

Hardware Technology Comparison

Resilient EV Fleets

1. **Diesel Generators**
2. **Gas and Propane Generators**
3. **Battery Energy Storage Systems (BESS)**
4. **Solar + BESS**
5. **Microgrid**
6. **Hydrogen Fuel Cell**

Table 1: Diesel Generators

Key Factors	Stationary (Permanent) and Mobile (Temporary) Deployment
Maturity and reliability	Diesel generators are a commercially established and widely used technology, with parts, service providers, and rental units commonly available. They can start quickly and can handle changes in electrical load, but actual performance depends on the selected equipment, site conditions, maintenance practices, and manufacturer operating limits. Mobile units use engine technology similar to that used in stationary units. They can be purchased or rented, often through a service contract, with the provider responsible for keeping the equipment maintained and ready to deploy. This can be a practical option for sites where footprint is limited and generator power is needed infrequently.
Power output and runtime	Diesel generators up to about 1.5 MW are commonly available, but usable output can vary based on temperature, elevation, emissions controls, fuel quality, maintenance condition, and manufacturer loading requirements. With appropriate sizing and a defined fueling plan, they may support critical charging through longer outages for a range of fleet sizes. Runtime depends on generator size, load level, stored fuel, refueling access, and any local run-hour restrictions. Mobile units can provide similar power ranges as stationary units, but runtime depends on the generator size, fuel tank capacity, dispatch timing, and whether refueling is available during the outage. Planning fuel access, connection equipment, and generator sizing in advance is important for keeping critical vehicles charged.
Upfront costs and ongoing expenses	Diesel generators are often among the lower-upfront-cost resiliency hardware options to purchase. Purchase costs may range from \$400–\$1,000/kW, excluding permanent installation and site work, depending on generator size, emissions rating, controls, and vendor scope. Ongoing expenses may range from \$0.30–\$0.60/kWh for fuel and maintenance, depending on fuel prices, load factor, runtime, maintenance needs, and contract terms. These ranges should be confirmed with current vendor quotes and project-specific assumptions. Diesel generators typically do not qualify for clean energy incentives. Mobile units can be purchased or rented, often through a service contract, and brought to the site during outages. Costs may include reservation fees, delivery or mobilization charges, hourly or per-use charges, connection support, and fuel.

Key Factors	Stationary (Permanent) and Mobile (Temporary) Deployment
Space and site constraints	A diesel generator needs a flat surface, such as a concrete pad or approved temporary staging area, and a protected area for fuel storage where applicable. For example, a 500 kW diesel generator may require roughly 60–100 sq. ft for the generator itself. With enough clearance around the unit, maintenance access, airflow, and fuel storage, the total footprint may reach 200–400 sq. ft depending on the configuration and local code requirements. Diesel generators can require less footprint than some other hardware options, but suitability depends on site layout, access, noise setbacks, and fuel-storage requirements. Mobile units require temporary space, safe access for delivery and refueling, and the necessary equipment to connect to the site electrical system. They may be useful for sites that cannot fit a permanent system.
Fuel supply and logistics	Diesel fuel is widely available and can be stored on site, but storage life depends on fuel quality, tank conditions, water control, temperature, and maintenance practices. Long-term storage may require periodic inspection, polishing, additives, or fuel replacement. Diesel has relatively high energy density compared with gaseous fuels, which can reduce storage volume for the same amount of energy delivered. For mobile units, fuel must either travel with the unit or be delivered to the site during an outage. Fuel delivery can be included as part of a service contract or arranged by the fleet. Outage planning should account for fuel supplier availability, road access, refueling safety, and the amount of reserve fuel required after grid power returns.
Environmental and community impact	Diesel generators generally produce higher on-site emissions and more noise than natural gas generators. Comparisons, such as approximately 40% higher carbon dioxide emissions per unit of energy or roughly 10 dB higher noise levels, should be confirmed against the specific equipment, load profile, emissions controls, and operating conditions. Local air-quality rules may limit how long or how often diesel generators can run, which can affect available backup time during an outage. Fleets should consider how emissions, noise, and fuel handling may affect neighboring residents and businesses. Permitting may be required depending on the air district, jurisdiction, generator size, runtime, and deployment type. Mobile diesel generators may still need local permits or approvals for temporary placement, electrical connection, fuel storage, and fire safety. Requirements may depend on deployment length, generator size, and local jurisdiction.

