



DC Combiner Trailer

2.5 MW Modular DC Power Aggregation and Distribution System

A centralized, trailer-mounted DC bus system with 10 bidirectional solid-state-protected ports for aggregating, routing, and distributing DC power across Envoltz 250 kW equipment platforms and customer loads.

Scalable. Bidirectional. Mission-Critical.

Technical White Paper

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Executive Summary

The Envoltz DC Combiner Trailer is a mobile, trailer-mounted DC bus aggregation and distribution platform designed to interconnect up to ten 250 kW Envoltz equipment modules in any configuration. With a maximum aggregate capacity of 2.5 MW, the DC Combiner serves as the central power routing hub for Envoltz’s modular DC equipment ecosystem—including the DC Genset Trailer, Battery Energy Storage System (BESS) Trailer, and Super Capacitor Trailer—as well as customer DC loads.

Each of the ten bidirectional input/output ports is protected by a solid-state circuit breaker (SSCB), providing microsecond-class fault isolation, arc-free switching, and unlimited electrical cycle life. The system eliminates the inefficiencies and failure modes associated with mechanical contactors and traditional AC distribution, enabling direct DC power aggregation with minimal conversion losses.

Optional integration with an Envoltz DC-to-AC Inverter Trailer extends the system’s capability to serve AC loads and to interconnect with the national electrical grid, enabling bidirectional grid-tied operation, demand response participation, and emergency islanded power supply.

What is a DC Combiner?

A DC Combiner is a centralized power aggregation node that connects multiple DC sources and loads on a common bus. Unlike traditional AC distribution panels, a DC Combiner operates natively in the DC domain, eliminating unnecessary DC-to-AC and AC-to-DC conversion stages. This results in higher system efficiency, reduced component count, and faster dynamic response to load transients and fault conditions.

System Overview

The DC Combiner Trailer is engineered as a ruggedized, road-transportable power distribution node. It receives and dispatches DC power across ten standardized ports, each rated for 250 kW continuous bidirectional operation. The internal DC bus architecture is designed for low-impedance, high-current operation with comprehensive monitoring, protection, and control.

Key Specifications

Parameter	Specification
Maximum Aggregate Capacity	2,500 kW (2.5 MW)
Number of Ports	10 bidirectional input/output
Per-Port Rating	250 kW continuous, bidirectional

Nominal DC Bus Voltage	400–850 VDC (configurable)
Circuit Protection	Solid-state circuit breakers (SSCB), all 10 ports
Fault Response Time	< 10 μ s (solid-state)
Communication Protocol	CAN bus, Modbus TCP/IP, EtherCAT
Monitoring	Per-port voltage, current, power, temperature; system-level SCADA integration
Enclosure Rating	NEMA 3R (outdoor, rain-tight)
Cooling	Forced-air with redundant fans; liquid cooling available for sustained full-load operation
Platform	Trailer-mounted, DOT-compliant, towable by Class 5+ vehicle
Dimensions (Trailer)	Approximately 20 ft L x 8.5 ft W x 10 ft H (road-legal)
Weight (Estimated)	< 14,000 lbs GVWR
Operating Temperature	-20°C to +50°C
Compliance	UL 1741, IEEE 1547 (with AC inverter option), NEC Article 690/705

DC Bus Architecture and Port Design

The DC Combiner Trailer is built around a low-impedance copper bus rated for the full 2.5 MW aggregate current at the nominal bus voltage. The bus is designed with redundant parallel conductors and thermal monitoring to ensure reliable operation under worst-case loading conditions.

Bidirectional Port Configuration

Each of the 10 ports is a fully bidirectional DC interface capable of sourcing or sinking up to 250 kW. This bidirectional capability is fundamental to the system’s flexibility: any port can connect to a DC source (genset, BESS, supercapacitor), a DC load, or another DC Combiner for cascaded configurations. The port assignment is software-configurable and can be changed in the field without hardware modification.

Port connectivity is standardized across the Envoltz 250 kW equipment family. Heavy-duty DC power connectors rated for the full port current are used at each interface point, with color-coded and keyed connections to prevent polarity reversal. Each port includes dedicated voltage and current sensing, temperature monitoring, and ground-fault detection.

