Transit Bus Component TECHNOLOGY FORUM

November 7, 2019 :: East Liberty, Ohio

An Interchange about the latest advancements in component offerings and testing centers for low and no emission buses, in partnership with the FTA's Transit Vehicle Innovation Deployment Centers.

Hosted by:

CALSTART

AGENDA

WiFi: GUEST (no password)

8:30 – 8:45	**Welcome**
8:45 – 9:00	**Opening Remarks**
9:00 – 10:00	**Overview of LoNo Component Assessment Program and Standardized Testing**
10:00 – 10:45	**Electrified Thermal Cooling and Heating Systems**
10:45 – 11:30	**Electric Axles and Wheel Motors**
11:30 – 12:30	**Networking Lunch**
12:30 – 1:15	**Power Electronics: Next Gen Inverters, Motors, DC/DC Converters, Fuel Cells, Chargers**
1:15 – 2:00	**Energy Storage**
2:00 – 3:00	**Systems Integration Perspectives and Offerings**
3:00 – 4:00	**Closing Remarks and TRC Tour (Buses provided by COTA)**
4:00	**Adjourn**

Opening Remarks

Fred Silver

Vice President and Bus/Mobility Team Leader

fsilver@calstart.org

CALSTART's 230 Member Companies and Organizations

(PARTIAL LISTING)

Making Clean Transportation Happen

Edison International – Energy for What's Ahead
South Coast AQMD
Wells Fargo
Bay Area Air Quality Management District
Southern California Gas Company – A Sempra Energy utility
San Joaquin RTD
New Flyer of America
Ford
UPS
Cummins
Westport
BAE Systems
Union of Concerned Scientists – Science for a healthy planet and safer world
ChargePoint
Southern Company
PepsiCo
Volvo – Volvo Group North America
American Power Group
Valley Pacific
Eaton
Altec
BYD
Gentherm
Hino Trucks
Hoist Liftruck
Sevcon
Caterpillar
Meritor
FedEx Express
Toyota
FPL
AxleTech International
GM
US Hybrid
PG&E
Allison Transmission
Black & Veatch – Building a world of difference
Siemens
Plug Power
SDG&E
Hollywood Trucks
Fuso
FedEx Ground
Tesla
Daylight Transport
Toshiba – Leading Innovation
Golden Gate Petroleum
Eberspächer
ARC
Phoenix Motorcars
Audi
AC Transit
ENC
Ballard
Port of Long Beach
Harris
Terex
Odyne
Mountain Transit
Manhattan Beer Distributors
Hummingbird
UQM Technologies
Ameresco – Green · Clean · Sustainable
Kenworth
Parker
Motiv
Los Angeles Department of Water & Power
Unicell
greencommuter
Advanced Vehicle Manufacturing
Anteater Express
Lightning Systems
Sandia National Laboratories
Malibu Inc
Real Power
Cummins
Volvo
Workhorse
Frito Lay
Envera
XL Hybrids
EMP – Powering the Future
Hydrogenics – Shift Power | Energize Your World
Bollinger Motors
Emerald Automotive
achates power
TransPower
Purolator – Where business is going
Efficient Drivetrains, Inc.
Oberon Fuels
Schneider Electric
WAVE
ESW America
Trillium CNG
Adomani
Proterra
Hyliion
e-Traction
SARTA
UTS
Cerritos College
Foothill Transit
EBG Resistors
ART
ViriCiti
motiv
Tula
SF Environment
ITRI
Emerald
SunLine Transit Agency
MTD Santa Barbara
New Eagle
Concord Minuteman Solutions Group
MST Monterey-Salinas Transit
Torrance Transit
I ✈ OAK – Park Close. Fly on time.
Orange EV
Tri Delta Transit
GreenPower Bus
Sturman Industries
effenco
AVTA – Antelope Valley Transit Authority
Clean Cities
UTA
City of Gardena – G Trans
ace parking
Sacramento Metropolitan Air Quality Management District
Cal State LA
VTA
Civic Projects
United States Postal Service
County of Los Angeles Public Works
ebus
LADOT Transit Services
chanje
First Priority GreenFleet

CALSTART – A National Organization 9 Offices
Six Regional Offices + Three Field Offices

TVIDC - CALTART Cooperative Agreement With the Federal Transit Administration

CALSTART

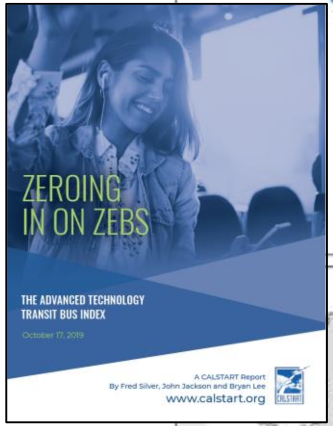
Federal Transit Administration

- Transit Vehicle Innovation Development Centers (TVIDC)
  - CALSTART will
    - Work to coordinate planning for implementation of the
      - Lo and No Emission Bus Component Assessment Program
      - And additional Standardized Bus Testing Facilities
  - Enable the deployment of innovative buses and their technologies including research and partnership development
  - Assist Transit Fleets and others nationwide in the planning for and deployment of low and no emission buses
    - An additional focus on Rural and Smaller Transit Bus Fleets

Zeroing in on ZEBS and Inventory Across the Nation

As of September 12th, 2019, there are:

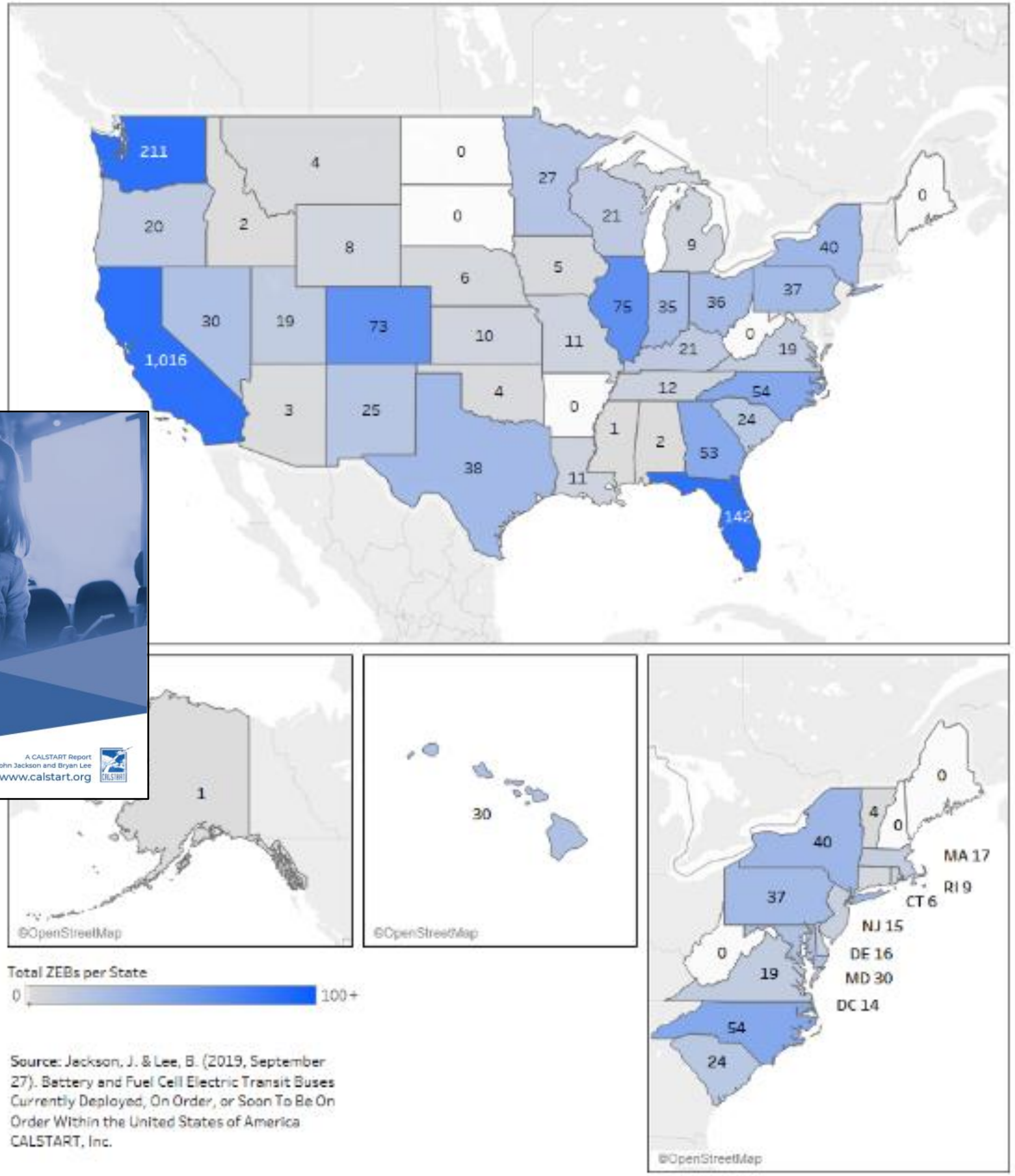
- Total Zero-emission Buses (ZEBs): **2,255**
  - Battery Electric Buses (BEBs): 2184
  - Hydrogen Fuel Cell Buses (FCBs): 71
- An increase of **36%** over the last calendar year.
- **202** transit agencies
  - Median number of ZEBs per property is six
  - 56 properties are in California.



https://calstart.org/wp-content/uploads/2019/10/Zeroing_In_on_ZEBs_Final_10182018-10.21.19.pdf

Battery and Fuel Cell Electric Transit Buses Currently Deployed, On Order, or Soon To Be On Order Within the United States of America

