WAVE

Wireless Advanced Vehicle Electrification

A High Performance 50kW Inductive Charger for Electric Buses

Hunter Wu

Special Session: Advances in Wireless Power for Electric Vehicles I

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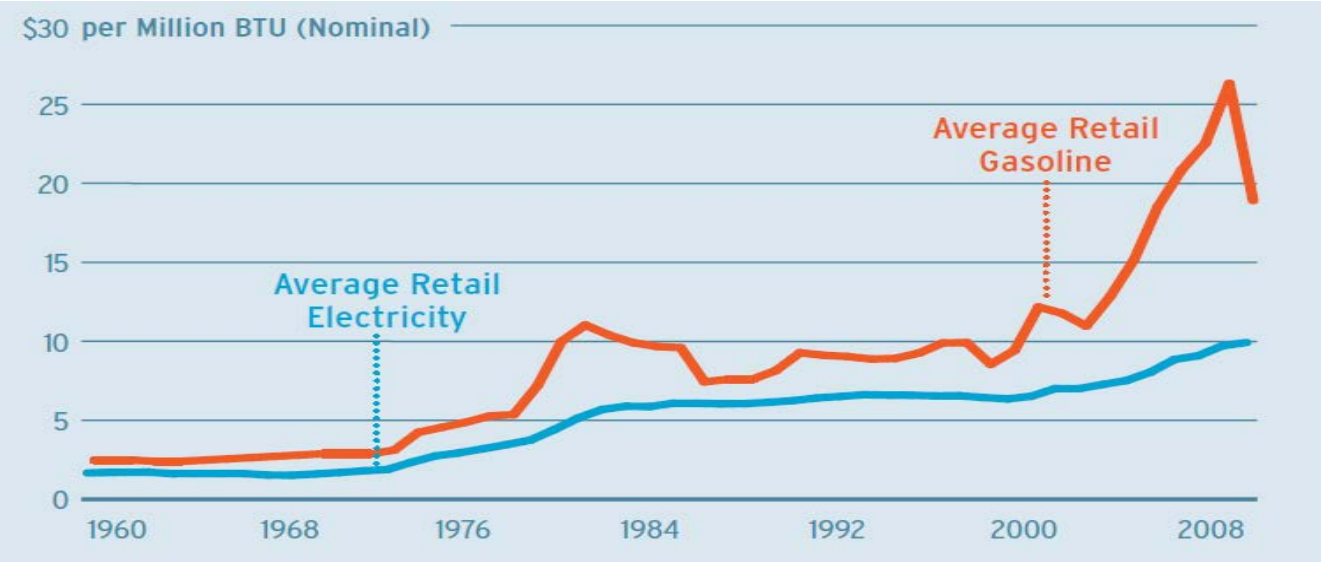
Wireless Advanced Vehicle Electrification

Outline

- Background & Introduction
- Specification of 5kW, 25kW, 50kW System
- Design Requirements
- System Integration
  - Electric Bus
  - Primary Infrastructure
- Current Projects
  - University of Utah
  - Long Beach Transit
  - Monterey-Salinas Transit

Introduction – Why Electric Buses

- Economic Security
  - Less volatile to oil price shocks



- Environmental Sustainability
  - Pollutants
  - Greenhouse gas emissions (saves 70-140 ton/bus year *)

* Calculation based on Argonne GREET model for diesel carbon consumption and California electric grid

