Mobility Behavior vs. Vehicle Specifications
Optimizing Consumer Autonomy and Environmental Impact in Light of Vehicle Electrification

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CONTENTS

1. Mobility – Scope and Vision

2. Vehicle and Consumer Basics

3. Mobility Behavior: Driving and Charging Patterns


5. Matching Vehicle Specifications and Mobility Behavior

6. Outlook and Proposed Work
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Automobile, Mobility ... Why Not Just “Cars”?

Mobility = Mobility Device + Mobility Consumer
Vision: Electric-Automated-Connected-Public

Connected via WiFi, Cellular

Dispatched via internet

Automated incl. Infrastructure

Electric and Wirelessly Powered
Key Elements to Assess Personal Mobility

- Driver Assistance
- Psychology
- Sociology
- Business
- Economics
- Technology
- Design
- Connected Mobility
- Resources
- Environment
- Alternative Energy
Overview Alternative Energy - Fuel Diversity

Source: http://www.afdc.energy.gov/ (adapted)
Alternative Fuel Vehicles – Electrification
<table>
<thead>
<tr>
<th>Year</th>
<th>Electric Only</th>
<th>Hybrid Electric</th>
<th>ICE Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980s</td>
<td>✔ Catalytic Converter ✔ Lead Acid</td>
<td>✔ Mild Hybrid ✔ Full Hybrid</td>
<td>✔ DI-Diesel</td>
</tr>
<tr>
<td>1990s</td>
<td>✔ NiMH ✔ Ethanol</td>
<td>✔ Start/Stop (Micro Hybrid)</td>
<td>✔ Natural Gas</td>
</tr>
<tr>
<td>2000s</td>
<td>✔ Fuel Cell Trials ✔ Wireless Charging (static)</td>
<td>✔ Plug-In Hybrid</td>
<td>✔ Ethanol</td>
</tr>
<tr>
<td>2010s</td>
<td>✔ Li-Ion</td>
<td>✔ Downsizing</td>
<td>✔</td>
</tr>
<tr>
<td>2020s</td>
<td></td>
<td>✔ Additional Efficiency Measures</td>
<td></td>
</tr>
</tbody>
</table>

Future Vision:
- 2035: >99% of new LDV + HDV with ICE

Additional Measures:
- Fuel Cell Trials
- Wireless Charging (static)
- Additional Efficiency Measures
- Metal Air
- H₂ Mass Market

Source: Author's own observation, except [1]: http://www.eia.gov/oiaf/aeo/tablebrowser/, reference case 2035, EIA, 2013
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Power Requirements to Move a Vehicle

- Required Power
- Power, 15% hill
- ICE Power, 1st
- ICE Power, 2nd
- ICE Power, 3rd
- ICE Power, 4th
- E-Motor Power

- Vehicle Speed [m/s]
- Power at Wheel [kW]
Combustion Engine and E-Motor Efficiency

Exemplary Combustion Engine (efficiency 35…10%)

Exemplary Electric Motor (efficiency 95…70%)
Engine >> Motor, Tank >> Battery = Done!? 

**Electric vs. Gasoline**

- No Tailpipe Emissions
- Greenhouse Gases/Pollution

- Utility Company
- OPEC

- 100+/- Mile Range
- 300+ Mile Range

- Hours to Recharge
- Minutes to Refuel

- 2 cents per mile
- 12 cents+ per mile

Market Penetration of Electrified Vehicles

Comparison Market Penetration HEV vs. PEV

PEV sales 12/2010 through 11/2012
HEV sales 12/1999 through 11/2001

Source: http://en.wikipedia.org/wiki/Plug-in_electric_vehicles_in_the_United_States
Demographics of Plug-In Consumers

- Average age of 55
- 74% are 45 years or older
- 61% are male
- 29% make more than $150,000 per year
- 82% make more than $100,000 per year
- Average household size of 2.7

Top 10 markets represent 2013 nearly 50%

Hype Cycles Regarding Electric Mobility

1990 - 2050

Hype 1: Ecology
- New CO₂ targets / Technology leap / market demand not satisfied

Hype 2: Peak of exaggerated expectations / hopes
- Disillusionment / "Valley of tears" / Intensive R&D activities to attain market maturity

Hype 3: More serial BEVs available
- Path of enlightenment / Sustainability awareness / Market-oriented industrialization

