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Analysis of In-Route Wireless Charging for the Shuttle System at Zion National Park

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Introduction

- Zion National Park began running a shuttle system in 1999 to reduce traffic congestion in the narrow canyon.
- Today's fleet is composed of 39 propane power units and 23 passenger trailers and recorded over 5 million passengers in FY2015.
- As the propane-powered fleet continues to age and maintenance costs increase, the National Park Service (NPS) is looking to convert 14 of its power units to electric vehicles.
- How can in-route charging reduce the energy storage requirements?

Photo by Robert Prohaska (NREL 37392)

WPTSim (Wireless Power Transfer) Tool

Route Segmentation

Speed
Position
Grade

Divide drive cycle into WPT, non-WPT, parked, and stationary charging segments

Vehicle and WPT Simulation

FASTSim for non-WPT segment

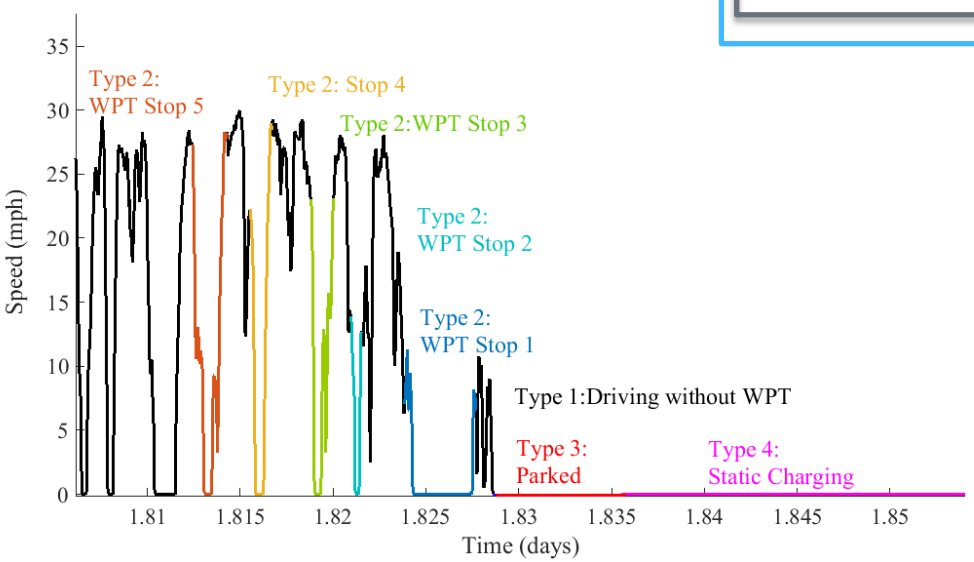
Co-simulation of WPT segment

FASTSim ⇄ WPTSim

Vehicle and Infrastructure Requirements

Battery use
WPT charging
Static charging
Trip statistics
etc.

WPTSim can be used as a design tool to calculate energy and power requirements for in-route charging



Segment Types:

(1) Driving without WPT
(2) Driving with WPT {includes stationary wireless charging}
(3) Parked
(4) Parked with stationary conductive charging {optional}