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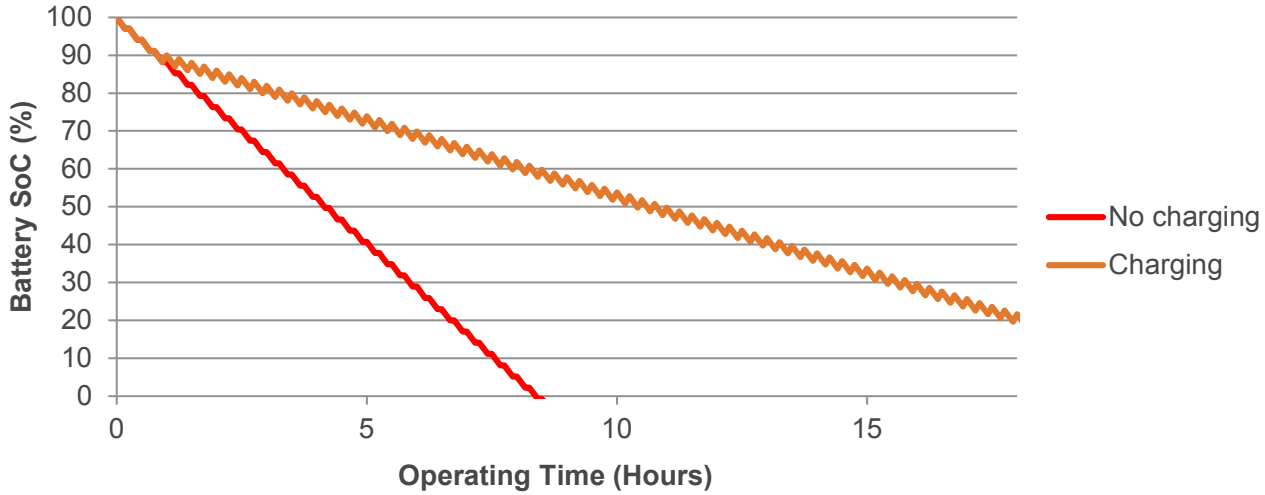
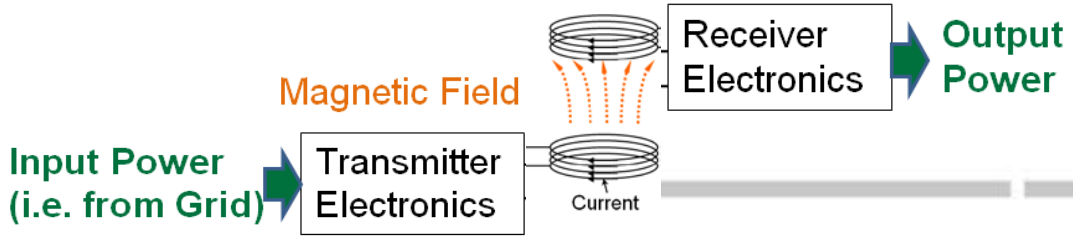
Introduction – Why En-Route Charging?

- Pure 40” electric buses
  - Typically travel: 120-140 Miles/day
  - Capacity: 300-700 kWh
  - Storage dependent on hotel loads
  - Longer routes: >1MWh
  - Impossible to package (>15,000 lbs)
  - Inefficient: moving batteries, not passengers
- En-route charging
  - Reduces batteries up to 80%



Introduction – Advantages of Inductive Charging

- Safely transfers power over surface road materials, snow, air gap
- Automatic charging with no user input required
- Ideal for static en-route charging



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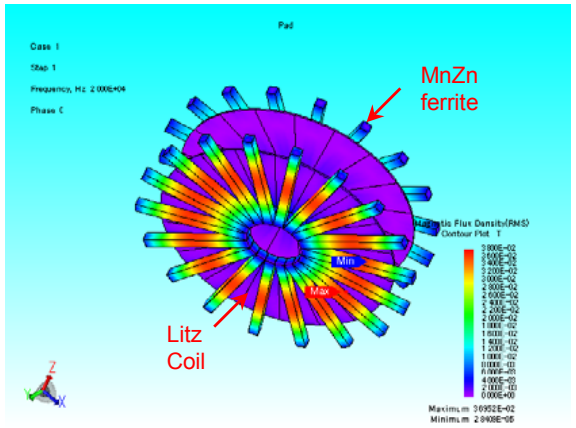
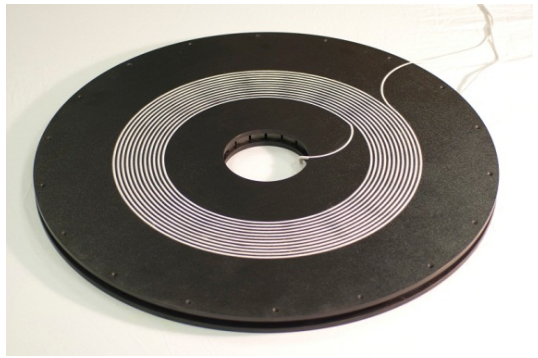
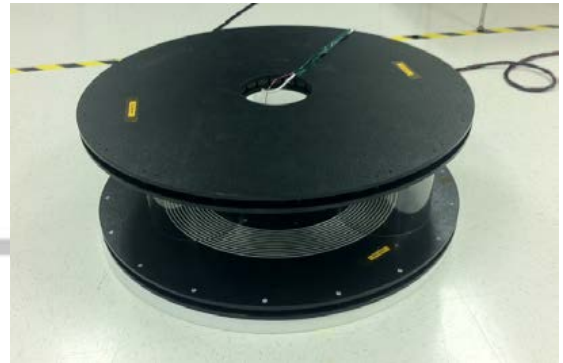
Specification of 5kW System