Key Factors	Stationary (Permanent) and Mobile (Temporary) Deployment
Charging strategy and load management	Diesel generators can handle load changes from EV charging, but charger sequencing, power limits, and minimum-load requirements should be reviewed with the generator manufacturer or vendor. Extended operation at very low load can create maintenance or performance issues for some generators, while large DC fast-charging steps may require appropriate controls or battery buffering. For short outages lasting a few hours, vehicles may be able to continue operating on their existing charge without a mobile generator. When a mobile unit is needed, it is brought on site and connected to existing chargers or electrical systems using preplanned connection equipment and operating procedures.

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Table 2: Gas and Propane Generators

Key Factors	Stationary (Permanent) and Mobile (Temporary) Deployment
Maturity and reliability	Natural gas and propane generators are commercially established technologies that have been used for decades in backup-power and fleet settings. Parts, service providers, and fuel infrastructure are commonly available, but equipment selection should confirm that the generator can support the selected EV charging hardware, site controls, and fleet power requirements. Mobile units use engine technology similar to that used in stationary systems. They can be purchased or rented, often through a service contract, with the provider responsible for maintaining and deploying the equipment. Mobile units may require additional fuel handling, storage, or delivery planning compared with diesel mobile units.
Power output and runtime	Natural gas and propane generators up to about 1.5 MW are commonly available, but usable output can vary based on site elevation, temperature, gas pressure, fuel quality, emissions controls, and manufacturer loading requirements. For sites with high energy needs, compatible generators can be operated in parallel using appropriate switchgear, controls, protection, and engineering review. Pipeline-connected generators may support extended runtime while gas service remains available and equipment operating limits are met; however, pipeline supply may be disrupted during some emergencies. Delivered CNG, LNG, or propane systems depend on stored fuel and refueling logistics. Mobile units can provide similar power ranges as stationary units. For mobile CNG or LNG units, runtime depends on stored fuel quantity, fuel delivery timing, and coordination with specialized fuel providers. Planning fuel access, connection equipment, and generator sizing in advance is important for keeping critical vehicles charged.

Key Factors	Stationary (Permanent) and Mobile (Temporary) Deployment
Upfront costs and ongoing expenses	Natural gas generators may cost around \$550–\$1,200/kW to purchase, excluding permanent installation and site work, depending on generator size, emissions rating, controls, fuel system requirements, and vendor scope. For pipeline-connected sites, ongoing expenses may range from \$0.10–\$0.25/kWh for fuel and maintenance, depending on local gas rates, load factor, runtime, maintenance needs, and contract terms. For delivered CNG, LNG, or propane, costs depend on delivery distance, storage requirements, supplier availability, and contract terms. These ranges should be confirmed with current vendor quotes and project-specific assumptions. Natural gas and propane generators typically do not qualify for clean energy incentives. Mobile units can be purchased or rented, often through a service contract, and brought to the site during outages. Costs may include reservation fees, delivery or mobilization charges, hourly or per-use charges, connection support, and fuel.
Space and site constraints	Natural gas and propane generators generally need more space than diesel generators of similar output because of fuel supply equipment, gas conditioning or pressure-regulation equipment, ventilation, clearances, and fire-safety requirements. For example, a 500 kW natural gas generator may require roughly 80–120 sq. ft for the generator itself, while the total installed footprint may be closer to 300–500 sq. ft once clearance, maintenance access, airflow, and fuel-system equipment are included. For delivered CNG, LNG, or propane systems, additional space may be needed for tanks, vaporizers, pressure regulation, truck access, and safety clearances. A mobile natural gas or propane generator requires temporary staging space, safe access for delivery and fuel handling, and the equipment needed to connect to the site electrical system. Mobile units may be practical where permanent equipment is not feasible, but footprint and fuel-logistics requirements should be confirmed before relying on this approach.
Fuel supply and logistics	Natural gas can be supplied through underground pipelines or delivered in compressed (CNG) or liquefied (LNG) form. Propane is typically delivered and stored in tanks on site. Pipeline gas can reduce on-site fuel storage needs, but it should not be treated as guaranteed during all outage scenarios because gas service can be affected by earthquakes, wildfires, shutoffs, pressure issues, or upstream system constraints. A backup fuel plan, such as propane or delivered CNG/LNG where feasible, may be appropriate for critical operations. For mobile units, fuel must either travel with the unit or already be available on site. CNG, LNG, and propane deliveries require specialized providers, safe staging areas, and clear access for delivery vehicles. Fuel planning should account for keeping critical vehicles charged during the outage and having enough fuel to support recovery once grid power is restored.

