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Folk Quantification of Transportation Energy:
an initial investigation of perceptions of automobile energy use

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Abstract

In this paper we seek to document what, if any, divergences exist between how experts and 'lay' people conceptualize the energy used in automobiles, motivated by previously-documented divergences in the home energy sector. From a total of 15 interviews with 19 individuals, we identify several common ways 'lay' people think about automobile energy use, and draw a number of conclusions relevant to the development of transportation energy policy.

In our informants' minds, automobiles use gasoline, rather than a more generic form of energy, and they therefore have a difficult time comparing energy use across activities. When asked to compare their total energy use for both residential and transportation activities, informants used dollars to provide a common unit of measurement.

Our informants thought of automobile efficiency almost exclusively as fuel economy and were aware of it, albeit based on inconsistent methods and varying degrees of rigor. They measure fuel economy almost exclusively in miles per gallon and demonstrated easy familiarity with this measure—they were very comfortable comparing their present cars with past cars, or with other cars in terms of fuel economy. However, the prevalence of this volumetric, more-is-better measure may present challenges for communication as alternative fuels (e.g. electricity) gain market share because such fuels may not comport with this measure in an intuitive way.

In-dash fuel economy displays seem to have made some drivers more aware that driving behavior is a factor in realized fuel economy, although it appears that this link could be strengthened if displays were to provide more pertinent information. However, in contrast to home energy use where active management is a primary means of saving energy, automobile energy use is considered primarily at the point of purchase rather than in daily driving decisions. Finally, our informants tended to evaluate their fuel economy relative to a benchmark of some kind, whether CAFE standards or their perception of the fleet (or vehicle class) average.

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1. Introduction and previous work

The manner in which individuals conceptualize energy in general and their use of energy in particular has important implications for the design of effective energy policy. A common method for accessing these conceptions utilizes semi-structured interviews. Using these methods, Kempton and Montgomery (1982) found that 'lay' and expert people had very different ways of thinking about energy. For the specific case of home energy bills, they found that lay people used different units to think about energy than specialists. In two separate studies on the use of home thermostats, Kempton (1986) and Kempton (1987) found that lay people used heuristics that were not technically 'correct' from the specialist's understanding, but were effective in regulating heat nonetheless. Kempton found the discrepancy in thinking between 'lay' and expert people was more pronounced in some areas (e.g., home heating system mechanics and the causes of heating load) than in other areas (e.g., how a thermostat works).[1]

Related early work in the science education literature uncovered similar results. Watts (1983) determined that British high school students held a large number of varyingly incorrect frameworks for understanding energy in general, although his methods were slightly different than a typical interview. He used stick-figure drawings depicting various activities and asked respondents whether the figures illustrated their personal conceptions of energy. Kruger (1990), in response to changing British curriculum requirements which would see the earlier teaching of energy fundamentals, investigated primary school teachers and found that many of their mental models were similar to the incorrect ones held by younger children; the teachers, however, were better able to recognize inconsistencies when confronted, and showed a desire to improve their understandings.

The divergence between 'lay' and expert understanding of energy has been attributed to a socialized or 'everyday' understanding of concepts and a symbolic one which is gained through scientific education, and the difficulty associated with switching between them (Solomon 1983). Since technical understandings are rarely required in day-to-day activities, gaps in understanding within the symbolic domain can often be ignored. However, incorrect conceptual frameworks for understanding energy use become significant when they produce counter-productive energy use behavior and when they are the basis for public policy that leads to unintended consequences.

We sought to determine whether similar divergence exists in how experts and lay people conceptualize the energy used in automobiles, and to identify common themes from which to draw a number of conclusions relevant to the development of transportation energy policy.

One common theme of the research that grew out of Kempton and other's work was a critique of the assumption that consumers behave in an economically rational manner with regards to energy savings. For instance, Dennis et al. (1990) found that consumers used simple measures and mental shortcuts when trying to save energy that were generally effective, but not necessarily economically rational, or the most effective steps they could be taking. Kempton and

[1] Specifically, Kempton contrasts the experts' model of heat as transferred from the building envelope to the surrounding air, with the rate of transfer driven by the temperature difference between interior and exterior, with a typical lay understanding of heat as somehow dissipating into the air of the home. In the former, the building's surface and surface area are relevant to energy use, while in the latter, the absolute volume is the relevant factor.

Layne (1994) also note many studies that found this same phenomenon; they attribute part of its cause to information overload, which masks the relevant economic information that would be required to act in a rational economic way. They suggest working on information delivery and pricing schemes as two ways to align consumers' economic interests with their understanding. Another approach to this phenomenon is illustrated in McKenzie-Mohr (1994) in which the author suggests that the best way for energy auditors to motivate their clients to take energy savings steps is to present their case in a vivid manner, harnessing fundamental economic behaviors. For instance, he argues that auditors should emphasize the money clients are losing by not implementing conservation measures, appealing to the fact that loss-aversion is generally stronger than the desire to make money.

In the transportation field, a similar question of economic rationality was recently addressed by Turrentine and Kurani (2007) who found that purchasers of hybrid vehicles do not systematically evaluate fuel economy considerations in their purchase decisions, even though economic models assume they do. In keeping with their finding, we conclude 'good' fuel economy may be a reward in and of itself for consumers, and also that rising fuel prices are making the issue of fuel economy even more salient for drivers. Furthermore, drivers do pay attention to signals relating to energy use in their vehicle purchase and use decisions, which has implications for future vehicle design and policy directives for such design.