Parameters	Value	Notes
Power Level	5kW	
Frequency	20kHz	
Air gap	6 – 10.5 in	Magnetic gap
Efficiency	> 90%	> 98% magnetic transfer
Voltage	300VDC	Output
Pad dimension	32-in diameter	
Pad weight	~ 45 lbs	
Misalignment	8 in @ 6 in gap	With maintained efficiency (conical shape)
EMF exposure	ICNIRP	Meets latest ICNIRP standards







Wu, H.H., et al., *A High Efficiency 5 kW Inductive Charger for EVs Using Dual Side Control.* IEEE Transactions on Industrial Informatics, 2012. **8**(3): p. 585-595.

Efficiency Breakdown

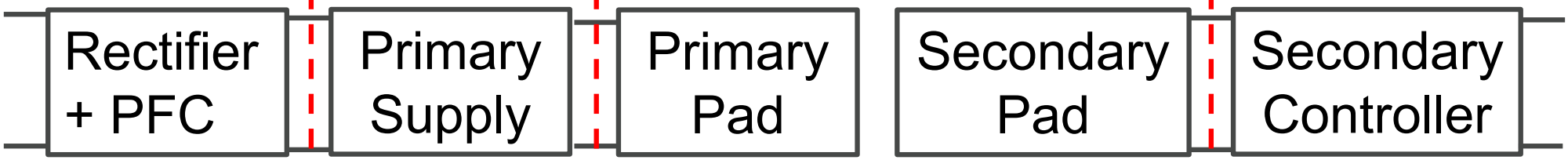
- 5kW 10” @ > 90% transfer efficiency

PFC stage:
- PF = 1
- η = 97-98%
- soft switching

Primary:
- 30 kVA
- η = 96-97%
- Hard switching

WPT pads:
- Unloaded Q=350
- η = 98-99%
- k = 0.17 – 0.34

Rectifier + Controller:
- 20 kVA
- η = 97-98%



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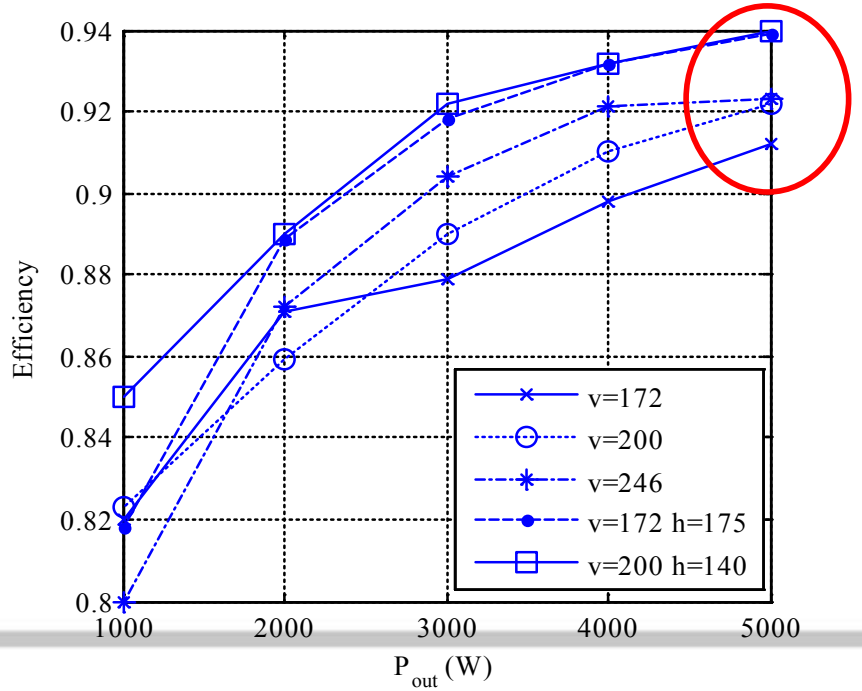
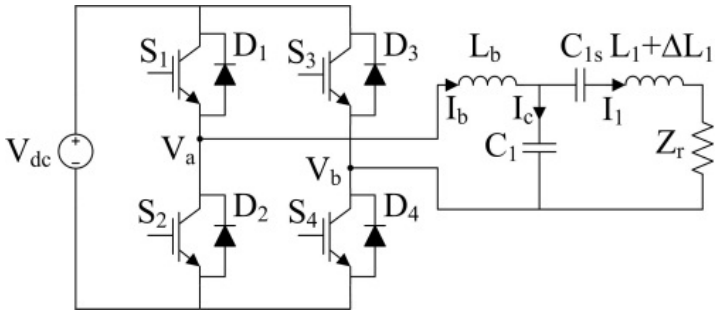
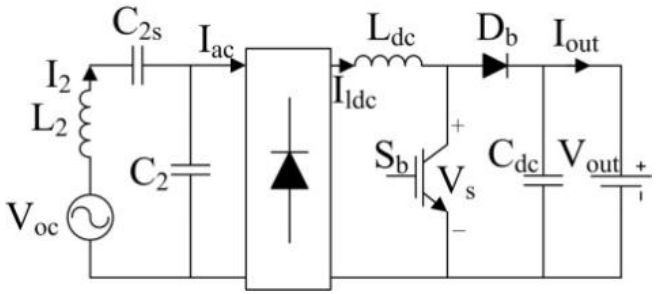
Efficiency Measurements

