U.S. Department of Energy – FreedomCAR and Vehicle Technologies Program

Advanced Vehicle Testing Activity - Hybrids, Hydrogen, and Other Alternative Fuel Vehicle Activities

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2006 FedFleet

INL/CON-06-11207
Advanced Vehicle Testing Activity - Background

• Part of the DOE’s FreedomCAR and Vehicle Technologies Program

• Testing partner – Electric Transportation Applications

• AVTA Goal – Provide benchmark data for technology modeling, and research and development programs, as well as to help fleet managers and other vehicle purchasers make informed purchase and operations decisions
Vehicle Testing Methods

• Baseline performance testing (dynamometer & closed track testing) – vehicle-to-vehicle comparisons of vehicle performance in controlled & repeatable environment

• Fleet (accelerated reliability) testing – vehicle performance in “real-world” fleet applications (HEVs 160,000 miles in 36 months)

• HEV end-of-life (at 160,000 miles) testing – conduct battery capacity & power testing
HEV Baseline Performance Testing

• 2002 Test Vehicles
  – Insight, Gen I Civic, Gen I Prius

• 2005 Test Vehicles
  – Accord, Gen II Prius, Silverado (2WD), Escape (2WD)

• 2006 Test Vehicles
  – Lexus RX400h, Toyota Highlander, Gen II Civic, Toyota Camry
HEV Baseline Performance MPG

Baseline Performance MPG (J1634 With & W/O Air)

Miles per Gallon

MPG SAE J1634 Air Off  MPG SAE J1634 Air On

Insight  Gen I Prius  Civic  Gen II Prius  Silverado  Accord  Escape
HEV MPG (J1634) - AC on/off Decrease

Percent MPG Difference (J1634 With & W/O Air)

-30% -25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25% 30%

Insight  Gen I Prius  Civic  Gen II Prius  Silverado  Accord  Escape  Average
28 HEVs - Fleet Testing Status

- 6 - 2001 Honda Insights: Aug/01 – March/05
- 6 - 2002 Gen I Toyota Prius: Nov/01 – April/05
- 4 - 2003 Honda Civics: May/02 – April/05
- 2 - 2004 Gen II Toyota Prius: Nov/03 – ongoing
- 2 - 2004 Chevrolet Silverado: Sept/04 – ongoing
- 2 - 2005 Honda Accord: Jan/05 – ongoing
- 2 - 2005 Ford Escape: April/05 – ongoing
- 2 - 2005 Lexus RX400h: May/05 – ongoing
- 2 - 2006 Toyota Highlander: Oct/05 – ongoing
1.7 Million HEV Fleet Test Miles
HEV Fleet Testing Fact Sheets

- Summarize real-world:
  - Vehicle use
  - Major maintenance & repair events
  - Mileage profile
  - Fuel use
  - Life cycle operating costs
HEV Maintenance / Repairs

- Date, mileage, description & cost/warranty

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### HEV Fleet Testing - Maintenance Sheet
2003 – Honda Civic Hybrid