Key Factors	Stationary (Permanent) and Mobile (Temporary) Deployment
Environmental and community impact	Natural gas and propane generators generally produce lower on-site carbon dioxide emissions and less noise than diesel generators, but the exact difference depends on the equipment, fuel, load profile, emissions controls, and operating conditions. Comparisons, such as approximately 25-30% lower carbon dioxide emissions or roughly 10 dB lower noise levels than diesel, should be confirmed for the selected equipment. Lower emissions or noise may reduce community concerns, but permitting approval remains dependent on local rules, air-quality requirements, fire safety requirements, and project-specific details. Mobile natural gas or propane generators may still need local permits or approvals for temporary placement, electrical connection, fuel storage, and fire safety. Requirements may depend on deployment length, generator size, fuel type, and local jurisdiction.
Charging strategy and load management	Natural gas and propane generators can work well with steady and predictable charging loads, but charger sequencing, power limits, minimum-load requirements, and sudden DC fast-charging steps should be reviewed with the generator manufacturer or vendor. Extended operation at very low load can create maintenance or performance issues for some generators. For short outages lasting a few hours, vehicles may be able to continue operating on their existing charge without a mobile generator. When a mobile natural gas or propane unit is needed, it is brought on site and connected to existing chargers or electrical systems using preplanned connection equipment and operating procedures.

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Table 3: Battery Energy Storage Systems (BESS)

Key Factors	Stationary (Permanent) and Mobile (Temporary) Deployment
Maturity and reliability	Battery energy storage systems (BESS) are commercially available in a range of configurations, and deployment experience for EV fleet resiliency continues to grow. BESS can respond quickly when vehicles start or stop charging, which may help sites with fast chargers where power demand can change quickly. Actual performance depends on system sizing, controls, battery chemistry, usable energy, reserve settings, temperature, age, and warranty limits. Mobile units use similar battery technology as stationary systems. They can be deployed for short-term backup power, but mobile capacity is often limited by transportation size and weight. A standalone mobile battery cannot recharge itself during an outage unless it is paired with an island-capable generation source or another approved charging source.
Power output and runtime	Standalone BESS systems delivering approximately 250 kW with 1 MWh of nameplate energy storage are commercially available, and modular systems can be deployed to increase power output and energy capacity. The usable energy available for charging is typically lower than nameplate capacity after accounting for reserve requirements, conversion losses, auxiliary loads, battery age, temperature, and operating limits. Runtime depends on usable storage capacity, charger power, number of vehicles charging, vehicle energy needs, and the emergency reserve maintained by the Energy Management System. Mobile units typically carry less energy than stationary systems. Their practical runtime depends on usable battery capacity, charger limits, transportation constraints, reserve settings, and whether another source is available to recharge the unit. As a result, they are usually best suited to serving a limited number of critical vehicles rather than supporting an entire fleet during longer outages.
Upfront costs and ongoing expenses	BESS units may cost around \$225–\$1,100/kWh to purchase, excluding permanent installation and site work, depending on battery capacity, power output, chemistry, controls, enclosure type, safety systems, and vendor scope. Increasing BESS capacity raises total cost and does not necessarily improve cost per kWh in EV fleet resiliency applications. Maintenance costs are estimated at approximately 2-3% of installed system cost per year. Tax credits and state or utility incentive programs may help offset a portion of the initial investment, depending on current program rules, eligibility, ownership structure, and project design.

