Determining Costs and Environmental Performance of Conventional and Alternative Vehicles

Photo credit: Michael Graham Richard/TreeHugger

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Transportation Research Conference
St. Paul, Minnesota
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U.S. Retail Gasoline Prices: Up over $1.00 in past year

Source: EIA. http://www.eia.doe.gov/oog/info/gdu/gasdiesel.asp
History of U.S. Retail Gasoline Prices, 1970-2012*

Source: Energy Information Agency, U.S. DOE. *Projected

- Iranian Revolution
- Decline of OPEC Control
- 9-11 Attacks
- Strong Worldwide Demand for Petroleum
- War in Libya
- Weak Economy post 2008 Crash

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History of U.S. Retail Gasoline Prices 1970-2012*

Source: Energy Information Agency, U.S. DOE  *projected
Some Interesting Times for Car Buyers

• More choices
  - hybrids----substantial consumer experience, improved reputation Honda, Toyota,
    offered on more vehicles– minivans, mid-size, pickups
    more manufacturers are offering--- Ford, Hyundai, Nissan
  - electric vehicles
    Nissan Leaf, Fiskar, Tesla , Toyota-Tesla partnership
  - extended range electric vehicles
    General Motors---Volt

• Industry Situation
  - availability of tax rebates on vehicles and charging stations
  - efforts to encourage public charging stations

• Status of Consumers
  - eager to cut gasoline expenses
  - goals of consumers to reduce GHG emissions from personal transportation

• Sources at Ford Motor Company predict that “one in four cars in the U.S. will be electrified by 2020. “
Plan for Today’s Talk

• Discuss capabilities of four types of vehicles
  – Conventional Vehicles (ICE)
  – Hybrids (HEV)
  – Electric Vehicles (EV)
  – Ext. Range /Plug-in Hybrid Electric Vehicles (PHEV)

• Demonstrate a consumer decision tool to anticipate consumer behavior

• Determine Costs of Ownership and Operation

• Compare GHG emissions of the four cars
Toyota Prius—Hybrid Electric Vehicle (HEV)

- Experience: 11 years in production, 1 million sold in U.S.
  > 2 million sold world
- Uses Regenerative Braking to Charge Battery—generates power as the vehicle is slowed by braking
- Battery Assists during acceleration
- Gasoline Engine starts and stops as needed --- delivering 48 MPG
- Excellent streamlining of car
- Price = $23,750 before credits
- Battery Longevity—minor issue
- In 2012 Prius Hybrid with 12 mile range

Source: JDPOWER.com
Source: Toyota.com Australia
on charge will be available (PHEV)
Nissan Leaf--- Electric Vehicle (EV)

- Available in U.S. market in Dec. 2010, 20,000 have been reserved
- Up to 100 mile range
- Lithium Battery Packs under the floor
- Can charge in 16 hours @120 Volts
- Can charge in 8 hours @ 240 Volts
- Rapid re-charge in 30 minutes@ 480 Volts
- Battery Pack has 100,000 mile warranty
- Rapid acceleration, 90 mph possible
- Can direct heating /cooling with cell phone, while plugged in
- Typically-- 4 miles per kiloWatt-hour
- Price = $34,780 with charge station
- Warning: You can’t drive non-stop to Grandma’s House for Thanksgiving in Duluth.
Lithium Ion Battery Packs, Charging Equipment

- Batteries are Under the floorboards
- New Plant Built in Smyrna, Tennessee
Chevrolet Volt-Extended Range Electric Vehicle, a PHEV (plug-in hybrid electric vehicle)

- Most expensive car in analysis $41,000 + $2,000 for 240V charging station
- 40 miles of travel in “charge-conserving mode” using battery
- 300 miles possible when generator is running on premium gasoline--- gets 34 miles per gallon of gas
- Generator does not re-charge battery, but produces power to turn the wheels
- Warranty on battery is 100,000 miles

Source: http://alnewchevyvolt.com/mge3.jpg
Toyota Matrix -
Internal
Combustion
Engine (ICE)