Hype 4: Consolidation
- More stringent CO₂ targets / Standardization / Market breakthrough / Productivity / Start of payback period

BEV breakthrough, but market entry of many competitors and clear volume increase

Source: Johann H. Thomforde, Competence & Design Center for Mobile Innovations, 2012
Challenges for EVs – Range, Charge, Cost

Challenges US consumers see regarding electric vehicles [1]
28% range and battery life
20% availability of charging stations
17% total cost/affordability
9% high [purchase] cost of vehicles

Challenges EU industry experts see regarding electric vehicles [2]
65% range
57% availability of charging stations
55% total cost/affordability
30% not suitable for everyday driving

Analysts expect EVs to have 2% to 3% share of the new-car market by 2020 [3]

The vast majority of consumers aren't adapting to or adopting the new technology for a variety of reasons:

**Price** – The average cost of a new vehicle is around $30,000, not including average dealer incentive of $2,446. The Volt is about $40,000. The Fisker Karma is close to $100,000. A Tesla Model S runs $62,400 to $87,400. That could change over time as more sales mean greater economies of scale and lower per-unit manufacturing costs. Plus, Nissan dropped the Leaf's price to under $30,000 before any tax incentives.

**Limited range** -- Gasoline has a great energy density, which means the amount of energy in a given volume of space. However, it must constantly be replaced. Batteries can be recharged, but they have a low energy density, which generally means that an electric car can travel fewer miles without recharging than car can do on a full tank of gas. This is an inconvenience that most consumers seem unwilling to put up with.

**Battery issues** -- Not only is there the question of how much energy the battery can store, but its life span. Batteries only recharge a certain number of times. There is the potential for this expensive component to need replacement after a number of years, although the models haven't been out long enough to see.

**Price of oil** -- Automobile technologies are like solar power: they get hot every time global oil prices significantly soar. Remember that oil prices jumped in 2008. Now that they are much lower again, consumers feel less pressure to make the move.

**Lack of charging stations** -- One of the moves that made petroleum-based automobiles popular was the building of fuel stations all over the country. Suddenly drivers could refuel and avoid being stranded. There isn't a broadly-available equivalent that will necessarily work with all electric cars. Better Place tried to combine tying the sale of cars (the Renault Fluence Z.E.) with a network of charging stations (in Israel and Denmark, for starters). People driving any electric car need to be able to plug in wherever they are.

**Inconsistent nature of tax subsidies** -- Tax subsidies of thousands of dollars in the U.S. have taken a big chunk off the price sticker of a new electric car. But that sort of public policy move is hardly guaranteed to remain. Consumers see enough other problems that reducing the tax bill doesn't become the major incentive for a purchase that legislators hoped it might.

Source: http://www.cbsnews.com/8301-505124_162-57586642/is-reality-pulling-the-plug-on-electric-cars/
EVs in the Eye of the Consumer

Assumption 1
Consumers see the EV as a vehicle option, which:
- costs more and offers less
- is a limited mobility device for unlimited mobility expectations
- is a change with regard to the system that works “well”
- requires to change behavior: i.e. plan ahead, less spontaneous, more confined
- might defy the purpose why one gets a car in the first place: to be independent

Assumption 2
As a solution to this limitation, one can:
- lower cost of vehicle (i.e. purchase price and cost of operation)
- improve range of operation (i.e. battery capacity)
- improve charging options (i.e. denser / more powerful charging network)

Assumption 3
Even if “2” works out, change in behavior still necessary and needs to be addressed
<table>
<thead>
<tr>
<th>Conventional Vehicle</th>
<th>Battery Electric Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Get in the car and go</td>
<td>Plan ahead and be reasonable</td>
</tr>
<tr>
<td>Refuel when you stop</td>
<td>Recharge while you park</td>
</tr>
<tr>
<td>One size fits all</td>
<td>A car specifically tailored for the job</td>
</tr>
<tr>
<td>Get what you pay for</td>
<td>Pay more, get less…</td>
</tr>
<tr>
<td>Low upfront cost</td>
<td>High(er) initial / low(er) reoccuring cost</td>
</tr>
<tr>
<td>Start engine, warm it up</td>
<td>Push button and go</td>
</tr>
<tr>
<td>High power = low mpg</td>
<td>High power + low guilt</td>
</tr>
<tr>
<td>Sound as feedback / style</td>
<td>Silent driving</td>
</tr>
<tr>
<td>Jerkiness from shifting</td>
<td>Shift-free driving</td>
</tr>
<tr>
<td>Pay for infrastructure</td>
<td>HOV-lane access, preferred parking, low tax</td>
</tr>
<tr>
<td>Go to gas station every week</td>
<td>Charge every night, car is always full</td>
</tr>
</tbody>
</table>
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CONTENTS

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Fleet Distribution – Where are the Vehicles?

