Grid-Aware EV Corridor Planning

UTAH STATE UNIVERSITY ASPIRE FOUNDATION

Executive Summary

This analysis designs an optimized transportation electrification system using real-world heavy-duty trucking data, the Utah Transit Authority (UTA) bus electrification demand, FrontRunner timetable data, utility tariffs, and a sim-plified grid-capacity representation. The analysis compares planning cases with different cost, operating, and grid-information inputs so that charging locations, charging schedules, local interconnects, upstream grid upgrades, and on-site storage can be evaluated as one coupled planning problem.

The central result is that grid constraints should be included directly in EV infra-structure planning. As described in Sec-tion 1 and Section 4, the grid-aware case allows the fleet optimizer tool and site optimizer tool to use site selection, charging timing, interconnect sizing, and storage together. When grid condi-tions are ignored until after charging decisions are made, the resulting system can require more grid investment and can impose larger power demands on the distribution system.

The second major result is that ramp-rate management can substantially reduce the grid impact of high-power trans-portation loads with comparatively small changes in net present cost. This is es-pecially important for multi-modal sites that combine heavy-duty truck charg-ing, bus charging, and short high-power rail charging events. As shown in Section 6, the evaluated single-site ramp-rate sweep uses local flexibility to smooth grid demand while preserving the vehicle service delivered at the site.

The planning takeaway is straightforward: EV infrastructure plans should be evaluated as transportation and grid plans at the same time. Grid-aware planning can reduce costly upgrades and improve grid compatibility, while ramp-rate-aware operation can make fast, flex-ible charging loads much easier for the grid to absorb. Municipality-level details are summarized in Section 5.4, with the full breakout provided in the companion municipal supplement.

1 Grid-Aware Planning Context

1.1 Importance of Grid-Aware Planning

High-power charging creates a planning problem that is different from ordinary energy growth. The total energy required by vehicles matters, but grid cost and feasibility are often driven by the timing and concentration of demand. A site that delivers modest total energy over a week can still require a large interconnect if many vehicles charge at the same time or if a rail pulse-charging event creates a short, sharp power peak.

The corridor analysis therefore treats grid infrastructure as part of the planning problem rather than as an after-the-fact cost. In a grid-aware planning case, charging demand, site selection, site operation, grid capacity, utility tariffs, interconnection cost, upstream upgrade cost, ramp-rate limits, and candidate storage are considered together. In a grid-unaware planning case, charging and site decisions are made without using the grid information, and grid costs are evaluated after those decisions have already been made.

1.2 Flexibility as a Grid Resource

Transportation electrification has useful flexibility. Some charging can move in time, some sites can use storage, and some grid needs are driven by sustained demand rather than every instantaneous pulse. The value of that flexibility is only visible if the planning model sees the grid constraint while it is making decisions.

The workflow in Section 2 defines the transportation and grid inputs used in this application. Section 3 then describes how those inputs are converted into a site-level optimization problem. Section 5 and Section 6 present the statewide and ramp-rate findings.

2 Input Data and Modeling Workflow

The analysis combines vehicle-demand outputs, public schedule data, utility tariff assumptions, and a simplified grid-capacity representation. The fleet optimizer tool provides the transportation-side charging demand and the site optimizer tool evaluates the grid, storage, and operating decisions at each site.

2.1 Transportation Demand Inputs

Table 1 summarizes the principal transportation and grid inputs. The heavy-duty truck, UTA bus, and electrified roadway demand traces provide the charging load that must be served. FrontRunner timetable data adds short high-power rail charging events at modeled multimodal charging sites.

2.2 Grid Capacity Input

The current grid-capacity input is based on Rocky Mountain Power transformer and load data combined with public load data to fill gaps. In this application, that representation is best understood as a planning signal that indicates where unused grid capacity may be available and where upstream upgrades may be required.

The capacity model will be expanded with newly acquired circuit and distribution-level data. That next version should allow grid constraints to be represented more specifically than the simplified capacity map used for the current results.

2.3 Core Planning Assumptions

The numerical assumptions used in the current run are summarized in Table 2 through Table 4. These values are included to make the scenario setup transparent rather than to present them as permanent design values.

Table 1: Principal inputs used in the corridor site optimization workflow.

Input	Application
UTA bus charging demand	One week of fully electrified UTA bus demand generated with the fleet optimizer tool and represented at five-minute resolution.
Heavy-duty truck static charging demand	One-day site demand profiles from the fleet optimizer tool, represented at one-minute resolution and repeated across the modeled week.
Heavy-duty truck electrified roadway demand	Dynamic electrified roadway energy demand from the fleet optimizer tool, represented at one-minute resolution.
FrontRunner timetable data	UTA GTFS stop times are used to place rail charging events at stations aligned with modeled multimodal charging sites.
Power systems capacity	A simplified grid-capacity input is used by the planning models, but the capacity map itself is not reported because it relies on non-public utility data.

Table 2: General planning assumptions.

Assumption	Value	Unit	Role
Optimization timestep	15	seconds	Base time interval for site optimization.
Optimization duration	1	week	Modeled operating horizon for the representative demand profiles.
Discount rate	20	percent per year	Discount rate used in the net-present-cost calculation.
System lifetime	30	years	Economic lifetime for grid infrastructure and recurring costs.
Utility tariff	Schedule 8	Rocky Mountain Power tariff	Tariff structure used in the corridor optimization.

3 Site Optimization Methodology

The site optimizer tool represents each charging site as a set of energy systems connected through a common electrical bus. Vehicle demand consumes energy from the bus, the grid supplies energy to the bus, and optional battery storage can either consume energy from the bus or return stored energy to the bus. The optimization chooses equipment sizes and time-varying energy flows simultaneously so that the site can serve the modeled transportation demand at minimum net present cost.

3.1 Objective and Discounting

In simplified form, the site objective is

$$\min \mathrm{NPC} = C_{\mathrm{capex}} + \sum_{m} \alpha_m \left(C_{\mathrm{utility},m} + C_{\mathrm{om},m} + C_{\mathrm{replacement},m}\right), \tag{1}$$

where C_{capex} includes initial capital costs for equipment such as local interconnection, upstream grid upgrades, storage, and chargers; $C_{\mathrm{utility},m}$ is the utility bill in month m; $C_{\mathrm{om},m}$ is operations and maintenance cost; $C_{\mathrm{replacement},m}$ is replacement cost; and α_m is the discount factor applied to month m:

$$\alpha_m = \frac{1}{(1+i)^{m/12}}. \tag{2}$$

Table 3: Battery assumptions used in the site optimizer tool.