Last Updated: September 27, 2019



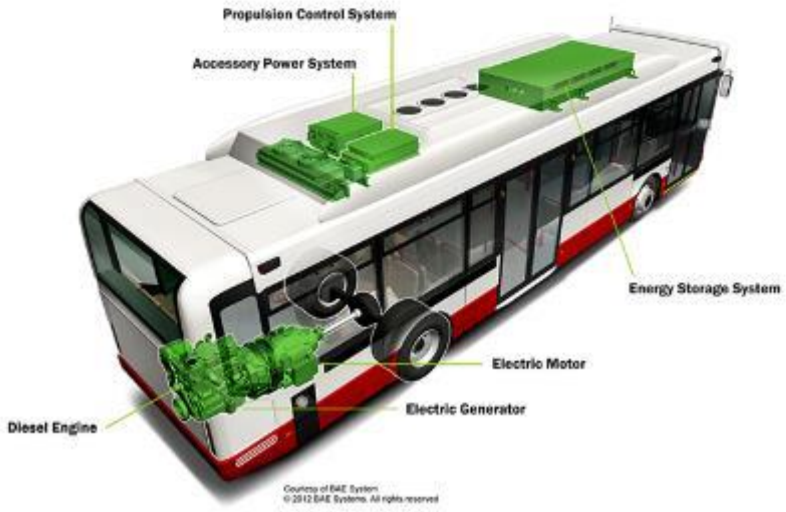
Forum Dialogue Today

Technology	ZEB Research and Development Needs
Vehicle Energy Storage Systems	• Incremental improvements to battery capacity, efficiency, and cycle lifetime • Cost reductions • Battery management systems • New battery chemistries • Advanced pressure vessels for gaseous H2 storage • Ultracapacitors /Flywheels
Propulsion and Energy Conversion	• Next generation Lower cost Fuel cells • Electrified Axles and wheel motors • Next generation power switches
Electrified Components and Enabling Technologies	• Develop more durable compressors and pumps • Experiment with new converter designs to improve efficiency • Develop more reliable inverter cooling systems
Heating, Ventilation, and Air Conditioning	• Integrating heat pumps into bus systems • Determining energy savings from improved insulation • Developing an air curtain for transit applications • Developing a Clean Emission Protocol for Fuel fired heaters
Automation	• Developing Next generation Smaller bus – Buy America/NHTSA • Demonstrate platooning on transit buses • Automatic breaking systems on larger buses • Full autonomy of 40 Foot bus
charging and Refueling Infrastructure	• Develop high voltage DC fast inductive charging • Bi-directional vehicle-to-grid integration • Ultracapacitor flash charging • Demonstrate microgrids and other grid resiliency technologies • Develop on-site hydrogen production technologies

In Search of Watts

Final Panel Today on the Needs of Transit Bus Systems Integrators and their Perspectives

- While the individual technologies, and components are important- The Voices of the Customer is paramount
- We will hear today from
  - Cummins- E Drivetrain
  - BYD – FC and E drivetrain
  - New Flyer
  - Stark Area RTA



8:45 – 9:00 a.m.

Opening Remarks

Kirt Conrad, Stark Area Regional Transit Authority

SARTA

CALSTART

9:00 – 10:00 a.m.

Overview of LoNo Component Assessment Program and Standardized Testing

Moderated by Stephen Brady, Booz Allen Hamilton

Christian Brodbeck, Auburn University

Walt Dudek, The Ohio State University, Transportation Research Center

David Klinikowski, Penn State University (Altoona)

CALSTART

Overview of LoNo Component Assessment Program and Standardized Testing

Transit Bus Component Tech Forum

Transportation Research Center
East Liberty, OH
November 7, 2019

Overview Contents

This overview will provide an overview of the Low and No-Emission Component Assessment Program (LoNo-CAP), including:

- Program description and purpose
- Applicant eligibility
- Eligible projects
- How to apply
- Application evaluation criteria
- Award selection and administration

Program Description and Purpose

Notice of Funding Opportunity (NOFO)

- On September 29, 2016, FTA announced the opportunity for eligible institutions of higher education to apply for funding to conduct testing, evaluation, and analysis of low or no emission (LoNo) components intended for use in LoNo transit buses used to provide public transportation (https://www.transit.dot.gov/research-innovation/lonocap).
- https://www.gpo.gov/fdsys/pkg/FR-2016-09-29/pdf/2016-23504.pdf
- The **deadline** for applications was **November 28, 2016**.

What is LoNo-CAP?

- New FTA Research Program in the FAST Act of 2015
- FTA was to competitively select "at least one" facility to conduct assessments of low and no emission vehicle components intended for use in transit buses
- Auburn University and The Ohio State University/Transportation Research Center were selected.
- Federal Funding Authorized at $3M annually in FY16-FY20 ($15M total FTA funding)
- Complements FTA Bus Testing Program ("Altoona")

What will LoNo-CAP do?

Per the FAST Act, LoNo-CAP will support LoNo component assessments in these areas:

- Maintainability
- Reliability
- Performance
- Structural Integrity
- Efficiency
- Noise

How will LoNo-CAP Work?

- Any party interested in having an assessment of a LoNo bus component performed can submit the component to the appropriate FTA-funded facility
- FTA will subsidize 50% of the established fee for testing that component (up to a total FTA contribution of $3M per year)
- All assessments subsidized by LoNo-CAP will be considered public information - the results of which will be summarized in individual component test reports and an annual report to Congress
- The conduct of an assessment will not provide relief from Bus Testing Requirements (49 CFR 665) for major bus model configuration changes

LoNo-CAP is NOT

- A program to fund the direct costs of component R&D
- A *technology demonstration* program to fund procurement & deployment of new components in transit service
- A University infrastructure capital program to fund the direct costs of equipment and facilities
- A replacement or substitute for Altoona testing of complete buses
- Congress has set funding to stand up two additional test centers related to low/no emission bus testing – details are under discussion.

Applicant Eligibility

Applicant Eligibility

- "The Secretary shall enter into a contract or cooperative agreement with, or make a grant to, at least one **institution of higher education** to operate and maintain a facility with:
  - (I) capacity to carry out transportation-related advanced component and vehicle evaluation;
  - (II) laboratories capable of testing and evaluation;
  - (III) direct access to or a partnership with a testing facility capable of emulating real-world circumstances in order to test low or no emission vehicle components installed on the intended vehicle;"
- Per the FAST Act, the FTA Bus Testing Facility ("Altoona") is specifically excluded from eligibility for LoNo-CAP

Eligible Projects

Eligible LoNo-CAP Projects

- LoNo components must be specifically intended for and/or enabling of low and no-emission transit buses
- Types of testing could include:
  - Laboratory testing
  - Hardware-in-the-loop testing
  - Testing on a test track
- Detailed standardized reports must be prepared and published for each component tested
- Content for an annual summary Report to Congress must be prepared and submitted to FTA

Examples of LoNo Components

LoNo components include, but are not limited to:

- Energy storage systems such as batteries, capacitors, flywheels, etc.
- Battery management systems
- Battery charging systems
- Hydrogen tanks and fuel systems
- Electric motors and generators
- Power electronic systems, motor drives, and controls
- Fuel cells and balance-of-plant
- Electrically-driven vehicle accessories
- Exceptionally-low emission internal combustion engines

Sample Assessments

- Component and sub-system product qualification testing to satisfy TVM and customer requirements
- Component and sub-system testing to support development of industry standards

Zero Emission

- Charge and discharge curves
- Response to cycling/aging of components – life expectancy
- Effects of extreme ambient conditions
- Safety during bus charging/refueling, operations, crash and post-crash
- Operational performance, safety, reliability, durability, and interoperability of battery chargers
- Performance and efficiency of vehicle accessories and HVAC systems
- Assessments of bus repower systems

Low Emission

- Exhaust after-treatment systems – operational performance and reliability
- Performance of alternative fuels during extreme ambient conditions
- Performance of new exceptionally-low emission ICE-based power systems

How to Apply

Proposal Submission

- Applications MUST be submitted through www.Grants.gov; search for "FTA-2016-008-TRI-LONO-CAP"
- **A valid application must include at least two forms:**
  - **SF424 Mandatory Form** (*common to all federal grant applications*)
  - **LoNo-CAP Supplemental Form** (*unique to LoNo-CAP*)
- Applications may include additional supporting documentation, including a proposal narrative (not to exceed 10 numbered pages), a test fee schedule, a program budget, resumes, maps, etc.
- Refer to the NOFO for a detailed list of required application content and procedures

Application Reviews

FTA Review and Selection

- FTA will assemble a technical evaluation panel (TEP)
- The TEP will review eligible applications and supporting documentation, and assign ratings of:
  - Recommended
  - Not Recommended
- FTA may seek clarification from proposers, if needed
- The FTA Administrator or designee will review the TEP ratings and select the institution(s) that will receive LoNo-CAP funding for FY16-FY20, and if more than one institution is selected, the funding allocation for each

Proposal Evaluation Criteria

Proposals will be evaluated based on the quality and extent to which they address the applicant's:

- Program Approach
- Organizational Capacity
- Program and Risk Management Plan
- Data Reporting and Dissemination
- Commitment to Accreditation, Codes, and Standards

Additional details are provided in the NOFO

Federal Award Notice

- FTA will announce the selected institution(s)
- All information submitted in or with LoNo-CAP applications should be public information, as it will be subject to public release.
- If an application must contain confidential business information, it must be flagged as such – see NOFO for details.

Award Administration

Award Administration

- Successful applicant(s) will receive a cooperative agreement, grant, or contract from FTA, at FTA's discretion
- The LoNo-CAP project agreement(s) will be managed by FTA's Office of Research, Demonstration, and Innovation
- The institution(s) will submit quarterly reports and invoices documenting which component tests were performed in the subject quarter
- FTA will review reports and invoices, and reimburse the institution(s) for 50% of the established fees for the tests conducted.

Award Administration (cont.)

