IEEE PES CHICAGO SECTION MONTHLY MEETING

DC AS A SERVICE APPROACH TO HIGH POWER COMMERCIAL VEHICLE CHARGING SYSTEMS

ABB Presentation on MW Depot Charging

THEODORE BOHN
Principal Electrical Engineer
Argonne National Laboratory
tbohn@anl.gov, 630-816-7382

October 13th, 2021
12:00-1:00 CST; Web Meeting

This work is supported by DOE-Vehicle Technology Office, Lee Slezak program manager

MEETING AGENDA

- IEEE P2030.13 draft standard overview, includes ‘DC as a Service’, microgrids
- MW/Multi-port charging; emphasis on multi-port; many vehicles.
- Review of coupler standards/capabilities; from 3 kW to MW+ (1500v/3000A)
- Overview of applications- array of industries (trucks, boats, planes, mining…..)
- DC-as-a-Service business case (utility owned electronics/storage) selling DC directly to customers; specifically high power vehicle/aircraft charging
- Examples of medium voltage power converter products (solid state transformers)

IEEE P2030.13 DRAFT STANDARD

- *“Guide for Electric Transportation Fast Charging Station Management System Functional Specification”* Launched in 2020, monthly meetings- 2023 completion target. (https://standards.ieee.org/project/2030_13.html)

- Leverages P2030 series of P2030.8 on AC microgrids, P2030.10 on DC microgrids and P2030.11 on DERMS.

- Focus on AC and DC coupled systems with integrated storage/generation, including DC as a Service business model of utility owned electronics/controls

INL XENDEE POWER FLOW ANALYSIS EXAMPLE

https://xendee.com/2021/08/04/summary-report-the-microgrid-fast-charging-station-designer-platform/

Power Flow Analysis Results and Valuation

The INL team simulated and validated the power flow analyses conducted by XENDEE for the grid-connected use cases in the real-time digital simulator (RTDS®). The results match within 5%. The RTDS model for the UCSD Microgrid is presented in Figure 7.

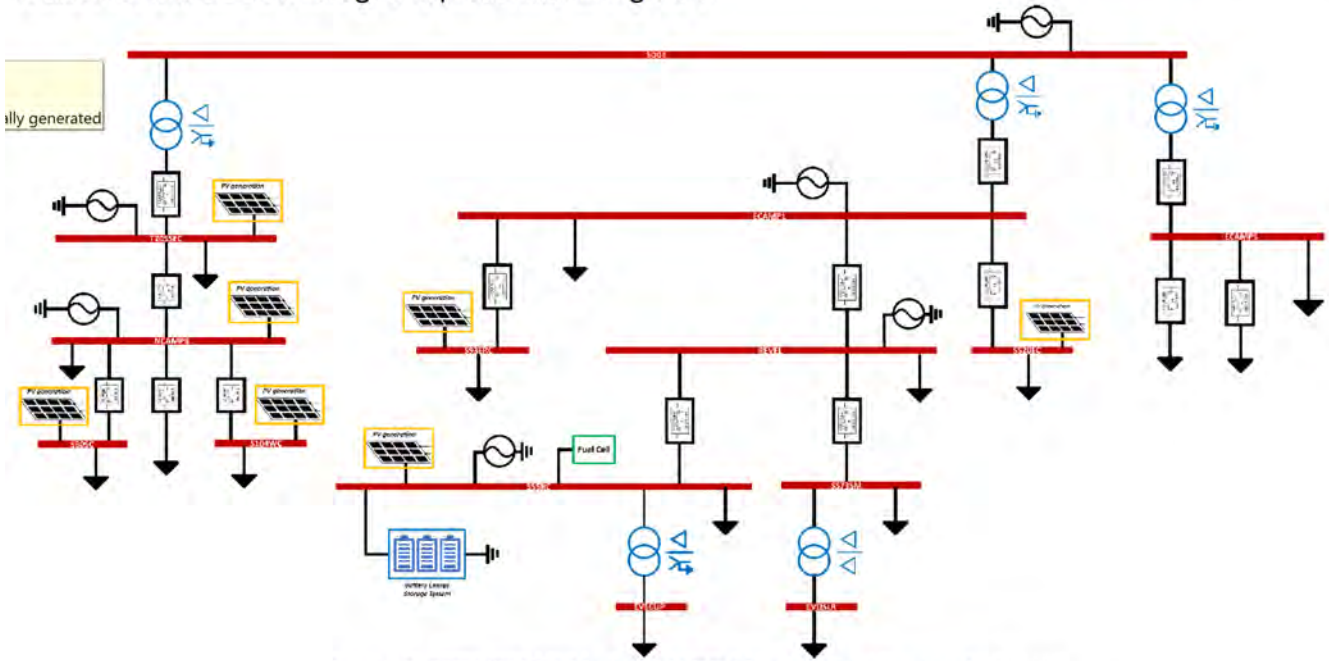


Figure 7: RTDS/RSCAD Model of UCSD Microgrid, grid connected case

CAPEX VS OPEX; COLOR OF PROJECT FUNDS MATTERS
RECENT EXAMPLES OF '…EVERYTHING AS A SERVICE'

- **DC as a Service (DCaaS):** Business model with utilities owning power conversion/storage equipment and controls; selling DC power directly onsite.

  - Charging as a Service (CaaS): Third party owns charging infrastructure and bills monthly for use of equipment and consumed energy/maintenance.

  - Energy as a Service (EaaS): Negotiated rates, bundled demand charges and energy services benefits, etc.

  - Vehicles as a Service (VaaS): Subscription fee based on vehicle usage

GM ULTIUM CHARGE 360 PARTNERS W/SCHNEIDER ECOSTRUXURE

- Schneider Electric brings an end-to-end EV infrastructure solution to GM Ultium Charge 360 fleet service offering fleet managers one-of-a-kind capabilities and benefits.https://www.se.com/us/en/about-us/newsroom/news/press-releases/schneider-electric-chosen-as-gm-preferred-provider-to-accelerate-us-fleet-customers-into-electric-vehicle-market-60f04ead3ecc8c16ac52bfd3

- Schneider Electric's new **EcoStruxure** for Automotive and Mobility solution, an offering specifically for fleet customers that will now be available through the **GM Ultium Charge 360 fleet service**, is an EV infrastructure solution providing utility rate negotiation and modeling, software integration, charging station agnostic solutions, and cybersecurity architecture.

- The service also provides end-point cloud integration connecting products, controls, software and services, and **Energy-as-a-Service design** and financial support for the infrastructure solution.

DOE FUNDED MW+ MULTI-PORT MD/HD VEHICLE CHARGING INDUSTRY STAKEHOLDER SUBGROUPS/WORK GROUPS (~500)

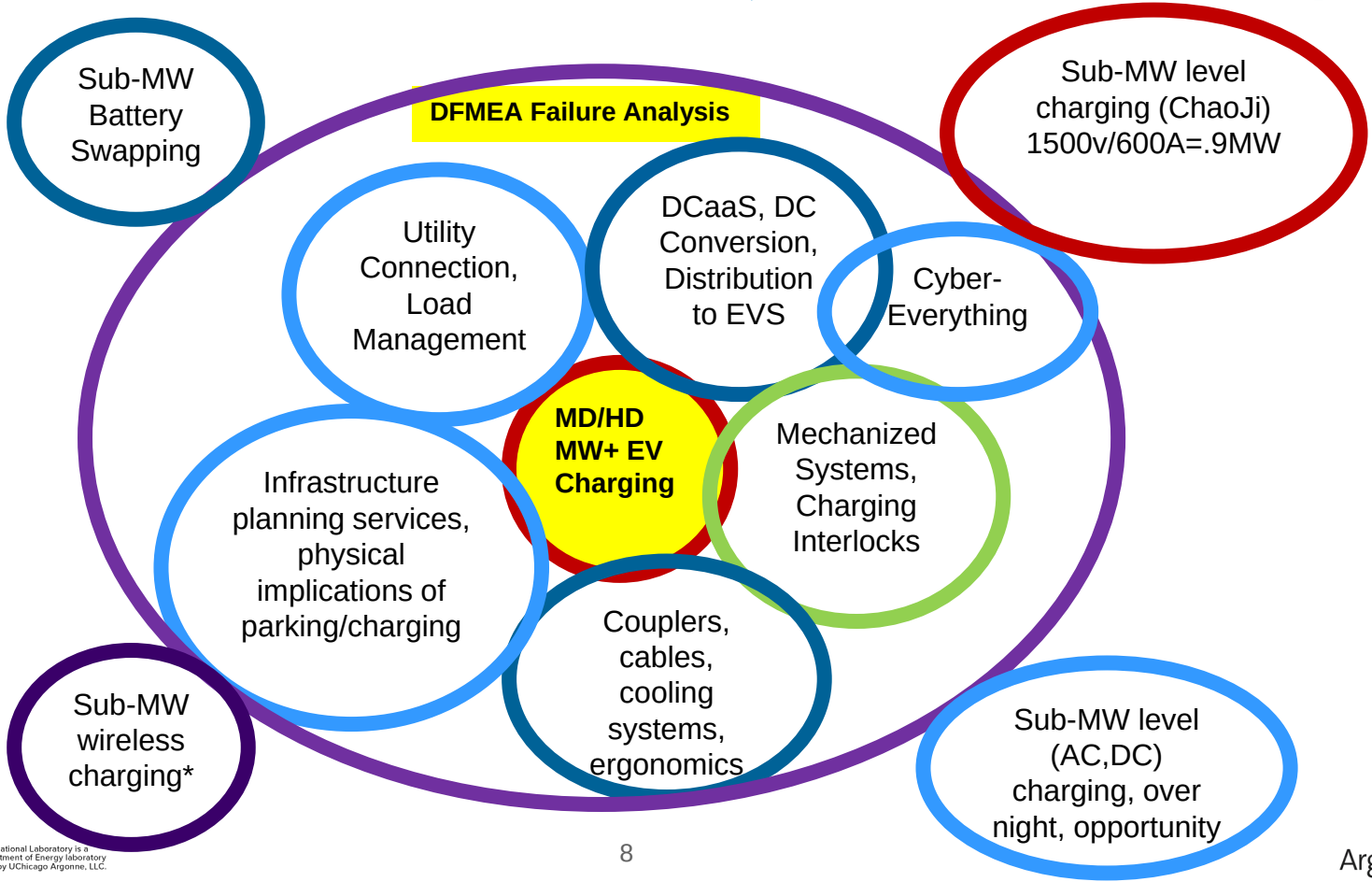
- **Year 1-** collect input for gap analysis report**; Year 2-** examine state of industry via case studies; **Year 3-** conduct component-system level interoperability/control testing on DCaaS testbed
- **Utilities(28), planning services(14), site operators (25)**
  Alliant, Black & Veatch, Burns & McDonnell, CTE, HDR Inc, AEP-Ohio, Duke Energy, EPRI, ITC Transmission, MG&E, PG&E, Seattle City Light, Southern Company, CTA-Chicago, Electrify America, EVgo, Tesla, Loves/Trillium, TA Petro

- **EVSE/power electronics (28), couplers/cable systems (11), ESS (9)**
  ABB, BTCPower, Chargepoint, Delta Products, Eaton, Efacec, Heliox, Siemens, PE Corp, Rhombus, Tritium, Marquette Univ., JMM Consulting, Huber-Suhner, ITT, Phoenix Contact, Power Hydrant, Rema, Schunk, Staubli, TE Connect, EVoke Systems, Indie Power Systems

- **Vehicle OEM/components (21), end users-customers (10)**
  Allison, Autocar Truck, BYD, Cummins, DTNA/Daimler, FCA, Ford, Gillig, MAN/VW Group, Navistar, New Flyer, Nova Bus, Orange EV, PACCAR/Peterbuilt, Proterra, Tesla, Xos, Transpower, Penske Leasing, Ruan Transportation, Zerology

- **DOE Funded Labs, coordinators, contractors, universities (36)**
  ANL, NREL, ORNL, PNNL, ThinkSmartGrid, EPRI, TSA-DHS, NHTSA, UL/kVA, NEMA

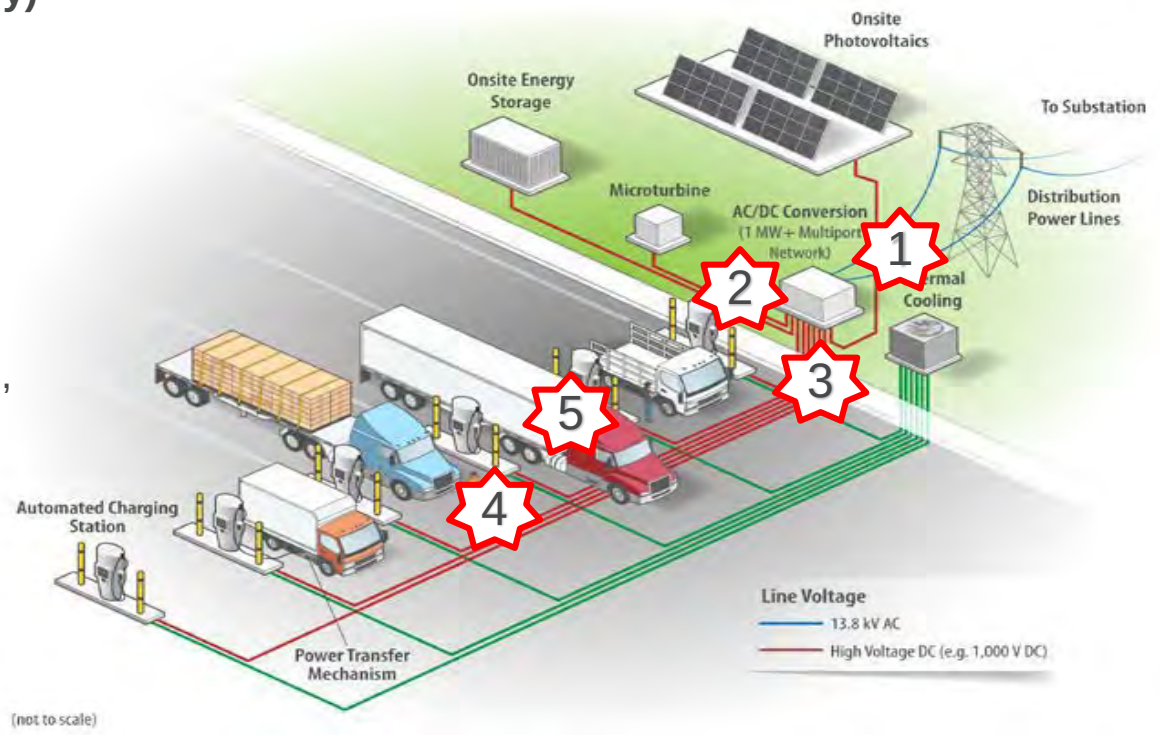
MD/HD ELECTRIC VEHICLE CHARGING (≥MW AND OTHER LEVELS)