What would the “best” vehicle based on the average usage look like?

Source: 2001 National Household Travel Survey; GM Data Analysis (Tate/Savagian) - SAE paper 2009-01-1311
What would the “best” vehicle based on the average usage look like?
Consumer Choice: Average vs. Extreme Case
### Average Use Case vs. Average Vehicle

<table>
<thead>
<tr>
<th></th>
<th>Average Daily Usage</th>
<th>Average US LDV</th>
<th>“Typical” Max. Indiv. Use Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Travel Distance</strong></td>
<td>25 mls(^1)</td>
<td>&gt; 300 mls(^1)</td>
<td>&gt;&gt; 300 mls(^1)</td>
</tr>
<tr>
<td><strong>Top Speed</strong></td>
<td>~ 35 mph(^\ast)</td>
<td>~ 120 mph(^\ast)</td>
<td>~ 100 mph(^\ast)</td>
</tr>
<tr>
<td><strong>Engine Power</strong></td>
<td>~ 30 kW(^\ast)</td>
<td>~ 165 kW(^4)</td>
<td>~ 200 kW(^\ast)</td>
</tr>
<tr>
<td><strong>Vehicle Occupation</strong></td>
<td>1.6(^2)</td>
<td>~ 5(^\ast)</td>
<td>~ 7(^\ast)</td>
</tr>
<tr>
<td><strong>All Wheel Drive, Airbag, …</strong></td>
<td>~ 7*10(^{-5}) (^3)</td>
<td>~ ?</td>
<td>~ ?</td>
</tr>
</tbody>
</table>

**Sources:**

- Sanna, L., “Driving the Solution – The Plug-In Hybrid Vehicle”, EPRI Journal Fall 2005
- “2009 National Household Travel Survey”, U.S. Department of Transportation, 2010
- “Analysis of CAFE Standards for Light Trucks and Increased Alternative Fuel Use”, Energy Information Administration, 2002

\(^1\) Author’s estimate
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Different Levels of Vehicle Electrification

Conventional

ICE Powered Vehicle (CV)

Electrified

Hybrid Electric Vehicle (HEV)

Plug-In Hybrid Electric Vehicle (PHEV)

Battery Electric Vehicle (BEV)
More Battery Capacity = More Autonomy

The Range Solution—Today and Tomorrow

- Larger Battery (a little extra charge)
- Range Extender (onboard generator)
- Dynamic Charging (charge as you go)
Alternative Range Solution: Battery Trailer

Source: http://www.youtube.com/user/ebuggy01
Alternative Range Solution: Spare Battery

„Reserve battery“ returnable modules also fulfil the function of absorbing crash energy

Zinc-air technology

Capacity of 4 kWh
Nissan LEAF "Go the Distance" Program

Weekend road trip? No Problem!

Nissan's "Go the Distance" Program delivers range when you need it!

- Program covers the cost of an Altima (participants can upgrade) rental car (up to $40/day)
- Nissan Rental Car for up to 10 days from time of purchase (rentals never expire)
- Program offered exclusively through Nissan Rental Car (NRC) and One?to?One Rewards dealers
- Nissan will apply points to customer's One?to?One Rewards card at the time of purchase (or lease) of a new Nissan LEAF (only)
- Points are stipulated to this program and cannot be used for any other purchase

Visit Nissan Sunnyvale for more details! Directions
**More / Faster Charging = More Autonomy**