Bus Voltage Management

The DC bus operates within a configurable voltage window of 400–850 VDC. Bus voltage regulation is coordinated across all connected equipment via the system’s CAN bus communication network. When multiple sources are connected, a droop-based or master/slave voltage regulation scheme ensures stable bus voltage under varying load conditions. The specific regulation mode is configurable via the system controller and can be adapted to the connected equipment mix.

Why a DC Bus?

Modern battery systems, solar arrays, fuel cells, and supercapacitors all generate DC power natively. Traditional approaches convert DC to AC for distribution, then back to DC at the load—losing 6–12% of energy in the double conversion. The Envoltz DC Combiner keeps power in the DC domain, eliminating unnecessary conversion stages and preserving energy for useful work.

Solid-State Circuit Breaker Protection

Every port on the DC Combiner Trailer is protected by a solid-state circuit breaker (SSCB). Unlike mechanical breakers or fuses, SSCBs use semiconductor switching devices—typically silicon carbide (SiC) MOSFETs or IGBTs—to interrupt fault current in microseconds. This capability is critical in DC power systems, where the absence of a natural zero-crossing (as exists in AC systems) makes mechanical arc extinction significantly more challenging and slower.

SSCB Performance Characteristics

Parameter	Solid-State CB	Mechanical CB
Fault Detection Time	< 1 μ s	5–50 ms
Fault Clearing Time	< 10 μ s	30–80 ms
Arc Generation	None (arc-free)	Yes (arc flash hazard)
Electrical Cycle Life	> 1,000,000 cycles	5,000–10,000 cycles
Mechanical Wear	None (no moving parts)	Progressive degradation
On-State Losses	0.1–0.3% (SiC MOSFET)	Negligible (contact resistance)
Bidirectional Capability	Inherent (MOSFET body diode)	Requires additional components
Remote Operation	Instant via digital control	Requires motorized actuator

Condition Monitoring	Continuous (junction temperature, leakage current)	Limited (trip counter, contact resistance checks)
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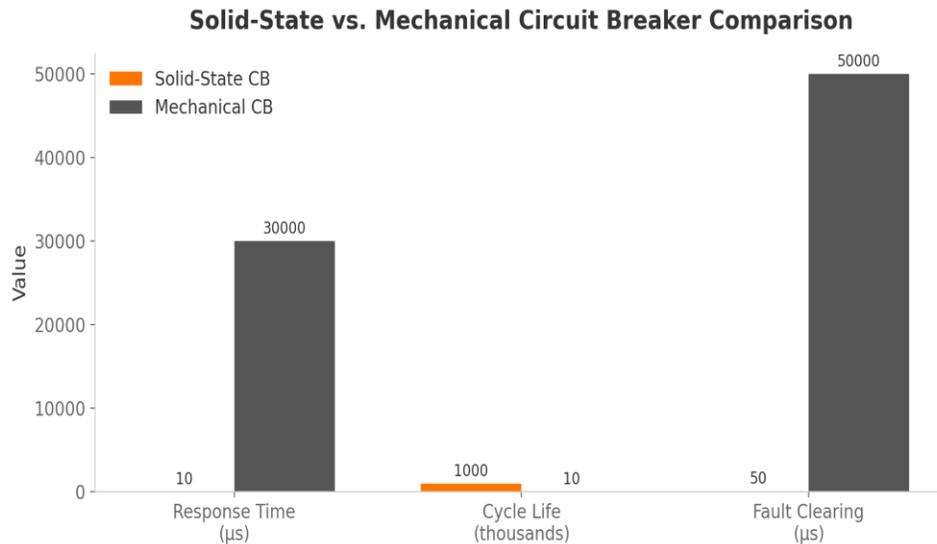


Figure: Solid-State vs. Mechanical Circuit Breaker Performance Comparison

Fault Protection Coordination

The 10 SSCBs are coordinated by the DC Combiner’s protection controller to provide selective fault isolation. When a fault is detected on any port, only the affected port is disconnected—the remaining nine ports continue normal operation with no interruption. The protection system supports configurable trip thresholds (overcurrent, overvoltage, undervoltage, ground fault, rate-of-change) and provides event logging with timestamped waveform capture for post-event analysis.

The SSCB architecture also enables soft-start and soft-shutdown sequencing for connected equipment. When a new source or load is connected, the SSCB can ramp current gradually through PWM-based current limiting, preventing inrush transients that could disturb the DC bus voltage or damage connected equipment.