Applicants must comply with FTA administrative requirements that include, but are not limited to:

- Submission of annual Certifications and Assurances
- Submission of quarterly Federal Financial Reports (FFRs) and Milestone Progress Reports (MPRs) in FTA's electronic award management system, TrAMS
- FTA Circular 6100.1E, "*Research, Technical Assistance and Training Program: Application Instructions and Program Management Guidelines*"
- Cooperating with and providing reasonable access to FTA and/or its designated independent evaluator

LoNo-CAP Program Information

Program website:
https://www.transit.dot.gov/research-innovation/lonocap

www.Grants.gov
grant opportunity FTA-2016-008-TRI-LONO-CAP

E-mail: LoNo-CAP@dot.gov

FTA LoNo-CAP Program Manager

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Discussion

AUBURN UNIVERSITY

LoNo Component Assessment Program

Transit Bus Component Technology Forum
November 7, 2019

Component Development Areas

- GPS and Vehicle Dynamics
- Cyber and Critical Infrastructure
- HVAC System Assessment
- Battery and Battery Management System Assessment
- Advanced Vehicle and Extreme Environment Electronics
- On Track Assessments

Strengths and Expertise

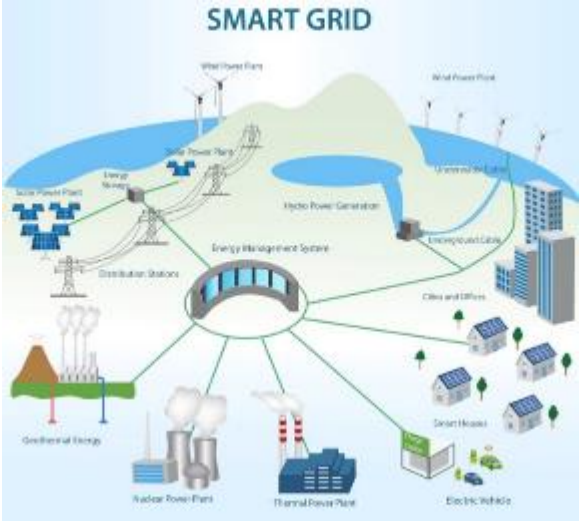
GPS and Vehicle Dynamics

- Advanced Driver-Assistance Systems (ADAS)
    - Road and Lane Detection
    - Develop, test, and apply use of data sources such as radar, LiDAR, automotive imaging
    - Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication
- Truck Platooning
    - Advancing platooning technology to improve fuel efficiency and safety

Strengths and Expertise

Cyber and Critical Infrastructure Security

- Vehicle-to-vehicle and Vehicle-to-Infrastructure communication
- Areas of emphasis
    - Smart Grid
    - Secure systems engineering
    - Critical Infrastructure Security
    - Internet of Things and Industrial Control Systems



Strengths and Expertise

Cyber and Critical Infrastructure Security

- Cyber areas that may relate to transit systems
    - Navigational techniques in GPS-degraded environments
    - Cyber security for navigation and control systems
    - Cyber vulnerability evaluation
        - Currently the focus has been on weapon systems
        - However may be critical in V2V or V2I

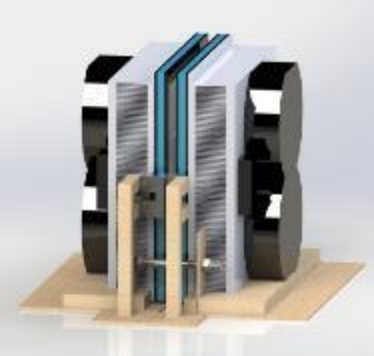
Partnerships Include

Strengths and Expertise

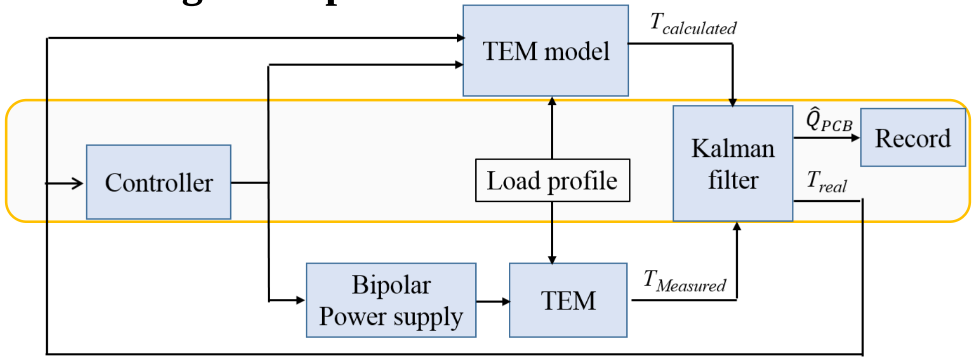
Battery and Battery Management Systems

- Battery testing and characterization
- Electrical and mechanical tests
  - Capacity Efficiency
  - State of Charge
  - Temperature profile
  - Heat generation
  - Critical Infrastructure Security

Thermoelectric Module (TEM)

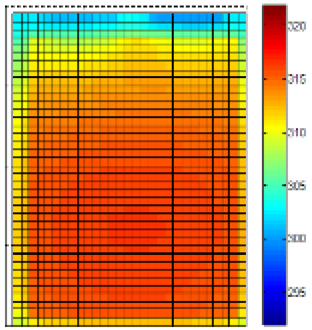


Working Principle



Heat generation measurement

Calorimeter



LoNo CAP Test Development

- Working with a Transit Vehicle Manufacturer (TVM) to develop Auburn’s first CAP test
- Test ADAS on TVM may include
  - Forward Collision Warning
  - Headway Monitoring Warning
  - Lane Departure Warning
  - Speed Limit Indicator
  - Pedestrian Danger Zone
  - Pedestrian Collision Warning


Image: Mobileye

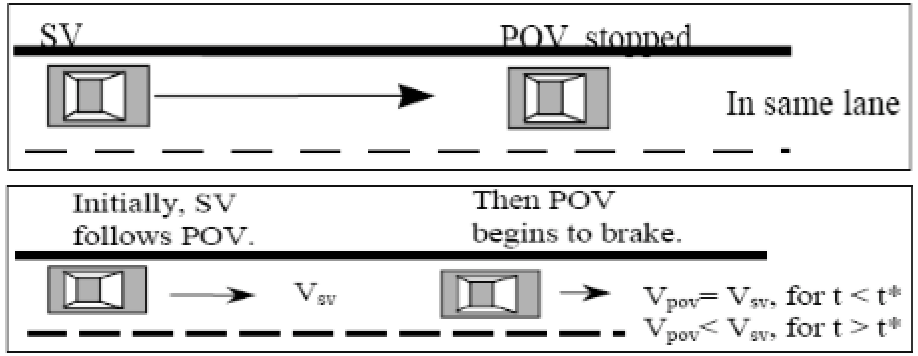


Image: NHTSA FCW Evaluation

LoNo CAP Test Development

- Modification of Test Track to meet TVM's Needs
- Add temporary pavement markings to test Lane Departure Warning
  - Dashed yellow or white line
  - Continuous yellow or white line
  - Raised markers
    - Type A or AY (Botts Dots)
    - Type C or D
    - Type G or H

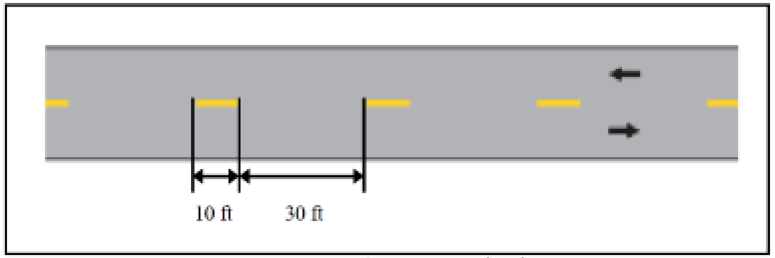


Image: NHTSA LDW Evaluation

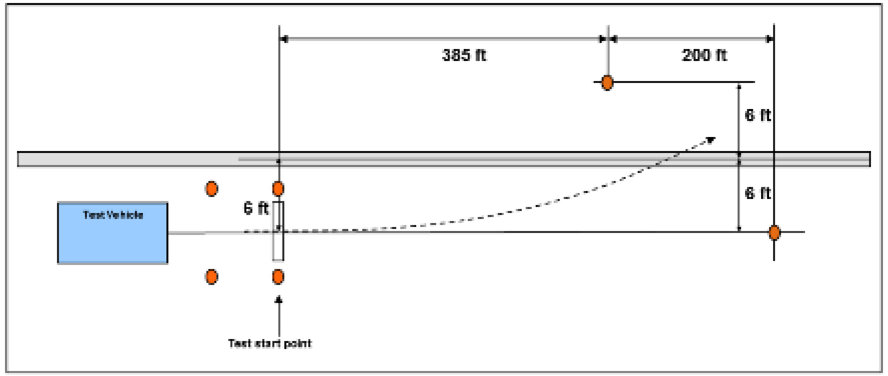


Image: NHTSA LDW Evaluation

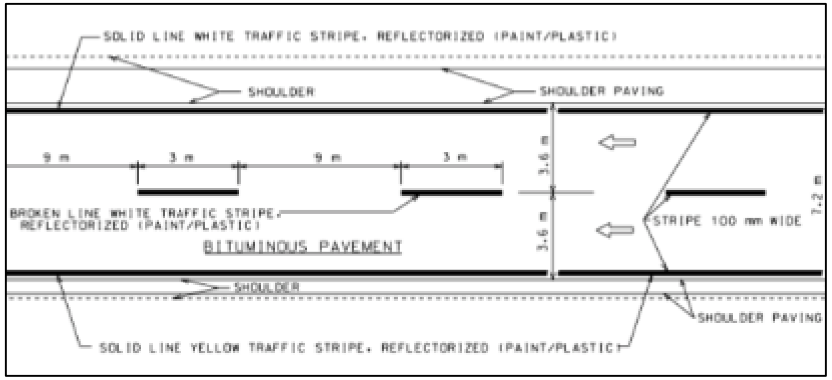


Image: Alabama DOT

Testing Fee Structure

- LoNo CAP funded under 49 U.S. Code 5312 (h) requires collection of fees to cover 50% of test costs
- Since standardized tests are not available for LoNo components, each test will be unique to the needs of the TVM or component manufacturer
- Tests may be geared to component development or evaluation, rather than a component pass/fail scenario

Testing Fee Structure

- Auburn has created a new budget to better estimate component tests
- A new “a-la-carte” budget has been created to allow TVM’s and Auburn to work together better estimate test costs
- Separate budget for test development and recurring tests
- TVM and component manufactures costs may include:
  - Cash
  - Equipment
  - Supplies
  - Wages
  - Travel

Test Development Fee

Battery State of Charge Test - First Test

Test Description: The battery state of charge consists of outfitting a battery electric bus with a data acquisition system to monitor the battery, vehicle speed, vehicle travel distance, and other data streams as needed. The actual state of charge test is planned to run for 8 hours per day over a 3 day period lasting for 24 hours total. For the first test, a test development time is factored, however, for additional tests, only a reduced setup time, testing time, and data processing/analysis time is used.