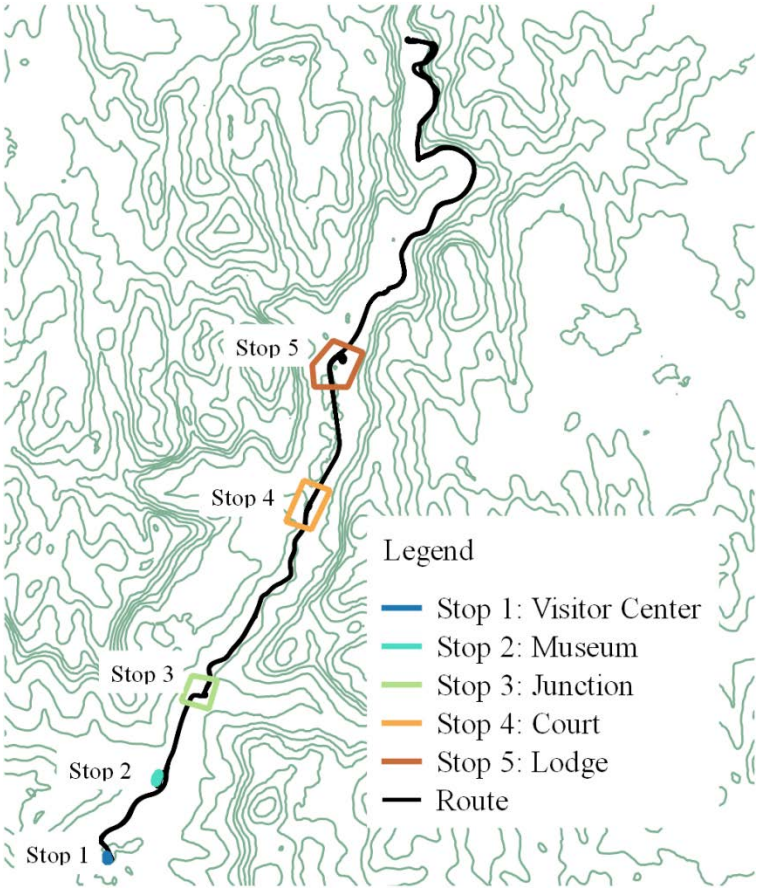
Data Collection and Processing - Zion Canyon Shuttle

- Data for this study were collected from a subset of 9 power units of the propane-powered fleet.
- These shuttles were used from May 11, 2016 to May 24, 2016 while on the spring schedule of the route.
- Logged data for this analysis include vehicle speed from the vehicle's controller area network (CAN) communication bus as well as high-precision GPS/GLONASS positional data for determining grade.

Photo by Robert Prohaska (NREL 37408)

Data Collection and Processing – Zion Canyon Shuttle

Route map with the GPS coordinates of potential in-route charging stops outlined.



Topographical data derived from ASTER GDEM, a product of METI and NASA.

- Stops beyond the Zion Lodge are not analyzed as electricity service beyond the lodge is consider unrealistic
- Analysis of the route data indicates that dwell times at Stop 1 and Stop 5 are the longest

Recorded vehicle data

Bus #	Operation		Mean Dwell Time (Min.)				
	Days in Use	*Trips*	*Stop 1*	*Stop 2*	*Stop 3*	*Stop 4*	*Stop 5*
41	9	76	3.74	1.67	1.23	1.50	3.21
42	9	75	3.98	1.70	1.36	1.58	3.21
43	10	76	3.95	1.74	1.31	1.59	3.63
44	11	87	4.19	1.65	1.15	1.45	3.36
45	7	63	3.85	1.76	1.34	1.58	3.32
46	9	74	3.87	1.78	1.13	1.51	3.21
47	9	74	4.00	1.73	1.25	1.54	3.23
48	11	95	3.83	1.65	1.29	1.65	3.37
49	10	76	3.82	1.66	1.32	1.55	3.05
Total	85	696	3.92	1.70	1.27	1.55	3.29

Data Collection and Processing – Zion Canyon Shuttle

- Data from 63 trips with a GLONASS-enabled GPS device have been used to develop a median fit elevation profile for the route
- Utilizing the GPS data to define the start of the route at the Visitors Center, this profile has been added to all identified trips along the route
- Grade for travel not along the route has been ignored due to its relative low grade and small portion of total miles travelled

Data from 63 trips with the derived mean elevation and grade

Vehicle Simulation Parameters

- The intent of the NPS solicitation is to convert the existing shuttles to electric vehicles
- This vehicle must maintain the existing passenger capacity of 105 people (7,144 kg) while not exceeding GVWR of 24,040 kg
- Simulation of a vehicle at 24,040 kg defined an energy storage capacity requirement of 435 kWh
- Baseline vehicle equates to an empty curb weight (excluding batteries and passengers) of 12,555 kg, which requires a challenging reduction of 4,327 kg

Photo by Robert Prohaska (NREL 37397)