- High efficiency at rated load
- Can achieve >90% with:
  - 98% PFC circuit [1]





Parameter	Value	Parameter	Value
V_{dc}	400V	C_{1s}	663nF
X_1	9.21Ω	L_1	177-188uH
$I_{1\ max}$	39A	$L_{1\ short}$	161-172uH
L_b	73.3uH	Switch	IRG7PH42UPBF
C_1	885nF	Diode	RHRG75120
ω	$1.257x10^5$ rad/s		

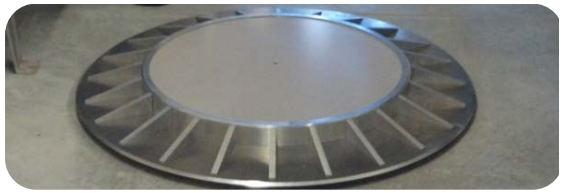


Parameter	Value	Parameter	Value
V_{out}	300V	L_{dc}	550uH
X_2	10.6 Ω	I_{out}	0-17A
C_2	745nF	Diode (D_b)	IDT16S60C
L_2	177-188uH	Switch	IRG7PH42UPBF
C_{2s}	666nF	Diode (Rect.)	RHRG75120

[1] F. Musavi, W. Eberle and W. G. Dunford, "A High-Performance Single-Phase Bridgeless Interleaved PFC Converter for Plug-in Hybrid Electric Vehicle Battery Chargers," IEEE Transactions on Industry Applications, vol. 47, no. 4, pp. 1833-1843, 2011

Specification of 25kW System

Parameters	Value	Notes
Power Level	25kW	Pad sized for 50kW
Frequency	20kHz	
Air gap	6-6.5 in	Physical air gap
Efficiency	> 90%	DC-DC efficiency (> 94% peak)
Voltage	300-400VDC	Output
Pad dimension	56” O.D.	32” of magnetic diameter
Pad weight	160 lbs	
Misalignment	6” @ 6” gap	With maintained efficiency
EMF exposure	ICNIRP	Meets latest ICNIRP standards



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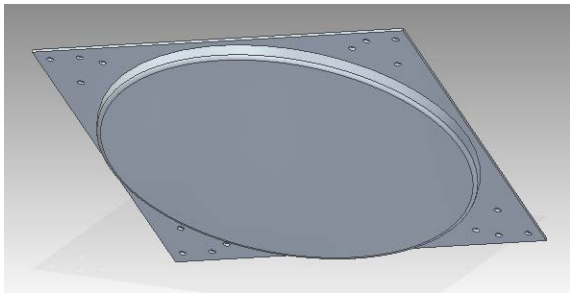
Specification of 50kW System

Parameters	Value	Notes
Power Level	50kW	
Frequency	23.4kHz	
Input Voltage	480V 3Ph	
Air gap	7 in	Physical air gap
Efficiency	> 90%	DC-DC efficiency (92% peak)
Voltage	330-390VDC	Output
Pad dimension	36” O.D.	
Pad weight	~60 lbs	
Misalignment	8” @ 7” gap	With maintained efficiency
EMF exposure	ICNIRP	Meets ICNIRP 1998 standards