**Advanced Vehicle Testing Activity**

<table>
<thead>
<tr>
<th>Date</th>
<th>Mileage</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/15/02</td>
<td>5,281</td>
<td>Change of air filters</td>
<td>$27.00</td>
</tr>
<tr>
<td>9/16/02</td>
<td>3,878</td>
<td>Change of air filters</td>
<td>$26.62</td>
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<tr>
<td>8/22/02</td>
<td>15,023</td>
<td>Replacement of air filters service</td>
<td>$21.28</td>
</tr>
<tr>
<td>9/24/02</td>
<td>19,226</td>
<td>Repair accident damage to left front (not included in maintenance costs)</td>
<td>$1,224.54</td>
</tr>
<tr>
<td>10/8/02</td>
<td>20,162</td>
<td>Change of air filters</td>
<td>$20.98</td>
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<tr>
<td>10/31/02</td>
<td>25,147</td>
<td>Change of air filters</td>
<td>$30.67</td>
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<tr>
<td>12/23/02</td>
<td>33,270</td>
<td>Change of air filters</td>
<td>$31.67</td>
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<tr>
<td>2/13/03</td>
<td>43,220</td>
<td>40,000 mile service</td>
<td>$341.68</td>
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<tr>
<td>2/13/03</td>
<td>43,220</td>
<td>Repair accident damage to rear bumper (not included in maintenance costs)</td>
<td>$334.42</td>
</tr>
<tr>
<td>3/14/03</td>
<td>43,311</td>
<td>Change of air filters</td>
<td>$36.67</td>
</tr>
<tr>
<td>4/22/03</td>
<td>62,573</td>
<td>Change of air filters</td>
<td>$30.67</td>
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<tr>
<td>5/1/03</td>
<td>69,332</td>
<td>Change of air filters</td>
<td>$30.67</td>
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<tr>
<td>5/31/03</td>
<td>74,253</td>
<td>30,000 mile service</td>
<td>$324.18</td>
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<tr>
<td>6/24/03</td>
<td>77,233</td>
<td>Replace rear tires and align front wheels</td>
<td>$150.50</td>
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<tr>
<td>6/30/03</td>
<td>77,283</td>
<td>Check Engine trouble light illuminated. Dealer tested; no problem found</td>
<td>warranty</td>
</tr>
<tr>
<td>7/7/03</td>
<td>80,425</td>
<td>Change of air filters</td>
<td>$31.08</td>
</tr>
<tr>
<td>7/28/03</td>
<td>80,630</td>
<td>Check Engine light illuminated. Dealer repaired an intermittent problem with a valve sticking</td>
<td>warranty</td>
</tr>
<tr>
<td>8/31/03</td>
<td>89,264</td>
<td>30,000 mile service</td>
<td>$324.18</td>
</tr>
<tr>
<td>9/2/03</td>
<td>99,353</td>
<td>Change of air filters</td>
<td>$31.08</td>
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<tr>
<td>9/12/03</td>
<td>99,657</td>
<td>Check Engine trouble light illuminated. Updated PCM software installed by dealer.</td>
<td>$50.00</td>
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<tr>
<td>10/4/03</td>
<td>103,210</td>
<td>Ignition system replaced</td>
<td>$50.00</td>
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<tr>
<td>10/25/03</td>
<td>103,210</td>
<td>Change of air filters</td>
<td>$105.23</td>
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<tr>
<td>11/22/03</td>
<td>98,255</td>
<td>Check Engine trouble light illuminated. Dealer replaced the Purge System pressure sensor</td>
<td>$50.00</td>
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<tr>
<td>1/15/04</td>
<td>98,282</td>
<td>Transmission slippage; Transmission replaced</td>
<td>$3,552.62</td>
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<tr>
<td>1/26/04</td>
<td>97,299</td>
<td>Check Engine trouble light illuminated. Catalytic converter replaced</td>
<td>$1,254.58</td>
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<tr>
<td>2/24/04</td>
<td>103,214</td>
<td>30,000 mile service</td>
<td>$280.65</td>
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<tr>
<td>4/16/04</td>
<td>113,884</td>
<td>30,000 mile service and accessory 12 volt battery replacement</td>
<td>$484.09</td>
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<tr>
<td>4/19/04</td>
<td>115,649</td>
<td>Replace bond ties</td>
<td>$112.00</td>
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<tr>
<td>5/27/04</td>
<td>119,273</td>
<td>Change of air filters</td>
<td>$31.92</td>
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HEV Fleet Testing Average MPG

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Fleet Testing MPG</th>
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<tbody>
<tr>
<td>Civic</td>
<td>37.6</td>
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<tr>
<td>Insight</td>
<td>45.2</td>
</tr>
<tr>
<td>Gen I Prius</td>
<td>41.0</td>
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<tr>
<td>Silverado</td>
<td>18.1</td>
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<tr>
<td>Accords</td>
<td>27.9</td>
</tr>
<tr>
<td>Gen II Prius</td>
<td>44.5</td>
</tr>
<tr>
<td>Escapes</td>
<td>27.4</td>
</tr>
<tr>
<td>RX40h</td>
<td>25.0</td>
</tr>
<tr>
<td>Highlander</td>
<td>24.6</td>
</tr>
</tbody>
</table>
HEV Maintenance / Repairs Summary

- Civic & Insight - 6 CVT failures in 4 units: 97k, 99k, 89k & 77k mi. Again: 157k & 146k mi.
- Insight battery control module & battery pack replaced: 72k miles
- Insight & Civic - 7 software upgrades & 3 catalytic converters replaced
- Gen I Prius - rack & pinion replacements 1st Prius: 106k, & 2nd Prius: 25k & 32k miles
- Silverado battery pack replaced: 36k miles
Life Cycle Costs - High Mileage HEVs

