Fuel Economy Information Project:
Research, Data Validation, and Technical Assistance Related to Collecting, Analyzing, and Disseminating Accurate Fuel Economy Information

Brian West, Bo Saulsbury (PI), John Thomas, Shean Huff, Tim LaClair
Oak Ridge National Laboratory

David Greene, *University of Tennessee*

DOE Management Team:
Dennis Smith, Linda Bluestein
Vehicle Technologies Office
U.S. Department of Energy

2015 DOE Vehicle Technologies Office Annual Merit Review
June 9, 2015

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

ORNL is managed by UT-Battelle for the US Department of Energy

Project ID TI057

OAK RIDGE National Laboratory

OVERVIEW

Timeline

- Annual, fiscal year project
- Ongoing research to support *Fuel Economy Guide* and fueleconomy.gov

Budget

- FY14: $1000k
- FY15: $975k
  - $600k for research to develop and validate fuel efficient driving and maintenance tips and provide technical assistance
  - $375k for research on market for fuel economy, official MPG vs. real world MPG, and "Personalized MPG"

Barriers Addressed

- Consumer reluctance to purchase new technologies
- Lack of technical experience with new fuels and vehicle technologies
- Consumers lack confidence in official MPG estimates and tend to undervalue the potential savings associated with fuel efficient vehicles
- Misinformation about fuel economy is widely disseminated
- "Conventional wisdom" about fuel economy changes as vehicle technologies evolve

Partners

- DOE Clean Cities
- ORNL (Project Lead)
- The University of Tennessee
- The University of California, Davis
- NREL and ANL
- Transportation Research, Inc.

PROJECT RELEVANCE

- ***Fuel Economy Guide*** **and fueleconomy.gov fulfill DOE's statutory responsibility to provide fuel economy information to the public in collaboration with EPA (49 USC 32908, 2006).**

- **Objectives (from FY15 Annual Operating Plan):**
  - **Promote consumer interest in fuel economy and advanced vehicle technologies in order to reduce dependence on petroleum and promote the use of clean energy alternatives.**
  - **Conduct research to support those functions and to improve understanding of the market for automotive fuel economy and advanced technology vehicles; conduct engineering research to validate and update fuel efficient driving and maintenance tips for fueleconomy.gov.**

OAK RIDGE National Laboratory

PROJECT RELEVANCE

Addresses specific barriers identified in *VTO's Multi-Year Program Plan 2011–2015*:

- Research to validate existing and develop new fuel efficient driving and maintenance tips; to understand how consumers use and value fuel economy information; and to analyze the relationship between official MPG estimates and real world MPG.
- Leads to new information and tools on fueleconomy.gov to address barriers:
  - consumer reluctance to purchase new technologies
  - consumers' lack of technical experience with new fuels and vehicle technologies

And other barriers:

- consumers lack confidence in official MPG estimates and tend to undervalue the potential savings associated with fuel efficient vehicles
- misinformation about fuel economy is widely disseminated
- "conventional wisdom" about fuel economy changes as vehicle technologies evolve

OAK RIDGE National Laboratory

PROJECT APPROACH: FY14 MILESTONES

FY14

- ✓ **Completed "Where the Energy Goes" charts for advanced technology gasoline and hybrid vehicles and deployed charts on fueleconomy.gov.**
- ✓ **Completed publication on fuel economy effects of vehicle alterations (low tire pressure, open windows, rooftop and hitch-mounted cargo, and trailer) and added information to fueleconomy.gov.**
- ✓ **Completed feasibility report on results of "Personalized MPG" research.**
- ✓ **Developed new fuel economy vs. speed curves for emerging vehicle technologies and deployed "Speed Penalty" tool on fueleconomy.gov.**
- ✓ **Completed assessment of hybrid vehicle sensitivity to driving style ("regenerative braking study").**

PROJECT APPROACH: FY15 MILESTONES

FY15

- ✓ **Published results quantifying light-duty vehicle powertrain efficiencies for standard EPA cycles, and documenting recent improvements in vehicle powertrains and tractive power requirements.**
- ✓ **Developed a consumer-oriented page on fuel octane and deployed page on fueleconomy.gov.**
- **Organize meeting of the fueleconomy.gov government/industry discussion group for continued discussion of future research activities** (on track)
- **Progress report on FY15 Personalized MPG estimates research** (on track).
- **Progress report on FY15 update to "Fuel Economy vs. Speed" analysis with emerging vehicles** (on track).

PROJECT APPROACH

- **Conduct research to validate existing and develop new fuel efficient driving and maintenance tips for fueleconomy.gov:**
  - **Conduct literature reviews, mine available data (EPA, OEMs, ANL, INL)**
  - **Design and execute on-road and laboratory vehicle experiments**
  - **Consult with FE discussion group and industry and Lab peers**
  - **Publish research results and update fueleconomy.gov**

- **Conduct research to develop personalized MPG estimates to address consumers' lack of confidence in official MPG estimates.**

- **Conduct research using "My MPG" data to analyze the relationship between official MPG estimates and real world MPG.**

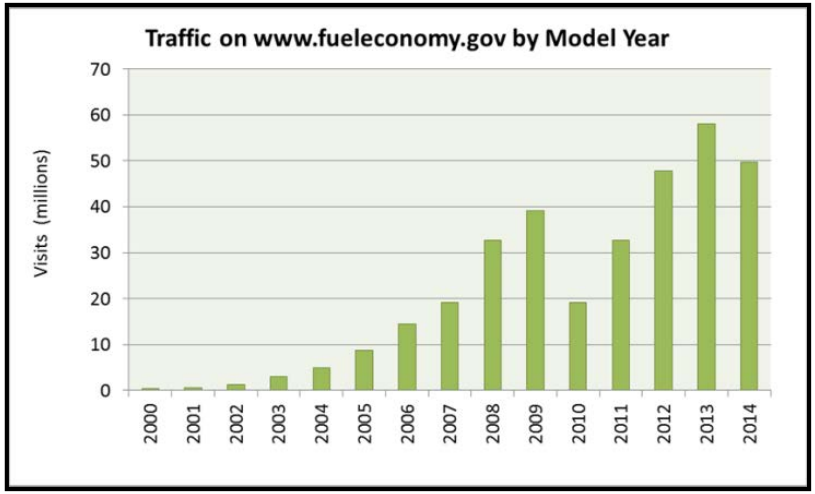
- **Conduct on-road and survey research to understand how consumers use and value fuel economy information.**

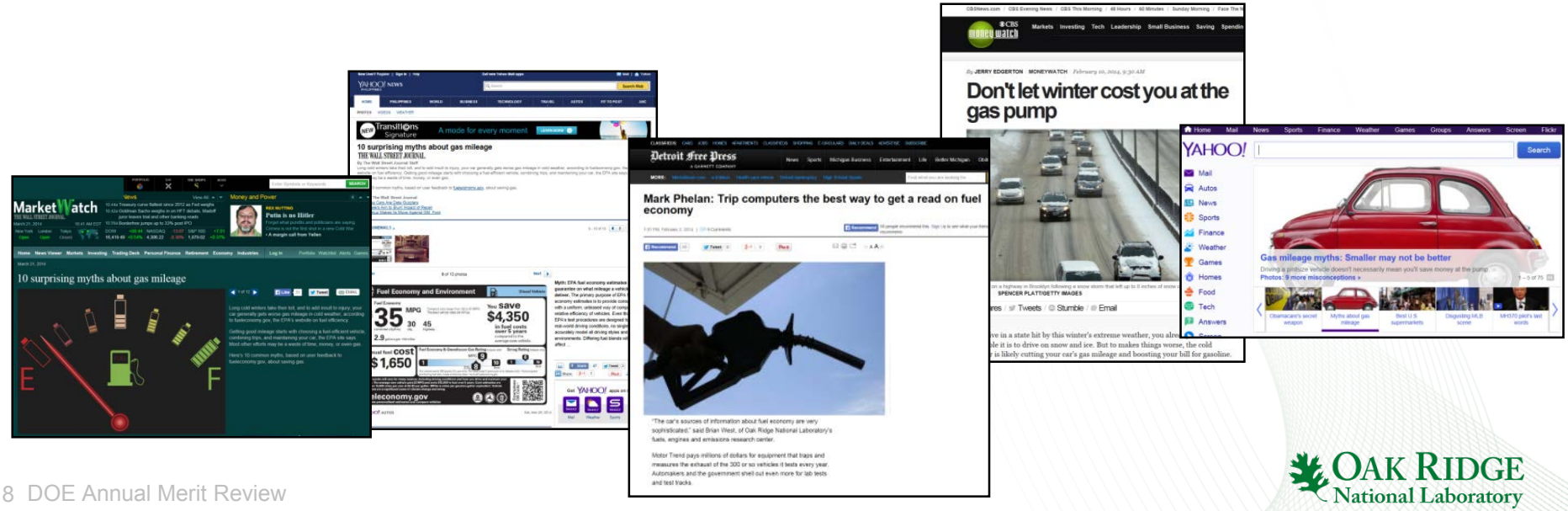
- **Provide direct consumer outreach and technical assistance; respond to questions from fueleconomy.gov users and the automotive and consumer media.**

- **Support Clean Cities Program with "on call" technical assistance.**

ACCOMPLISHMENTS AND PROGRESS

- **FE.gov hosted >49.7 million user sessions in MY14**
  - **>350 million users sessions since 1999.**
- **FE.gov cited in >2,500 media articles and blog posts since 2013.**
  - **Continue to be important resource for media stories about gasoline prices, fuel economy, AFVs, and electric drive vehicles.**