2. Methods

We performed 15 total telephone-based interviews with 19 people (four of the interviews were with couples; see Table 1), including 10 men and 9 women. We primarily employed convenience sampling—informants were individuals who were easy for us to contact and talk to, mostly friends and family members, although we were also referred to additional informants by initial contacts (i.e., snowball sampling). Two reasons led us to use these sampling methods: First, interviewing people with whom we had an existing relationship ensured the prior establishment of trust so informants were likely to be truthful and at ease. Second, the efficiency was necessary given the limited time available for this research. With convenience sampling, we were able to target individuals based on known characteristics and to assemble an overall sample expected to give a wide variety of meaningful responses to our questions. That is, we sought to interview a sample with diversity in key attributes (e.g., age, location, world view, vehicles owned) and propensity to have at least some thoughts on energy use in their vehicle purchase and use decisions.[2] Thus, our results should not be considered representative of the United States population, but may be interpreted as indicative of a particular cluster of energy conscious automobile users. In this sense, our research has more in common with scenario analysis than the results of a random sampling and, as such, certainly contains bias. However, Parnell and Larsen (2005) argue that "10 good interviews can provide the skeleton of a theoretic structure" (p. 789). So, our sample may be thought of as mapping the boundaries of the possible variation. Given our sampling technique, we likely scoped out one end of the bell curve, rather than its whole range.

[2] The motivation was practical. Previous research suggests that many people do not consider energy use at all and would therefore have difficulty providing relevant comment on our topic of investigation (Turrentine and Kurani 2007). We conducted several initial interviews selected without consideration of energy consciousness and found similar results, with very little to none of our conversation even related to energy. For instance, when asked "How does your car use energy?" one pilot informant was stumped and said, "What do you mean?"

Our data should not be interpreted as indication of the relative frequencies of the views our informants expressed in the general population.

Our informants lived all over the United States, from Alaska to Massachusetts and Los Angeles to Minneapolis. Additionally, two informants were from southern Ontario in Canada. The informants drove a variety of vehicles, from hybrid electrics to Ford pickup trucks. A summary of relevant demographic and car ownership information for our sample is included in Table 1.

Table 1: Sample characteristics

Name[3]	Current vehicle (fuel other than gasoline)	Age	Location
Bob & Linda	Subaru Forrester, Volvo Cross Country, Ford Focus	Early 50s	Washington
Daniel	Lexus IS300	Early 30s	California
Debbie	Geo Metro, Honda Fit	Early 60s	Alaska
Herman & Lisa	Volkswagen Passat, Chevrolet Tahoe	Early 60s	Colorado
Jessica & Paul	Toyota Prius, Subaru Forrester	Mid 50s	Minnesota
Katie	Geo Prizm	Mid 50s	Minnesota
Margaret	Honda Civic Hybrid	Late 40s	Illinois
Mary	Chrysler 300M	Late 40s	Ontario
Megan	Volkswagen Beetle (straight vegetable oil)	Late 20s	California
Patrick	Chrysler Pacifica	Early 60s	Alaska
Rebecca & Charles	Toyota Prius, Plymouth Voyager	Early 50s	Minnesota
Roy	Ford Ranger	Early 40s	Ontario
Sara	Hyundai Elantra	Mid 20s	Massachusetts
Scott	Toyota Corolla	Early 30s	Washington
Theo	Mercedes 300D (biodiesel)	Mid 20s	California

2.1. Interview protocol

In all our interviews, we began talking in general terms about the informant's current and past vehicles. Energy use was discussed only when the conversation moved in this direction on its own, although we actively sought to keep the conversation on energy topics once they were raised. The reason for this approach was to maintain a 'beginner's mind' in each interview, completely open to how the informant would conceive of energy use rather than imposing our views in the form of a question. However, initial interviews indicated that energy use was not always a fruitful topic of conversation when informants were asked about their cars, so we did assert some guidance toward the topic.[4] As such, the responses about energy use are likely not completely devoid of influence from us, although we made every effort to ask open-ended, non-leading questions. We composed and utilized an interview-guiding protocol to help maintain consistency between interviews, but all interviews were one-on-one, leaving our results open to interviewer bias as well.

Our interviews generally included questions about vehicle purchase decisions and how current cars were used. We started with general dialog about present and past vehicles, attempting to

[3] All the names given are pseudonyms.

[4] Several informants focused much of the conversation on the environmental impact of their vehicles; for these interviews, intentional steering towards energy was less necessary.

determine what factors had been considered in their purchase and use. We then asked people to recollect positive and negative features of past cars. By that point, the concept of energy use had usually come up in some way (typically in the mention of fuel economy) and we would gently steer the conversation to focus on this topic.

Notwithstanding the above discussion, and as previously mentioned, the purpose of these interviews was not to obtain a statistically representative sample, but to glean what information we could through this informal technique. The choice to not use a structured questionnaire style survey allowed informants freedom to choose their own terms in expressing their thoughts on automobile energy use, rather than responding to the unavoidable structure of a survey, which was imperative for our study. It also allowed us to follow up in greater detail on items that appeared to be of interest to our study and to assist informants to some degree if they were having difficulty understanding some of the more abstract of our questions. To emphasize, the results should not be considered representative, and must be applied only to our limited sample.

3. Results

After conducting the interviews, we collectively reviewed all transcripts and identified common themes. There was a surprising amount of similarity among our interviews, but substantial differences as well. Below, we cover seven major themes: broad conceptualizations of energy, units, tracking energy use, fuel economy improvements, relativity in energy savings, vehicle purchase considerations, and the influence of gasoline price. In each case, we provide a preliminary discussion focused on the potential implications of the findings, supported by representative quotations from our informants.

