Making Zero Emissions operations more resilient

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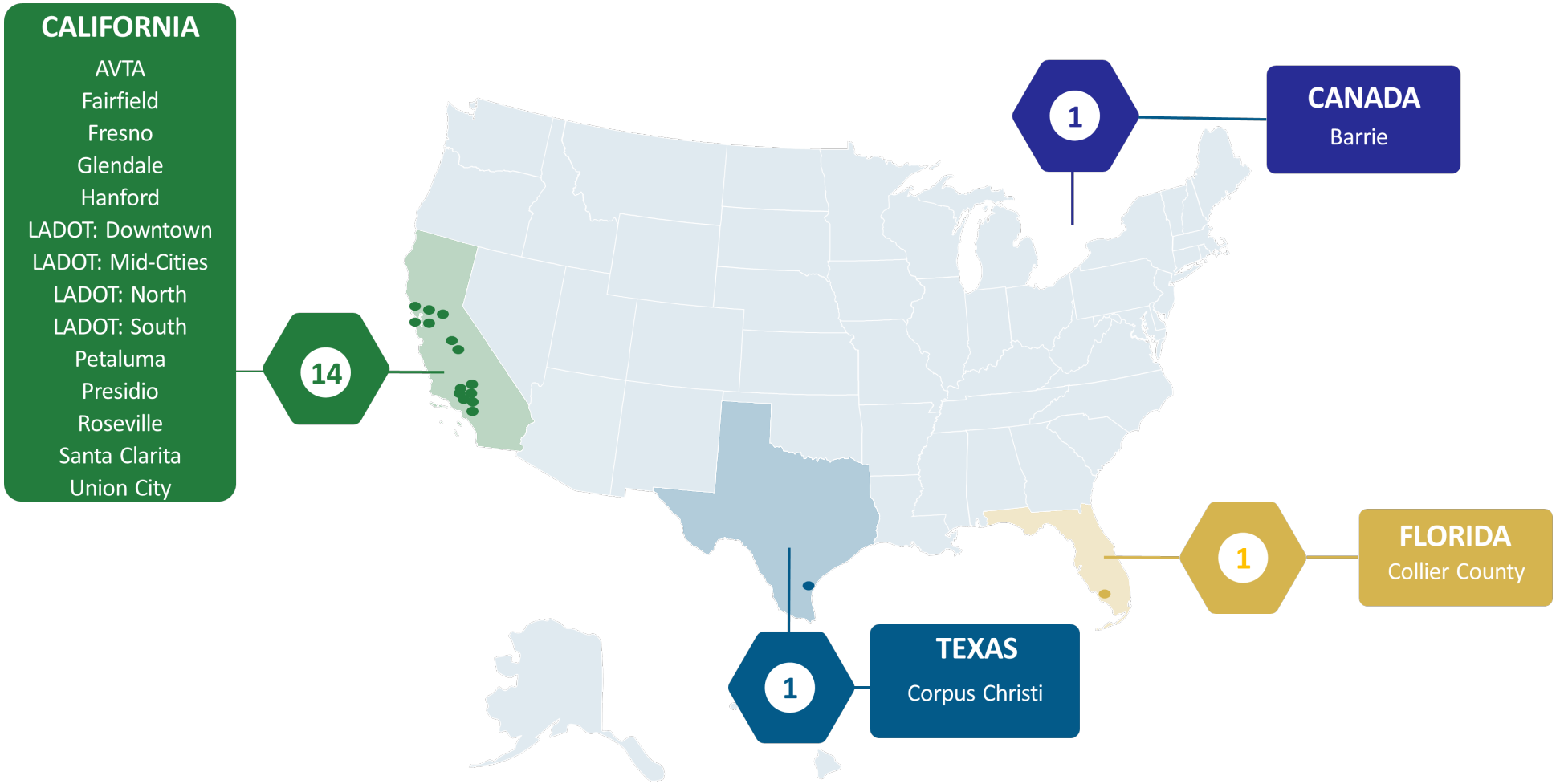
MV's Zero Emission Experience



