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# MOTORISTS' VIEWS OF FUEL ECONOMY AND ADVANCED VEHICLE TECHNOLOGIES

BRANDON SCHOETTLE
MICHAEL SIVAK

UNIVERSITY OF MICHIGAN
TRANSPORTATION
RESEARCH INSTITUTE

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Brandon Schoettle
Michael Sivak

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

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16. Abstract

This report focuses on consumer-acceptance issues related to fuel-saving and advanced vehicle technologies. The main objective of this survey was to understand the overall importance of fuel economy, consumer preferences, and general knowledge regarding various advanced vehicle technologies and vehicle types (i.e., powertrains, including electric and fuel-cell vehicles) when deciding which vehicle to own. Of special interest were the factors that consumers consider to be problematic or disadvantages that may impede greater acceptance of advanced vehicle technologies, as well as general willingness to pay for various levels of improvement in fuel economy.

The following advanced vehicle technologies were included in the survey: continuously variable transmissions (CVT), cylinder deactivation, diesel engines, gasoline-hybrid vehicles, stop-start engine systems, supercharging, turbocharging, and twincharging. The survey yielded completed responses from 674 vehicle owners (or lessees) 18 years of age or older.

Overall, fuel economy is important to consumers and they generally do not care specifically how fuel savings are achieved. Knowledge and opinions were mixed, with older respondents and males being more likely to have stronger opinions (both positive and negative) and to claim to know more about the technologies covered by the survey than younger respondents and females. As expected, willingness to pay for improved fuel economy was directly related to the magnitude of the improvement.

An overview of advanced vehicle technology market-share trends during the past 40 years is also included.

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# Contents

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# Introduction

The topics of improved fuel economy and reduced vehicle emissions have been the focus of increasing public attention over the past several years. Higher gas prices have sparked greater interest in fuel economy on the part of consumers, while the latest updates to CAFE requirements (EPA/NHTSA, 2010; 2012) have required additional efforts by manufacturers to reduce fuel consumption and emissions as well. This pressure for improvement from both sides of the equation has not only led to considerable increases in average vehicle fuel economy (Sivak and Schoettle, 2015a) and corresponding reductions in emissions (Sivak and Schoettle, 2015b), but has also helped stimulate the innovation of new technologies to achieve these goals.

This report focuses on consumer-acceptance issues related to fuel-saving and advanced vehicle technologies. It documents the results of a survey that was conducted to gain an understanding of the overall importance of fuel economy, consumer preferences, and general knowledge regarding various advanced vehicle technologies and vehicle types (powertrains) when deciding which vehicle to own. Of special interest are the factors that consumers consider to be problematic or disadvantages that may impede greater acceptance of advanced vehicle technologies.

# Background

## Historical market shares of fuel-saving and advanced vehicle technologies

Advanced powertrain and engine technologies (with various fuel-saving effects) have been available to vehicle buyers for several decades. Largely in response to the spikes in oil prices beginning in the 1970s, the majority of new technologies have been intended to save fuel (and recently, to reduce emissions). Recently, the number of such technologies has rapidly increased. To better understand the different options available to vehicle buyers and their purchasing preferences, we have charted the evolving mix of fuel-saving technologies and their corresponding market shares over the past 40 years, for model years 1975 through 2014 (EPA, 2014). In this section, these technologies are presented and discussed in the following groups:

- Emerging technologies (less than 50% market share)
- Established technologies (greater than 50% market share)
- Obsolete technologies (superseded or continuously low market share)

*Emerging technologies* (Figure 1). Several of the currently emerging technologies have experienced a very rapid rise in market share. Direct injection's market share has risen the fastest, from 2% to 38% in just six years. Continuously variable transmissions (CVT), turbo, and cylinder deactivation have also seen a rapid increase in market share over the past 10 years. Stop-start systems, a relatively new technology, are also being rapidly introduced (about 5% market share in just three years). Four-wheel drive vehicles (although generally considered to have lower fuel economy than a comparable two-wheel drive) have slowly gained market share during this period, and their percentage continues to increase. Gasoline hybrids have emerged more slowly than most other technologies, having achieved only 4% market share over 15 years of availability. While diesel engines saw an initial spike of interest in the late 1970s and early 1980s, diesel technology remained at less than 1% market share until model year 2014.

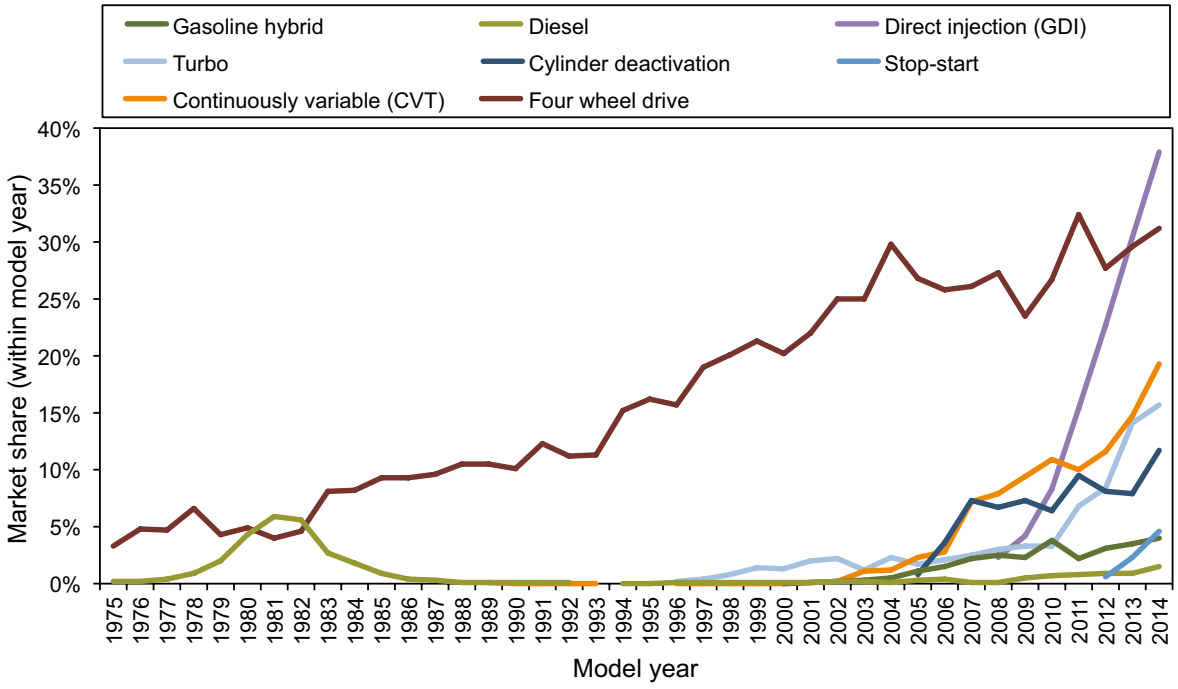


Figure 1. Market share of emerging fuel-saving and related technologies (less than 50% of market share), 1975 to 2014 (EPA, 2014).

*Established technologies* (Figure 2). Several of the established technologies have only recently attained a large market share (e.g., variable-valve timing, multivalve, 6+ gears), while several others have maintained large market shares for several decades (e.g., gasoline engines, two-wheel drive, port injection, automatic transmissions with lockup). However, the market shares for a number of these long-term established technologies are in decline (e.g., two-wheel drive, port injection, automatic transmissions with lockup), generally being replaced by one of the emerging technologies. For example, as one fuel-injection method often supersedes the previous methods, the rising market share of direct injection (see Figure 1) corresponds to the dropping market share of port injection. Similarly, as more vehicles are equipped with four-wheel drive (see Figure 1), shares of two-wheel drive correspondingly decline. Increasing diesel and gasoline-hybrid vehicle sales account for the slight decline in gasoline vehicle sales over the past decade.

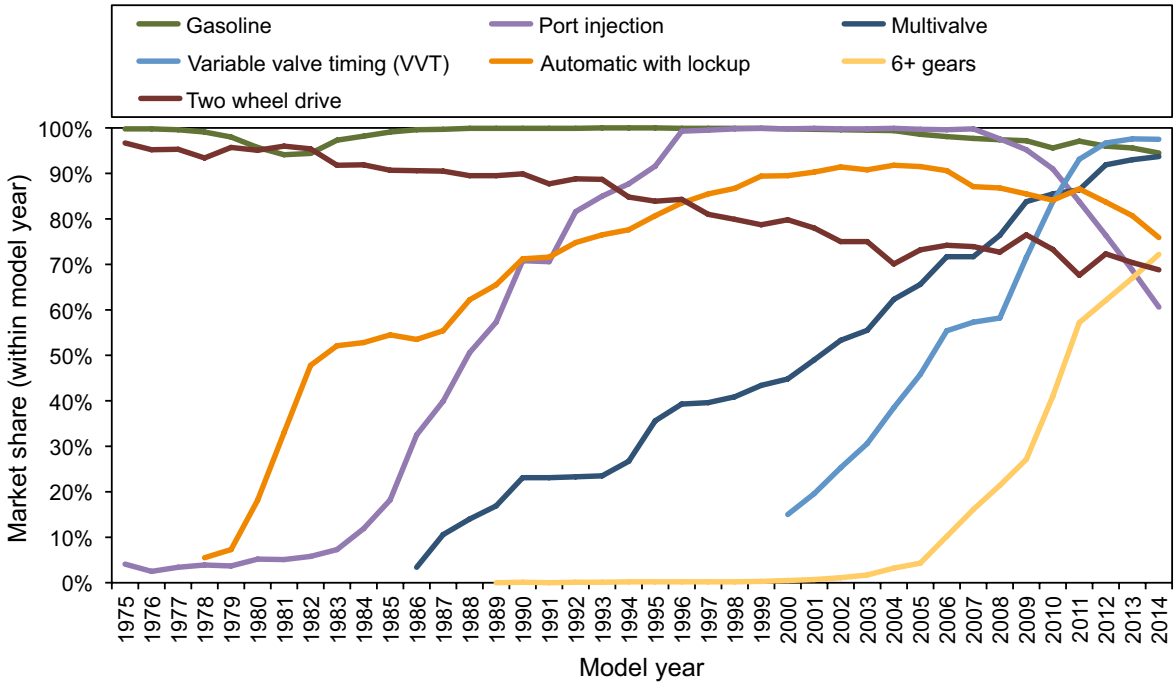


Figure 2. Market share of established fuel-saving and related technologies (greater than 50% of market share), 1975 to 2014 (EPA, 2014).

*Obsolete technologies* (Figure 3). As described in the previous section, the technologies described here were either superseded by more advanced technologies (e.g., fuel-injection methods), or changed as another, mutually exclusive technology is applied (e.g., automatic with lockup versus without lockup, manual versus automatic transmissions of either kind versus continuously variable transmissions). Carbureted engines were superseded simultaneously by throttle-body injection and port injection, with port injection eventually superseding throttle-body injection as well. Manual transmissions never held a majority of the market share during the 40 years examined, and their popularity continues to decline each year. While automatic transmissions without lockup had been replaced over the years by those with lockup due to greater fuel efficiency (from less slippage in the transmission), a new style of automatic transmission (automated manual) has emerged that is technically an automatic without lockup, but is lighter and functions more like a manual transmission by using an automatically engaged clutch. As such, these types of automatic transmissions without lockup are *more* fuel efficient than a comparable automatic transmission with lockup.

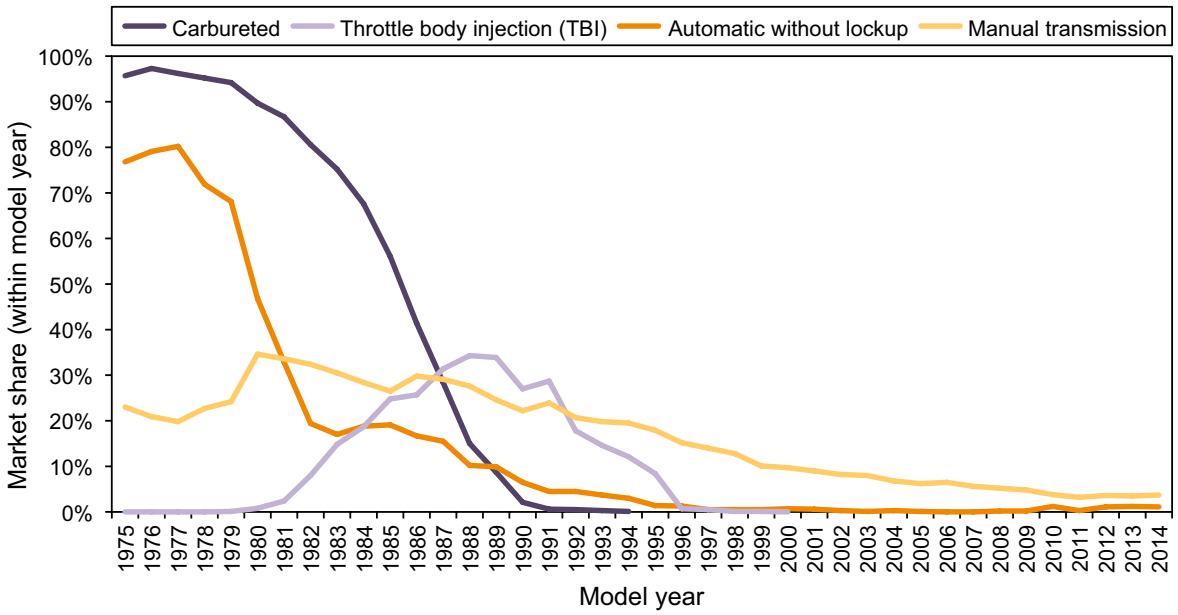


Figure 3. Market share of obsolete fuel-saving and related technologies (superseded or continuously low market share), 1975 to 2014 (EPA, 2014).