3.1. The concept of energy, evaluated broadly

We were initially interested in how people understood their cars to use energy, but found that this formulation stifled further discussion. The informants we spoke to generally did not think about how their cars use ‘energy.’ After some interviewing experience, however, we found that people *do* think about how their cars use gasoline, most commonly in the units of miles per gallon (mpg).[5] We also found that our informants pay more attention to the fuel economy of their vehicle when purchasing a car and less attention when using it. Thus, people are aware of fuel economy but the concept of ‘energy’ seems foreign to most.

The implications are profound: the inability to think broadly in terms of ‘energy’ and to convert between energy units (e.g., kilowatt hours, gallons of fuel, megajoules) makes evaluation of relative energy use across applications and energy forms very difficult. In general, people had good knowledge of the form of energy used for the services they enjoy (e.g., the stove is electric, the heat is natural gas, the car uses gasoline from crude oil), but were completely unable to

[5] Other units included dollars, carbon dioxide emissions, kilometers per tank, and efforts to distinguish between fossil and non-fossil energy. A more obscure example of alternative units mentioned was braking energy expressed in the amount of water it could boil.

compare energy use across services and primary energy sources.[6] The dominance of energy use consideration at the point of vehicle purchase rather than during vehicle use will be discussed in the section 'purchase point considerations.'

Informants had a very hard time both understanding and answering a question regarding the proportion of their personal energy use dedicated to transportation. The preferred metric when we did receive an answer was in dollars, indicating an energy comparison clouded by relative prices, which is consistent with the findings of Kempton and Layne (1994). In general, the challenge of converting between dissimilar energy units seemed insurmountable for most. One informant, Katie, explicitly stated,

> I am not aware of any units that would allow me to compare them [my car's energy use and home's energy use].

Another informant, Roy, answered the comparative energy use question by stating,

> I burn just as much as we burn at home, as in total bills. I spend one hundred to one hundred fifty dollars per week in fuel. You work that out at the end of the month, it almost works out to your total utilities. Plus or minus just a little under. Like I say, the car is a little less, but…it's another expense. Then if you have a payment on top of it, another four to five hundred, it's like carrying a house. I would stick to that. But…not everyone lives in a $300,000 house.

Finally, Scott answered by saying,

> Uhhhh, I haven't thought about how vehicle energy use compares to other energy use. They don't seem directly comparable in the sense that, you know, if I want heat, I don't think about whether I should turn on my furnace or go out and sit in my car. Only once have we… used the car as a generator – we plugged a portable DVD player in to watch movies when the power went out. In that sense, no, I haven't thought about how many dollars or Btu's or whatever per kilowatt-hour are we getting through the car.

However, a few informants in our sample broke this mold, seeming very knowledgeable about energy, switching between units with relative ease. Interestingly, one common unit of choice for comparing energy for these informants was units of carbon dioxide (CO_2) equivalent emissions. For example, one informant, Margaret, stated,

> Once I went to see how much you pay for gas and electricity as well as some conversion factors to determine CO_2 emissions…In Illinois we have 70% electricity from nuclear, so in terms of home electricity use, this is the lowest contributor, then comes home heating using natural gas, and then

[6] Note, our informants generally considered electricity an energy source, indicating confusion with the distinction between energy carriers (e.g., electricity and hydrogen) and the primary energy source(s) from which they are derived.

> transportation. We leave the house for the day, so we don't cool it or light it, no electronic equipment during the day, I do that at work [incomprehensible]. For the limited amount of time we use electricity, it's a comparatively small impact relative to driving.

These results suggest that the growing interest in global climate change and CO_2 emissions might provide a unit that would allow people to easily compare one aspect of their energy use across sources and end uses.

3.2. The units used - folk quantification of transportation energy

Almost universally, people think about their vehicle's energy consumption in mpg. The concept of fuel economy, expressed as mpg, was consistently the first mention of energy that emerged in our conversations. Furthermore, the first mention of these units was generally made in reference to a vehicle purchase decision, although it was also made in the context of vehicle use, especially for vehicles equipped with a fuel economy display in the instrument panel.

Several implications can be drawn. First, it appears that providing information can add a concept to the popular lexicon (how well it is understood and whether it truly impacts behavior are other questions). Displaying the United States Environmental Protection Agency (EPA) estimates of fuel economy (in mpg) prominently on window stickers seems to have engrained this concept as an attribute in vehicle purchase decisions as far back as the early 1980s (Dennis, Soderstrom et al. 1990). Similarly, displaying fuel economy on the instrument panel seems to be starting to engrain the concept that driver behavior is a factor for realized fuel economy.

In fact, the concept of fuel economy, especially measured in mpg, seems to have gained such traction with the American populace that it may act as a constraint on the terms available for expressing the energy use in automobiles. Specifically, it appears that energy use metrics for automobiles, like other energy use metrics in the United States (e.g., Energy Star labels) are formulated such that more is better. Higher mpg indicates better fuel economy and more stars indicate better energy efficiency. Contrast this with the energy efficiency metric for vehicles in Europe and Canada, liters per 100 kilometers, where less is better.

Finally, the mpg unit of measure for energy use in vehicles is by volume (i.e., the service provided, miles, per *volume* of fuel, gallons). This metric may prove problematic as alternative fuels with varying volumetric energy density, like ethanol, become more prevalent. For example, one informant, Herman, mentioned this confusion for flex-fuel vehicles, saying he had heard that the "fuel economy" (measured in mpg) was a lot worse when using E85 and that the "fuel cost" (measured in dollars per week) would thus be much higher.[7] In addition, Herman was concerned that the "force-fed" blending of ethanol with gasoline was reducing his fuel economy.