17 sites and 300+ Zero Emissions Vehicles
Future: 200+ ZE vehicles at 11 sites (new and existing)

MV's Zero Emission Experience

OEMs: New Flyer, MCI, BYD, Proterra, Karsan, Lightning eMotors, Chevy, Ford

Case Study

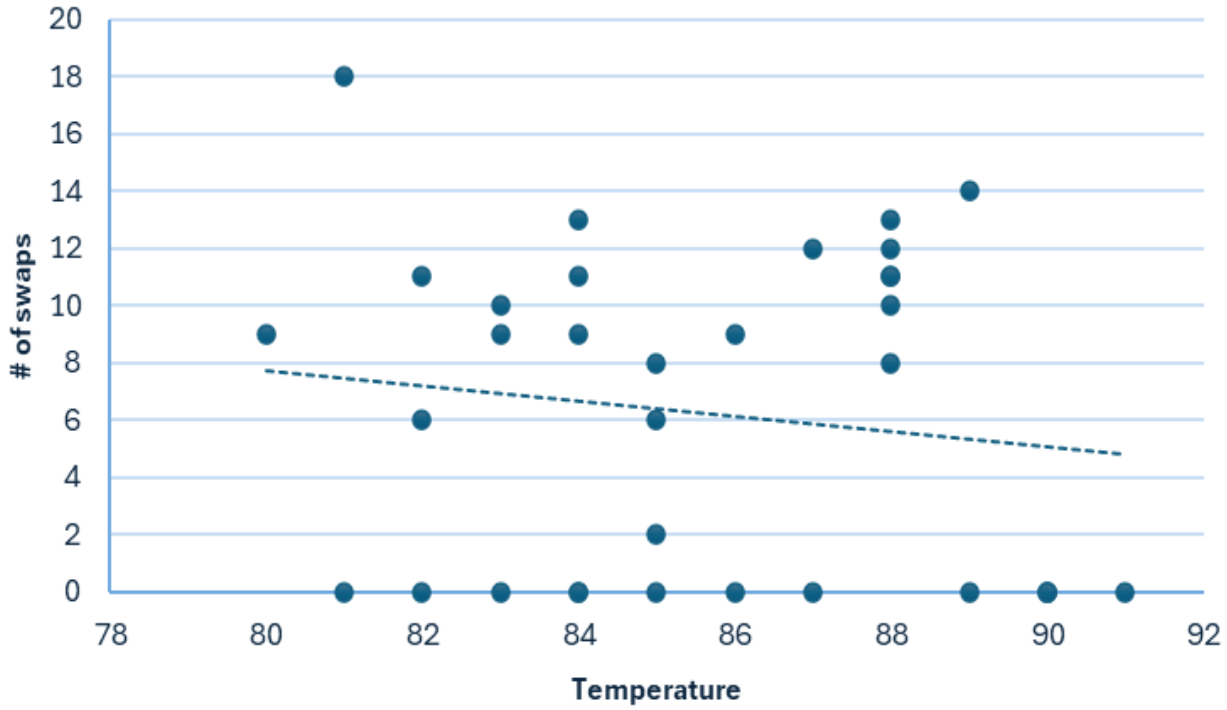
Analysis and Recommendations for ZE Operations Resiliency in high temperatures

During the **summer**, one of our ZE operations on the West Coast was experiencing **decreased range** and increasing numbers of **bus swaps**.