<table>
<thead>
<tr>
<th>Type</th>
<th>Power supply</th>
<th>Voltage</th>
<th>Max current</th>
<th>Charg Time*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Single phase - 1,9 kW</td>
<td>120 VAC</td>
<td>16 A</td>
<td>12-16 hours</td>
</tr>
<tr>
<td>Level 2</td>
<td>Single phase - 3,3 kW</td>
<td>230 VAC</td>
<td>16 A</td>
<td>6-8 hours</td>
</tr>
<tr>
<td>Level 2</td>
<td>Single phase - 7 kW</td>
<td>230 VAC</td>
<td>32 A</td>
<td>3-4 hours</td>
</tr>
<tr>
<td>Level 2</td>
<td>Single phase - 18 kW</td>
<td>230 VAC</td>
<td>80 A</td>
<td>1-2 hours</td>
</tr>
<tr>
<td>Level 3</td>
<td>Three phase - 10 kW</td>
<td>400 VAC</td>
<td>16 A</td>
<td>2-3 hours</td>
</tr>
<tr>
<td>Level 3</td>
<td>Three phase - 24 kW</td>
<td>400 VAC</td>
<td>32 A</td>
<td>1-2 hours</td>
</tr>
<tr>
<td>Level 3</td>
<td>Three phase - 43 kW</td>
<td>400 VAC</td>
<td>63 A</td>
<td>20-30 min</td>
</tr>
<tr>
<td>Level 3</td>
<td>Direct current - 50 kW</td>
<td>400-500 VDC</td>
<td>100 - 125 A</td>
<td>20-30 min</td>
</tr>
<tr>
<td>Level 3</td>
<td>Direct current** - 90 kW</td>
<td>480 VDC</td>
<td>200 A</td>
<td>15 min</td>
</tr>
<tr>
<td>Gasoline</td>
<td>Gas station - ≈10MW</td>
<td>--</td>
<td>20 l/min</td>
<td>3-4 min</td>
</tr>
</tbody>
</table>

*) Time to recharge 25kWh (≈ 75mls range), except “Gasoline” (≈ 300mls range)

**) Tesla Supercharger

EV Consumer Charging Behavior

**EV Project Electric Vehicle Charging Infrastructure Summary Report**

Region: ALL  
Report period: October 2012 through December 2012  
Number of EV Project vehicles in region: 4783

<table>
<thead>
<tr>
<th>Charging Unit Usage</th>
<th>Residential</th>
<th>Private Nonresidential</th>
<th>Publicly Available</th>
<th>Publicly Available DC Fast</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of charging units</td>
<td>4,819</td>
<td>78</td>
<td>1,988</td>
<td>54</td>
<td>6,939</td>
</tr>
<tr>
<td>Number of charging events</td>
<td>341,828</td>
<td>1,699</td>
<td>36,990</td>
<td>8,089</td>
<td>388,606</td>
</tr>
<tr>
<td>Electricity consumed (AC MWh)</td>
<td>2,827.92</td>
<td>14.83</td>
<td>311.16</td>
<td>58.39</td>
<td>3,212.30</td>
</tr>
<tr>
<td>Percent of time with a vehicle connected to charging unit</td>
<td>42%</td>
<td>10%</td>
<td>5%</td>
<td>2%</td>
<td>31%</td>
</tr>
<tr>
<td>Percent of time with a vehicle drawing power from charging unit</td>
<td>8%</td>
<td>3%</td>
<td>2%</td>
<td>2%</td>
<td>6%</td>
</tr>
</tbody>
</table>

**Number of Charge Events**

- 88% Residential Level 2
- 10% Private Nonresidential Level 2
- 2% Publicly Available DC Fast

**Electricity Consumed**

- 88% Residential Level 2
- 10% Private Nonresidential Level 2
- 2% Publicly Available DC Fast

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# Questionnaire to Quantify Mobility Behavior

## Question 1: In a regular week, during which you commute to work, how many miles do you drive every single day?

<table>
<thead>
<tr>
<th></th>
<th>Daily Total Driving (Miles)</th>
<th>Daily Highway Driving (Miles)</th>
<th>Explanation (Not Required)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regular Day example</strong></td>
<td>30</td>
<td>20</td>
<td>Drive 30mls this day, 20 mls on highway</td>
</tr>
<tr>
<td>Monday</td>
<td>25</td>
<td>20</td>
<td>Live close to the highway, drive to work</td>
</tr>
<tr>
<td>Tuesday</td>
<td>25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Wednesday</td>
<td>25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Thursday</td>
<td>25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Friday</td>
<td>25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Saturday</td>
<td>30</td>
<td>10</td>
<td>Weekly Grocery shopping</td>
</tr>
<tr>
<td>Sunday</td>
<td>10</td>
<td>0</td>
<td>Diving around town, no highway driving</td>
</tr>
</tbody>
</table>