[7] Herman's exact quote was, "That level of SUV now has flex fuel… we have a good friend who is a Chevy dealer… one of his big concerns is that the sticker in the window puts down what the fuel economy is based on gasoline and for the flex fuel V8 Chevy Tahoe it lists it at 16 city, 21 highway, using gas. With the ethanol it's going to be 12 to 13 city and 16 highway, so you're going to buy more fuel by 10-15 percent and not get much of a reduction in cost, so the total fuel cost is going to be higher with ethanol. He's been holding his breath as these cars go out for what the reaction is going to be when people realize they're not getting 16 to 21 miles per gallon but 12 to 13 and 16 miles."

This difficulty for comparing alternative fuels only becomes worse when more fuels are added where volume is not only an inconsistent measure of energy, but not a viable measure at all (e.g., with kilograms of hydrogen or kWh of electricity). Thus, the commercialization of alternative fuels with different energy content and form may require measurement in gallons-gasoline-equivalent (gge) for an apples-to-apples comparison by consumers. Defining gge for all fuels would require significant regulatory rulemaking to establish the conversion factors (e.g., including energy conversion efficiencies for different vehicle platforms).

Informants also used dollars when thinking about gasoline consumption of their cars, but in unexpected ways. Most informants knew how much it would usually cost to fill their tank, with some liking a smaller tank because of the reduced cost per tank.[8] One woman, Rebecca, said one of the main things she likes about her Prius is that,

> It's got a smaller tank, and I really like that it is only $16, well, now it's probably more like $21, to fill it up. And the tank isn't very big, so it goes fast to fill it. I really like just getting in and out [of the station] quickly.

Other Prius owners mentioned the fact that they didn't have to fill up as often, using the metric of time between fill-ups. Still others expressed the wish that they could drive less and/or use less gas in light of the current high gas prices, suggesting that they were tracking total expenditures on gas. However, this suggestion was later belied by the informants' uncertainty over how much gas they purchased in a year. Table 2 summarizes the most common metrics employed by our informants in the quantification of their transportation energy.

Table 2: Metrics used in the quantification of transportation energy

Metric	Frequency
Miles per gallon	13
Cost of a tank of gas	5
Cost of maintenance	2
Time between fill up or frequency of fill up	1
Distance per tank	1

3.3. Tracking energy use

Many informants did keep track of their fuel economy, although the consistency of their records and rigor of their estimation methods varied. Daniel was typical when he said,

> I mentally do the math at the pump still—like I'm buying 10 gallons and I've gone 200 miles, that's 20 miles per gallon.

Similarly, Debbie said,

[8] The interesting implication here is that the dollars spent per tank may be more relevant than the quantity in the tank or the frequency of filling up in an individual's understanding of their fuel economy. At best, this metric would yield incomplete information about overall energy use and efficiency.

> We are quite aware of fluids going through the automobile: gasoline, oil… Even though we don't write it down, we have a sense for how well the vehicle is doing. I was surprised at 40 [mpg]… I thought it was more like 38 [mpg].

Scott said that he calculates his mileage at every fill up carefully enough to notice differences in his driving or vehicle configuration.

> When I'm driving around the city a lot, I get 32 or 31 [mpg]. When I'm just doing a road trip… and don't have anything on top of the car… I'll get 38 [mpg]. I try to keep the roof rack off the car when I'm not using it… and keep my tires inflated to 35 psi. The roof rack creates a lot of wind resistance – I can hear it – and I also notice about a 1 mile per gallon decrease in mileage when I have roof racks on. As far as tire pressure… I've just heard that it matters.

A number of informants also had a display in their vehicle showing instantaneous, and sometimes cumulative fuel economy. These displays are becoming more common in both hybrid and non-hybrid vehicles. But for some informants, these displays seemed less useful than the rough calculations they would make at the pump. For example, Daniel said,

> My car now has a miles per gallon 'speedometer' thing, but that is like useless, because either you'll be accelerating, and getting like 10 miles per gallon, or you'll be coasting and getting 80.

Other informants did seem to gain valuable feedback from the displays as to the impact of their driving behavior on fuel economy.[9] When asked whether she noticed the fuel economy display in her Toyota Prius, Jessica said,

> Oh totally! You find yourself going slowly, it really is a game to see how high you can get that…You really can get quite obsessive. You'll coast down hills, and you find yourself noticing topography around you. I don't notice it much anymore, actually, but I did when we first had [the Prius]. I noticed so many little hills near the house that I hadn't paid any attention to before.

And Paul, Jessica's husband, reinforced her statement when he said,

> There's a learning effect that is very apparent, in that you learn not to accelerate or brake suddenly; you really do drive differently. There is this option to coast, where you can elect to store the kinetic energy, but I tend not to use that drive mode unless I am watching the display, the one that shows where the energy is going/coming from, the routing between the engine and the battery.

[9] This phenomenon was most pronounced among hybrid owners, who may be more attuned to vehicle energy use than non-hybrid owners.