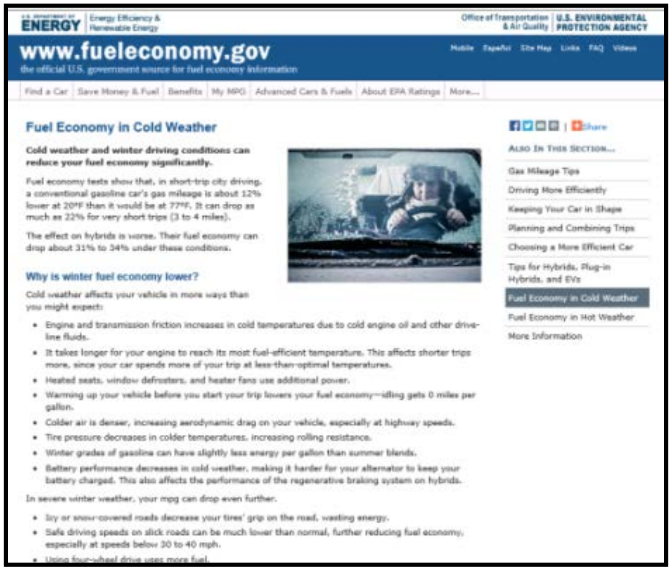


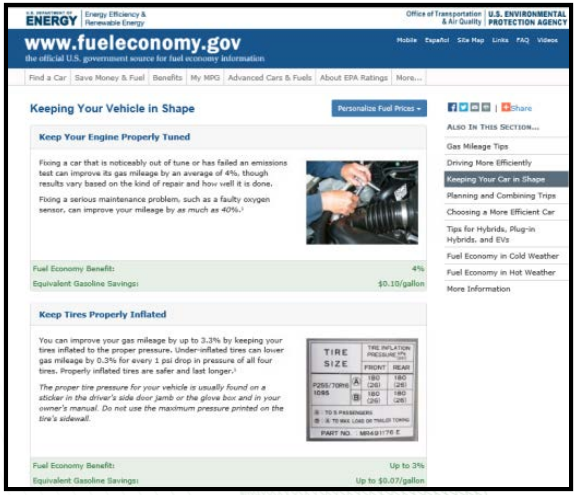


OAK RIDGE National Laboratory

ACCOMPLISHMENTS AND PROGRESS

- **Continued to validate existing and add new fuel efficient tips, especially for hybrids, PHEVs, and EVs**
  - **Driving more efficiently**
  - **Keeping your car in shape**
  - **Planning and combining trips**
  - **Choosing a more efficient vehicle**
  - **Tips for hybrids, PHEVs, and EVs**
  - **Tips for cold and hot weather** (Backup Slide)





OAK RIDGE National Laboratory

ACCOMPLISHMENTS AND PROGRESS

- **Researched effects of intake air filter condition** (backup slide)
  - Commonly held misconception that dirty air filter decreases fuel economy

- **Published SAE Paper *Effect of Intake Air Filter Condition on Light-Duty Gasoline Vehicles,* and SAE Paper *Effect of Air Filter Condition on Diesel Vehicle Fuel Economy***

- **Added new information on fueleconomy.gov**

Replacing a Clogged Air Filter on Modern Cars Improves Performance but Not MPG

Replacing a clogged air filter on vehicles with fuel-injected, computer-controlled gasoline engines—such as those manufactured from the early 1980s to the present—or diesel engines does not improve fuel economy, but it can improve acceleration.

Replacing a clogged air filter on an older vehicle with a carbureted engine can improve both fuel economy and acceleration by a few percent under normal replacement conditions.[2, 3, 4]

SAE International

Effect of Air Filter Condition on Diesel Vehicle Fuel Economy

2013-01-0311
Published
04/08/2013

SAE International

Effect of Intake Air Filter Condition on Light-Duty Gasoline Vehicles

2012-01-1717
Published
09/10/2012

John Thomas, Brian West, Shean Huff and Kevin Norman
Oak Ridge National Laboratory

ABSTRACT

Proper maintenance can help vehicles perform as designed, positively affecting fuel economy, emissions, and the overall driveability. This effort investigates the effect of one maintenance factor, intake air filter replacement, with primary focus on vehicle fuel economy, but also examining emissions and performance. Older studies, dealing with carbureted gasoline vehicles, have indicated that replacing a clogged or dirty air filter can improve vehicle fuel economy and conversely that a dirty air filter can be significantly detrimental to fuel economy. The effect of clogged air filters on the fuel economy, acceleration and emissions of five gasoline fueled vehicles is examined. Four of these were modern vehicles, featuring closed-loop control and ranging in model year from 2003 to 2007. Three vehicles were powered by naturally aspirated, port fuel injection (PFI) engines of differing size and cylinder configuration: an inline 4, a V6 and a V8. A turbocharged inline 4-cylinder gasoline direct injection (GDI) engine powered vehicle was the fourth modern gasoline vehicle tested. A vintage 1972 vehicle equipped with a carburetor (open-loop control) was also examined.

Results reveal insignificant fuel economy and emissions sensitivity of modern vehicles to air filter condition, but measureable effects on the 1972 vehicle. All vehicles experienced a measured acceleration performance penalty with clogged intake air filters.

INTRODUCTION

The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy and the U.S. Environmental Protection Agency (EPA) jointly maintain a fuel economy website (www.fueleconomy.gov), which helps fulfill their responsibility under the Energy Policy Act of 1992 to provide accurate fuel economy information [in miles per gallon (mpg)] to consumers. The site provides information on EPA fuel economy ratings for passenger cars and light trucks from 1984 to the present and other relevant information related to energy use such as alternative fuels, and driving and vehicle maintenance tips. In recent years, crude oil price fluctuations and subsequent price fluctuations in the price of gasoline and diesel fuels have renewed interest in vehicle fuel economy in the United States. User sessions on the fuel economy website have increased year-to-year, approaching 1 million in 2001, 5 million in 2004, and exceeding 30 million in 2008 and 2009. As a result of this renewed interest, and the age of some of the references cited in the tips section of the website, DOE authorized the Oak Ridge National Laboratory (ORNL) Fuels, Engines, and Emissions Research Center (FEERC) to initiate studies to validate and improve these tips. This paper documents a study aimed specifically at the effect of engine air filter condition on fuel economy.

A vehicle's published EPA fuel economy rating is determined by driving the vehicle over prescribed cycles on a chassis dynamometer. In the United States, city fuel economy is measured using the Urban Dynamometer Driving Schedule, also known as the Federal Test Procedure (FTP). Highway fuel economy is measured using the Highway Fuel Economy Test (HFET). Another relevant test is the US06, an aggressive (high speed, high load) test used to confirm emissions compliance during aggressive driving. Typically, fuel economy results from this test are not reported, but EPA uses results from the US06 and other cycles to adjust the FTP and HFET results [1], and these adjusted fuel economy rates are what are reported on the vehicle manufacturer's window sticker, in the Fuel Economy Guide [2], and on the fueleconomy.gov website. (Note that prior to 2008, city and highway fuel economy adjustment factors were 0.90 and 0.78, respectively.) Unadjusted fuel economy data will be presented in this paper.

ACCOMPLISHMENTS AND PROGRESS

- **Researched fuel economy effects of air conditioner use**
- **Published SAE Paper *Effects of Air Conditioner Use on Real-World Fuel Economy***
- **Added new information on fueleconomy.gov**

ENERGY Energy Efficiency & Renewable Energy | Office of Transportation & Air Quality | U.S. ENVIRONMENTAL PROTECTION AGENCY

www.fueleconomy.gov
the official U.S. government source for fuel economy information

Mobile Español Site Map Links FAQ Videos

Find a Car | Save Money & Fuel | Benefits | My MPG | Advanced Cars & Fuels | About EPA Ratings | More...

Fuel Economy in Hot Weather

Hot weather can actually increase your fuel economy. Your engine warms up to an efficient temperature faster; summer grades of gasoline can have slightly more energy; and warm air causes less aerodynamic drag than cold air.

However, keeping passengers comfortable in hot weather by rolling down the windows or using the air conditioning (AC) can reduce fuel economy.

Running your car's air conditioning is the main contributor to reduced fuel economy in hot weather. Its effect depends on a number of factors, such as the outside temperature, humidity, and intensity of the sun. Under very hot conditions, AC use can reduce a conventional vehicle's fuel economy by more than 25%.[1,2] The AC's effect on hybrids, plug-in hybrids, and electric vehicles (EVs) can be even larger on a percentage basis.[2]

Driving with your windows down can also reduce fuel economy. Open windows increase aerodynamic drag (wind resistance), making your vehicle use more energy to push through the air. This effect is quite small at low speeds but increases at highway speeds.[1,3]

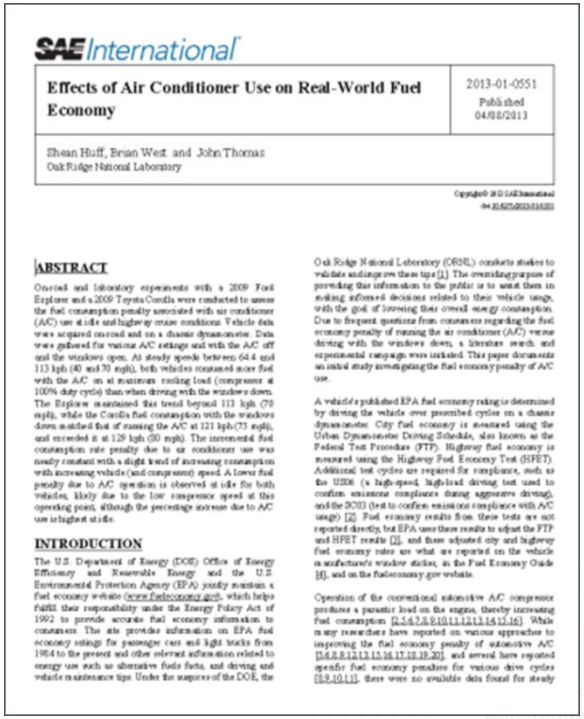
What can I do to improve my fuel economy in hot weather?

- Roll the windows down at lower speeds; use the AC at highway speeds.
- Don't use the AC more than needed or set the temperature lower than needed.
- Park in the shade or use a sunshade so that the cabin doesn't get as hot.
- Drive with the windows open for a short time before using the AC. Letting hot air out of the cabin first will put less demand on the AC and help your vehicle cool faster.
- Don't idle with the AC running before driving. Turn the AC on after you begin to drive or after airing out the cabin briefly. Most AC systems will cool the vehicle faster while driving.
- Read your owner's manual. Most manuals explain how the AC system controls work and how to best use and maintain the AC system.[4]
- For plug-in hybrids and electric vehicles, pre-cooling the cabin while plugged into the charger can extend your vehicle's range. Also, using a warmer temperature setting for the AC will use less battery power.