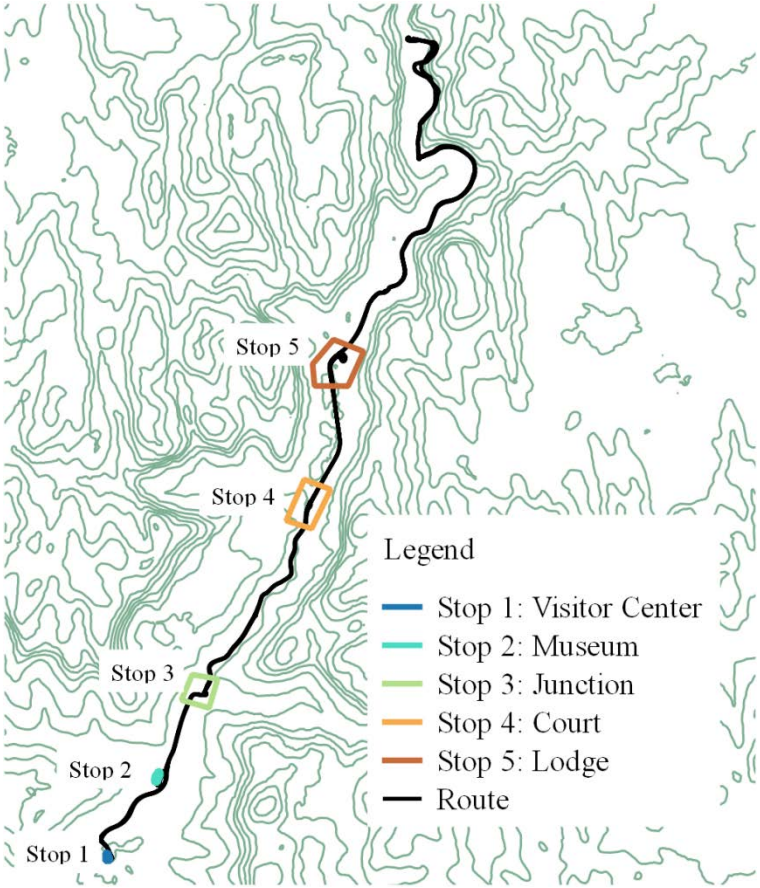
Baseline vehicle FASTSim parameters

Parameter	Description	Value
baseVehKg	Mass of vehicle (w/o batteries)	19,690 kg
vehKg	Total simulated mass of vehicle	24,040 kg
kgPerKwh	Battery mass per kWh of total energy	10 kg/kWh
maxEssKwh	Battery energy	435 kWh
maxSoc	Maximum state of charge	0.9
minSoc	Minimum state of charge	0.1
maxEssKw	Peak continous battery power	215 kW
maxMotorKw	Peak continous motor power	170 kW
auxKw	Auxillary component load	2.5 kW
wheelRrCoef	Rolling resistance	0.0080
dragCoef	Drag coeficient	0.800
transEff	Transmission / Driveline Efficiency	0.92

WPT Cases and Simulation Results

- Given the dwell time analysis and the availability of electricity, the following WPT cases have been identified:
  - (1) WPT at Stops 1 and 2
  - (2) WPT at Stops 1 and 5
  - (3) WPT at Stops 1, 2, and 5
  - (4) WPT at Stops 1, 2, 3, 4, and 5
- These cases have been simulated with WPT power capabilities of 100 kW, 150 kW, and 200 kW

Route map with the GPS coordinates of potential in-route charging stops outlined.



Topographical data derived from ASTER GDEM, a product of METI and NASA.

WPT Cases and Simulation Results

- Minimum state of charge (SOC) shown is the global minimum across all days in the data. This SOC has been used to determine whether additional capacity can be removed when >10%. This capacity has been removed in steps of 5 kWh
- The sweep of WPT power levels has assumed the same power level at each location unless removing more capacity exceeds a 2-C rate charge for the batteries
- Net trip energy is calculated by taking the total energy used to complete the route and subtracting the energy captured during the WPT stops