MW+ MULTI-PORT EV CHARGING SYSTEM LABELED SEGMENTS LEADING TO DESCRIBING STATE-OF-READINESS/GAPS

From Source to Load (grid-to-battery)

1) Utility Interconnection
2) AC/DC Power Conversion
3) DC Distribution, w/DER Elements
4) DC Dispenser Electronics, Cables, Couplers, Micro-siting
5) Vehicle Inlet, Battery-BMS, Safety



BALANCING ACT; SCALING, FINANCING, EXPANDABILITY, INTEROPERABILITY

- This work group is focused on multi-port MD/HD electric bus and MD/HD truck charging source-to-destination (utility interconnection to battery terminal), up to 1MW or above
- More realistically multiple vehicles at a single location, addressing utility interconnection **pad mounted transformer 2.5MVA limitations.**
- At the 1MW-2.5MW level, ignoring losses this equates to simultaneous charging of

  - **1 to 2.5** charging ports at **1MW** each
  - **2 to 5** charging ports at **500kW** each
  - **10 to 25** charging ports at **100kW** each
  - **50 to 125** charging ports at **20kW** each

- One can do the math on oversubscription of 4-10x for sharing DC sources (10's at MW level to hundreds at the 100kW/20kW per port from one 480vac/2.5MW AC-DC conversion feed (**1500vdc*1666A=2.5MW** DCaaS DC bus distribution feed)

GRADIENT OF EV CHARGING COUPLERS WITH POWER LEVELS/VEHICLES

- **Light duty vehicles**, some school buses use **AC SAE J1772 Level 2** (208/240vac-80A) chargers; 30A/7kW nominal; 80A/**19.2kW max.**
- **Medium Duty (commercial) vehicles** can use **SAE J3068** AC; 3-phase; 63A/480v**(53kW)** **Advanced versions on J3068** can handle 120A/480v**(99kW)**, or **Tesla** at 160A**(120kW dc)** **Higher voltage SAE J3068-DC6** can push 320A(2x160A) **up to 1000vdc (600vdc today)**
- **Light-Medium Duty vehicles;** can use **J1772-CCS** 1000vdc/350A-500A **(up to 500kW)**
- **Medium/Heavy Duty bus** (port/drayage trucks) can use **SAE J3105 (/1, 2, 3) <600kW**
- **Medium/Heavy Duty trucks** can use CharIN **MCS;** under 1000vdc/1000A **(1MW)** today, potential for **1500v/3000A (4.5MW) in the future**

J1772->19.2kW

J3068->53kW-99kW(ac) 120kW-320kW (DC6)

J1772-CCS 350-500kW(DC)

J3105->600kW

CharIN-MCS 350kW-1.5MW

MW MULTIPORT ELECTRIC TRUCK-BUS CHARGING COUPLERS

- SAE-IEC Combination Charging System (CCS) DC couplers (w/liquid cooled cables) can deliver up to 1000v/500A (.5MW) today

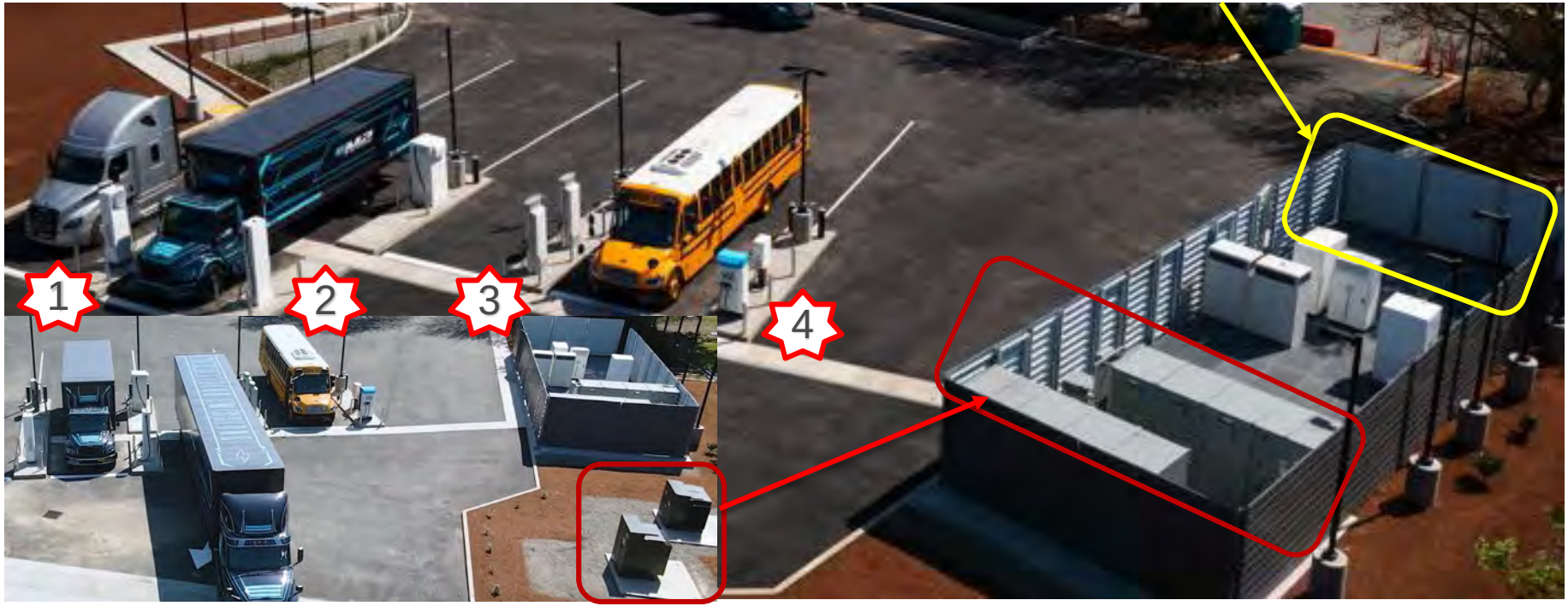
- The CharIN ‘Mega Charging System’ (MCS) coupler of 1500v(max)/3000A(max){4.5MW}; prototypes running at 3000A. PLC vs CAN comm testing. Schedule shows standard specifications set by end of 2021, public release Q1-2022? https://www.charin.global/technology/mcs/

- SAE J3105(-1, -2, -3) Overhead Pantograph; 600kW-MW+ mechanized couplers

				CharIN			Proposed
	GB/T	New GB/T	CHAdeMO	CCS1	CCS2	Tesla	MCS
							
Max Power	950V x 250A = 237.5 kW	1500V x 600A = 900 kW	1000V x 400A = 400 kW	1000V x 500A = 500 kW	1000V x 500A = 500 kW	410V x 610A = 250 kW	1500V x 2000A = 3 MW??
Range add /minute charge	1.5 miles	5.8 miles	2.6 miles	3.2 miles	3.2 miles	1.6 miles	19.2 miles
Communication Protocol	CAN (SAE J1939)	CAN (SAE J1939)	CAN (ISO 11898)	PLC (ISO 15118)	PLC (ISO 15118)	CAN (SAE J2411)	CAN or Ethernet (ISO 15118)
Location Used	China, India	China	Global	US	EU, South Korea, Australia	Global	US?, EU?
Related Standards	IEC 61851	IEC 61851	IEC 61851 IEEE 2030.1	IEC 61851 SAE J1772	IEC 61851	none	none
Notes	none	Liquid Cooled under development in development	Liquid Cooled under development	Liquid Cooled	Liquid Cooled	Liquid Cooled	Liquid Cooled

ELECTRIC ISLAND CHARGING PLAZA; PORTLAND (DTNA, PGE)

5MW (2x2.5MW transformers), reconfigurable gutters/covers, 4 charging islands {left to right} (ABB, BTCP, Chargepoint, Power Electronics SA/Proterra), Phase 2: MCS/MW EVSE, V2G capabilities and peak shaving energy storage



PRACTICAL EXAMPLES OF SITE PLANNING: ONTARIO CALIFORNIA

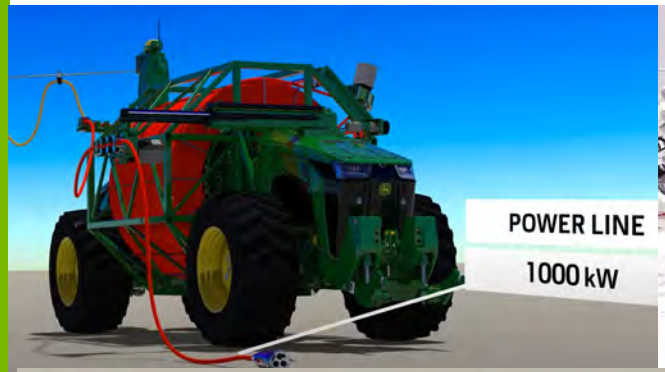
TA Petro Ontario California truck stop ~600 parking spots (on left); again as many on right. Electrifying up to 1200 parking/charging spots is both an opportunity and a challenge

TRU ELECTRIFICATION TIMELINE (2023, 2026), EXAMPLES

- Mandate is nearly set for California eTRU anti-idle compliance
  - January 2023, all new trailers will have electric anti-idle capability (eTRU)
  - January 2027 **ALL TRUs in California** (in state/transit) need retrofit eTRUs
- Smart Charging to leverage flexibility on powering more TRUs managing peak vs average; up to facility limit; safety disconnect and immobilization features

JOHN DEERE TETHERED AUTONOMOUS SWARM TRACTOR(S) (1MW, 8KV 3KM)

- Prototype showing future of electrified agriculture- 1MW today, tethered to swarm
- Future could be more 500kW battery powered tractors….MCS automated connectors?
  https://www.youtube.com/watch?v=fzl3wkkKtoA



CROSS OVER OF CHARGING SOLUTIONS TO OTHER AREAS

- *The gradient of conductive and wireless charging standards cover small-medium-large/heavy on road vehicles; aviation, mining, agriculture, marine, construction….*
- *Interoperability of components and systems create economies of scale, especially for wireless and conductive couplers used in multiple industry segments. Standards for each application covered by separate organizations.*

26 CCS Inlets on a Bangkok ferry

Construction/arborist platform- fits on sidewalk, 60' reach

BANGKOK FERRY CHARGING EXAMPLE (26 CCS PORTS)

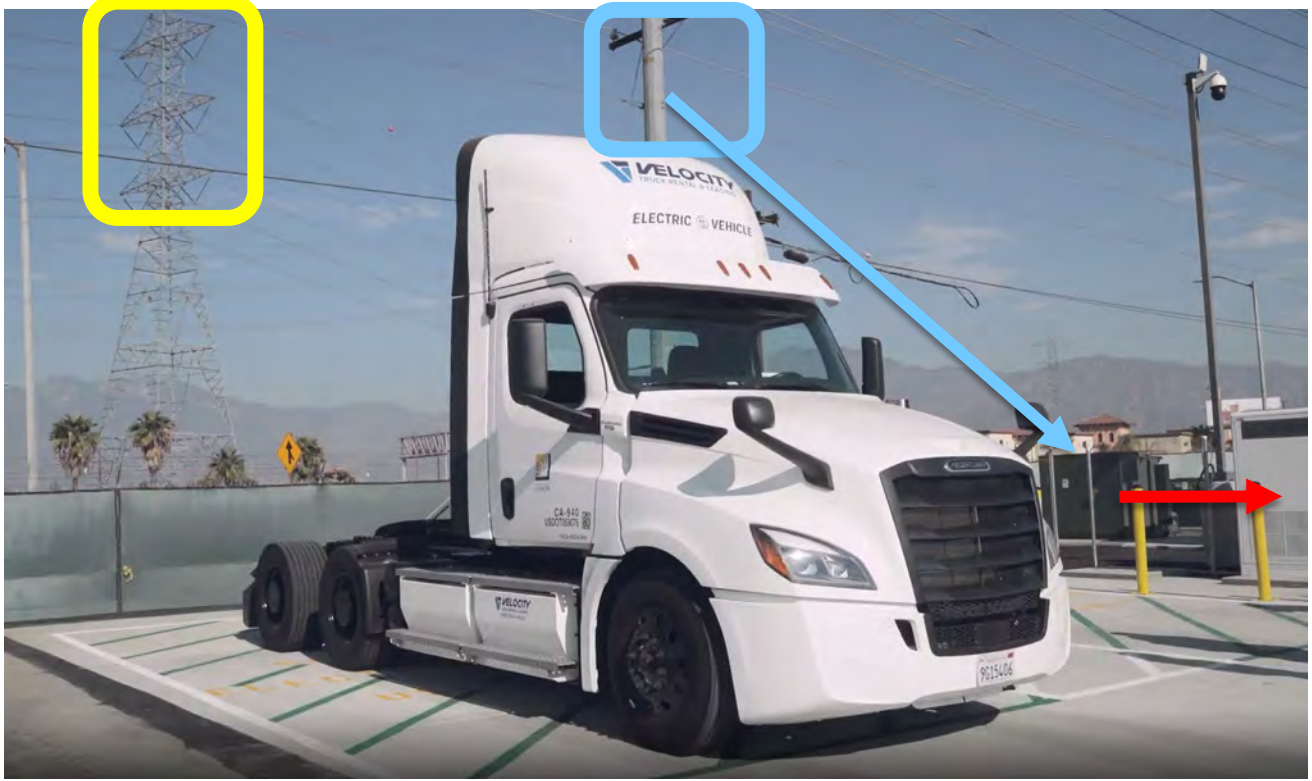
- 800kWhr battery, 235 passengers, 15-20 minute recharge=3C-4C or 2.4MW-3.2MW; **3MW/26=115kW per port**
  https://insideevs.com/news/466633/electric-ferry-26-plugs-dc-fast-charging/

BANGKOK FERRY CHARGING EXAMPLE (26 CCS PORTS)

- *Floating Dock with 14 dual output EVSEs (cord handling/storage not evident, tools on right?) Suspect photo is not of full installation, just placed components. 4000A power feed?*

REPRESENTATIVE TRANSIMISSION-DISTRIBUTION-LV PATH

- Photos of the ABB/SCE-Irwindale CA, showing **transmission(HV)**, **distribution(MV)**, **charger(LV)**, DC
  https://energized.edison.com/stories/sce-celebrates-arrival-of-new-electric-big-rig