Share

ALSO IN THIS SECTION...

- Gas Mileage Tips
- Driving More Efficiently
- Keeping Your Car in Shape
- Planning and Combining Trips
- Choosing a More Efficient Car
- Tips for Hybrids, Plug-in Hybrids, and EVs
- Fuel Economy in Cold Weather
- Fuel Economy in Hot Weather
- More Information



SAE International

Effects of Air Conditioner Use on Real-World Fuel Economy

2013-01-0551
Published 04/08/2013

Shean Huff, Brian West and John Thomas
Oak Ridge National Laboratory

ABSTRACT

Onroad and laboratory experiments with a 2009 Ford Explorer and a 2009 Toyota Corolla were conducted to assess the fuel consumption penalty associated with air conditioner (AC) use at idle and highway cruise conditions. Vehicle data were acquired on-road and on a chassis dynamometer. Data were gathered for various AC settings and with the AC off and the windows open. At steady speeds between 64.4 and 113 kph (40 and 70 mph), both vehicles consumed more fuel with the AC on at maximum cooling load (compressor at 100% duty cycle) than when driving with the windows down. The Explorer maintained this trend beyond 113 kph (70 mph), while the Corolla fuel consumption with the windows down matched that of running the AC at 121 kph (75 mph), and exceeded it at 129 kph (80 mph). The incremental fuel consumption rate penalty due to air conditioner use was nearly constant with a slight trend of increasing consumption with increasing vehicle (and compressor) speed. A lower fuel penalty due to AC operation is observed at idle for both vehicles, likely due to the low compressor speed at this operating point, although the percentage increase due to AC use is highest at idle.

INTRODUCTION

The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy and the U.S. Environmental Protection Agency (EPA) jointly maintain a fuel economy website (www.fueleconomy.gov), which helps fulfill their responsibility under the Energy Policy Act of 1992 to provide accurate fuel economy information to consumers. The site provides information on EPA fuel economy ratings for passenger cars and light trucks from 1984 to the present and other relevant information related to energy use such as alternative fuels facts, and driving and vehicle maintenance tips. Under the auspices of the DOE, the Oak Ridge National Laboratory (ORNL) conducts studies to validate and improve these tips [1]. The overriding purpose of providing this information to the public is to assist them in making informed decisions related to their vehicle usage, with the goal of lowering their overall energy consumption. Due to frequent questions from consumers regarding the fuel economy penalty of running the air conditioner (AC) versus driving with the windows down, a literature search and experimental campaign were initiated. This paper documents an initial study investigating the fuel economy penalty of A/C use.

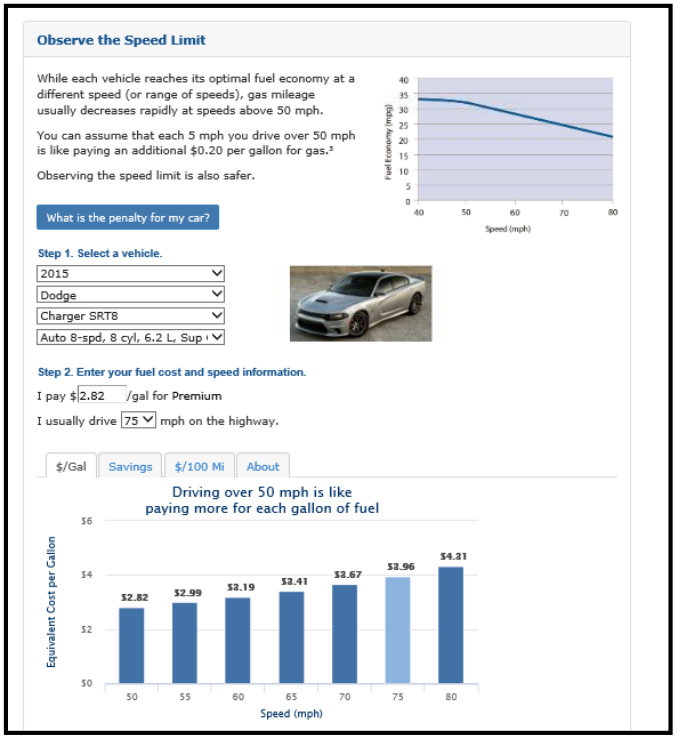
A vehicle's published EPA fuel economy rating is determined by driving the vehicle over prescribed cycles on a chassis dynamometer. City fuel economy is measured using the Urban Dynamometer Driving Schedule, also known as the Federal Test Procedure (FTP). Highway fuel economy is measured using the Highway Fuel Economy Test (HFET). Additional test cycles are required for compliance, such as the US06 (a high-speed, high-load driving test used to confirm emissions compliance during aggressive driving), and the SC03 (test to confirm emissions compliance with A/C usage) [2]. Fuel economy results from these tests are not reported directly, but EPA uses these results to adjust the FTP and HFET results [3], and these adjusted city and highway fuel economy rates are what are reported on the vehicle manufacturer's window sticker, in the Fuel Economy Guide [4], and on the fueleconomy.gov website.

Operation of the conventional automotive A/C compressor produces a parasitic load on the engine, thereby increasing fuel consumption [2,3,4,7,8,9,10,11,12,13,14,15,16]. While many researchers have reported on various approaches to improving the fuel economy penalty of automotive A/C [3,4,7,8,9,12,13,15,16,17,18,19,20], and several have reported specific fuel economy penalties for various drive cycles [8,9,10,11], there were no available data found for steady

OAK RIDGE National Laboratory

ACCOMPLISHMENTS AND PROGRESS

- **Researched effects of vehicle speed on fuel economy** (backup slide)
- **Published SAE Paper *Predicting Light-Duty Vehicle Fuel Economy as a Function of Highway Speed.*** (Effort included data mined from OEM partner as well as ORNL test data.)
- **Developed new fuel economy vs. speed curves for emerging vehicle technologies and deployed "Speed Penalty" tool on fueleconomy.gov** (milestone)



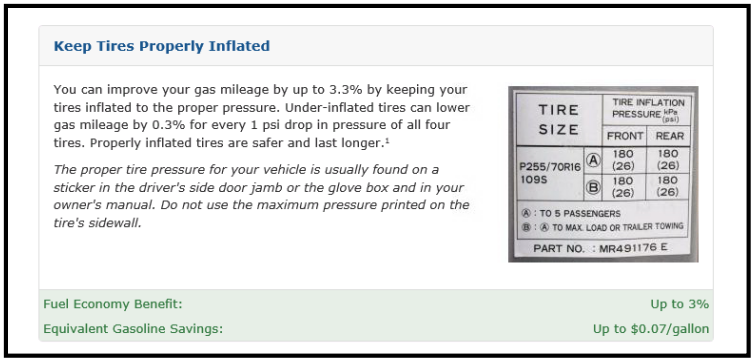
OAK RIDGE National Laboratory

ACCOMPLISHMENTS AND PROGRESS

- **Researched fuel economy effects of vehicle alterations** (backup slide)

- **Published SAE Paper *Fuel Economy and Emissions Effects of Low Tire Pressure, Open Windows, Roof Top and Hitch-Mounted Cargo, and Trailer*** (milestone)

- **Added new information on fueleconomy.gov**



Keep Tires Properly Inflated

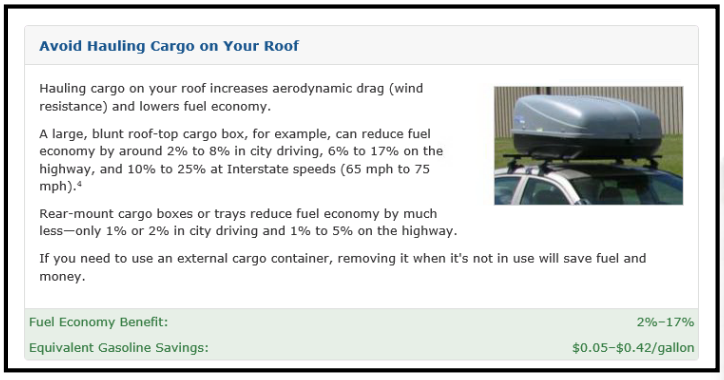
You can improve your gas mileage by up to 3.3% by keeping your tires inflated to the proper pressure. Under-inflated tires can lower gas mileage by 0.3% for every 1 psi drop in pressure of all four tires. Properly inflated tires are safer and last longer.[1]

The proper tire pressure for your vehicle is usually found on a sticker in the driver's side door jamb or the glove box and in your owner's manual. Do not use the maximum pressure printed on the tire's sidewall.

TIRE SIZE		TIRE INFLATION PRESSURE kPa (psi) FRONT	REAR
P255/70R16 109S	Ⓐ	180 (26)	180 (26)
	Ⓑ	180 (26)	180 (26)

Ⓐ : TO 5 PASSENGERS
Ⓑ : Ⓐ TO MAX. LOAD OR TRAILER TOWING
PART NO. : MR491176 E

Fuel Economy Benefit: Up to 3%
Equivalent Gasoline Savings: Up to $0.07/gallon



Avoid Hauling Cargo on Your Roof

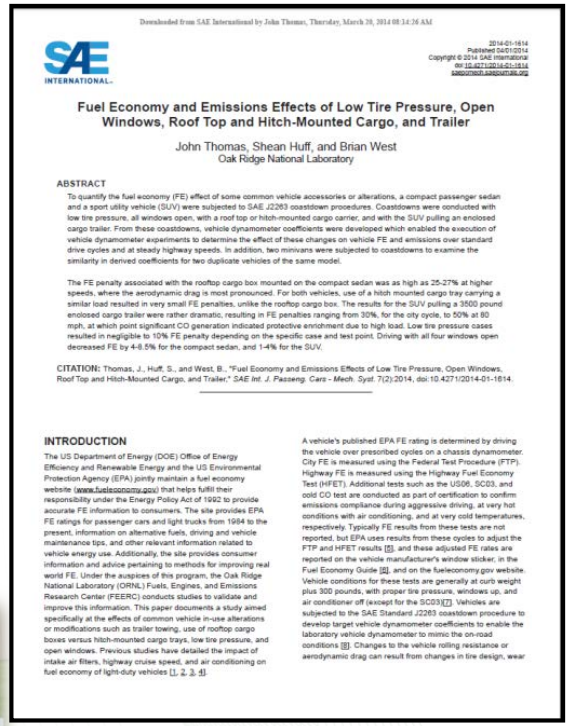
Hauling cargo on your roof increases aerodynamic drag (wind resistance) and lowers fuel economy.

