An Opportunistic Wireless Charging System Design for an On-Demand Shuttle Service

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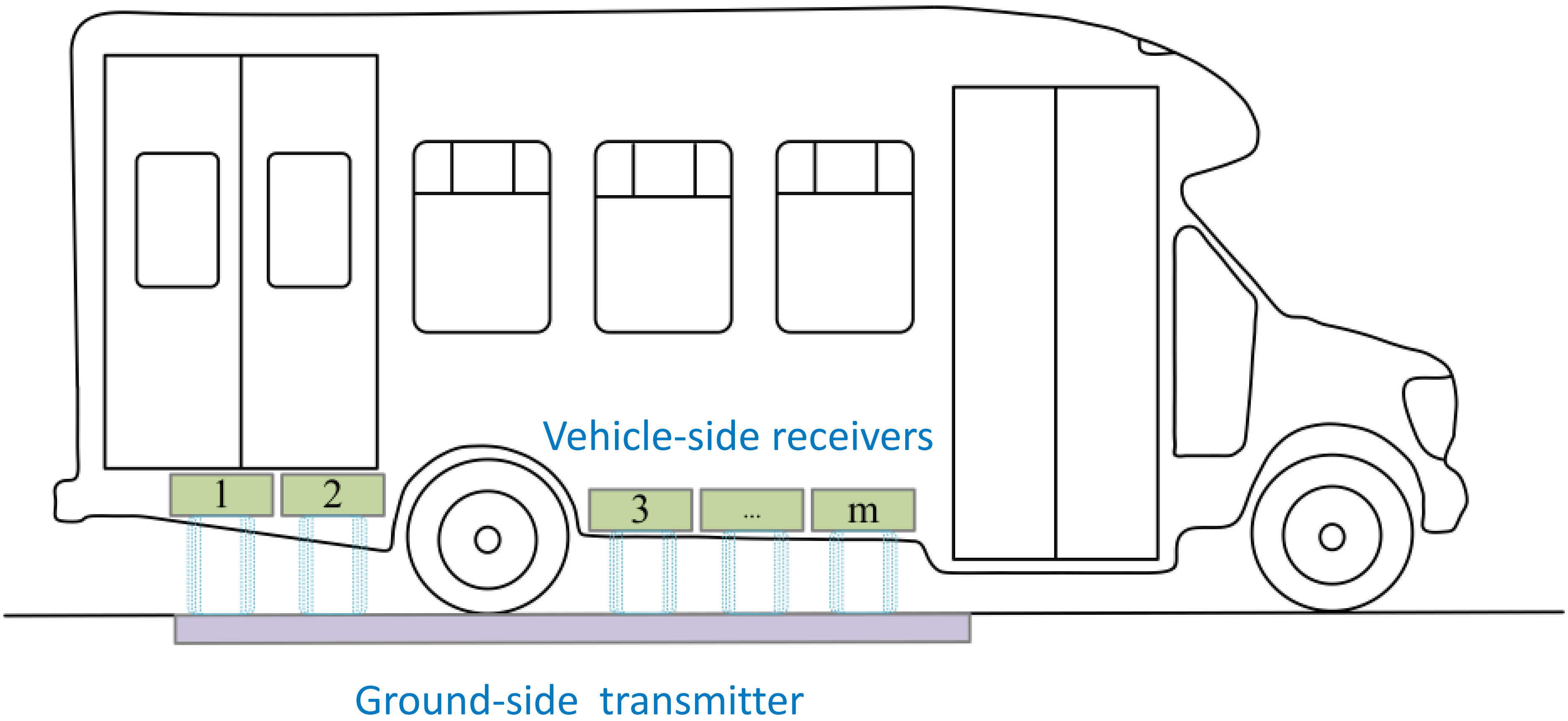
On-Demand NREL Employee Shuttle

Photo by Dennis Schroeder (NREL 32221)

Charging through Wireless Power Transfer (WPT)



Typical Shuttle Route

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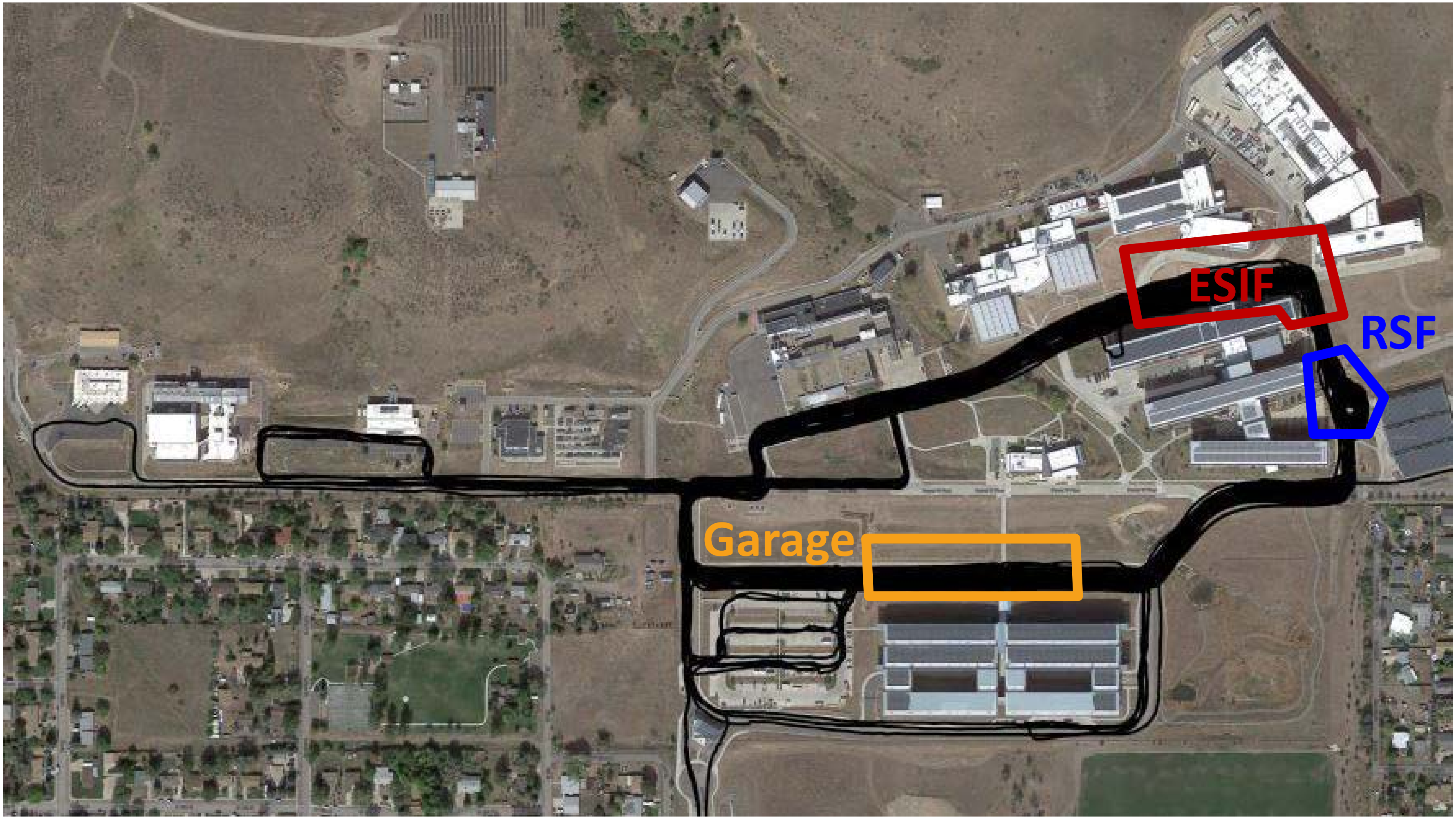
Typical Shuttle Route – Charging Locations Identified