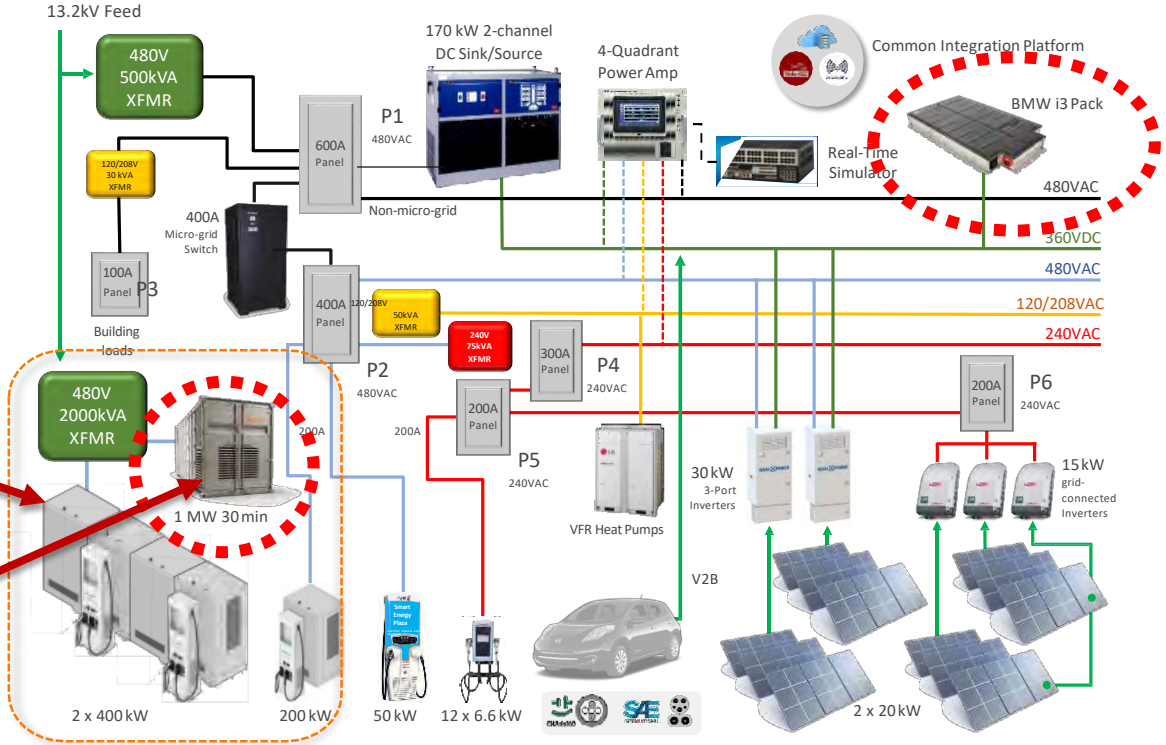
CLASS 8 TRUCK EV CHARGING LOW VOLTAGE-DC PATHWAYS

ANL SMART CHARGING PLAZA; AC AND DC COUPLER STORAGE, MW CHARGE

Mitigating the impacts of high-power charging with energy storage

1+MW Total DC EVSEs (2x400kW+1x200kW +50kW..)

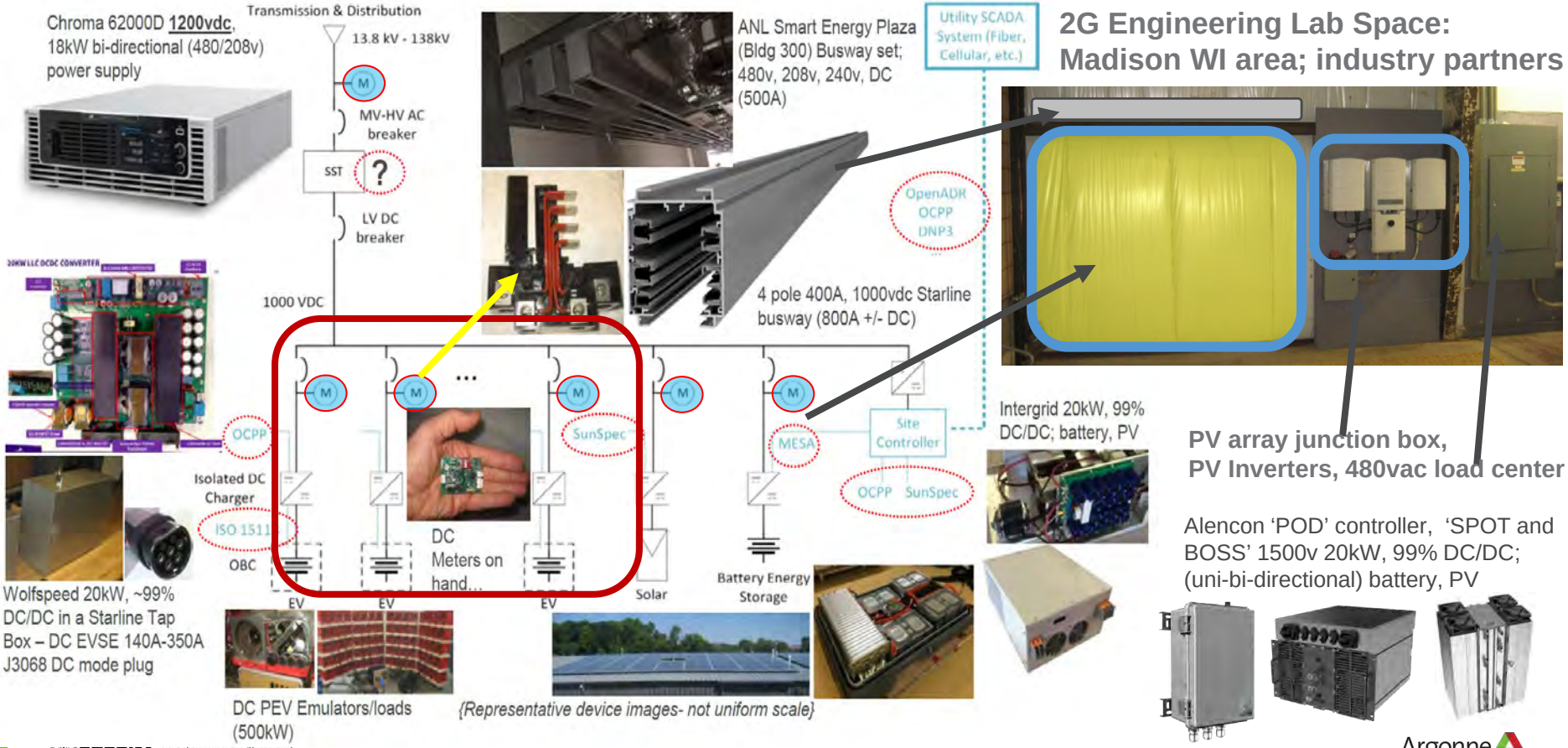
- 2667kVA transformer and switchgear
- 1 MW/500kWhr AC coupled Y-Cube storage
- 33kWhr DC coupled BMW i3 pack on DC busway



ANL AC COUPLED MW (COMBINED) DC CHARGING/BATTERY

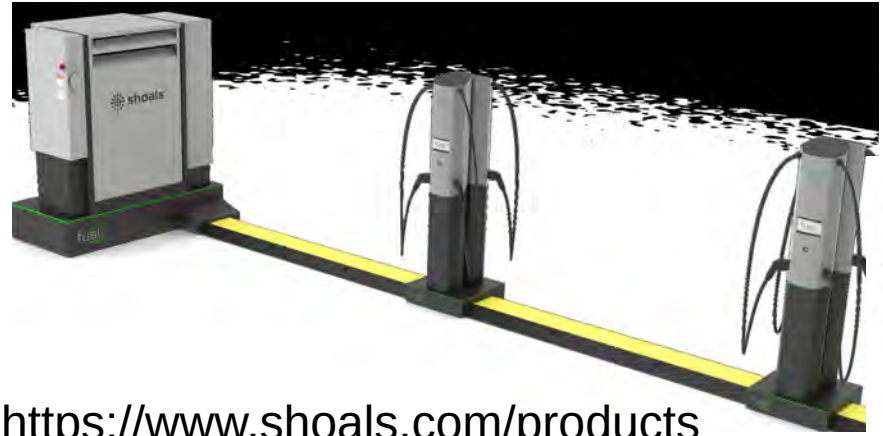
- 5x 200kW power conversion cabinets, 3x 500A dispensers (1500A/1MW total)
- Aggreko 1 MW 480vac coupled storage system, 80kW on PV canopy
- Dedicated metering (Schneider SCADA) on each branch/device

ANL DC AS A SERVICE TESTBED; METER LOCATIONS, TRANSACTIONS

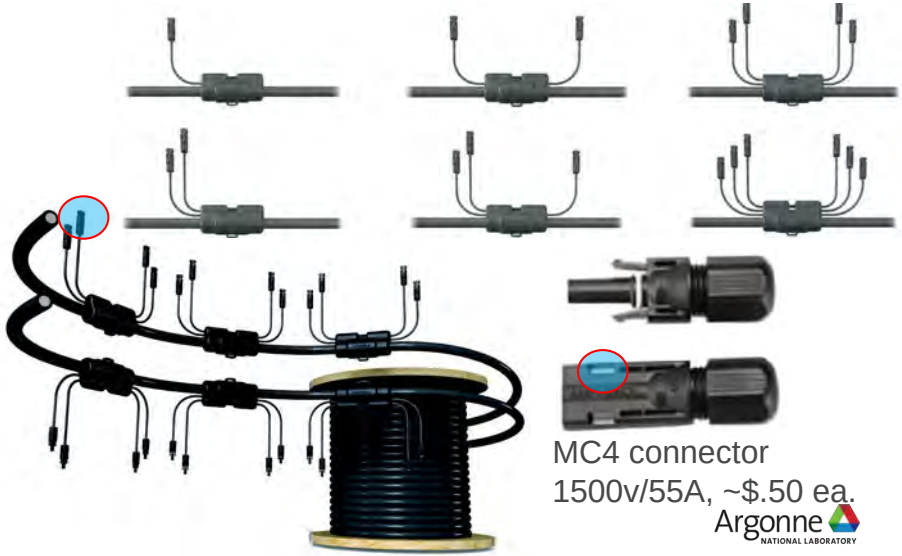


COMMERCIALLY AVAILABLE 1MW DC DISTRIBUTION EXAMPLES-SHOALS

- Shoals ‘Big Lead Assembly’ (BLA) method for attaching awg#8 taps to 600MCM aluminum trunk wire at MW levels (1500vdc/666A) in PV systems (75kW taps)
  https://pv-magazine-usa.com/2021/05/04/shoals-reports-12-revenue-growth-plots-to-accelerate-its-ev-charging-strategy/
- Now applied to EV charging systems (out vs in), with MC4 tap at each charging kiosk (DC/DC converter-cables-contactors-controls). Plug and play solution.
- NRTL listed (which applications?); pre-terminated assembly rolls out, fast install
- MC4 connector location for a sealed meter? (instead of socket meter)



https://www.shoals.com/products

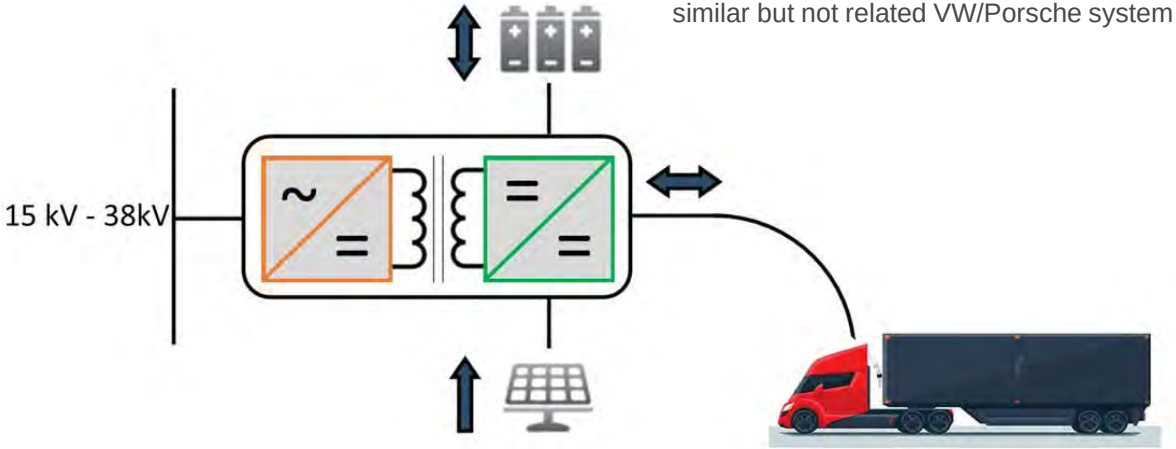


MC4 connector
1500v/55A, ~$.50 ea.

RESILIENT POWER SYSTEMS; MW LEVEL TRAILER CHARGING/STORAGE

- **Containerized EV Supercharging Stations;** Up to 20 DC fast chargers in a single container that eliminates grid upgrades and reduces space, on-site labor, permitting, and engineering costs by over 90%. **6x 500kW charging outputs**; https://www.resilientpowersystems.com/xfc-500.html;
- **Continuous local and remote control**DC to 1000Hz power systems
- Fast response (>10kHz)
- OCPP control
- SEL RTAC Interface
- EtherCat, Modbus, Ethernet, DNP3 Serial, IEC (
- **Operating Modes**Port power control (each DC
- VAR compensation
- Power Factor regulation
- Voltage regulation
- Active Filtering
- Fault Support
- Peak Shaving
- Geomagnetic Induced Current mitigation

similar but not related VW/Porsche system



ELECTRIC ERA STORAGE (SEATTLE) PARTNERS W/TRITIUM; 1500VDC

- https://www.electriceratechnologies.com/ 14,000lbs, DC link to Tritium Chargers

PERFORMANCE SPECIFICATIONS

BEGINNING OF LIFE

AC Connection	480 VAC - 3 Phase - 60 Hz
Maximum AC Output Current	775 Amps
Usable Energy	303 kWh
Continuous Discharge Power	625kW @ 480V
Average Charge Power	300 kW
Maximum Battery Voltage	1489 VDC
Round Trip Efficiency	88.00%
Nominal Lifetime	10 Years + 10,000 Cycles
Overcurrent Protection Device	800A AC Fuse
Depth of Discharge	100%

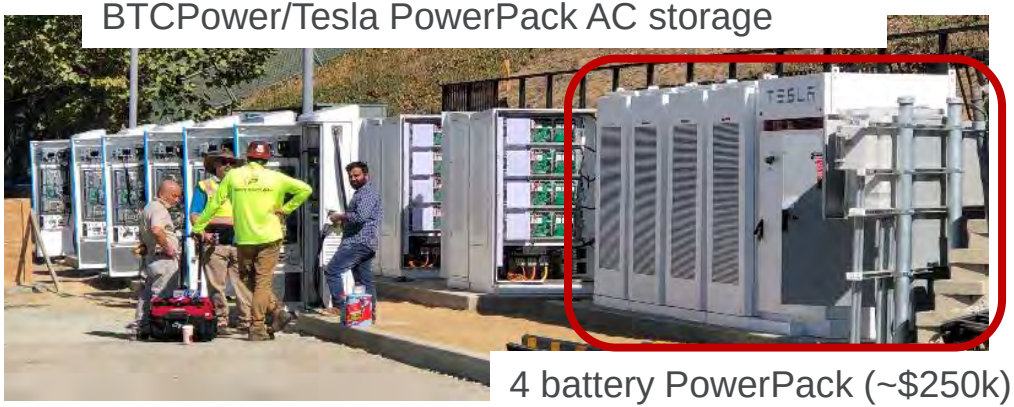
MEASUREMENT SYSTEMS FOR MD/HD EV CHARGING; W/STORAGE

- Examples below of battery storage system coupled at 480vac panel for peak shaving/demand management. (Siemens, BTCP w/Tesla-Fluence storage) These are not integrated systems; only co-located, point of common coupling.