A large, blunt roof-top cargo box, for example, can reduce fuel economy by around 2% to 8% in city driving, 6% to 17% on the highway, and 10% to 25% at Interstate speeds (65 mph to 75 mph).[4]

Rear-mount cargo boxes or trays reduce fuel economy by much less—only 1% or 2% in city driving and 1% to 5% on the highway.

If you need to use an external cargo container, removing it when it's not in use will save fuel and money.

Fuel Economy Benefit: 2%–17%
Equivalent Gasoline Savings: $0.05–$0.42/gallon



Downloaded from SAE International by John Thomas, Thursday, March 20, 2014 08:34:26 AM

SAE INTERNATIONAL

2014-01-1614
Published 04/01/2014
Copyright © 2014 SAE International
doi: 10.4271/2014-01-1614
saemobilus.sae.org

Fuel Economy and Emissions Effects of Low Tire Pressure, Open Windows, Roof Top and Hitch-Mounted Cargo, and Trailer

John Thomas, Shean Huff, and Brian West
Oak Ridge National Laboratory

ABSTRACT

To quantify the fuel economy (FE) effect of some common vehicle accessories or alterations, a compact passenger sedan and a sport utility vehicle (SUV) were subjected to SAE J2263 coastdown procedures. Coastdowns were conducted with low tire pressure, all windows open, with a roof top or hitch-mounted cargo carrier, and with the SUV pulling an enclosed cargo trailer. From these coastdowns, vehicle dynamometer coefficients were developed which enabled the execution of vehicle dynamometer experiments to determine the effect of these changes on vehicle FE and emissions over standard drive cycles and at steady highway speeds. In addition, two minivans were subjected to coastdowns to examine the similarity in derived coefficients for two duplicate vehicles of the same model.

The FE penalty associated with the rooftop cargo box mounted on the compact sedan was as high as 25-27% at higher speeds, where the aerodynamic drag is most pronounced. For both vehicles, use of a hitch mounted cargo tray carrying a similar load resulted in very small FE penalties, unlike the rooftop cargo box. The results for the SUV pulling a 3500 pound enclosed cargo trailer were rather dramatic, resulting in FE penalties ranging from 30%, for the city cycle, to 50% at 80 mph, at which point significant CO generation indicated protective enrichment due to high load. Low tire pressure cases resulted in negligible to 10% FE penalty depending on the specific case and test point. Driving with all four windows open decreased FE by 4-8.5% for the compact sedan, and 1-4% for the SUV.

CITATION: Thomas, J., Huff, S., and West, B., "Fuel Economy and Emissions Effects of Low Tire Pressure, Open Windows, Roof Top and Hitch-Mounted Cargo, and Trailer," *SAE Int. J. Passeng. Cars - Mech. Syst.* 7(2):2014, doi:10.4271/2014-01-1614.

INTRODUCTION

The US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy and the US Environmental Protection Agency (EPA) jointly maintain a fuel economy website (www.fueleconomy.gov) that helps fulfill their responsibility under the Energy Policy Act of 1992 to provide accurate FE information to consumers. The site provides EPA FE ratings for passenger cars and light trucks from 1984 to the present, information on alternative fuels, driving and vehicle maintenance tips, and other relevant information related to vehicle energy use. Additionally, the site provides consumer information and advice pertaining to methods for improving real world FE. Under the auspices of this program, the Oak Ridge National Laboratory (ORNL) Fuels, Engines, and Emissions Research Center (FEERC) conducts studies to validate and improve this information. This paper documents a study aimed specifically at the effects of common vehicle in-use alterations or modifications such as trailer towing, use of rooftop cargo boxes versus hitch-mounted cargo trays, low tire pressure, and open windows. Previous studies have detailed the impact of intake air filters, highway cruise speed, and air conditioning on fuel economy of light-duty vehicles [1, 2, 3, 4].

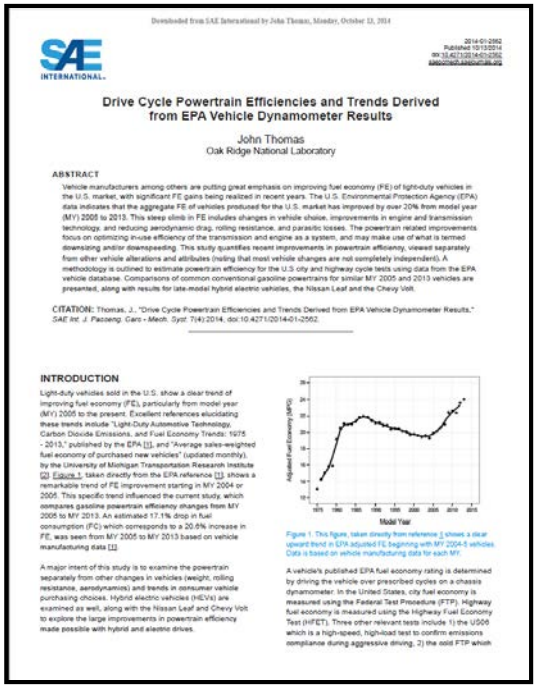
A vehicle's published EPA FE rating is determined by driving the vehicle over prescribed cycles on a chassis dynamometer. City FE is measured using the Federal Test Procedure (FTP). Highway FE is measured using the Highway Fuel Economy Test (HFET). Additional tests such as the US06, SC03, and cold CO test are conducted as part of certification to confirm emissions compliance during aggressive driving, at very hot conditions with air conditioning, and at very cold temperatures, respectively. Typically FE results from these tests are not reported, but EPA uses results from these cycles to adjust the FTP and HFET results [5], and these adjusted FE rates are reported on the vehicle manufacturer's window sticker, in the Fuel Economy Guide [6], and on the fueleconomy.gov website. Vehicle conditions for these tests are generally at curb weight plus 300 pounds, with proper tire pressure, windows up, and air conditioner off (except for the SC03)[7]. Vehicles are subjected to the SAE Standard J2263 coastdown procedure to develop target vehicle dynamometer coefficients to enable the laboratory vehicle dynamometer to mimic the on-road conditions [8]. Changes to the vehicle rolling resistance or aerodynamic drag can result from changes in tire design, wear

OAK RIDGE National Laboratory

ACCOMPLISHMENTS AND PROGRESS

- **Quantified light-duty vehicle powertrain efficiencies for standard EPA cycles and documented recent improvements in vehicle powertrains and tractive power requirements**

- **Published article "Drive Cycle Powertrain Efficiencies and Trends Derived from EPA Vehicle Dynamometer Results" in *SAE International*** (milestone)



Drive Cycle Powertrain Efficiencies and Trends Derived from EPA Vehicle Dynamometer Results

John Thomas
Oak Ridge National Laboratory

ABSTRACT

Vehicle manufacturers among others are putting great emphasis on improving fuel economy (FE) of light-duty vehicles in the U.S. market, with significant FE gains being realized in recent years. The U.S. Environmental Protection Agency (EPA) data indicates that the aggregate FE of vehicles produced for the U.S. market has improved by over 20% from model year (MY) 2005 to 2013. This steep climb in FE includes changes in vehicle choice, improvements in engine and transmission technology, and reducing aerodynamic drag, rolling resistance, and parasitic losses. The powertrain related improvements focus on optimizing in-use efficiency of the transmission and engine as a system, and may make use of what is termed downsizing and/or downspeeding. This study quantifies recent improvements in powertrain efficiency, viewed separately from other vehicle alterations and attributes (noting that most vehicle changes are not completely independent). A methodology is outlined to estimate powertrain efficiency for the U.S city and highway cycle tests using data from the EPA vehicle database. Comparisons of common conventional gasoline powertrains for similar MY 2005 and 2013 vehicles are presented, along with results for late-model hybrid electric vehicles, the Nissan Leaf and the Chevy Volt.

CITATION: Thomas, J., "Drive Cycle Powertrain Efficiencies and Trends Derived from EPA Vehicle Dynamometer Results," *SAE Int. J. Passeng. Cars - Mech. Syst.* 7(4):2014, doi:10.4271/2014-01-2562.

INTRODUCTION

Light-duty vehicles sold in the U.S. show a clear trend of improving fuel economy (FE), particularly from model year (MY) 2005 to the present. Excellent references elucidating these trends include "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 - 2013," published by the EPA [1], and "Average sales-weighted fuel economy of purchased new vehicles" (updated monthly), by the University of Michigan Transportation Research Institute [2]. Figure 1, taken directly from the EPA reference [1], shows a remarkable trend of FE improvement starting in MY 2004 or 2005. This specific trend influenced the current study, which compares gasoline powertrain efficiency changes from MY 2005 to MY 2013. An estimated 17.1% drop in fuel consumption (FC) which corresponds to a 20.6% increase in FE, was seen from MY 2005 to MY 2013 based on vehicle manufacturing data [1].

A major intent of this study is to examine the powertrain separately from other changes in vehicles (weight, rolling resistance, aerodynamics) and trends in consumer vehicle purchasing choices. Hybrid electric vehicles (HEVs) are examined as well, along with the Nissan Leaf and Chevy Volt to explore the large improvements in powertrain efficiency made possible with hybrid and electric drives.