• 1.8 Liter Engine
• Matrix is the Hatchback version of the Corolla
• Most Popular car in the world
• About 30 MPG
• Cost is about $20,000
Economic Analysis Used

- Determine Accumulated Discounted Value of Expenditures Made Over Life of the Car
- What is a car, but a series of expenditures that one assumes for the life of the vehicle?
- Focused on expenditures for ownership, fuel, engine maintenance, battery replacement, assume rapid charging stations in the home---”points of difference”
- Ignored depreciation, license fees, insurance, storage
- Users experiment with flat projections of fuel cost for life of the vehicle
- Force consumers to identify their discount rate
Building up Assumptions

• Assumed 15,000 miles per year for Minnesotans
  – (12,000 miles per year assumed by EPA)

• Battery Replacement Cost in Year 8—a very conservative estimate--- 100,000 mile warranty (150,000 in CA)
  – Battery life hasn’t been a big issue with hybrids

• Cost of Gasoline Engine Maintenance per 3,000 miles ---- oil change, muffler, anti-freeze, filters for oil, air, and gasoline, starter battery and starter-- $60.84 per 3,000 miles

• Price of residential electricity
  – For U.S. 11.26 cents per kWh in 2009
  – MN equaled 9.74 cents per kWh in 2009

  – Source: http://www.eia.doe.gov/fuelelectric.html
GHG Emissions from Gasoline and Electricity

- 10% ethanol blend is most gasoline
  - Gasoline is $92 \text{g CO}_2\text{e} \times 121 \text{MJ/gal} = 24.52 \text{ lb./gal}$
  - Ethanol is $42 \text{ g. CO}_2\text{e} \times 89 \text{ MJ/gal} = 8.23 \text{ lb./gal}$

  (Liska et al., Journal of Industrial Ecology, 13,58-74 (2009))

  Therefore, E10 equals 22.89 lb. CO2 e/ gal.

- U.S. electricity typically emits 1306.18 lb/ MWh

- MN electricity emits 1781.44 lb/ MWh (36% > national avg.)

http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2010V1_0_year07_SummaryTables.pdf
# Input—Assumptions in Yellow Cells

## Car Pricing & Performance Assumptions

<table>
<thead>
<tr>
<th></th>
<th>Conventional Vehicle</th>
<th>Hybrid Vehicle</th>
<th>Electric Vehicle</th>
<th>Extended Range Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negotiated Purchase Price (plus charging station*)</td>
<td>$20,000</td>
<td>$23,750</td>
<td>$34,780</td>
<td>$43,000</td>
</tr>
<tr>
<td>Down Payment (if financed) or Total Purchase Price</td>
<td>$5,000</td>
<td>$5,000</td>
<td>$5,000</td>
<td>$5,000</td>
</tr>
<tr>
<td>Enter months of car loan</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Enter interest rate on car loan</td>
<td>5.00%</td>
<td>5.00%</td>
<td>5.00%</td>
<td>5.00%</td>
</tr>
<tr>
<td>Income Tax Credits for Hybrid, Electric &amp; Charging Station</td>
<td>-</td>
<td>$8,500</td>
<td>$8,500</td>
<td>$8,500</td>
</tr>
<tr>
<td>Cost of Battery Service Assumed in Year 8</td>
<td>$2,000</td>
<td>$8,000</td>
<td>$8,000</td>
<td>$8,000</td>
</tr>
<tr>
<td>Miles per Gallon of Gasoline</td>
<td>30</td>
<td>48</td>
<td>8,000</td>
<td>34</td>
</tr>
<tr>
<td>Miles per kiloWatt-hour of Electricity</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Expected Miles per Year</td>
<td>15,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Miles from Grid Electricity (less or equal to above figure)</td>
<td>8,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Gasoline and Electricity Prices, Greenhouse Gas Emissions Rates and Discount Rate

