulate auto industry	2009 - present
U.S. (CARS)	Stimulate auto industry and reduce GHG emissions	2009 - present

Sources: (9,10,11,12,13)

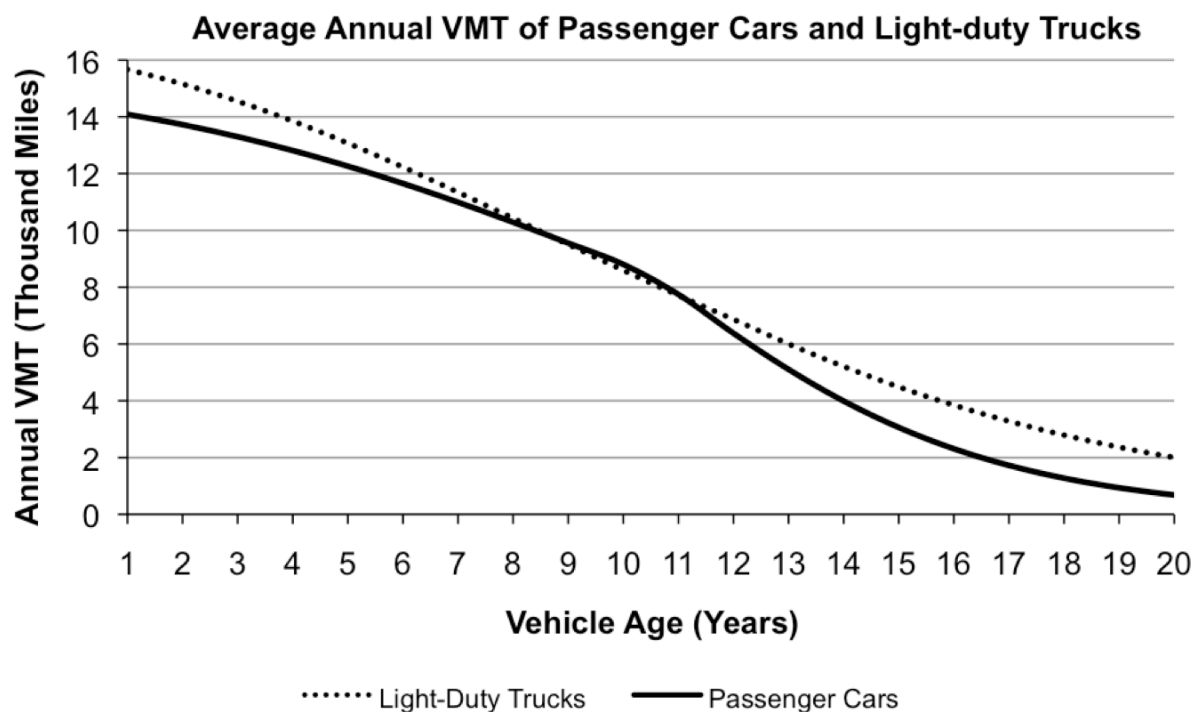
Although no program to date has focused solely on GHG emissions reduction, a number of recent scrappage programs make GHG emissions reduction an ancillary goal by setting fuel economy or grams of CO<sub>2</sub>e per km requirements on the replacement vehicles. These upgrades range from a fuel economy improvement of 5-9 miles per gallon (MPG) in the U.S. CARS program to 120 g CO<sub>2</sub>e per km (roughly 46 MPG) minimum in Italy's scrappage program (9,13). However, despite aggressive upgrade requirements in some countries, all scrappage programs in 2009 also require the scrapped vehicle be older than a minimum age (9-15 years) which lessens the effectiveness of the programs for reasons described below. The one exception is the U.S. CARS program.

Unlike the subset of gross emitters that exists for criteria pollutants, low fuel economy vehicles – which produce the largest amount of CO<sub>2</sub>e emissions per mile travelled – are dispersed among all vehicle ages and values. A minimum age restriction will inadvertently exclude newer, low fuel economy vehicles from participation in the program. In addition, simply replacing an old vehicle with a new vehicle may not automatically lead to a fuel economy improvement, as the fuel economy of new vehicles has not changed significantly since the 1980s. In the years 1981-2006, the average fuel economy of all passenger cars and light-duty trucks fluctuated between 24.6 and 25.8 MPG (14).