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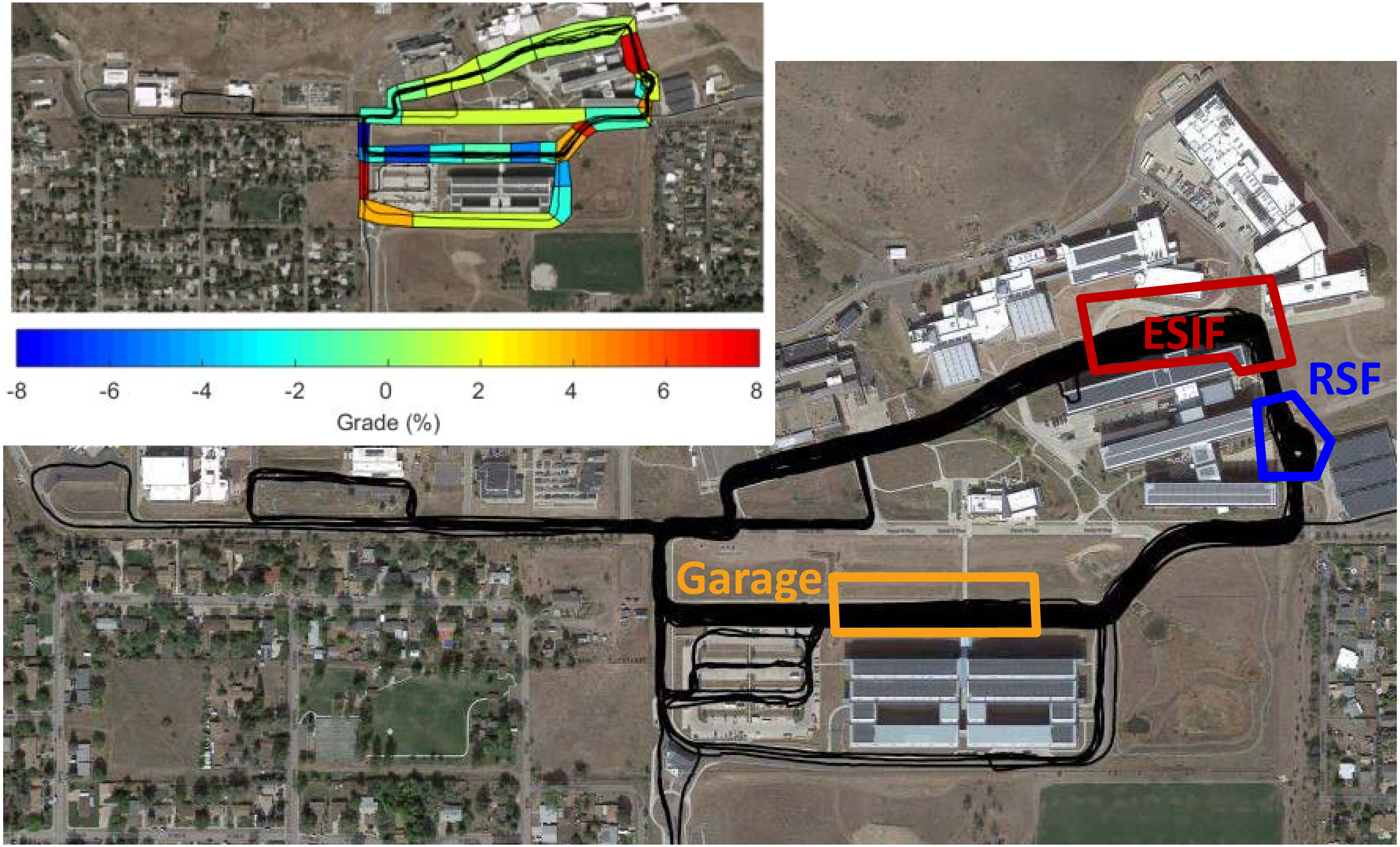
Typical Shuttle Route – Grade Applied



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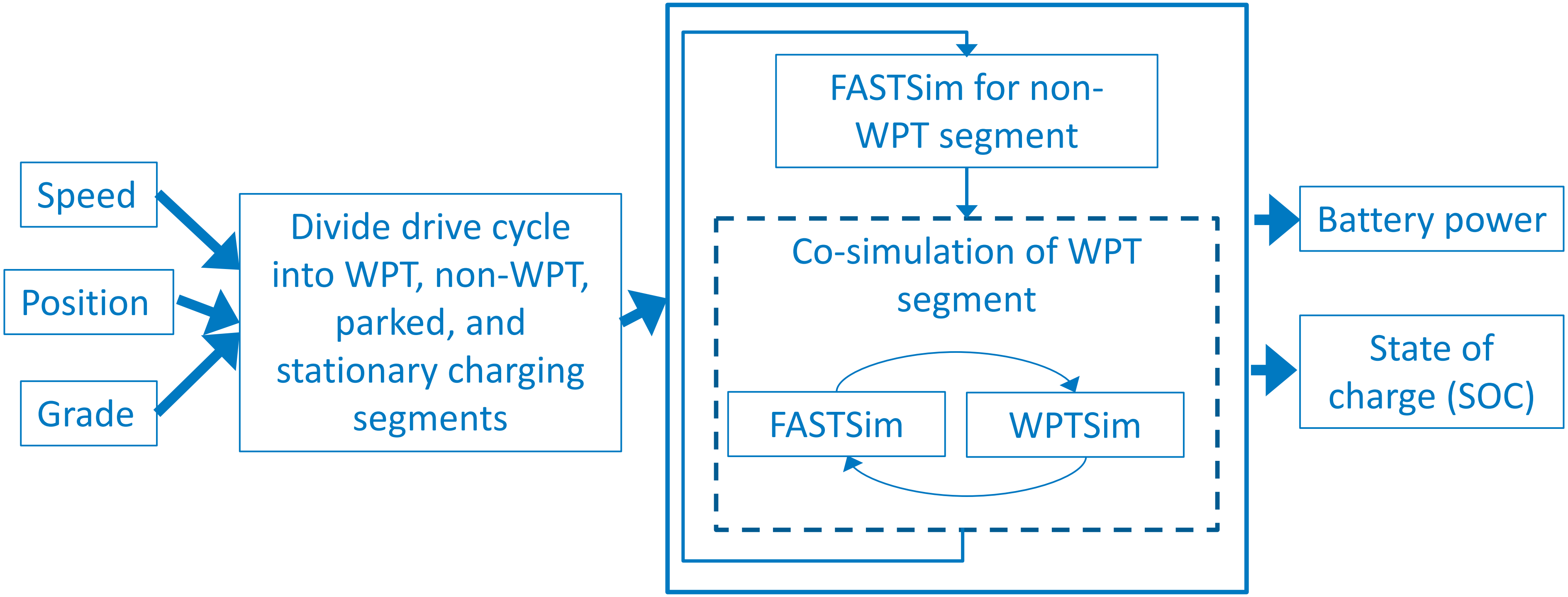
WPTSim: MATLAB-Based Simulator



Validation with Smith Electric Vehicles Newton

Photo by Dennis Schroeder (NREL 32221)

Followed shuttle in troop transport truck and recorded vehicle data

- Speed
- Location (lat/lon)
- Battery power
- Starting and ending SOC

Simulation with WPTSim (excluding WPT) resulted in simulated vehicle within 0.4 kWh of battery energy.