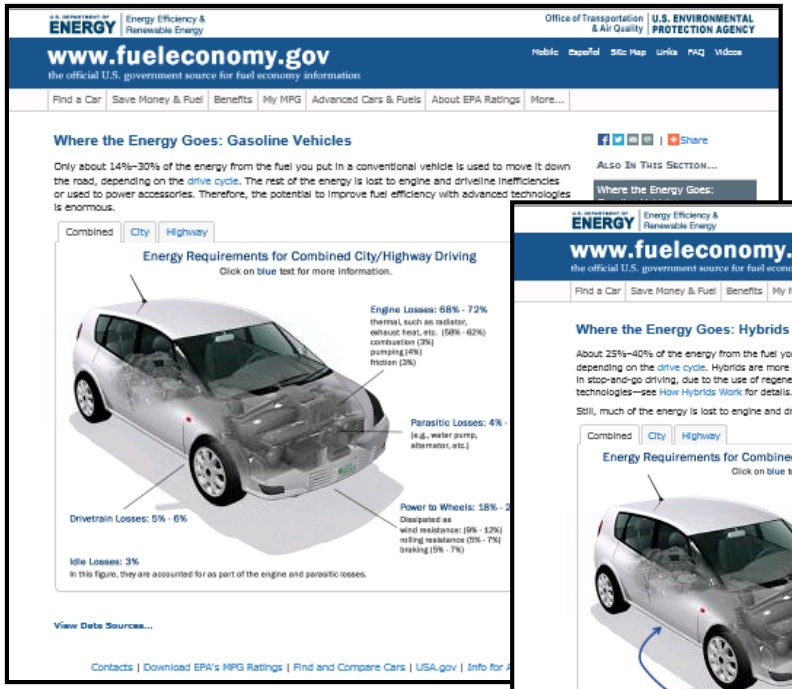
Model Year

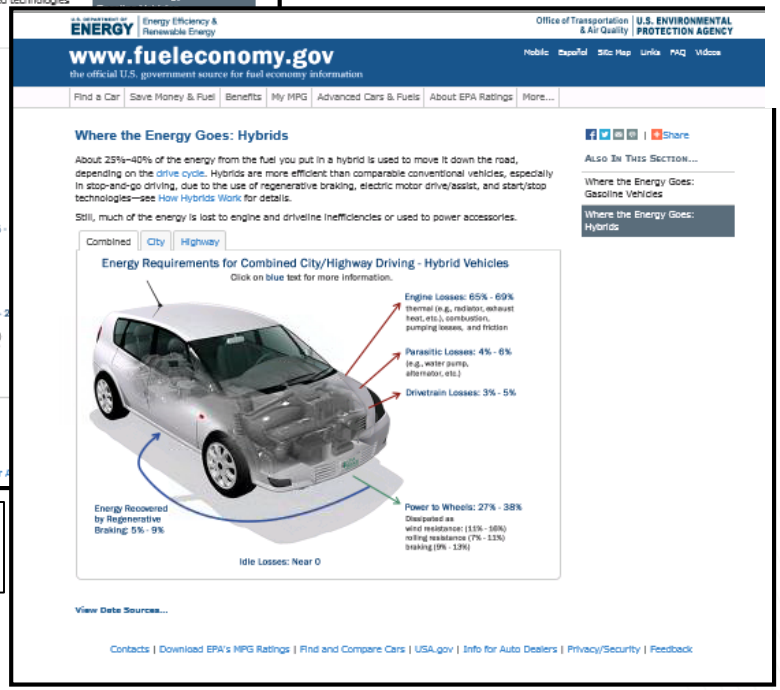
Figure 1. This figure, taken directly from reference [1] shows a clear upward trend in EPA adjusted FE beginning with MY 2004-5 vehicles. Data is based on vehicle manufacturing data for each MY.

A vehicle's published EPA fuel economy rating is determined by driving the vehicle over prescribed cycles on a chassis dynamometer. In the United States, city fuel economy is measured using the Federal Test Procedure (FTP). Highway fuel economy is measured using the Highway Fuel Economy Test (HFET). Three other relevant tests include 1) the US06 which is a high-speed, high-load test to confirm emissions compliance during aggressive driving, 2) the cold FTP which

ACCOMPLISHMENTS AND PROGRESS

- **Completed "Where the Energy Goes" analyses for advanced technology gasoline and hybrid vehicles** (milestone)
- **Updated/added new pages on fueleconomy.gov**





Pages on fueleconomy.gov updated based on new powertrain efficiency analysis

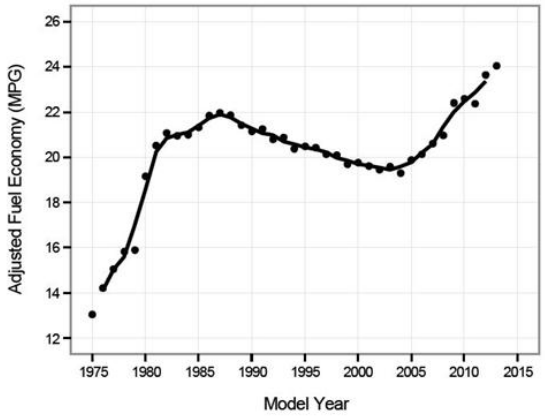


Figure above shows significant improvement in light duty vehicle fuel economy since ~2005. Figure taken from "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 – 2013," EPA-420-R-13-11, U.S. EPA, Office of Transportation and Air Quality

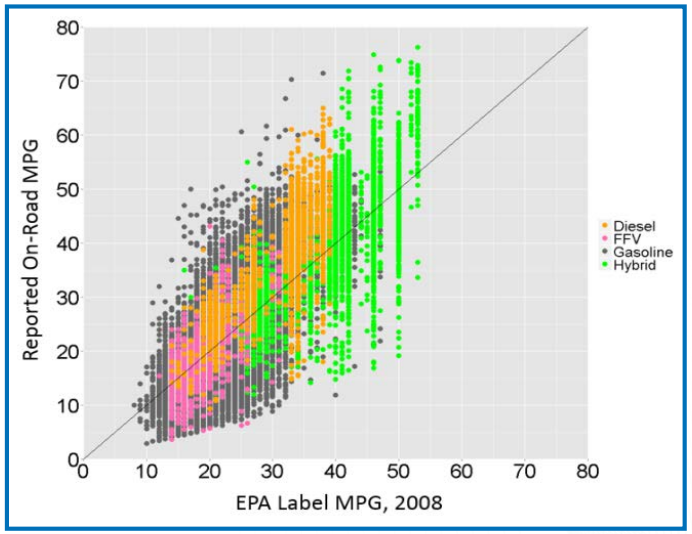
OAK RIDGE National Laboratory

ACCOMPLISHMENTS AND PROGRESS

- **Analyzing the relationship between official MPG estimates and real world MPG** (backup slide)

THE UNIVERSITY of TENNESSEE KNOXVILLE

- **Current "MY MPG" analysis show great variability in individuals' own MPG estimates relative to official government estimates, but evidence of only modest bias relative to the sample average. *Estimates are inaccurate for many individuals even though they may be unbiased for the population as a whole* (preliminary, unpublished).**



My MPG On-Road vs. EPA Label MPG Estimates for All Vehicle Types

- **Also, there is preliminary evidence that the shortfall between test cycle MPG numbers (used to measure compliance with regulations) has been increasing since 2005, which could affect the benefits realized by fuel economy and greenhouse gas emissions standards.**

OAK RIDGE National Laboratory

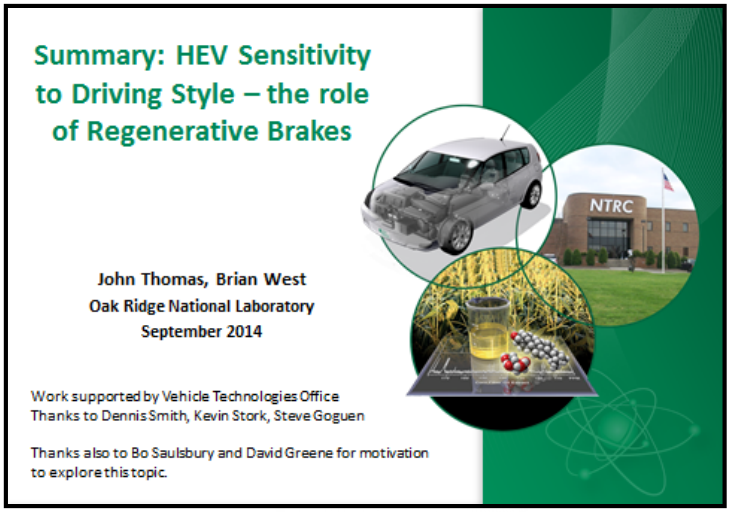
ACCOMPLISHMENTS AND PROGRESS

- **Completed assessment of hybrid vehicle sensitivity to driving style ("regenerative braking study")**

- **Added information to fueleconomy.gov** (milestone)

Summary of Analysis and Findings

- A Tractive Power Model was exercised to compare tractive energy use for a vehicle with hybrid and conventional powertrain over cycles with various intensities
- Results show that for the most aggressive cycles, the ***hybrid fuel economy is more significantly affected*** due to the limitations of the regenerative brakes.
  - While the hybrid vehicle will sometimes require higher total tractive power due to higher weight (from additional powertrain), the hybrid will use less fuel than the conventional vehicle on virtually any given cycle, and the percent change in fuel use from mild to aggressive driving is more significant.

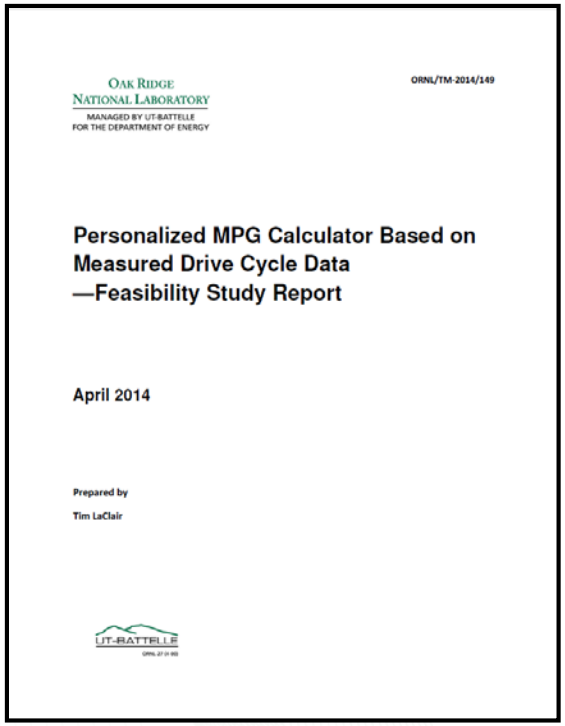


OAK RIDGE National Laboratory

ACCOMPLISHMENTS AND PROGRESS

- **Continued research on "Personalized MPG"**

- **Consumers lack confidence in official MPG estimates ("Your mileage will vary"); contributes to consumers undervaluing fuel economy.**
- **"Personalized" MPG estimates based on individual drive cycles (as recorded by OBD devices) could help reduce this lack of confidence.**
- **Current study: can we develop a reasonably accurate (within 5%) model of MPG based on individual drive cycle and publicly available vehicle characteristics?**
- **Goal: a tool on fueleconomy.gov that can generate a Personalized MPG estimate for any vehicle based on the user's individual drive cycle data.**
- **Published feasibility report on results in 2014** (milestone)


OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2014/149

Personalized MPG Calculator Based on Measured Drive Cycle Data —Feasibility Study Report

April 2014

Prepared by
Tim LaClair

UT-BATTELLE

OAK RIDGE National Laboratory

ACCOMPLISHMENTS AND PROGRESS

- **Developed consumer-oriented "Octane" page on fueleconomy.gov** (2015 milestone)

ENERGY Energy Efficiency & Renewable Energy | Office of Transportation & Air Quality | U.S. ENVIRONMENTAL PROTECTION AGENCY

www.fueleconomy.gov
the official U.S. government source for fuel economy information

Mobile Español Site Map Links FAQ Videos

Find a Car | Save Money & Fuel | Benefits | My MPG | Advanced Cars & Fuels | About EPA Ratings | More...