Personnel	Hourly Rate	Test Development Time	Test Setup Time	Lab/Field Testing Time	Data Processing and Analysis	Total
Faculty #1 Time(hourly)	$ 119.06	4				$ 476.24
Faculty #2 Time (hourly)	$ 119.06	0				$ -
Research Engineer #1 Time(hourly)	$ 55.29	6	4			$ 563.40
Research Engineer #2 Time (hourly)	$ 55.29	0		24		$ 1,326.96
Research Technician #1 Time(hourly)	$ 38.46	4	4			$ 307.68
Research Technician #2 Time (hourly)	$ 38.46	0				$ -
Graduate Student #1 Time (hourly)	$ 24.03	8		8	4	$ 480.60
Graduate Student #2 Time (hourly)	$ 24.03	0				$ -
Graduate Student #3 Time (hourly)	$ 24.03	0				$ -
Fringe Benefits	$ 140.65					$ 917.26
Test Track Use (hourly)	$ 112.00			24		$ 2,688.00
Test Track Non-Driver Support (hourly)	$ 54.00					$ -
Test Track Vehicle (hourly)	$ 59.50					$ -
Test Specific Equipment	$ 1,000.00					$ 1,000.00
Travel	$ 300.00					$ 300.00
					Total Direct Cost	$ 8,160.22
		Total Person Hours	92		Total Indirect Cost	$ 3,917.91
		Total Person Days	11.5		Total Cost	$ 12,078.13

Recurring Test Fee Structure

Battery State of Charge Test - Additional Tests

Personnel	Hourly Rate	Test Development Time	Test Setup Time	Lab/Field Testing Time	Data Processing and Analysis	Total
Faculty #1 Time(hourly)	$ 119.06					$ -
Faculty #2 Time (hourly)	$ 119.06					$ -
Research Engineer #1 Time (hourly)	$ 55.29		2			$ 110.58
Research Engineer #2 Time (hourly)	$ 55.29			24		$ 1,326.96
Research Technician #1 Time(hourly)	$ 38.46		2			$ 76.92
Research Technician #2 Time(hourly)	$ 38.46					$ -
Graduate Student #1 Time(hourly)	$ 24.03			8	4	$ 288.36
Graduate Student #2 Time(hourly)	$ 24.03					$ -
Graduate Student #3 Time(hourly)	$ 24.03					$ -
Fringe Benefits	$ 140.65					$ 501.86
Test Track Use (hourly)	$ 112.00			24		$ 2,688.00
Test Track Non-Driver Support (hourly)	$ 54.00					$ -
Test Track Vehicle (hourly)	$ 59.50					$ -
Test Specific Equipment	$ 100.00					$ 100.00
Travel	$ 300.00					$ 300.00
					Total Direct Cost	$ 5,392.68
		Total Person Hours	64		Total Indirect Cost	$ 2,589.49
		Total Person Days	8		Total Cost	$ 7,982.16

LoNo Bus Testing Center Update

- Auburn awarded FTA funding for the design of a full LoNo bus testing facility
- Currently working on the design to construct a bus testing facility to duplicate the capabilities of Penn State University's Bus Testing Center
- However, Auburn is working with FTA to alter the scope of the planned facility currently being designed
- Revised strategy would be to develop a test center that is complementary to, rather than competitive with, the bus testing centers at Penn State University and Ohio State University
- This complimentary site would position the Auburn LoNo Transit Vehicle Innovation and Development Center to better meet the needs of the TVMs and the transit authorities

AUBURN UNIVERSITY

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THE OHIO STATE UNIVERSITY TRANSIT RESEARCH AND COMPONENT TESTING SOLUTIONS

Walt Dudek
November 2019

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

The Ohio State University

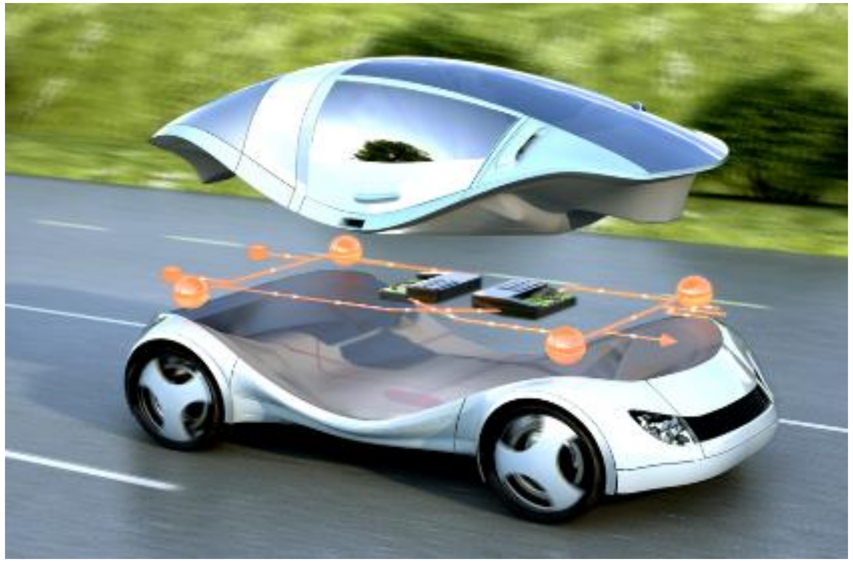
THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

- More than **5,000** researchers
- **18** colleges and schools
- **66,0000+** students across all campuses
- Nearly **$1B** in annual research expenditures
- Ranked in the **Top 20** US Public Universities
- Ranked **fourth** among all U.S. universities in industry-sponsored research, with more than half of that research conducted in the College of Engineering
- The breadth, scope and excellence of our research programs make Ohio State a **leading force of innovation and change** – locally, nationally and globally

Center for Automotive Research

REINVENTING MOBILITY AT CAR

- Advanced powertrain and vehicle electrification for improved efficiency
- Increased vehicle intelligence, connectivity and autonomy
- Net carbon free fuels
- Weight reduction
- New mobility solutions and business models, smart cities, urban logistics



OSU'S FTA LONO COMPONENT ASSESSMENT TEAM

OSU has assembled a team of three world-class laboratories to test components destined for zero emission buses at the **Ohio State's LoNo CAP Test Center**.

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

gti®

TRC

OSU's team are experts at evaluating and documenting performance improvements at the component, system, or vehicle levels.

LABORATORY FOCUS AREAS

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

- Component, System, and Vehicle level evaluations
- HD Chassis Dynamometer Test Facility
- Individual system and component benchmarking for LoNo technologies including energy storage, power electronics, systems integration, and electric chargers

TRC

- Vehicle level evaluations on a private independent proving ground
- Full life durability testing including braking, noise, towing, structural integrity, hoisting, and repair time tracking
- Performance testing including acceleration, gradeability, and top speed
- Autonomous and ADAS component evaluations and test development

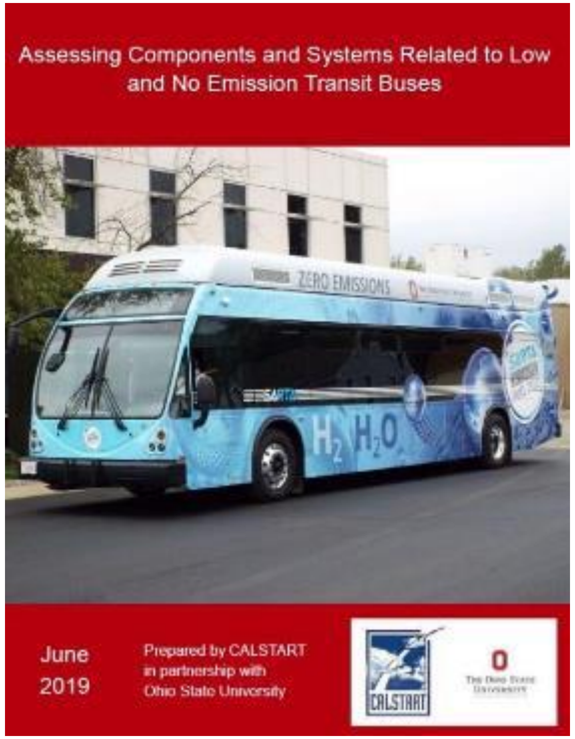
gti

- Component and system level evaluations
- System durability for fuel cell stacks and related systems including lifecycle and performance evaluations
- Gaseous fuel refueling hardware evaluation and performance testing

OSU TRANSIT INDUSTRY SURVEY

Goal - Identification of technological issues which are preventing transit agencies from fully utilizing their LoNo busses

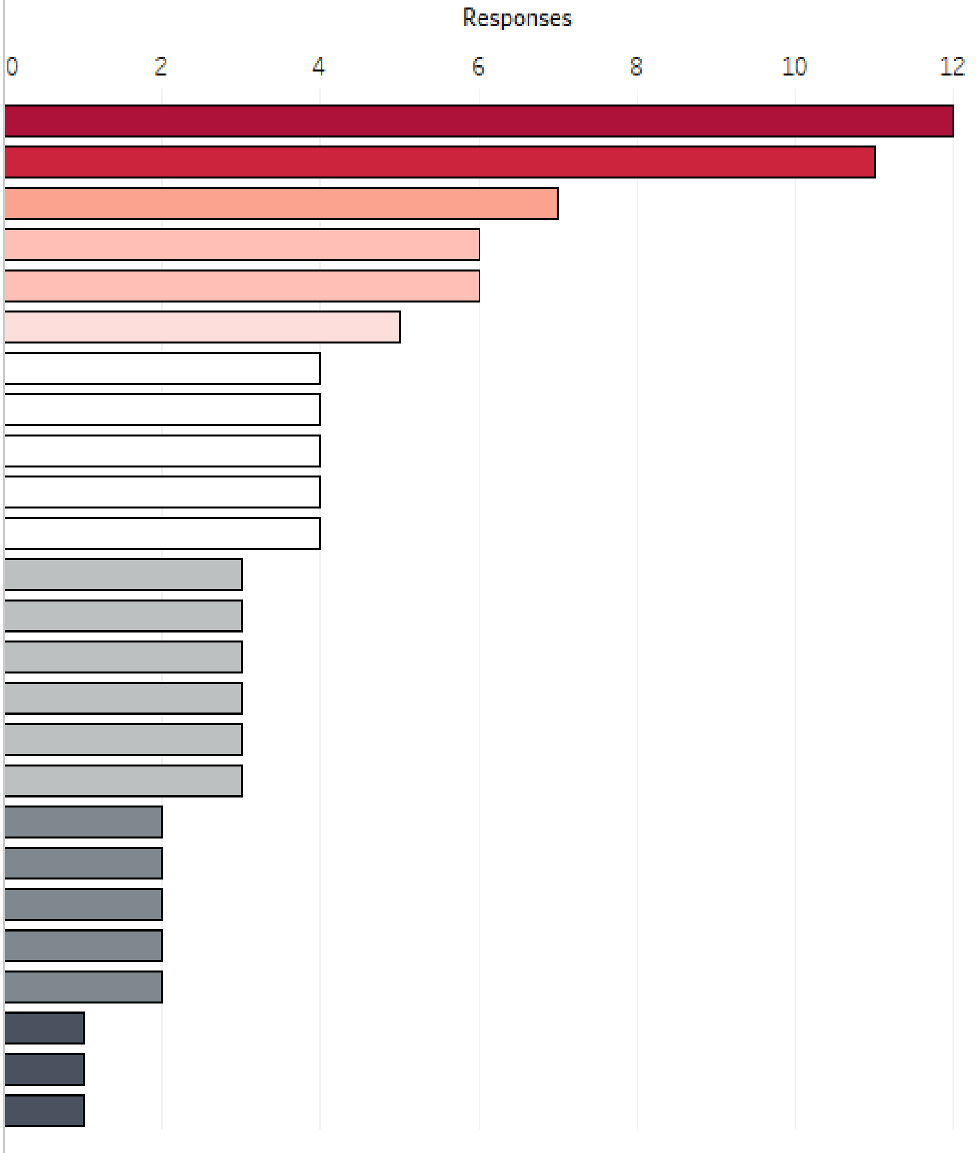
- Survey was self-funded by OSU
- Interviewed 19 organizations including transit agencies, TVMs, and component suppliers
- Full report available at lono.osu.edu



