Fuji Electric Corp. of America

DC Quick Charging for Electric Vehicles
August 2012
Who is Fuji Electric?

- Fuji Electric Corporation, Ltd. (based in Tokyo, Japan)
  - Established in 1923
  - Leader in industrial manufacturing
  - $8 billion in annual revenue
  - 25,000 employees worldwide
  - Over 300 DC Quick Chargers deployed to date
  - Global businesses in Asia, China, Europe, and Americas

Fuji Electric Corporation of America (based in Edison, NJ)
- Wholly owned subsidiary of Fuji Electric Co, Ltd.
- Established 1970
- Responsible for the sales, marketing and distribution throughout the Americas
- 16 business units with products ranging from Semiconductors and Drives to Radiation Detection Equipment and Power Supply products.
- All products with a focus on energy and the environment
Fuji Electric – Global Sales Breakdown

**Components**

- **Power Electronics**
  - Inverters
  - Motors
  - Uninterruptible power supply systems (UPSs)
  - Electric equipment for railcars
  - Chargers for EVs, powertrains for EVs
  - Power conditioners

- **Electronics**
  - Power semiconductors
  - Photoconductive drums
  - Solar cells
  - Magnetic disks

- **ED&C Components**
  - Magnetic contactors
  - Molded-case circuit breakers
  - Earth-leakage circuit breakers
  - Push buttons and indicator lights

- **Vending Machines**
  - Food/beverage vending machines
  - Currency handling systems

**Plant**

- **Energy**
  - Thermal/geothermal power generation facilities
  - Hydroelectric power generation facilities
  - Nuclear power-related equipment
  - Radiation control systems

- **Industrial Systems**
  - Industrial drive systems
  - Measurement systems
  - Industrial power supply systems
  - Air conditioning equipment for data centers

- **Social Systems**
  - Power transmission and distribution systems
  - Power receiving and distribution substation equipment
  - Watt-hour meters
  - Energy monitoring systems
  - New energy systems
## Fuji Electric – Model Specifications

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<tr>
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<tr>
<td>Standards</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>Voltage Range</td>
<td>DC50 to 500V</td>
</tr>
<tr>
<td>Current Range</td>
<td>DC0 to 62A</td>
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<tr>
<td>Maximum Power</td>
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Quick Charging
What is Quick charging?

**DC Quick Charging**
- 3Ф 208V
- 300-500V DC +CAN
- 25-50 kW
- 16-24 kWh
- 3 phase 208V AC is converted to DC.
- DC is sent directly to the EV Battery.
- BMS commands charging current via CAN

**Level 2 AC Charging**
- 1Ф 208V
- 1Ф 240V
- 3-6 kW
- 3-6 kW
- 16-24 kWh
- 208V AC is sent through the charger to the Vehicle
- The On-Board Charger converts the AC to DC
- DC Charging is limited to the Power of the On-Board Charger
Charge Power vs. Charge Time

- Significant decrease in Charging Time as Power increases from 0-15kW
- Power greater than 20kW shows only marginal decreases in charging time
- Fuji Electric 25 kW DC Quick Charger provides a charge in about 60 minutes
The Time and The Place for Quick Charging...

**DC NOT LIKELY**
DC Quick Chargers will be unlikely for residential use due to high cost and power restrictions; May be cost prohibitive for small offices.

**Deciding Factor:**
**SPEED**
DC Charging will dominate for public use. Speed is the most important factor for fast/public applications (i.e. public parking, fleets, etc).

**Cost**
AC Charging units will be inconvenient for Public use due to the long charging times; For Public applications, SPEED is the primary factor.

**Applications for DC Quick Charging**
- Most convenient charging option, offering EV owners an 80% charge in under 60 minutes
- Ideal for public parking, retail locations, fleets, rental cars, etc.
- Ability to charge many cars each day due to short charging time; Best option for any public charging infrastructure

**Applications for AC Charging**
- Primary purpose is for residential homes, most likely to be used by the majority of consumers
- Charging will typically be done overnight due to long charging time
- Level I and II chargers may be found in non-residential locations (ex. Workplace Charging) for EV owners to use

**Fast**
Deciding Factor: ALIENATING

Private

Public

Location

Charging Speed
Will Quick Charging Harm the Battery?
Will Quick Charging Harm the Battery?

How CHAdeMO Quick Charging Works…

- BMS Decides the Charging Rate Based on Battery Conditions
- The Charger is Given the Proper Voltage and Rate to Charge via CAN
- The Charger Pre-charges the Circuit to the Voltage given by the BMS and Limits Charging to the Specified Rate
- Improvements in battery technology can be implemented without a change to the charger. The BMS can specify a higher charging rate to the existing infrastructure.
Will Quick Charging Harm the Battery?