MV's ZE Group obtained access to operational data:

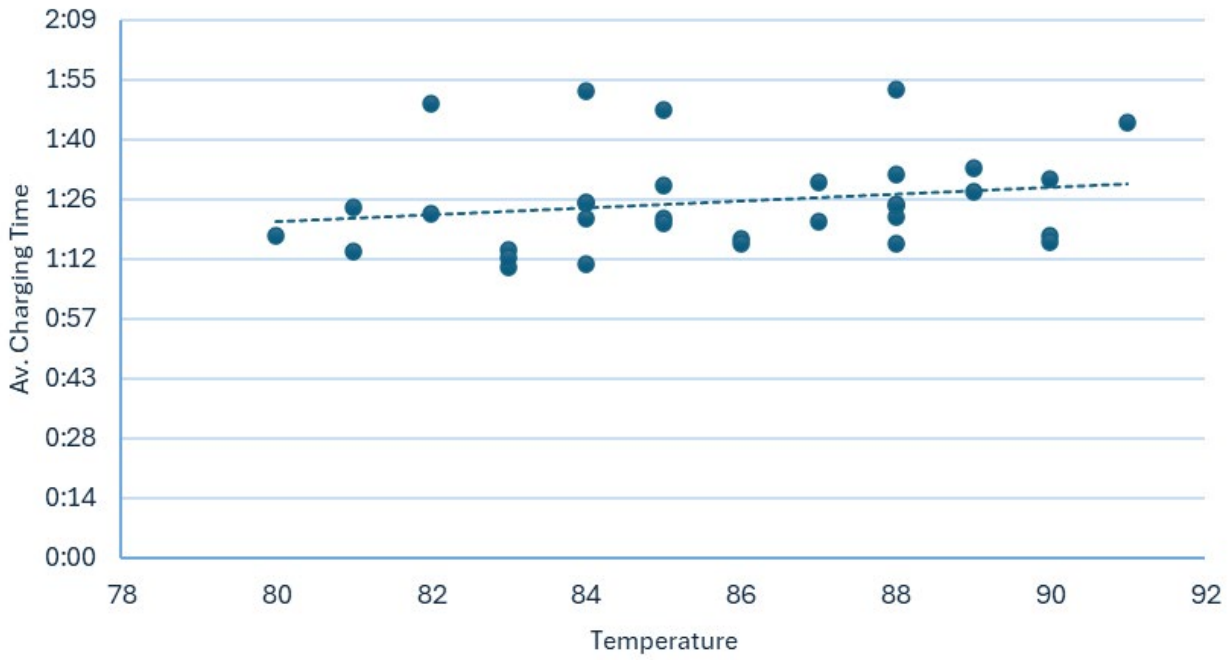
- Mileage
- Charging times
- Routes
- State of Charge
- Bus swaps
- Battery Telematics

Effects of temperature on bus swaps



- Counterintuitive finding: as temperature increases, the number of swaps decreases.
- This means that temperature is not the only factor in decreased range.
- Buses ranged from 56 to 117 miles before being swapped, with an average of 92 miles.
  - This is a reduction of ~25% in range due to higher temperatures.

Temperature Effects on charging time



- Expected result: as temperature increases, the charging time increases (~1 min per 1°F).
- High temperatures:
  - slow down the charging process itself.
  - deplete batteries to a lower SOC, which requires more time to fully recharge.
- Recommendations
  - Cover chargers from direct sunlight.
  - Intensify charging at night and periods with lower temperature.

Effect of chargers on bus swaps

Charger	Swaps
B1-A	6
B6-A	4
H5-B	4
B1-B	3
B2-A	3
B2-B	3
H1-B	3
H2-B	3
H3-B	3
H4-B	3
H6-B	3

- This does not indicate causality: the charger itself is not producing low range, but some chargers may be slower or less effective than others, which can delay the recharging of the fleet.
- Recommendations
  - Chargers must be cleaned and maintained as defined by the OEM. The ones with most issues should be given priority for inspection.

Fleet swap counts

Bus #	Swaps
318	17
316	15
315	13
302	12
314	12
307	11
310	11
320	11
304	10
306	10
308	10
322	10
319	9

- Half of the buses accounted for almost 70% of the swaps.
- Recommendations
  - Complete PMIs on time and accurately.
  - Buses with most issues should be given priority for inspection.
  - Rotate buses across routes and drivers to balance mileage and energy consumption to mitigate battery degradation.