Battery assumption	Value	Unit	Role
Capital cost	600	dollars per kWh	Installed battery energy cost.
Replacement cost	180	dollars per kWh	Battery replacement cost used after the initial installation.
Operating cost	1	dollars per kWh-year	Annual battery operations and maintenance cost.
Charge efficiency	93	percent	Efficiency from common bus to stored energy.
Discharge efficiency	93	percent	Efficiency from stored energy to common bus.
Charge rate	1	C	Maximum charge power relative to installed energy capacity.
Discharge rate	1	C	Maximum discharge power relative to installed energy capacity.
State-of-charge range	20 to 80	percent	Allowed operating range for stored energy.

Table 4: Grid and rail assumptions used in the site optimizer tool.

Grid and rail assumption	Value	Unit	Role
Upstream grid upgrade cost	5,000	dollars per kW	Capital cost for upstream capacity added beyond available capacity.
Upstream grid upgrade O&M	50	dollars per kW-year	Annual operations and maintenance cost for upstream upgrades.
Local interconnection cost	500	dollars per kW	Capital cost for local interconnect capacity.
Grid averaging window	30	minutes	Window over which interconnect and upstream capacity are evaluated.
Grid thermal time constant	5	minutes	Time constant used in the weighted-average grid-power model.
Grid-aware ramp time	30	minutes	Time to ramp from 0 to 100 percent of interconnect capacity in the grid-aware full-system case.
FrontRunner pulse duration	75	seconds	Duration of each modeled rail charging event.
FrontRunner pulse power	4	MW	Power of each modeled rail charging event.

3.2 Energy Balance and Utility Billing

The principal physical constraint is energy balance. For each time interval,

$$E_{\text{grid},t} + \sum_{s\in\mathcal{S}} E_{s,t}^{\text{dis}} = E_{\text{demand},t} + \sum_{s\in\mathcal{S}} E_{s,t}^{\text{ch}}, \qquad (3)$$

where $E_{\text{grid},t}$ is imported grid energy, $E_{\text{demand},t}$ is vehicle charging demand, and $E_{s,t}^{\text{ch}}$ and $E_{s,t}^{\text{dis}}$ are storage charge and discharge energy for storage technology s.

Grid power in each interval is

$$P_{\text{grid},t} = \frac{E_{\text{grid},t}}{\Delta t}, \qquad (4)$$

and utility demand charges are based on the peak billing-interval power within the applicable billing period:

$$P_{\text{peak},m} = \max_{t\in\mathcal{T}_m} P_{\text{grid},t}. \qquad (5)$$

3.3 Interconnection and Upstream Capacity

The local grid interconnect is sized using a weighted average of grid power over a 30-minute window. The weights simulate a transformer thermal response: a single 15-second pulse has less effect than sustained loading, while repeated or prolonged loading increases the modeled thermal state over time. Let $\overline{P}_{\text{grid},t}$ represent that thermally weighted average. The model requires

$$\overline{P}_{\text{grid},t} \le P_{\text{interconnect}} \quad \forall t. \qquad (6)$$

Upstream grid upgrade capacity is then the maximum amount by which the thermally weighted grid demand exceeds the available capacity signal:

$$P_{\text{upgrade}} = \max_t \Big(\max\big(\overline{P}_{\text{grid},t} - P_{\text{available},t}, 0 \big) \Big). \qquad (7)$$

3.4 Storage and Ramp-Rate Constraints

Battery operation is limited by installed energy capacity, charge and discharge power, efficiency, and allowable state of charge. The charge and discharge limits can be written as

$$0 \le E_{s,t}^{\text{ch}} \le \rho_s^{\text{ch}} E_s \Delta t, \qquad (8)$$

$$0 \le E_{s,t}^{\text{dis}} \le \rho_s^{\text{dis}} E_s \Delta t, \qquad (9)$$

where E_s is installed storage energy capacity and ρ_s^{ch} and ρ_s^{dis} are charge and discharge rate limits. Stored energy must remain within the allowed state-of-charge range,

$$\underline{\sigma}_s E_s \le E_{s,t} \le \overline{\sigma}_s E_s, \qquad (10)$$

and evolves according to

$$E_{s,t+1} = E_{s,t} + \eta_s^{\text{ch}} E_{s,t}^{\text{ch}} - \frac{1}{\eta_s^{\text{dis}}} E_{s,t}^{\text{dis}}. \qquad (11)$$

The grid system can also limit how quickly grid power changes from one interval to the next. In simplified form,

$$\begin{gathered} -r_{\text{down}} P_{\text{interconnect}} \\ \le P_{\text{grid},t} - P_{\text{grid},t-1} \le \\ r_{\text{up}} P_{\text{interconnect}}, \end{gathered} \qquad (12)$$

where r_{up} and r_{down} are allowed upward and downward ramp fractions per timestep. This treatment lets the optimizer evaluate smoother grid operation as part of the site design problem.

4 Scenario Design

4.1 Grid-Aware and Grid-Unaware Cases

The full-system results compare two planning cases: grid aware and grid unaware. Both cases serve the modeled transportation demand. The difference is whether grid information is included during planning or only evaluated afterward.

Table 5: Scenario definitions used for the grid-aware and grid-unaware corridor comparison.

Scenario element	Grid-aware case	Grid-unaware case
Grid capacity	Included during fleet and site planning.	Evaluated after charging and site decisions are made.
Grid tariffs	Included during decision-making.	Utility charges calculated after decisions are made.
Local interconnect	Sized as part of site optimization.	Calculated after decisions are fixed.
Upstream upgrades	Avoided when existing available capacity can be used.	Calculated after decisions are fixed.
Ramp rate	Constrained to a 30-minute 0 to 100 percent interconnect ramp in the full-system grid-aware case.	No ramp-rate restriction is applied.
On-site storage	Installed where cost-effective or needed to satisfy grid constraints.	Not installed as an active planning option.

The comparison is intentionally conservative in one respect: the grid-unaware case is not penalized for fast ramping during planning. That gives the grid-unaware case more operational freedom while still showing the value of considering grid constraints directly.

4.2 Relationship to the Municipal Supplement

The main results in Section 5 emphasize statewide and systemwide outcomes. Municipality-level breakouts are summarized in Section 5.4 and collected in the companion municipal supplement. The supplement is intentionally separate because it contains many repeated local figures that are useful for detailed review but would overwhelm the main narrative.

5 Grid-Aware Planning Results

5.1 Grid-Aware Corridor Buildout

The grid-aware corridor buildout places and sizes sites while accounting for grid capacity, tariff costs, storage, interconnection, and ramp-rate limits. Figure 1 and Figure 2 show the resulting grid-aware site maps for 2035 and 2045.