*Trends in engine size, power, and CAFE performance* (Figure 4). While the majority of the new technologies discussed here have been intended to save fuel and reduce emissions, these advanced technologies have also allowed for consistent *decreases* in engine displacement and *increases* in overall horsepower, resulting in a large increase in the ratio of horsepower to displacement, as shown in Figure 4 (top panel). Also shown in Figure 4 (bottom panel) are the corresponding CAFE performance levels over the same period. (CAFE standards were first applicable for passenger cars and light trucks in model years 1978 and 1979, respectively [NHTSA, 2002]. Consequently, CAFE data prior to those model years do not exist.)

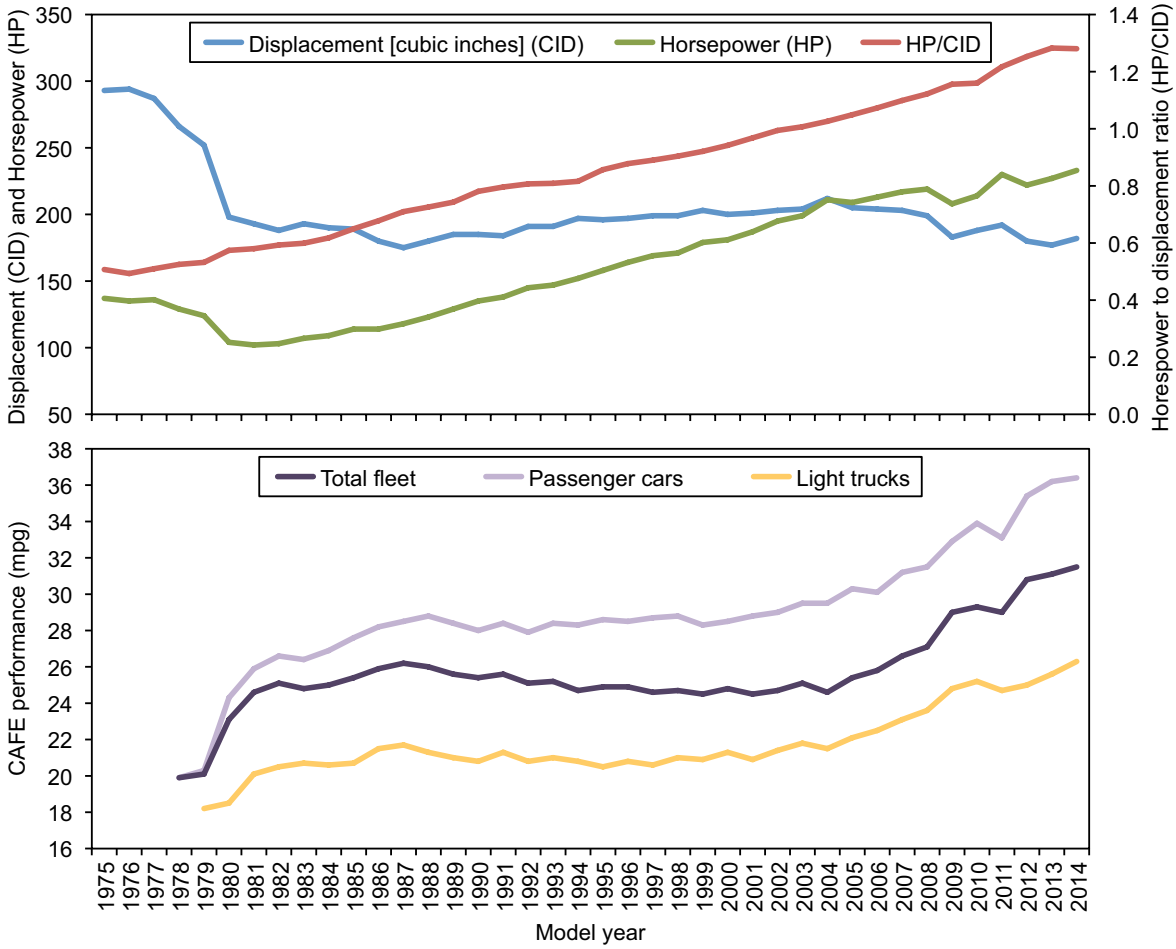


Figure 4. Top panel: Trends in engine displacement, overall horsepower, and horsepower to displacement ratio, 1975 to 2014 (EPA, 2014). Bottom panel: Trends in CAFE performance, 1978 to 2014 (NHTSA, 2014).

**Technical details and highlights of current technologies**

Detailed tables describing relevant aspects of the advanced powertrain and engine technologies are presented in Appendix A, Tables A-1 to A-5. The following aspects are detailed in each table:

a) Descriptions of each technology and the general efficiency benefit
b) Fuel-efficiency benefit (%)
c) Average implementation cost per vehicle ($)
d) Payback period (in years, based on values for b and c above)
e) Premium fuel requirement (%)
f) Descriptions of other possible advantages or disadvantages for each technology
g) Availability for model year 2015 (%)

**Selection of technologies for inclusion in the survey**

Because the purpose of the survey was to gauge consumer opinions about fuel-saving and advanced vehicle technologies, it seemed most appropriate to focus the questions on the emerging technology group. Furthermore, supercharging and twincharging technologies were added, while direct injection (due to its highly technical nature) and four-wheel drive (due to the general lack of fuel-savings) were excluded. Based on the above reasoning, and taking into consideration that the remaining emerging technologies are generally optional equipment (and thus a choice exists for the consumer to purchase or not), the final list of technologies selected for inclusion in the survey is as follows:

- Continuously variable transmissions (CVT)
- Cylinder deactivation
- Diesel engines
- Gasoline-hybrid vehicles
- Stop-start engine systems
- Supercharging
- Turbocharging
- Twincharging

# Method

## Survey instrument

An online survey was conducted using SurveyMonkey (www.surveymonkey.com), a web-based survey company. A questionnaire was developed to examine several topics related to fuel economy and advanced vehicle technologies. The text of the questionnaire is included in Appendix B. The survey was performed in April 2015.

## Respondents

SurveyMonkey's Audience tool was used to target and recruit vehicle owners (and lessees) 18 years and older from SurveyMonkey's respondent databases in the U.S. The recruitment resulted in 890 replies from potential respondents. Fully completed surveys were received for 674 respondents. The final response rate (i.e., total completed divided by total eligible, or 674/890) was 75%.

Demographic breakdowns for the respondents are presented in Table 1.

## Statistically significant demographic effects

For each question in the survey, the responses for each age group and gender were compared using one-way analysis of variance (ANOVA). In addition to reporting the overall trends, we will describe demographic trends that were found to be statistically significant at $p \leq .05$ (95% confidence level). The margin of error at the 95% confidence level for the overall results is +/- 3.8%.

Table 1
Demographic breakdown for the final 674 respondents.

| Demographic aspect | | Percent |
|---|---|---|
| Age group | 18 to 29 | 11.4 |
| | 30 to 44 | 23.0 |
| | 45 to 59 | 30.7 |
| | 60 or older | 34.9 |
| Gender | Female | 48.8 |
| | Male | 51.2 |
| Income | $0 to $24,999 | 6.6 |
| | $25,000 to $49,999 | 13.4 |
| | $50,000 to $74,999 | 15.0 |
| | $75,000 to $99,999 | 14.4 |
| | $100,000 to $124,999 | 11.1 |
| | $125,000 to $149,999 | 5.9 |
| | $150,000 to $174,999 | 6.5 |
| | $175,000 to $199,999 | 3.1 |
| | $200,000 or more | 9.6 |
| | Prefer not to answer | 14.2 |
| U.S. region | New England | 6.7 |
| | Middle Atlantic | 12.4 |
| | North Central | 20.4 |
| | South Atlantic | 17.2 |
| | South Central | 11.0 |
| | Mountain | 10.8 |
| | Pacific | 21.4 |
| Vehicle owned or leased | Owned | 95.7 |
| | Leased | 4.3 |

# Results

## Importance of fuel economy

Nearly all respondents said that fuel economy was important to them when deciding what vehicle to purchase. (Overall, only 2.1% said that fuel economy was not at all important to them.) Figure 5 summarizes the results for all respondents, while Table 2 presents a complete summary of responses by gender and age.

Females rated the importance of fuel economy higher than males did, with 56.2% saying it was very important, compared with 42.3% of males. Furthermore, males were five times more likely to say that fuel economy was not at all important (3.5% versus 0.6%).

There was also an age effect, as the three younger age groups were all more likely to say that fuel economy was very important compared with the oldest group. The youngest drivers were also less likely to say that it was not at all important compared with the oldest drivers (0.0% versus 3.8%).

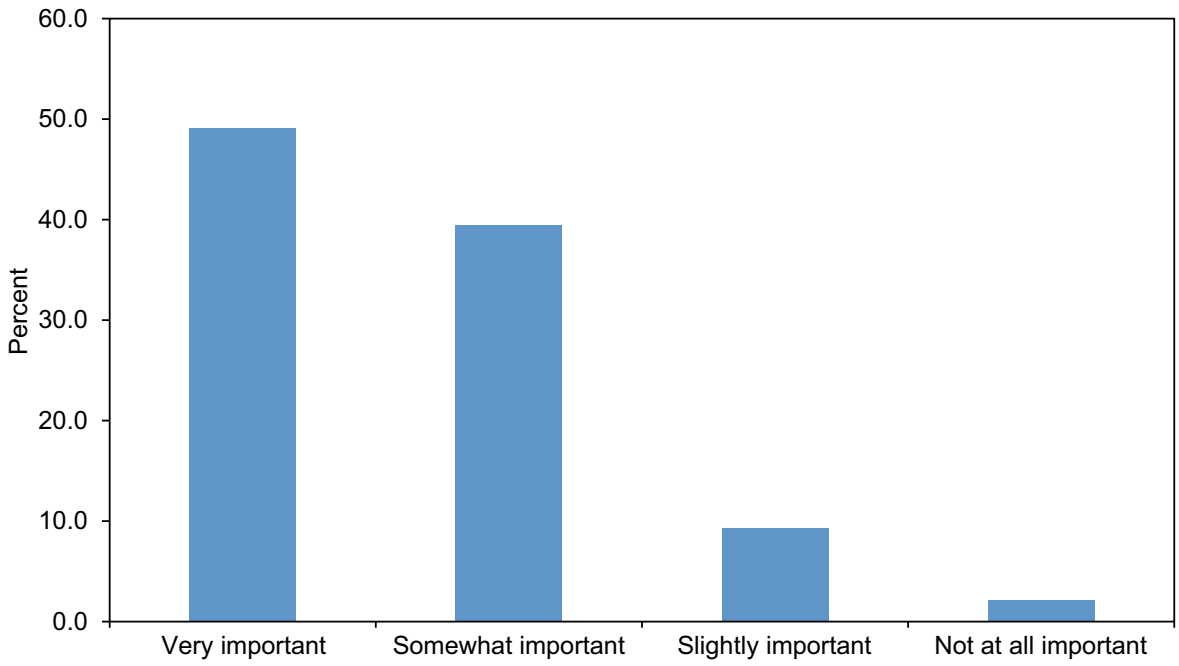


Figure 5. Summary of responses to Q2: "*How important is fuel economy to you when deciding what vehicle to own or lease?*"

Table 2
Percentage of responses, by gender and age, to Q2:
"*How important is fuel economy to you when deciding what vehicle to own or lease?*"

| Response | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| Very important | 56.2 | 42.3 | 54.5 | 56.1 | 52.7 | 39.6 | *49.1* |
| Somewhat important | 35.9 | 42.9 | 40.3 | 34.8 | 38.6 | 43.0 | *39.5* |
| Slightly important | 7.3 | 11.3 | 5.2 | 6.5 | 8.2 | 13.6 | *9.3* |
| Not at all important | 0.6 | 3.5 | 0.0 | 2.6 | 0.5 | 3.8 | *2.1* |

**Preferred source of fuel savings and emissions reductions**

The majority of respondents said that it does not matter to them how a vehicle saves fuel and reduces emissions (51.8%). However, engine improvements (23.9%) and alternative fuels (20.2%) were the most common responses for those who do have a preference. Figure 6 summarizes the results for all respondents, while Table 3 presents a complete summary of responses by gender and age.