Key Factors	Stationary (Permanent) and Mobile (Temporary) Deployment
Space and site constraints	The space needed for a battery system depends on storage capacity, power rating, enclosure type, fire-safety requirements, and maintenance access. For example, a BESS delivering approximately 250 kW with 1 MWh of nameplate energy storage may require roughly 250–400 sq. ft for the equipment container before accounting for enough clearance around the unit, fire access, and separation requirements. Additional battery units can sometimes be added as the fleet grows, but expansion depends on available space, electrical capacity, permitting, interconnection limits, and whether the original design allows modular growth.
Fuel supply and logistics	BESS does not require fuel delivery. Energy is stored from the grid, on-site solar, or another approved electrical source identified in the site’s operating plan. To keep the battery ready for outages, fleets can schedule charging during lower-cost hours where the applicable rate schedule supports that strategy. The operating plan should reserve enough usable battery capacity for emergency charging and avoid using all stored energy for bill savings before an outage occurs.
Environmental and community impact	BESS produces no on-site emissions during operation and operates quietly, which may reduce community concerns for sites near residential areas. Permitting can be less complex than for fuel-powered backup options in some jurisdictions, but requirements vary by system size, battery chemistry, fire code, spacing, safety systems, and the authority having jurisdiction. BESS can support long-term air quality goals when paired with appropriate charging and operating practices.
Charging strategy and load management	Stored energy from BESS may help lower electricity bills by avoiding high-cost periods (peak shaving) and shifting vehicle charging to off-peak hours (load shifting). Savings depend on the applicable rate schedule, charging profile, battery operating strategy, interconnection limits, and reserve requirements. Using stored energy for peak shaving requires careful planning and a robust Energy Management System (EMS, software that controls how power flows to the chargers) so the battery is not drawn down below the reserve needed for outages. Fleet operators should decide how much battery capacity to reserve for emergencies versus how much to use for everyday savings.

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Table 4: Solar + BESS

Key Factors	Stationary (Permanent) Deployment
Maturity and reliability	Solar and BESS systems are well-established in the broader energy market and continue to evolve as a resiliency option for EV fleets. Day-to-day energy-management performance depends on solar production, battery size, controls, and site load. The ability to support fleet charging during an outage depends on system sizing and whether the solar, battery, inverter, controls, and interconnection design are approved and configured for islanded operation.
Power output and runtime	Solar and BESS systems can be configured at different power and energy levels. Example systems in the approximately 0.5–1 MW range with 2–4 MWh of battery storage may be commercially available, but actual sizing depends on the fleet load, outage-duration target, solar production profile, usable battery capacity, reserve requirements, and site constraints. The battery component delivers power to chargers, while solar panels may recharge the battery during daylight hours. During a grid outage, solar can recharge the battery only if the system is designed, approved, commissioned, and controlled for islanded operation.
Upfront costs and ongoing expenses	Solar and BESS systems are typically among the higher-upfront-cost resiliency hardware options. Purchase costs may range from \$1,000–\$1,200/kW for solar equipment and \$225–\$1,100/kWh for battery storage, excluding permanent installation and site work, depending on battery capacity, power output, chemistry, controls, interconnection scope, and vendor assumptions. Ongoing expenses may include solar maintenance and monitoring, battery maintenance, controls, warranty support, and performance monitoring. These ranges should be confirmed with current vendor quotes and project-specific assumptions. Tax credits and state or utility incentive programs may help offset a portion of the initial investment, depending on current rules and project eligibility. Exporting or selling excess solar power depends on the applicable interconnection approval, metering configuration, tariff, and program eligibility.
Space and site constraints	Solar panels need a large amount of space. For example, a solar array sized around 1 MW may require roughly 4–6 acres depending on panel type, layout, shading, setbacks, and access requirements. The battery footprint depends on storage capacity and enclosure design; for reference, a 1 MWh battery container may require roughly 250–400 sq. ft before accounting for clearance and safety requirements. Limited space at fleet sites may mean this option only supports partial fleet charging during an outage. Permitting for solar panels, battery equipment, interconnection, fire safety, and electrical work can take significant time and should be planned early.