Feedback systems like fuel economy displays are increasing the awareness of the impact driver behavior can have on vehicle fuel economy. This result is similar to those observed for residential energy consumption feedback systems. A review by Darby (2006) found that real time electricity and gas meters typically reduce consumption by 5-15%. Parker et al. (2006) report residential consumption reductions of a similar magnitude. There are several implications. Researchers in Europe have documented a 10-42% change in fuel economy due to driver behavior (Samuel, Morrey et al. 2005). More fuel efficient driving behavior is also correlated with lower accident rates (DOE and EPA 2007; NHTSA 2007). If drivers are motivated to reduce fuel consumption and are provided with feedback on how to accomplish this goal through modified driving behavior, the impact on fleet-wide fuel economy and safety could be substantial. But there is clear discrepancy in the value of the information to the end-user among current devices. As several informants noted, an instantaneous calculation may not lead to improvements in fuel economy since it may be difficult for drivers to translate what appears to be wild fluctuations in fuel economy to their overall driving patterns. At the other extreme, digesting all the information provided in a Prius display[10] was too much for some informants: both Jessica and Rebecca even mentioned that they were less safe drivers during their first few months of hybrid ownership because of the distraction of the display. Thus, there appears to be potential benefit from additional research into the ideal format of real-time vehicle status and fuel economy information provided to the driver.

Kempton and Montgomery (1982) found that people had difficulty estimating how much they spent on energy or used in a year. Similarly, we found that when asked, no informant knew how much gasoline they used in a year off hand, but several people said they could calculate it. The most common method described was the division of an estimate of the miles driven last year by average fuel economy. Most informants were fairly confident about the number of miles they had driven in the past year, to the thousands place, without averaging over the vehicle lifetime. Sara knew offhand that she had driven 18,000, 12,000, and 10,000 miles per year in her first three years of ownership, respectively:

> That first year I put on 18,000 miles, which I was shocked at, but I was going up to Maine pretty much every weekend to visit and to ski. Then the next year, I put on 12,000, and that was with commuting 20 minutes each way. The year after it was 10,000, and then this year, I don't know, I'm probably going to put on 4, maybe less.

3.4. Improving fuel economy

We were interested in how respondents thought their cars used energy (i.e., to what services and/or losses does the energy go). We thought one way of getting at that topic would be to ask if they drove in any particular way to minimize gasoline use or increase fuel economy, since fuel economy appeared to be a quantity that respondents paid attention to. We found informants

[10] The Toyota Prius display includes a real-time "energy monitor" depicting power flows within the vehicle, fuel economy averaged over the previous 30 minutes, and outside temperature, among other things.

could identify several ways to improve their fuel economy, but this identification generally did not translate into understanding[11] or action.

When prompted with this question, most informants were able to list actions they thought would improve fuel economy. However, these actions generally did not come up before our prompting the topic and many informants believed these actions would have only a limited effect on vehicle fuel economy. For example, Bob said,

> Well, it does get better mileage with the higher octane gas. But I think that's about all we can do to affect the mileage.[12]

The most commonly mentioned actions affecting fuel economy are summarized in Table 3 below. In our conversations, many informants claimed to do the actions they identified as improving fuel economy. However, it was often unclear whether these statements were biased by our prompting of the topic and it was also unclear whether the actions were motivated by considerations other than fuel economy improvement. For example, Herman said,

> We try desperately hard to avoid that extra trip up or down the pass. Like today we combined going to church with our bike ride… We think differently than the people who live in what would be considered a town center… For some time, partly because of fuel conservation, but partly time too, living where we live – which really, it seems like it's way out of the city but it's under 20 minutes to the town center – but I think for a long time we have thought that way [of combining errands to reduce trips].

We also found that lifestyle considerations often trump fuel savings in driver behavior and vehicle purchase decisions. Megan said she commuted daily while living in Alaska due to location of home and work and poor weather and now commutes to San Francisco twice per week due to location of home and school. She also said that she drives quickly because her time is limited. Lisa and Herman said the primary purchase consideration for one of their vehicles was the ability to pull their recreational camping trailer.

When informants did not undertake the actions they identified as improving fuel economy, they generally explained why they didn't or won't. For example, two informants, Sara and Jessica, explicitly pointed out that they could get better gas mileage if they weren't always in such of a hurry and drove more slowly, but said that conditions in their lives did not permit reduced speed. Additionally, Margaret said,

[11] For example, recall Scott said, "As far as tire pressure… I've just heard that it matters."

[12] It is interesting to note that octane is an auto-ignition inhibiter with almost zero impact on energy density of the fuel or fuel economy of the vehicle (unless vehicle design includes high compression ratios to take advantage of high octane fuel) (Beck 2006). Most passenger cars do not have high compression ratios and therefore would not benefit from high octane fuel. However, the perception of high-octane fuel as 'high performance' has been nurtured to justify the higher price and this high performance status has translated into 'better fuel economy,' at least in Bob's mind.

> I read about some ways of driving that could improve [fuel economy]. But it is somewhat more difficult. When I'm in a hurry and I need to get somewhere fast, I drive less mindfully of the efficiency.

And Theo said,

> I'm sure I could drop my fuel consumption by 15 percent if I was really conservative in my driving. [Although] I'd piss off a lot of people on the road.

Conversely, Debbie acknowledged that part of the reason the observed fuel economy for their Geo Metro is high is because,

> We use our vehicle for recreational purposes rather than business purposes, so generally we're not on a strict timeline and so it's easy for us to think about driving at 50 miles per hour instead of 60 miles per hour and the fact that that does improve the performance, miles per gallon.

Roy also described a change in his behavior to reduce speed and improve fuel economy,

> I'm on the highway usually, I'm always in the hammer lane, *always*. If everybody's doing 150 [km/h], me too. Now, I'm keeping it down to 100-110, not in the hammer lane, and I've seen quite a difference on the fuel.