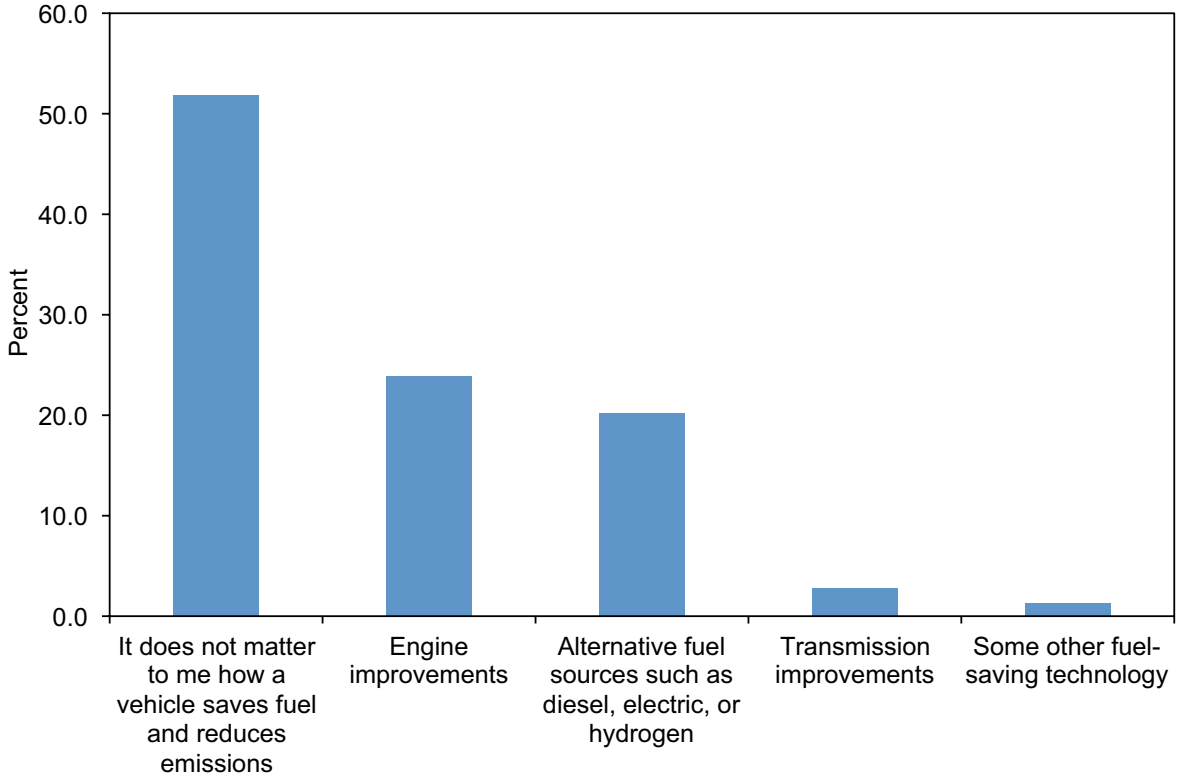


Figure 6. Summary of responses to Q3: "*I prefer fuel savings and emissions reductions to come from…*"

Table 3
Percentage of responses, by gender and age, to Q3:
"*I prefer fuel savings and emissions reductions to come from…*"

| Response | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| It does not matter to me how a vehicle saves fuel and reduces emissions | 53.5 | 50.1 | 51.9 | 56.8 | 52.2 | 48.1 | *51.8* |
| Engine improvements | 21.6 | 26.1 | 19.5 | 16.1 | 24.2 | 30.2 | *23.9* |
| Alternative fuel sources such as diesel, electric, or hydrogen | 20.4 | 20.0 | 24.7 | 22.6 | 20.8 | 16.6 | *20.2* |
| Transmission improvements | 3.3 | 2.3 | 2.6 | 1.9 | 2.4 | 3.8 | *2.8* |
| Some other fuel-saving technology | 1.2 | 1.4 | 1.3 | 2.6 | 0.5 | 1.3 | *1.3* |

**Likelihood of owning a vehicle that requires premium fuel**

A large majority (72.6%) said that they would be less likely to own or lease a vehicle that requires premium fuel. Figure 7 summarizes the results for all respondents, while Table 4 presents a complete summary of responses by gender and age.

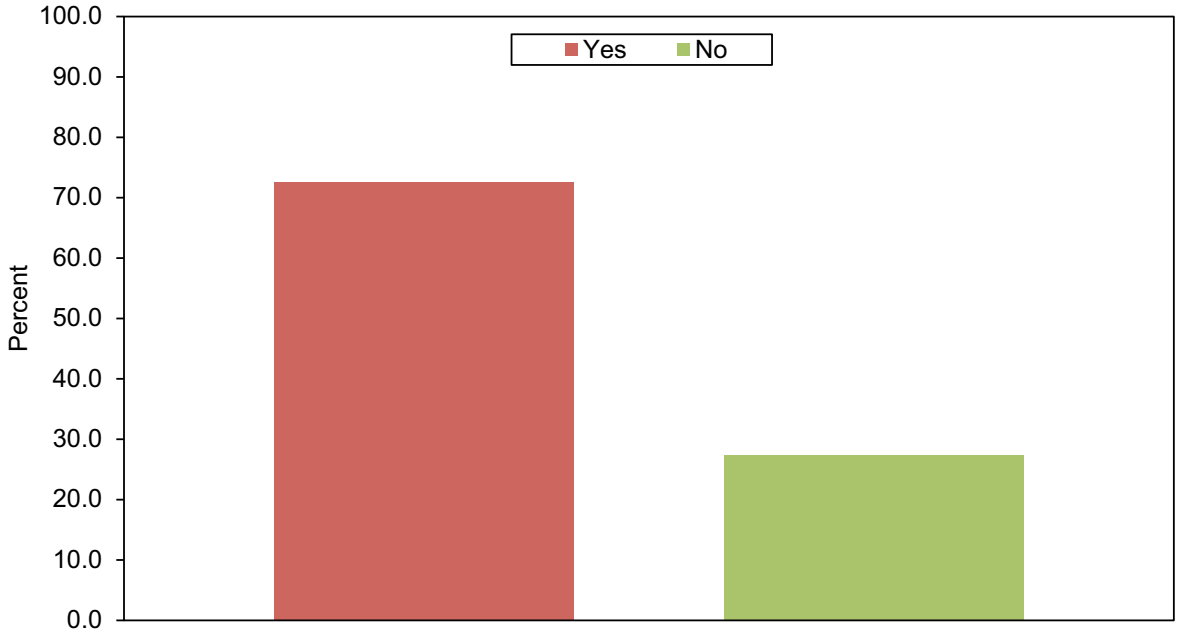


Figure 7. Summary of responses to Q4: "*Would you be less likely to own or lease a vehicle if it were required to use premium fuel?*"

Table 4
Percentage of responses, by gender and age, to Q4:
"*Would you be less likely to own or lease a vehicle if it were required to use premium fuel?*"

| Response | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| Yes | 70.5 | 74.5 | 77.9 | 71.0 | 73.4 | 71.1 | *72.6* |
| No | 29.5 | 25.5 | 22.1 | 29.0 | 26.6 | 28.9 | *27.4* |

**Knowledge of advanced vehicle technologies**

Knowledge of advanced vehicle technologies varied considerably, depending on the technology in question. A majority of people felt that they basically understand how diesel engines and gasoline-hybrid vehicles work (89.9% and 89.5%, respectively). On the other hand, a majority of people said that they had never heard of twincharging (65.7%), cylinder deactivation (59.6%), or continuously variable transmissions (50.3%). Figure 8 summarizes the results for all respondents, while Table 5 presents a complete summary of responses by gender and age.

Males expressed greater knowledge of advanced vehicle technologies compared with females. (This was even the case for technologies that both genders expressed familiarity with, such as diesel engines and gasoline-hybrid vehicles.)

Older respondents were more likely to say they were more knowledgeable about these technologies than younger respondents. The largest differences between the oldest and youngest age groups in understanding how a technology works were observed for cylinder deactivation, diesel engines, supercharging, and turbocharging.

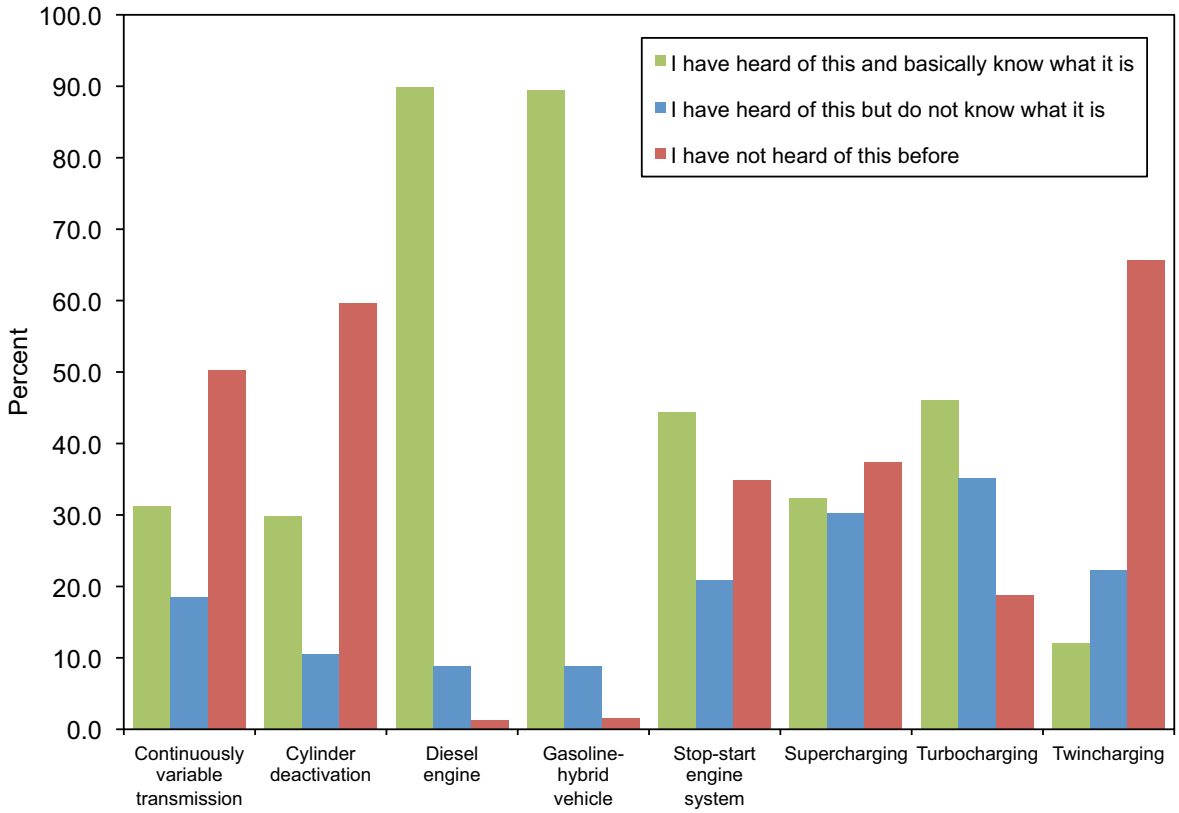


Figure 8. Summary of responses to Q5: "*Have you ever heard of the following advanced fuel-saving vehicle technologies?*"

Table 5
Percentage of responses, by gender and age, to Q5:
"*Have you ever heard of the following advanced fuel-saving vehicle technologies?*"

| Technology | Response | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|---|
| | | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| Continuously variable transmission | I have heard of this and basically know what it is | 16.4 | 45.2 | 24.7 | 32.9 | 24.6 | 37.9 | *31.2* |
| | I have heard of this but do not know what it is | 21.0 | 16.2 | 24.7 | 20.0 | 17.4 | 16.6 | *18.5* |
| | I have not heard of this before | 62.6 | 38.6 | 50.6 | 47.1 | 58.0 | 45.5 | *50.3* |
| Cylinder deactivation | I have heard of this and basically know what it is | 7.6 | 51.0 | 15.6 | 29.0 | 20.3 | 43.4 | *29.8* |
| | I have heard of this but do not know what it is | 11.6 | 9.6 | 10.4 | 11.0 | 9.7 | 11.1 | *10.5* |
| | I have not heard of this before | 80.9 | 39.4 | 74.0 | 60.0 | 70.0 | 45.5 | *59.6* |
| Diesel engine | I have heard of this and basically know what it is | 83.6 | 95.9 | 76.6 | 87.7 | 89.9 | 95.7 | *89.9* |
| | I have heard of this but do not know what it is | 14.3 | 3.8 | 20.8 | 11.0 | 8.7 | 3.8 | *8.9* |
| | I have not heard of this before | 2.1 | 0.3 | 2.6 | 1.3 | 1.4 | 0.4 | *1.2* |
| Gasoline-hybrid vehicle | I have heard of this and basically know what it is | 85.1 | 93.6 | 87.0 | 88.4 | 89.9 | 90.6 | *89.5* |
| | I have heard of this but do not know what it is | 12.8 | 5.2 | 10.4 | 10.3 | 8.7 | 7.7 | *8.9* |
| | I have not heard of this before | 2.1 | 1.2 | 2.6 | 1.3 | 1.4 | 1.7 | *1.6* |
| Stop-start engine system | I have heard of this and basically know what it is | 27.1 | 60.9 | 41.6 | 48.4 | 38.2 | 48.1 | *44.4* |
| | I have heard of this but do not know what it is | 25.2 | 16.5 | 27.3 | 17.4 | 20.0 | 20.8 | *20.8* |
| | I have not heard of this before | 47.7 | 22.6 | 31.2 | 28.4 | 44.4 | 31.9 | *34.9* |
| Supercharging | I have heard of this and basically know what it is | 11.9 | 51.9 | 18.2 | 30.3 | 25.1 | 44.7 | *32.3* |
| | I have heard of this but do not know what it is | 33.4 | 27.2 | 40.3 | 32.3 | 29.5 | 26.4 | *30.3* |
| | I have not heard of this before | 54.7 | 20.9 | 41.6 | 37.4 | 45.4 | 28.9 | *37.4* |
| Turbocharging | I have heard of this and basically know what it is | 24.0 | 67.0 | 22.1 | 38.7 | 44.9 | 59.6 | *46.0* |
| | I have heard of this but do not know what it is | 45.9 | 24.9 | 51.9 | 38.7 | 34.8 | 27.7 | *35.2* |
| | I have not heard of this before | 30.1 | 8.1 | 26.0 | 22.6 | 20.3 | 12.8 | *18.8* |
| Twincharging | I have heard of this and basically know what it is | 4.6 | 19.1 | 9.1 | 15.5 | 9.2 | 13.2 | *12.0* |
| | I have heard of this but do not know what it is | 20.4 | 24.1 | 26.0 | 29.0 | 19.8 | 18.7 | *22.3* |
| | I have not heard of this before | 75.1 | 56.8 | 64.9 | 55.5 | 71.0 | 68.1 | *65.7* |

**General opinion of advanced vehicle technologies**

A majority felt positively (either very or somewhat) about these technologies, with the exception of continuously variable transmissions (48.2% said very or somewhat positive). The technology with the most negative ratings was stop-start engine systems (17.3% said very or somewhat negative). Figure 9 summarizes the results for all respondents, while Table 6 presents a complete summary of responses by gender and age.