## Question 2: How many miles do you drive on a non-regular day?

<table>
<thead>
<tr>
<th>Days per year for each incidence</th>
<th>Daily Total Driving (Miles)</th>
<th>Daily Highway Driving (Miles)</th>
<th>Explanation (Not Required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Regular Day Example</td>
<td>3</td>
<td>40</td>
<td>35 Drive to San Francisco 3 times a year, mostly highway driving</td>
</tr>
<tr>
<td>Holiday/Vacation 1</td>
<td>1</td>
<td>400</td>
<td>380 Drive to LA from Palo Alto, mostly highway driving</td>
</tr>
<tr>
<td>Holiday/Vacation 2</td>
<td>2</td>
<td>50</td>
<td>40 Drive around LA in the same trip, for 2 days</td>
</tr>
<tr>
<td>Holiday/Vacation 3</td>
<td>1</td>
<td>400</td>
<td>370 Drive to Palo Alto from LA, tour in the city before departure</td>
</tr>
<tr>
<td>Holiday/Vacation 4</td>
<td>3</td>
<td>180</td>
<td>170 Drive to Monterey bay, daily round trip, 3 times a year</td>
</tr>
<tr>
<td>Short/Business Trip 1</td>
<td>2</td>
<td>40</td>
<td>20 Business trip to San Jose, 2 times a year</td>
</tr>
<tr>
<td>Short/Business Trip 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tour with Visiting Friend 1</td>
<td>5</td>
<td>40</td>
<td>5 Drive to Milpitas to meet visiting friends, 5 times a year</td>
</tr>
<tr>
<td>Tour with Visiting Friend 2</td>
<td>3</td>
<td>60</td>
<td>15 Drive to Fremont to meet visiting friends, 3 times a year</td>
</tr>
<tr>
<td>Tour with Visiting Friend 3</td>
<td>5</td>
<td>15</td>
<td>15 tour in downtown Palo Alto area</td>
</tr>
<tr>
<td>Other Incidence 1</td>
<td>2</td>
<td>5</td>
<td>0 Drive to hospitals</td>
</tr>
</tbody>
</table>
Sum of Individuals Yields Average… and More

Cumulative Daily Distance / Total [%]

Daily Total Travel Distance per Vehicle [mls]

- Persona 1
- Persona 2
- Persona 3
- Persona 4
- Persona 5
- Persona 6
- Persona 7
- Persona 8
- Persona 9
- Persona 10
- Average
- NHTS
## Average Driving and Foregone Trips

<table>
<thead>
<tr>
<th>Persona#</th>
<th>Annual MPG</th>
<th>MPGe (Approximate)</th>
<th>Foregone Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persona1</td>
<td>49</td>
<td>60</td>
<td>72</td>
</tr>
<tr>
<td>Persona2</td>
<td>49</td>
<td>71</td>
<td>70</td>
</tr>
<tr>
<td>Persona3</td>
<td>50</td>
<td>105</td>
<td>99</td>
</tr>
<tr>
<td>Persona4</td>
<td>50</td>
<td>59</td>
<td>73</td>
</tr>
<tr>
<td>Persona5</td>
<td>49</td>
<td>61</td>
<td>85</td>
</tr>
<tr>
<td>Persona6</td>
<td>49</td>
<td>62</td>
<td>90</td>
</tr>
<tr>
<td>Persona7</td>
<td>50</td>
<td>53</td>
<td>49</td>
</tr>
<tr>
<td>Persona8</td>
<td>50</td>
<td>67</td>
<td>99</td>
</tr>
<tr>
<td>Persona9</td>
<td>50</td>
<td>56</td>
<td>61</td>
</tr>
<tr>
<td>Persona10</td>
<td>50</td>
<td>53</td>
<td>49</td>
</tr>
</tbody>
</table>

1: urban dweller no commute by car, weekend trips 200mls, vacation 350mls
2: photographer, coaches students, visits son in Davis quarterly
3: teacher 20mls commute, run errands 10mls
4: employee 50mls commute, weekend at family villa 100mls
5: employee 60mls commute, weekend errands 15mls, vacation 300mls
6: employee 36mls commute, weekend errands 15mls, vacation 350mls
7: sales person 90-145mls p. day, vacation 300mls
8: employee 50mls commute, weekend errands 15mls, vacation 80mls
9: employee with 40mls commute, shuttle kids 60, vacation 300mls
10: consultant commute 45 / 150 / 300mls, weekend 40mls
**Assumption:** Daily commute is 40 mls round trip and doing that electrically is the “cleaner” option, but consumers want to have peace of mind that they can drive 300 mls with their vehicle without “complicated” recharging.