OSU INDUSTRY SURVEY RESULTS

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

No.	Issues
1	HVAC Impact on Range/Fuel Economy
2	HVAC Efficiency in Climate Extremes
3	Third Party Servicing of Parts
4	Air Compressors (Blower Durability)
5	Warranty Response Times
6	Increase H2 Storage Pressure
7	Battery Testing Regarding Performance and Durability
8	H2 Compressors (Blower durability)
9	Human Factor on Fuel Economy
10	Software Glitches
11	Waste Heat Capture
12	"Cheap" Components vs Military Grade
13	Charging System Standards
14	Cooling Systems (Water Pumps & Fans)
15	Fuel Cell Sensors & Valves
16	Fuses
17	Weight Reduction
18	Accessory Drives
19	Bus Yard Positioning
20	Doors and ADA Ramp Operation
21	Hardware Location e.g. roof
22	Small Fans
23	Auto docking
24	Chaining System
25	DC-DC Inverters



OSU INDUSTRY SURVEY RESULTS

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

Laboratory			Rank	Issues
O	TRC		1	HVAC Impact on Range/Fuel Economy
O	TRC		2	HVAC Efficiency in Climate Extreems
	TRC		3	Third Party Servicing of Parts
		gti	4	Air Compressors (Blower Durability)
		gti	6	Increase H2 Storage Pressure
O			7	Battery Testing Regrading Performance and Durability
		gti	8	H2 Compressors (Blower Durability)
O	TRC		9	Human Factor on Fuel Economy
O		gti	13	Charging System Standards
O		gti	14	Cooling Systems (Water Pumps and Fans)
		gti	15	Fuel Cell Sensors and Valves
O		gti	18	Accessory Drives
	TRC		19	Doors and ADA Ramp Operation
O	TRC		20	Hardware Location e.g. roof
O			25	DC:DC Inverters

SAMPLE COMPONENT PROGRAMS – OSU CHASSIS DYNAMOMETER LABORATORY

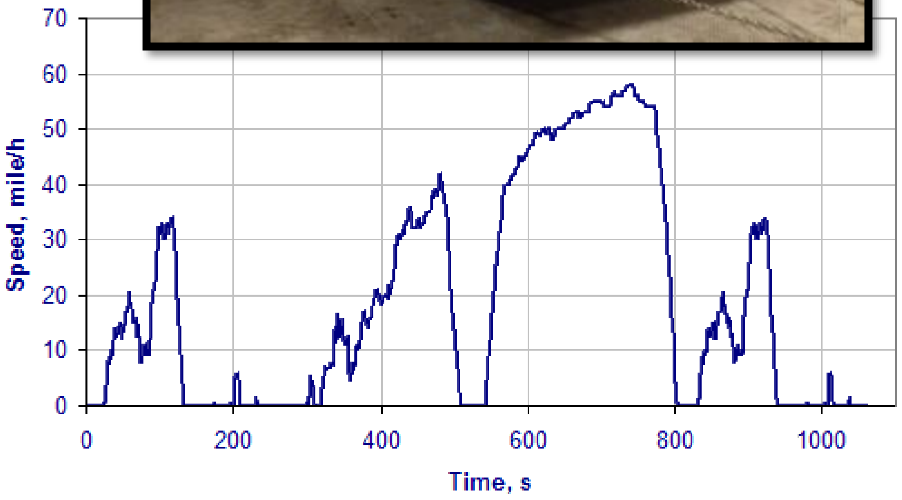
THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

Real-world route performance – vehicle range evaluation over actual in-use route

Electric Range/Fuel Efficiency comparison with terrain and environmental simulation

Evaluation of driver behavior on BEB range

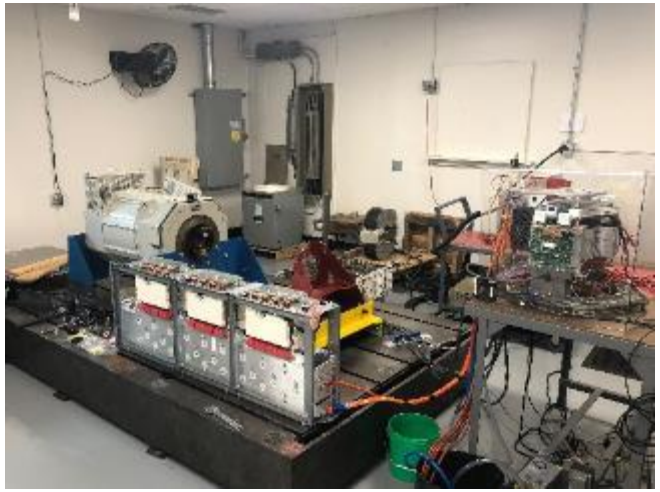
kWh per Mile Rates			
	2.50	3.25	3.75
	2.33	3.00	3.50
	2.75	3.50	4.00



SAMPLE COMPONENT PROGRAMS – OSU POWER ELECTRONICS LABORATORY

Dedicated laboratory space for the development and validation of electrification powertrain system components including drives, motors, and auxiliaries

- Focus on e-mobility including electric machines, power electronics, electrical driveline components, and micro-hybrid start/stop systems
- Linked systems including thermal management, energy storage, control systems hardware and software, and auxiliary electronics
- Controlled operating conditions



Evaluation of efficiency and durability of driveline motors and components

DC:DC Inverter performance testing

Hardware-in-the-loop analysis of system component changes

SAMPLE COMPONENT PROGRAMS – OSU ENERGY STORAGE LABORATORY

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

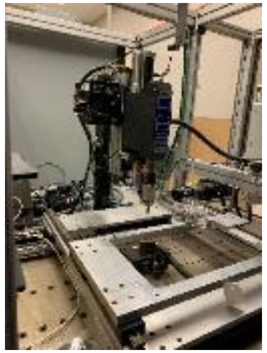
- Battery Cycling Lab
- High Voltage Lab
- BMS/HIL Lab
- Pack Fabrication Lab

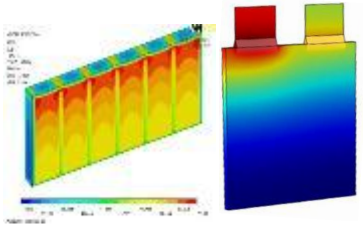
Cell/Module Cycler

Arbin INSTRUMENTS

MACCOR

Spot Welder →



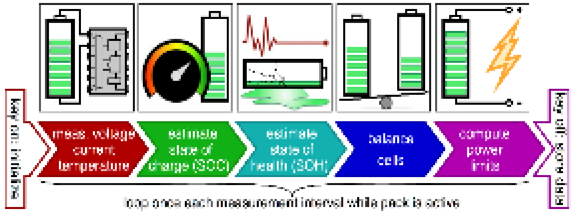


Thermal Management

Independent verification of pack performance characteristics

In-use measurement of current pack capacity and state of health

Evaluation of environmental impact on pack performance and lifecycle



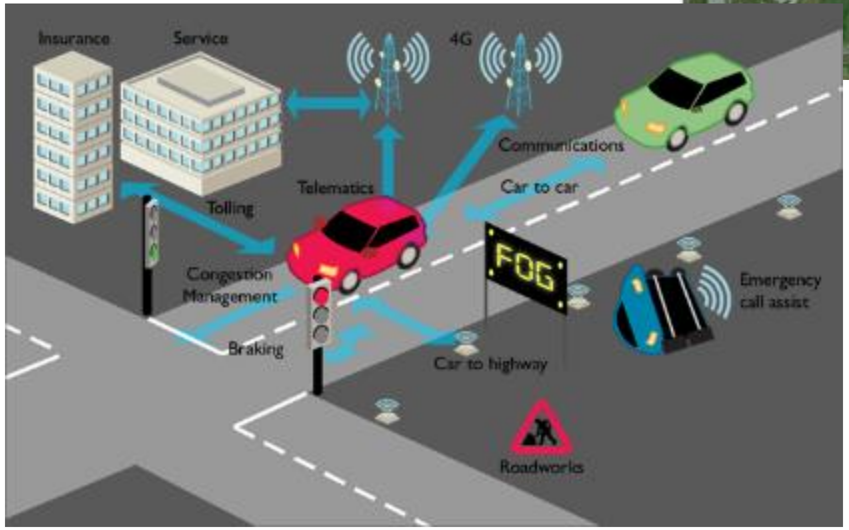
dSPACE

NATIONAL INSTRUMENTS

MathWorks

SAMPLE COMPONENT PROGRAMS – TRC PROVING GROUND FACILITY

- Bus durability course
- Smart Center
- Vehicle dynamic test area
- 24/7 Mechanic support