Participation rates may be further limited in age-based programs due to differences in income among vehicle owners. Data from the 2001 National Household Travel Survey show that households with annual income levels above \$50,000 own 46% of the vehicles in the U.S. fleet and use 50.4% of the motor fuel. However, for the subset of vehicles 10 years or older (a typical age-based eligibility requirement), these higher income households own just 33% of the vehicles. Fuel economy, on the other hand, does not change significantly with income. Households earning over \$50,000 per year have an average fuel economy of 20.0 MPG while those earning less than \$50,000 have an average of 20.4 MPG (15). Since middle and upper-income vehicle owners are

particularly important in vehicle replacement programs because they have the most available money to participate, scrappage programs should make eligibility requirements that support participation from this group.

However, even when a program has requirements that allow greater participation, the cost per ton of abatement remains uncertain without exact knowledge of the remaining mileage in the scrapped vehicle and the new mileage in the replacement vehicle. Data from the U.S. Department of Transportation (DOT), represented in Figure 1, and similar data from Oak Ridge National Laboratory show how on a fleet-wide basis newer cars are driven further per year than older ones (14, 16). The extent to which this mileage increase occurs in vehicle scrappage programs is uncertain and will likely depend on the type of vehicle being replaced and the income level of the participant. However, we can reasonably conclude that prematurely retiring a vehicle may have reduced short-term GHG emission reduction benefits if the replacement vehicle is driven considerably farther than the scrapped vehicle.



**Figure 1 Annual mileage of passenger cars and light-trucks versus vehicle age.**

Source: (16)

Two state scrappage programs that targeted criteria pollutants show inconsistent, and in some cases, high abatement costs. The Colorado Total Clean Cars Program, run between December 1993 and April 1994, scrapped 271 vehicles and repaired 218. The state estimated that the program reduced 204.6 tons of carbon monoxide (CO) at a cost of \$2,294 per ton and 41 tons of hydrocarbons at a cost of \$11,438 per ton (11). In 1993, the Illinois state program scrapped 207 vehicles and calculated hydrocarbons reductions cost \$7,575 per ton and nitrogen oxide (NOx) reductions cost \$47,205 per ton (12). In a multi-state study of criteria pollutant damage and abatement costs, Wang et al. (17) estimate average cost ranges of \$2,400 - \$9,900 per ton for hydrocarbon abatement, \$4,800 - \$10,600 for NOx abatement and around \$2,700 for CO abatement. Although the programs in Colorado and Illinois were small in scope, the abatement

costs per ton are mostly consistent with the results from the multi-state study. Due to the wide range in abatement costs, these studies show that the cost-effectiveness of using scrappage programs for criteria pollution abatement is inconclusive.

The cost effectiveness of a scrappage program focused on GHG reduction compared to other GHG abatement options depends on the program design. Assuming a best case scenario in which a low fuel economy vehicle (e.g. 12 MPG) with tens of thousands of miles remaining (e.g. 40,000 mi or 64,374 km) is replaced with a high fuel economy vehicle (e.g. 45 MPG) and all other driving behavior and emission factors are ignored, the use-phase savings over the 40,000 miles will be about 28 metric tonnes (t) of CO<sub>2</sub>e emissions. This calculation uses 11.32 kg of CO<sub>2</sub>e emissions per gallon, an estimate based on EPA data for fuel combustion and upstream CO<sub>2</sub>e emissions attributable to fuel production and distribution derived from the GREET model (18). The fuel is assumed to be reformulated gasoline containing 10 percent ethanol by volume. Although published estimates of CO<sub>2</sub>e emissions attributable to corn ethanol vary widely, our calculations are based on a comprehensive study by Farrell et al. (19) that suggests a gallon of corn ethanol produces 13 percent fewer GHG emissions than gasoline. Thus, with a \$1,400 incentive and no administrative costs, the cost of abatement is around \$50/tonne of CO<sub>2</sub>e. Whether a \$1,400 incentive will sufficiently entice a vehicle owner towards that magnitude of upgrade is beyond the scope of this study. However, the basic example above serves to illustrate the extent to which a vehicle replacement must increase fuel efficiency to compete with other, non-transportation GHG abatement options.

