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• The Other Blue Football Field in the United States
Vehicle / Infrastructure Testing Experience

- 144 million test miles accumulated on 11,700 electric drive vehicles and 16,600 charging units
- EV Project: 8,228 Leafs, Volts and Smarts, 12,363 EVSE and DCFC, reporting 4.2 million charge events, 124 million test miles. At one point, 1 million test miles every 5 days
- Charge Point: 4,253 EVSE reporting 1.5 million charges
- PHEVs: 15 models, 434 PHEVs, 4 million test miles
- EREV: 2 models, 156 EREV, 2.3 million test miles
- HEVs: 24 models, 58 HEVs, 6.4 million test miles
- Micro hybrid (stop/start) vehicles: 3 models, 7 MHVs, 608,000 test miles
- NEVs: 24 models, 372 NEVs, 200,000 test miles
- BEVs: 48 models, 2,000 BEVs, 5 million test miles
- UEVs: 3 models, 460 UEVs, 1 million test miles
- Other testing includes hydrogen ICE vehicle and infrastructure testing
Why Plug-in Electric Vehicles (PEVs)?
Areas of Concern with Transportation Oil Dependency

• Energy security
  – Insufficient domestic supply of easily obtainable oil forces us to rely on imports
  – Global supply has reached “Peak Oil” (?)

• Global climate change
  – Tailpipe and smoke stack CO₂ emissions

• Economic stability
  – Unbalanced supply and demand affect all levels of the economy (global, national, personal)
Advantages to PEVs as a Solution to Oil Dependency

• Displace petroleum consumption with electricity
• Diversify our transportation energy sources
• Enable *alternatives*
  – Use domestically generated electricity from a variety of sources
  – Use existing infrastructure
  – Leverage nuclear and renewable energy sources (wind, solar, hydropower, geothermal)
Challenges of PEVs as a Solution to Oil Dependency

• Current technology limitations (batteries!) and potentially a shortage of domestic materials

• Some infrastructure required
  – Charging stations (short term)
  – Communication between vehicles and electric grid (mid-term)
  – Additional electricity generation / transmission / distribution (long-term)

• Consumer market acceptance
Review of Vehicle Technologies
Comparison of Vehicle Technologies

- Conventional vehicle with internal combustion engine (ICE) only
Comparison of Vehicle Technology

- Hybrid Electric Vehicle (HEV) with ICE and electric drive
- Does not plug in to electric grid

Examples:

- Toyota Prius
- Honda Insight
- Ford Fusion Hybrid
Comparison of Vehicle Technology

• Plug-in Hybrid Electric Vehicle (PHEV) with ICE and electric drive

Examples:

Chevy Volt
Comparison of Vehicle Technology

- Battery Electric Vehicle (BEV) with electric drive only

Examples:

- Nissan Leaf
- Tesla Roadster
Vehicle Technology Summary

• ICE: only energy storage is hydrocarbon fuel – typically gasoline or diesel

• HEV: has 2 onboard energy sources – typically gasoline and electricity. All energy originates from gasoline and the battery is only used to recover braking energy. It can be charged by the ICE engine when it is efficient to do so

• PHEV can be fueled with both gasoline from the pump and electricity from the grid. When the battery is charged, the gasoline engine may not even be used (All Electric Capable), or is used when the electric motor is not powerful enough by itself (Blended). When the battery is nearly empty, the vehicle operates like a typical HEV

• BEV has one onboard energy source – electricity, obtained by plugging in (charging). When the battery is depleted, BEVs can’t be driven until recharged - like running out of gas, but takes longer to ‘refuel’

• A PEV includes both PHEVs and BEVs – both are “plugged in”
On-Road driving is Recorded and Analyzed

- In vehicle logger transmits data over cell modem to INL
Conceptual Comparison of Vehicle Operation

Conventional vehicle

HEV

PHEV10 (all-electric capable)

BEV (100 mi range)
Electrified Vehicle Powertrain Architectures

Battery Options
- Energy Capacity
- Peak Power
- Chemistry
- Voltage

Conventional vehicle
- Belt Alternator Starter
- Hybrid Malibu
- BMW 1 Series

Mild Hybrid (HEV)
- Integrated Starter Generator
- Honda Civic
- Honda Insight

Full Hybrid (HEV)
- Power Split
- Toyota Prius
- Ford Fusion
- Chevrolet Malibu
- Hyundai Sonata
- Infiniti Q45 (?)