5.2 Systemwide Results

The systemwide results in Figure 3 through Figure 7 show the scale of the infrastructure challenge. By 2045, the modeled system reaches more than $1.5B in net present cost and more than 150 MW of upstream grid upgrades. These values include the cost of serving charging demand, the cost of local and upstream grid capacity, storage deployment where selected, and utility bills over the modeled system lifetime.

5.3 Grid-Aware Versus Grid-Unaware Planning

The grid-aware versus grid-unaware comparison in Figure 8 through Figure 11 shows why grid constraints need to be included during planning. When grid knowledge is available during optimization, the model can use site selection, timing flexibility, interconnect sizing, and storage to reduce system cost and grid burden. When grid conditions are evaluated only after decisions are fixed, the model loses those degrees of freedom.

A key planning note is that every individual site does not necessarily become cheaper when grid information is included. The optimization is systemwide, so some local choices can become more expensive if they lower total system cost. The public planning conclusion is broader: grid-aware planning gives the system more op-

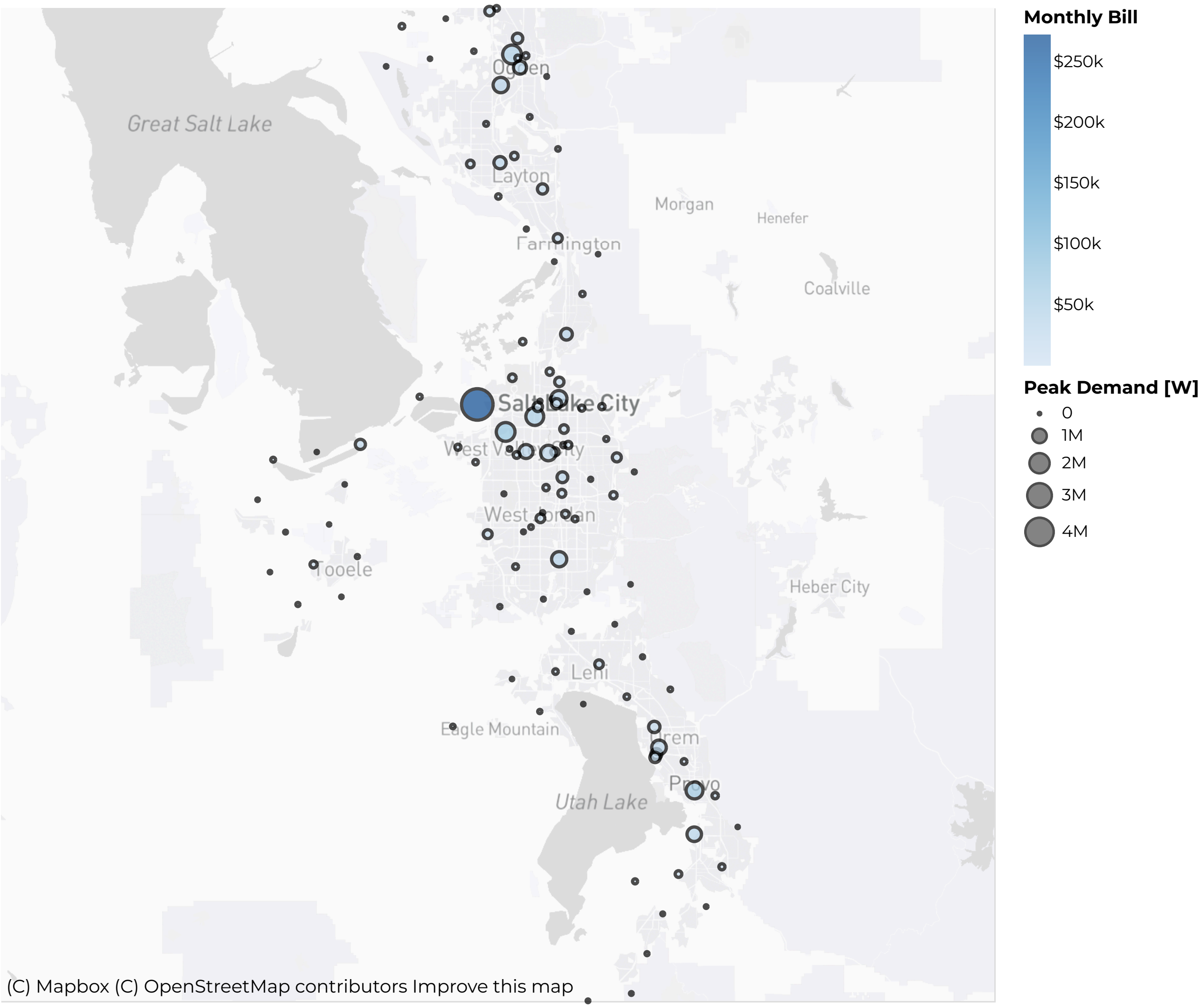

Figure 1: Grid-aware corridor site map for 2035.

tions before expensive infrastructure decisions become locked in.

5.4 Municipal Summary

The municipality-level results show where the systemwide optimization places cost and grid upgrades across local areas. Figure 13 and Figure 14 provide selected municipal views, while the companion municipal supplement provides the full set of cost, grid upgrade, battery, demand, utility bill, and unit-cost breakouts.

These local results should be read as outputs of a corridor-wide optimization rather than independent municipal plans. A local increase in cost or grid upgrade need can be part of a lower-cost corridor solution if it helps avoid larger constraints elsewhere in the corridor.

The supplement highlights two local planning mechanisms that support the systemwide conclusion. First, smaller municipalities can see major relative benefits from grid-aware planning because avoiding a single discrete grid upgrade can be large compared with the rest of the local charging cost. Second, the demand-capacity examples show that grid-aware operation can reduce demand during the traditional peak-demand portion of the day, when available grid capacity is most constrained.