- **DC Coupled Storage:** Could use ANSI C12.32 meters and matching voltage-current transducers (TBD standard…) for DC delivered power/energy including separate measurement from local generation, grid tied converter (both ways)

Siemens/Fluence-Penske, Ontario CA

BTCPower/Tesla PowerPack AC storage



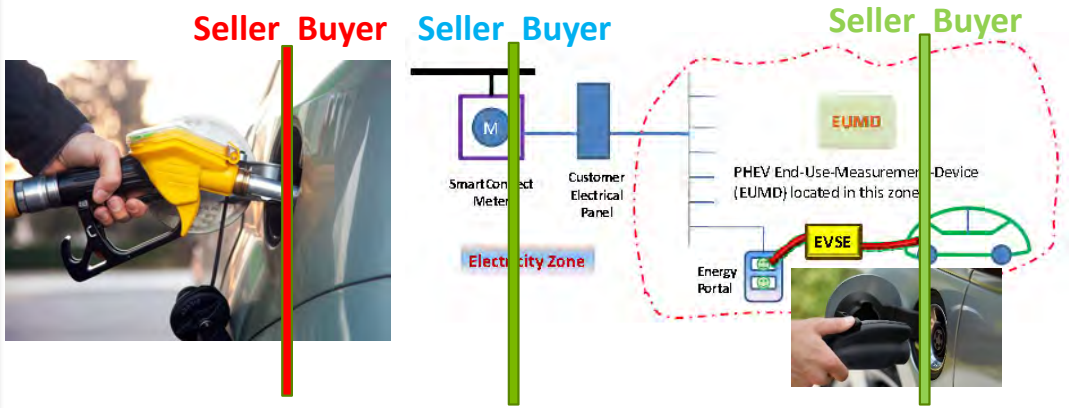
4 battery PowerPack (~$250k)

NIST Handbook 44-3.40 Measurement Requirements for Commercial Dispensing of Electricity as a Fuel

Weights and Measures Enforcement at State Level (not federal level)

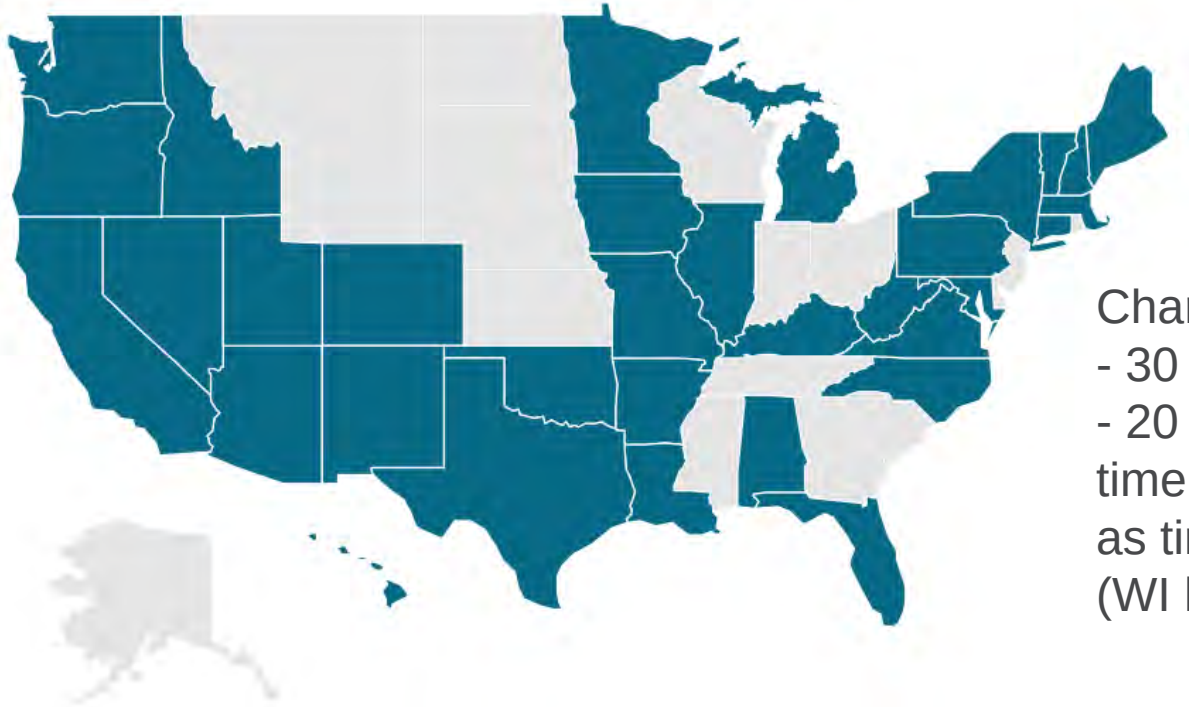
Line of demarcation for the point of sale of electricity for EV charging is at the tip of the charging cable (like liquid fueling), not at the feed circuit, as is the case for utility service

- NIST HB44-3.40 was released in 2016, adopted by most states, enforced only in California as of January 2021
- Type approval certification of 'system level' dispensed energy accuracy and billing information is required for **ALL** commercial EV charging stations before deployment
- Only three manufacturers have type approved (AC) stations as of May 2021 (Evercharge, ChargePoint, BTCPower)



Comparison of the line of demarcation at the point-of-sale for liquid fuels, utility distribution of electricity and commercial dispensing of electricity as a fuel (at the edge of the vehicle).

STATES THAT ALLOW NON-UTILITY ELECTRICAL ENERGY SALES



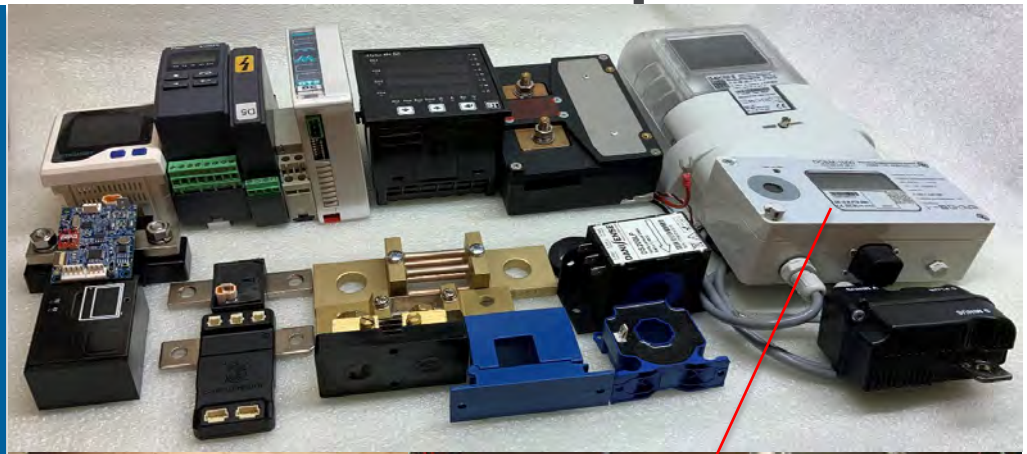
Charging Electric Vehicles:
- 30 of 50 say OK
- 20 are undecided; limited to time based sales, changing as time moves on/evolution (WI has a compromise)

Source: Chargepoint, North Carolina Clean Energy Technology Center

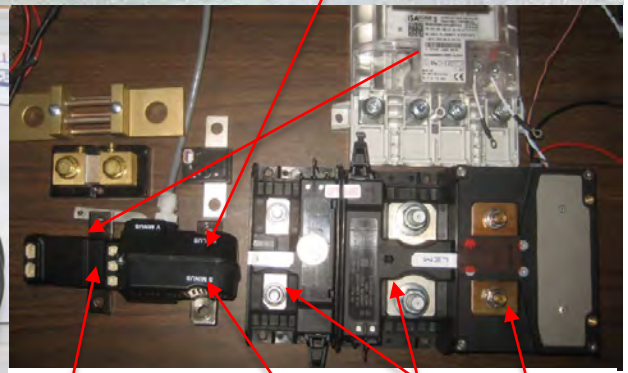
Concerns About Lack of Adequate EVSE-Ready DC Meter Solutions that Meet HB44-3.40 Requirements

Industry request letter for independent third party benchmark study of rated DC meters along with cable loss errors.

- ANL researchers completed the benchmark study with input and assistance from DC meter manufacturers; top 10 models tested.
- Selection criteria based on present CCS-Tesla voltage and current levels (350A-500A, 1000v) with HB44-3.40 tolerance of +/- 1% error at the end of the charging cable (w/cable loss)
- Voltage and current transducer errors are combined with meter errors and voltage-drop errors of output cable. Photos on this slide show styles of sensors; conventional shunt, isolated shunt, Hall and fluxgate types.



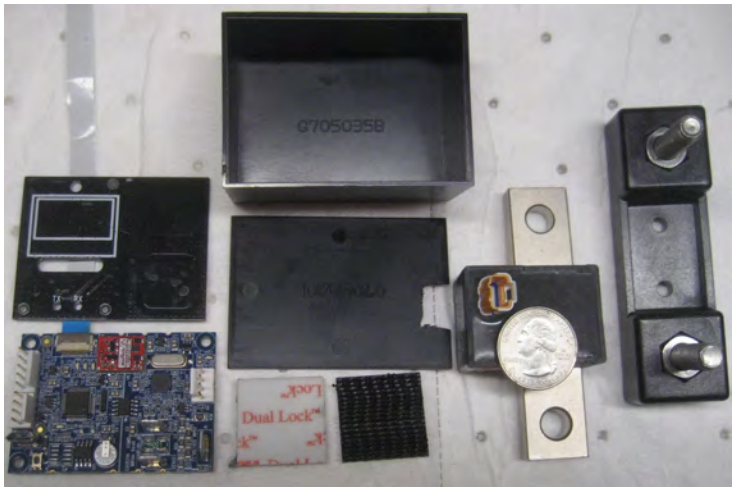
LEM DCBM ~1000 Euro



IVT sensor, Porsche, LEM, Tritium

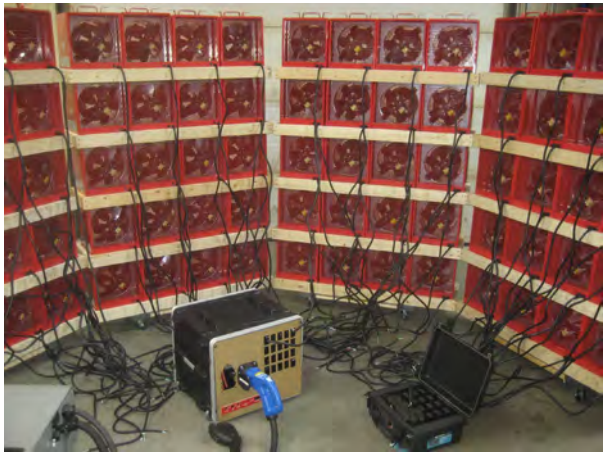
ANL DC METER SIZE, INTEGRATED SENSORS

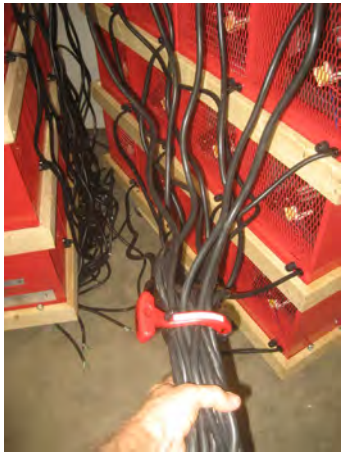
- 40mm x 60mm single sided board, 4500v isolation, 1200vdc input, mounted on ~ $50 500A isolated shunt (4 pin meter connector matches 4 pin shunt connector)
- PB1559 potbox and lid (2” x 3” x 1.5”-$1) used to mount meter over shunt, mounted with duolock pads, seal applied to cover; voltage sense lead, data out
- OLED display, monitor pilot/state EVSE directly; meter powers shunt; <1W, 5vdc



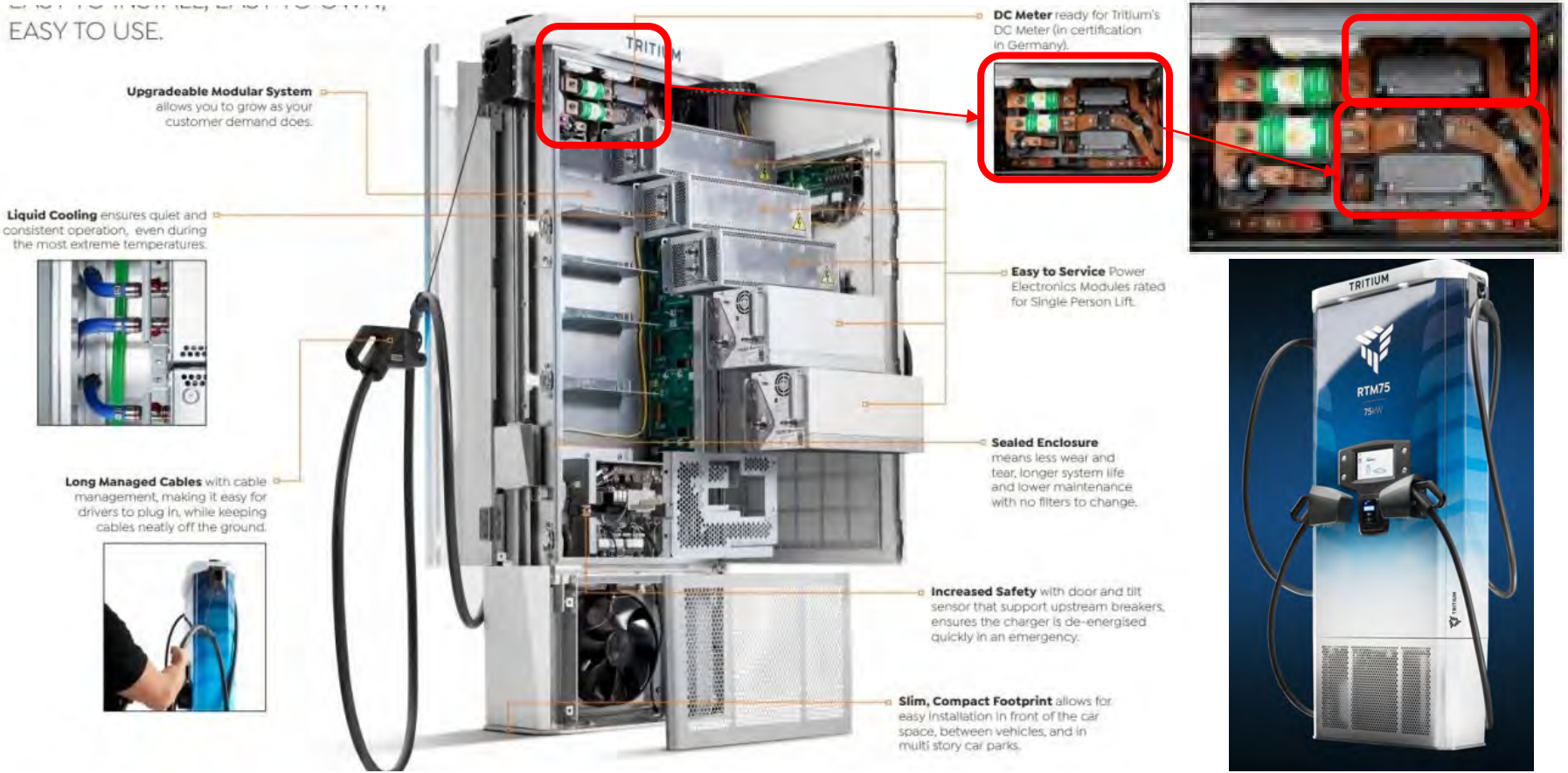
FULL POWER TEST LOAD OPTIONS; BUILD-BUY

- ANL built and uses the SmartLoadDAQ© transportable EVSE test system, based on 6kW NRTL listed 12”x10”x10” air cooled loads in series/parallel; 80 total for 480kW/1000v/480A, 960A at 500v, 1920A at 250v in 20 load steps, closed loop
- The system is van transportable, moved on carts and setup by one person, no forklift; UPS shippable. A mock setup is shown at an Electrify America station. 12vdc/240vac inverter used for cooling fan power to 80 loads in field.