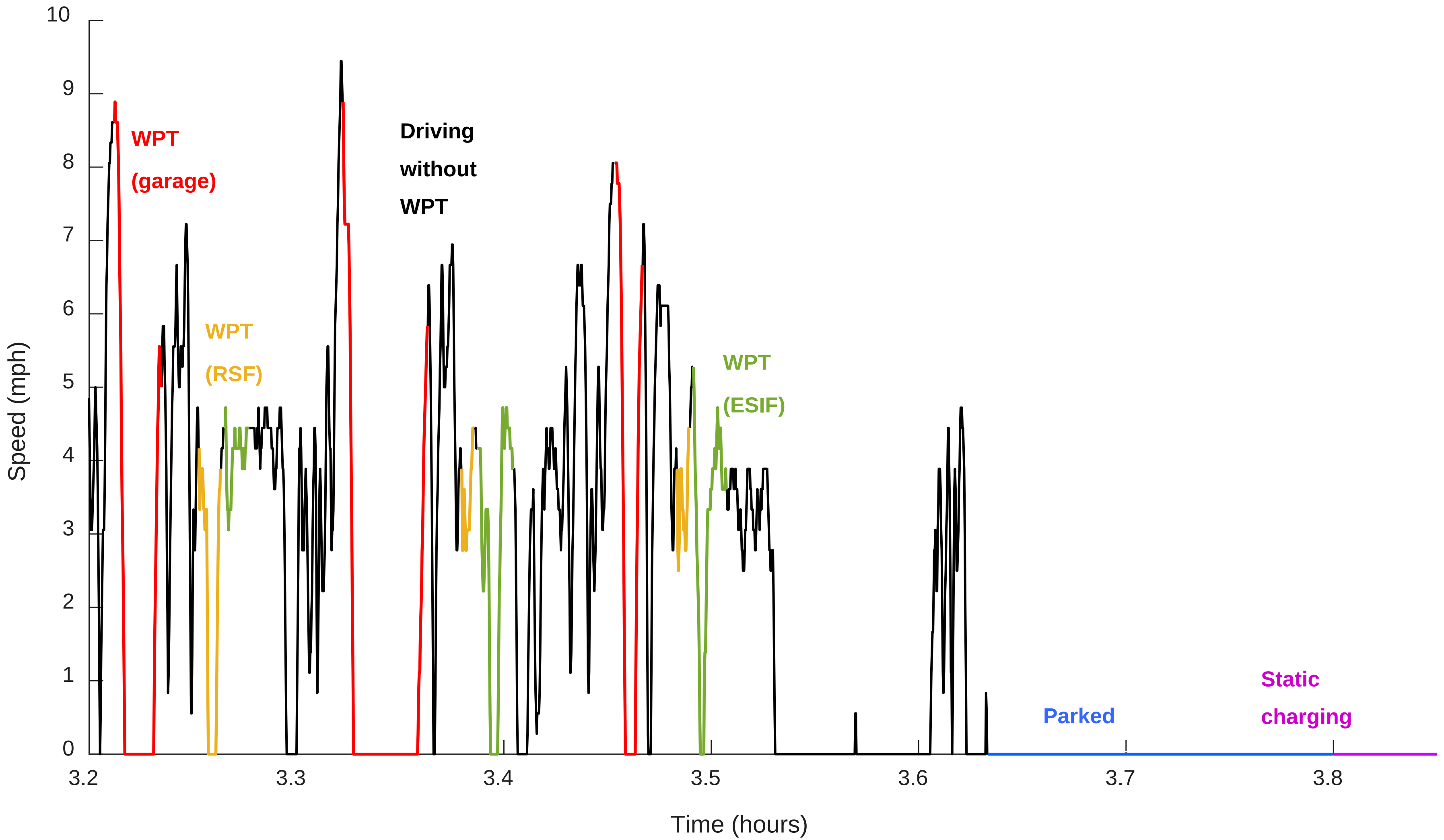
Battery power constraints of simulation achieved 99.9% of actual speed profile.

These results lead to the use of the following parameters for the electric shuttle simulations.

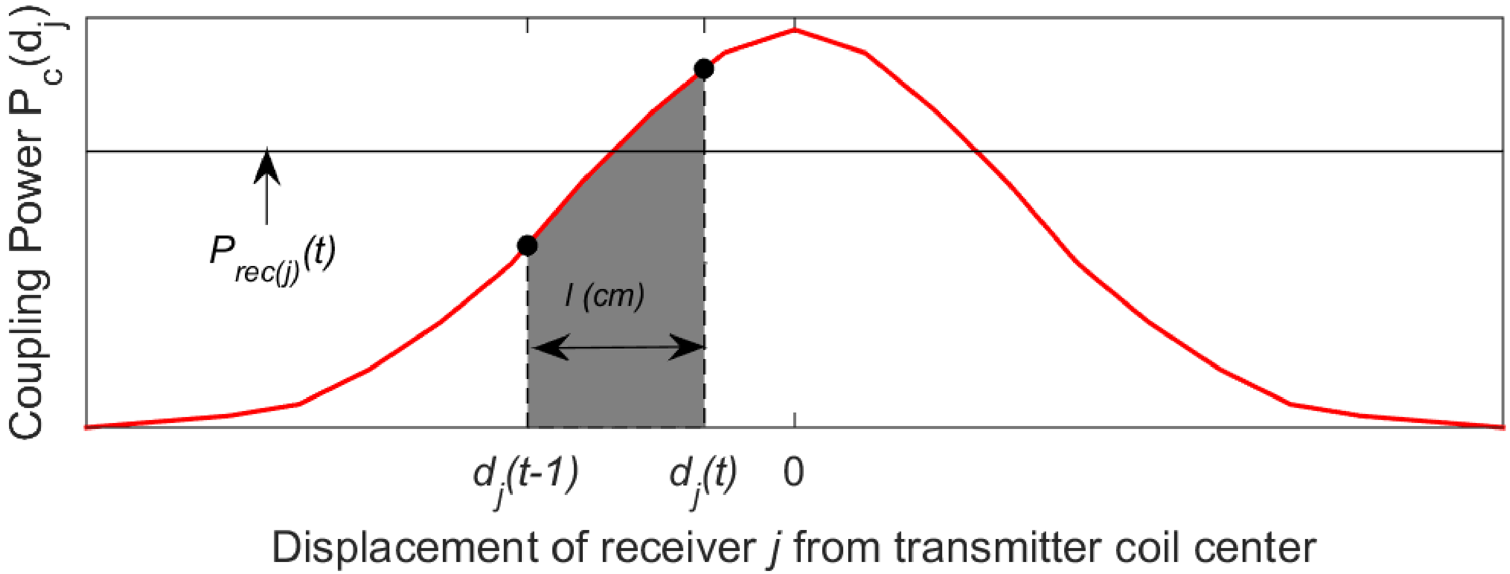
TABLE II
ELECTRIC SHUTTLE PARAMETERS

M	Vehicle mass without battery	6,800 kg
M_B/kWh	Additional battery mass [12]	100 kg/kWh
SOC_{min}	Minimum usable SOC	10%
SOC_{max}	Maximum usable SOC	90%
$P_{aux,on}$	Auxiliary load while driving	5 kW
$P_{aux,off}$	Auxiliary load while stationary charging	0.1 kW
P_{static}	Stationary charger power	20 kW