Males generally held more extreme views (both positive and negative) while females tended to have more neutral feelings about these technologies, with the exception of gasoline-hybrid vehicles (males were slightly more neutral about this technology). The largest differences between the genders related to opinions about the three boosting (i.e., forced induction) technologies (superchargers, turbochargers, and twinchargers).

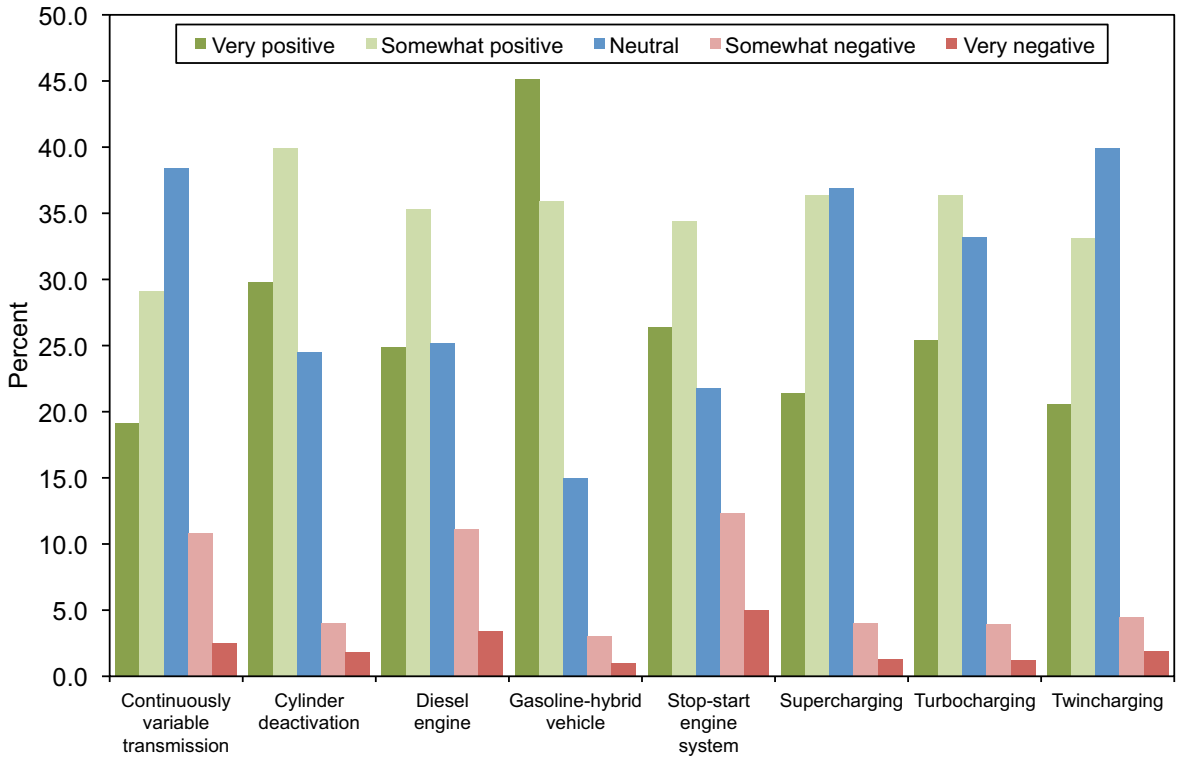


Figure 9. Summary of responses to Q6: "*What is your general opinion about the following technologies?*"

Table 6
Percentage of responses, by gender and age, to Q6:
"*What is your general opinion about the following technologies?*"

| Technology | Response | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|---|
| | | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| Continuously variable transmission | Very positive | 16.1 | 22.0 | 15.6 | 18.7 | 18.4 | 21.3 | *19.1* |
| | Somewhat positive | 25.2 | 32.8 | 36.4 | 27.7 | 26.6 | 29.8 | *29.1* |
| | Neutral | 48.9 | 28.4 | 45.5 | 39.4 | 43.0 | 31.5 | *38.4* |
| | Somewhat negative | 7.9 | 13.6 | 2.6 | 11.6 | 10.6 | 13.2 | *10.8* |
| | Very negative | 1.8 | 3.2 | 0.0 | 2.6 | 1.4 | 4.3 | *2.5* |
| Cylinder deactivation | Very positive | 25.8 | 33.6 | 16.9 | 36.8 | 30.0 | 29.4 | *29.8* |
| | Somewhat positive | 41.0 | 38.8 | 51.9 | 33.5 | 41.1 | 39.1 | *39.9* |
| | Neutral | 29.5 | 19.7 | 29.9 | 23.9 | 23.2 | 24.3 | *24.5* |
| | Somewhat negative | 2.7 | 5.2 | 1.3 | 5.2 | 4.8 | 3.4 | *4.0* |
| | Very negative | 0.9 | 2.6 | 0.0 | 0.6 | 1.0 | 3.8 | *1.8* |
| Diesel engine | Very positive | 20.1 | 29.6 | 11.7 | 31.6 | 25.6 | 24.3 | *24.9* |
| | Somewhat positive | 36.5 | 34.2 | 50.6 | 36.8 | 29.0 | 34.9 | *35.3* |
| | Neutral | 27.4 | 23.2 | 22.1 | 18.1 | 32.4 | 24.7 | *25.2* |
| | Somewhat negative | 12.8 | 9.6 | 13.0 | 9.7 | 9.7 | 12.8 | *11.1* |
| | Very negative | 3.3 | 3.5 | 2.6 | 3.9 | 3.4 | 3.4 | *3.4* |
| Gasoline-hybrid vehicle | Very positive | 48.3 | 42.0 | 36.4 | 47.7 | 45.9 | 45.5 | *45.1* |
| | Somewhat positive | 36.5 | 35.4 | 50.6 | 32.3 | 34.3 | 34.9 | *35.9* |
| | Neutral | 13.1 | 16.8 | 11.7 | 16.1 | 15.5 | 14.9 | *15.0* |
| | Somewhat negative | 1.2 | 4.6 | 1.3 | 3.2 | 2.9 | 3.4 | *3.0* |
| | Very negative | 0.9 | 1.2 | 0.0 | 0.6 | 1.4 | 1.3 | *1.0* |
| Stop-start engine system | Very positive | 29.5 | 23.5 | 32.5 | 32.3 | 23.2 | 23.4 | *26.4* |
| | Somewhat positive | 33.1 | 35.7 | 35.1 | 38.7 | 31.9 | 33.6 | *34.4* |
| | Neutral | 23.4 | 20.3 | 18.2 | 19.4 | 27.1 | 20.0 | *21.8* |
| | Somewhat negative | 9.1 | 15.4 | 11.7 | 5.8 | 14.5 | 14.9 | *12.3* |
| | Very negative | 4.9 | 5.2 | 2.6 | 3.9 | 3.4 | 8.1 | *5.0* |
| Supercharging | Very positive | 16.1 | 26.4 | 7.8 | 27.7 | 19.8 | 23.0 | *21.4* |
| | Somewhat positive | 32.2 | 40.3 | 44.2 | 27.7 | 38.6 | 37.4 | *36.4* |
| | Neutral | 45.3 | 29.0 | 41.6 | 40.0 | 37.2 | 33.2 | *36.9* |
| | Somewhat negative | 4.6 | 3.5 | 5.2 | 3.2 | 4.3 | 3.8 | *4.0* |
| | Very negative | 1.8 | 0.9 | 1.3 | 1.3 | 0.0 | 2.6 | *1.3* |
| Turbocharging | Very positive | 16.7 | 25.8 | 7.8 | 28.4 | 20.3 | 33.6 | *25.4* |
| | Somewhat positive | 34.3 | 35.1 | 41.6 | 29.0 | 43.0 | 33.6 | *36.4* |
| | Neutral | 43.5 | 33.0 | 44.2 | 38.7 | 31.9 | 27.2 | *33.2* |
| | Somewhat negative | 3.6 | 4.9 | 6.5 | 3.2 | 3.9 | 3.4 | *3.9* |
| | Very negative | 1.8 | 1.2 | 0.0 | 0.6 | 1.0 | 2.1 | *1.2* |
| Twincharging | Very positive | 15.2 | 25.8 | 3.9 | 28.4 | 17.4 | 23.8 | *20.6* |
| | Somewhat positive | 31.0 | 35.1 | 41.6 | 25.8 | 38.6 | 30.2 | *33.1* |
| | Neutral | 47.1 | 33.0 | 49.4 | 39.4 | 38.6 | 38.3 | *39.9* |
| | Somewhat negative | 4.0 | 4.9 | 5.2 | 5.2 | 4.8 | 3.4 | *4.5* |
| | Very negative | 2.7 | 1.2 | 0.0 | 1.3 | 0.5 | 4.3 | *1.9* |

**Knowledge of advanced vehicle technologies on their personal vehicle**

For most technologies, the vast majority of respondents knew (or claimed to know) whether their vehicle had such technologies or not. Respondents were most likely to report having continuously variable transmissions (9.6%), yet were also most likely to not know if their vehicle had this technology (19.4%). Twincharging was the least likely technology for respondents to affirmatively report having on their vehicle (0.6%), while diesel engines were most likely to be confirmed as not being present on the vehicle (90.7%). Figure 10 summarizes the results for all respondents, while Table 7 presents a complete summary of responses by gender and age.

Females were more likely to report not knowing if a specific technology was present on their vehicle.

Similarly, younger respondents were also more likely to report not knowing if a specific technology was present on their vehicle, and the likelihood of not knowing decreased markedly as respondent age increased.

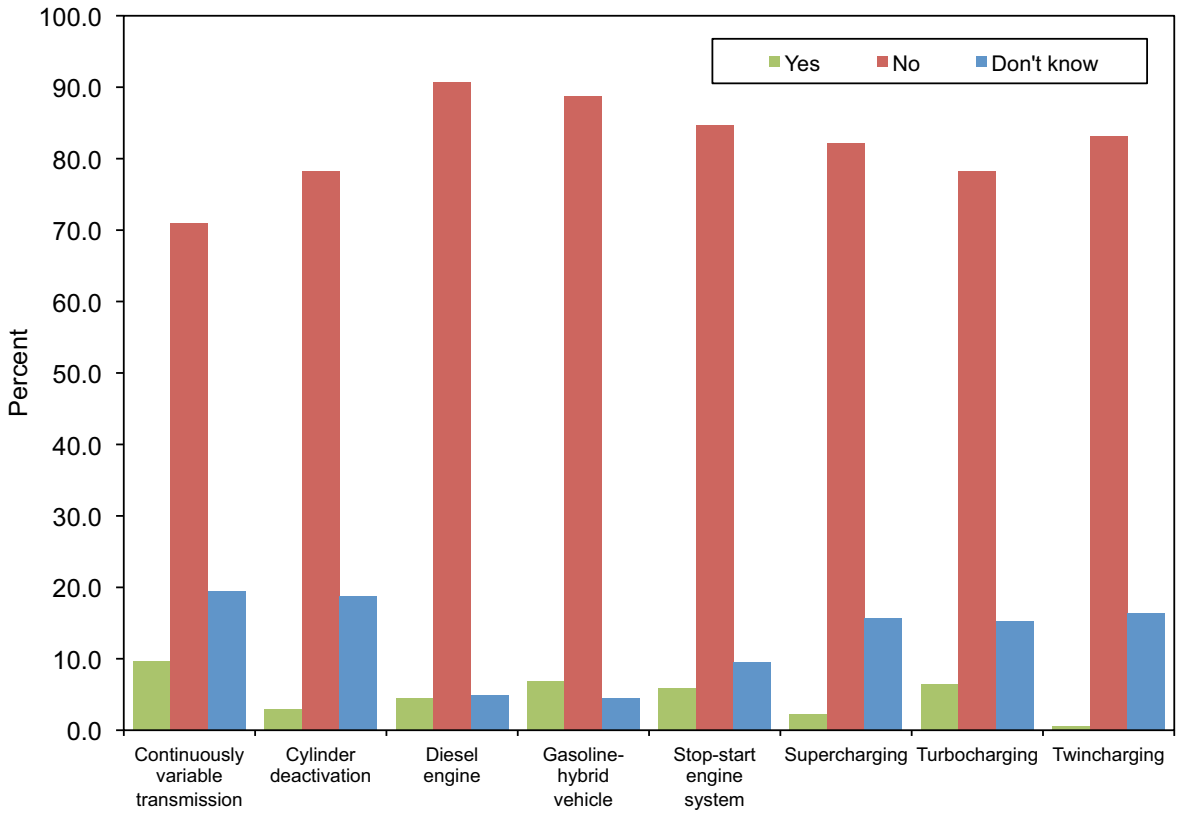


Figure 10. Summary of responses to Q7: "*Do you know if the vehicle you drive most often has any of the following advanced fuel-saving vehicle technologies?*"