<table>
<thead>
<tr>
<th>Model</th>
<th>Mileage</th>
<th>Cents per Mile</th>
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<tbody>
<tr>
<td>Civic</td>
<td>161.5k</td>
<td>22.0</td>
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<tr>
<td>Civic</td>
<td>161k</td>
<td>23.9</td>
</tr>
<tr>
<td>Insight</td>
<td>160k</td>
<td>19.4</td>
</tr>
<tr>
<td>Insight</td>
<td>146k miles</td>
<td>17.7</td>
</tr>
<tr>
<td>Gen I Prius</td>
<td>165k miles</td>
<td>17.7</td>
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<tr>
<td>Gen I Prius</td>
<td>160k miles</td>
<td>18.7</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>21.5</td>
</tr>
</tbody>
</table>

(All 36 months of testing except 146k miles Insight - 41 months)
Life Cycle Costs - Low Mileage HEVs

Low Mileage HEV Life Cycle Costs

- Ownership
- Main/Repair
- Registration
- Gas ($2.50/gal)
- Insurance

Total: 131.3 cents/mile
Life Cycle Costs - By HEV Model

Costs include: Insurance, maintenance & repairs (excludes any collision costs), fuel @ $2.50 gallon, registration, and purchase – sales cost (or lease cost for Silverado)
HEV MPG: Fleet SAE J1634 & EPA

Fleet, Baseline Performance and EPA Fuel Economy Testing Results

- Fleet Testing
- J1634 - Air On
- J1634 - Air Off
- EPA City
- EPA Highway

Miles per Gallon

Civic, Insight, Gen I Prius, Gen II Prius, Accord, Silverado, Escape, RX400h, Highlander
HEV End-of-Life (160K miles) Battery Capacity

End of Life Battery Capacity Test Findings

- Nominal
- C1 Capacity

<table>
<thead>
<tr>
<th>Ampere-Hours</th>
<th>Civic 1</th>
<th>Civic 2</th>
<th>Insight 1</th>
<th>Insight 2</th>
<th>Prius 1</th>
<th>Prius 2</th>
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<tbody>
<tr>
<td>6.0</td>
<td>6.0</td>
<td>6.5</td>
<td>5.6</td>
<td>6.5</td>
<td>6.5</td>
<td>6.5</td>
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<tr>
<td>4.1</td>
<td>4.1</td>
<td></td>
<td></td>
<td>5.4</td>
<td></td>
<td></td>
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<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td>2.6</td>
<td></td>
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</table>

*Gen I Prius
HEV End-of-Life Phase II (J1634) vs. Onboard Vehicle Computer MPG

<table>
<thead>
<tr>
<th>End-of-life Phase II MPG Testing</th>
<th>Onboard computer mpg percentage above Phase II SAE J1634 mpg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civic 1 AC off</td>
<td>+21.7%</td>
</tr>
<tr>
<td>Civic 1 AC on</td>
<td>+21.0%</td>
</tr>
<tr>
<td>Insight 1 AC off</td>
<td>+11.0%</td>
</tr>
<tr>
<td>Insight 1 AC on</td>
<td>+11.7%</td>
</tr>
<tr>
<td>Gen I Prius AC off</td>
<td>+15.7%</td>
</tr>
<tr>
<td>Gen I Prius AC on</td>
<td>+14.7%</td>
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</tbody>
</table>
Additional HEV Testing

- Hydrogen ICE HEV Hydrogen Prius from SCAQMD/Quantum
- Plug-in HEV Dodge Sprinter (lithium)
- Plug-in HEV Escape (lithium or lead) from Energy CS
- Plug-in Prius (lithium) from Energy CS
- Other OEM HEVs &/or Plug-ins (Gen II Civic & Toyota Camry)
APS Alternative Fuel (Hydrogen) Pilot Plant

• First U.S. H2 station in operation (June 2002)
• Partners: Arizona Public Service (APS), Electric Transportation Applications (ETA), U.S. Department of Energy, & Idaho National Laboratory (INL)
Pilot Plant Layout

- Hydrogen Fuel Cell
- 2 H2 High psi tanks
- H2 Low psi tank
- H2 Compressor
- 2 CNG Compressors
- 6 CNG Tanks (3 psi levels)
Pilot Plant - Hydrogen Subsystem