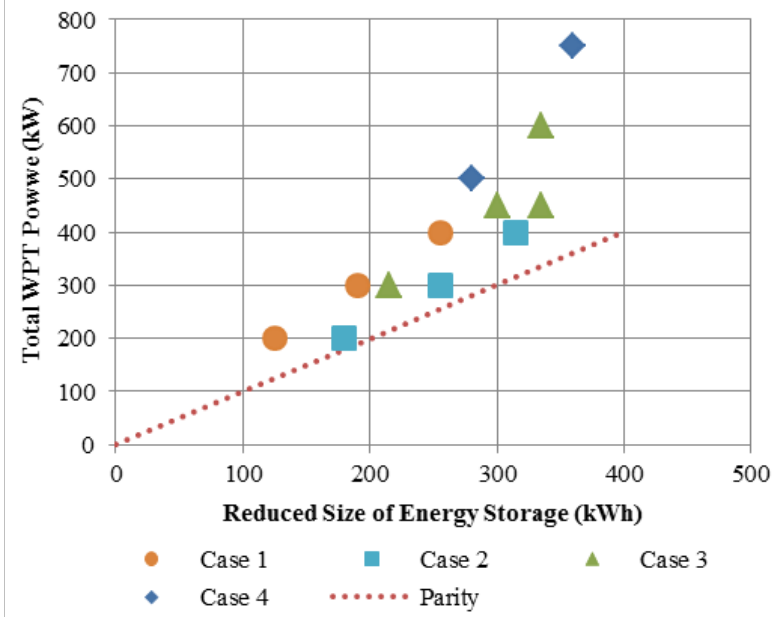
Battery capacity reductions for WPT cases

Case	WPT Stop Power (kW)					Battery		Net Trip Energy	
	Stp 1	*Stp 2*	*Stp 3*	*Stp 4*	*Stp 5*	*Total capacity (kWh)*	*Min. SOC (%)*	*Mean (kWh)*	*Std. Dev. (kWh)*
Base	-	-	-	-	-	435	10.3	30.50	0.90
# 1	100	100	-	-	-	310	11.9	21.24	2.76
# 2	100	-	-	-	100	255	11.7	18.19	3.03
# 3	100	100	-	-	100	220	11.3	15.33	3.26
# 4	100	100	100	100	100	155	11.1	10.55	3.65
# 1	150	150	-	-	-	245	11.7	16.64	4.19
# 2	150	-	-	-	150	180	12.0	12.27	4.58
# 3	150	150	-	-	150	135	12.3	8.13	4.95
# 4	150	150	150	150	150	75	17.4	2.15	5.24
# 1	200	200	-	-	-	180	11.2	12.06	5.67
# 2	200	-	-	-	200	120	12.4	6.61	6.09
# 3	200	200	-	-	200	100	38.0	2.52	6.21
# 3	200	100	-	-	200	100	20.4	4.15	5.16

WPT Cases and Simulation Results

- An examination of the relationship between energy capacity reduced and total WPT power from all WPT stops was used to understand utilization of the installed WPT infrastructure
- None of the cases reaches parity between power of WPT (kW) provided and energy capacity of battery (kWh) removed
- Assuming that a WPT system in this scenario can only provide value by the removal of battery capacity, the table provides a perspective of the allowable material cost for these WPT systems (with a battery cost of $230/kWh) for 14 vehicle conversions

Battery capacity reductions versus total WPT power at all stops



Allowable costs of WPT case 1 and case 2

WPT Power at all Stops (kW)	Total WPT System Cost ($)	
	Case 1	*Case 2*
100	402,500	579,600
150	611,800	821,100
200	821,100	1,014,300

Conclusions and Future Work

- A fleet equipped with in-route wireless charging has the opportunity to reduce battery pack size and mass
  - Reducing more than half of the battery capacity is possible with a WPT system at the locations defined for fast charging in the solicitation (case 1)
  - However, case 2 represents the scenario with the highest WPT equipment utilization as measured by kWh capacity reduced.
- Demand charges will affect the operational cost of fueling. More work is required to understand which cases provide similar charges to the baseline overnight charging case.
- Inclusion of the summer schedule in this analysis will be required as it may impact the stop dwell time. Likewise, a study of dwell time flexibility to reduce variability could improve the battery reduction results.
- Further work will consider battery life impacts of WPT charging as higher rates will improve the design constraints.

Thank You!

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