One major shortcoming of studies that attempt to calculate GHG emission reductions is they tend to include only use-phase emissions. As described by Kim et al. (20), this approach overestimates the emission saving potential because of the embedded energy in the vehicle. The only way for a vehicle scrappage program to have a net GHG emissions reduction is for the use-phase savings to exceed the other phases of a vehicle's life. In a lifecycle assessment of a 1995 generic passenger sedan, Sullivan et al., (21) find that the material production, manufacturing, repair and maintenance, and the end-of-life (EOL) phases account for 13% of all CO<sub>2</sub>e emissions. Spitzley et al., (22) found this percentage to be slightly lower at 10%. A similar range is estimated by Wee et al. (23) who report that 80-85% of life-cycle GHG emissions from a vehicle occur during the use-phase. An accurate calculation of dollars per ton of abated pollutant needs to consider all phases of a vehicle's life. If vehicles are retired early, additional new cars are necessary to replace them, resulting in more production-related emissions.

## RESULTS

Due to the inherent uncertainty in calculating GHG emission reductions in Cash-for-Clunker programs, we present a framework below to ensure that non use-phase GHG emissions caused by early retirement and subsequent replacement of a vehicle are, at minimum, offset by emissions reductions in the use-phase. This framework is represented in Equation 1, where *UPE* refers to use-phase GHG emissions, *NPE* refers to non use-phase GHG emissions and the subscripts, *OLD* and *NEW* refer to the vehicle being scrapped and the replacement vehicle, respectively.

$$UPE_{OLD} - UPE_{NEW} \geq NPE \quad (1)$$

Sullivan et al. (21) estimate non use-phase GHG emissions attributable to vehicle manufacturing, materials production and end-of-life (EOL) disposal of around 7.5 t CO<sub>2e</sub>. While this figure applies to passenger vehicles, a corresponding emissions estimate of approximately 10.7 t CO<sub>2e</sub> is assumed for light-duty trucks – roughly 42 percent higher. The estimate for light-duty trucks is calculated by multiplying the passenger car emissions estimate by the weight ratio of light-duty trucks to passenger cars. The weight ratio is calculated from average fuel economy and curb weight correlations for model year 2008 light-duty vehicles published by the United States Environmental Protection Agency (24).

We evaluate four mileage-based scenarios for passenger cars and light-duty trucks in which the reduction in use-phase emissions from the purchase of a higher fuel economy vehicle are large enough to offset non use-phase emissions. The scenarios use different combinations of two variables: remaining life (either three years or five years) and annual VMT of the replacement vehicle (either unchanged mileage from the scrapped vehicle or increased mileage based on data in Figure 1). Three years was chosen as a reasonable age for premature scrappage based on past scrappage programs. Five years presents an upper limit to years remaining and would only be achieved through a significantly higher incentive value. Additionally, since the annual VMT in the replacement vehicle during those forgone years is highly uncertain, we calculate both the constant mileage case and the increased mileage case to give an upper and lower bound on potential emissions. We use data from the National Highway Traffic Safety Administration (16) to translate remaining years into remaining miles. The average age at which passenger cars and light-duty trucks are scrapped in the U.S. is 13.2 and 14.5 years, or 152,137 miles (244,841 km) and 176,954 miles (284,780 km), respectively (16). Scrapping vehicles 3 years or 5 years prior to these average ages corresponds to the VMT data shown in Table 2.

**TABLE 2 Total VMT Based on Vehicle Age and Remaining Useful Life**

VMT Assumption	Vehicle Type	Useful Life (yrs)	VMT: Old Vehicle (mi)	VMT: New Vehicle (mi)
Constant VMT	Passenger Car	5	42,769	42,769
Constant VMT	Light-duty Truck	5	34,383	34,383
Increased VMT	Passenger Car	5	42,769	66,189
Increased VMT	Light-duty Truck	5	34,383	72,291
Constant VMT	Passenger Car	3	22,928	22,928
Constant VMT	Light-duty Truck	3	18,076	18,076
Increased VMT	Passenger Car	3	22,928	41,114
Increased VMT	Light-duty Truck	3	18,076	45,370