- Oxygen
- Water
- Electricity

H₂ Generator → Dryer → Low Pressure Storage

Compressor → Filter → High Pressure Storage

H₂ Out
Pilot Plant - Hydrogen Subsystem

- Proton Energy Systems’ HOGEN PEM stationary fuel cell operating in reverse
- 9 Norman hydrogen filters
- Hydrogen Lectrodryer
- Hydrogen compressor
- Hydrogen - 99.9997% purity
Pilot Plant - Hydrogen Storage

- Low pressure storage (lower tank) - 8,955 scf @ 150 psi
- High pressure storage (upper 2 tanks) - 17,386 scf @ 6,000 psi (total both tanks)
Hydrogen Gas & Flame Detectors

- Six combustible H2 detectors
- Six IR/UV flame detectors (1 more at dispensing island)
- Tied to automated shutdown system
Pilot Plant - CNG Subsystem

Street Service Low Pressure Natural Gas

Boost Compressor

Main Compressor

High Pressure Storage (3 levels)

CNG Output
CNG Subsystem

- Boost Compressor: 60 psi
- CNG Main Compressor: 5,000 psi
- CNG Storage/Pressure: 6 tanks, 22,500 scf
- 3 Low: 3,600 psi
- 2 Medium: 4,500 psi
- 1 High: 5,000 psi
H2 & HCNG Fueling Dispensers

- Metering & electronic billing interface
- Fully permitted for hydrogen, CNG, & H/CNG motor fuel dispensing
- Public access
Pilot Plant Monitoring

- 7,200 kg of H2 produced at 6,000 psi
- 6,000 fueling events
- 300,000+ hydrogen test miles
Initial H2 & HCNG vehicle testing

- Dodge van on 15% HCNG (continues)
- Ford F150 up to 30% HCNG (continues)
- Ford F150 up to 50% HCNG (completed)
- 100% H2 Mercedes Benz van (completed)
15% HCNG Dodge Van

- 5.2 L CNG V8 (no modifications)
- 71k HCNG test miles: no problems
- 15% HCNG, 27k data miles: 15.5 miles/GGE

<table>
<thead>
<tr>
<th>Percentage change in 15% HCNG emissions compared to 100% CNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total hydrocarbons</td>
</tr>
<tr>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>Oxides of nitrogen</td>
</tr>
<tr>
<td>Carbon dioxide</td>
</tr>
</tbody>
</table>
30% HCNG F150

- 5.4 L V8 CNG engine, added supercharger, ignition mods & exhaust gas recirculator
- 54k 30% HCNG miles: 17.5 miles/GGE

<table>
<thead>
<tr>
<th>Fuel Blend</th>
<th>0 to 60 mph (secs.)</th>
<th>Miles/ GGE</th>
<th>Range (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% CNG</td>
<td>10.10</td>
<td>23.3</td>
<td>122</td>
</tr>
<tr>
<td>15% HCNG</td>
<td>10.97</td>
<td>22.6</td>
<td>110</td>
</tr>
<tr>
<td>30% HCNG</td>
<td>12.68</td>
<td>23.5</td>
<td>102</td>
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</table>
# 30% HCNG F150 Emissions

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Percentage Change in Emissions Testing</th>
<th>NMHC</th>
<th>CH₄</th>
<th>HC</th>
<th>CO</th>
<th>NOₓ</th>
<th>CO₂</th>
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<tbody>
<tr>
<td>Gasoline</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
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<tr>
<td>CNG</td>
<td>-80</td>
<td>+967</td>
<td>+35</td>
<td>-63</td>
<td>-34</td>
<td>-24</td>
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<tr>
<td>15% HCNG</td>
<td>-78</td>
<td>+1000</td>
<td>+40</td>
<td>-70</td>
<td>-26</td>
<td>-27</td>
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<tr>
<td>30% HCNG</td>
<td>-89</td>
<td>+1050</td>
<td>+37</td>
<td>-73</td>
<td>-25</td>
<td>-28</td>
<td></td>
</tr>
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</table>

NMHC=Non-Methane Hydrocarbons   CH₄=Methane  
HC=Total Hydrocarbons          CO=Carbon Monoxide  
NOₓ=Oxides of Nitrogen          CO₂=Carbon Dioxide
50% HCNG F150

- Modifications: SVO heads, supercharger, exhaust intercooler, ignition system, & exhaust gas recirculator
- Three 3,600 psi tanks with 3 kg H2 storage

Percent reduction in emissions (HCNG versus gasoline-fueled F-150)