Selecting the Right Octane Fuel

What is octane rating?

Octane rating is the measure of a fuel's ability to resist "knocking" or "pinging" during combustion, caused by the air/fuel mixture detonating prematurely in the engine.

In the U.S., unleaded gasoline typically has octane ratings of 87 (regular), 88–90 (midgrade), and 91–94 (premium). Gasoline with an octane rating of 85 is available in some high-elevation areas of the U.S. (more about that below).

The octane rating is prominently displayed in large black numbers on a yellow background on gasoline pumps.

What octane fuel should I use in my vehicle?

You should use the octane rating required for your vehicle by the manufacturer. So, check your owner's manual. Most gasoline vehicles are designed to run on 87 octane, but others are designed to use higher octane fuel.

Why do some manufacturers require or recommend the use of higher octane gasoline?

Higher octane fuels are often required or recommended for engines that use a higher compression ratio and/or use supercharging or turbocharging to force more air into the engine. Increasing pressure in the cylinder allows an engine to extract more mechanical energy from a given air/fuel mixture but requires higher octane fuel to keep the mixture from pre-detonating. In these engines, high octane fuel will improve performance and fuel economy.

What if I use a lower octane fuel than required for my vehicle?

Using a lower octane fuel than required can cause the engine to run poorly and can damage the engine and emissions control system over time. It may also void your warranty. In older vehicles, the engine can make an audible "knocking" or "pinging" sound. Many newer vehicles can adjust the spark timing to reduce knock, but engine power and fuel economy will still suffer.

Will using a higher octane fuel than required improve fuel economy or performance?

It depends. For most vehicles, higher octane fuel may improve performance and gas mileage and reduce carbon dioxide (CO_2) emissions by a few percent during severe duty operation, such as towing a trailer or carrying heavy loads, especially in hot weather. However, under normal driving conditions, you may get little to no benefit.

Why does higher octane fuel cost more?

The fuel components that boost octane are generally more expensive to produce.

Is higher octane fuel worth the extra cost?

If your vehicle requires midgrade or premium fuel, absolutely. If your owner's manual says your vehicle doesn't require premium but says that your vehicle will run better on higher octane fuel, it's really up to you. The cost increase is typically higher than the fuel savings. However, lowering CO_2 emissions and decreasing petroleum usage by even a small amount may be more important than cost to some consumers.

What is 85 octane, and is it safe to use in my vehicle?

The sale of 85 octane fuel was originally allowed in high-elevation regions—where the barometric pressure is lower—because it was cheaper and because most carbureted engines tolerated it fairly well. This is not true for modern gasoline engines. So, unless you have an older vehicle with a carbureted engine, you should use the manufacturer-recommended fuel for your vehicle, even where 85 octane fuel is available.

Can ethanol boost gasoline's octane rating?

Yes. Ethanol has a much higher octane rating (about 109) than gasoline. Refiners usually blend ethanol with gasoline to help boost its octane rating—most gasoline in the U.S. contains up to 10% ethanol. Blends of up to 15% ethanol are available in some areas, and several manufacturers approve using this blend in recent-model vehicles.

OAK RIDGE National Laboratory

ACCOMPLISHMENTS AND PROGRESS

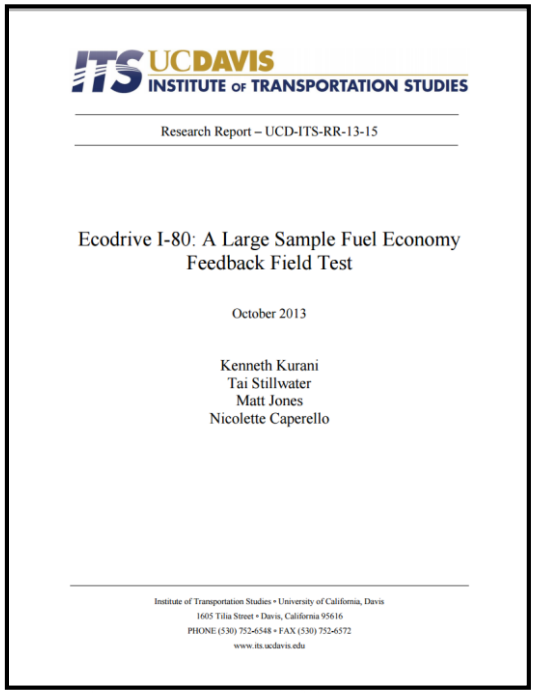
- **Completed research on "driver feedback devices"**

- **Energy feedback to drivers appears to produce measurable increases in on-road MPG.**

- **Feedback device can help average driver improve MPG by about 3%; driver who uses feedback device specifically to save fuel can improve MPG by about 10%.**

- **Variation in MPG improvements by screen design ranged from 1.6% to 2.9%.**

- **People know few effective actions to improve MPG; feedback can facilitate learning and new habits.**



ITS UCDAVIS
INSTITUTE OF TRANSPORTATION STUDIES

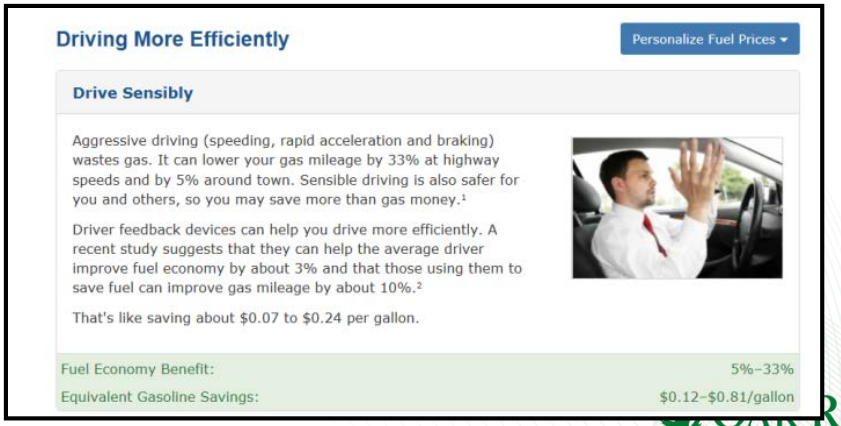
Research Report – UCD-ITS-RR-13-15

Ecodrive I-80: A Large Sample Fuel Economy Feedback Field Test

October 2013

Kenneth Kurani
Tai Stillwater
Matt Jones
Nicolette Caperello

Institute of Transportation Studies • University of California, Davis
1605 Tilia Street • Davis, California 95616
PHONE (530) 752-6548 • FAX (530) 752-6572
www.its.ucdavis.edu



Driving More Efficiently

Personalize Fuel Prices

Drive Sensibly

Aggressive driving (speeding, rapid acceleration and braking) wastes gas. It can lower your gas mileage by 33% at highway speeds and by 5% around town. Sensible driving is also safer for you and others, so you may save more than gas money.[1]

Driver feedback devices can help you drive more efficiently. A recent study suggests that they can help the average driver improve fuel economy by about 3% and that those using them to save fuel can improve gas mileage by about 10%.[2]

That's like saving about $0.07 to $0.24 per gallon.

Fuel Economy Benefit:	5%–33%
Equivalent Gasoline Savings:	$0.12–$0.81/gallon

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

This project was not reviewed in 2014.

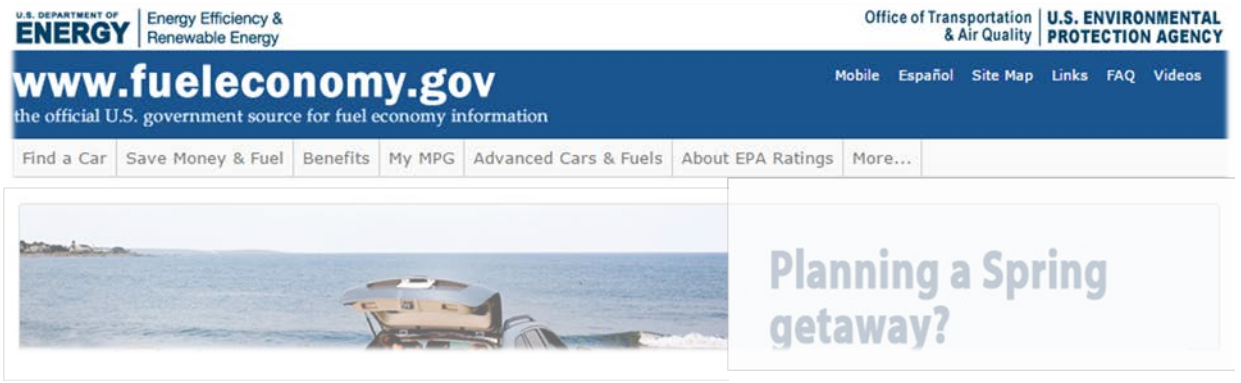
COLLABORATION AND COORDINATION

- **DOE Clean Cities provides funding and project guidance and oversight.**
- **ORNL conducts research and analysis to validate existing, and develop new fuel efficient driving and maintenance tips and to develop personalized MPG estimates to address consumers' lack of confidence in official MPG estimates.**
- **The University of Tennessee uses "My MPG" data to analyze the relationship between official MPG estimates and real world MPG.**
- **The University of California, Davis conducts research to understand how consumers use and value FE information**
- **NREL conducts research on alternative fuels and AFVs to support the AFDC website.**
- **ANL conducts research to support the GREET model and on idle reduction, and makes available advanced vehicle data from their vehicle research efforts (leverages other VTO programs).**
- **Transportation Research Center, Inc., provides contract vehicle test track services such as coast downs to establish vehicle dynamometer coefficients.**