NOTE: 1 mi = 1.609344 km

Use-phase emissions for the old and new vehicle are calculated as shown in Equation 2, where *VMT* represents the total miles travelled by the vehicle, *MPG* represents the vehicle's EPA combined city/highway fuel economy rating, and *FE* represents GHG emissions per unit of fuel. Fuel-related emissions are estimated to be around 11.32 kg CO<sub>2e</sub> per gallon as described earlier.

$$UPE = \frac{VMT}{MPG} \times FE \quad (2)$$

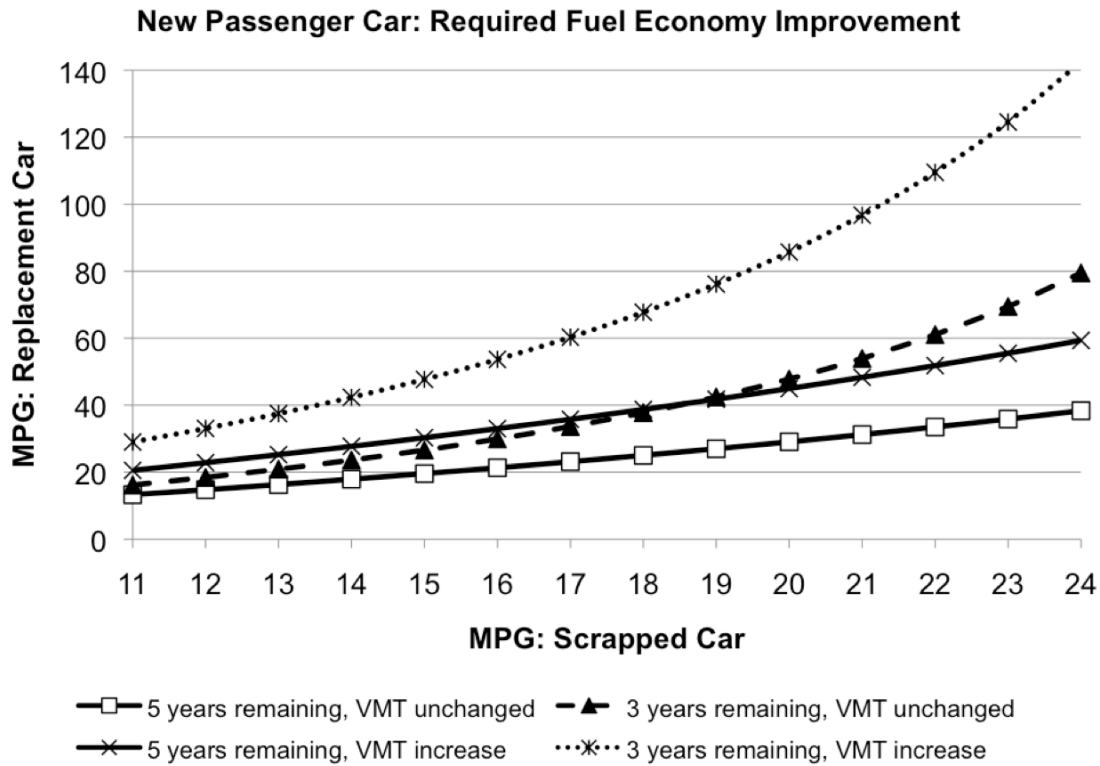


Equations 1 and 2 are combined and rearranged to express the required minimum fuel economy rating of the new vehicle as a function of VMT, fuel economy, fuel-related emissions and non use-phase emissions as shown in Equation 3. VMT values from Table 2, estimates for fuel-related emissions and non use-phase emissions, and a range of fuel economy ratings for the old vehicle are input into Equation 3 to calculate minimum fuel economy requirements for new passenger cars and light-duty trucks. Figures 2 and 3 illustrate the results of these calculations.