Controlled on-road efficiency evaluation

Determination of the service impacts of component changes

Functional impacts of accessory or loading changes

Automation/ADAS impacts on efficiency or driver performance

SAMPLE COMPONENT PROGRAMS – GTI HYDROGEN LABORATORY

Focus Areas

- Innovation, Design, Fabrication, Deployments, Operations, Data Collection/Analysis, Codes & Standards, Hazard Reviews

Capabilities

- Large-Scale Environmental Chamber
- Three-Bank, High-Pressure Hydrogen Cascade
  - Wide Temperature Range (-40 to 160ºF)
  - Fully Instrumented
    - Precision scale, mass flow meters, high-speed data acquisition
  - 700 bar (10ksi) H2 testing
- Fuel cell testing capabilities

Fuel cell stack performance, durability, and lifecycle testing

Fuel cell component durability evaluations + component replacement evaluations

Analysis of storage pressure impacts on system range and efficiency

CONTACT

car.osu.edu

Walt Dudek

Director, Commercial Vehicle Research and Test Laboratory

Dudek.12@osu.edu

Penn State Bus Research and Testing Program

November 2019
Transit Bus Component Technology Forum,
East Liberty, Ohio

David Klinikowski
Director, Bus Research and Testing
Assistant Research Professor
Larson Transportation Institute
College of Engineering
Penn State University
University Park, Pa

PennState
College of Engineering

Presentation Objective

- Overview of Penn State Program
- Overview of Facilities and Tests
- Penn State Low-No Testing Capabilities
- Future Needs

The Penn State "Altoona" Bus Testing Program

- Penn State. Test track is independently owned and operated, non-profit
- Program established in 1989 by STURRA legislation
- Penn State developed testing procedures and protocols for Diesel, CNG, LNG, propane, methanol, hybrid-electric, battery electric and hydrogen fuel cell buses
- Penn State developed the Pass/Fail protocol with FTA for bus testing
- 30 years of Penn State bus testing experience at one facility provides consistent, repeatable test results that allows standardized comparison of bus models

A2LA

ACCREDITED

Mechanical Testing Certificate 3172.01

Penn State is a certified and accredited laboratory under ISO-17025 for bus testing

Mandated Tests

Eight evaluation categories

1. Maintainability
2. Reliability
3. Safety-Braking
4. Performance
5. Structural Integrity and Durability
6. Fuel Economy
7. Noise
8. Emissions

Opportunity for Additional, Affordable, Proprietary Testing

- Manufacturers often collect additional non-mandated test data on components and systems for little to no cost during the normal test program
- Components are tested operating under real-world conditions on a bus in simulated transit service
- Penn State technicians and engineers work with manufacturers to obtain maximum benefit from testing
- Collected data is proprietary

Typical Non-Mandated Testing Performed at Altoona

- Electric vehicle battery performance and Durability
- Electrically driven accessories
- Drive motors, gear boxes and drive axles
- Inverters, DC/DC converters
- Charging systems/efficiency
- Controls and diagnostic systems
- Data collections for model validation

Penn State's Extensive Experience

486 Bus Models Tested

Number of Buses	Service –Life Category
197	12-Year, 500,000 Mile
78	10-Year, 300,000 Mile
130	7-Year, 250,000 Mile
26	5-Year, 150,000 Mile
55	4-Year, 100,000 Mile

38 Low-No buses tested since 1998

9700+ Failures Encountered

Battery and electric drive components
Chassis/structure
Suspension
Engine/drive train
Exhaust/emissions
Electrical wiring (high and low voltage)
Air conditioning/heating
Brakes/axles
Steering/electric electric
Fuel systems/CNG cylinders
Seats/lifts/doors/windows

Quantity and Class of Failure

CLASS 1:	Potential for serious injury or crash	46
CLASS 2:	Bus inoperable, interrupting service 184	215
CLASS 3:	Bus operational but must be removed from service	5,175
CLASS 4:	Degrades operation, may be repaired during next scheduled service	4,338
TOTAL:		9,774

Based on data from 486 buses completing structural durability test as of June 2019.

Body Cracking

Frame Rail Crack

Altoona Facility

- 7,000 Square ft. facility
- Bus maintenance and repair
- 4 testing and maintenance bays
- Administrative Offices

Penn State Test Track Facilities

Test Capacity

- Over the past 10 years, the average number of buses submitted for testing was 15 buses per year
- Approximately 1/3 third were partial tests
- Penn State facility can test 14 buses simultaneously
- Penn State has two structural durability test tracks (unused capacity)
- Capacity can be increased by adding additional staff
- Delays in total testing time are largely caused by the FTA approval process and from failures, parts deliveries, etc. during testing
- Track currently operates 24 hours/day, 6 days/week

Pennsylvania Safety Transportation and Research Track
PennSTART

- Testing and hands-on training for new ITS, tolling, and signal equipment;
- Safe, simulated training for higher-speed and mobile work-zone operations;
- Safety certification training opportunities;
- Simulated environments for temporary traffic control device testing and evaluation;
- Smart truck-parking applications and other opportunities for commercial vehicle technology partnerships; and
- Controlled environments to test various connected and automated vehicle technologies for infrastructure equipment, fleets, and other applications.

PennStart Facility Concept

Low-No Testing Capability

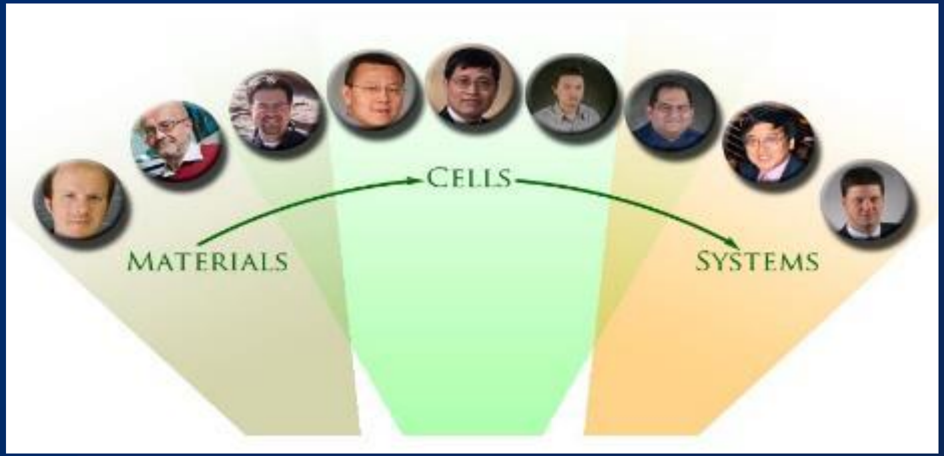
Vehicle Testing Laboratory

- 10,000 ft^2 maintenance/testing
- Large-roll (72-in diameter) dynamometer
  - Horiba Automotive Test Systems
  - Electronic simulation
- Battery/electric drive test area
  - Aerovironment AV-900, ABC-150
  - 250kW power processing
  - Large environmental chamber for EV component testing (-65 to 85 C)
- Full-Scale Emissions Laboratory

Low-No Facilities

- Facilities Include:
  - Battery Charging
  - Hydrogen fueling station
  - LNG, CNG, Propane, gasoline, diesel
  - Hardware-in-the-loop test and simulation

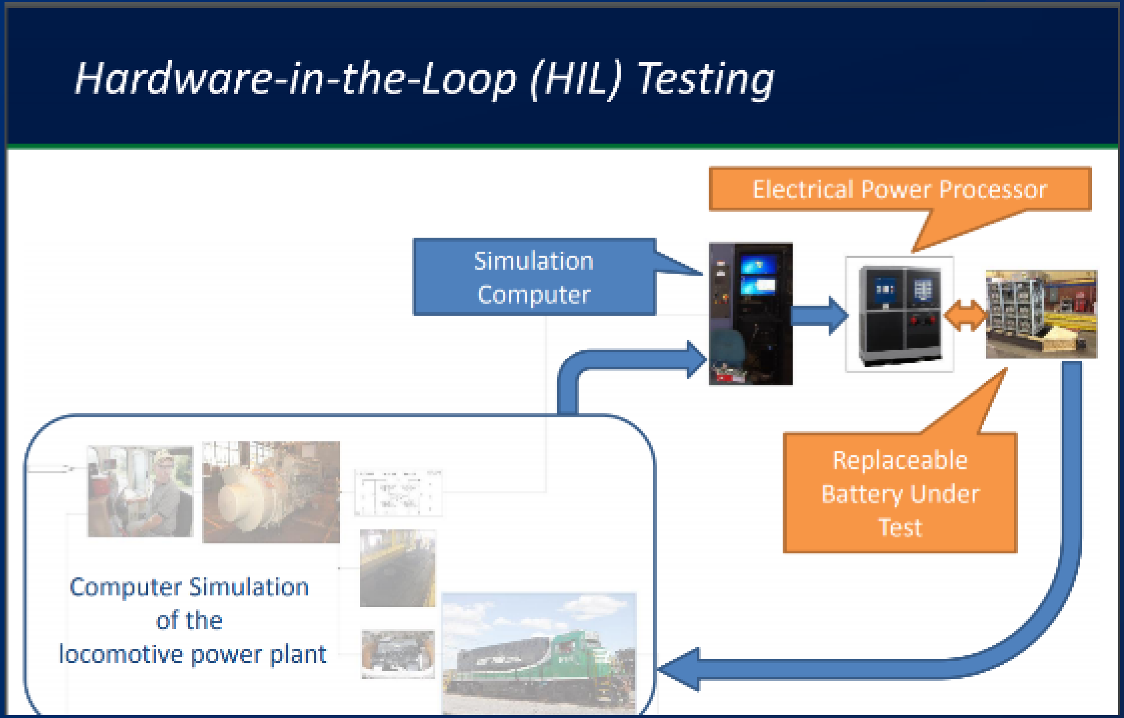
Penn State Advanced Vehicle Technology



- Battery & Energy Storage Technology (BEST Center)
  - Electrochemical Laboratory
  - Materials Chemistry and Polymer Synthesis Lab
  - Energy Nanostructure Lab
  - Electrochemistry Engine Center
  - Battery manufacturing Lab
  - Mechatronics Research lab
  - Battery Testing Lab

Battery System Testing

Individual Cells up to Full Pack



Electrical and Thermal Modeling
Battery Safety Monitoring
System Characterization
Power Optimization

Penn State Advanced Vehicle Team

EV Education and Training:

The interdisciplinary group of students that make up Penn State's Advanced Vehicle Team are doing more than working on cars. Their projects will impact the hybrid-electric vehicle industry, furthering the pursuit of better, more sustainable transportation.