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Design Requirements

- Inductive charging
  - Safety
    - High voltage
    - Magnetic field
  - Alignment detection
  - Foreign object
    - Can
    - Cat
  - EMC capability
  - Reliability
- Wireless communications
- HMI

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Design Requirements

- Mechanical
  - Weight
  - Size
  - G-shock
  - Vibration
  - Water/dust-proof
- Thermal
  - Operating temperature range
  - Liquid cooling requirement

Integration – Electric Bus

- High Voltage
  - Allow inductive and conductive charging
  - Matches BMS charging voltage
  - HV connectors
- Mechanical
  - Mounting
  - Conduit
  - Vehicle ground clearance
- Software
  - Handshaking
  - Charging status
  - Vehicle status
- Thermal
  - Liquid cooling

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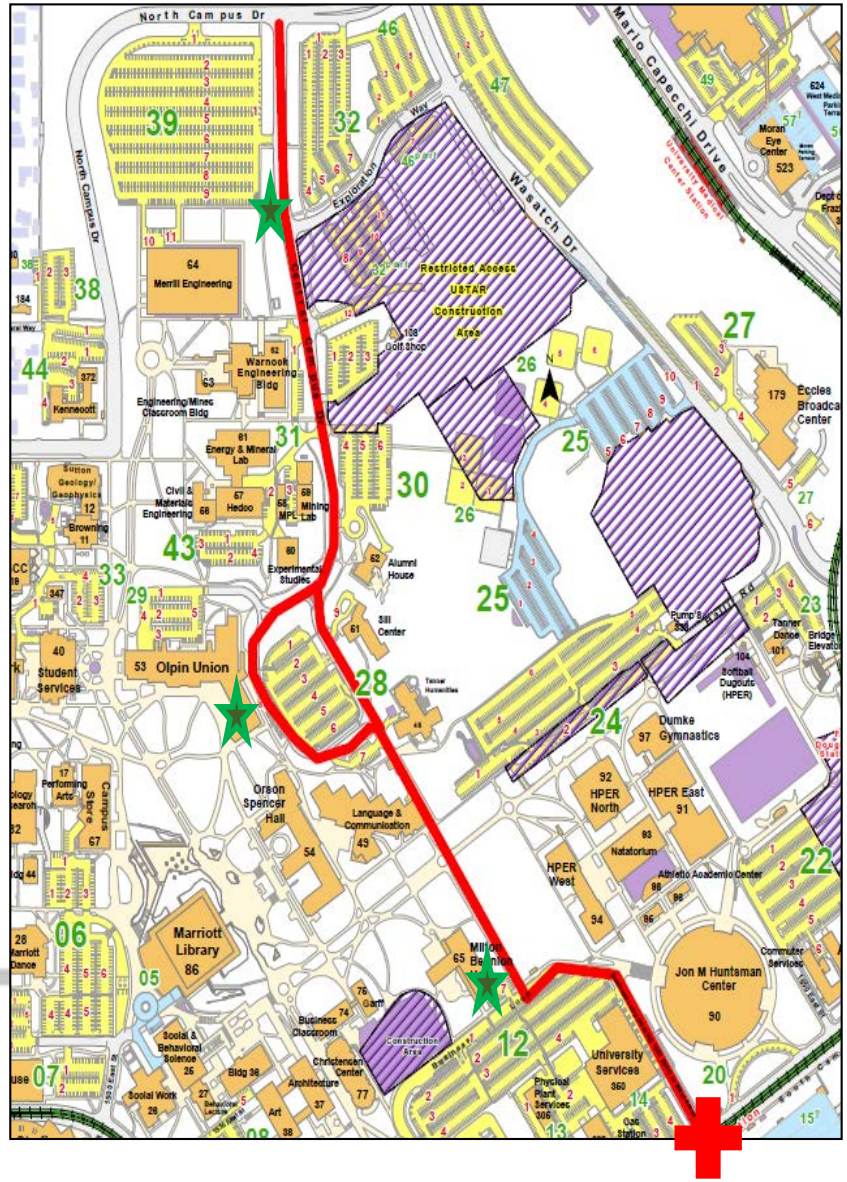
Integration – Primary Infrastructure

- Electrical grid
  - Transformers
  - Electrical panels
- Primary pad
  - Road loading condition
  - Freeze thaw cycle
- Primary charging station
  - Operating Environment