Blended Plug-in Hybrid (PHEV)
- Power Split
- Toyota Prius
- Ford Escape
- Chevrolet Volt
- GM 2 Mode SUV

Extended Range Electric Vehicle (EREV)
- Conversion
- Toyota Prius
- Ford Escape
- Ram Pickup
- Hymotion Prius
- Eetrex Escape

Battery Electric Vehicle (BEV)
- Production
- Tesla Roadster
- Mitsubishi i-Miev
- Nissan Leaf (2011)
- Ford Focus (2012)
- Prius (2012)
- Fisker Karma (2012 ?)
- Chevrolet Volt (2011)
- US Postal Service LLVs

Cost (currently dominated by battery)

Dates given are announced target years for start of production
Grid-Connected Charging Infrastructure Overview
Vehicle Electrification: Grid Impacts

- In the U.S., current grid capacity could supply electricity for 70% of our vehicles without adding capacity, but assumes:
  - Vehicles would only charge off-peak
  - “Perfect” distribution of electricity
  - No local impacts such as overburdening neighborhood transformers
- PEVs will not cause a grid “meltdown” but we clearly need to work to reduce vehicle rollout impacts
- Smart charging will be key to lowering costs and minimizing impacts
- Time of day pricing is important
- Administration Goal: 1 Million Plug-in Vehicles by 2015
Build-out of Charging Infrastructure

- Key today: Home Charging
  - Need to get the cost and installation process right. Currently a significant barrier

- Work and Public Access Charging
  - Expensive if not well utilized
  - Expensive to fully cover full driving patterns

- Ideally need market pull to determine public infrastructure build-out
  - PHEVs may be key to help initiate market pull for public infrastructure
Innovative Approaches

• Battery swapping (Project Better Place retrenchment)
  – Requires OEM buy-in
• Fast Charging (becoming less innovative)
• Innovative Financing
• Secondary use of batteries
  – Utility ancillary services
  – Bulk energy storage
  – Increase present value
• Vehicle to Grid (V2G)
Charging Definitions

- Defined in Society of Automotive Engineers (SAE) J1772
  - AC (On-board vehicle charger)
    - Level 1: 120V AC (up to 16 Amps, ~ 1.92kW Max)
    - Level 2: 240V AC (up to 80 Amps, ~ 20kW Max)
    - Level 3: > 20kW (proposed)
  - DC Charging (Off-board vehicle charger)
    - Level 1: Up to 20kW (proposed)
    - Level 2: Up to 80kW (proposed)
    - Level 3: >80kW (proposed)
  - There may be other levels proposed
- What is called “fast charging” today is DC Level 2
- Most vehicles have onboard chargers that operate at 3.3 or 6.6 kW. Tesla charges at 10 kW. Energy is supplied to the vehicle via electric vehicle supply equipment (EVSE) at AC Level 2
Selecting the EVSE or DCFC Type & Rate

- **AC Level 1** (supplies electricity to on-board DC Charger)
  - 110 VAC EVSE should be connected to commercial grade NEMA outlet and dedicated branch circuit
  - Convenience charge cord typically provided with PEV used for emergency purposes.
  - Charge times range from 6+ hours (PHEV) to 24+ hours (BEV) for a full recharge
  - Could be used to charge PHEV on a daily basis but dissatisfaction can occur if PHEV does not fully charge