Penn State Hydrogen Research (H_2E Center)

Penn State Center, Future Needs

- From 1998 through 2018, funding was flat at $3 Million per year (20 years with no increase, while CPI rose over 50%)
- Supplemental funding was recently provided to cover salaries
- Funding shortage resulted in deferred repair and replacement of equipment and personnel cuts
- Continued operation beyond 2021 will require a level of funding at $5 Million/year

10:00 – 10:45 a.m.

Electrified Thermal Cooling and Heating Systems

Moderated by Ben Mandel, CALSTART

Jason House, Chicago Transit

Attila Illes, Eberspaecher

Steve Johnson, Thermo King


JASON HOUSE
Asst. Chief Bus Equipment Engineer
11/07/2019
NOT IN SERVICE
electric bus
NOT IN SERVICE
cta
701

Heating - Pull Up Requirement

From 2013 APTA Bus Procurement Guidelines (BTS-BPG-GL-001-13)

ALTERNATIVE

Colder Ambient Conditions

The pull-up requirements for the heating system shall be in accordance with Section 11.1of APTA's *Recommended Practice* "Transit Bus HVAC System Instrumentation and Performance Testing." With ambient temperature at -20 °F, and vehicle cold soaked at that temperature, the bus heating system shall warm the interior passenger compartment to an average temperature of 70 °F ±2 °F within 70 minutes.

Heating – Summary

Key Points

- Electric bus heating is a challenge.
- Lack of diesel engine greatly reduces heating source for electric bus.
- Diesel fired aux heater is a must for Chicago climate.
  - Improves driving range by reducing HVAC electrical demand
  - Not popular for the clean / green story.

- Solution TBD
  - Bigger aux heaters? Modular? With modulating burners?

Cooling - Pull Down Requirement

From 2013 APTA Bus Procurement Guidelines (BTS-BPG-GL-001-13)

DEFAULT

Capacity and Performance Requirements

The air-conditioning portion of the HVAC system shall be capable of reducing the passenger compartment temperature from 115 to 95 °F in less than 20 minutes after engine start-up. Engine temperature shall be within the normal operating range at the time of start-up of the cool-down test, and the engine speed shall be limited to fast idle, which may be activated by a driver-controlled device. During the cool-down period, the refrigerant pressure shall not exceed safe high-side pressures, and the condenser discharge air temperature, measured 6 in. from the surface of the coil, shall be less than 45 °F above the condenser inlet air temperature. The appropriate solar load as recommended in the APTA "Recommended Instrumentation and Performance Testing for Transit Bus Air Conditioning System," representing 4 p.m. on August 21, shall be used. There shall be no passengers on board, and the doors and windows shall be closed.

ALTERNATIVE

Hotter Ambient Conditions

The air conditioning portion of the HVAC system shall be capable of reducing the passenger compartment temperature from 110to 70°F ±3°F in less than 30 minutes after system engagement for 30, 35 and 40ft buses. Engine temperature shall be within the normal operating range at the time of start-up of the cool-down test, and the engine speed shall be limited to fast idle at three-quarters max governed speed that may be activated by a driver-controlled device. During the cool-down period, the refrigerant pressure shall not exceed safe high-side pressures, and the condenser discharge air temperature, measured 6 in. from the surface of the coil, shall be less than 45 °F above the condenser inlet air temperature. No simulated solar load shall be used. There shall be no passengers on board, and the doors and windows shall be closed.

Cooling - Summary

Key Points

- Cooling performance on electric bus meets criteria.
  - Performance about the same as diesel bus. Slight improvement due to lack of diesel engine.

Stabilization Requirement

From 2013 APTA Bus Procurement Guidelines (BTS-BPG-GL-001-13)

Interior temperature distribution shall be uniform to the extent practicable to prevent hot and/or cold spots. After stabilization with doors closed, the temperatures between any two points in the passenger compartment in the same vertical plane, and 6 to 72 in. above the floor, shall not vary by more than 5 °F with doors closed. The interior temperatures, measured at the same height above the floor, shall not vary more than ±5 °F from the front to the rear from the average temperature determined in accordance with APTA's "Recommended Instrumentation and Performance Testing for Transit Bus Air Conditioning System." Variations of greater than ±5 °F will be allowed for limited, localized areas provided that the majority of the measured temperatures fall within the specified requirement.

Stabilization Key Points

- In the past, CTA has experienced large temperature gradient from front to rear on diesel buses.
- Rear seat bench area too hot.
  - Caused by poor airflow distribution and proximity to engine

- Dedicated insulated ducting throughout bus improves temperature uniformity.
  - Controlled pressure drops throughout length of bus for even airflow
  - Minimizes losses to ceiling compartments (improves supply air temp at vents)
  - Maximizes airflow mixing

New and Future CTA HVAC Strategies

CTA HVAC Strategies for current and future procurements

- Driver Heated Seats
- Hydronic aux heat convector heat in drivers area
- Dedicated HVAC ducting for improved airflow.
- Minimum airflow requirements
- Ensure data is captured in rear most row of seats (additional set of thermal couples beyond APTA recommended instrumentation standard) for HVAC testing
    - Add: Rear temperature sensor for monitoring (non control) located at the furthest aft passenger seating.

Questions

?

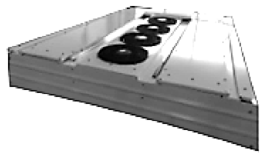
Climate Control Systems Bus & Coach

A WORLD OF COMFORT

Eberspächer

Thermal Management Hybrid & Electric bus

Air-Conditioning Heat Pump



Hydronic L

Hydronic M

Airtronic

Air-Conditioning Heat Pump

Electrical water heater

Air-Conditioning All-Electric

Electrical water heater

Drivers seat AC system

Convector

Heater blower

Control unit

Water pump

Transit Bus Component Technology Forum
November 6-7, 2019

All-Electric HVAC System Efficiency

All-Electric HVAC Systems

It Started A Long Time Ago With The ATTB
Advanced Technology Transit Bus – 1996/97

All-Electric HVAC System

Benefits:

- Saves fuel by eliminating the effect of variable engine RPM on load and demand
- Optimum A/C unit capacity at all bus speeds
- Dramatically improved reliability
- Hermetically sealed and tested at the factory, no field plumbing, evacuation and charging
- Integrated electric compressors with variable speed control
- Reduced number of maintenance items
- No tubing or hoses needed in engine compartment to connect the HVAC unit and compressor
- Energy efficient R407C refrigerant

Defining HVAC System Efficiency

- Where do you want to go? 110 degrees F to 70 degrees F? How long should it take? Average 60K BTU/HR stabilized?
- The amount of power being input (Kw) vs the amount of power being used to achieve a defined output (Kw) determines efficiency.
- If the output of the HVAC system needs to be 18 Kw, how many Kw is required to achieve that output?
- There may be more than one method to achieve the 18 Kw output. Which method requires the least input to get there?

Strategies to Improve HVAC Efficiency

- Use smaller capacity compressors requiring less power at pull down but enough capacity to cool the bus at a constant BTU/HR

- A programmable and configurable microprocessor capable of reading pressure and temperature transducers, controlling frequency and making decisions to adjust the loads based on the demand for cooling.

Strategies to Improve HVAC Efficiency

• Variable frequency control for the electric compressors, 75Hz for pull down and variable down to 25Hz to match load demand

• Battery chilling / heating systems integral to the HVAC system rather than stand-alone systems.

• Variable frequency or voltage to control fan and blower speeds will reduce the parasitic load vs one or two fixed speeds

- **The current pull down specifications do not provide an accurate assessment of the performance capability of the electric HVAC unit.**

- The opportunity exists to create a specification based on delivered capacity under real life operating conditions.

- The power consumption for the same amount of cooling is less with the all-electric HVAC.

- The all-electric HVAC unit provides the same capacity regardless of engine speed and may be sized smaller than the conventional system because the excess capacity is not needed.

- **The Houston Pull Down is a test to prove only that the HVAC system will cool the bus on a hot day.**

- Buses are not operated like the Houston Pull Down test.

- Electric HVAC shows what the bus can do under normal operation. How much capacity is available at engine idle?

- The White Book Pull Down, although it's based on engine RPM as well, has proven to be a more realistic specification for all-electric HVAC systems until an industry wide specification is created for all-electric HVAC.

HVAC Efficiency and Passenger Comfort

- HVAC operation costs money but it has been accepted that we will pay to achieve passenger comfort.

- The HVAC has always been the single largest load on the bus and striving for better efficiency is not a new initiative.

- The traditional measure of efficiency has been fuel economy. The new measure of efficiency for E-Buses is battery range.

- Turn off the HVAC and fuel economy goes up and the batteries will maintain their charge and range will go up.

- The goal is to get the most efficient package possible without sacrificing passenger comfort.

10:45 – 11:30 a.m.