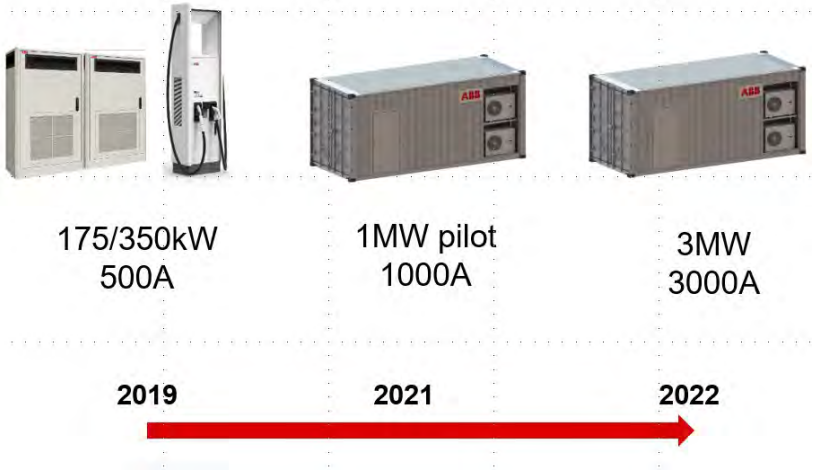


TRITIUM RTM75; 25KW POWER MODULE BASED DC EVSE; 2*METER LOCATION



CURRENT EVENTS; ABB TERRA360 CHARGER; CONFIGURABLE MODULES

- ABB latest product, 4x outputs one station https://new.abb.com/ev-charging/terra-360
- Configurable from 120kW-360kW
- Other ABB presentations show DC coupled groups of stations, up to 3000A output



EVOLUTION OF THE EV CHARGING SITE

"Advanced energy services"

Weather Forecast

Predictive load profiles

Fleet schedules

Energy trading

Bi-directional inc. V2G

"Charging site"

"Site energy optimization"

"Peak shaving"
One-direction

EVSS fuse"

"Don't blow the

Charger Charger Charger Charger Charger

BESS Solar Wind Buildings Substation

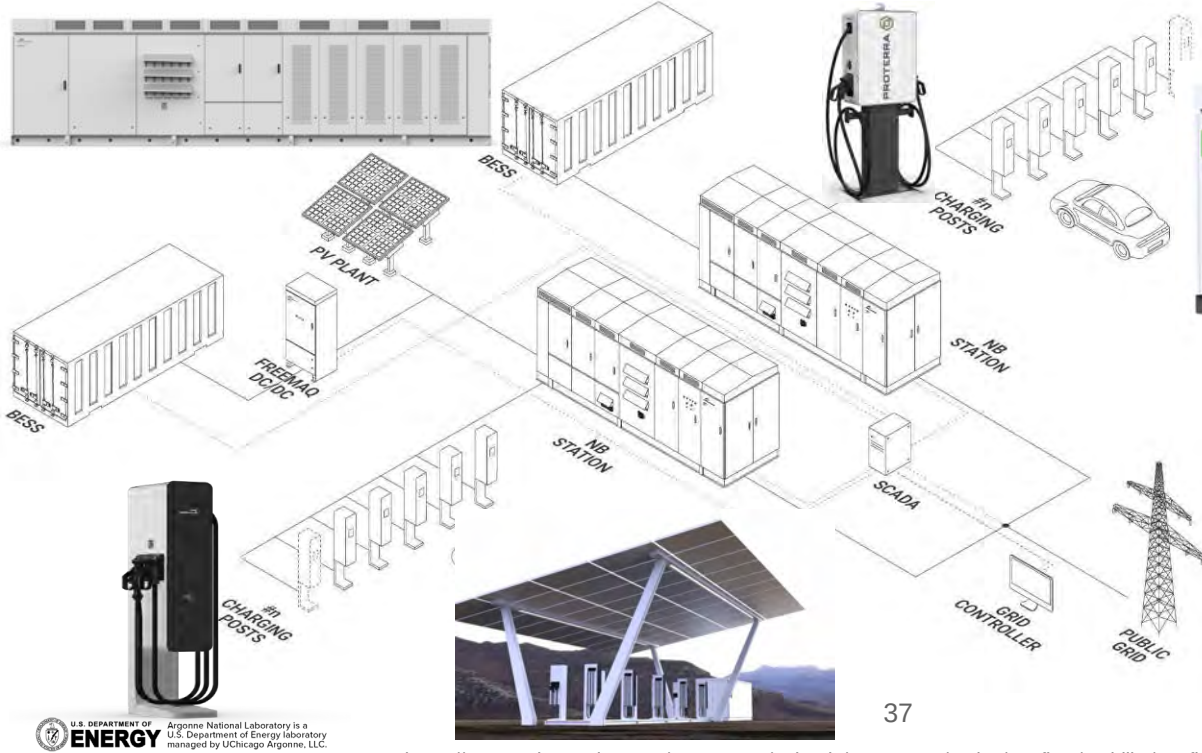
"Mission critical"

20 MW

Johann Peeters; ABB, ICNC21 Slide

DC COUPLED PV-STORAGE W/SCADA POWER ELECTRONICS SA NB1400

NBSHV1400S at 1.5MW (1000vdc/1400A), 4x600kW pantographs; 6x 350kW CCS1, up to 20 total ports 40 sequential; Solar + storage coupled to the 1.4MW charging station skid, including the MV switchgear.
https://www.proterra.com/press-release/proterra-chargers-enable-fleet-electrification/



https://power-electronics.com/wp-content/uploads/Descargas/Ingles/Leaflets/Mobility/Leaflet_Nube_station.pdf

LOW VOLTAGE 480VAC-DC CONVERSION TODAY VS FUTURE SST SOLUTION

http://siconelectric.com/2-2-ev-charger-module.html

Sicon 'commodity' EV Charging power module example (cost vs performance); 480vac input, 1000vdc output; 15kW/30kW each, stacked in EVSE chassis (up to 360kW; 18 modules shown here); DC dispenser post; 15kW module 9kg-230*500*88mm; 30kW module 15kg-230*502*132mm

Uses interlaced series resonance soft switch technology to reduce the tolerance of power devices.

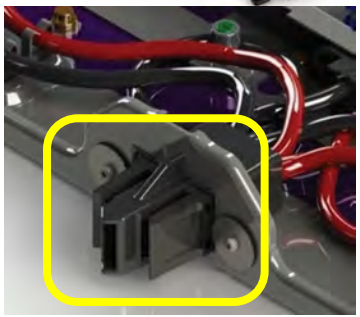
Point of consideration: Cost/density of existing 'commodity power supply' vs SST

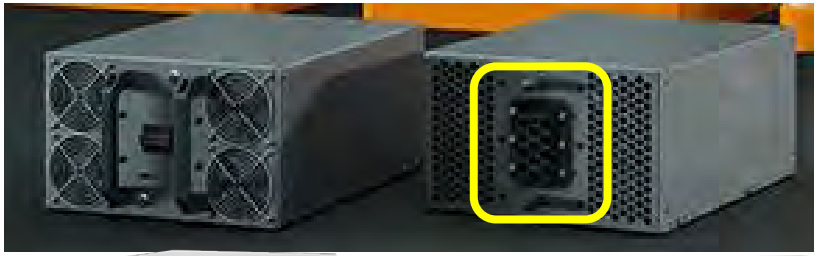
480VAC-DC CONVERSION ROOM FOR CONNECTION STANDARD?

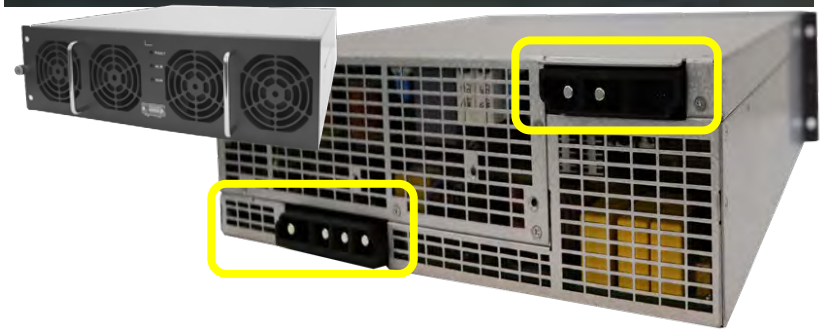
https://www.infypower.com/30kw-1000v-ev-charger-module-reg1k0100g.html
https://kempower.com/charging-solutions/products/s-series-charging-system/

Infy Power, Kempower power modules for EV charging; 30kW, 50kW per chassis
480vac input, 1000vdc output; blind mate power in-out connectors on the rear.

Point of Consideration: Is it time for a blind mate standard for connectors/mounting?

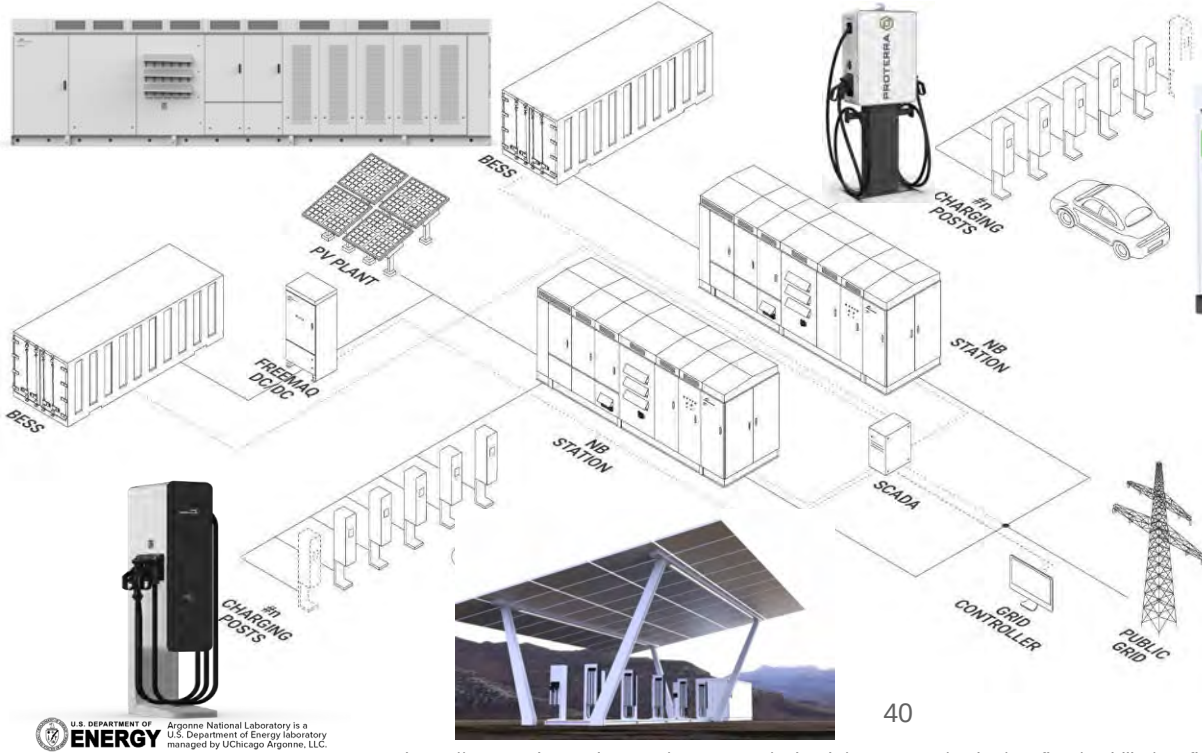






DC AS A SERVICE/INTEGRATED PV-STORAGE W/SCADA POWER ELECTRONICS SA NB1400: {1.5MW, 500KW PORTS}

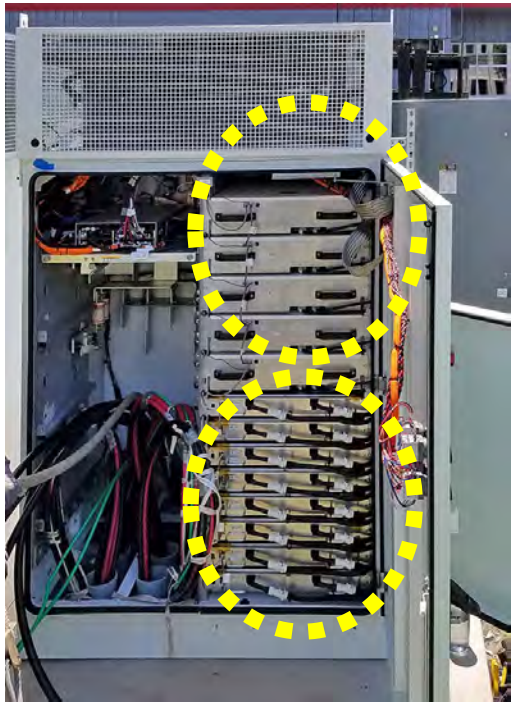
NBSHV1400S at 1.5MW (1000vdc/1400A), 4x600kW pantographs; 6x 350kW CCS1, up to 20 total ports 40 sequential; Solar + storage coupled to the 1.4MW charging station skid, including the MV switchgear.
https://www.proterra.com/press-release/proterra-chargers-enable-fleet-electrification/