- **AC Level 2** (supplies electricity to on-board DC Charger)
  - 240 VAC EVSE connected to dedicated branch circuit
  - Charge times range from 2 (PHEV) to 8 hours (BEV) for a full recharge
  - Good for malls, movie theatres, work place
Selecting the EVSE or DCFC Type & Rate

• DC (Off-board Charger, directly charges the vehicle battery pack. Does not use the onboard charger)
  – DC Level 2 (>20kW and up to 80kW)
  – 50kW is the most commonly used power output today (Nissan Leaf)
  – Provides 2 to 4 miles range per minute of charge
  – Good for City corridors, convenience stores and fast food restaurants
Examples of Level 1 EVSE
Examples of Level 2 EVSE Hardware
Examples of DC Fast Charging
Commercial Site Considerations

- Geographic Coverage / Planning
- Local attraction(s)
- Proper charger level for location
- ADA Requirements
- Lighting / Security
- Signage
- Access
- Local Permitting Authority
Signage Examples
PEV Sales and Announcements
U.S. PEV Sales

Data obtained at:

Data obtained at:
## Plug-in Electric Vehicle U.S. Production Status

<table>
<thead>
<tr>
<th>MAKE</th>
<th>MODEL</th>
<th>POWER-TRAIN</th>
<th>ESTIMATED U.S. AVAILABILITY DATE</th>
<th>ELECTRIC TOTAL RANGE (MI) (estimated)</th>
<th>BATTERY CAPACITY (kWh)</th>
<th>BATTERY SUPPLIER</th>
<th>EPA FUEL ECONOMY (Electric MPGe/ Gasoline Only mpg)</th>
<th>BASE MSRP (PRIOR TO INCENTIVIZED &amp; DEST FEE)</th>
<th>TOTAL SALES (IF AVAILABLE)</th>
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<td>Lightion Motors</td>
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<td>LIV Prime</td>
<td>REV</td>
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<td></td>
<td>$19,600</td>
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<td>$150,000</td>
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*Last Revised: 3/6/2014*
The U.S PEV production document was created for informational purposes only, using publicly available resources. It is not guaranteed to be 100% accurate,
EV Project Vehicle and Charging Profiles
**EV Project Deployments**

- **EVSE**
  - 8,251 Residential Level 2 EVSE
  - 4,005 Public Level 2 EVSE
  - 107 DCFC (DC Fast Chargers)
  - 12,363 Total EVSE & DCFC

- **Vehicles**
  - 5,788 Nissan Leafs
  - 2024 Chevy Volts
  - 416 Car2Go
  - 8,228 Total vehicles
## Vehicle Profiles (4th quarter 2013 data)

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<thead>
<tr>
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<th>Leafs</th>
<th>Volts</th>
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<td>1,611</td>
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<tr>
<td>Number of Trips</td>
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<tr>
<td>Distance (million miles)</td>
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<tr>
<td>Average (Ave) trip distance</td>
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<td>Ave distance per day</td>
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<td>Ave number (#) trips between charging events</td>
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<td>Ave distance between charging events</td>
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<td>Ave # charging events per day</td>
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Vehicle Charging (4th quarter 2013 data)

- **Leafs**
  - Battery State of Charge (SOC) at the Start of Charging Events
  - Battery State of Charge (SOC) at the End of Charging Events
  - Frequency of Charging by Charging Location

- **Volts**
  - Battery State of Charge (SOC) at the Start of Charging Events
  - Battery State of Charge (SOC) at the End of Charging Events
  - Frequency of Charging by Charging Location and Type
Level 2 EVSE Use (4th quarter 2013 data)

- Residential and public connect time and energy use are fairly opposite profiles. Weekday data

Legend: 92 day reporting quarter. Data is max (blue line), mean (black line) and minimum (red line), for the reporting period. Dark gray shaded is plus and minus 25% quartile.
Residential Level 2 EVSE Connect (4th quarter 2013)