Arc-Free Protection in DC Systems

DC arcs are inherently more dangerous than AC arcs because there is no natural zero-crossing to extinguish the arc. A DC arc, once struck, can sustain itself indefinitely until the circuit is broken by force. Solid-state circuit breakers eliminate arc hazards entirely by interrupting current through semiconductor switching, with zero physical contact separation. This is a fundamental safety advantage for high-power DC systems.

Compatible Equipment and System Configurations

The DC Combiner Trailer is designed to integrate with the full range of Envoltz 250 kW DC equipment platforms. Each platform connects to the DC Combiner via a single standardized port, and any combination of equipment can be connected simultaneously up to the 10-port limit.

DC Genset Trailer (250 kW)

The Envoltz DC Genset Trailer couples an engine-driven generator with a controlled rectifier to produce regulated DC power at the bus voltage. It functions as a dispatchable DC source that can be started and stopped on demand. Multiple DC Genset Trailers can be paralleled through the DC Combiner for increased generation capacity, with load sharing coordinated by the combiner's control system.

BESS Trailer (250 kW)

The Envoltz Battery Energy Storage System (BESS) Trailer provides bidirectional energy storage using lithium iron phosphate (LFP) battery modules. Through the DC Combiner, the BESS can absorb excess generation from gensets or other sources, time-shift energy delivery, provide peak shaving, and supply instantaneous backup power during source transitions. The bidirectional port of the DC Combiner seamlessly manages charge and discharge cycles.

Super Capacitor Trailer (250 kW)

The Envoltz Super Capacitor Trailer provides high-power, fast-response energy buffering. Supercapacitors excel at absorbing and delivering short-duration, high-current transients—such as motor starting surges, regenerative braking energy, or rapid load steps—that would otherwise stress batteries or cause bus voltage sags. Connected to the DC Combiner, the supercapacitor trailer acts as a dynamic power buffer that complements the steady-state energy delivery of gensets and BESS units.

Customer DC Loads

Any DC load operating within the bus voltage range (400–850 VDC) and rated at or below 250 kW per port can be connected directly to the DC Combiner. Multiple ports can supply larger loads when paralleled at the load side. Typical customer DC loads include electric drive systems, DC-powered industrial equipment, EV charging infrastructure, electrolysis systems, and data center power feeds.