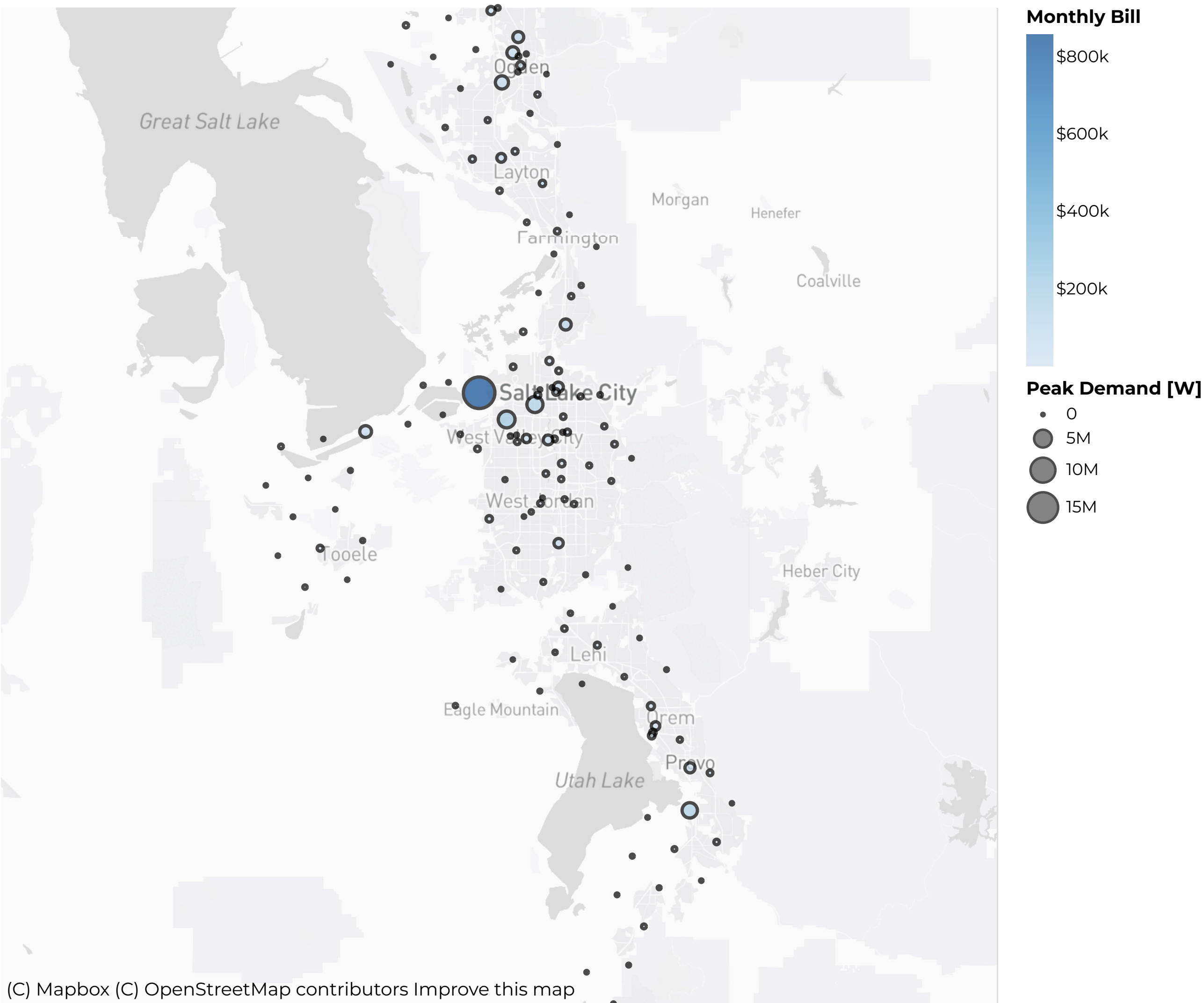

Figure 2: Grid-aware corridor site map for 2045.

6 Ramp-Rate Planning Results

6.1 Multimodal Ramp-Rate Challenge

High-power charging loads can change much faster than many grid planning tools or tariffs currently value. Multimodal charging sites are the clearest example: truck charging, bus charging, and rail pulse charging can overlap, and the power electronics at the site can change grid demand within seconds.

6.2 Ramp-Rate Sweep Results

The single-site ramp-rate sweep evaluates this issue by applying different maximum grid ramp times to a multimodal site. Figure 15 shows that increasing the minimum ramp time has a limited effect on net present cost. The optimizer responds by changing the balance of grid interconnect capacity and battery dispatch, rather than by failing to serve demand.

Figure 16 shows the grid-power effect during a rail pulse-charging event. With a short ramp time, grid demand can swing from less than 250 kW to more than 2 MW in seconds. With a one-hour ramp time, grid demand is essentially flat across

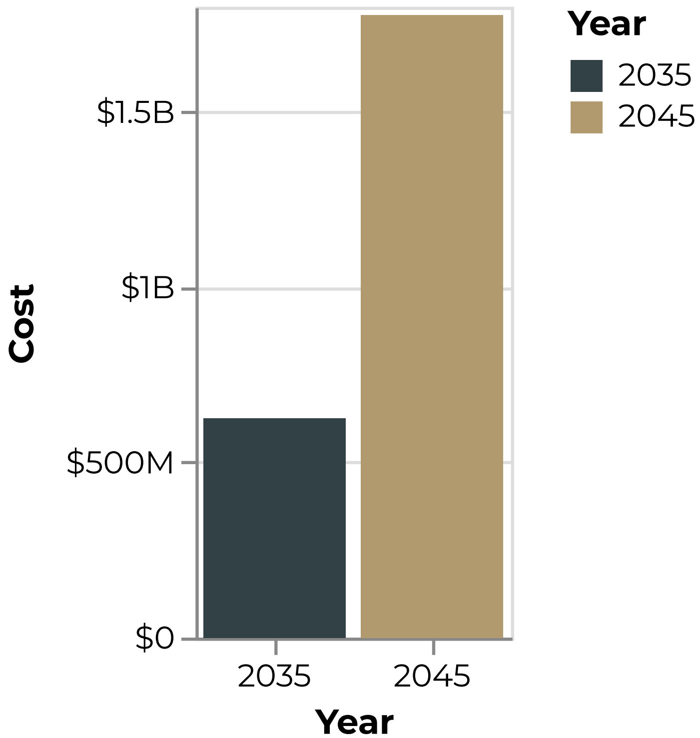

Figure 3: Net present cost by modeled year for the grid-aware full-system design.

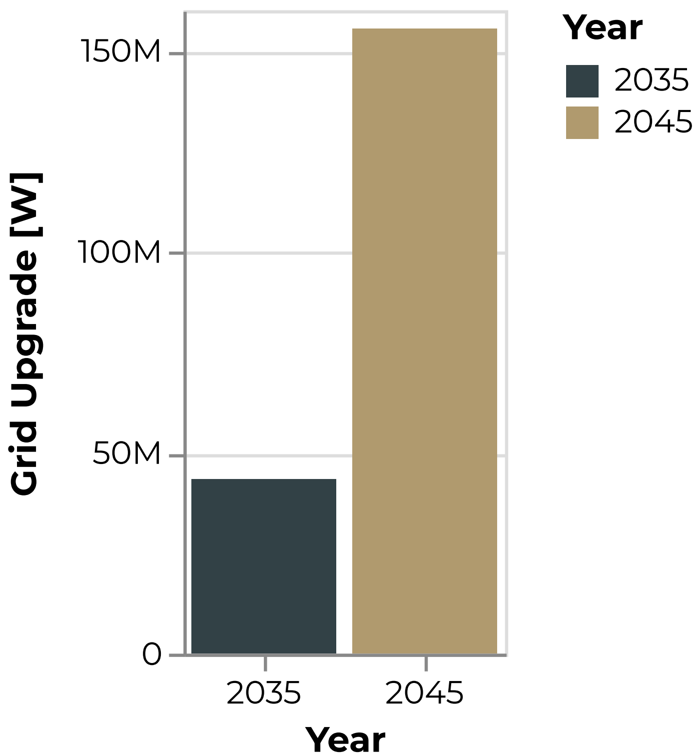

Figure 4: Upstream grid upgrades by modeled year for the grid-aware full-system design.

the charging event at about 1 MW while the site uses local flexibility to handle the short pulse.