• San Diego and San Francisco, with Residential L2 Time-of-Use (TOUI) rates, are similar to other regional EVSE connect profiles. Weekday data

Legend: 92 day reporting quarter. Data is max (blue line), mean (black line) and minimum (red line), for the reporting period. Dark gray shaded is plus and minus 25% quartile.
Residential Level 2 EVSE Connect (4th quarter 2013)

• Time of use rates in San Diego and San Francisco clearly impact when vehicle charging times are set. Weekly data

Legend: 92 day reporting quarter. Data is max (blue line), mean (black line) and minimum (red line), for the reporting period. Dark gray shaded is plus and minus 25% quartile.
Accomplishments - Charging Location Preference for Nissan Leaf drivers

Group of 707 Nissan Leafs with Access to Workplace Charging 2012 – 2013

Days When Vehicles Were Parked at Work

Days When Vehicles Were Not Parked at Work

In aggregate, workplace vehicle drivers had little use for public infrastructure on days when they went to work
DC Fast Charger (DCFC) Use

- 4th quarter 2013, DCFC weekday use profiles
- 95 DCFC, 11,704 charge events, & 109 AC MWh

- EV Project Leafs 18% charge events and 16% energy used
- 1.3 average charge events per day per DCFC
- 24.6 minutes average time connected
- 24.6 minutes average time drawing energy
- 9.3 kWh average energy consumed per charge
• DCFC installation costs do not include DCFC hardware costs
Nissan Leaf – Onroad DCFC & Level 2 Charging Results

DC Fast Charge Effects on Battery Life and Performance Study – 50,000 Mile Update

Four model year 2012 Nissan Leaf battery electric vehicles were instrumented with data loggers and were being operated over a fixed on-road test cycle. Each vehicle is charged twice daily, with two vehicles charged at AC Level 2 (L2), and two DC fast chargers (DCFC) with a 50kW charger. The traction battery packs are removed and tested when the vehicles were new, and at 10,000 mile intervals. Battery tests include constant current discharge capacity, electric vehicle power characterization, and high peak power tests. The testing will continue to at least 50,000 miles at which point the battery testing results will determine if testing continues in additional 10,000 mile increments. This fact sheet summarizes the measured changes in capacity at 10,20,30,40, and 50 thousand miles relative to baseline test results.

<table>
<thead>
<tr>
<th>1011 L2</th>
<th>4582 L2</th>
<th>2183 DCFC</th>
<th>2078 DCFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline (New)</td>
<td>23.31</td>
<td>23.56</td>
<td>23.36</td>
</tr>
<tr>
<td>10,000 Miles</td>
<td>21.75</td>
<td>22.3</td>
<td>21.97</td>
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<tr>
<td>20,000 Miles</td>
<td>21.53</td>
<td>21.51</td>
<td>21.64</td>
</tr>
<tr>
<td>30,000 Miles</td>
<td>19.99</td>
<td>20.2</td>
<td>19.42</td>
</tr>
<tr>
<td>40,000 Miles</td>
<td>18.10</td>
<td>18.34</td>
<td>17.53</td>
</tr>
<tr>
<td>50,000 Miles</td>
<td>17.51</td>
<td>17.77</td>
<td>16.94</td>
</tr>
</tbody>
</table>

Table 1 - C6 Energy capacity (KWh)

<table>
<thead>
<tr>
<th>1011 L2</th>
<th>4582 L2</th>
<th>2183 DCFC</th>
<th>2078 DCFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10k Miles (Oct-Jan)</td>
<td>26.6</td>
<td>26.6</td>
<td>32.7</td>
</tr>
<tr>
<td>10-20k Miles (Jan-Mar)</td>
<td>22.7</td>
<td>22.5</td>
<td>27.6</td>
</tr>
<tr>
<td>20-30k Miles (Apr-Jul)</td>
<td>35.7</td>
<td>36.0</td>
<td>39.8</td>
</tr>
<tr>
<td>30-40k Miles (Jul-Oct)</td>
<td>38.2</td>
<td>36.4</td>
<td>40.8</td>
</tr>
<tr>
<td>40-50k Miles (Oct-Mar)</td>
<td>23.2</td>
<td>23.6</td>
<td>27.3</td>
</tr>
</tbody>
</table>