System Configuration Flexibility

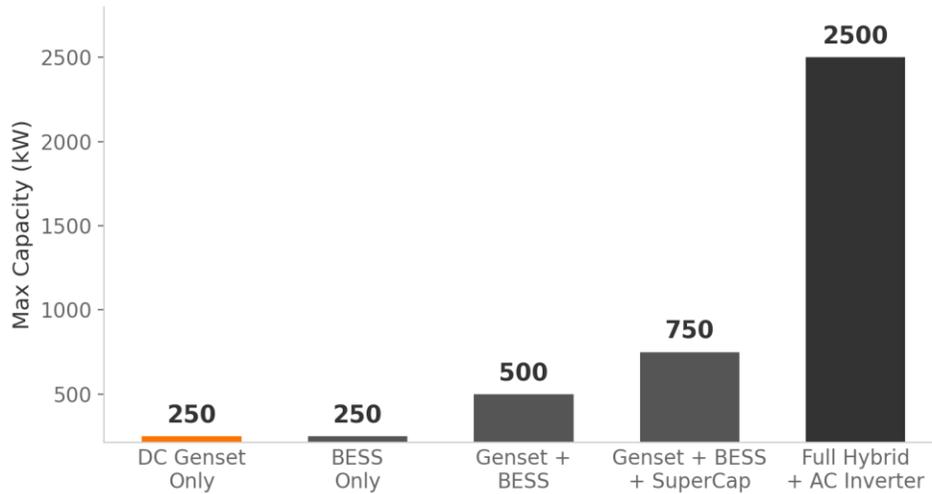


Figure: Example System Configuration Flexibility and Capacity

DC Combiner Maximum Aggregate Power Capacity

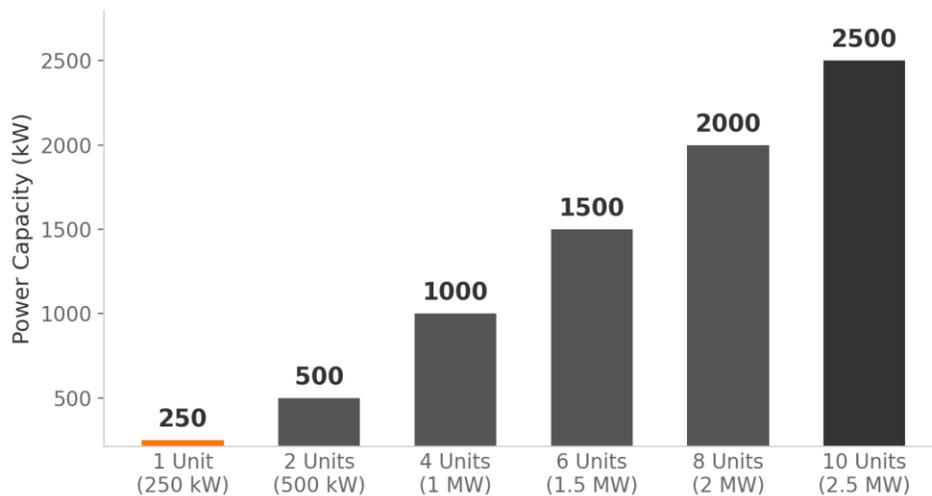


Figure: DC Combiner Aggregate Power Capacity by Number of Connected Units

DC-to-AC Inverter Trailer and Grid Interconnection

While the DC Combiner is optimized for native DC distribution, many applications require AC power delivery or grid interconnection. Envoltz offers a DC-to-AC Inverter Trailer as an optional companion unit that connects to one or more ports of the DC Combiner, converting the aggregated DC power to AC for delivery to AC loads or for synchronization with the utility grid.

DC-to-AC Inverter Trailer Specifications

Parameter	Specification
Rated Output Power	250 kW per unit (scalable with multiple units)
AC Output Voltage	480 VAC, 3-phase, 60 Hz (configurable for 50 Hz export)
Inverter Topology	Three-level NPC or T-type, SiC MOSFET-based
Peak Efficiency	> 98% (at rated power)
Total Harmonic Distortion	< 3% THD at rated load
Grid Synchronization	IEEE 1547-2018 compliant; anti-islanding, voltage/frequency ride-through
Islanding Capability	Standalone microgrid mode with voltage/frequency forming
Transfer Time	< 20 ms (grid-to-island or island-to-grid)
Power Factor	Adjustable, ± 0.85 leading/lagging
Protection	Integrated AC-side overcurrent, ground fault, and arc-fault protection
Platform	Trailer-mounted, DOT-compliant, matched to DC Combiner form factor

AC Load Support

When connected to the DC Combiner, the DC-to-AC Inverter Trailer provides clean, regulated 480 VAC 3-phase power suitable for standard industrial and commercial AC loads. The inverter's low THD and adjustable power factor make it compatible with sensitive loads including variable frequency drives, lighting systems, HVAC equipment, and general-purpose distribution panels.

Multiple DC-to-AC Inverter Trailers can be connected to the DC Combiner simultaneously, operating in parallel to serve larger AC loads. The inverters synchronize their output waveforms automatically to maintain balanced 3-phase power delivery.

National Grid Interconnection

The DC-to-AC Inverter Trailer is designed for full compliance with IEEE 1547-2018 and relevant utility interconnection requirements, enabling direct connection to the national electrical grid.

Grid-tied operation enables several high-value use cases:

- **Grid Export:** Surplus DC generation (from gensets, BESS, or renewables) can be exported to the grid as revenue-generating power or demand offset.
- **Grid Import:** The system can draw power from the grid to charge BESS units, supplementing on-site generation during off-peak rate periods.

- Demand Response: The BESS and supercapacitor assets, managed through the DC Combiner, can participate in utility demand response programs—dispatching stored energy during peak demand events.
- Backup and Islanding: In the event of a grid outage, the inverter transitions to island mode within 20 ms, maintaining uninterrupted power to critical loads from the DC Combiner’s connected sources.
- Frequency and Voltage Support: The inverter can provide ancillary services including reactive power compensation and frequency regulation, supporting local grid stability.

Bidirectional Grid-Tied Operation

The combination of the DC Combiner and DC-to-AC Inverter Trailer creates a fully bidirectional grid interface. Energy can flow from the grid into the DC bus for battery charging, or from the DC bus out to the grid for export. This bidirectional capability transforms the Envoltz modular equipment platform from a standalone power system into a grid-interactive distributed energy resource (DER).