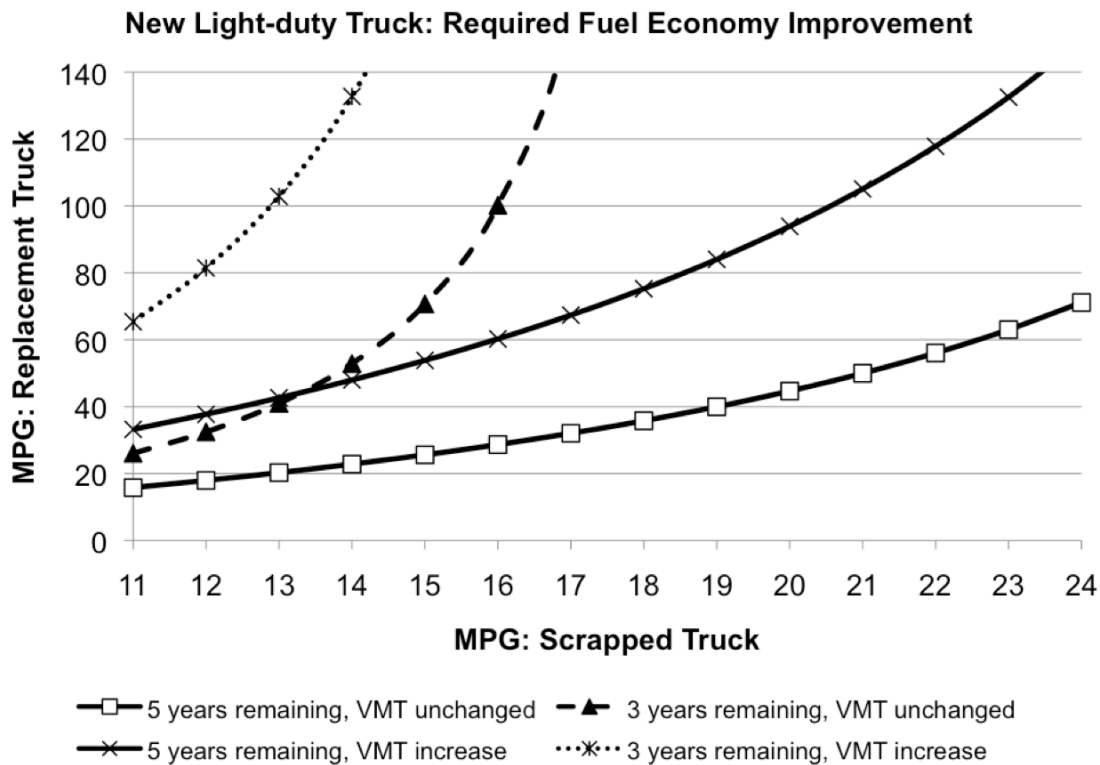
$$MPG_{NEW} \geq \left[ \frac{VMT_{NEW} \times FE}{\left( \frac{VMT_{OLD}}{MPG_{OLD}} \right) \times FE - NPE} \right] \quad (3)$$

The new vehicle MPG requirements vary widely depending on the assumptions used. For example, a passenger car with five years remaining and a fuel economy rating of 17 MPG would need to be replaced with a 23 MPG new car if annual VMT is the same for both vehicles. On the other hand, if the new car has higher VMT for those five years, it would need to be replaced by a 36 MPG new car to achieve the same GHG emissions reduction. The results for light-duty trucks are more extreme, as the required emissions offset is 42 percent higher. A light-duty truck with five years remaining and a fuel economy rating of 14 MPG would need to be replaced by a new truck with a fuel economy rating of 23 to 48 MPG depending on the VMT assumptions. For passenger cars and light-duty trucks with only three years of remaining useful life, the MPG requirements to achieve the emissions offsets are much higher.

In our analysis, we evaluate EPA combined fuel economy ratings from 11 to 24 MPG for the scrapped vehicle. Under our proposed program, scrapped vehicles that average above 24 MPG are still eligible for the program, however, in all but one of the scenarios considered, the new vehicle would need to be a zero GHG emissions vehicle because the reduction in use-phase GHG emissions from a new internal combustion engine or hybrid-electric vehicle would not be sufficient to offset non use-phase emissions.