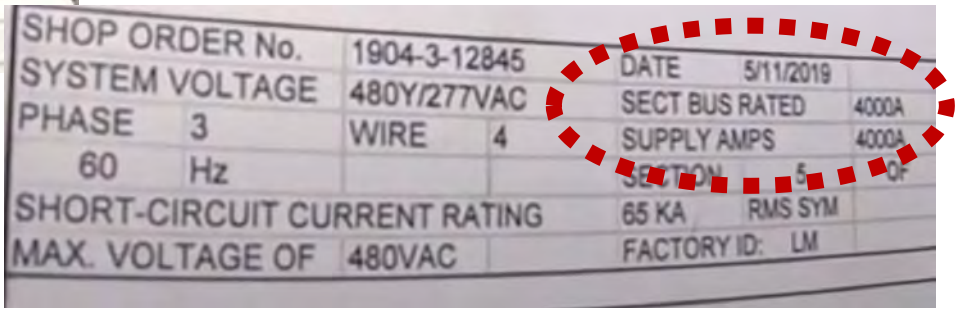


https://power-electronics.com/wp-content/uploads/Descargas/Ingles/Leaflets/Mobility/Leaflet_Nube_station.pdf

MW+ MULTIPORT CHARGING INTERCONNECTION LOW-MEDIUM VOLTAGE POWER-CURRENT REQUIREMENTS

- **SuperCharger V3:** based on Tesla MegaPack/PowerPack energy storage utility electronics
- 1MW per Cabinet; 4x 250kW dispensers per cabinet; 6 cabinets (6MW), 24 stall in Vegas
- Only 2500kVA transformer; 4000A Panelboard (4000a/6=666A each) 2.5W/24=~100kW ea





TESLA SUPERCHARGER V3- NAMEPLATE RATINGS 350KW+575KW=925KW

https://youtu.be/5FWlFdLwV94?t=245

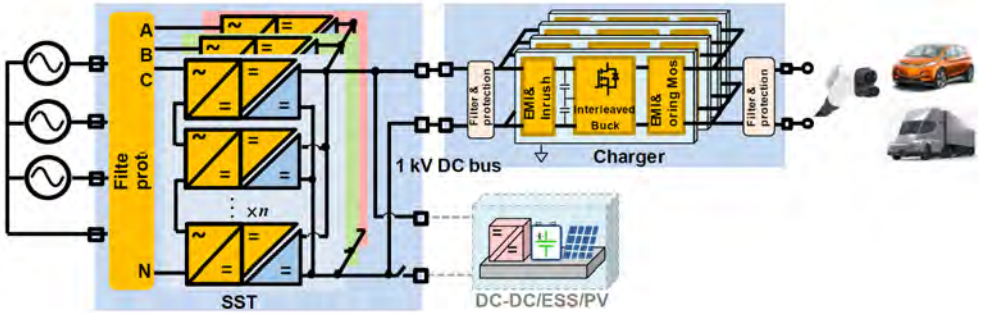
Nameplate ratings: ***Input*** *480vac/430A (350kW, 5*70kVA modules)*
DC In/Out(shared)*: 575kW (880v-1000v, 640Adc);* ***Port DC:*** *250kW, 500v*631A*

DELTA ELECTRONICS DCAAS XFC-SST ARCHITECTURE

- Medium voltage converters on each phase leg; interleaved output converter(s)
  https://www.energy.gov/sites/prod/files/2020/06/f75/elt241_zhu_2020_o_4.27.20_642PM_LT.pdf

Motor Control Center (MCC) panel

Someday?

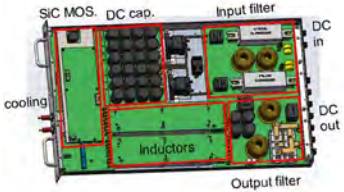


3-Φ MVAC input:
- 4.8kV/13.2kV
- iTHD<5%, PF≥0.98
- 60Hz±10%

SST DC output:
- 1050V±3%
- 400kW power
- Interface for ESS/PV

Charger output:
- 200V~1000VDC
- 400A max current
- SAE J1772 charging interface CCS1

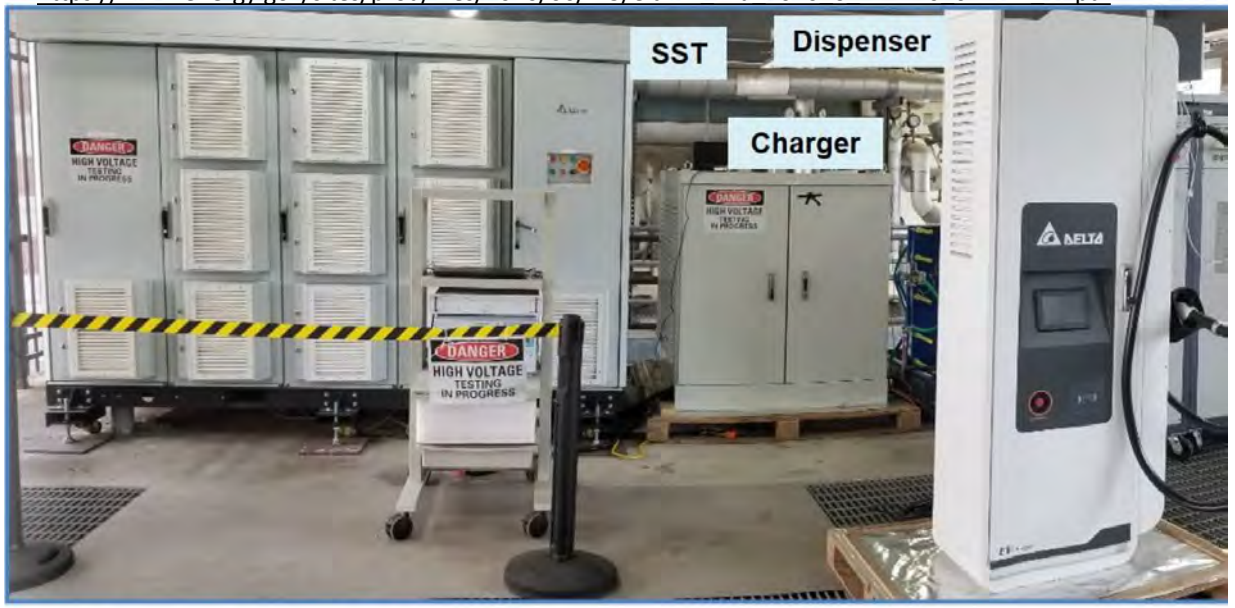
- Size:33.4”x7.8”x7.8”
- Weight: 51 lb



- Size:16.5”x3.1”x30”
- Weight: 79 lb
- Power density: 77W/in³

DELTA ELECTRONICS DCAAS XFC-SST ARCHITECTURE- AMR2021

- Medium voltage converters on each phase leg; interleaved output converter(s)
  https://www.energy.gov/sites/prod/files/2020/06/f75/elt241_zhu_2020_o_4.27.20_642PM_LT.pdf



Test with battery emulator
- Input 13.2kVac,
- Output 200V-990V, up to 500A;
- Full range up to 400kW

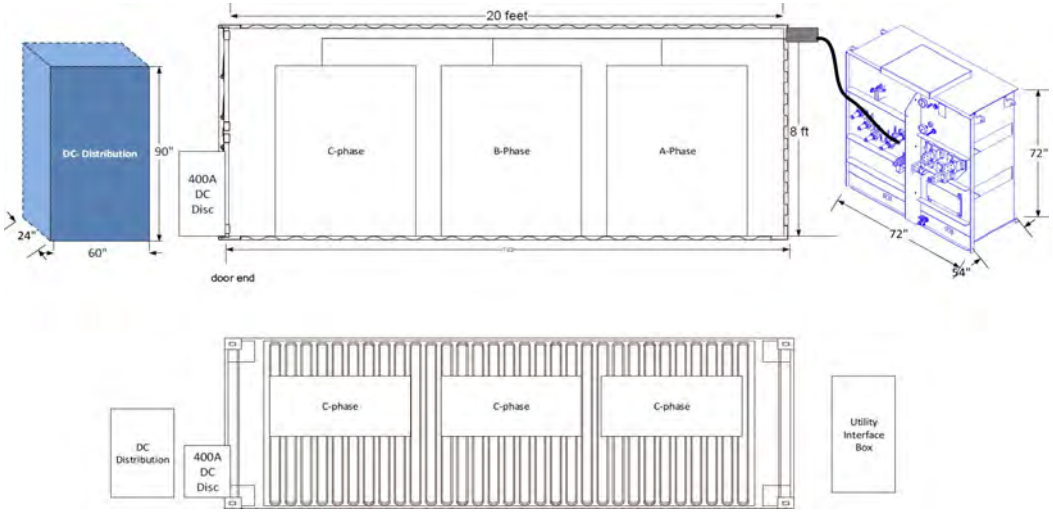
DOE-FOA1919 DCAAS MW CHARGING PROJECT, SST BASED DESIGN

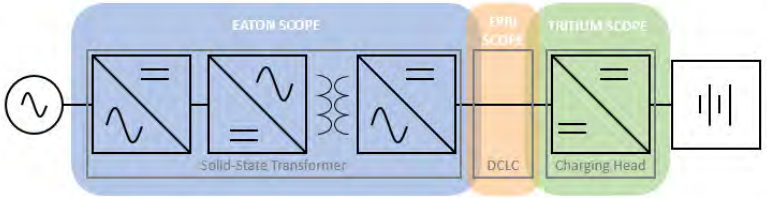
https://assets.ctfassets.net/ucu418cgcnau/1P1nWb9gNfeq8XFz1unE97/d5757037d67da55fa2100f33169e89da/D1-2_3_Simpson_Collins_201118_-_IWC_XFC_DCaaS.pdf

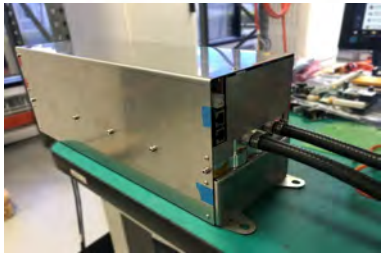
EPRI Prime Contractor; Eaton, Tritium, ANL, NREL sub-recipients

DOE Funded multi-year project with Eaton producing medium voltage-DC (SST) electronics and DC distribution system switchgear, Tritium producing 25kW output dispenser electronics blocks, up to 350kW per dispenser (14x blocks), 1MW total DC power

System level testing at NREL/ESIF in 2021, demonstration sites in ~2022/2023







EPRI SST PROJECT; TARGET DESIGN & SYSTEM LEVEL CAPABILITIES

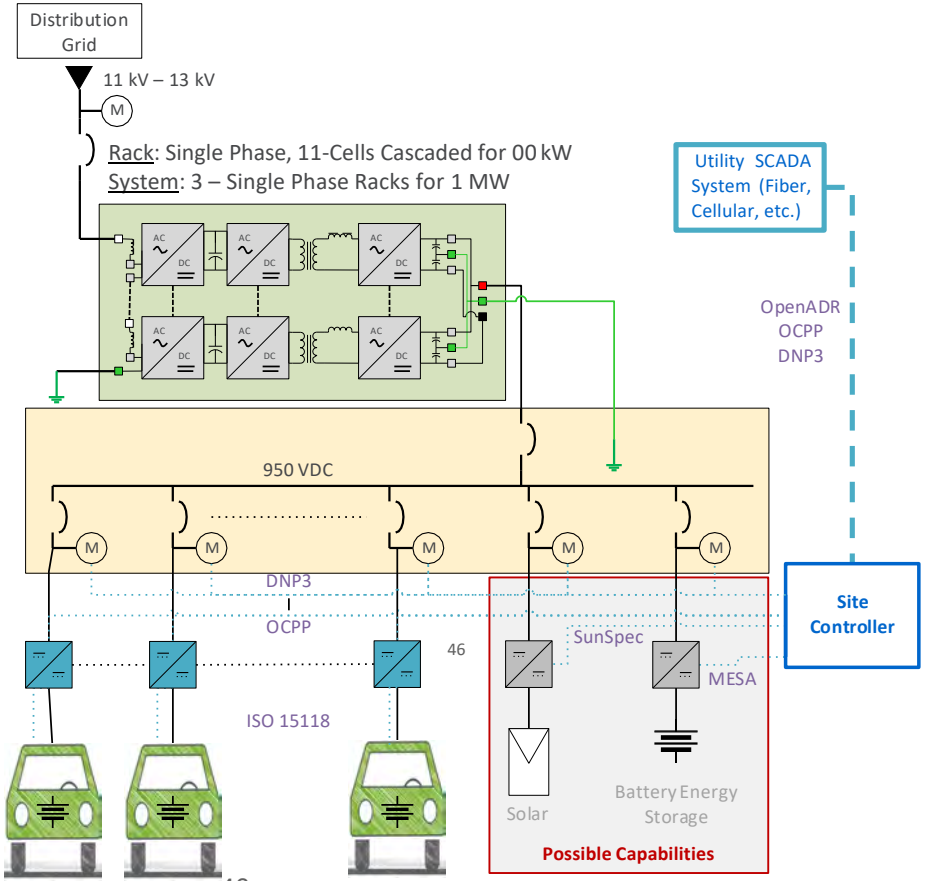
Core Components of Project

Medium Voltage Converter
(Solid State Transformer)

DC Load Center
(~1000 VDC)

Head-End Units
(Isolated 350kW)

Testing with XFC Capable Vehicles
(Light-Duty and/or Medium/Heavy Duty)



GRID-EMOTION™ CHARGING POINTS AND SYSTEMS, CONTAINERIZED CHARGERS AND DIGITAL SOLUTIONS

Containerized charger and substation

Your solution for fast energization

- Up to 500kW power
- Grid-forming power converter
- Battery racks and battery management system
- Designed for grid integration of EV charging infrastructure depots and terminals
- For power requirement up to 500kW and energy storage of 670kWh
- Remote monitoring and control system
- Standardised enclosure for fast delivery at site

- Prefabricated walk-in, modular outdoor enclosure
- Thermally insulated for increased equipment lifetime
- Robust and light weight design
- Wide range of ratings & capacities as well as layouts in steel, concrete and GRP
- Protection degree: IP 43/23D (MV switchgear/transformer)

HITACHI ABB

GRID-EMOTION™ CHARGING POINTS AND SYSTEMS, CONTAINERIZED CHARGERS AND DIGITAL SOLUTIONS

Battery Energy Storage System (BESS)

Stationary BESS for small depots or city terminals

- Up to 500kW power
- Grid-forming power converter
- Battery racks and battery management system
- Designed for grid integration of EV charging infrastructure depots and terminals
- For power requirement up to 500kW and energy storage of 670kWh
- Remote monitoring and control system
- Standardised enclosure for fast delivery at site