<table>
<thead>
<tr>
<th></th>
<th>Conventional Vehicle</th>
<th>Hybrid Vehicle</th>
<th>Electric Vehicle</th>
<th>Extended Range Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline (E10) Price for life of car</td>
<td>$4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Addl. Cost of Premium Gasoline Per Gallon</td>
<td>$0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity Price (Grid) per kWh for life of car</td>
<td>$0.0974</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Engine Maintenance Per 3000 miles</td>
<td>$60.84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal Discount Rate Applied to Costs</td>
<td>6.00%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG Emissions per MWh of Electricity (Tons)</td>
<td>1781.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG Emission per Gallon of Gasoline (E10)</td>
<td>22.89</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Affects Fuel Cost of Extended Range Electric only)  
(See attached page.)
# Calculated Values

## Compare Monthly Fuel Costs

<table>
<thead>
<tr>
<th>Monthly Payments, Gas Usage and GHG Emissions in First Five Years</th>
<th>Conventional Vehicle</th>
<th>Hybrid Vehicle</th>
<th>Electric Vehicle</th>
<th>Extended Range Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly Car Payments (if financed)</td>
<td>$283.07</td>
<td>$353.84</td>
<td>$420.32</td>
<td>$575.44</td>
</tr>
<tr>
<td>Monthly Opportunity Cost of Down Payment or Purchase</td>
<td>$25.00</td>
<td>$25.00</td>
<td>$25.00</td>
<td>$25.00</td>
</tr>
<tr>
<td>Average Monthly Gasoline Payments</td>
<td>$166.67</td>
<td>$104.17</td>
<td>-</td>
<td>$72.92</td>
</tr>
<tr>
<td>Average Monthly Engine Maintenance Costs</td>
<td>$25.35</td>
<td>$25.35</td>
<td>-</td>
<td>$11.83</td>
</tr>
<tr>
<td>Average Monthly Electrical Payments</td>
<td>-</td>
<td>-</td>
<td>$30.44</td>
<td>$16.23</td>
</tr>
<tr>
<td>Monthly Costs (ownership, fuel, engine maint.)</td>
<td>$500.09</td>
<td>$508.35</td>
<td>$475.76</td>
<td>$701.42</td>
</tr>
<tr>
<td>Difference in Monthly Payments in first 5 years vs. Conventional</td>
<td>-</td>
<td>-</td>
<td>$8.27</td>
<td>$20.34</td>
</tr>
</tbody>
</table>

## Annual Greenhouse Gas Emissions

| Annual Gasoline Usage (gal.) | 500.0 | 312.5 | 205.9 |
| Annual Electricity Usage from Grid (kWh) | - | - | 3,750 | 2,000 |
| Annual GHG Emissions from Gasoline Usage (lb. of CO2 equiv.) | 11,445 | 7,153 | - | 4,713 |
| Annual GHG Emissions of Electricity Source (lb. of CO2 equiv.) | - | - | 6,679 | 3,562 |
| Total Annual GHG Emissions (lb. of CO2 equivalent) | 11,445 | 7,153 | 6,679 | 8,275 |
| Annual GHG Reduction in Metric Tonnes per Year | - | - | 1.947 | 2.162 |
| Effective CO2 Tax Charged to Self by Owning Alternative Vehicle per Metric Tonne | $4 | (11) | $140 |

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See the CO2 Tax on the Extended Range Electric Vehicles
Hybrid Car Example of Accumulated Discounted Costs of Ownership and Operation—5yr. Loan, $4.00 gas, Battery Replacement in Year 8

Accumulated Discounted Costs of Ownership and Operation of Conventional, Hybrid, Electric, and Extended Range Electric Vehicles by Year

- Loan Paid Off
- Battery Replaced
- Down Payment

- Conventional
- Hybrid
- Electric
- Ext. Range Elect.

Years of Operation

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Baseline Graph, assuming $4.00 gas, 15k miles, 9.74 cent electricity

Accumulated Discounted Costs of Ownership and Operation of Conventional, Hybrid, Electric, and Extended Range Electric Vehicles by Year

Years of Operation

$0, $10,000, $20,000, $30,000, $40,000, $50,000, $60,000

Conventional
Hybrid
Electric
Ext. Range Elect.
Graphs of Accumulated Discounted Costs and GHG Emissions

Accumulated Discounted Costs of Ownership & Operation in Year 15

- Ext. Range Electric: $50,018
- Electric: $33,955
- Hybrid: $38,974
- Conventional: $41,688

Annual GHG Emissions (lb.)