Table 7
Percentage of responses, by gender and age, to Q7:
"*Do you know if the vehicle you drive most often has any of the following advanced fuel-saving vehicle technologies?*"

| Technology | Response | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|---|
| | | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| Continuously variable transmission | Yes | 6.4 | 12.8 | 14.3 | 7.7 | 8.2 | 10.6 | *9.6* |
| | No | 63.2 | 78.3 | 49.4 | 72.3 | 70.5 | 77.4 | *70.9* |
| | Don't know | 30.4 | 9.0 | 36.4 | 20.0 | 21.3 | 11.9 | *19.4* |
| Cylinder deactivation | Yes | 1.8 | 4.1 | 1.3 | 0.0 | 5.3 | 3.4 | *3.0* |
| | No | 69.0 | 87.0 | 59.7 | 81.3 | 76.3 | 83.8 | *78.2* |
| | Don't know | 29.2 | 9.0 | 39.0 | 18.7 | 18.4 | 12.8 | *18.8* |
| Diesel engine | Yes | 3.3 | 5.5 | 2.6 | 7.1 | 3.4 | 4.3 | *4.5* |
| | No | 88.1 | 93.0 | 87.0 | 87.7 | 91.8 | 92.8 | *90.7* |
| | Don't know | 8.5 | 1.4 | 10.4 | 5.2 | 4.8 | 3.0 | *4.9* |
| Gasoline-hybrid vehicle | Yes | 5.2 | 8.4 | 3.9 | 5.8 | 7.7 | 7.7 | *6.8* |
| | No | 86.9 | 90.4 | 87.0 | 89.0 | 88.4 | 89.4 | *88.7* |
| | Don't know | 7.9 | 1.2 | 9.1 | 5.2 | 3.9 | 3.0 | *4.5* |
| Stop-start engine system | Yes | 3.6 | 8.1 | 3.9 | 5.2 | 4.8 | 8.1 | *5.9* |
| | No | 80.2 | 88.7 | 76.6 | 85.8 | 85.0 | 86.0 | *84.6* |
| | Don't know | 16.1 | 3.2 | 19.5 | 9.0 | 10.1 | 6.0 | *9.5* |
| Supercharging | Yes | 0.6 | 3.8 | 3.9 | 2.6 | 1.4 | 2.1 | *2.2* |
| | No | 73.9 | 90.1 | 61.0 | 79.4 | 82.1 | 91.1 | *82.2* |
| | Don't know | 25.5 | 6.1 | 35.1 | 18.1 | 16.4 | 6.8 | *15.6* |
| Turbocharging | Yes | 4.0 | 8.7 | 1.3 | 9.0 | 5.3 | 7.2 | *6.4* |
| | No | 71.1 | 85.2 | 64.9 | 72.9 | 78.7 | 86.0 | *78.3* |
| | Don't know | 24.9 | 6.1 | 33.8 | 18.1 | 15.9 | 6.8 | *15.3* |
| Twincharging | Yes | 0.3 | 0.9 | 1.3 | 0.0 | 1.4 | 0.0 | *0.6* |
| | No | 73.6 | 92.2 | 64.9 | 82.6 | 81.2 | 91.1 | *83.1* |
| | Don't know | 26.1 | 7.0 | 33.8 | 17.4 | 17.4 | 8.9 | *16.3* |

**Preference for advanced vehicle technologies**

Respondents were asked to rank (forced rank) their preference for each advanced vehicle technology at two different gasoline prices: $2.50/gallon and $5.00/gallon (1 = most-preferred technology, 8 = least-preferred technology). At both prices, gasoline-hybrid vehicles were the most preferred technology, while twincharging was rated as the least preferred. Figure 11 summarizes the results for all respondents, while Tables 8 and 9 present complete summaries of responses by gender and age.

Males (and all respondents overall) rated continuously variable transmissions and cylinder deactivation as their second and third choices (although in reverse order at the higher gasoline price). However, females rated stop-start engine systems as their third choice at the lower gasoline price, and their second choice at the higher gasoline price.

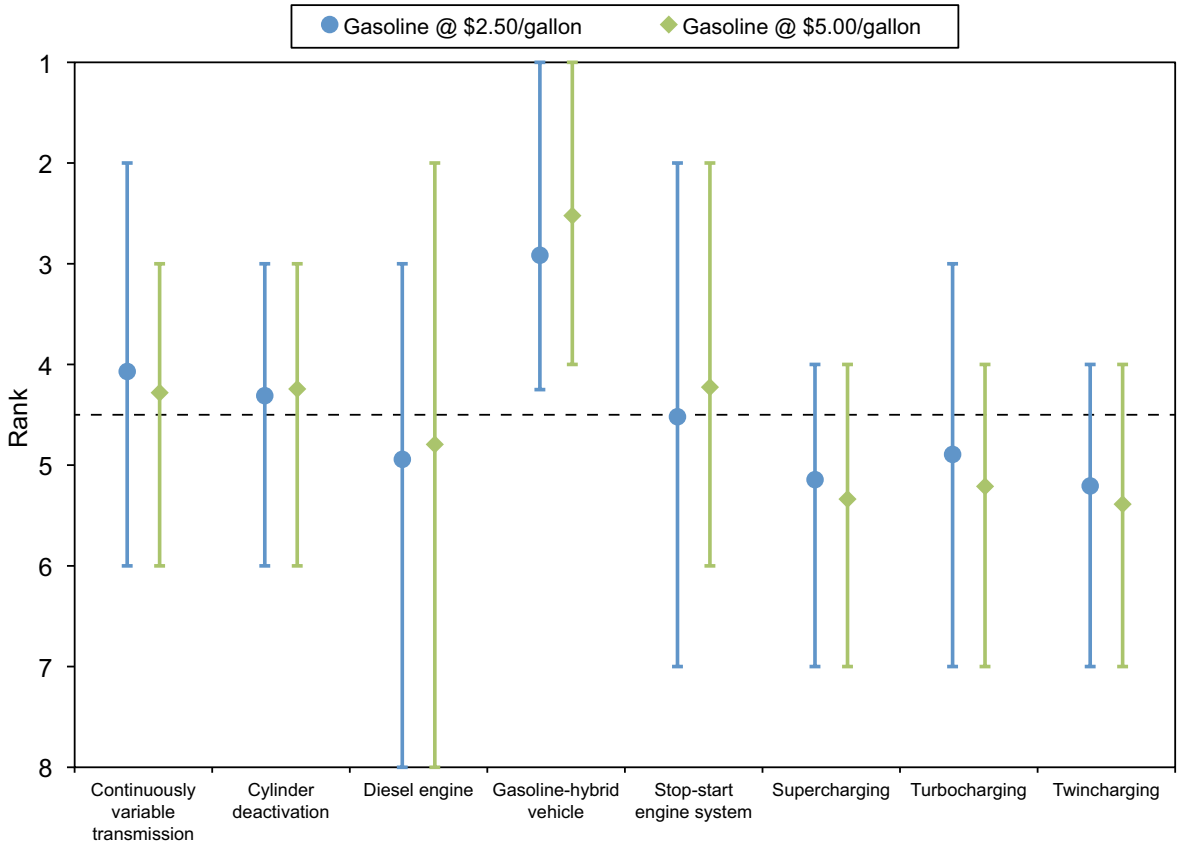


Figure 11. Combined summary of responses to Q8 and Q9: "*Please rank your preference for having the following fuel-efficient technologies on your personal vehicle if the price of gasoline were $2.50 per gallon (Q8) or $5.00 per gallon (Q9).*" The symbols mark the average rank for each technology, while the error bars show the span between the 25th- and 75th-percentiles. The dashed line indicates the midpoint (4.5) in the rankings.

Table 8
Average ranking, by gender and age, for Q8: "*Please rank your preference for having the following fuel-efficient technologies on your personal vehicle if the price of gasoline were $2.50 per gallon."* (1 = most-preferred technology, 8 = least-preferred technology; the highest ranking technology for each column is shown in **bold**.)

| Technology | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| Continuously variable transmission | 3.9 | 4.2 | 3.9 | 4.4 | 3.9 | 4.1 | *4.1* |
| Cylinder deactivation | 4.3 | 4.3 | 4.2 | 4.2 | 4.4 | 4.3 | *4.3* |
| Diesel engine | 5.1 | 4.8 | 5.0 | 4.5 | 5.2 | 5.0 | *4.9* |
| Gasoline-hybrid vehicle | **2.6** | **3.2** | **2.7** | **3.1** | **2.7** | **3.1** | ***2.9*** |
| Stop-start engine system | 4.2 | 4.8 | 4.5 | 4.2 | 4.6 | 4.6 | *4.5* |
| Supercharging | 5.4 | 4.9 | 5.2 | 5.3 | 5.2 | 5.0 | *5.1* |
| Turbocharging | 5.2 | 4.6 | 5.4 | 5.1 | 4.9 | 4.6 | *4.9* |
| Twincharging | 5.3 | 5.2 | 5.1 | 5.3 | 5.1 | 5.2 | *5.2* |

Table 9
Average ranking, by gender and age, for Q9: "*Please rank your preference for having the following fuel-efficient technologies on your personal vehicle if the price of gasoline were $5.00 per gallon."* (1 = most-preferred technology, 8 = least-preferred technology; the highest ranking technology for each column is shown in **bold**.)

| Technology | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| Continuously variable transmission | 4.2 | 4.4 | 4.3 | 4.5 | 4.1 | 4.3 | *4.3* |
| Cylinder deactivation | 4.4 | 4.1 | 4.5 | 4.0 | 4.2 | 4.3 | *4.2* |
| Diesel engine | 5.0 | 4.6 | 5.0 | 4.5 | 4.9 | 4.9 | *4.8* |
| Gasoline-hybrid vehicle | **2.3** | **2.7** | **2.7** | **2.7** | **2.3** | **2.5** | ***2.5*** |
| Stop-start engine system | 4.0 | 4.5 | 4.2 | 4.1 | 4.2 | 4.3 | *4.2* |
| Supercharging | 5.4 | 5.3 | 5.3 | 5.4 | 5.4 | 5.2 | *5.3* |
| Turbocharging | 5.3 | 5.1 | 5.0 | 5.4 | 5.4 | 5.0 | *5.2* |
| Twincharging | 5.3 | 5.4 | 5.0 | 5.4 | 5.4 | 5.5 | *5.4* |

**Perceived disadvantages of advanced vehicle technologies**

Respondents were asked to list (in an open-ended question) any major disadvantages with these advanced vehicle technologies that they were aware of. The majority of respondents said that they were unaware of any major disadvantages (73.1%). The technology with the most specific mentions for having a major disadvantage related to "dirty or smelly emissions for diesel engines" (4.6%). Figure 12 summarizes the results for all respondents, while Table 10 presents a complete summary of responses by gender and age.

Females were more likely than males to say they were not aware of any major disadvantages (80.9% versus 65.8%, respectively).

Similarly, younger respondents were more likely than older respondents to say they were not aware of any major disadvantages.

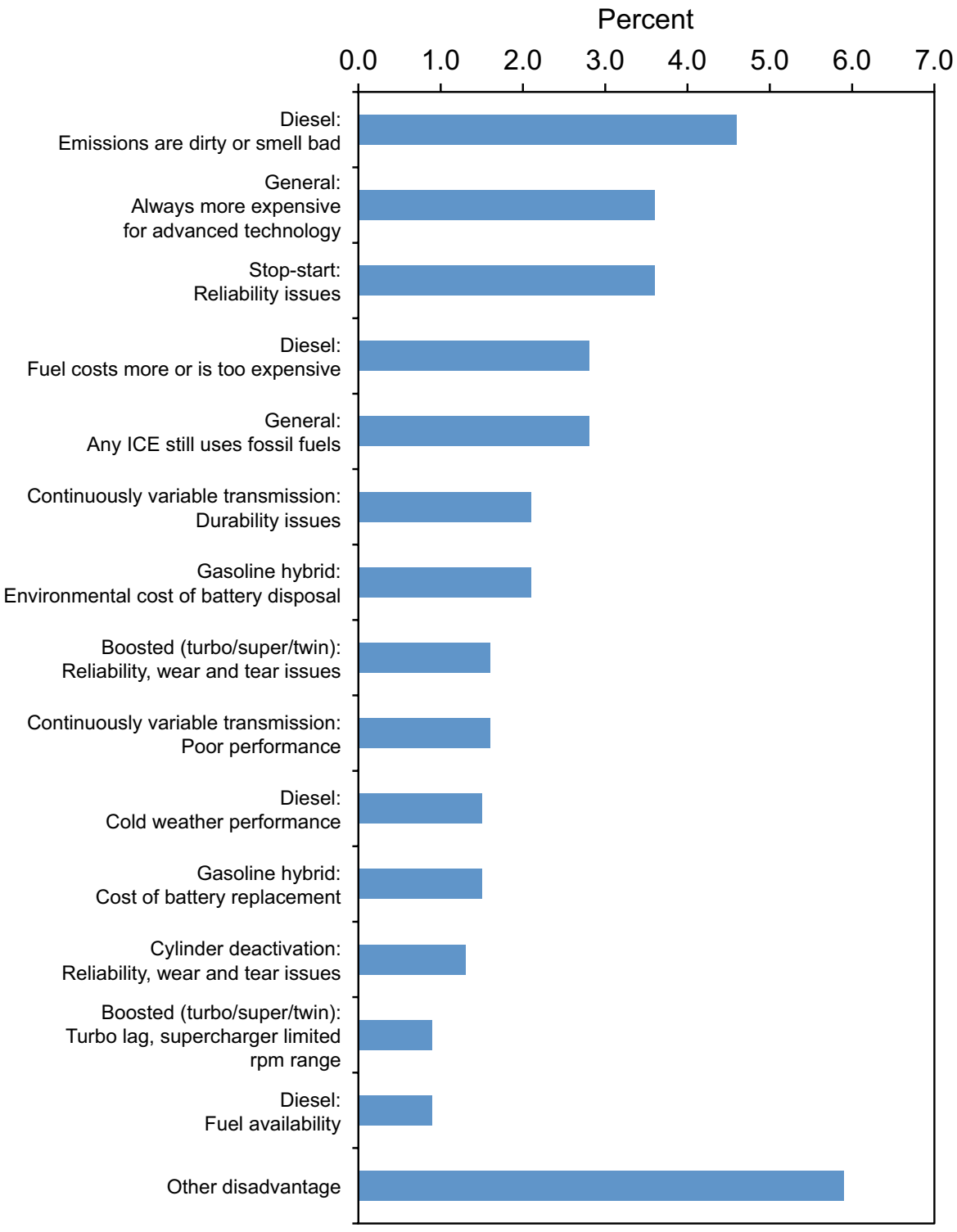


Figure 12. Summary of responses to Q10: "*Are there any major disadvantages associated with any of these fuel-efficient technologies that you are aware of?*" (Only those mentioning a major disadvantage are summarized in this figure.)