Cell and Module Overvoltage and High Heat will Damage Battery Systems

BMS (Battery Management System)

- Responsible for monitoring cell and module voltages and temperature
- Controls battery contactors to start or stop battery charging and use
- Manages balance of SOC from module to module (cell to cell)
- Determines State of Health for EV Battery
- Manages the rate of charge in DC Quick Charging to ensure the battery is not harmed while charging

Cell Variation (LFP Example)

- Every battery has some variation in cell to cell resistance and capacity
- Resistance changes with cell age and cell temperature

Battery Voltage: 10.8v
Will DC Quick Charging Harm the Battery?

No.

FEA’s 25kW Quick Charger is a safe method for charging electric vehicles, even with regular use.

Here’s Why:
The Nissan leaf has a 24 kWh battery pack, and FEA’s charger is 25kw so it will charge the battery in about an hour. Therefore it will generally charge at the c-rate of the battery. C-rate charging is within normal operating parameters. *It’s that simple.*
What is C-Rate?

• C-Rate is the current at which a battery or cell can discharge in about one hour
  – Is equal to the nameplate capacity number in Amps
    – “Nameplate Capacity” refers to the capacity advertised by the battery manufacturer
    – For a 20Ah cell, C-Rate is 20Amps

• Cycle Current for batteries and cells is defined in term of “C-Rate”
  – Charging a 20Ah cell at 2C is the same as charging at 40Amps
  – Charging any cell at 2C will take about ½ hour for 100% depth of charge
  – Discharging a 20Ah cell at C/2 is the same as discharging at 10Amps
  – Discharging any cell at C/2 will take about 2 hours for 100% depth of discharge

• Cycle Life is Typically Defined as the Number of Cycles a Battery or Cell can Operate until the Capacity Drops to 80% of the Nameplate Capacity

• Cycle life for any given cell is determined at some charge and discharge rate. Different chemistries of Lithium Ion Cells have different cycle life and at different rates.
  – Typical published cycle life rates vary from 1C to 3C
  – 1C Charge rate for cycle life is very common
How is Nissan Leaf Battery Arranged?

360V (nominal), Lithium Manganite Chemistry (LiMn2O4), 48 Modules of 4 cells, Cell Voltage between 3.4V and 4.2V (3.8V nominal)

- 3.8V Cells in Series Yield 7.6V Module Voltage
- 33.1Ah Cells in Parallel Yield 66.2Ah Modules
- 48 Modules in Series Yield 364.8V at 66.2Ah (24kWh)
- C-Rate for the battery is 66.2 Amps

364.8V, 66.2Ah, 24kWh

- Nissan offers a 100,000 mile Warranty on the Battery
- Averaging 100 Mile Range per Charge
- Battery Cycle Life is Estimated at 1000 Cycles

Important because this is the key to the safety of DC Quick Charging. FEA’s maximum capacity is ~62 Amps, and we are therefore charging at approximately C-Rate
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- Maximum Current of Fuji Electric 25kW Charger is 62Amps
- 62 Amps is about a 1C Charge Rate for the Nissan Leaf
- Typical Cycle Life for Lithium Ion Cells are Between 1000 and 3000 Cycles at 1C
What is a Typical Cycle Life?

This A123 Chart shows 100% DOD Charging at 1C Rate, Discharging at 2C Rate with a battery life of over 3,000 cycles. …Cycle life data shows that cell still has 90% capacity at 3,000 cycles.
“Repeated use of a DC Fast Charge, "Level 3" quick-charge unit negatively affects the long-term performance of the battery pack that powers most plug-in vehicles, right? Wrong, according to Mitsubishi. Officials over at Mitsubishi believe that even daily use of a quick-charge unit won’t have much overall affect on the battery pack found in the 2012 Mitsubishi i. Bryan Arnett, manager of electric vehicle product strategy at Mitsubishi Motors North America, told Green Car Reports, "We expect a daily quick charge not to have a significant toll on battery life."

According to Arnett, the automaker expects its battery packs to retain around 80 percent of their original capacity after ten years of real-world use. That 80 percent estimate reportedly includes frequent use of a quickcharge station.

Still, Mitsubishi is smart enough not to really encourage exclusive use of quick-charge stations. Rather, the automaker is implying that a once-a-day quick-charge won’t hurt life or capacity much, so go ahead and quickcharge your i whenever necessary.”

Source: Green Car Reports, 10/9/11, Eric Loveday
Quick Charging and The Grid
How Will Quick Charging Impact the Grid?