Current Project – UofU

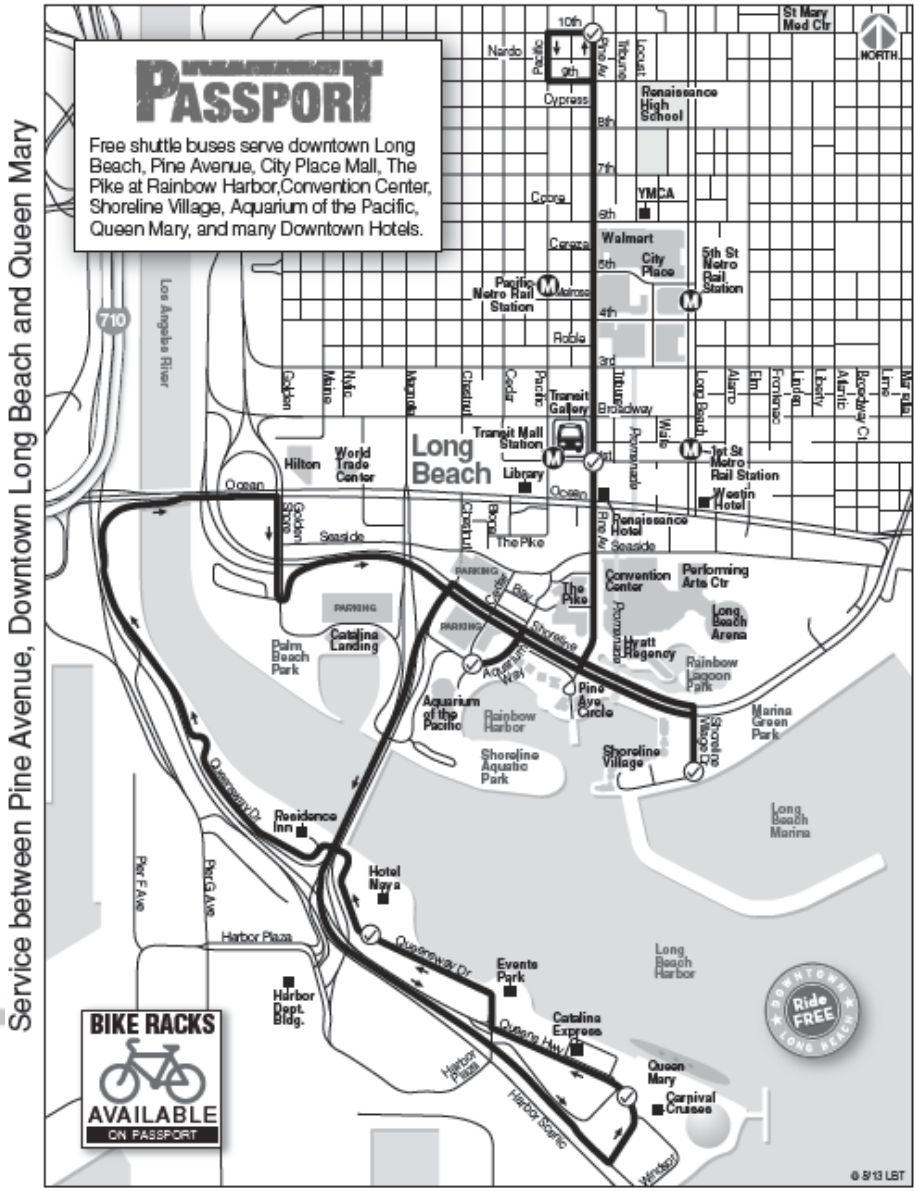
- Charge for: 5min of 15min
- 1.6M route
- One 50kW charger
- Complete Coach Works bus
- Bus length: 40ft
- Battery: 213 kWh
- Propulsion: 180 kW
- Fully operational Q2 2014

First Commercial Demo



Current Project – LBT

- Charge for: 10-20min of 1hour
- 8.6M route
- Two 50kW charger, 10 buses
- BYD bus
- Battery: 324 kWh
- Fully operational Q3 2014



Current Project – MST

- Charge for: 10min of 30min
- 4.5M route
- One 50kW charger
- Complete Coach Works bus
- Battery: 213 kWh
- Fully operational Q1 2015

Conclusions

- Electric buses offers many advantages
- Inductive charging can make electric buses more commercially feasible
- Many vehicle integration aspects to consider
- Questions and Answers?

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