Segmenting the Drive Cycle



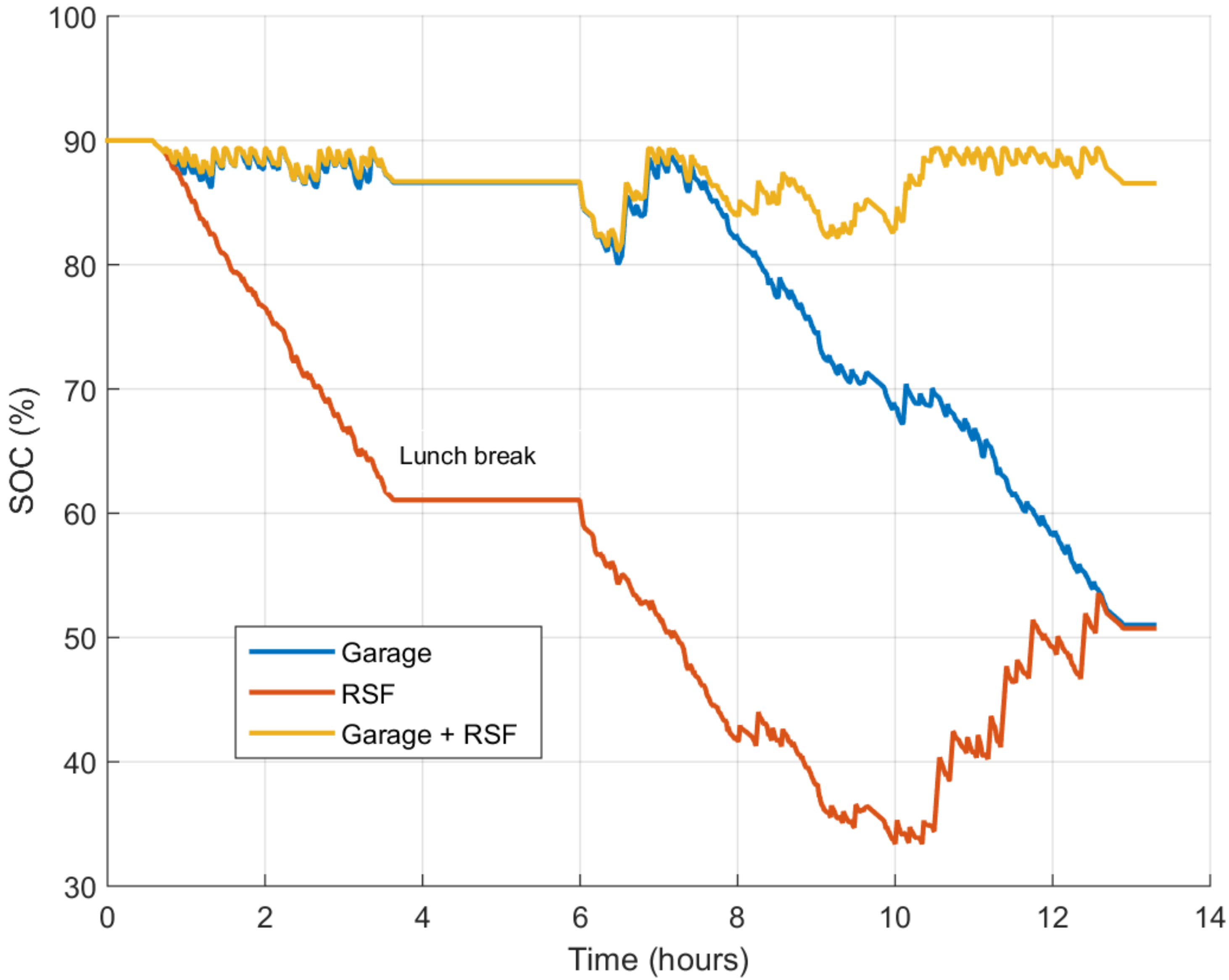
Wireless Power Estimation



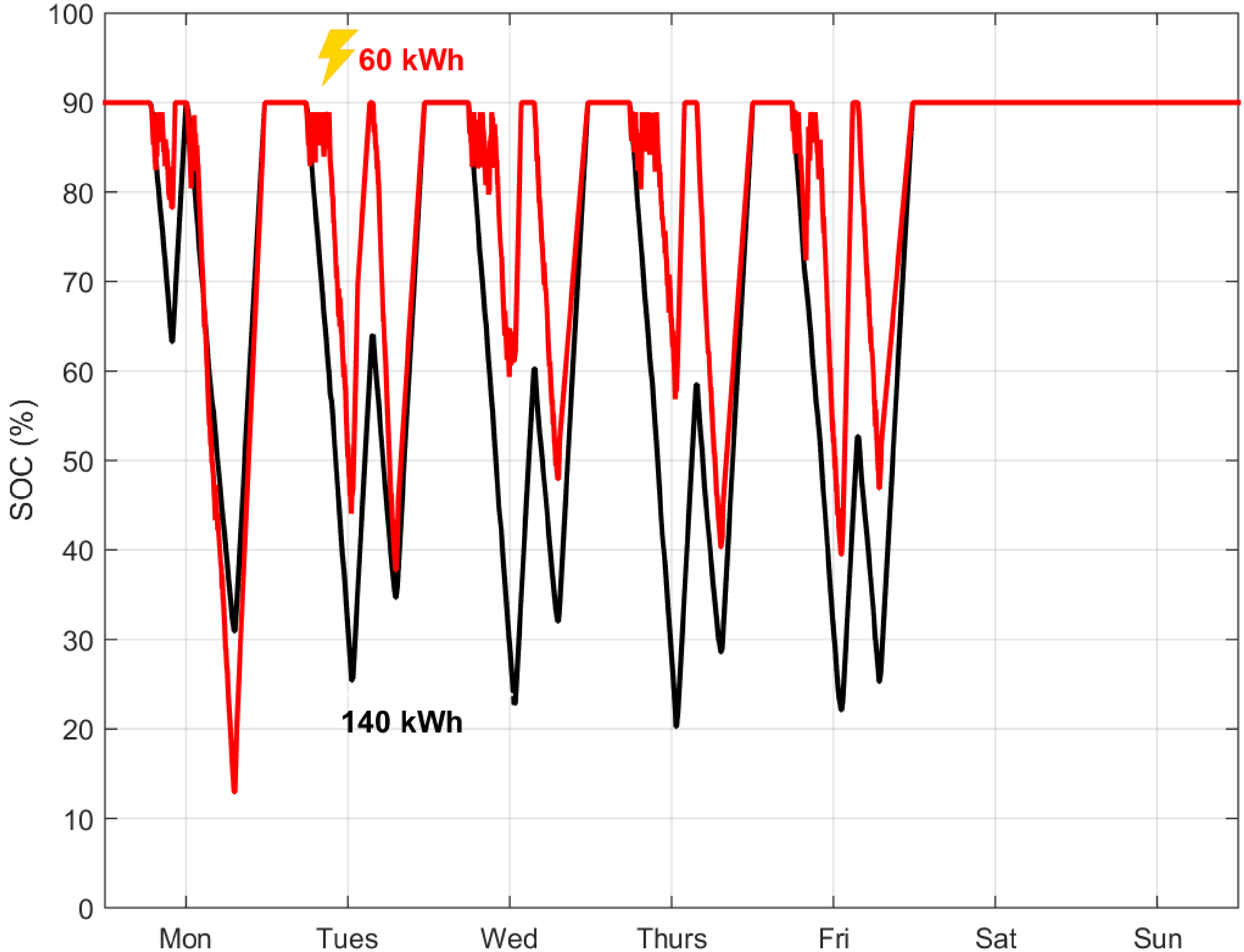
$$P_{rec(j)}(t) = \frac{1}{T}\int_{t-1}^{t} P_c\big(d_j(\tau)\big)d\tau \approx \frac{1}{l+1}\sum_{k=0}^{l} P_c(d_J(k))$$

- To calculate the wireless power available to the vehicle, an approximated integration at 1-cm resolution of the coupling power is developed using a linear interpolation of the positional coupling data between transmitter and receiver based on vehicle position over the 1-second simulation time step.
- The co-simulation with FASTSim allows for vehicle power constraints to limit the power received based on battery demand for the time step.
- This methodology allows for simulation of power transfer while the vehicle is in motion.