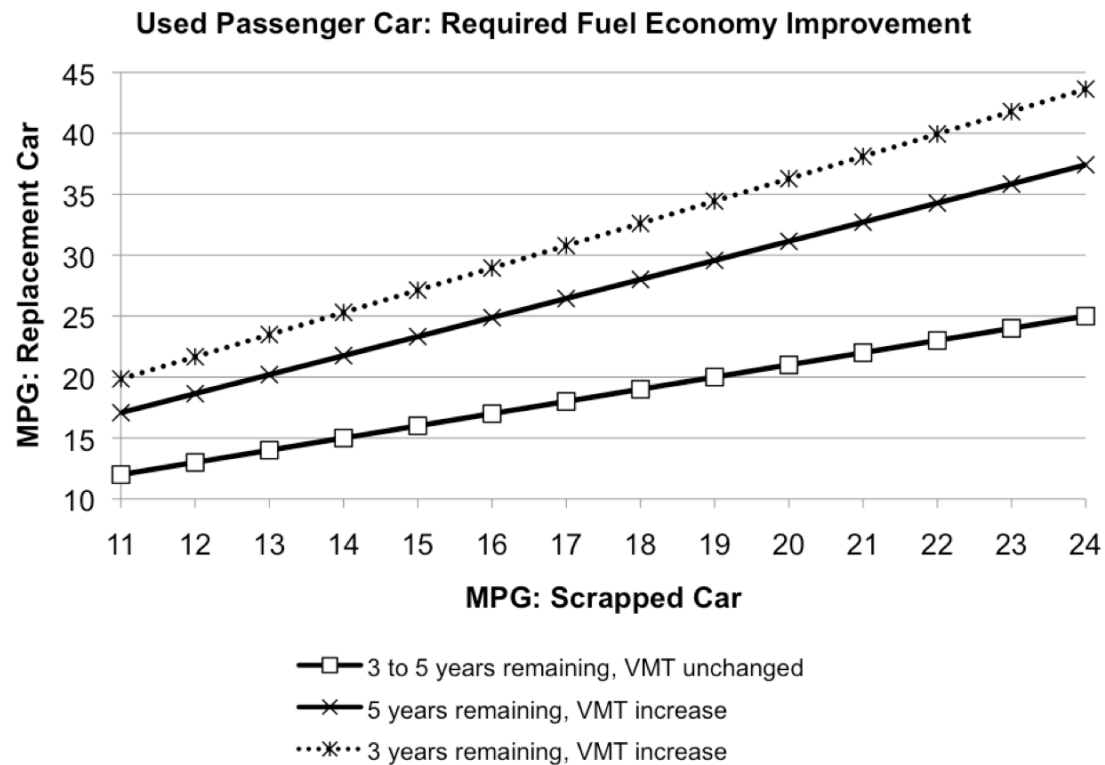


**Figure 2 Minimum fuel economy improvement for purchase of a new passenger car.**

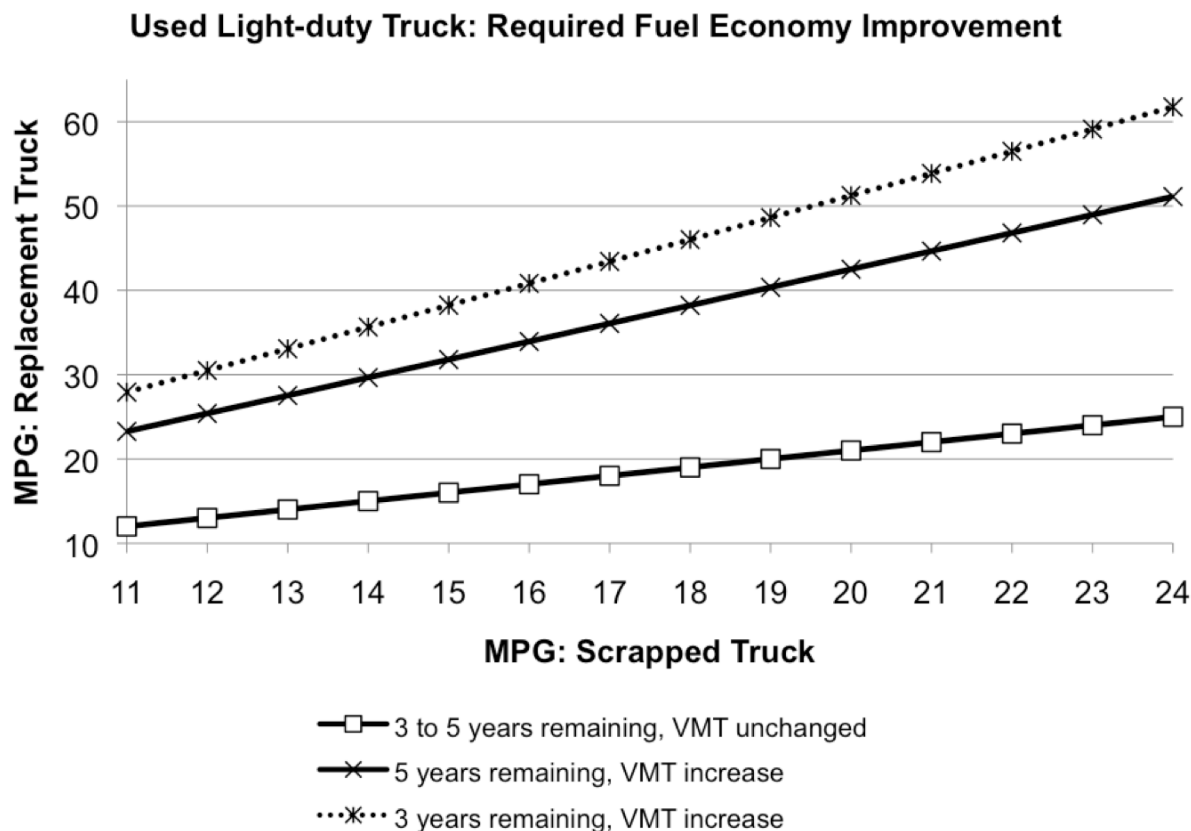


**Figure 3 Minimum fuel economy improvement for purchase of a new light-duty truck.**

If the Cash-for-Clunkers program is designed to permit used vehicle purchases instead of new vehicle purchases, we assume only the EOL GHG emissions need to be offset: 0.147 t CO<sub>2</sub>e and 0.209 t CO<sub>2</sub>e for passenger cars and light-duty trucks respectively. Figures 4 and 5 illustrate the minimum fuel economy improvements required for used vehicle purchases. For both passenger cars and light-duty trucks with three to five years remaining, a fuel economy improvement of only 1 MPG is sufficient to offset EOL GHG emissions if VMT remains unchanged. If VMT increases, MPG requirements are higher but can be met with available used vehicles under some of the scenarios considered. Permitting the purchase of used vehicles is particularly attractive from a GHG emissions reduction perspective if the intended participant is a low-income driver with a very old, low-MPG car or truck.



**Figure 4 Minimum fuel economy improvement for purchase of a used passenger car.**



**Figure 5 Minimum fuel economy improvement for purchase of a used light-duty truck.**

### Aligning the Incentive

Incentives in other vehicle scrappage programs have various forms such as a voucher for a new vehicle, a tax rebate, a waiver for vehicle registration, or money towards public transportation. As noted by the ECMT (10), vehicle owners will generally only scrap a vehicle if the incentive is larger than the trade-in value of the vehicle minus the expected repair and maintenance costs. As the difference between these costs grow, the vehicle owner's motivation to scrap the vehicle also grows. Two conclusions can be drawn from this insight: owners with the highest motivation are those with the most inexpensive vehicles and the number of willing participants should increase with larger incentives.