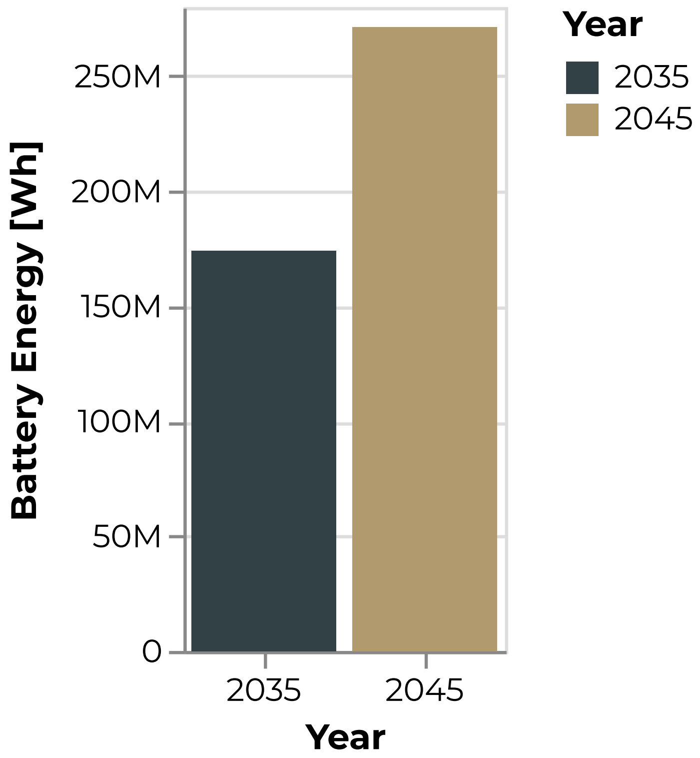

Figure 5: Installed battery energy by modeled year for the grid-aware full-system design.

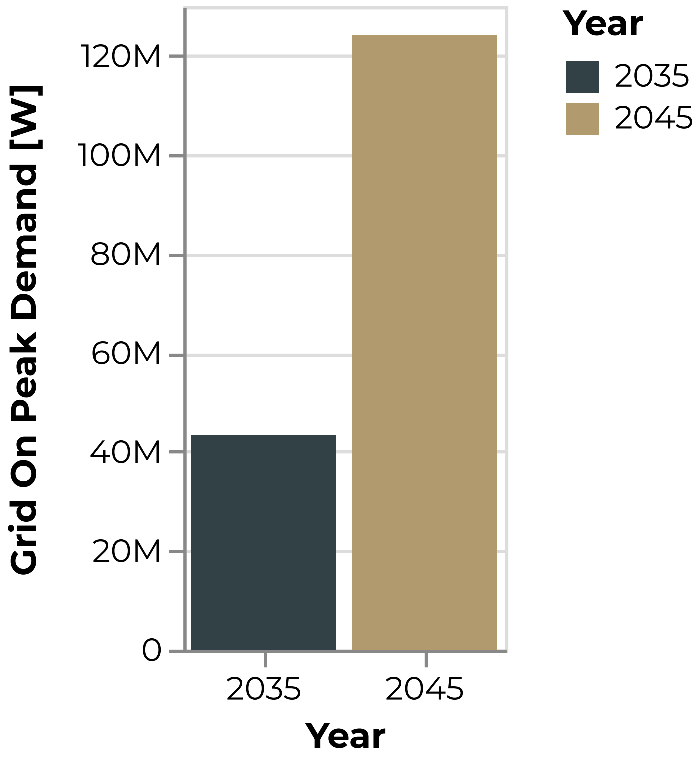

Figure 6: Combined on-peak billing demand by modeled year for the grid-aware full-system design.

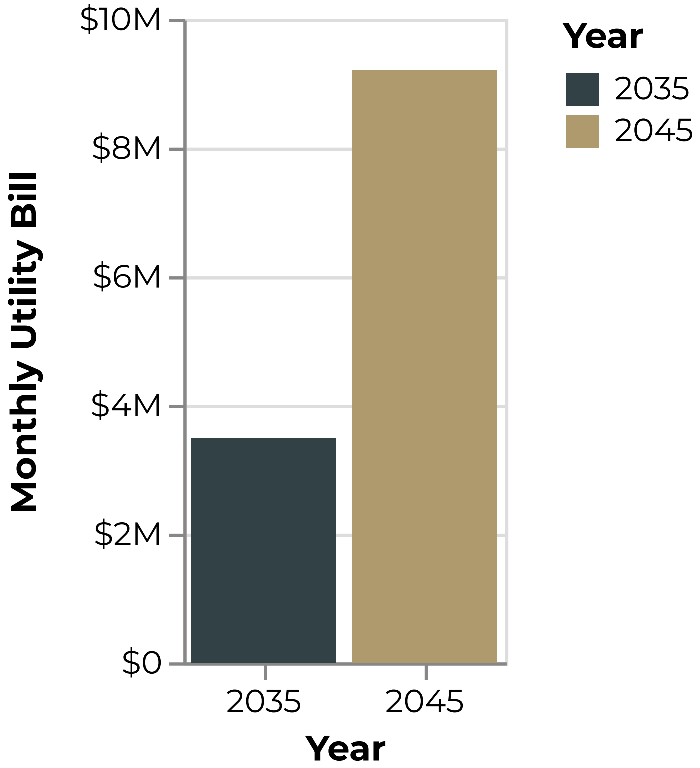

Figure 7: Combined monthly utility bill by modeled year for the grid-aware full-system design.