Table 2 - Average pack temperature during all charging through mileage accumulation interval (°C)

Figure 1 – Percent change in C6 energy capacity from baseline


Please note that the text includes figures and tables with data, which are essential for understanding the study's findings.
Commercial EVSE Level 2 Installation Costs

- Nationally, commercially sited Level 2 EVSE averaged $4,000 for the installation costs. EVSE cost excluded
- There is much variability by region and by installation
- Multiple EVSE at one site drive down per EVSE install cost
- Tennessee and Arizona have average installation costs of $2,000 to $2,500
- Costs driven by poor sitting requests
  - Example: mayor may want EVSE by front door of city hall, but electric service panel is located at the back of the building

<table>
<thead>
<tr>
<th>Region</th>
<th>Count of Permits</th>
<th>Average Permit Fee</th>
<th>Minimum Permit Fee</th>
<th>Maximum Permit Fee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>72</td>
<td>$228</td>
<td>$35</td>
<td>$542</td>
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<tr>
<td>Los Angeles</td>
<td>17</td>
<td>$195</td>
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<tr>
<td>San Diego</td>
<td>17</td>
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<td>Texas</td>
<td>47</td>
<td>$150</td>
<td>$37</td>
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<td>Tennessee</td>
<td>159</td>
<td>$71</td>
<td>$19</td>
<td>$216</td>
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<tr>
<td>Oregon</td>
<td>102</td>
<td>$112</td>
<td>$14</td>
<td>$291</td>
</tr>
<tr>
<td>Washington</td>
<td>33</td>
<td>$189</td>
<td>$57</td>
<td>$590</td>
</tr>
</tbody>
</table>
Residential EVSE Level 2 Installation Costs

• Nationally, 4,466 residential sited Level 2 EVSE averaged $1,300 for the installation costs. EVSE cost excluded
• Max $8,429, min $250, mean $1,414, medium $1,265
• High cost drivers
  – Replacing residential electrical service ($8,429) or not installing near the service panel
  – Desire to site away from the house
  – Cutting concrete or asphalt driveway, or other surfaces
• Low cost drivers
  – Existing 240 V outlet in the garage ($250)
  – Simple addition of a breaker and minimal conduit run
  – Space in the garage
Couple of Slides on Safety and First Responders
Third Party Conversion of a HEV to a PHEV
Third Party Conversion of a HEV to a PHEV
PEVs Are Not Unique When it Comes to Vehicle Based Thermal Anomalies

• According to the NFPA, between 1980 and 1982, there was an average of approximately 447,000 highway vehicle fires per year; between 2009 and 2011, there was an average of approximately 187,500 highway vehicle fires per year (http://avt.inel.gov/pdf/energystorage/FinalReportNFPA.pdf)

Port of Newark, Sandy event
Impact of salt water flooding
Thermal Events Lessons Learned

- Unintended battery discharging and resulting thermal events have not occurred in any production vehicle the AVTA has tested during 144 million test miles, with 11,700 electric drive vehicles.

- Full battery thermal events can be suppressed or “finished” by:
  - Disassembling the pack (thus discharging) and applying water to the cool the pack to avoid in-pack and in-vehicle combustible materials from burning.
  - Allowing the event to continue unsuppressed and ensuring personnel and facility safety. Will ultimately result in all combustible materials burned and vehicle destroyed (but the fire will be out!!!!)
  - Using trained electrical safety worker to discharge the pack while applying cooling water it to stop combustible materials from burning (INL’s most recent experience).