An advantage of using a fuel economy based requirement like the framework suggested above is the incentive created by enabling consumers to save money on gasoline bills. This incentive comes at no cost to the overseeing agency but should be considered when determining which, and how many, vehicle owners will participate.

Ideally, an incentive will only be offered if a vehicle has a certain number of years or miles remaining. Evidence shows that when vehicle owners make this estimate, they tend to overestimate the remaining years useful life (19). A mechanic could provide a more accurate assessment. California's South Coast Air Quality District's vehicle scrappage program uses pre-certified mechanics to ensure its 3-year life remaining requirement is met (25). Since 1997, this program has an 18% rejection rate of vehicles based on not meeting the 3-year requirement (25). Of course, this additional step of using a mechanic adds to the total program cost.

A simpler and lower cost option would be to base the incentive value on the model year or odometer reading. The U.S. CARS program requires scrapped vehicles to be model year 1984 or younger (13). However, such a lenient maximum age requirement does little to ensure additionality. The Swedish vehicle scrappage program has a more reasonable age requirement but improperly aligns its incentives. For scrapped vehicles between 7 and 16 years old, a rebate of SEK 1200 (\$160) is awarded, but vehicles 16 years old or older have a SEK 1700 (\$227) incentive (26). While such a system may prevent vehicle abandonment, it motivates vehicle owners to wait before participating.