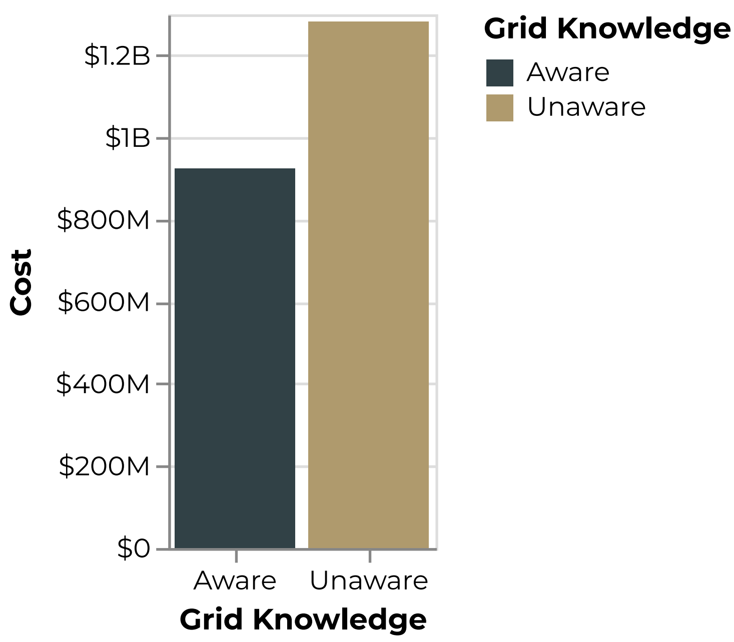

Figure 8: Net present cost comparison between grid-aware and grid-unaware planning.

6.3 Planning Implication

This result suggests that planning processes and tariffs should account for rapid changes in grid demand, not just monthly peak demand. A ramp-rate constraint, an operational charge, or another tariff mechanism could all create incentives for smoother grid behavior. The important point is

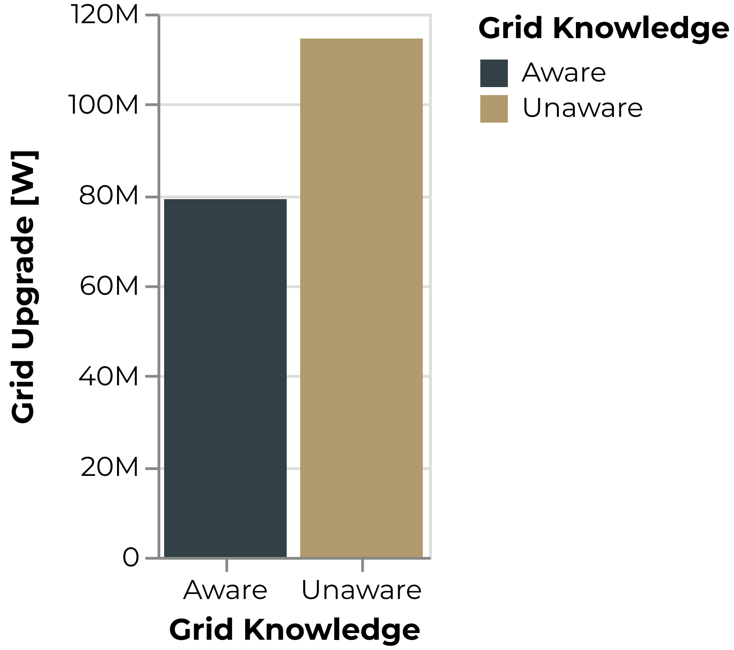

Figure 9: Upstream grid upgrade comparison between grid-aware and grid-unaware planning.

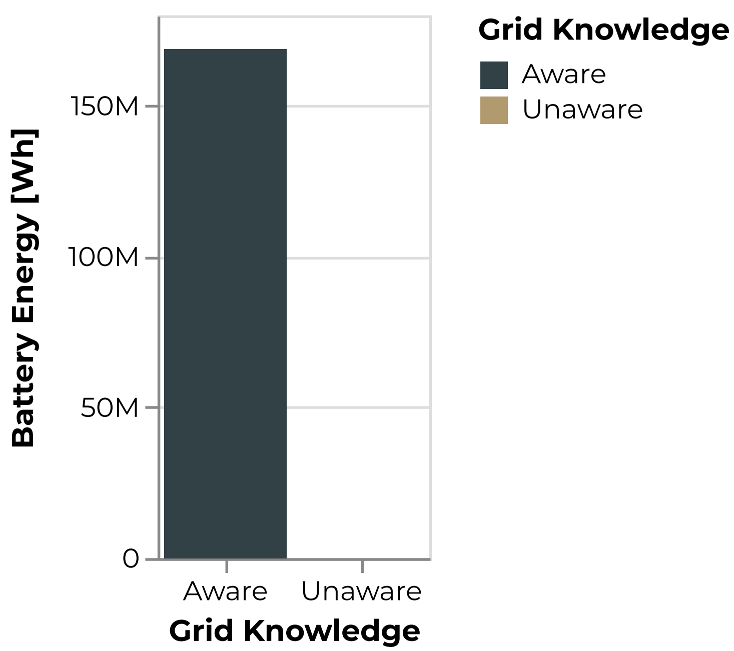

Figure 10: Installed battery energy comparison between grid-aware and grid-unaware planning.

the planning signal: transportation sites can often serve the same vehicles while presenting a much smoother load to the grid.

7 Conclusions and Planning Implications

The corridor results support three planning conclusions.

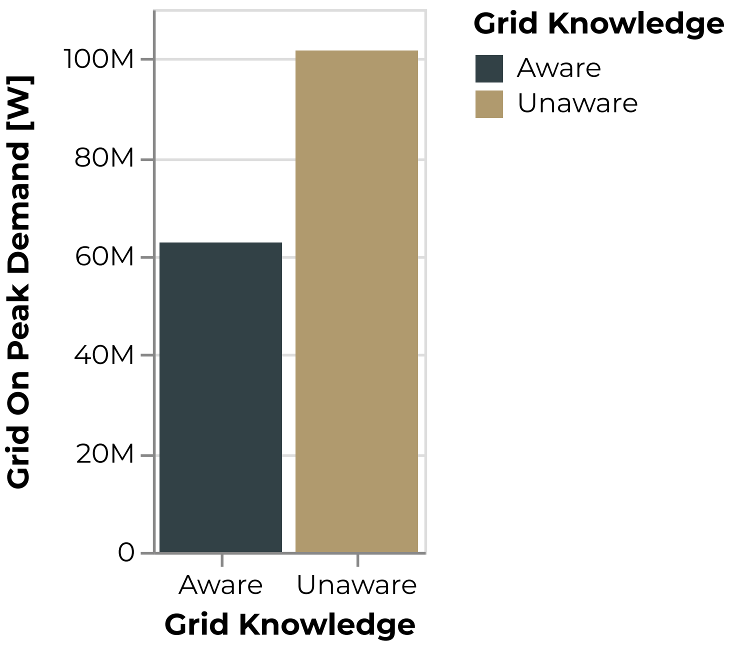

Figure 11: Combined on-peak billing demand comparison between grid-aware and grid-unaware planning.