<table>
<thead>
<tr>
<th></th>
<th>HC</th>
<th>CO</th>
<th>NO_x</th>
<th>CO_2</th>
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<tbody>
<tr>
<td>Reduction</td>
<td>-3.5%</td>
<td>-43.3%</td>
<td>-97.0%</td>
<td>-16.7%</td>
</tr>
</tbody>
</table>
HCNG ICE Vehicle Testing

- APS meter reader fleet 12 Bifuel vehicles
- 1,600 fueling events, 190k miles using 10,600 GGE of 15% HCNG
- Public Fleet - private Bifuel conversions
- 350 fueling events, 36k miles (estimated), 1,800 GGE of HCNG blends (mostly 15%)
5.4L 16-Valve 100% H2 ICE Pickup

- 5.4L V-8, 100% H2, 16V, converted by ETEC
- 5 spd manual, supercharged (3 psi boost), H2 fuel injectors, & air-to-water intercooler
- Hardened valves & seats, & forged pistons (12:1 compression), lean-burn mode
- 3 Dynetek tanks (aluminum vessel & fiberglass wrap)
  3,000 psi – 6.5 kg onboard
5.4L 16-Valve 100% H2 ICE Pickup

- Max speed 1 mile: 81 mph ¼ mile: 58 mph
- Acceleration (0 to 50 mph): 18.1 seconds
- SAE J1634 (AC on): 14.5 miles/GGE
- SAE J1634 (AC off): 18.0 miles/GGE
- 45 mph constant speed: 27.0 miles/GGE
- Range - 95 to 175 miles (14.5 to 27 mi/GGE)
- Fleet testing (3.5K miles) results: 17.0 miles/GGE = 110 miles range
5.4L 32-Valve 100% H2 ICE Pickup

• 5.4L V-8, 100% H2 32-valve, converted by ETEC
• Automatic transmission, H2 fuel injectors, 12 lbs supercharger boost, & air-to-air intercooler
• Hardened valves & seats, & forged pistons 11.5:1 compression, lean-burn mode
• 15.3 kg onboard H2 storage
• 3 Dynetek tanks 5,000 psi, 15.3 kg H2 onboard
• Fleet testing (7.5k miles): 15.3 miles/GGE & 230 miles range
6L V-8 100% H2 ICE Pickup

- Base vehicle: Chevrolet 1500HD crew cab (4 door) with 6L V8 CNG engine
- Converted by ETEC/Roush
- 4-speed automatic, supercharger, electronic port fuel injection, liquid-to-air intercooler
- Integration of powertrain control module & development of H2 lean-burn control strategies
6L V-8 100% H2 ICE Pickup

- Implementation of J1850 communications to maintain seamless integration with existing OEM equipment
- 10.5 kg onboard H2 storage @ 5,000 psi
- 180 Horsepower & 260 lb-ft torque
- Anticipated 15 miles/GGE = 155 miles range
6L V-8 100% H2 ICE Pickup

- Targeted to meet NOx requirements for 2007 Tier II, Bin 7 standards
- HC<10 ppm & NOx<25 ppm on engine dynamometer
- Nine vehicles being produced in 1st run
- To be baseline performance tested
- Track 8 unit fleet in Vancouver
INL Oil Bypass Filter Evaluation

• Examine oil bypass filter effectiveness, & quantify engine oil use reductions

• 1.3 million miles on 11 buses & 6 Tahoes

• Test oil quality for 28 variables - total base number, oxidation & nitration levels, contaminants (metals, water, soot, & fuel), & track makeup oil use

• Buses 90% & Tahoes 80% of oil changes avoided
318 INL Alternative Fuel Vehicles

- 79 B20 motor coach buses
- 7 Dedicated LNG motor coach buses
- 154 Bi-fuel light-duty CNG vehicles
- 52 Bi-fuel E85 (85% ethanol) pickups/SUVs
- 22 Bi-fuel LNG pickups
- 2 CNG vans
- 2 Propane vans
INL Alternative Fuel Infrastructure

- LNG / CNG station at site
- CNG station in Idaho Falls
- E85 (85% ethanol / 15% gasoline) station at site
- B20 (20% biodiesel / 80% diesel) station at site
- Adding E85 fueling in Idaho Falls
Acknowledgement

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FreedomCAR and Vehicle Technologies Program

Vehicle Systems Team Leader, Tien Duong
Project Leader and VSATT Lead, Lee Slezak