- Ext. Range Electric: 8,276
- Electric: 6,680
- Hybrid: 7,153
- Conventional: 11,445
Electric Car is Still Lowest for life of Vehicle down to $2.41 per Gal. Gasoline
However, the cars have different capabilities

- Electric Vehicles (Evs) may give you range anxiety.
- You can’t drive an EV out to Montana to join Grandmother for a Thanksgiving deer hunt.
- Perhaps you like the interior space and feel of the Chevy Volt
- Etc.

http://www.calamusoutfitters.com/mule-deer-hunting.htm
If Cars are driven 8800 miles /yr, with $4.00 gas, the conventional car has lowest lifetime cost.
Baseline Graph, assuming $4.00 gas, 15k miles, 9.74 cent electricity

Accumulated Discounted Costs of Ownership and Operation of Conventional, Hybrid, Electric, and Extended Range Electric Vehicles by Year

Years of Operation

$0, $10,000, $20,000, $30,000, $40,000, $50,000, $60,000

Conventional
Hybrid
Electric
Ext. Range Elect.

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At $4.50 per gasoline and 15,000 mpy, we see a few changes in costs.
If Gasoline Goes to $5.00 per Gallon, Electric Vehicles Become More Attractive

Accumulated Discounted Costs of Ownership and Operation of Conventional, Hybrid, Electric, and Extended Range Electric Vehicles by Year

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With Power Pricing for Evening Charging at $.05/kWh and Gasoline at $4.00 /gal.

Accumulated Discounted Costs of Ownership and Operation of Conventional, Hybrid, Electric, and Extended Range Electric Vehicles by Year

- Conventional
- Hybrid
- Electric
- Ext. Range Elect.

Years of Operation

$- 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$-

41,688
What Happens to Electrics and Ext. Range Electrics when Tax Credits End with $4.00 Gas and 15,000 mpy?

Accumulated Discounted Costs of Ownership and Operation of Conventional, Hybrid, Electric, and Extended Range Electric Vehicles by Year

- Conventional
- Hybrid
- Electric
- Ext. Range Elect.
If Consumer buys 50% windpower, what happens to GHG emissions at 15K mpy for MN drivers?

To

Annual GHG Emissions (lb.)

<table>
<thead>
<tr>
<th>Type</th>
<th>Ext. Range Electric</th>
<th>Electric</th>
<th>Hybrid</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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A Different Strategy of Battery Usage with Ford Fusions (41 City/36 Highway)-$28,600
By Substituting the Ford Fusion Hybrid ($28.6k) for the Prius and a Camry ($23.5k) for the Matrix--
Hyundai Sonata Hybrid Delivering 35 City/40 Highway for $26,800
GMC and Chevy Hybrid Pickups Available with MPG Improved 33%
Electric Vehicles for Regular Daily Miles

- 50 kWh battery
- Range of 80 miles
- Can be recharged in 6-8 hours on 220V
- This vehicle is manufactured in Turkey and will be distributed in the U.S. in 2010
- Batteries are built by Smith Batteries of the UK, firm with long record of building vehicle batteries
- Could be attractive for repair and delivery services
- Top speed of 75 mph
- Perhaps a replacement for the 140,000 USPS delivery vans now in service

Ford Transit Connect (EV)
Conclusions

• Alternative vehicles cost more, but can be cost-effective while reducing GHG emissions, if you drive enough miles.
• Emissions of electric vehicles can be cut further when utilities increase the proportion of renewables in their portfolio.
• Electric Vehicles are the newcomers, with the shortest operational record, but are very efficient in converting energy.
• Electric Vehicles are cost-effective choices with tax credits, if the consumer can tolerate range issues.
• EVs may be well-suited as fleet vehicles around a city.
• Lots of operational experience is available with hybrids.
• If annual miles driven are low, more expensive vehicles are hard to justify.
• Power pricing plans of utilities may make EVs even more economical if consumers charge at off-peak hours.
Thanks!

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• tiffa002@umn.edu