PROPOSED FUTURE ACTIVITIES

- **Continue to provide technical assistance for fueleconomy.gov users, the automotive and consumer media, and the Clean Cities Program.**
- **Expand research (gather data from a larger vehicle sample) to develop personalized MPG model and calculator.**
- **Continue research using "My MPG" data to analyze relationship between official MPG estimates and real world MPG.**
- **Continue research to understand how consumers use and value fuel economy information.**
- **Research to validate existing/develop new fuel efficient driving and maintenance tips:**
  - **Evaluate emerging vehicles and "opportunity vehicles," mine data from partners to expand fuel economy vs. speed database, refine models (e.g., model by vehicle type)**
  - **Re-assess air conditioning penalty as new technologies emerge**
  - **Quantify effect of pre-heating/pre-cooling cabin for plug-in vehicles in cold/hot weather**
  - **Assess fuel economy penalty associated with accessory loads (heated seats, defroster, headlights, electronics)**
  - **Assess effects of additional accessories/alterations/maintenance**
    - **Truck bed covers/caps, roof racks (possible OEM data mining)**
    - **Alternate tire/tire sizes (e.g., snow tires, low rolling resistance tires)**
    - **Wheel alignment**
    - **More tire pressure data recommended**

Summary



RELEVANCE

- **FE.gov fulfills DOE's statutory responsibility to provide fuel economy information to the public; Research and Technical Assistance efforts ensure that information is accurate, up-to-date, and useful**

APPROACH

- **Gather relevant information through vehicle experiments, data mining from literature or national lab and industry partners**

ACCOMPLISHMENTS

- **Numerous accomplishments in transferring engineering data to consumer information on fe.gov**

COLLABORATIONS

- **Work closely with other NLs, Universities, industry partners and contractors**

FUTURE WORK

- **Continue to provide technical assistance to fe.gov users, media, Clean Cities**
- **Research improved driving tips, personal mpg**

OAK RIDGE National Laboratory

Technical Backup Slides

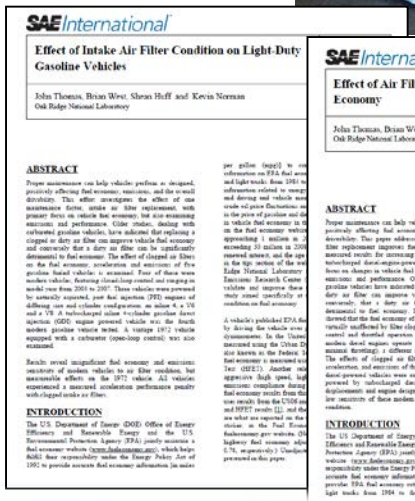
Backup Slide: Air Filter Study Approach and Conclusions

Approach

- 5 gasoline and 3 diesel vehicles evaluated with clean and clogged intake air filters
- Shop towels used to create a consistent clogged filter state
- Dynamometer drive cycle tests conducted for fuel economy and emissions. Full power acceleration tests conducted to assess vehicle performance

Results Summary:

- Clogged intake air filters had no measureable effect on modern gasoline or diesel vehicle fuel economy
- Carbureted vehicle fuel economy was affected by the dirty filter, consistent with the 1970s literature (due to "choking" effect and decrease in air:fuel ratio, increase in CO emissions)
- Full power acceleration is reduced by filter clogging for all vehicles
- No other significant powertrain behavior changes were noted
- Website updated based on new publications



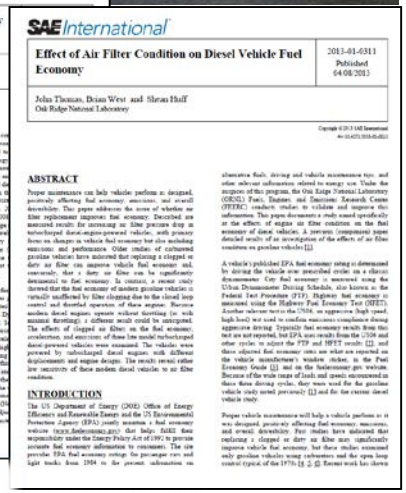
SAE International

Effect of Intake Air Filter Condition on Light-Duty Gasoline Vehicles

John Thomas, Brian West, Shean Huff and Kevin Norman
Oak Ridge National Laboratory

ABSTRACT

INTRODUCTION



SAE International

Effect of Air Filter Condition on Diesel Vehicle Fuel Economy

2013-01-6311
Published
04/08/2013

John Thomas, Brian West and Shean Huff
Oak Ridge National Laboratory

ABSTRACT

INTRODUCTION

Carbureted 1972 Pontiac Grandville confirmed results from 1970s literature

NEW INFORMATION: Replacing a Clogged Air Filter on Modern Cars Improves Performance but Not MPG

A new study shows that replacing a clogged air filter on cars with fuel-injected, computer-controlled gasoline engines does not improve fuel economy but it can improve acceleration time by around 6 to 11 percent. This kind of engine is prevalent on most gasoline cars manufactured from the early 1980s onward.

Tests suggest that replacing a clogged air filter on an older car with a carbureted engine may improve fuel economy 2 to 6 percent under

OAK RIDGE National Laboratory

Backup Slide: Effect of Cargo Carriers, Trailers, etc.

- Conducted Lit review; Limited amount of published data
- Experimental campaign
  - Configure vehicles and perform coastdowns to determine road load force
    - Per SAE J2263 (Road Load Measurement Using Onboard Anemometry and Coastdown Techniques)
  - Duplicate road load force in vehicle laboratory and conduct repeatable experiments

Coastdowns conducted at Transportation Research Center test track

Results Summary

- Tire Pressure and the hitch mounted Cargo Tray had small effects on the compact sedan (<5%) and minimal effects on the sport utility vehicle (<1%).
- Large box Trailer at the maximum allowable towing capacity ***doubled fuel consumption*** of the sport utility vehicle at speeds over 65 mph.
- Roof top Cargo Box with the compact sedan decreased the fuel economy by almost 27% at 80 mph.
- Hitch mounted Cargo Tray gave much better FE results, compared to the roof top Cargo Box, for both the SUV and compact sedan for all three test cycles examined.
- Emissions not significantly affected by vehicle configuration with the exception of the cargo Trailer case, which led to protective enrichment and significantly increased CO emissions at high speed.

Fuel economy and emissions tests conducted at ORNL

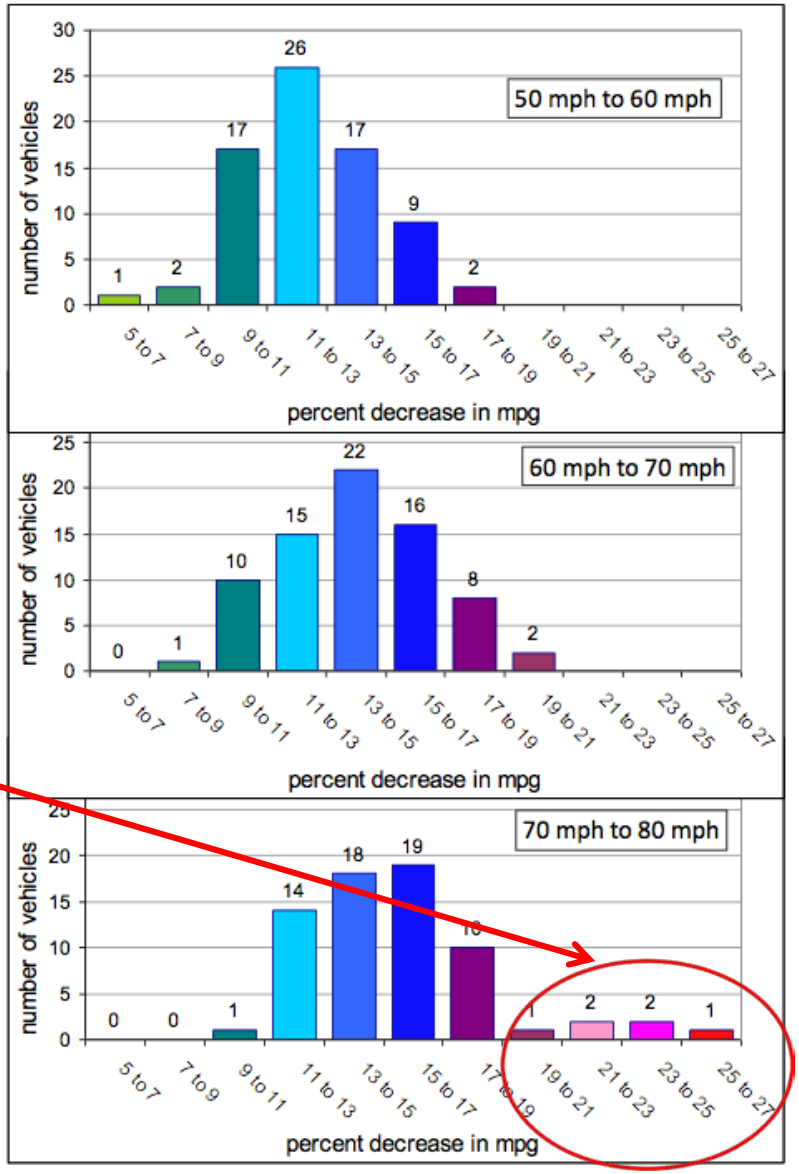
OAK RIDGE National Laboratory

Backup Slide: Fuel Economy versus Highway Speed

OEM proving ground data combined with ORNL experiments to assess over 70 vehicles