Generally, informants recognized that actual fuel economy would be influenced by a combination of many factors and would vary from one tank to the next. The factors include the fuel efficiency rating, driving behavior, and other, unknown factors. Jessica and Paul, hybrid owners, illustrate this perception:

> On the interstate, it gets about 43-45, because I go 70 [mph]. In town, it's probably in the high 40s. The mileage isn't as good in the winter, but I don't know why…– Jessica

> And if you can get on secondary roads where you can keep it in that 50 mph range, you can get upwards of 50 miles per gallon, but you can't get that when you're going 65-70 miles per hour. –Paul

Some informants identified driving habits they had that lowered their fuel economy, but that they were unwilling to change, consciously trading off fuel economy and comfort or speed. As mentioned, two informants talked about how fast they drove in these terms, and Daniel expressed skepticism that the EPA estimates of fuel economy would apply to his particular driving style:

> But that 50-miles-per-gallon thing is baloney. That's like if you drive perfect. But I have the a/c on all the time, so I get like 39 miles per gallon, again, mostly in the city.

Table 3: Factors perceived as affecting fuel economy

Characteristic	Freq.	Context and/or concept conveyed by informants	EPA estimated fuel savings (%)
Vehicle Attributes Affecting Fuel Economy			
Vehicle size / engine size	7		
Vehicle fuel	6	E85 delivers lower fuel economy, diesel better fuel economy	
Embodied Energy	2		
Number of cylinders and engine design	2	Engine friction, modern engines built with more rings, how hard the engine has to work, cylinder deactivation	
Actions to Improve Fuel Economy			
Speed	8	Reduce speed to improve fuel economy	7-23 ($0.23-0.74/gal)
Sudden acceleration or hard braking	7	Braking dissipates energy, acceleration affects "stoichiometric combustion"	5-33 ($0.16-1.06/gal)
Tire pressure	4	Received knowledge, not sure why works	Up to 3 ($0.10/gal)
Accessories other than A/C	3	Accessories must use energy, but not sure how much	Mentioned but not quantified
Air conditioning	3	Accessory load lowers fuel economy	5-25
Freeway driving	3	Highway mileage is better than city (common knowledge), but informants unclear as to why	
Regular oil changes	3	Oil quality and matching the type of oil to the season	1-2 ($0.03-0.06/gal)
Avoid traffic jams	2	Listen to radio, be aware of construction, timing of trips	
Driver attitude	2	Reducing hard acceleration, braking and driving speed	
City driving	2	Stop-and-go, braking, and enhanced vehicle wear and tear in city driving lead to lower fuel economy	
Fuel additives	2	Advertisements claim fuel economy improvement, but informants generally skeptical of these claims	
Manual/automatic transmission	2	Manual transmissions have better fuel economy (common knowledge), but informants unclear as to why and several mentioned hearing that new automatics are actually no longer less fuel efficient than manuals	
Reduce unnecessary idling	2	Don't start the car until ready to go, turn off rather than idle, store car in garage so don't need to de-ice	Mentioned but not quantified
Tune-ups and maintenance	2	Air flow through vehicle cited as important	4-10 ($0.13-0.32/gal)
Anticipate traffic signals	1		
Drafting	1	Driving closely behind a large truck improves fuel economy due to reduced wind resistance	
Octane rating	1	Higher "performance" gasoline gives higher mileage	
Price of gas	1	Avoid "suspiciously low prices" because low price may signal poor quality, which would get poor mileage	
Remove excess weight	1	Box of books in the trunk	1-2 per 100 lbs. ($0.03-0.06/gal)
Roof rack/aerodynamics	1	Wind noise indicates lower fuel economy	Mentioned but not quantified
Actions to Reduce Total Fuel Use			
Use alternate mode	7	Mode-switching (e.g., to bicycle, bus, walking)	
Reduce trips	6	Combine errands to reduce total driving, carpooling	Mentioned but not quantified
Vehicle selection	2	In multiple-car households, try to use the more fuel efficient vehicle more frequently	Mentioned but not quantified
Reduce air travel	1		
Exogenous Factor Impacting Fuel Economy			
Season	4	Winter driving uses more fuel because the heater is on. Hybrid owners commented that their fuel economy was reduced in the winter	Mentioned but not quantified
Miserable weather	2	Increased idling time (e.g., pedestrians crossing, warming up car)	

Note: EPA estimated fuel savings are from DOE and EPA (2007). They are included to give a sense for how well perceptions of fuel economy improvements translate into actual savings.

3.5. Energy savings: it's all relative

Vehicle energy efficiency is evaluated relative to other vehicles. That is, when people say they have 'good' or 'bad' fuel economy, the statement is grounded in some evaluation of their fuel economy *relative* to what they perceive for other vehicles and the fleet average. Our sampled informants generally did not have a concept of the *absolute* quantity of energy used in their transportation, how it compared to their other energy uses, or what is possible for transportation energy use (e.g., could a car get 100 mpg?). But they generally did have a concept of the relative energy use vis-à-vis other vehicle options and driving patterns, and evaluated themselves as being better than average in some way, relative to at least some benchmark.

For example, Megan said,

> What matters more is what I can do relative to what else is out there. And so I feel like my car is using less energy than the majority of the other cars, so relatively speaking I'm doing well with my energy use.

This result suggests that we will do only as well as we set the bar. In other words, "good" and "bad" fuel economy is effectively defined in the public mind relative to the Corporate Average Fuel Economy (CAFE) standards (as expressed via on-road vehicle performance) or relative to another perceived benchmark (e.g., typical sport-utility vehicles, SUVs).[13] Thus, if CAFE standards are set at 20 mpg and a person buys a 22 mpg vehicle, they will feel good about "saving gas," and the 40 mpg hybrid will be impressive only until the 80 mpg vehicle is unveiled.