Level 1 and Level 2 Charging
- Single Phase Power Supply
- Limited Ability to Control Usage
- Potential for Smart Grid / Demand Response to manage charge times in evening
- Distributed infrastructure. Many potential points to upgrade
- Difficult to plan infrastructure upgrades to meet increased demand (rely on permitting house surveys to find high EV adoption locations)

DC Quick Charging
- Three Phase Power Supply
- PFC on Charger. Balanced loading
- Able to plan infrastructure upgrades with planned installations in high traffic areas
- Network statistics can track usage trends and allow for demand response and tiered billing to create incentive to increase usage during off peak hours
- Drivers are more likely to be “topping off” and will be more flexible around charging times
- Power for 25kW Charger is easier to accommodate with out infrastructure upgrades than 50kW Charger
Demand Charges

- Based on the peak kW usage during the billing period
- Can be more than $20 per kW in some areas
- Billed even if the event occurs once in the billing period for a relatively short duration

Peak Usage
17 kWh, Peak 3 kW
Quick Charging Standards
### What are the Current Standards?

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<th>SAE</th>
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<td>Communication</td>
<td>CAN</td>
<td>PLC</td>
</tr>
<tr>
<td>Isolation / Safety</td>
<td>Defined and Tested</td>
<td>Released 8/2012</td>
</tr>
<tr>
<td>Charging Protocol</td>
<td>Defined and Tested</td>
<td>Released 8/2012</td>
</tr>
<tr>
<td>Vehicle Charging Interface</td>
<td>(2) Plugs required on the vehicle</td>
<td>(1) Plug for AC and DC Charging</td>
</tr>
<tr>
<td>Years in Use</td>
<td>4 (July 2008)</td>
<td>0</td>
</tr>
<tr>
<td>Chargers In Use</td>
<td>1582 (1304 Japan)</td>
<td>0</td>
</tr>
<tr>
<td>Adopted by</td>
<td>Nissan, Mitsubishi, Subaru, Toyota</td>
<td>GM, Ford, BMW, Daimler AG, Volkswagen</td>
</tr>
<tr>
<td>Expected Release Date</td>
<td>Now</td>
<td>August 2012</td>
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**Fun Trivia:** CHAdeMO is an abbreviation of “CHArge de MOve”, equivalent to “charge for moving”, and is a pun for O cha demo ikaga desuka in Japanese, meaning “How about some tea” (while charging) in English.
What are the Current Standards?

- There is currently a demand for CHAdeMO Quick Chargers to support current vehicle sales.
- Current CHAdeMO vehicles will be on the road for the next 10 years.
- Electric Vehicles with the SAE standard will likely not be on the road until 2014.
- It makes sense to install infrastructure to support existing CHAdeMO Vehicles.
- The Quick Chargers installed should be a compromise on Unit Price and Operating Cost.
- The Quick Chargers should be installed with a minimum impact to the existing grid.
Lessons Learned... at Fuji Electric
A Surprising Connection: **Vending Machines**

- Fuji Electric is one of Japan’s largest manufacturers of vending machines, producing over 500 units per day.

- Synergies exist between vending machine design/construction and EV Charging Stations.
EV Chargers vs. Vending Machines: Market Similarities

**Similarities**
- Complex product
- Importance of data
- Individual Point-of-Sale
- Size & Shape
- 3rd Party Supported Products
- High volume required
- Importance of manufacturing design
- Similar sales channels
- Low competitor differentiation
- New technology development is key
- Modular approach to offer custom solutions

**Impact on FEA EV Strategy**
- Modular 25kW unit for EV Chargers
- DFA, DFM
- Design components to limit size and weight
- Standardized manufacturing process
- Point-of-Sale capabilities
- Various transactional types
- Designed to allow for outdoor use
- Lower manufacturing cost
- Transaction value similar to vending

**We know what you’re thinking...**

Confidential and Proprietary Information to Fuji Electric Corporation of America
What about GAS STATIONS?

• Similarities between EV Chargers and Gas Stations are not as significant as may be assumed
• Important to keep an open mind with emerging technologies and markets… *the most obvious comparisons may not be the best ones.*

• **Why Are Gas Stations DIFFERENT than EV Chargers?**
  – Higher transaction cost (~$50)
  – Locations require significant infrastructure
  – Environmental issues and permit requirements
  – Potential for odors and leaks
  – Need large centralized install (not scalable)

• **What does this mean for EV Chargers?**
  – Opens the realm of possibilities for location of EV Chargers
  • Small business
  • Parks
  • Chain Stores

  ……*similar to vending machines*
Vending Machine Production Process

As Charger Sales Increase, Manufacturing Efficiencies must be Improved (much like vending machine production)
Thank You