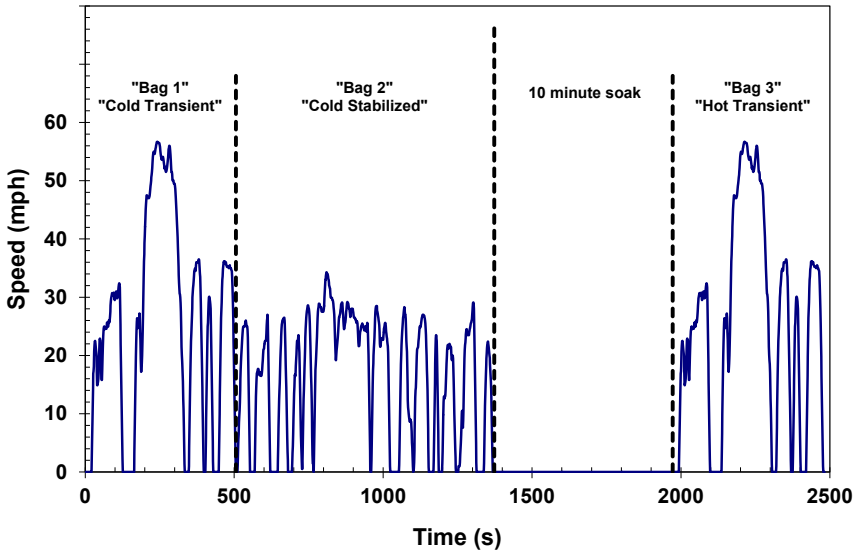
- 74 Vehicle database (ORNL, Chrysler)
- SS speeds of 50, 60, 70 & 80mph.
- Examine % mpg change for 10mph change
- Avg. mpg change: 12.4% , 14.0% and 15.4% for 60 vs. 50, 70 vs. 60, 80 vs. 70 mph respectively. Histogram also shows trend .
- Special cases: cyl. deactivation & protective enrichment revealed more extreme FE loss at higher speeds

- **No strong trend by vehicle type observed**
- **Slight shift to greater % FE loss at higher speeds**

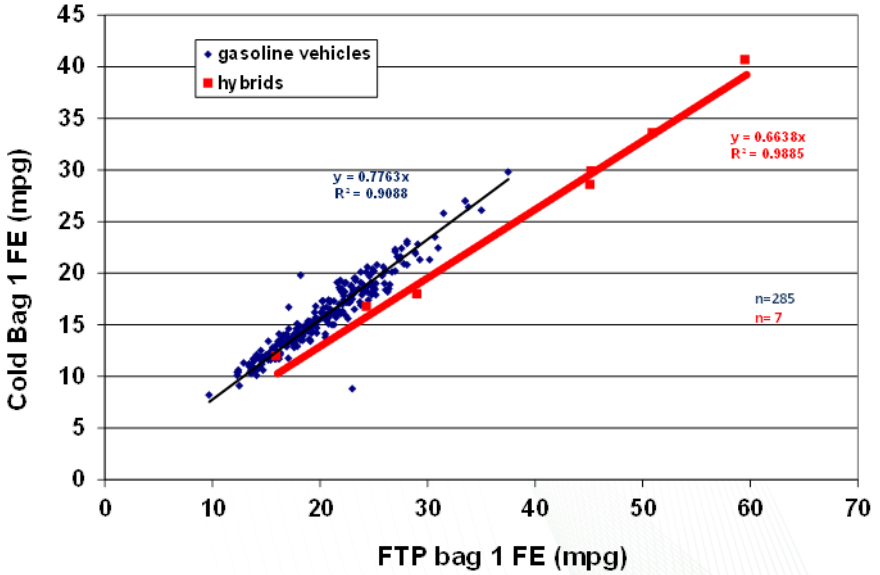


Backup Slide: Quantifying effects of cold weather on fuel economy

- **Cost prohibitive to conduct significant number of cold laboratory experiments**
  - **Mined available EPA "city cycle" data for 20°F and 77°F cold starts**
    - **Certification requires "city test" results at 77°F (FTP) and 20°F ("cold CO")**
      - **Identical drive cycle, differ only in ambient temperature**
  - **Analysis of these two datasets provides direct comparison of 20°F and 77°F fuel economy, allows quantitative advice on cold weather page**
    - **Comparing Bag 1 (20F vs 77F) yields "short trip" comparison**
    - **Comparing full city test yields "longer trip" comparison**



City test conducted in 3 phases
Engine is "cold" for Bag 1



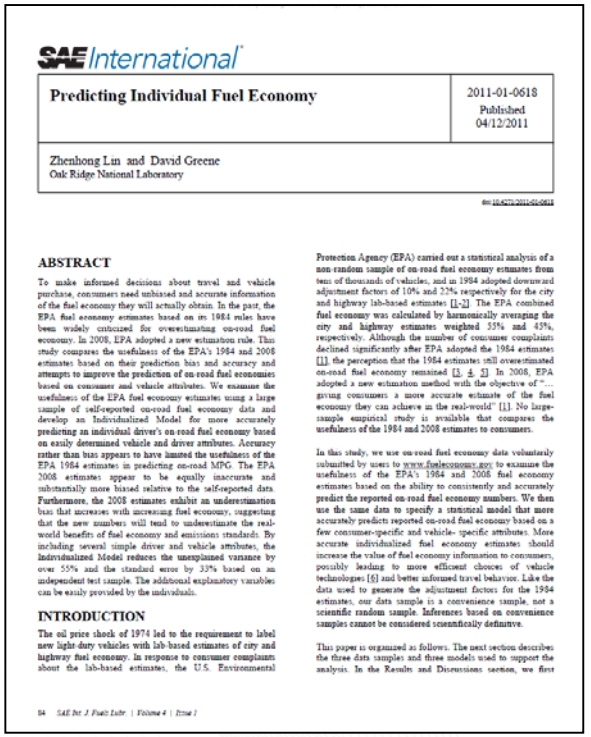
Largest FE difference for Bag 1 (short trip). Hybrids more severely impacted (34%) than conventional vehicles (22%)

OAK RIDGE National Laboratory

Backup Slide: "My MPG" Database

- **Analyzing the relationship between official MPG estimates and real world MPG**

- **Conducted analysis of 3,000 in-use MPG data (Greene et al. 2006) and 35,000 in-use MPG data (Lin and Greene 2011) from the fueleconomy.gov "My MPG" database.**


SAE International

Predicting Individual Fuel Economy

2011-01-0618
Published
04/12/2011

Zhenhong Lin and David Greene
Oak Ridge National Laboratory

ABSTRACT

To make informed decisions about travel and vehicle purchase, consumers need unbiased and accurate information of the fuel economy they will actually obtain. In the past, the EPA fuel economy estimates based on its 1984 rules have been widely criticized for overestimating on-road fuel economy. In 2008, EPA adopted a new estimation rule. This study compares the usefulness of the EPA's 1984 and 2008 estimates based on their prediction bias and accuracy and attempts to improve the prediction of on-road fuel economies based on consumer and vehicle attributes. We examine the usefulness of the EPA fuel economy estimates using a large sample of self-reported on-road fuel economy data and develop an Individualized Model for more accurately predicting an individual driver's on-road fuel economy based on easily determined vehicle and driver attributes. Accuracy rather than bias appears to have limited the usefulness of the EPA 1984 estimates in predicting on-road MPG. The EPA 2008 estimates appear to be equally inaccurate and substantially more biased relative to the self-reported data. Furthermore, the 2008 estimates exhibit an underestimation bias that increases with increasing fuel economy, suggesting that the new numbers will tend to underestimate the real-world benefits of fuel economy and emissions standards. By including several simple driver and vehicle attributes, the Individualized Model reduces the unexplained variance by over 55% and the standard error by 33% based on an independent test sample. The additional explanatory variables can be easily provided by the individuals.

INTRODUCTION

The oil price shock of 1974 led to the requirement to label new light-duty vehicles with lab-based estimates of city and highway fuel economy. In response to consumer complaints about the lab-based estimates, the U.S. Environmental Protection Agency (EPA) carried out a statistical analysis of a non-random sample of on-road fuel economy estimates from tens of thousands of vehicles, and in 1984 adopted downward adjustment factors of 10% and 22% respectively for the city and highway lab-based estimates [1-2]. The EPA combined fuel economy was calculated by harmonically averaging the city and highway estimates weighted 55% and 45%, respectively. Although the number of consumer complaints declined significantly after EPA adopted the 1984 estimates [1], the perception that the 1984 estimates still overestimated on-road fuel economy remained [3, 4, 5]. In 2008, EPA adopted a new estimation method with the objective of "... giving consumers a more accurate estimate of the fuel economy they can achieve in the real-world" [1]. No large-sample empirical study is available that compares the usefulness of the 1984 and 2008 estimates to consumers.

In this study, we use on-road fuel economy data voluntarily submitted by users to www.fueleconomy.gov to examine the usefulness of the EPA's 1984 and 2008 fuel economy estimates based on the ability to consistently and accurately predict the reported on-road fuel economy numbers. We then use the same data to specify a statistical model that more accurately predicts reported on-road fuel economy based on a few consumer-specific and vehicle- specific attributes. More accurate individualized fuel economy estimates should increase the value of fuel economy information to consumers, possibly leading to more efficient choices of vehicle technologies [6] and better informed travel behavior. Like the data used to generate the adjustment factors for the 1984 estimates, our data sample is a convenience sample, not a scientific random sample. Inferences based on convenience samples cannot be considered scientifically definitive.

This paper is organized as follows. The next section describes the three data samples and three models used to support the analysis. In the Results and Discussions section, we first

- **Studies indicated that EPA combined city/highway MPG estimates, adjusted for shortfall between test procedure values and real world experience, were very nearly unbiased estimators of MPG estimates reported by individuals. However, the accuracy of the EPA adjusted MPG estimates for any particular vehicle was poor, with a 95% confidence interval of +/- 7 MPG.**

- **Project is funding an update of 2011 study by The University of Tennessee. Current study analyzes 75,000 in-use MPG data from My MPG.**

OAK RIDGE National Laboratory