**Question:** What is the “lightest” option for the extra 260 mls?

<table>
<thead>
<tr>
<th></th>
<th>Gasoline Range Extender</th>
<th>Larger Battery Pack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (miles)</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>Energy Required (kWh)</td>
<td>66.3</td>
<td>66.3</td>
</tr>
<tr>
<td>Efficiency</td>
<td>0.4 X 0.85</td>
<td>-</td>
</tr>
<tr>
<td>Gasoline / Battery Weight (kg)</td>
<td>15.5</td>
<td>522.4</td>
</tr>
<tr>
<td>Equipment Weight (kg)</td>
<td>117</td>
<td>-</td>
</tr>
<tr>
<td>engine, fuel system, exhaust</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Additional Weight (kg)</strong></td>
<td><strong>132.5</strong></td>
<td><strong>522.4</strong></td>
</tr>
</tbody>
</table>

Lifetime Externalities for Electrified Vehicles

# PEV vs. BEV – A Minimum Winning Game?

<table>
<thead>
<tr>
<th></th>
<th>Consumer</th>
<th>Manufacturers</th>
<th>Utilities</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Battery Only Electric</strong></td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Plug-In Hybrid Electric</strong></td>
<td>✔</td>
<td>?</td>
<td>✔</td>
<td>?</td>
</tr>
</tbody>
</table>
Expectation: Shift from BEV to PHEV and REV
Two Main Thrusts in Electrification

Improved Technology and Infrastructure
- Electrified Vehicles Becoming Viable -
  e.g. battery, extender, charge network

New Mobility Solutions and Behavioral Changes
- Consumers Adapting to Limitations -
  e.g. e-commuter + sharing, apps
Mobility Behavior vs. Vehicle Specifications

CONTENTS

1. Mobility – Scope and Vision
2. Vehicle and Consumer Basics
3. Mobility Behavior: Driving and Charging Patterns
5. Matching Vehicle Specifications and Mobility Behavior
6. Outlook and Proposed Work
Outline for a Proposed Research Project

1. Analyze National Household Travel Survey and additional sources, identify similar mobility behaviors, define categories by actual needs, and set assumptions for perceived consumer needs
   **Goal:** quantification and categorization of mobility behavior

2. Describe and categorize vehicle types by level of electrification and build impact simulation model with mobility behavior as input
   **Goal:** simulation model to calculate environmental impact and personal autonomy

3. Apply database and model and calculate environmental impact and autonomy when consumer and vehicle categories as defined under 1-2 are matched to reach optimum for environment and mobility
   **Goal:** characterization of optimal vehicle fleet composition

4. Determine vehicle purchase and operating cost to quantify consumer burden when transitioning to optimal fleet composition, take into account additional (practical, emotional, economical...) factors, and consider measures to mitigate financial burden
   **Goal:** recommendations for a more sustainable vehicle fleet composition and how the optimal mix can be attained through incentives, if necessary
Key Questions for Vehicle Electrification

Under which conditions will electrified vehicles:

• slow down global warming?
• decrease dependence on (foreign / scarce) resources?
• decrease air pollution?
• integrate into electric infrastructure?
• become the better alternative for consumers?

⇒ There is (probably) not just one answer!

Climate   Resources   Pollution   Infrastructure   Consumers
Initial Literature Review of Related Work

- Michaelk, J et al; “Valuation of plug-in vehicle life-cycle air emissions and oil displacement benefits”, 2011
- Karabasoglu, O.; Michalek, J; “Influence of driving patterns on lifetime cost and life cycle benefits of hybrid and plug-in electric vehicle powertrains”, forthcoming 2013
- Helms, H et al; “Electric vehicle and plug-in hybrid energy efficiency and life cycle emissions”, 2010
- Johansson-Stenman, O; Martinsson, P.; “Honestly, why are you driving a BMW?”; Journal of Economic Behavior & Organization; 2006