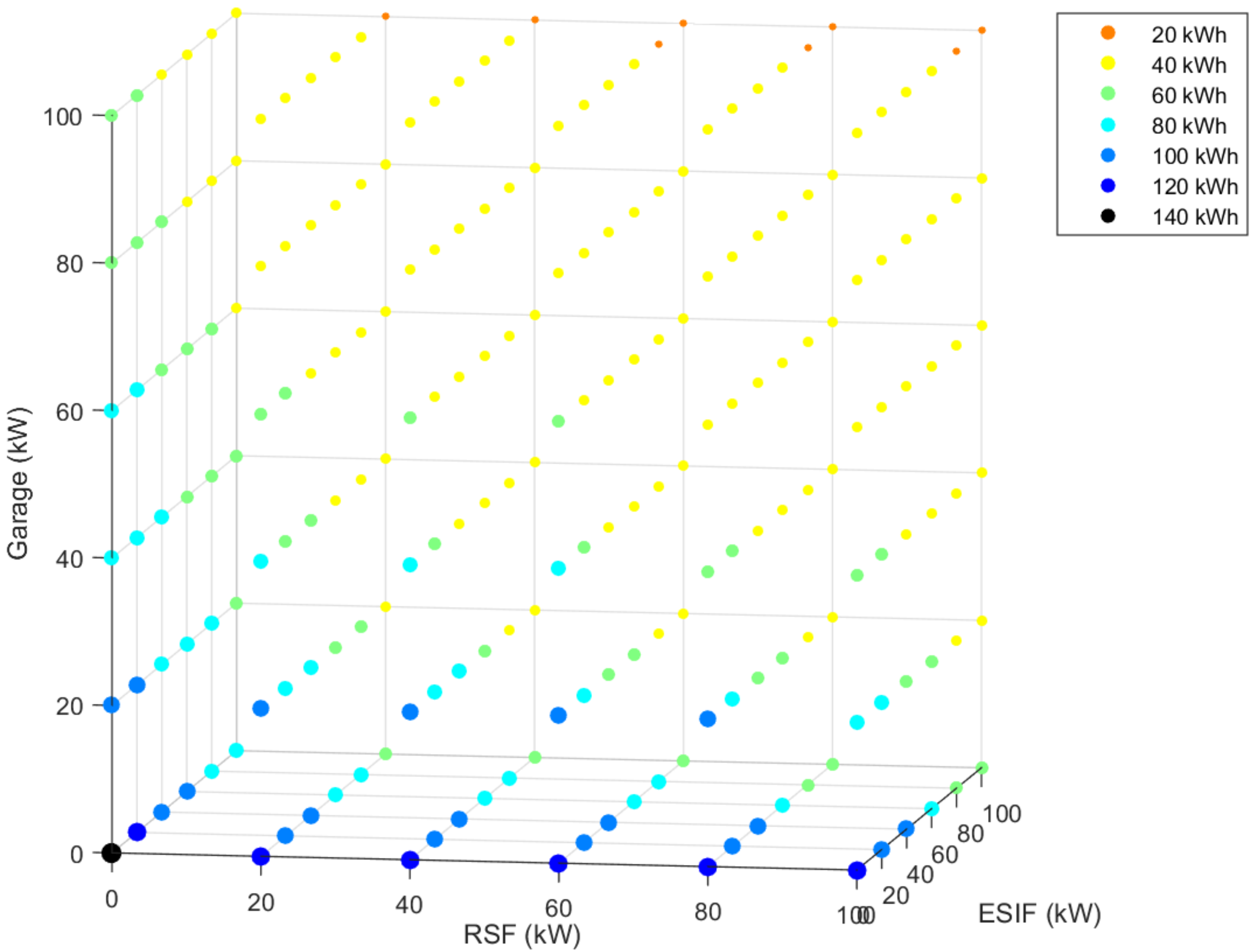
Complementary WPT Charging Locations



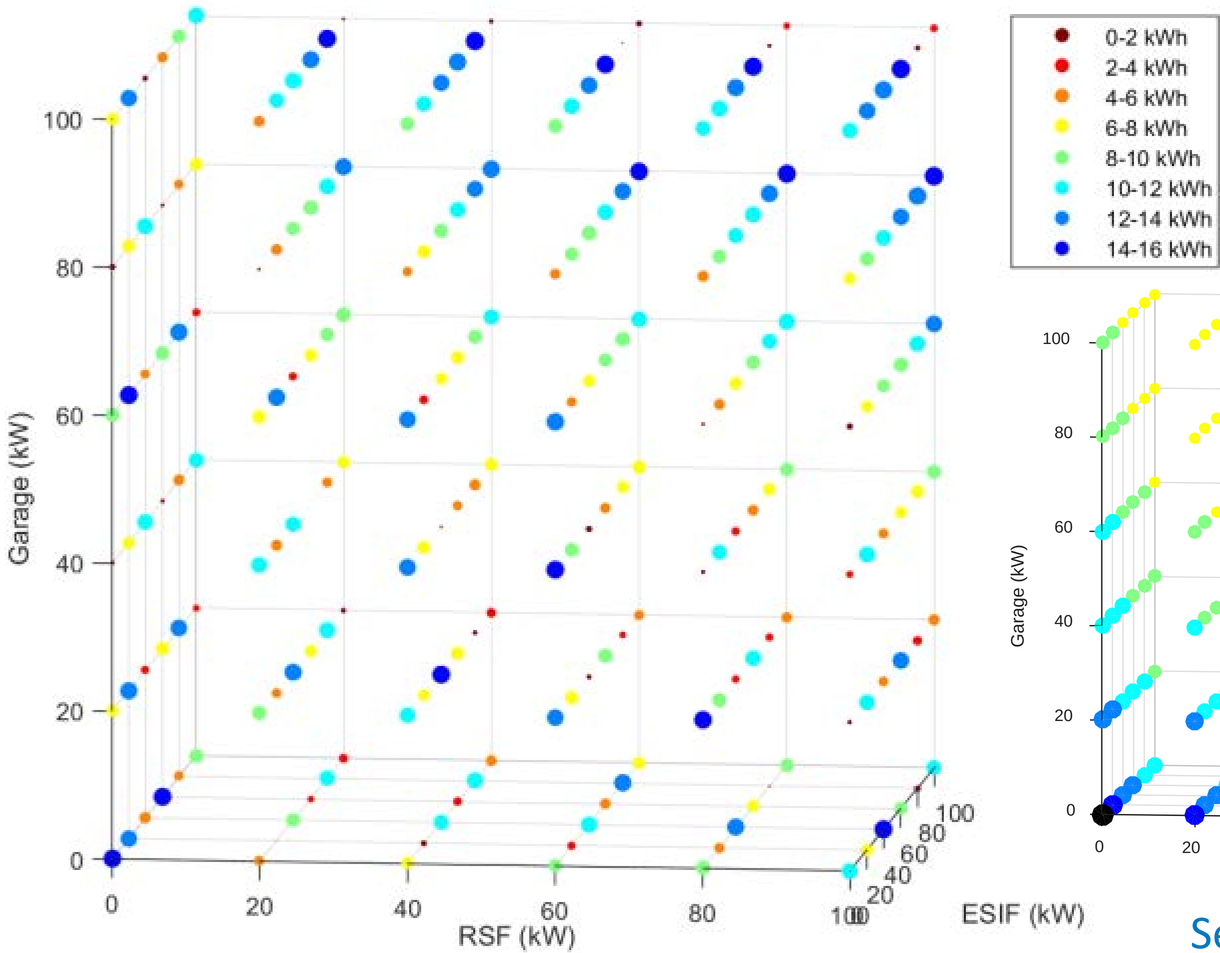
State of Charge Over a Work Week



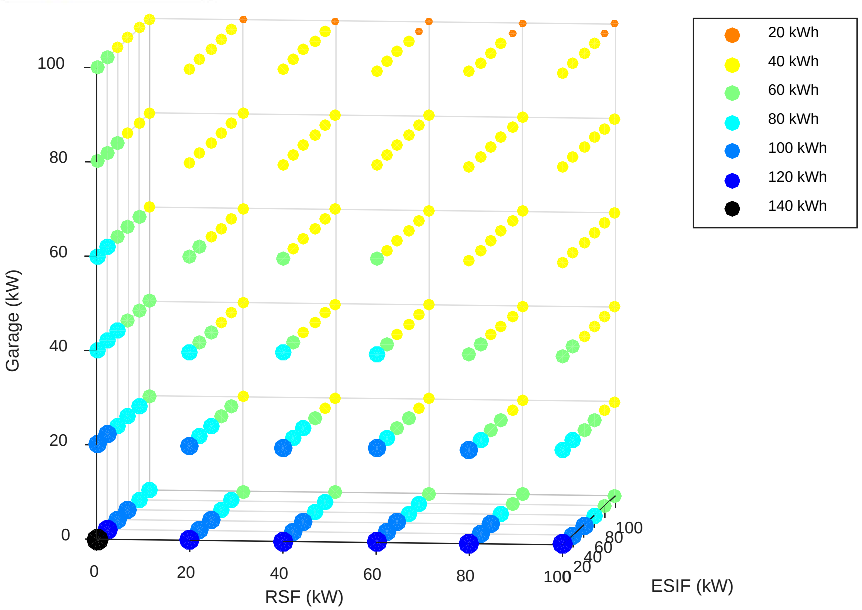
Required Battery Size



Excess Battery Capacity

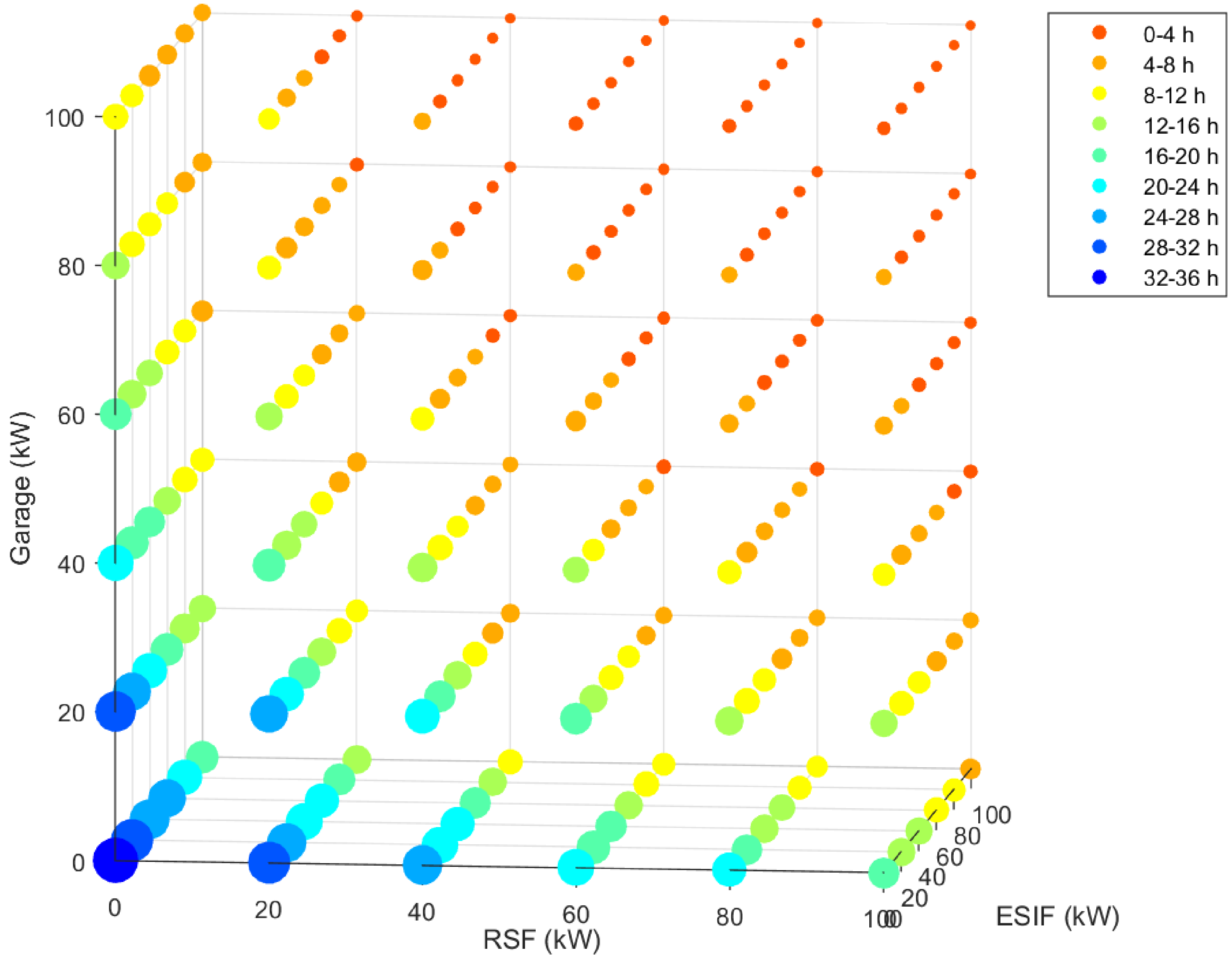


Excess battery capacity

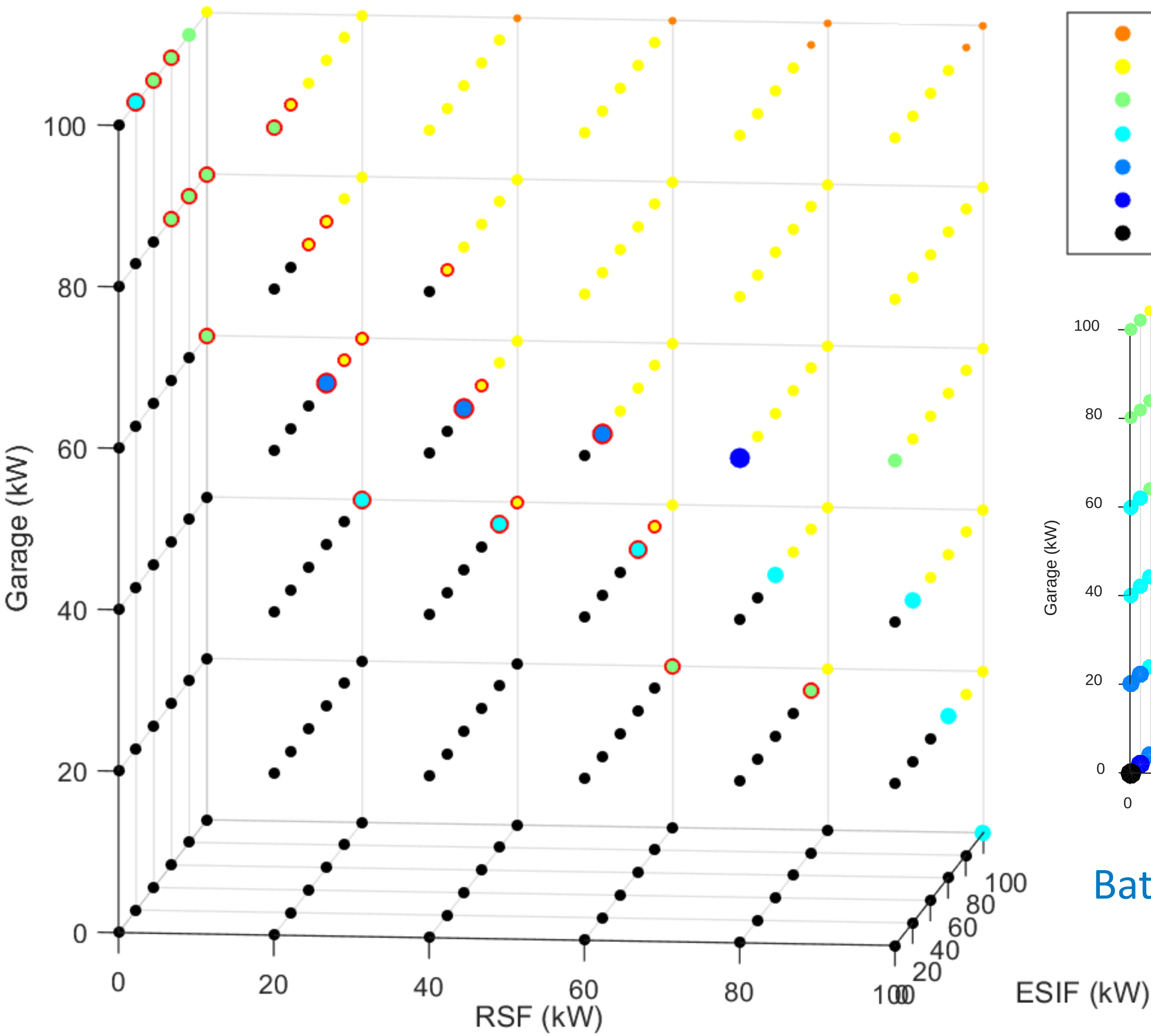


Selected battery size

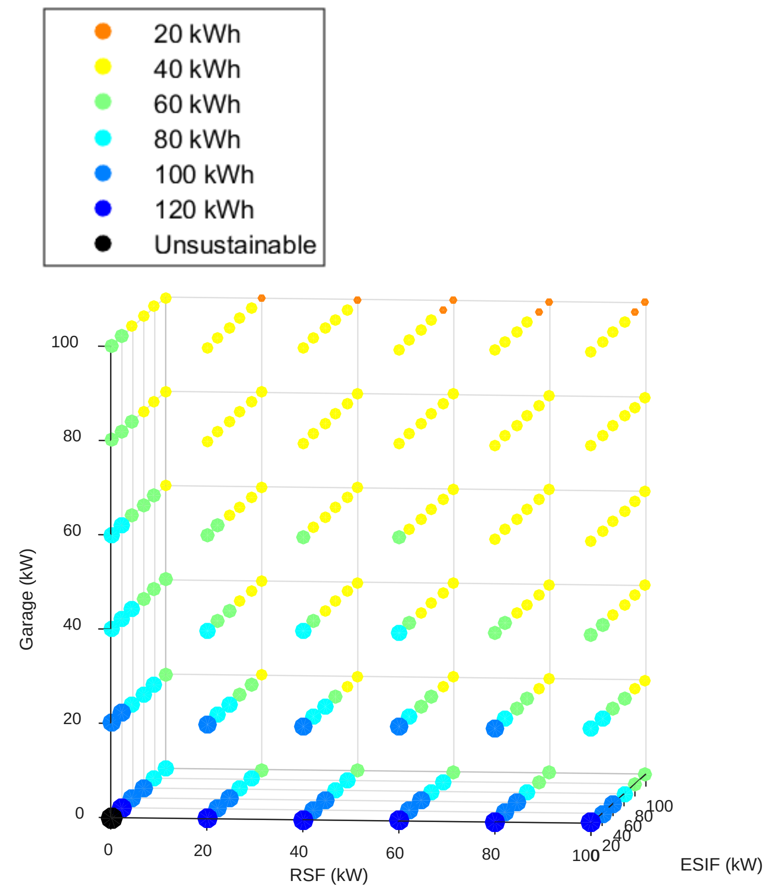