Efficiency and Performance Advantages

The DC Combiner architecture delivers measurable efficiency advantages over traditional AC-based power distribution by minimizing unnecessary power conversion stages.

DC vs. AC Distribution Efficiency

Parameter	DC Combiner (Direct DC)	Traditional AC Distribution
Source-to-Bus Efficiency	98–99%	92–96% (DC→AC conversion)
Bus-to-Load Efficiency	99%+ (DC-DC or direct)	92–96% (AC→DC at load)
Overall Round-Trip Efficiency	97–98%	85–92%
Conversion Stages (DC Source to DC Load)	0–1	2–3
Reactive Power Management	Not applicable (DC)	Required (capacitor banks, PF correction)
Conductor Utilization	100% (no skin effect)	~85% (skin/proximity effects at 60 Hz)
Harmonic Filtering	Not required	Required (THD compliance)

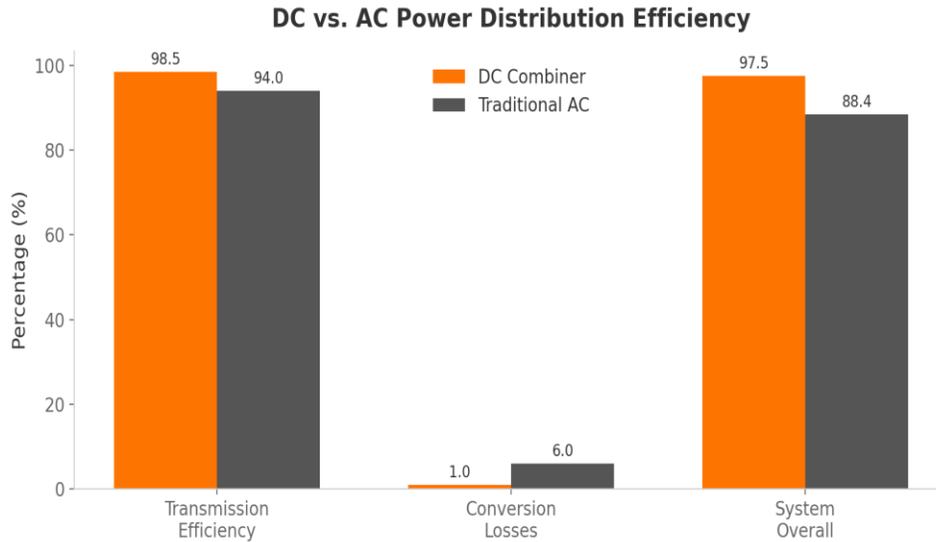


Figure: DC Combiner vs. Traditional AC Distribution Efficiency Comparison

Safety Features

The DC Combiner Trailer incorporates multiple layers of safety protection to ensure personnel and equipment safety in all operating conditions.

Safety Feature	Description
Solid-State Fault Isolation	All 10 ports protected by SSCBs with < 10 μ s fault clearing; arc-free operation eliminates arc flash hazard at the combiner
Ground Fault Detection	Per-port ground fault monitoring with configurable trip thresholds and alarm annunciation
Overvoltage / Undervoltage Protection	Bus voltage monitoring with automatic load shedding and source disconnection for out-of-range conditions
Overcurrent Protection	Per-port current limiting and trip coordination; selectively isolates faulted circuits without affecting healthy ports
Thermal Protection	Bus bar temperature monitoring, SSCB junction temperature sensing, and ambient temperature interlocks; forced-air cooling with redundant fan sets
Emergency Stop	Hardwired E-stop on trailer exterior; opens all SSCBs simultaneously and de-energizes the DC bus within microseconds

Lockout/Tagout Provisions	Mechanical disconnect at each port for maintenance isolation; LOTO-compatible design per OSHA 29 CFR 1910.147
Enclosure Protection	NEMA 3R rated enclosure; touch-safe design with IP-rated connectors; no exposed energized conductors during normal operation
Event Logging	Continuous data recording of all port voltages, currents, temperatures, and protection events with timestamped waveform capture

Platform and Mobility

The DC Combiner is built on a heavy-duty, DOT-compliant trailer platform engineered for rapid deployment and relocation. The trailer is towable by standard Class 5 or larger trucks, enabling transport on public roads without oversize permits. All DC power connectors and control interfaces are externally accessible with weatherproof covers, enabling fast connection and disconnection in the field.