3.6. Purchase point considerations

Our interviews confirmed the general understanding that purchasing a vehicle involves juggling a large number of factors. When speaking of purchasing cars, many factors other than fuel economy were discussed; some of the more common are listed in Table 4.

Several informants mentioned fuel economy as a high priority, but also took other considerations into account when they became engaged in the vehicle purchasing process. Sara illustrates this accounting, with more awareness of the difference between her intention and her actual purchase than most.

> Thinking back to when I bought the car, and I thought that fuel efficiency was the main thing I was in the market for, but I am remembering, and it's kind of painful…I went in and told the sales guy my number one priority was fuel efficiency, and so I was shown all sorts of options, and I must admit, I didn't go with, well, you have to understand, I was like 'I am going to be spending more on this than I have on anything, so I'd better like it. So I admit that one of the other cars that kept coming up was a Mazda that had

[13] Although we did not ask it, the same is likely true for safety standards. Thus, a five-star crash test rating is only meaningful to the extent that it is better than a four-star rating. Likewise, it is likely that few people have a concept of the risk of injury or death while driving in anything other than relative terms (e.g., less risky than last year, or less risky than crab fishing).

better efficiency, but it was too sporty for me, even though several people told me it was a better car for the price, but in the end I was like, 34 or 35 miles per gallon highway, what's the difference? I like this one better. And before I bought it, I would have thought that only fuel efficiency would matter.

Table 4: Factors mentioned as important in vehicle purchase decisions

Characteristic	Frequency
Price	8
Function (e.g., hauling, towing, 4 wheel drive)	8
Fuel Economy	7
Safety	5
Style / color	5
Reliability	4
Available on the lot	3
Lowering environmental impact (including potential for fuel switching)	3
Maintenance cost	3
Size	3
Accessories (e.g., sunroof, stereo)	2
Comfort	1
Vehicle history	1

A Honda Civic hybrid owner, Margaret, did not mention fuel efficiency per se, but stated that her primary consideration was an "obsession" with reducing her "impact." Both Scott and Debbie also seemed strongly motivated by minimizing their environmental impact in their vehicle purchase decisions.

> My husband at the time was trying to get me to look at some Acura or something, and was saying things about the engine. And I said, 'Look, it could have a windmill at the top and only go top speed 40 miles per hour, and I would still want the hybrid.' I was obsessed with reducing my impact. – Margaret

> I really believe I should minimize my impact on the environment, and also I'm trying to be thrifty, and people driving SUVs are just stupid for spending so much money on gas. I have no idea why people would do that. I can kind of understand the safety argument – having a two-ton steel cage around you and being four feet higher than those of us in Corollas, but that's just a tradeoff I make. – Scott

Debbie chose the word "unconscionable" in describing the strength of her motivation to place energy use as the top priority in vehicle purchase (and many other) decisions, and apparently made some effort to consider full lifecycle energy use rather than just fuel economy.[14]

> It is unconscionable that we would own a vehicle that wasn't fuel efficient… it's a matter of right living…but the capital investment is part of the cost to the system and the cost of a Prius was a bigger drag on the system than we could justify.

Other informants were motivated to save energy by financial and other factors rather than reducing environmental impact. These are summarized in Table 5.

Table 5: Motivations for saving energy in transportation

Motivation	Frequency
Reduce environmental impact (including greenhouse gas emissions)	5
Saving money	4
Reduce war and conflict	2
Risk of peak oil	1
Right living	1
Part of modern culture	1

As noted previously, it appears the prominence of the EPA estimated fuel economy (in mpg) on window stickers has raised public awareness at least during vehicle purchasing. Interestingly, this mindset is opposite from what Kempton and Montgomery (1982) found for household energy use, where operational decisions like thermostat settings and turning off lights were the primary actions taken to save energy. No informants in Kempton and Montogmery's (1982) study considered moving to a smaller house, but many of our informants mentioned downsizing to a smaller vehicle as a primary option for saving energy. Perhaps the discrepancy in transaction costs explains this difference since cars are more easily bought and sold than houses. Thus, there appears to be a fundamental difference in how people attempt to minimize energy use in transportation and in households.

Working counter to these expressions of interest in fuel economy for reduced impact, another common theme was the implicit inverse relationship between safety and fuel economy. Smaller vehicles are perceived as being more fuel efficient but also less safe than larger vehicles. For example, Mary said,

> I like the feeling of having a big car because if you get into an accident you feel more protected. I never felt safe in the Toyota, and the Honda Civic if I was driving on the highway. I prefer a more full sized car, rather than a smaller car, even though it does worse on gas.

[14] Scott also claimed to have done some "lifecycle" calculations when considering vehicle purchases, although he could not remember the specific method of calculation.

Similarly, Patrick said,

> I've got a fondness for big old gas guzzlers… I like the mechanics of large rides… they were made out of real metal… there was quality in the workmanship.

One informant, Bob, said that he felt like he could no longer be safe in a fuel-efficient car, saying,

> It was a small car, and it ran great and got great mileage. But you know, with all those SUVs around now, I wouldn't want to drive it now. You know, it's like an arms race out there. In a car like that, you can't see, and you have to wonder if you got in an accident with a Chevy Suburban or a Dodge Ram what would happen to you. You'd be obliterated. If everyone would go back to driving cars like that [the Mazda], I'd be delighted.

Later, the same informant commented about a car he owned at the moment (in response to the arms race):

> It's a pretty big car, and you know, you are paying for all that armor. It adds weight to the car and that lowers the mileage.