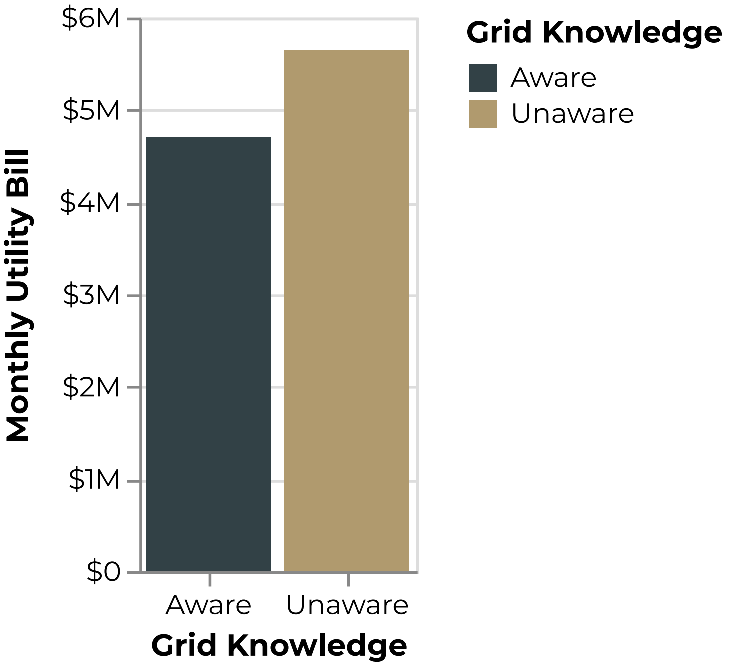

Figure 12: Combined monthly utility bill comparison between grid-aware and grid-unaware planning.

First, grid-aware planning should be part of EV infrastructure planning from the beginning. Siting and operating decisions made without grid information can appear reasonable from a transportation perspective while still creating avoidable grid upgrade needs. Including grid capacity and tariff information during planning lets the model use transportation flexibility, storage, and interconnection sizing to reduce total system cost and grid burden.

Second, ramp rate should be treated as a first-order planning consideration for high-power transportation sites. The right implementation

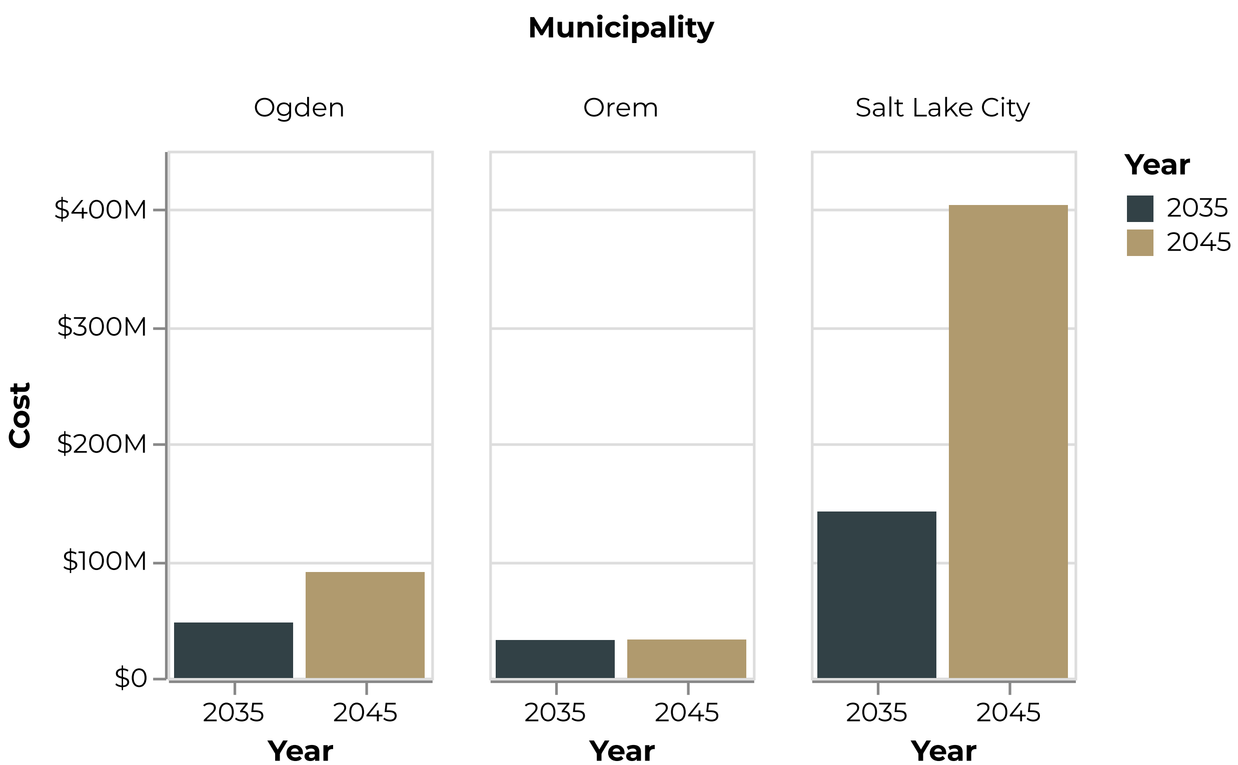

Figure 13: Net present costs for selected municipalities by modeled year.