Table 10
Percentage of responses, by gender and age, to Q10:
"*Are there any major disadvantages associated with any of these fuel-efficient technologies that you are aware of?*" (Percentages sum to more than 100 because selection of more than one response was allowed.)

| Response | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| No major disadvantages | 80.9 | 65.8 | 77.9 | 76.8 | 74.4 | 68.1 | *73.1* |
| Diesel: Emissions are dirty or smell bad | 4.9 | 4.3 | 3.9 | 1.3 | 6.8 | 5.1 | *4.6* |
| General: Always more expensive for advanced technologies | 1.8 | 5.2 | 3.9 | 1.3 | 4.3 | 4.3 | *3.6* |
| Stop-start: Reliability issues | 3.6 | 3.5 | 0.0 | 1.9 | 5.3 | 4.3 | *3.6* |
| Diesel: Fuel costs more or is too expensive | 1.2 | 4.3 | 1.3 | 1.3 | 2.4 | 4.7 | *2.8* |
| General: Any ICE still uses fossil fuels | 2.4 | 3.2 | 3.9 | 5.2 | 2.4 | 1.3 | *2.8* |
| Continuously variable transmission: Durability issues | 1.2 | 2.9 | 0.0 | 1.3 | 1.0 | 4.3 | *2.1* |
| Gasoline hybrid: Environmental cost of battery disposal | 1.5 | 2.6 | 1.3 | 3.9 | 2.9 | 0.4 | *2.1* |
| Boosted (turbo/super/twin): Reliability, wear and tear issues | 0.3 | 2.9 | 2.6 | 0.0 | 1.4 | 2.6 | *1.6* |
| Continuously variable transmission: Poor performance | 0.3 | 2.9 | 0.0 | 1.3 | 1.4 | 2.6 | *1.6* |
| Diesel: Cold weather performance | 1.2 | 1.7 | 0.0 | 0.0 | 2.4 | 2.1 | *1.5* |
| Gasoline hybrid: Cost of battery replacement | 1.5 | 1.4 | 0.0 | 0.6 | 1.9 | 2.1 | *1.5* |
| Cylinder deactivation: Reliability, wear and tear issues | 1.2 | 1.4 | 0.0 | 0.0 | 1.9 | 2.1 | *1.3* |
| Boosted (turbo/super/twin): Turbo lag, supercharger limited rpm range | 0.0 | 1.7 | 0.0 | 0.6 | 1.0 | 1.3 | *0.9* |
| Diesel: Fuel availability | 0.6 | 1.2 | 0.0 | 0.6 | 1.0 | 1.3 | *0.9* |
| Other disadvantage | 4.9 | 7.0 | 7.8 | 7.1 | 3.9 | 6.4 | *5.9* |

**Willingness to pay for improved fuel economy**

As expected, willingness to pay for improved fuel economy was directly related to the magnitude of the improvement. Whereas $1,000 was the 90$^{th}$ percentile amount for a 5% improvement, it was the 75$^{th}$ percentile for a 10% improvement, and the 50$^{th}$ percentile (median) for a 25% improvement. Furthermore, the percentage of those unwilling to pay anything for a 5% improvement (58.0%) is reduced to half for a 25% improvement (29.2%). Table 11 presents a complete summary of responses by gender and age.

Willingness to pay for improved fuel economy peaks in the 30-44 year-old age group. Although a larger percentage of the youngest respondents were willing to pay some amount (> $0) for such technologies, the 30-44 year-old age group was consistently willing to pay the most, with amounts decreasing as ages get younger and older.

Table 11
Percentage of responses, by gender and age, to Q11:
"*How much EXTRA would you be willing to pay above the normal cost of a vehicle to achieve the following levels of improvement in fuel economy?*"

| Improvement | Measure | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|---|
| | | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| 5% | 10th percentile | $0 | $0 | $0 | $0 | $0 | $0 | *$0* |
| | 25th percentile | $0 | $0 | $0 | $0 | $0 | $0 | *$0* |
| | 50th percentile (median) | $0 | $0 | $1 | $0 | $0 | $0 | *$0* |
| | 75th percentile | $450 | $300 | $500 | $500 | $250 | $200 | *$300* |
| | 90th percentile | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 | *$1,000* |
| | Percent responding $0 | 59.6% | 56.5% | 46.8% | 52.3% | 61.8% | 62.1% | *58.0%* |
| 10% | 10th percentile | $0 | $0 | $0 | $0 | $0 | $0 | *$0* |
| | 25th percentile | $0 | $0 | $0 | $0 | $0 | $0 | *$0* |
| | 50th percentile (median) | $100 | $400 | $250 | $500 | $100 | $100 | *$200* |
| | 75th percentile | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 | *$1,000* |
| | 90th percentile | $2,000 | $2,000 | $2,000 | $3,000 | $2,000 | $2,000 | *$2,000* |
| | Percent responding $0 | 42.2% | 35.7% | 29.9% | 32.3% | 43.5% | 42.1% | *38.9%* |
| 25% | 10th percentile | $0 | $0 | $0 | $0 | $0 | $0 | *$0* |
| | 25th percentile | $10 | $0 | $10 | $0 | $0 | $0 | *$0* |
| | 50th percentile (median) | $700 | $1,000 | $1,000 | $1,400 | $1,000 | $600 | *$1,000* |
| | 75th percentile | $2,000 | $2,500 | $2,500 | $3,000 | $2,000 | $2,000 | *$2,500* |
| | 90th percentile | $5,000 | $4,000 | $5,000 | $5,000 | $4,200 | $4,000 | *$5,000* |
| | Percent responding $0 | 32.5% | 26.1% | 19.5% | 25.2% | 32.9% | 31.9% | *29.2%* |

**Preference for advanced vehicle types (powertrains)**

Respondents were asked to rank (forced rank) their preference for each advanced vehicle type (i.e., powertrain type) at two different gasoline prices: $2.50/gallon and $5.00/gallon (1 = most-preferred technology, 6 = least-preferred technology). At both prices, gasoline-hybrid vehicles were the most preferred vehicle type, while diesel internal-combustion engines were rated as the least preferred. Figure 13 summarizes the results for all respondents, while Tables 12 and 13 present complete summaries of responses by gender and age.

At the lower gasoline price, males rated gasoline internal-combustion engines as their second choice, while females preferred plug-in hybrids as their second choice. At the higher gasoline price, there was no significant effect of gender in the ranking order.

At the lower gasoline price, the second choice of younger groups was either plug-in hybrids (18-29 year-olds) or electric vehicles (30-44 year-olds), while the second choice of both older groups was the gasoline internal-combustion engine. At the higher gasoline price, the two oldest age groups rated gasoline-hybrid vehicles as their top choice, while the two youngest groups rated electric vehicles as their top choice. The youngest group rated gasoline-hybrid vehicles as their second choice, but plug-in hybrids were the most popular second choice for all other age groups.

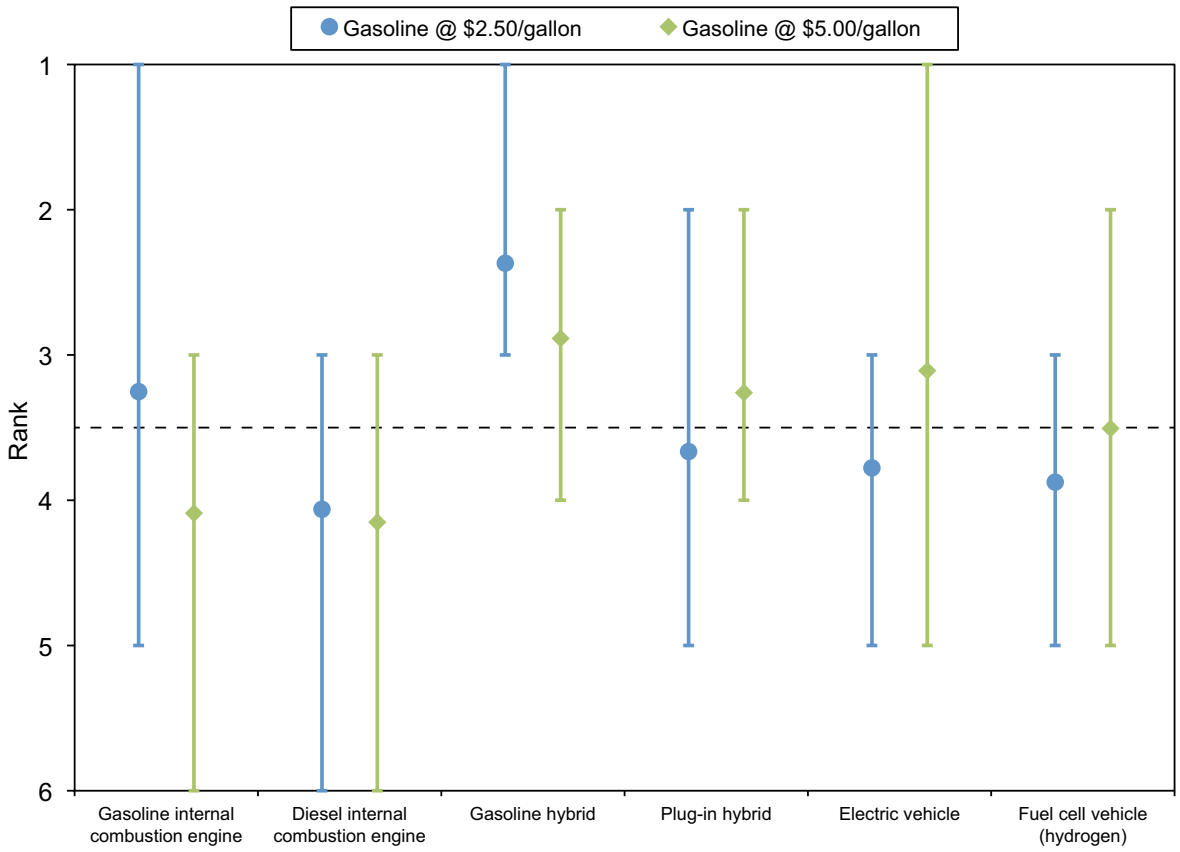


Figure 13. Combined summary of responses to Q12 and Q13: "*Please rank the following vehicle types in order of your preference for owning or leasing each type if the price of gasoline were $2.50 per gallon (Q12) or $5.00 per gallon (Q13).* " The symbols mark the average rank for each technology, while the error bars show the span between the 25th- and 75th-percentiles. The dashed line indicates the midpoint (3.5) in the rankings.

Table 12
Average ranking, by gender and age, for Q12: "*Please rank the following vehicle types in order of your preference for owning or leasing each type if the price of gasoline were $2.50 per gallon.*" (1 = most-preferred vehicle type, 6 = least-preferred vehicle type; the highest ranking vehicle type for each column is shown in **bold**.)

| Vehicle type | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| Gasoline internal-combustion engine | 3.6 | 3.0 | 3.6 | 3.6 | 3.1 | 3.1 | *3.3* |
| Diesel internal-combustion engine | 4.2 | 3.9 | 4.3 | 3.9 | 4.2 | 4.0 | *4.1* |
| Gasoline hybrid | **2.2** | **2.6** | **2.4** | **2.7** | **2.2** | **2.3** | ***2.4*** |
| Plug-in hybrid | 3.5 | 3.8 | 3.4 | 3.7 | 3.7 | 3.7 | *3.7* |
| Electric vehicle | 3.6 | 3.9 | 3.5 | 3.3 | 3.9 | 4.1 | *3.8* |
| Fuel cell vehicle (hydrogen) | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.8 | *3.9* |

Table 13
Average ranking, by gender and age, for Q13: "*Please rank the following vehicle types in order of your preference for owning or leasing each type if the price of gasoline were $5.00 per gallon.*" (1 = most-preferred vehicle type, 6 = least-preferred vehicle type; the highest ranking vehicle type for each column is shown in **bold**.)

| Vehicle type | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| Gasoline internal-combustion engine | 4.2 | 4.0 | 4.4 | 4.5 | 4.0 | 3.8 | *4.1* |
| Diesel internal-combustion engine | 4.3 | 4.0 | 4.4 | 4.1 | 4.2 | 4.1 | *4.2* |
| Gasoline hybrid | **2.8** | **2.9** | 3.1 | 3.3 | **2.8** | **2.7** | ***2.9*** |
| Plug-in hybrid | 3.2 | 3.3 | 3.3 | 3.1 | 3.2 | 3.4 | *3.3* |
| Electric vehicle | 2.9 | 3.3 | **2.6** | **2.6** | 3.3 | 3.5 | *3.1* |
| Fuel cell vehicle (hydrogen) | 3.5 | 3.5 | 3.2 | 3.4 | 3.6 | 3.6 | *3.5* |

**Perceived disadvantages of advanced vehicle types (powertrains)**

Respondents were asked to list any major disadvantages with these advanced vehicle types that they were aware of. The majority of respondents said that they were unaware of any major disadvantages (64.7%). The technology with the most specific mentions for having a major disadvantage related to the limited travel range of electric vehicles (11.9%). Figure 14 summarizes the results for all respondents, while Table 14 presents a complete summary of responses by gender and age.