Effects of routes on bus swaps

Routes	% Swaps
E	58%
B	38%
D	3%
F	1%
A	0%

- Route E concentrated more than half of the swaps. Together with route B, they accounted for 96% of the swaps.
- Recommendations
  - Identify what is different or special about these routes.
  - Dispatch and supervisors to monitor closely these routes.
  - Fully charged buses and maintenance trucks staged along the route.
  - Additional training for drivers if required.
  - Bus rotation across routes.

Time of day for bus swaps

Time of day	% Swaps
12-13	0%
13-14	0%
14-15	1%
15-16	3%
16-17	7%
17-18	18%
18-19	18%
19-20	33%
20-21	10%
21-22	9%
22-23	1%

- Unsurprisingly, almost 90% of the swaps occur between 5 PM and 10 PM when buses have been running for most of the day and SOC is low.
- Recommendations
  - Deploy fully charged buses along the route at these periods for quick response.
  - Revise extra board, supervisors, dispatchers, and technicians' schedules during hot months to better cover these periods.

SOC at time of swap

SOC at Swap	% Swaps
+90%	0%
80-90%	1%
70-80%	0%
60-70%	0%
50-60%	1%
40-50%	1%
30-40%	2%
20-30%	9%
10-20%	72%
0-10%	13%

- 94% of swaps were made at SOC 30% of less.
- Swaps at SOC +30% may be an adequate proactive measure but can also be delayed to extend vehicle usage.
- Recommendations
  - Use telematics to verify SOC in real time, especially in challenging routes.

What do we do with all this data?

Summer Readiness Program

Spring

- Complete PMIs, maintenance campaigns, and warranty work timely
- Ensure access to bus and charger telematics
- Ensure that chargers are operational
- Train your dispatchers, technicians, and drivers
- Revise techs, supervisors, and dispatcher schedules
- Evaluate route modifications

Summer

- Store long-term inoperative buses indoor at 50% SOC
- Try to park buses in covered or shaded areas
- Maintain proper tire inflation
- Ensure that battery strings are balanced at all times
- Rotate buses across routes and drivers
- Monitor the temperature forecast for the next 48 hours

Over 80°F

- Hold daily meetings between operations, maintenance, and safety to plan for next two days
- Instruct drivers to start cabin pre-conditioning at pre-trip only and while plugged in
- Monitor bus and charger telematics: location, SOC, temperature
- Check and clean chargers daily and report issues

Over 90°F

- Mostly use chargers that are covered from the sun
- Intensify charging at night and times with lower temperature
- Start swapping buses at 20-30% SOC
- Assign BEBs to shorter routes/blocks
- Send supervisors to areas and routes with issues
- Add radio control and dispatch staff, and extra board drivers

Over 100°F

- Conduct hourly all-calls for SOC, temperature, and dashboard fault codes
- Implement temporary detours on difficult routes
- Maintenance to reduce non-urgent non-safety related work
- Deploy maintenance trucks with technicians to areas with issues
- Stage fully charged spare buses in areas with issues

Winter Readiness Program

Fall

- Complete PMIs, maintenance campaigns, and warranty work timely
- Ensure access to bus and charger telematics
- Ensure that chargers are operational
- Train your dispatchers, technicians, and drivers
- Revise techs, supervisors, and dispatcher schedules
- Evaluate route modifications
- Evaluate a resiliency plan for power loss

Winter

- Store long-term inoperative buses indoor (if possible) at 50% SOC
- Try to park and charge buses indoors; maintain buses charged
- Maintain proper tire inflation and tire tread
- Ensure that battery strings are balanced at all times
- Rotate buses across routes and drivers
- Monitor the temperature forecast for the next 48 hours