Conductive Charging Time Used per Week



Potentially Self-Sustainable Scenarios

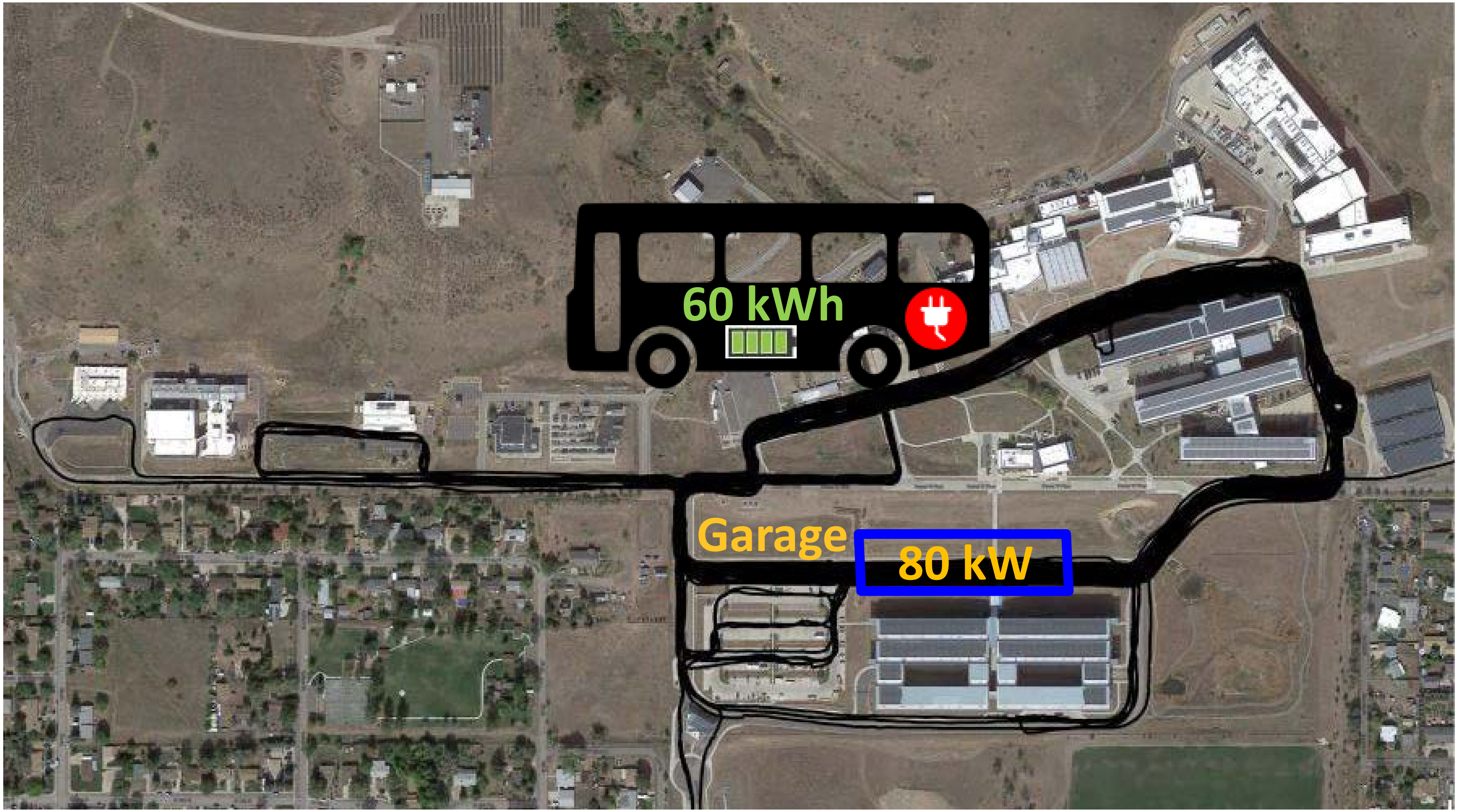


Battery size without conductive charging



Battery size with conductive charging

1^{st} Potential Implementation



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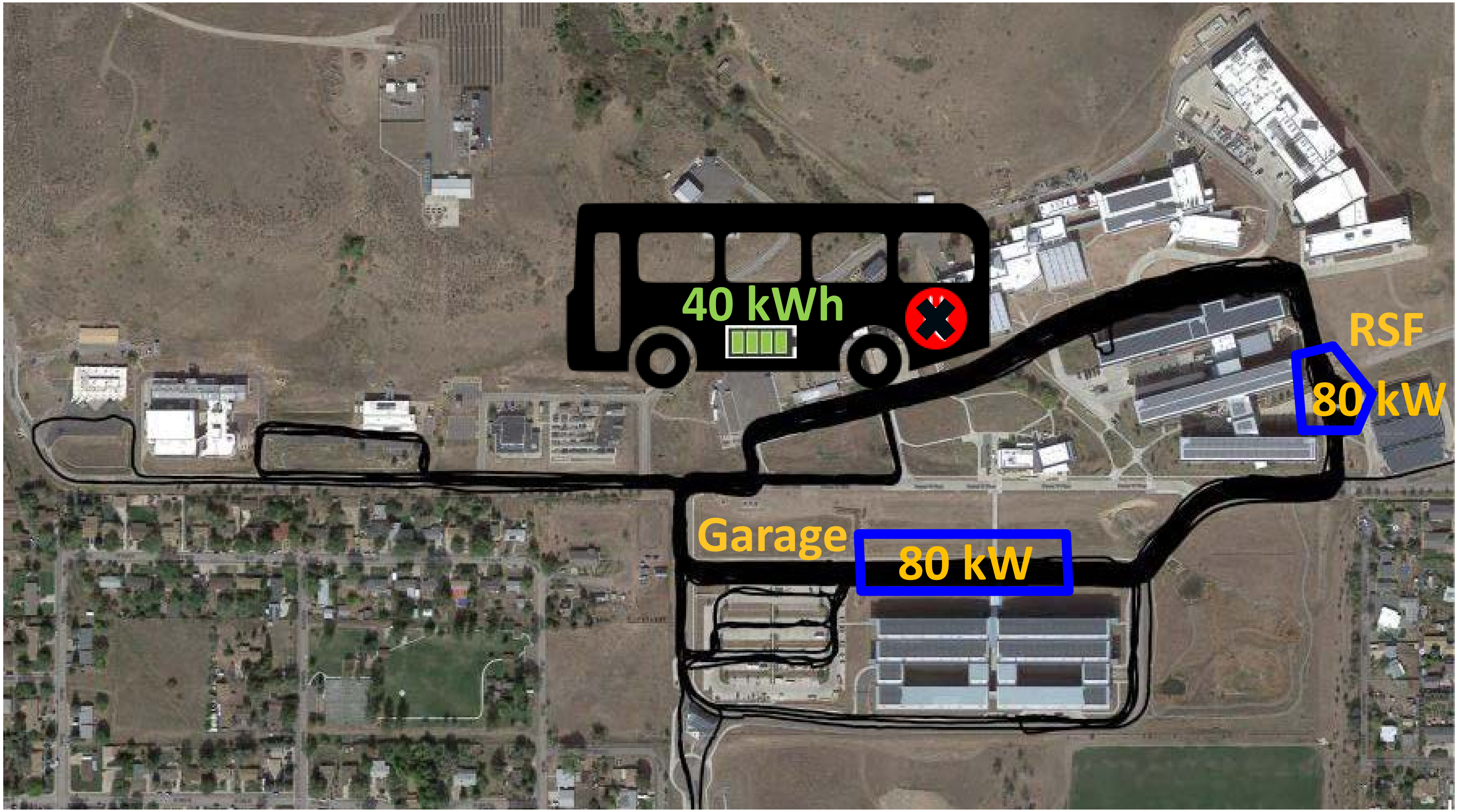
2nd Potential Implementation