Females were more likely than males to say they were not aware of any major disadvantages (72.9% versus 56.8%, respectively).

Younger respondents were more likely than older respondents to say they were not aware of any major disadvantages.

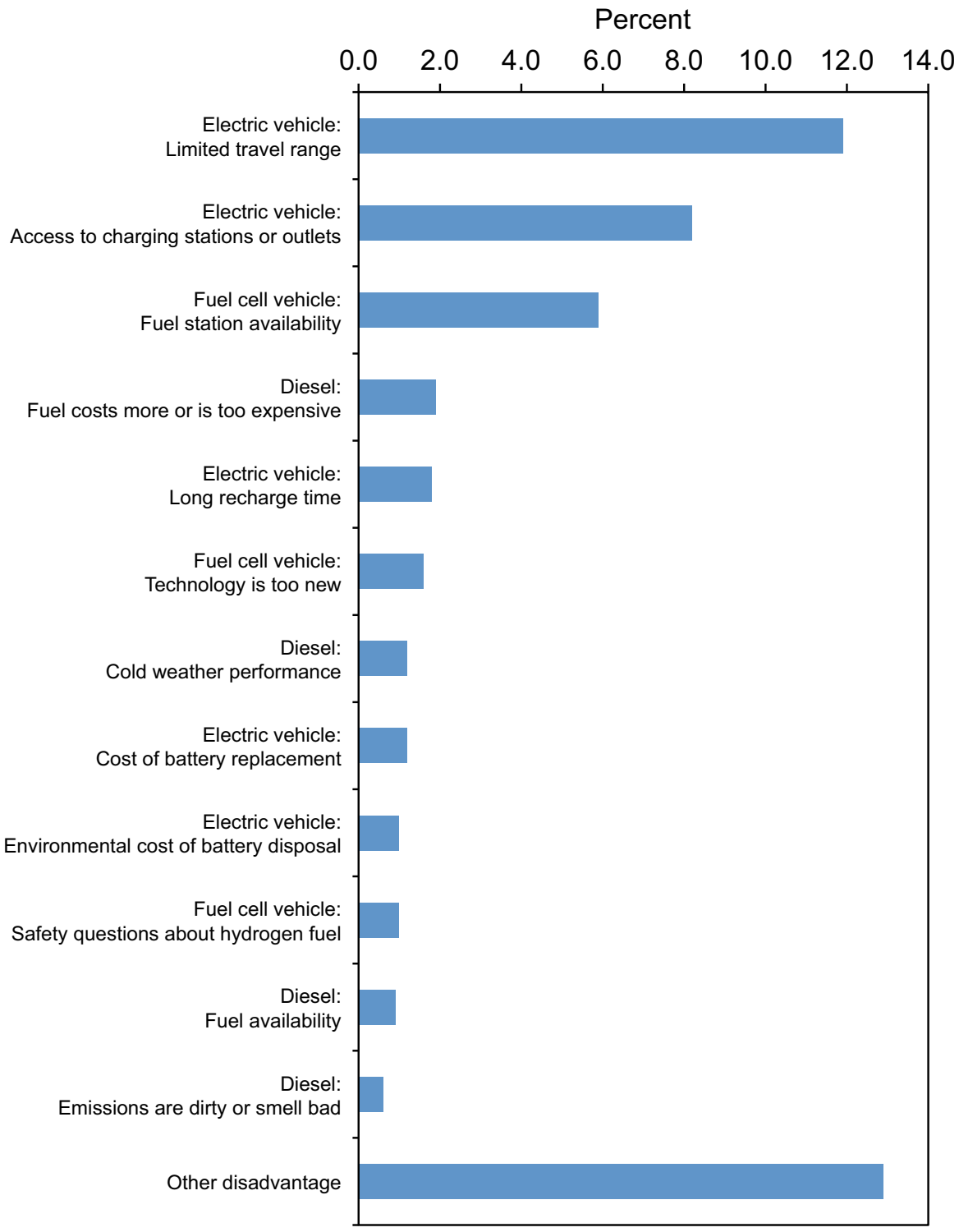


Figure 10. Summary of responses to Q14: "*Are there any major disadvantages associated with any of these different vehicle types that you are aware of?*" (Only those mentioning a major disadvantage are summarized in this figure.)

Table 14
Percentage of responses, by gender and age, to Q14:
"*Are there any major disadvantages associated with any of these different vehicle types that you are aware of?*" (Percentages sum to more than 100 because selection of more than one response was allowed.)

| Response | Gender | | Age | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | Female | Male | 18-29 | 30-44 | 45-59 | 60+ | |
| No major disadvantages | 72.9 | 56.8 | 68.8 | 71.0 | 67.1 | 57.0 | *64.7* |
| Electric vehicle: Limited travel range | 8.8 | 14.8 | 10.4 | 10.3 | 9.2 | 15.7 | *11.9* |
| Electric vehicle: Access to charging stations or outlets | 7.6 | 8.7 | 3.9 | 7.7 | 8.2 | 9.8 | *8.2* |
| Fuel cell vehicle: Fuel station availability | 1.5 | 10.1 | 5.2 | 2.6 | 4.3 | 9.8 | *5.9* |
| Diesel: Fuel costs more or is too expensive | 2.1 | 1.7 | 1.3 | 1.3 | 2.4 | 2.1 | *1.9* |
| Electric vehicle: Long recharge time | 1.2 | 2.3 | 2.6 | 1.3 | 1.4 | 2.1 | *1.8* |
| Fuel cell vehicle: Technology is too new | 0.3 | 2.9 | 0.0 | 1.9 | 0.5 | 3.0 | *1.6* |
| Diesel: Cold weather performance | 1.2 | 1.2 | 0.0 | 0.0 | 1.9 | 1.7 | *1.2* |
| Electric vehicle: Cost of battery replacement | 0.6 | 1.7 | 0.0 | 0.6 | 2.4 | 0.9 | *1.2* |
| Electric vehicle: Environmental cost of battery disposal | 0.9 | 1.2 | 1.3 | 0.6 | 2.4 | 0.0 | *1.0* |
| Fuel cell vehicle: Safety questions about hydrogen fuel | 0.6 | 1.4 | 0.0 | 1.3 | 1.0 | 1.3 | *1.0* |
| Diesel: Fuel availability | 0.9 | 0.9 | 0.0 | 0.6 | 1.0 | 1.3 | *0.9* |
| Diesel: Emissions are dirty or smell bad | 0.3 | 0.9 | 0.0 | 0.0 | 1.4 | 0.4 | *0.6* |
| Other disadvantage | 9.7 | 15.9 | 14.3 | 12.3 | 10.6 | 14.9 | *12.9* |

## Key Findings

**Importance of fuel economy and sources of fuel savings or emissions reductions**

- Nearly all respondents (98%) reported that fuel economy was important on some level to them when making vehicle purchase decisions; about half (49%) gave it the top rating of "very important".

- The majority of respondents (52%) do not care how a vehicle is able to achieve fuel savings and reduce emissions; however, engine improvements (24%) and alternative fuels (20%) were the most common specific responses.

**Premium fuel**

- A large majority of respondents (73%) said that they would be less likely to own or lease a vehicle that was required to use premium fuel.

**General opinion of advanced vehicle technologies**

- A majority of respondents have positive opinions of each advanced technology presented, with the exception of continuously variable transmissions (48% held positive views of that technology).

- Males tended to have stronger opinions (both positive and negative) than females.

**Knowledge of advanced vehicle technologies and vehicle types**

- General knowledge of the different technologies was mixed but generally low; the only technologies that a majority claimed to understand the workings of were gasoline-hybrids and diesel engines (both 90%).

- Most respondents claim to be aware of the presence (or absence) of advanced technologies on their vehicle; continuously variable transmission was the most common technology reported in their personal vehicles (10%), but also the most likely for respondents to not know if they had (19%).

- Males and older respondents were both more likely to know about advanced technologies in general and to know what equipment is installed on their vehicle.

**Preferences and willingness to pay for advanced vehicle technologies and vehicle types**

- At both lower ($2.50/gal) and higher ($5.00/gal) gas prices, respondents preferred gasoline-hybrid technology over all others; continuously variable transmissions and cylinder deactivation were the second and third highest rated (although in reverse order at the higher gasoline price).

- Willingness to pay for improved fuel economy was directly related to the magnitude of the improvement. $1,000 was the 90$^{th}$ percentile amount for a 5% improvement, the 75$^{th}$ percentile for a 10% improvement, and the 50$^{th}$ percentile (median) for a 25% improvement.

- At both lower ($2.50/gal) and higher ($5.00/gal) gas prices, respondents preferred gasoline-hybrid vehicles over other vehicle types (i.e., powertrain types); females preferred plug-in hybrids as their second choice, while males preferred gasoline internal-combustion engines.

**Perceived disadvantages of advanced vehicle technologies and vehicle types**

- Most respondents (73%) reported no awareness of major disadvantages with advanced vehicle technologies; diesel emissions were the most mentioned specific disadvantage (5%).

- Females and younger respondents were less likely to report a specific disadvantage with advanced technologies than males and older respondents.

- Most respondents (65%) reported no awareness of major disadvantages with advanced vehicle types (i.e., powertrains); limited travel range of electric vehicles was the most mentioned specific disadvantage (12%).

- Females and younger respondents were less likely to report a specific disadvantage with advanced vehicle types than males and older respondents.

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# Appendix A: Relevant aspects of advanced powertrains and engine technologies

Table A-1. Relevant aspects of advanced transmissions.

| Aspect | Continuously variable (CVT) | Automated manual (*without lockup torque converter*) | Higher gear ratios (≥ 6 gears) | Automatic with lockup torque converter |
|---|---|---|---|---|
| Description | Continuously variable transmissions (CVT); uses belts (or chains) and pulleys instead of gears [also called: gearless, one-speed auto, variable pulley, infinitely variable transmission (IVT)] | Similar design to a manual transmission using a clutch (instead of torque converter for traditional automatics), but does not require the driver to operate the clutch, automatically engaging the clutch and shifting gears for the driver | Higher number of gears (and thus more gear ratios) | Locking of the torque converter in automatic transmissions |
| General efficiency benefit | Infinite number of possible gear ratios (limited by the min and max ratios of the system) to enable optimal engine rpm at various speeds | Improved fuel efficiency due to lighter transmission weight and reduced energy losses in the transmission | More gear ratios enable optimal (lower) engine rpm at various speeds | Prevents transmission slippage, improving powertrain efficiency |
| Fuel efficiency benefit [1] | 6% | 7% | 6% | 1% |
| Average implementation cost per vehicle [2] | $298 | $163 | $141 | $35 |
| Payback period [3] | 3.9 years | 1.8 years | 1.8 years | 2.6 years |
| Premium fuel [4] | 4.1% | 24.2% | 27.6% | 14.9% |
| Other advantages | + Smoother acceleration because there is no shifting of gears<br>+ No downshifting or upshifting on hills (gear hunting) | + Benefits of manual transmission (lighter and lower energy loss) but with automatic shifting | | |
| Disadvantages | - Often slow to respond when accelerating<br>- Different feel and sound when driving (no shifting)<br>- Can be loud at higher rpm | | | |
| Availability [5] | 7.5% | 10.5% | 89.0% | 75.1% |

[1] EPA (2015)
[2] Converted to 2015 dollars (EPA, 2008).
[3] Assumes 11,364 annual vehicle-miles (Sivak, 2015) and $3.00/gal for gasoline.
[4] Percentage requiring premium gasoline; the average for all MY2015 vehicles is 14.3%.
[5] Percentage of all models available for MY2015 (EPA, 2015).

Table A-2. Relevant aspects of forced induction (boosting).

| Aspect | Supercharged | Turbocharged | Twincharged |
|---|---|---|---|
| Description | Forced induction of intake air via belt-driven compressor | Forced induction of intake air via exhaust-gas-driven compressor | Uses both supercharging (for initial boost) and turbocharging (for boost at higher rpm) |
| General efficiency benefit | Allows for retaining power while reducing engine size (or increasing power while retaining size) | Allows for retaining power while reducing engine size (or increasing power while retaining size) | Allows for retaining power while reducing engine size (or increasing power while retaining size) |
| Fuel efficiency benefit [1] | 7.5% (average) | | |
| Average implementation cost per vehicle [2] | $435 (turbocharged + downsized) | | |
| Payback period [3] | 4.6 years | | |
| Premium fuel [4] | 8.9% | 15.5% | 100.0% |
| Other advantages | + Does not have a delay or lag before boost occurs as is the case with turbo<br>+ Boost corresponds to engine rpm, without surging as can occur with turbo boost | + Does not require any engine power to operate as a supercharger does<br>+ Recycles engine exhaust gases that would otherwise be wasted<br>+ Generally more efficient and powerful than supercharged engines | + Has no delay as the supercharger provides the initial boost at low rpm, but also suffers no parasitic power loss as the turbo provides boost at higher rpm |
| Disadvantages | - Requires power from engine to function (i.e., parasitic power loss)<br>- Increases intake air temperature more than turbo or natural aspiration | - Delay (lag) before boost while exhaust gas pressure and rpm both increase<br>- Limited rpm boost range | - Additional cost and weight of using both technologies |
| Availability [5] | 4.5% | 36.4% | 0.2% |

[1] EPA (2015)
[2] Converted to 2015 dollars (EPA, 2008).
[3] Assumes 11,364 annual vehicle-miles (Sivak, 2015) and $3.00/gal for gasoline.
[4] Percentage requiring premium gasoline; the average for all MY2015 vehicles is 14.3%.
[5] Percentage of all models available for MY2015 (EPA, 2015).