Under 50°F

- Hold daily meetings between operations, maintenance, and safety to plan for next two days
- Instruct drivers to start cabin pre-conditioning at pre-trip only and while plugged in and only use cabin heating as needed
- Monitor bus and charger telematics: location, SOC, temperature
- Check and clean chargers daily and report issues, if applicable

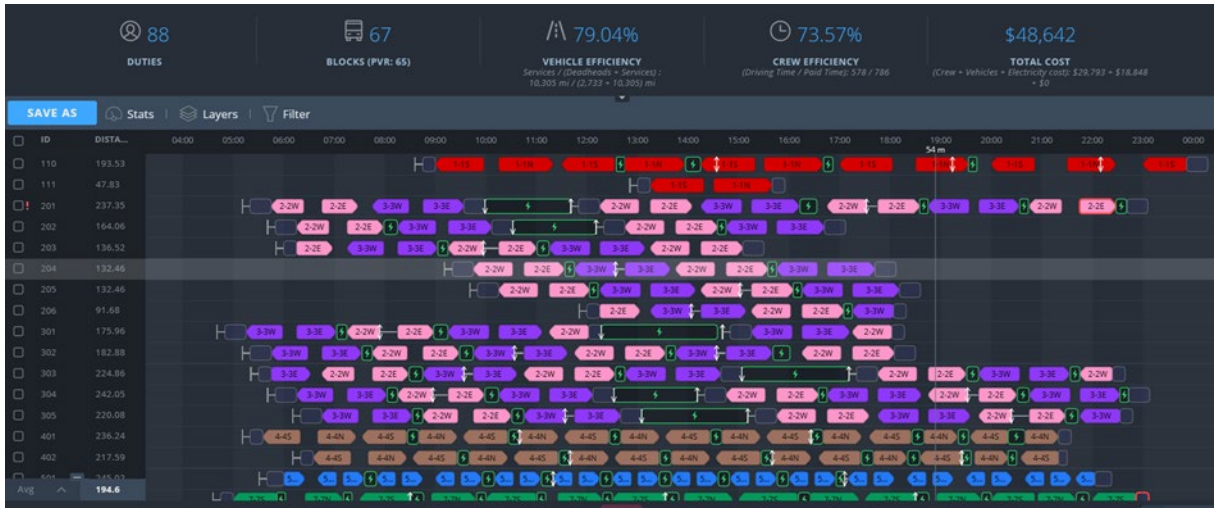
Under 40°F

- Intensify charging during the day with higher temperatures
- Install charger covers
- Start swapping buses at 20-30% SOC
- Assign BEBs to shorter routes/blocks
- Send supervisors to areas and routes with issues
- Add radio control and dispatch staff, and extra board drivers

Under 30°F

- Conduct hourly all-calls for SOC, temperature, and fault codes
- Implement temporary detours as needed
- Maintenance to reduce non-urgent non-safety related work
- Deploy maintenance trucks with technicians to areas with issues
- Stage fully charged spare buses in areas with issues

Modeling of schedules and daily operations



optibus

- Predictive modeling to evaluate future impacts of ZE fleet.
- MV's transit planning team is certified to use Optibus Zero Emissions module.
- Route Planning incorporating service variables:
  - Battery size or range
  - Energy consumption
  - Charging power
  - Road conditions and traffic
  - Topography
  - Climate
  - Staffing