The trailer includes leveling jacks, tie-down provisions, and fork pockets for final positioning at the deployment site. Cable management trays and strain-relief anchors are provided at each port location to support organized and safe cable routing in multi-unit installations.

The design philosophy aligns with the Envoltz 250 kW equipment family: every trailer is independently mobile, independently functional, and can be combined in any number or arrangement to meet the power requirements of the application. The DC Combiner Trailer is the central hub that makes this modular, plug-and-play architecture possible.

Key Market Applications

Oil and Gas / Industrial Field Operations

Remote well sites, pipeline construction, and offshore support operations require flexible, high-power electrical infrastructure that can be deployed and relocated rapidly. The DC Combiner enables operators to aggregate power from multiple gensets and BESS units to supply electric drive systems, electric fracturing equipment, wireline units, and other DC-powered oilfield equipment—eliminating the need for multiple independent power systems.

Marine and Shipyard

Electric and hybrid-electric marine vessels increasingly use DC distribution buses for propulsion and auxiliary power. The DC Combiner Trailer provides shore-side power aggregation for vessel charging, hybrid drive testing, and shipyard power distribution. With the DC-to-AC inverter option, it can also provide shore power conversion for vessels requiring AC-based hotel loads.

Construction and Temporary Power

Large construction sites, events, and disaster recovery operations require temporary power systems that can scale with demand. The DC Combiner allows operators to start with a single genset and BESS, then add capacity as the site load grows—without redesigning the electrical distribution. The grid-tie option enables permanent utility connection when available, with seamless fallback to on-site generation.

EV Charging Infrastructure

DC fast charging stations require high-power DC feeds. The DC Combiner can aggregate power from local BESS, gensets, and grid connections to supply multiple DC fast chargers from a centralized, managed power bus. The supercapacitor trailer provides transient buffering for the high pulse loads characteristic of DC fast charging, protecting the grid connection and extending battery life.

Microgrid and Distributed Energy

The DC Combiner, paired with the DC-to-AC Inverter Trailer, forms the core of a rapidly deployable microgrid. It can integrate diverse generation sources (diesel, natural gas, solar, battery), manage energy storage, and provide both DC and AC distribution—all from a mobile, modular platform that can be commissioned in hours rather than months.

Rapid Deployment Advantage

Traditional electrical infrastructure requires months of engineering, permitting, and construction. The Envoltz DC Combiner system deploys in hours: tow the trailers to the site, connect the standardized DC cables, power up, and configure via the integrated controller. This speed-to-power capability is a critical differentiator for time-sensitive operations in oil and gas, emergency response, and military applications.

Conclusion

The Envoltz DC Combiner Trailer is the central power routing and protection hub for the Envoltz 250 kW modular equipment platform. With 10 bidirectional, solid-state-protected ports and a 2.5 MW aggregate capacity, it enables the flexible interconnection of DC gensets, battery storage, supercapacitors, and customer loads in any combination required by the application.

The solid-state circuit breaker architecture provides microsecond-class fault protection, arc-free operation, and unlimited cycle life—setting a new standard for safety and reliability in mobile DC power distribution. Optional DC-to-AC inverter integration extends the system to serve AC loads and interconnect with the national grid, transforming the modular Envoltz platform into a grid-interactive distributed energy resource.

Designed, engineered, and manufactured in the United States, the DC Combiner Trailer reflects Envoltz's commitment to delivering robust, field-proven power solutions for the most demanding industrial, marine, and energy applications.

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Company

Envoltz has been producing mobile battery power solutions since 2015 for a variety of industrial and utility customers. Envoltz's core strength comes from its ability to provide development and deployment of custom electrical and mechanical solutions. Many Envoltz products, such as cable pullers and wireline units, are turnkey products. For special projects, Envoltz collaborates with other manufacturers to integrate Envoltz products into the customer's existing design.

Envoltz also integrates batteries and other components into independent or semi-independent power networks at the request of customers. This specialized approach promotes flexibility and modularity, with systems converting, storing, and supplying energy on demand. Envoltz staff can address the customer's most complicated power problems.

100% U.S. Workforce

The U.S. Department of Energy identifies growth of the power electronics industry within the U.S. and allied nations as a critical strategic goal. Envoltz supports this goal with a 100% domestic workforce.