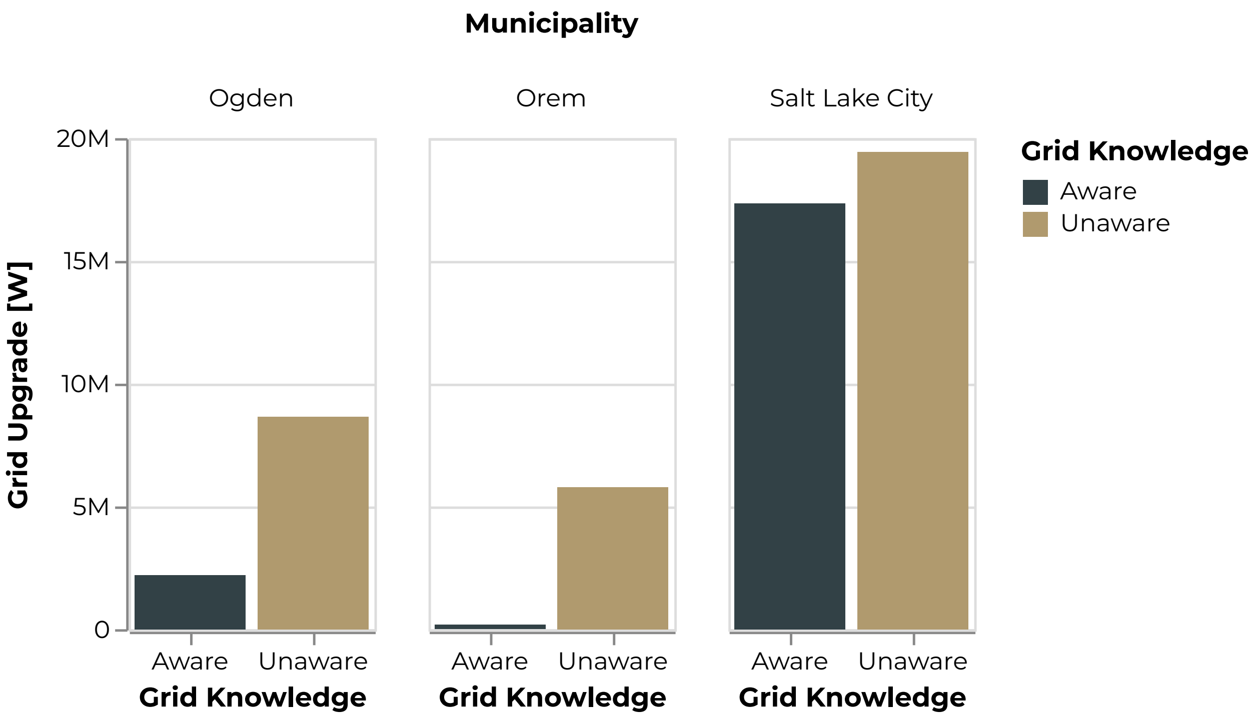

Figure 14: Required grid upgrades for selected municipalities by grid-awareness case.

could be an interconnection requirement, a tariff charge, an operating constraint, or some combination of those mechanisms. The result in Section 6.2 shows why the issue matters: the same

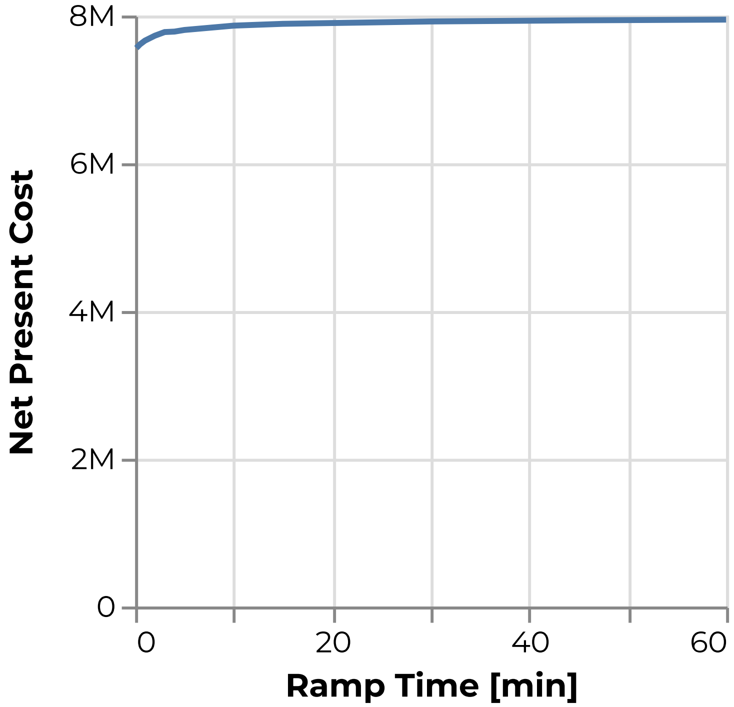

Figure 15: Net present cost as a function of minimum grid ramp time.

charging event can appear to the grid as a sharp multi-megawatt swing or as an essentially flat load, depending on the operating rules and site design.

Third, future corridor analyses should use more detailed distribution data as it becomes available. The current results use a simplified capacity representation built from transformer and load data with public data used to fill gaps. Circuit and distribution-level data will improve the ability to identify specific constraints, estimate upgrade needs, and target locations where transportation electrification can proceed with lower grid impact.

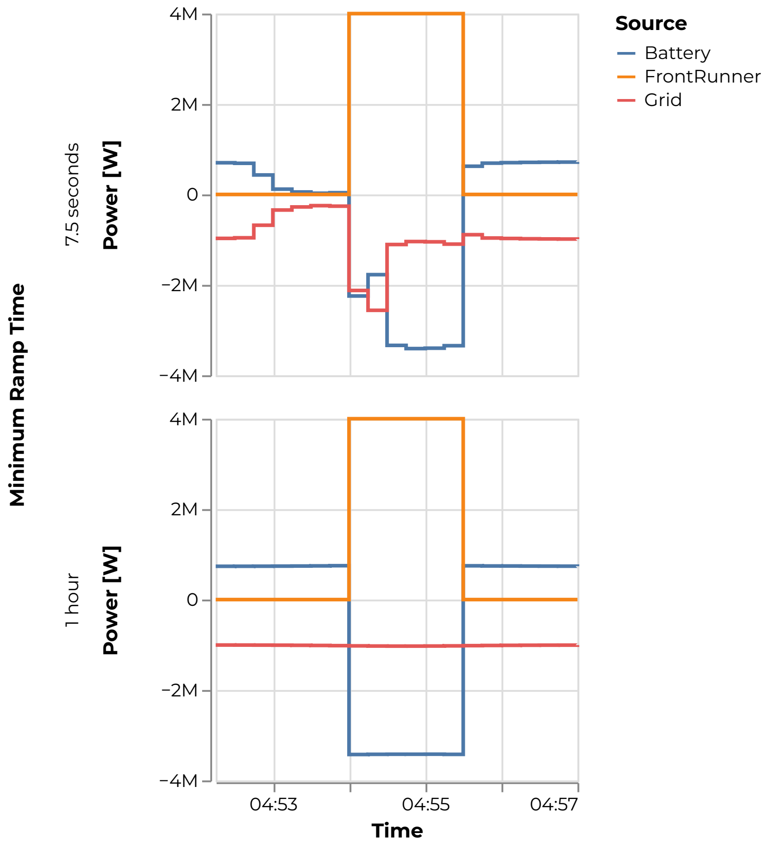

Figure 16: Grid power during a FrontRunner pulse-charging event under short and one-hour ramp-time assumptions.