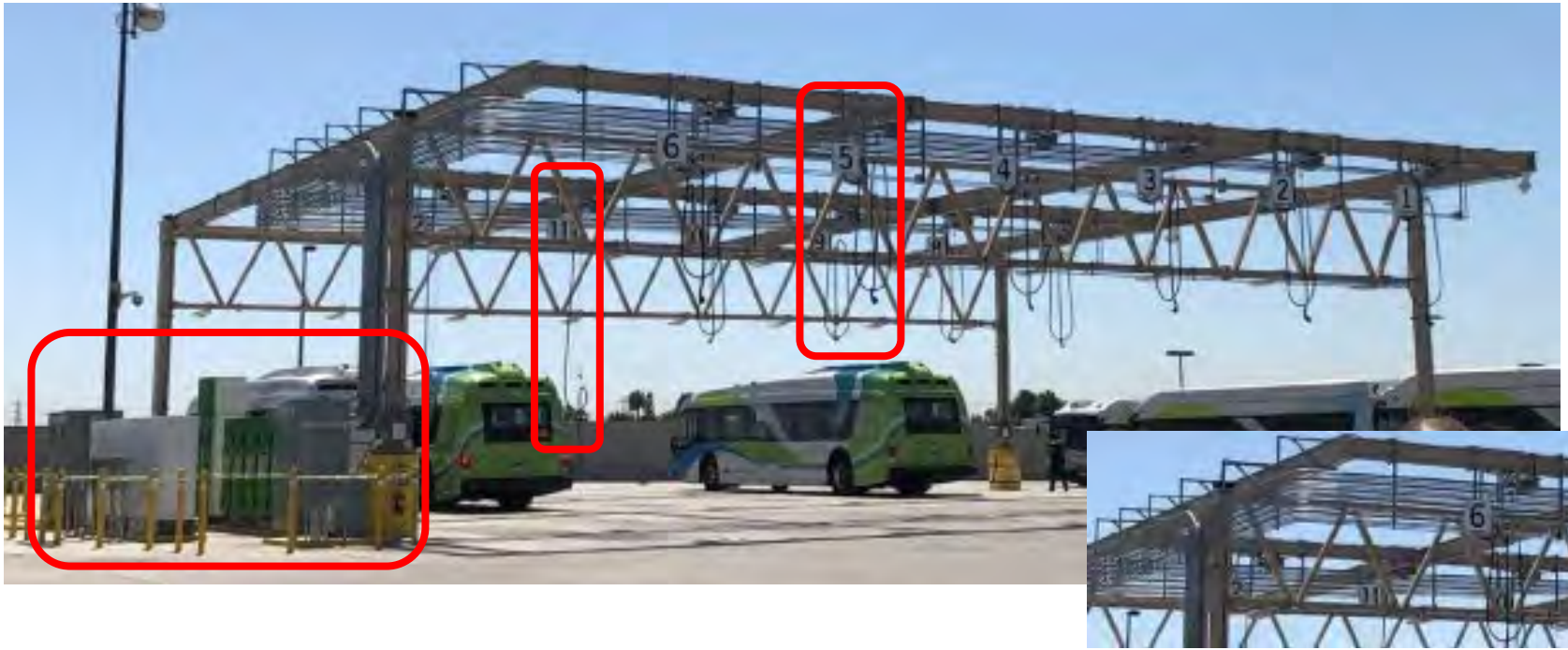
EARLY TESLA GRAPHIC ON MEGACHARGER (BIGGER SUPERCHARGER)

TRUCK CHARGING DISPENSER CABLE LAYOUT ROUTES POWER-CHARGING COUPLER TO VEHICLE ~3 WAYS:

- **Front/side:** Curb/charging island mounted dispensers, cord retrievers
- **Overhead:** On gantry or building structure, tethered cables/retrievers
- **Beneath:** Flush mounted, pop up/flip up; no bollards

BUS DEPOT, 12X 150KW(?) (PV CANOPY?) OVERHEAD CABLE ROUTING CHARGING INSTALLATION

- Observations on clearance height, cost of steel, cranes and scissors lifts to assemble, massive runs of conduit, long charging cord length/retrievers



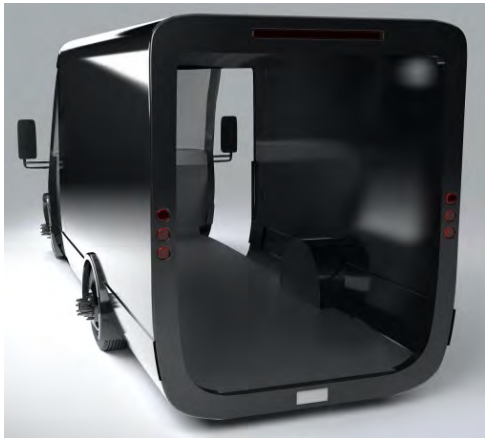
FLUSH MOUNTED CAVOTEC POP UP/HATCH PITS FOR CHARGING CABLE HANDLING W/WO AUTOMATED CONNECTION SYSTEM (ROBOT)

Cavotec Systems Products

PowerHydrant Robotic Coupler Products

BACK OF THE ENVELOPE- CLASS 4 DELIVERY VEHICLE ENERGY CONSUMPTION AND CHARGING SPEED/DURATION

- Reference observation/SCE/CALSTART study on eStar, Smith vehicles https://calstart.org/wp-content/uploads/2018/10/Battery-Electric-Parcel-Delivery-Truck-Testing-and-Demonstration.pdf
- ~5kW AC charging rate, 12-15hr recharge(60kWhr), ~ 1kWhr/mile
- Compared to Bollinger Deliver-E vehicle with 70kWhr,105, 140,175, 210 kWhr battery translates 70-210 mile range
- Basic recharge rate/duration: 20kW=20 miles/charging hour, 3.5-10.5hrs 100kW=100 miles/charging hours; <1hr-2.1hrs



BACK OF THE ENVELOPE- CHARGING CLASS 8 LINE HAUL TRACTORS

https://www.trucks.com/2019/09/05/everything-we-know-about-the-tesla-semi-truck/

- Class 8 trucks loaded to 80,000lb GVW consumes ~2kWhr/mile (or more)
- Replacing 400 miles range (800kWhr) in 30 minutes requires (2C) 1.6MW
- Shorter route vehicles have smaller battery capacity, shorter recharge time
- Overnight charging (8hrs) requires {average} 100kW for 800kWhr

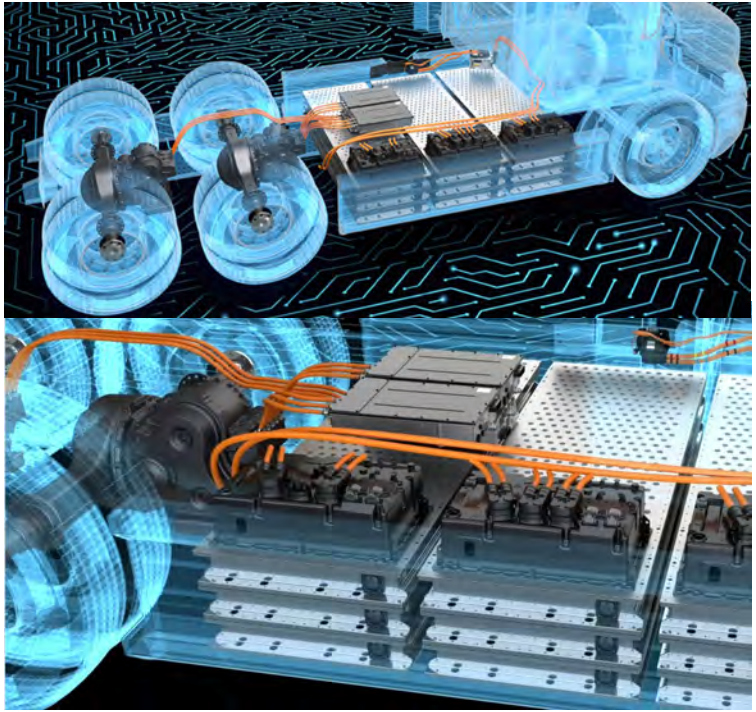
Volvo VNR

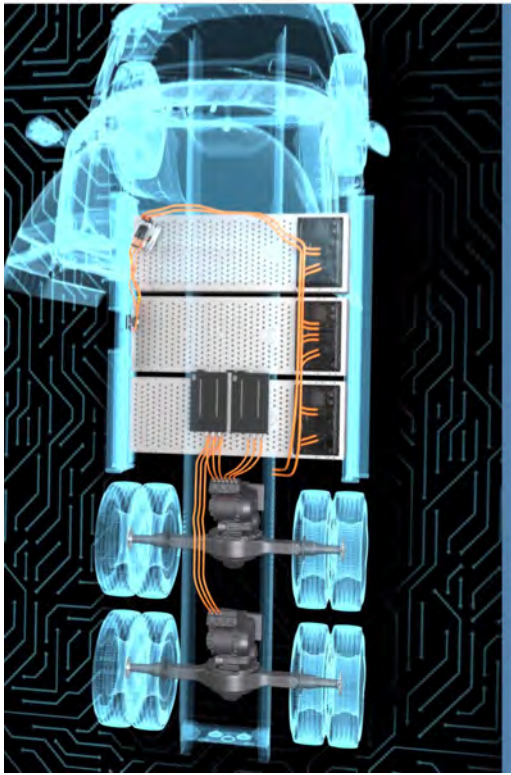
Tesla Semi

Freightliner eCascadia

CLASS 8 TRUCK EV POWERTRAIN COMPONENTS- DTNA

- eCascadia (Detroit ePowertrain components), charging port, batteries, electronics, eAxles, etc; https://demanddetroit.com/epowertrain/, https://freightliner.com/trucks/ecascadia/





ROAD.

An eAxle is an electric drivetrain component that's key to making an electric powered truck less complex and more productive. By integrating an electric motor, transmission and specialized electronics within a compact unit, the eAxle can directly and efficiently power a truck's wheels. The Detroit ePowertrain provides two Detroit eAxle designs that can be combined to meet the demands of any job:

Dual motor

- Max torque - 23,000 lb-ft
- Max power - 360 hp

Single motor

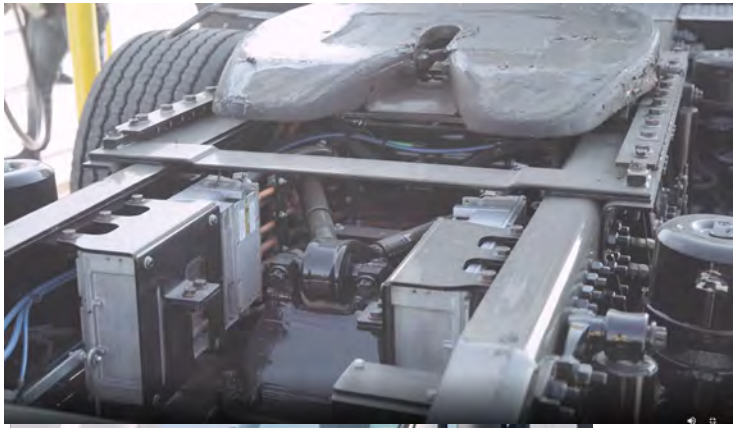
- Max torque - 11,500 lb-ft
- Max power - 180 hp

Three Detroit battery options offer a range of sizes and average, zero-to-full charging times:

- 210 kWh: 1.5 to 4 hours
- 315 kWh: 2 to 6 hours
- 475 kWh: 2 to 6 hours

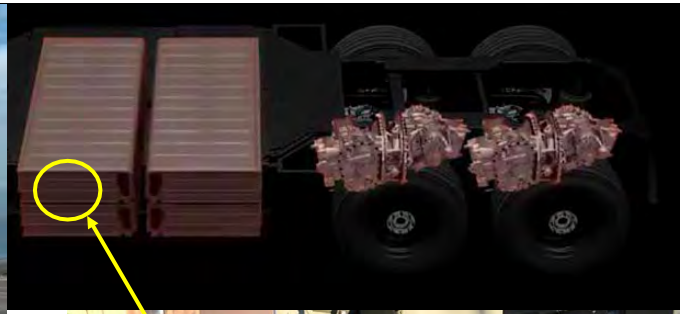
CLASS 8 TRUCK EV POWERTRAIN COMPONENTS- DTNA

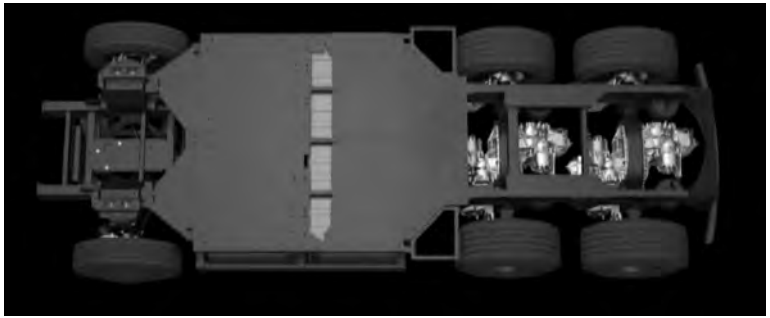
- eCascadia (Detroit ePowertrain components), charging port, batteries, electronics, eAxles, etc; https://demanddetroit.com/epowertrain/, https://freightliner.com/trucks/ecascadia/



TESLA SEMI (BATTERY PLACEMENT, INLET LOCATION, POWER PATHWAYS); 300-500 MILE RANGE; $150K-$180K

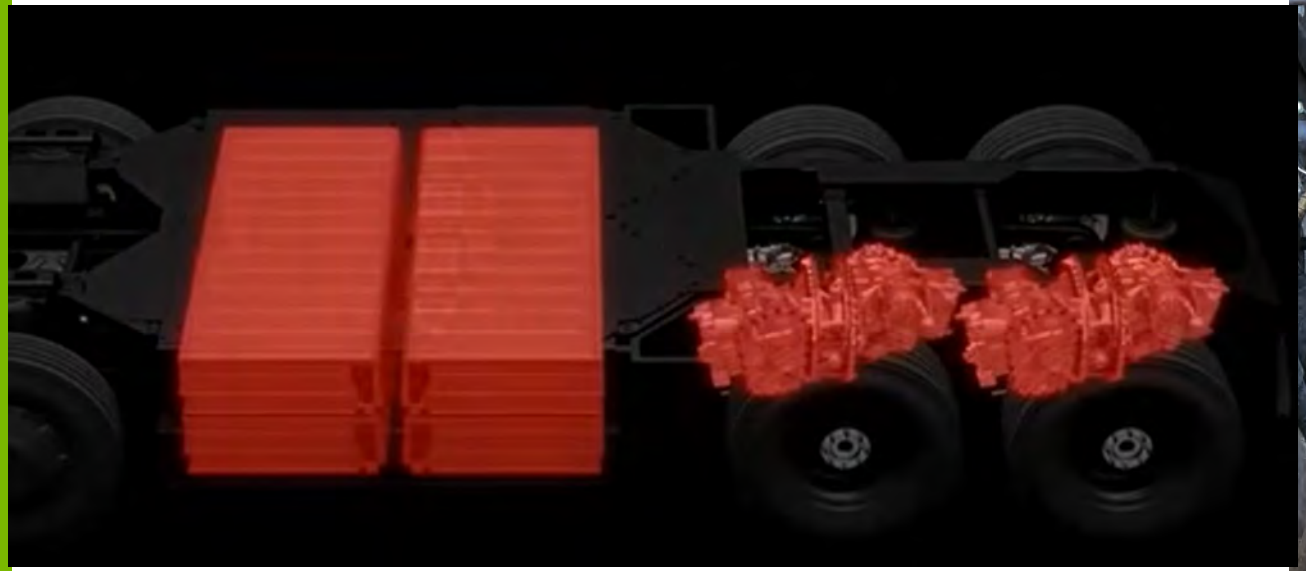
Batteries under cab, inlet just ahead of first rear axle, street side