Finally, it was interesting to hear respondents recall the element of chance (fate according to some) in vehicle purchase decisions. Debbie described the purchase of her first vehicle as the following.

> That's the car I bought because the car dealer in Port Byron, where Dad had done a little business, for some reason had got this new Chevy Nova on the lot and was willing to give Dad, and therefore me, a good deal on it, so that's why I bought the Chevy Nova. For no other reason. I had done absolutely no other looking or shopping or anything. I don't think I even… I might have driven it. But I think it was mostly Dad saying, 'you want to buy a car? That's the car.'

This type of chance acquisition, or acquisition of convenience, was particularly true for first vehicles, which were oftentimes inherited from family members. On the other hand, Patrick related his vehicle ownership history as essentially a sequence of chance encounters and transactions. Among other things, he said:

> I purchased my first vehicle from the auction lot of the state highway department, so that was a piece of crap… I literally walked to work in college in Fairbanks where it was negative 40, so my boss eventually gave me an old Rover Sedan and that was a cool car, in the Rover mindset, a good ride for college.

Thus, it is important for researchers interested in choice parameters and thought processes involved in energy consciousness to include a stochastic component. It is a fallacy to think that all decisions are planned (with or without energy as a consideration) since at least some actions are wholly circumstantial and serendipitous.

3.7. The influence of gasoline price

Our interviews generally imply that while gasoline price has not been a primary consideration in the past, fuel prices are now reaching a point where they are affecting consumer behavior, both in vehicle purchase and use decisions. For example, when asked about desirable qualities in a new vehicle purchase, Mary said,

> If I was going to replace my car… [gas price] would be an issue now because [they] are so damn expensive. You know what we're paying for a liter of gas here now? $1.08 [CDN].

For vehicle use decisions, Patrick summed up the comments of many other respondents when he said,

> Fuel efficiency hasn't been a consideration in the past, but as price goes up, it is becoming one. I have to do a lot of driving in the real-estate business, so cost is important. Gas becomes a luxury rather than a utility as price goes up… maybe you don't idle for listening to the radio but wear out the battery instead. Do you want the heater on while waiting for a friend or go chilly on it? With homes, there are probably more people going chilly. Do you lubricate differently or change tires to change mileage? Heating fuel cost has tripled and the same with gasoline, leaving the family budget with only maybe 200 dollars disposable money – that's not recreational.

And, in reminiscing about his first car, Herman said,

> Of course, we didn't give a rip about what kind of mileage it got because gas was like 19 cents a gallon. When I got my Volkswagen, I drove it to Iowa and it cost me three bucks to fill it up.

Other respondents expressed various desires for mode switching, motivated by the high gas prices, but it is unclear whether any were following through with their statements. The exception may be Daniel, who, when asked what the largest expense of owning a car was, responded (interviewer speech in italics),

> Well, I'd like to say that I took the bus today for the second time…*What prompted you to start taking the bus?* Well, in addition to gas being $3.75, parking got expensive, and this is partly my fault,[15] because the city rezoned the land, and so now developers want to buy it, and they raised their rates to $100 a month, but the commuter bus pass is only $56, and I get that pre-tax

[15] Daniel is a planner for the city of Los Angeles.

purchase break. It's a nice bus. It's an express one, but still it takes time, and there are some people with hygiene and showering issues.

These findings suggest short-term mode and vehicle use changes motivated by high gas prices. If true (i.e., acted upon), it is a substantial result considering recent work by Hughes et al. (2006) showing that the short-run price elasticity of gasoline demand is very small.

4. Conclusions

From our interviews, we have drawn the following general conclusions.

- **Cars use gasoline.** In other words, our informants did not think about their vehicles using "energy," but rather about their vehicles using gasoline (measured in gallons).
- **Dollars compensate for an inability to convert energy units.** The inability to think broadly in terms of "energy" and to convert between energy units (e.g., kilowatt hours, gallons fuel, megajoules) makes evaluation of relative energy use across applications and energy forms very difficult. Thus, money becomes the common unit for measuring all energy use, and price differentials can confound actual energy use differences.
- **Fuel economy is measured in miles per gallon.** The prominence of mpg as a metric of energy use in our informants' minds suggests that providing information does work for getting a concept into the popular lexicon (i.e., EPA estimated mpg on window stickers). Furthermore, this information appears to influence purchase behavior, at least in informant statements. But, it appears we have become trained to think in more-is-better terms and to quantify energy use volumetrically, both of which may present challenges for communication as alternative fuels gain market share.
- Similarly, **in-dash fuel economy displays seem to be gaining popularity**, although further development may be necessary to engrain the concept of driver behavior as a factor in realized fuel economy, and to improve the displays' effectiveness in conveying information.
- **People already track their fuel economy,** independent of information provided by vehicle systems (e.g., in-dash fuel economy display), although the consistency of their records and rigor of their estimation methods vary.
- **Energy savings are relative.** Our informants tended to evaluate their fuel economy relative to a benchmark of some kind—whether CAFE standards or their perception of the fleet (or vehicle class) average. Thus, the CAFE standards give us a lever to redefine 'good' or 'bad' fuel economy. For instance, if CAFE standards are set at 30 mpg and a person buys a 32 mpg vehicle, they will feel good about 'saving gas.'
- **Gasoline prices** are reaching the point where they are influencing both vehicle purchase decisions and vehicle use behavior.
- **Purchase dominates.** Consideration of energy use is more prominent at the point of vehicle purchase rather than during vehicle operation.

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