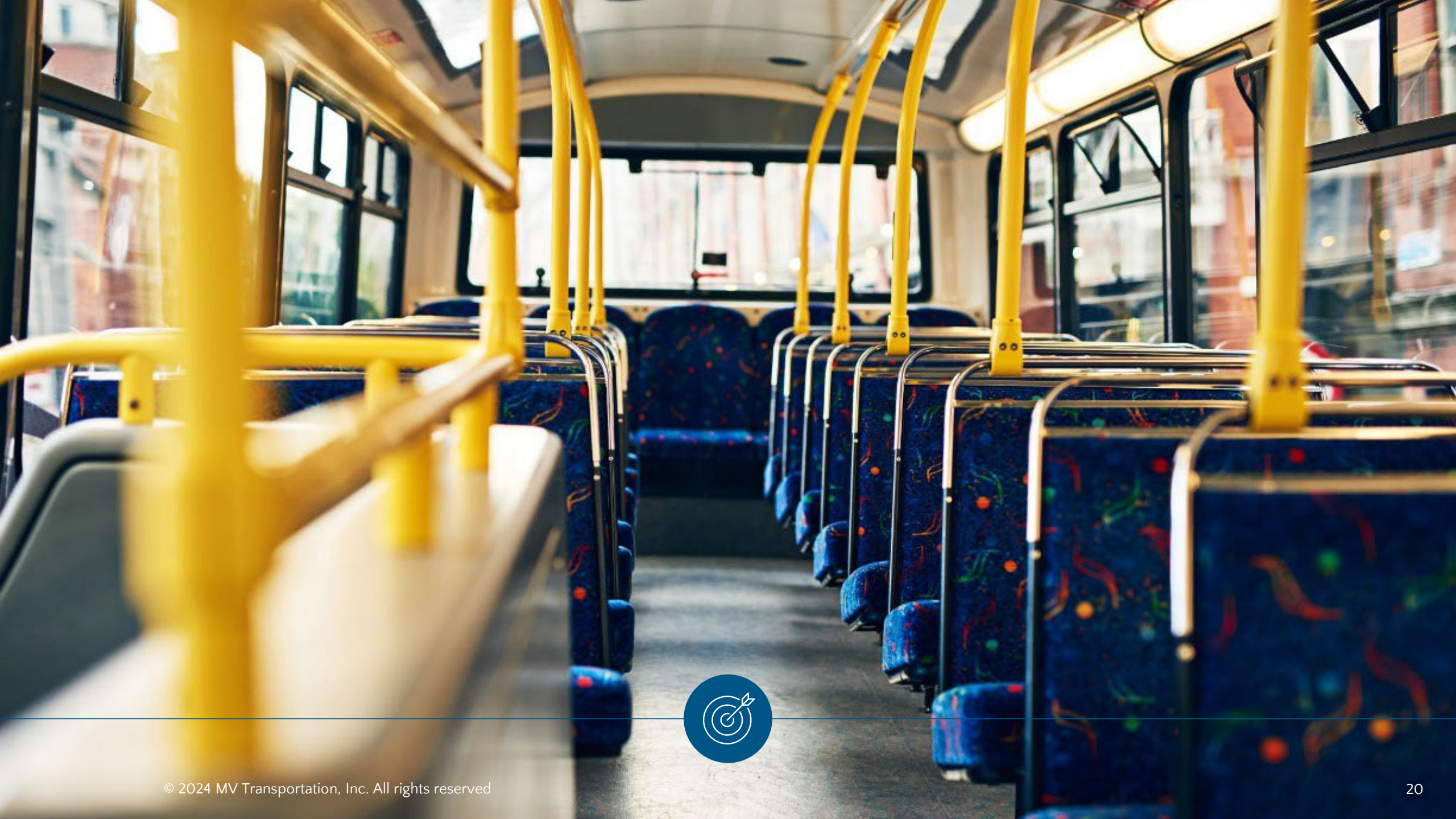
Site plan design and operational procedures

- Facility design, including charging/fueling infrastructure to determine:
  - Station location
  - Vehicle spacing
  - Yard workflow
  - Thermal event mitigation
  - Resiliency
- Development of SOPs and best practices for:
  - Personal protection equipment
  - Charging equipment
  - Electric vehicle emergency response

Next steps

Current focus

- Effect of temperature and driver behavior on range deterioration and energy consumption.
- Battery State of Health degradation to determine effects on future range and battery lifecycle.



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