Table A-3. Relevant aspects of advanced variable valve systems.

| Aspect | Variable valve timing (VVT) | Variable valve lift (VVL) | Camless valvetrain |
|---|---|---|---|
| Description | Allows for different valve timing under different circumstances; often used together with VVL to allow infinite valve control | Allows for different valve lift heights (including zero) under different circumstances; often used together with VVT to allow infinite valve control | Uses actuators instead of camshaft(s) to open intake and exhaust valves; most sophisticated and flexible implementation of VVT + VVL |
| General efficiency benefit | Allows for different intake and exhaust valve timing under different circumstances to improve efficiency (standard valve timing is fixed) | Allows for different intake and exhaust valve lift heights (including zero) under different circumstances to improve efficiency (standard valve lift height is fixed) | Both valve timing and valve lift can be infinitely adjusted independently for each valve and for each cycle, allowing multiple lift events per cycle (or zero lift events) |
| Fuel efficiency benefit [1] | 5% (VVT + VVL) | | 5-15% |
| Average implementation cost per vehicle [2] | $406 (VVT + VVL) | | $584 |
| Payback period [3] | 6.3 years | | 4.7 years @ 10% improvement |
| Premium fuel [4] | 14.6% | 8.1% | 0.0% |
| Other advantages | | | |
| Disadvantages | - More complex to design and operate than traditional camshafts | - More complex to design and operate than traditional camshafts | - More expensive and complex to design and operate than traditional camshafts |
| Availability [5] | 95.6% | 27.8% (same for VVT + VVL) | 8.5% |

[1] EPA (2015)
[2] Converted to 2015 dollars (EPA, 2008).
[3] Assumes 11,364 annual vehicle-miles (Sivak, 2015) and $3.00/gal for gasoline.
[4] Percentage requiring premium gasoline; the average for all MY2015 vehicles is 14.3%.
[5] Percentage of all models available for MY2015 (EPA, 2015).

Table A-4. Relevant aspects of advanced fuel management.

| Aspect | Gasoline direct injection (GDI or GDPI) | Non-hybrid Stop/Start | Cylinder deactivation |
|---|---|---|---|
| Description | Direct injection of fuel into the cylinder rather than the air intake tract | Automatically shuts off the engine whenever the vehicle idles, automatically restarting again when accelerator is applied [also called integrated starter/generator (ISG)] | Ability to turn off (deactivate) one or more cylinders at cruising speeds [also called variable displacement] |
| General efficiency benefit | Allows more precise control of fuel delivery timing for more efficient combustion | Improves fuel efficiency by reducing excessive or unnecessary idling | Allows for retaining larger engine sizes while improving efficiency at cruising speeds |
| Fuel efficiency benefit [1] | 12% (with boosting) | 8% | 7.5% |
| Average implementation cost per vehicle [2] | $403 (alone) ($838 with boosting) | $687 (using 42-volt system) | $241 |
| Payback period [3] | 5.7 years (with boosting) | 6.8 years | 2.5 years |
| Premium fuel [4] | 16.5% | 27.6% | 7.1% |
| Other advantages | | | + Can use existing VVT and/or VVL (or camless) technology to deactivate cylinders |
| Disadvantages | - Can cause significantly more particulate emissions than traditional ICE<br>- Detergents in fuel to clean intake valves do not work if fuel is directly sprayed into each cylinder | - Initial adjustment period for users (some users may think vehicle has stalled)<br>- May require redesigned/improved battery and serpentine belt systems | - Not applicable for 4-cylinder or smaller engines as the reduced number of operating cylinders causes excess vibration<br>- Possible uneven cooling |
| Availability [5] | 59.2% | 23.9% | 9.0% |

[1] EPA (2015)
[2] Converted to 2015 dollars (EPA, 2008).
[3] Assumes 11,364 annual vehicle-miles (Sivak, 2015) and $3.00/gal for gasoline.
[4] Percentage requiring premium gasoline; the average for all MY2015 vehicles is 14.3%.
[5] Percentage of all models available for MY2015 (EPA, 2015).

Table A-5. Relevant aspects of other transmission or drivetrain technologies.

| Aspect | Manual transmission | 2-wheel drive | Gasoline hybrid | Diesel |
|---|---|---|---|---|
| Description | Manually shifted (i.e., stick shift, standard transmission). | Uses either front (FWD) or rear (RWD) wheel drive only | Traditional gasoline powered hybrid | Diesel fuel used instead of gasoline |
| General efficiency benefit | Generally better fuel economy than equivalent automatic | Generally better fuel economy than equivalent 4-wheel drives (4WD or AWD, including part-time) | Improved fuel efficiency using battery power and/or ICE for direct power | Higher energy content per volume than gasoline (10-15%) |
| Fuel efficiency benefit [1] | 10% | (not available) | 35% (MY2015 average) | 20-35% |
| Average implementation cost per vehicle [2] | † | (not available) | (not available) | $4,870 ‡ |
| Payback period [3] | † | (not available) | (not available) | 16.6 years @ 28% improvement |
| Premium fuel [4] | 9.3% | FWD: 1.7%<br>RWD: 26.1% | 21.7% | (not applicable) |
| Other advantages | + Less expensive<br>+ Lower weight<br>+ Less complex<br>+ Less 'slip' than automatics and CVTs | + Lighter, less complex transmissions than 4WD | | + Generally able to use biodiesel if desired<br>+ Usually operate at lower rpm<br>+ More torque at low rpm |
| Disadvantages | - Learning curve for new users<br>- Some automatics are starting to equal manual transmissions in terms of fuel economy | - Less traction in snow, sand, mud, and rain than 4WD (but FWD > RWD in these conditions)<br>- FWD layout may limit the size of the engine that can be installed | - Possible need for battery replacement | - Significantly higher initial vehicle purchase price<br>- Higher price for fuel at the pump<br>- More challenging emissions control |
| Availability [5] | 16.2% | 63.1% | 3.7% | 2.9% |

[1] EPA (2015)
[2] Converted to 2015 dollars (EPA, 2008).
[3] Assumes 11,364 annual vehicle-miles (Sivak, 2015) and $3.00/gal for gasoline.
[4] Percentage requiring premium gasoline; the average for all MY2015 vehicles is 14.3%.
[5] Percentage of all models available for MY2015 (EPA, 2015).
‡ Belzowski and Green (2013).
† Manual transmissions generally cost less than automatic transmissions. Therefore, we do not list an implementation cost or payback period, as this technology would have a lower initial cost (i.e., negative implementation cost) compared with a traditional automatic transmission.

# Appendix B: Questionnaire

**Motorists' Views of Fuel Economy and Advanced Vehicle Technologies**

**Introduction (all respondents)**

We are conducting a survey of motorists concerning their views on fuel economy and advanced vehicle technologies.

Each person's understanding of the technical issues in this survey will vary, but we are interested in gathering responses from all motorists, regardless of their current knowledge level.

In this survey, when we use the term *vehicle*, we mean any type of passenger vehicle, including cars, sport utility vehicles (SUVs), vans, minivans, and pickup trucks.

1) Please select one option that best describes your CURRENT vehicle:

I drive a vehicle that is owned (either by me or someone else)
I drive a vehicle that is leased (either by me or someone else)

I do not drive a vehicle → ***Thank and end survey***

2) How important is fuel economy to you when deciding what vehicle to own or lease?

Very important
Moderately important
Slightly important
Not at all important

3) Please describe your preference for the way a vehicle saves fuel and reduces emissions.

I prefer fuel savings and emissions reductions to come from…

Engine improvements
Transmission improvements
Alternative fuel sources such as diesel, electric, or hydrogen
Some other fuel-saving technology (please describe): _____
It does not matter to me how a vehicle saves fuel and reduces emissions

4) Would you be less likely to own or lease a vehicle if it were required to use premium fuel?

Yes

No

5) Have you ever heard of the following advanced fuel-saving vehicle technologies?

*Please select one response per technology.*

| | I have heard of this and basically know what it is | I have heard of this but do not know what it is | I have not heard of this before |
|---|---|---|---|
| Continuously variable transmission (CVT) | O | O | O |
| Cylinder deactivation | O | O | O |
| Diesel engine | O | O | O |
| Gasoline-hybrid vehicle | O | O | O |
| Stop-start engine system | O | O | O |
| Supercharging | O | O | O |
| Turbocharging | O | O | O |
| Twincharging | O | O | O |

6) What is your general opinion about the following technologies?

*Please select one response per technology.*

| | Very positive | Somewhat positive | Neutral | Somewhat negative | Very negative |
|---|---|---|---|---|---|
| **Continuously variable transmission (CVT):** An automatic transmission with an unlimited number of effective gear ratios to enable optimal engine rpm at various speeds. However, unlike a traditional automatic transmission, CVTs use pulleys and belts instead of gears. | O | O | O | O | O |
| **Cylinder deactivation:** Ability to turn off (deactivate) one or more engine cylinders at cruising speeds. Allows for retaining larger, more powerful engine sizes while improving efficiency at cruising speeds. Also called *variable displacement*. | O | O | O | O | O |
| **Diesel engine:** A vehicle that uses diesel fuel instead of gasoline. Diesel has higher energy content per gallon than gasoline (10%-15%), and these vehicles are also generally able to use cleaner-burning biodiesel if desired. | O | O | O | O | O |
| **Gasoline hybrid:** Combines gasoline engines and electric motors to improve fuel economy. The gasoline engine provides most of the vehicle's power with the electric motor providing additional power when needed. The electric power is generated from regenerative braking and from the gasoline engine, so gasoline hybrids don't have to be plugged into an electrical outlet to recharge. | O | O | O | O | O |
| **Stop-start engine system:** Automatically shuts off the engine whenever the vehicle idles, automatically restarting again when the accelerator is applied. Improves fuel efficiency by reducing excessive or unnecessary idling. | O | O | O | O | O |
| **Supercharging:** Forced air intake to the engine with a compressor that is driven by an engine belt. Allows for retaining power while reducing engine size (or increasing power while retaining size). | O | O | O | O | O |
| **Turbocharging:** Forced air intake to the engine with a compressor that is driven by engine exhaust gases. Allows for retaining power while reducing engine size (or increasing power while retaining size). | O | O | O | O | O |
| **Twincharging:** Uses both supercharging (at lower rpm) and turbocharging (at higher rpm). | O | O | O | O | O |

7) Do you know if the vehicle you drive most often has any of the following advanced fuel-saving vehicle technologies?

*Please select one response per technology.*

*Hold your mouse cursor over each item for a description of that technology.*

| | Yes, my vehicle has this technology | No, my vehicle does not have this technology | I do not know if my vehicle has this technology |
|---|---|---|---|
| Continuously variable transmission (CVT) | O | O | O |
| Cylinder deactivation | O | O | O |
| Diesel engine | O | O | O |
| Gasoline-hybrid vehicle | O | O | O |
| Stop-start engine system | O | O | O |
| Supercharging | O | O | O |
| Turbocharging | O | O | O |
| Twincharging | O | O | O |

8) Please rank your preference for having the following fuel-efficient technologies on your personal vehicle if the price of gasoline were $2.50 per gallon.

*1 = most-preferred technology, 8 = least-preferred technology*

*Hold your mouse cursor over each item for a description of that technology.*

| | Enter rank (1-8) |
|---|---|
| Continuously variable transmission (CVT) | |
| Cylinder deactivation | |
| Diesel engine | |
| Gasoline hybrid vehicle | |
| Stop-start engine system | |
| Supercharging | |
| Turbocharging | |
| Twincharging | |

9) Please rank your preference for having the following fuel-efficient technologies on your personal vehicle if the price of gasoline were $5.00 per gallon.

*1 = most-preferred technology, 8 = least-preferred technology*

*Hold your mouse cursor over each item for a description of that technology.*

| | Enter rank (1-8) |
|---|---|
| Continuously variable transmission (CVT) | |
| Cylinder deactivation | |
| Diesel engine | |
| Gasoline hybrid vehicle | |
| Stop-start engine system | |
| Supercharging | |
| Turbocharging | |
| Twincharging | |

10) Are there any major disadvantages associated with any of these fuel-efficient technologies that you are aware of?

No

Yes – Please list the technology (or technologies) and describe the disadvantage(s):

_____

11) How much EXTRA would you be willing to pay above the normal cost of a vehicle to achieve the following levels of improvement in fuel economy?

*Please enter a dollar amount for each row. Please enter 0 if you would not be willing to pay extra for a given level of improvement.*

| | Dollar ($) amount |
|---|---|
| 5% improvement | |
| 10% improvement | |
| 25% improvement | |

12) Please rank the following vehicle types in order of your preference for owning or leasing each type if the price of gasoline were $2.50 per gallon.

*1 = most-preferred vehicle type, 6 = least-preferred vehicle type*

*Hold your mouse cursor over each item for a description of that vehicle type.*

| | Enter rank (1-6) |
|---|---|
| Gasoline internal-combustion engine | |
| Diesel internal-combustion engine | |
| Gasoline hybrid | |
| Plug-in hybrid | |
| Electric vehicle | |
| Fuel cell vehicle (hydrogen) | |

13) Please rank the following vehicle types in order of your preference for owning or leasing each type if the price of gasoline were $5.00 per gallon.

*1 = most preferred vehicle type, 6 = least preferred vehicle type*

*Hold your mouse cursor over each item for a description of that vehicle type.*

| | Enter rank (1-6) |
|---|---|
| Gasoline internal-combustion engine | |
| Diesel internal-combustion engine | |
| Gasoline hybrid | |
| Plug-in hybrid | |
| Electric vehicle | |
| Fuel cell vehicle (hydrogen) | |

14) Are there any major disadvantages associated with any of these different vehicle types that you are aware of?

No

Yes – Please list the vehicle type(s) and describe the disadvantage(s):

_____

Thank you for taking the time to complete this survey!

**(end survey)**