- However, this should only be undertaken by electric safety trained workers with large battery pack safety and equipment experience.
- Hours or days when the vehicle may not be in a safe location.
Thermal Events Lessons Learned

• The need for first responder training was recognized by U.S. DOE, U.S. DOT (NHTSA), and National Fire Protection Association (NFPA). DOE, DOT, NFPA, and INL developed a vehicle fire suppression lessons-learned program
  – OEMs, through the Alliance of Automobile Manufacturers, participated and contributed vehicle-sized lithium ion battery packs
  – Packs were used to demonstrate suppressed outcomes via the NFPA fire trainer vehicle
  – Target audience was first responders
  – Film is part of the education and training materials
**NFPA Project - Goal**

- Identify full-scale heat release rate (HRR) and fire suppression testing of PEVs with large format Li-ion batteries
- In particular, members of the emergency response community had questions regarding
  - Appropriate PPE to be used for responding to PEV fires
  - Tactics for suppression of fires involving PEV batteries
  - Best practices for tactics and PPE to be used during overhaul and post-fire clean-up operations
- One laboratory test was conducted to determine HRR
- Six, full-scale fire suppression tests were conducted to collect data and evaluate any differences associated with PEV fires as compared to traditional ICE vehicle fires
  - Three of the Battery “A”, 4.4 kWh lithium ion battery pack
  - Three of the Battery “B”, 16 kWh lithium ion battery pack
NFPA HRR Test

• The objective of the HRR testing was to determine the amount of energy released from the battery alone when it was ignited by an external ignition source.

• Secondary testing objective was to verify the battery could be induced into thermal runaway with the external ignition source (propane fueled burners positioned beneath the battery) for use during the full-scale fire suppression tests and to collect data as to the indications that the battery was experiencing thermal runaway.

• Based on a review of NFPA data on vehicle fire risk, flammable or combustible liquids or gases were the first item ignited in 31% of U.S. highway vehicle fires, resulting in 70% of civilian deaths, 58% of civilian injuries, and 31% of the direct property damage. As such, a pool fire scenario under the PEV was selected as the likely ignition scenario where the batteries become near fully involved and “burning on their own.”

(http://avt.inel.gov/pdf/energystorage/FinalReportNFPA.pdf)
• 22 hours after testing – self reignition
• At the conclusion of testing, an OEM’s procedure for soaking PEV batteries in a salt bath were followed before shipping the six damaged battery packs. This method requires a minimum of 24 hours of submersion
NFPA - Best Practices

A small sample of findings are listed below

• Use standard vehicle firefighting equipment and tactics in accordance with department SOPs/SOGs
• All personnel should wear and utilize full PPE and SCBA as required at all vehicle fires
• Use water or other standard agents for PEV fires
• The use of water does not present an electrical hazard to firefighting personnel
• If a PEV battery catches fire, it will require a large, sustained volume of water
  – Battery A required 275 to 1,060 gallons
  – Battery B required 1,165 to 2,639 gallons
• If a Lithium Ion (Li-Ion) HV battery is involved in a fire, there is a possibility that it could reignite after extinguishment. If available, use thermal imaging to monitor the battery. Do not store a vehicle containing a damaged or burned Li-Ion HV battery in or within 50 feet of a structure or other vehicle until the battery can be discharged
NFPA Report

- **NFPA Final Report and Appendices**

- **NFPA Final Report only**

- **NFPA Appendix A**
  - [http://avt.inel.gov/pdf/energystorage/AppendixBthruE1NFPA.pdf](http://avt.inel.gov/pdf/energystorage/AppendixBthruE1NFPA.pdf)

- **NFPA Appendix B**
  - [http://avt.inel.gov/pdf/energystorage/AppendixBthruE1NFPA.pdf](http://avt.inel.gov/pdf/energystorage/AppendixBthruE1NFPA.pdf)
The Other Blue Football Field
The Other Blue Turf - Barrow, Alaska High School Football – Home of the “Whalers”
Arctic Ocean in the Background (08/01/10)
Additional Questions?