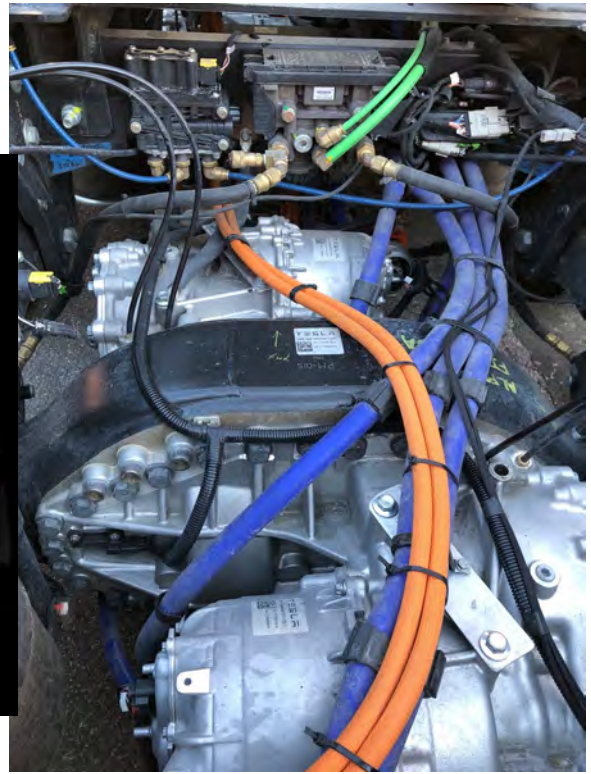




TESLA SEMI PHYSICAL POWERTRAIN VS GRAPHIC RENDERING

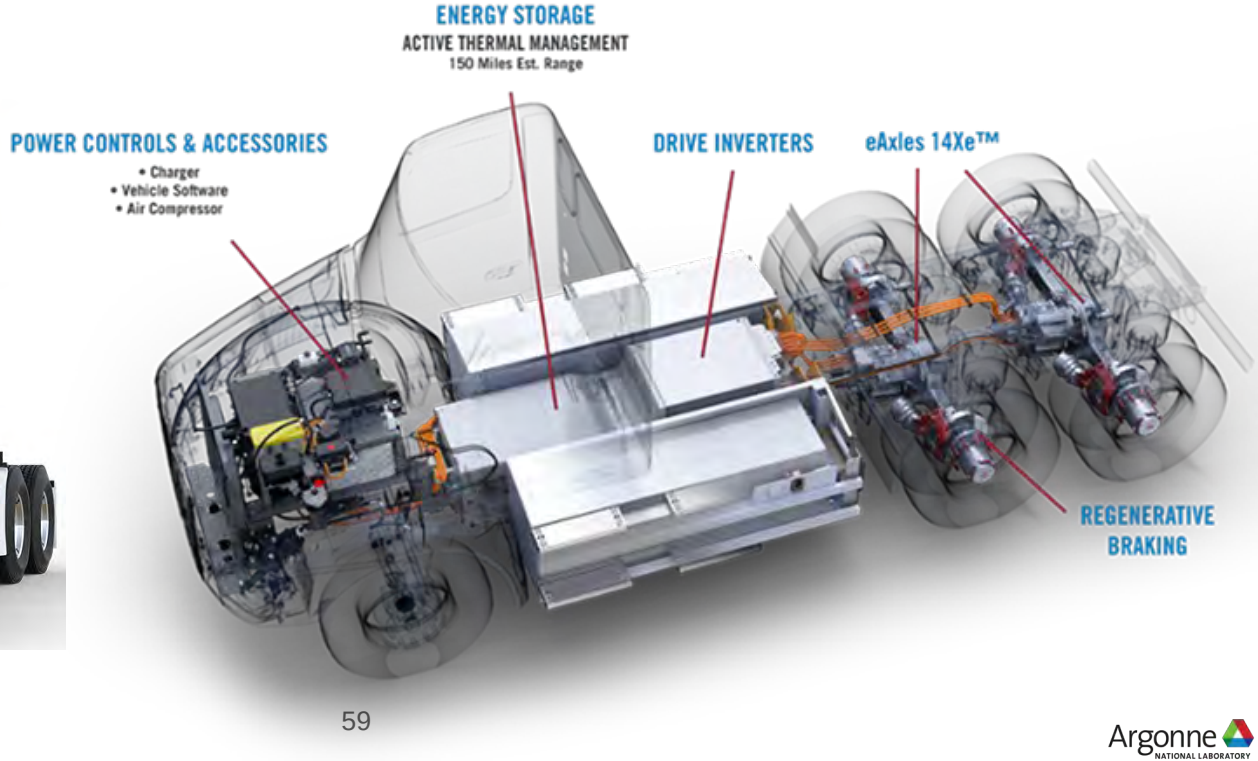
Rear motor assembly and battery packs highlighted





CLASS 8 TRUCK EV POWERTRAIN COMPONENTS- PETERBILT

- 579EV Regional haul & Drayage, charging port, batteries, electronics, eAxles, etc; https://www.peterbilt.com/electric-vehicles



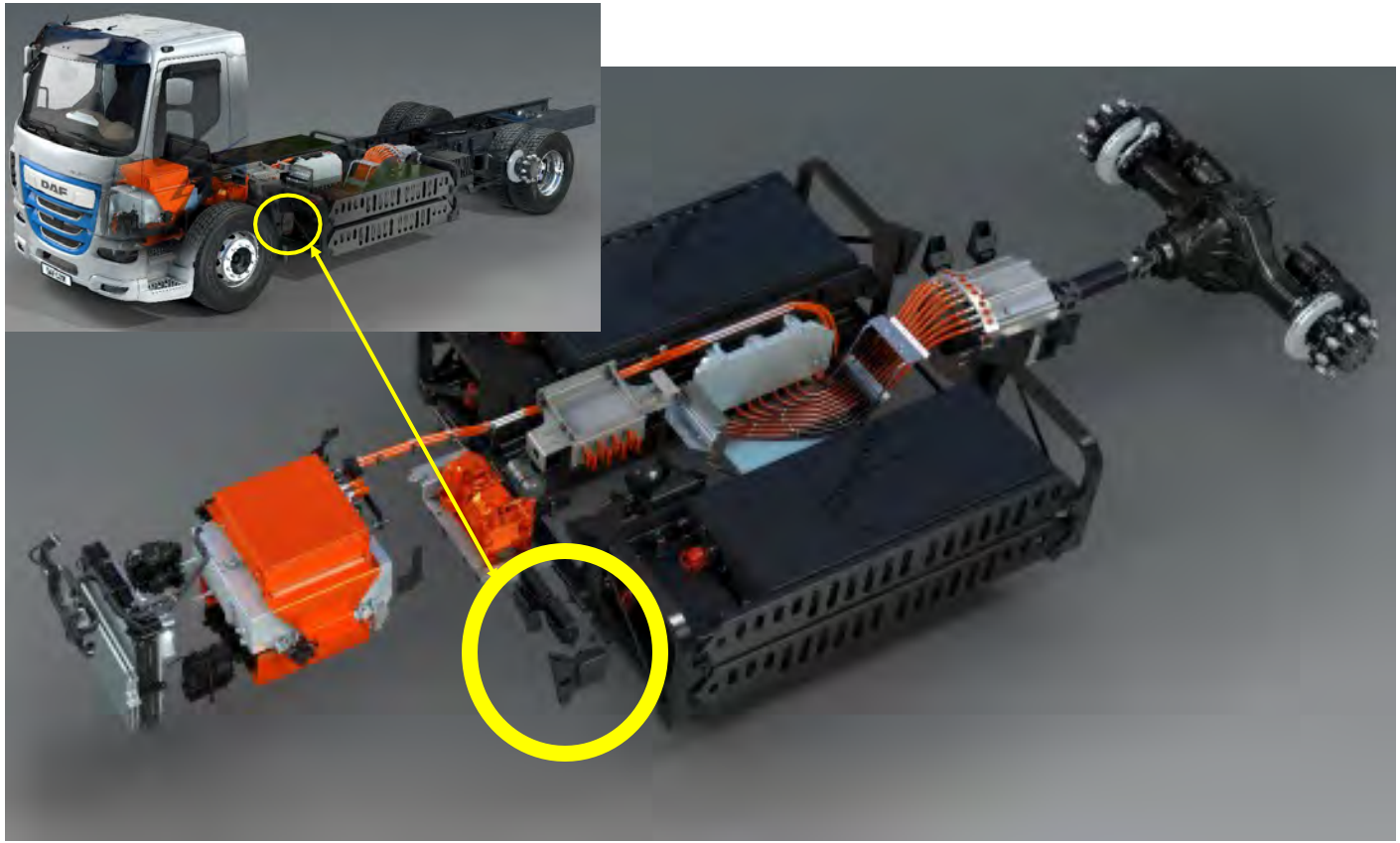
CLASS 8 ELECTRIC TRUCK EXAMPLE: PETERBILT MODEL 579 W/MERITOR-TRANSPOWER EPC POWERTRAIN (8X44KWHR)

- Twelve Class 8 Electric Peterbilt 579's being built for Port of Long Beach
- Recent DOE FOA award to PACCAR/Peterbuilt for 1MW wireless charging version, with subcontract to WAVE/Utah State University
- 490 HP, ~250 mile range, 350-440 kWh, recharges in less than five hours
- Uses the first five gears of an Eaton AutoShift 10-speed transmission

DAIMLER ECASCADIA CLASS 8; PILOT FLEET W/PENSKE

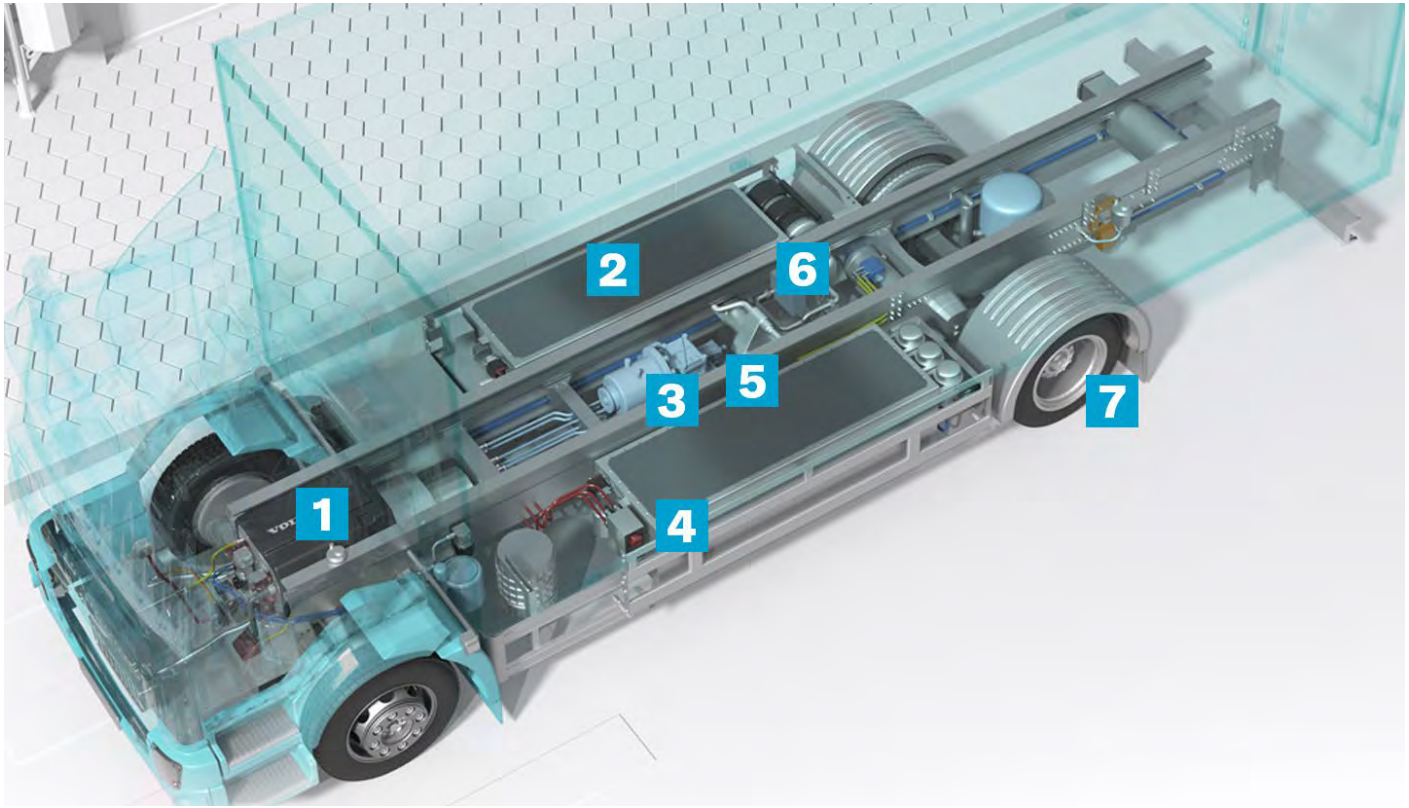
DAF-PACCAR STRAIGHT TRUCK

BATTERIES BETWEEN FRONT/REAR AXLES, INLET BEHIND FRONT WHEELS



VOLVO FL ELECTRIC STRAIGHT TRUCK

BATTERIES ON FRAME RAILS, INLET(4) BEHIND FRONT WHEELS



https://www.volvotrucks.com/en-en/news-stories/magazine-online/2019/nov/tech-in-focus-volvo-fl-electric.html

CUMMINS EOS CONCEPT URBAN TRACTOR

- Class 7; 18,000lb tractor weight
- 140kWhr, 100 mile range

NEURON PROTOTYPE CLASS 8 TRACTOR