Key Factors	Stationary (Permanent) Deployment
Fuel supply and logistics	Solar and BESS systems do not require delivered fuel. Energy comes from sunlight and can also be drawn from the grid during lower-cost hours to charge the battery. During an outage, the ability to use solar generation depends on island-capable inverters, controls, protective equipment, and interconnection approval. An Energy Management System (EMS, software that controls how power flows to the chargers) is typically used to manage stored energy, maintain emergency reserve, and prioritize selected fleet charging over other site loads where the electrical design supports that operating mode.
Environmental and community impact	Solar and BESS systems produce no on-site emissions during operation and operate quietly, supporting local air-quality and community-impact goals. Life-cycle emissions and environmental impacts depend on equipment manufacturing, battery chemistry, disposal or recycling practices, and the electricity used to charge the battery. Lower noise and no on-site combustion may reduce community concerns, but permitting approval still depends on local requirements, fire code, interconnection review, site layout, and project-specific details.
Charging strategy and load management	Solar and BESS may support critical vehicle charging during grid outages when the system is sized for the protected load and approved for islanded operation. Potential benefits outside of emergencies include lower energy costs from avoiding high-cost energy periods (peak shaving) and shifting charging to off-peak hours (load shifting). Savings depend on the applicable rate schedule, charging profile, interconnection limits, solar production, battery operating strategy, and reserve requirements. Using stored energy for peak shaving requires careful planning and a robust Energy Management System so the battery is not drawn down below the reserve needed for outages.

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Table 5: Microgrid

Key Factors	Stationary (Permanent) Deployment
Maturity and reliability	Microgrid components such as generators, solar, batteries, controls, and switchgear are commercially available, but combining them into one system for EV fleet charging can be complex and project-specific. Deployment experience for EV fleet resiliency is still developing, and performance depends on system design, controls, commissioning, testing, interconnection approval, and operator training. Microgrids may become more common as controls and vendor experience continue to mature.
Power output and runtime	Microgrid power output and runtime vary based on the selected hardware, such as generators, solar panels, battery storage, and in some cases small wind turbines. The battery may help manage fast charger load changes, while generators or solar panels may recharge the battery over time if the system is designed to operate that way. During an outage, a microgrid can support selected loads only if it has approved islanding capability, protective equipment, controls, commissioning, and operating procedures. An Energy Management System (EMS) can manage which chargers run and at what power level, but total charging capacity may still be limited by available generation, battery state of charge, fuel supply, interconnection limits, and the protected-load design.
Upfront costs and ongoing expenses	Microgrid costs vary widely based on system size, selected technologies, controls, interconnection scope, site work, permitting, and vendor responsibilities. Total costs need to account for power generation, energy storage capacity, electrical infrastructure, controls, communications, construction, commissioning, and ongoing operations. Purchase costs can be upwards of \$2 million, excluding permanent installation and site work, depending on design and hardware mix. Ongoing expenses may range from \$120,000–\$350,000 per year for fuel, maintenance, software, monitoring, insurance, and testing. These ranges should be treated as planning-level assumptions and confirmed with current vendor quotes and site-specific scope.
Space and site constraints	Microgrid space needs vary depending on which components are included. Solar arrays require roof, canopy, or ground area; battery systems can range from cabinet-scale units to containerized systems; generators need their own footprint plus space for fuel systems; and wind turbines, where considered, require suitable wind resource, setbacks, zoning approval, and access. Site planning should account for local building rules, fire access, clearances, maintenance access, utility interconnection equipment, communications equipment, and safe separation between components.

Key Factors	Stationary (Permanent) Deployment
Fuel supply and logistics	Microgrid fuel needs vary based on which power sources are included in the system. If the microgrid includes a generator, fuel planning follows the same considerations as standalone generators, such as diesel storage, delivered propane or CNG/LNG, or a natural gas pipeline connection. If the system relies on solar panels, battery storage, and wind turbines, no delivered fuel may be needed, but the system still depends on available renewable generation, battery state of charge, controls, and outage duration.
Environmental and community impact	Microgrid environmental impact varies based on the combination of hardware selected and how the system is operated. Solar, wind, and battery components produce no on-site emissions during operation and operate quietly, while generator components may produce emissions and noise similar to standalone generators. Permitting is generally more complex than for single-technology solutions because each component, the islanding design, interconnection, fire safety, and electrical configuration may require separate review or approval.
Charging strategy and load management	Microgrid charging capacity may be limited or flexible depending on which hardware is included, whether the system has approved islanding capability, and whether a continuous fuel or generation source is available. The Energy Management System can control how much power goes to each charger, prioritize selected vehicles, and balance available power across the system, but it cannot create capacity beyond the generation, storage, and interconnection limits designed into the project. The EMS may give fleet operators more control over how backup power is distributed during an outage compared with some single-technology options.