Odometer readings could also be used. For example, since the average VMT at the time of scrappage in U.S. is 152,137 miles (244,841 km) for passenger cars and 176,954 miles (284,780 km) for light-duty trucks (16), a scrappage program could scale the rebate according to the number of miles a vehicle is below that threshold. Because such a requirement would naturally exclude a number of potential participants, it could be phased in over multiple years, starting at a maximum mileage well above the average scrappage VMT. A mileage-based eligibility would provide certainty in emission savings, simplify the scrapping procedure, and help a program be truly additional.

The incentive in a Cash-for-Clunker program with a GHG mitigation objective should be directly linked to the expected amount of CO<sub>2</sub>e mitigated. The CARS program also fails to properly align its incentive because it rewards participants for their increase in miles-per-gallon, not total gallons saved. A simple calculation illustrates this point. For a constant 10,000 miles per year traveled, a CARS participant could upgrade from a 13 MPG passenger car to a 22 MPG passenger car and save 315 gallons of gasoline per year, whereas another participant could upgrade from a 18 MPG vehicle to a 28 MPG but only save 198 gallons. Even though the first participant saves almost 60% more gasoline per year than the second, they receive a smaller rebate (\$3,500 instead of \$4,500) because the fuel economy improvement is less than 10 MPG. As pointed out by Larrick and Soll (27) there is a public misconception that fuel economy increases are linearly correlated to decreases in gallons consumed. The program outlined above not only links greater fuel savings to greater rebates, but also ensures the savings account for the non use-phase emissions.

### **Determining Program Length**

The majority of Cash-for-Clunker programs last on the order of months rather than years, attempting to quickly and efficiently remove a set of target vehicles. For example, the CARS program was originally scheduled to end after four months or after \$1 billion funding was spent, whichever came first. This short timeline prompted vehicle owners to act so quickly that the funding was spent after four days. However, a long-term Cash-for-Clunker program may be more suitable to CO<sub>2</sub>e reduction because with such a program policymakers could send a clear, long-term signal to auto manufacturers to produce more fuel-efficient vehicles. Considering the 4-6 year vehicle product planning, design, and introduction cycles where major retooling of automobile plants is needed, such longer term programs could actually induce technology changes.

Long-term programs would also compliment the timing of new, more stringent CAFE standards. The new CAFE standards announced in May, 2009, increase the required fuel efficiency of new vehicles, but will do nothing to ensure new vehicles are actually purchased. A prolonged Cash-for-Clunker program working in tandem with CAFE standards would hasten the

vehicle turnover rate, provide more fuel-efficient vehicle options for consumers, and increase the effectiveness of the CAFE standards.

Reduced market distortions are another advantage of long-term programs. As demonstrated with the CARS program and others, automakers vie for market share in short-term programs by creating incentives of their own, further driving down the prices of vehicles. In 1997, the scrappage program in Italy caused the car price index of new cars to decrease by 3.5% (10).

Long-term programs are not without drawbacks. As Innes et al. (28) point out, the longer a program runs the longer a vehicle owner will wait before scrapping a vehicle. Owners have more to gain if they scrap their vehicle next year, as opposed to this year. This problem is easily overcome by having a maximum total mileage requirement as described above, thus inducing owners to delay their vehicle replacement only until that mileage requirement is reached.

## **CONCLUSION**

The above study has described a potential framework for a Cash-for-Clunker program with a GHG reduction objective. While such a program is unlikely to compete with alternative GHG abatement measures on a cost per ton basis, it provides a mechanism to increase vehicle turnover rate: a feature lacking in other transportation-related GHG reduction measures.

Because the GHG emissions associated with vehicle manufacturing, materials production, and scrapping equal roughly 10-15% of a vehicle's lifecycle emissions, any program that seeks to reduce GHG emissions through scrappage should seek to save more GHG emissions than this amount. A fuel economy-based eligibility system with no minimum age requirement could achieve this upgrade using the framework developed above. Such a program would be open to any vehicle owner, assuming the fuel economy upgrade is large enough. To help lower the cost per ton of abatement, such a program could include a maximum odometer reading, phased in over multiple years to ensure a specific life remains in the vehicle. An additional benefit to the program is that it would send a clear, long-term signal to automakers to produce high fuel economy vehicles.

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