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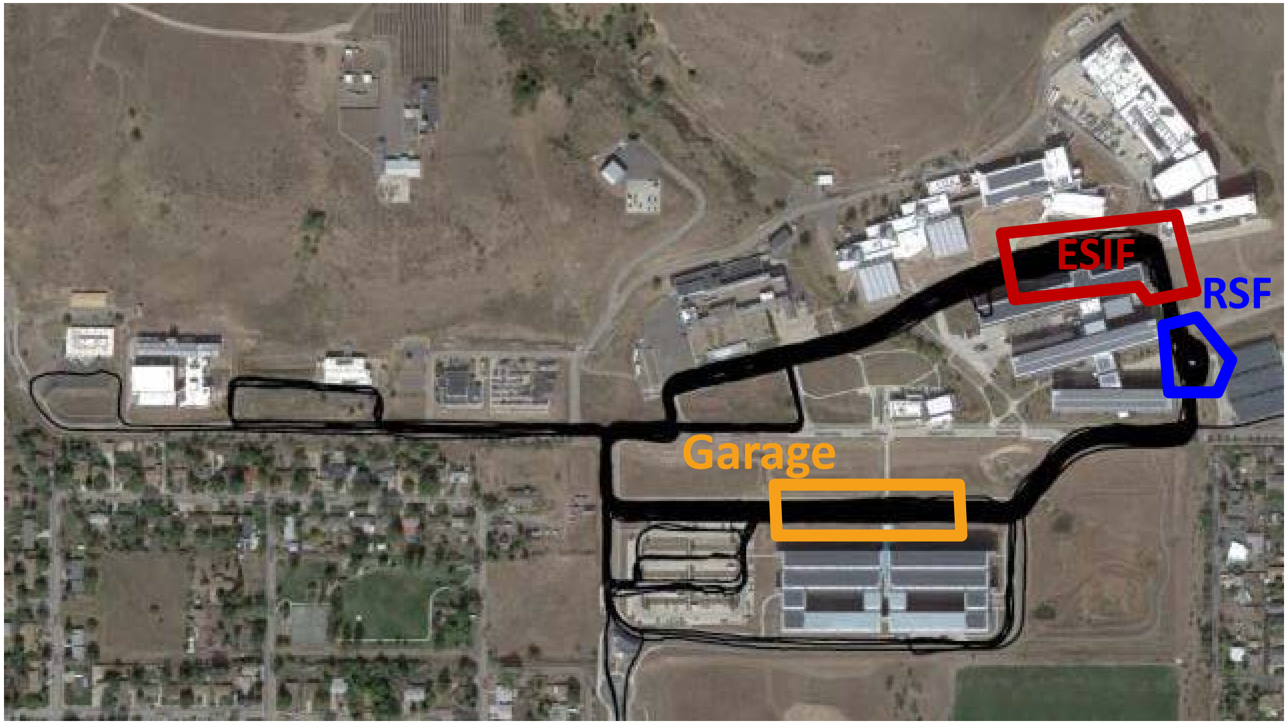
Potential Implementations

Battery Size	Garage	RSF	ESIF	Self-Sustaining?
60 kWh	80 kW	--	--	No
40 kWh	80 kW	80 kW	--	Yes



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Conclusions and Future Work

- WPTSim simulates WPT at fine granularity for opportunistic or dynamic charging applications
  - Design for realistic vehicle use using actual one-second speed, position, and grade data
  - No artificial limits on speed or stop locations
  - Determine pad spacing and power for dynamic applications
- For this use case, even one WPT charging location can more than halve the required battery size
- Further work will consider battery impacts of WPT charging and impact of battery fade on battery right-sizing

Thank you!

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