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Table 6: Hydrogen Fuel Cell

Key Factors	Stationary (Permanent) Deployment
Maturity and reliability	Hydrogen fuel cells are an emerging option for EV fleet resiliency. Fuel cell technology is used in stationary power and transportation applications, but fleet-charging resiliency deployments remain less common than generators, batteries, or solar-plus-storage systems. Vendor support, hydrogen supply, permitting experience, and service availability may be limited by region. Fleets considering hydrogen should expect longer planning timelines and should confirm provider availability, safety requirements, and fuel supply before selecting this technology.
Power output and runtime	Hydrogen fuel cell systems can be built from modular units, such as 125 kW blocks, that may be combined to reach higher power levels depending on the system design. Runtime depends on usable hydrogen stored on site, power output, fuel-cell efficiency, weather, auxiliary loads, hydrogen quality, delivery logistics, and operating limits. These systems may provide continuous energy for longer outages when enough hydrogen is stored or delivered, but this should be confirmed through vendor sizing and site-specific modeling. Some fuel cells may respond more slowly to sudden changes in power demand, so they are often paired with a battery to handle rapid load spikes from DC fast chargers. An Energy Management System can schedule charging sequentially or in staggered groups to help the fuel cells operate at a consistent level.
Upfront costs and ongoing expenses	Hydrogen fuel cells are typically among the higher-upfront-cost resiliency hardware options to purchase. Purchase costs for the equipment can be upwards of \$7,000/kW, including hydrogen storage infrastructure, depending on system size, storage capacity, safety systems, vendor scope, and site requirements. Ongoing maintenance expenses may be around \$100/kW per year, and hydrogen fuel costs may be approximately \$16/kg, but both should be confirmed against current supplier pricing, delivery distance, contract terms, and project assumptions. Hydrogen fuel cells may qualify for federal tax incentives depending on current tax law, ownership structure, technology eligibility, and project specifics; customers should confirm eligibility with tax and legal advisors.
Space and site constraints	Hydrogen fuel cells require space for the fuel cell equipment, hydrogen storage, safety systems, and delivery access. Hydrogen storage tanks often account for much of the footprint because high-pressure storage requires safety clearances and protective measures. For example, a 1 MW system may require up to roughly 10,000 sq. ft when accounting for storage, safety clearances, and access areas, but the actual footprint depends on pressure, stored hydrogen quantity, equipment layout, local codes, and vendor design. Site planning should account for local fire codes, required distances from buildings and property lines, ventilation, emergency access, and fuel delivery vehicle access.

Key Factors	Stationary (Permanent) Deployment
Fuel supply and logistics	Hydrogen must be delivered to the site or produced on site and stored under high pressure or in another approved storage configuration, following strict safety protocols. Access to hydrogen production, delivery, and maintenance support remains more limited than conventional fuels, so availability may vary by region. Fleets should confirm fuel supply contracts, delivery frequency, storage quantity, emergency access, and backup delivery options before selecting this technology. Fuel planning should support both continued critical charging during an outage and recovery after grid power is restored.
Environmental and community impact	Hydrogen fuel cells produce electricity, water, and heat during operation and produce no direct combustion emissions at the point of use. They also run significantly quieter than fuel-burning generators. Life-cycle emissions depend on how the hydrogen is produced, transported, and stored; hydrogen made from nonrenewable sources can create significant upstream emissions. Permitting for hydrogen systems involves complex requirements related to storage, handling, ventilation, fire safety, and high-pressure equipment, which may require additional time and coordination with local authorities.
Charging strategy and load management	Hydrogen fuel cells generally operate best with steady, continuous power output. They may be paired with a battery to absorb rapid load spikes from DC fast chargers, allowing the fuel cell to maintain more consistent output. An EMS can schedule vehicles to charge sequentially or in staggered groups, helping the fuel cells operate at a steadier level and helping manage the available hydrogen supply. Actual runtime and charging capacity should be confirmed through vendor sizing, fuel-supply planning, and site-specific outage scenarios.

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