Electric Axles and Wheel Motors

Moderated by Jason Gies, Navistar

Jim Castelaz, Motiv Power Systems

Jim Keane, Meritor

Keith Rubenacker, Zf North America

Edwin Shaw, E-traction

MOTIV POWER SYSTEMS

Freeing Fleets from Fossil Fuels

Transit Bus Component Technology Forum

November 7, 2019

Jim Castelaz

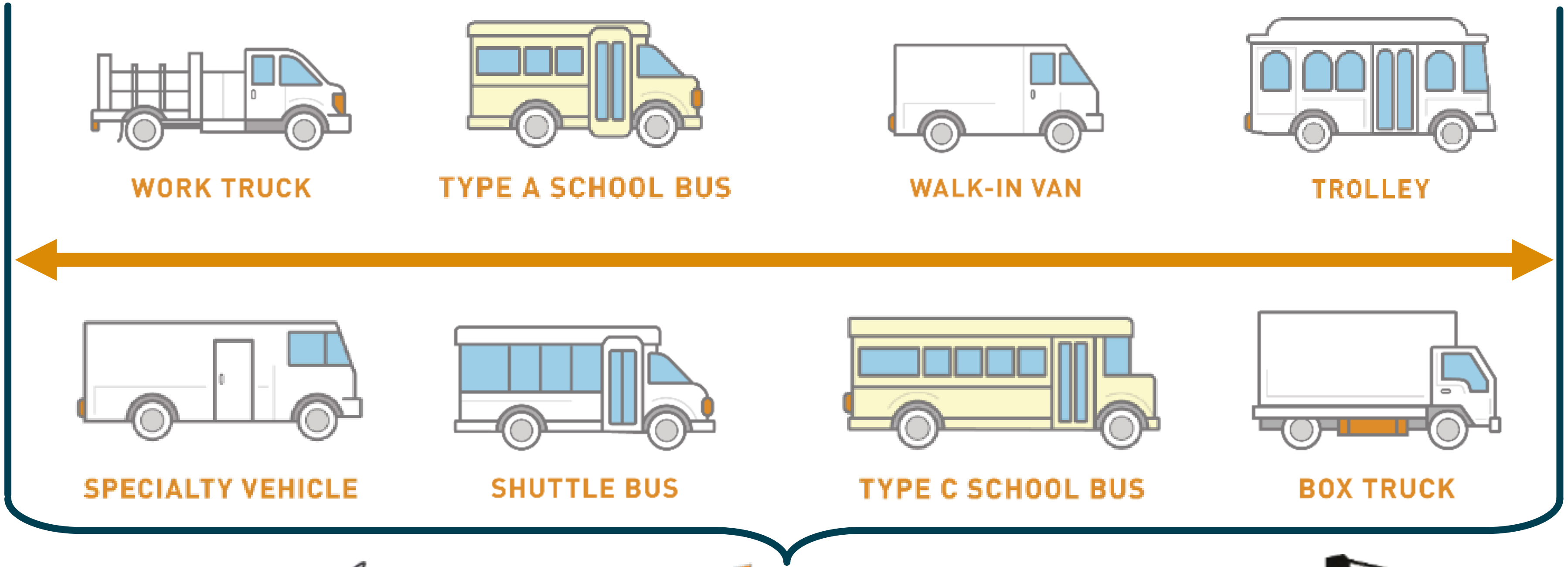
Founder and CTO

Intro to Motiv Power Systems

- Software and power electronics specialists in the commercial EV market with over 20 patent applications and 10 patents awarded protecting our IP
- Ford eQVM approved all-electric chassis built with commercially proven components
- Industry leading truck and bus body partners
- HQ in San Francisco Bay Area, chassis electrification in Indiana and Michigan

Motiv-powered All-Electric Trucks and Buses

Our Focus – Medium Duty Trucks and Buses



Passenger Cars

High volume/model
Low Configurability

Class 8 Trucks

Medium volume/model
Low Configurability

OEMs Not Focused on Medium Truck – The Complexity and Diversity Requires Unique Technology Which Motiv Has Developed. Low Infrastructure Costs Given Overnight Depot Parking Ease Fleet Conversion Costs.

Vehicle Applications and Body Partners

EPIC E-450
Class 4

CHAMPION® REV GROUP
COLLINS® REV GROUP
TRANS TECH
Rockport COMMERCIAL VEHICLES
CTEC
UTILIMASTER A SPARTAN MOTORS COMPANY

EPIC F-59
Class 5/6

UTILIMASTER A SPARTAN MOTORS COMPANY
SUMMIT BODYWORKS
STARCRAFT BUS a division of Forest River, Inc.

EPIC F-53
Class 6

WINNEBAGO
SUMMIT BODYWORKS
HOMETOWN TROLLEY GREEN

MOTIV

History – Technology Development

2009
Founded

2012
Launched Prototype All-Electric powertrain at NTEA Work Truck Show

2013

1st E-450 Type A Electric School Bus deployed in California (industry first)

2015

- E-450 Google shuttle buses deployment
- F-59 AmeriPride step vans deployment

2016

- Increased Deployments / Repeat Orders
- CARB Approval for powertrain

CALIFORNIA
AIR RESOURCES BOARD

2017

- Ford eQVM approval (industry first)
- F-59 Type C with Forest River and Creative Bus Sales

eQVM

FOREST RIVER

First 8 Years Focused on Software and Power Electronics Technology Development, Primarily Grant-Funded

History – Commercialization

2018

- CARB Certified for electric chassis
- New Partnerships

2019

- All-Electric USPS step van deployed
- BMW Lithium Ion battery packs
- New customers and partners
- F-550 Prototype with Dana

Last 2 Years Focused on Major Fleet Customers, New Battery Technology and Shift to Product Revenue


MOTIV
DANA
SPICER
ELECTRIFIED WITH tm4

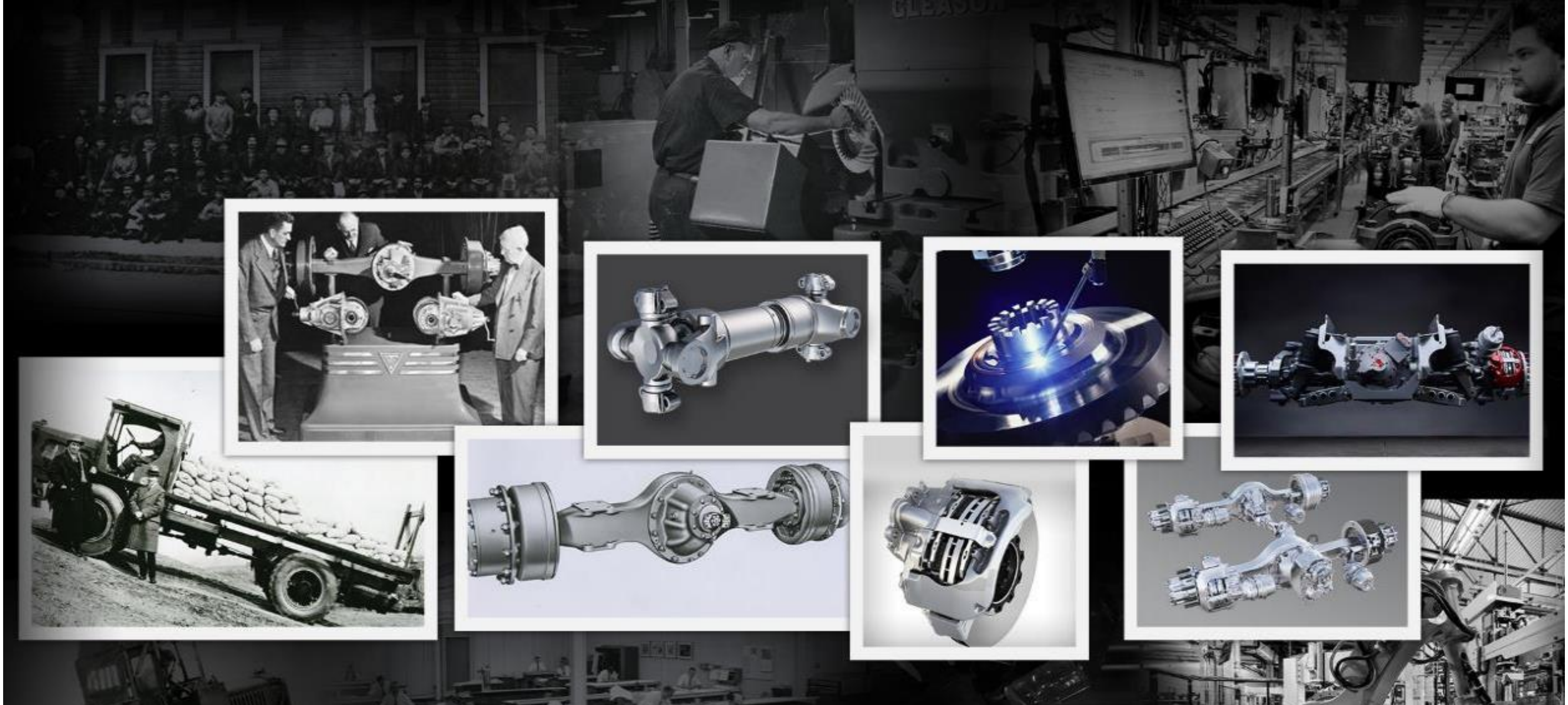
MOTIV POWERED

EPIC All-Electric Chassis for Class 4 - 6 Applications

Thank You

Meritor eMobility Solutions

Jim Keane
Director, Specialty



More than 100 years of serving our customers with axles, brakes, drivelines, and aftermarket solutions.

Global Footprint and Market Leadership Positions

9 GLOBAL OFFICES

Osasco, Brazil
Shanghai, China
Mysore, India
Cameri, Italy
Yokohama, Japan
Hoofddorp, Netherlands
Zurich, Switzerland
Redditch, UK
Troy, Michigan, USA*

10 MAJOR TECHNICAL CENTERS & ENGINEERING OFFICES

Sunshine, Australia
Osasco, Brazil
Shanghai, China
Suzhou, China
Bangalore, India
Mysore, India
Cameri, Italy
Ciénega de Flores, Mexico
Cwmbran, UK
Troy, Michigan, USA

10 DISTRIBUTION CENTERS

Derrimut, Australia
Osasco, Brazil
Edmonton, Canada
Mississauga, Canada
Neuwied, Germany
Pune, India
Ciénega de Flores, Mexico
Cwmbran, UK
Santa Fe Springs, California, USA
Florence, Kentucky, USA

37 MANUFACTURING SITES

Sunshine, Australia
Steyr, Austria
Caxias do Sul, Brazil
Osasco, Brazil (2)
Resende, Brazil
Xuzhou, China
Vrchlabí, Czech Republic
Saint-Étienne, France
Vénissieux, France
Jamshedpur, India
Mysore, India
Pantnagar, India
Pune, India
Cameri, Italy
Ciénega de Flores, Mexico
Escobedo, Mexico
Jurong Town, Singapore
Lindesberg, Sweden
Izmir, Turkey
Cwmbran, UK
Livermore, California, USA
Chicago, Illinois, USA
Plainfield, Indiana, USA
Florence, Kentucky, USA
Frankfort, Kentucky, USA
Franklin, Kentucky, USA
Howell, Michigan, USA
Livonia, Michigan, USA
Fletcher, North Carolina, USA
Forest City, North Carolina, USA
Laurinburg, North Carolina, USA
Morganton, North Carolina, USA
Manning, South Carolina, USA
York, South Carolina, USA
Morristown, Tennessee, USA
Oshkosh, Wisconsin, USA

7 JOINT VENTURES

Caxias do Sul, Brazil
Xuzhou, China
Vénissieux, France
Mysore, India (2)
Escobedo, Mexico
Izmir, Turkey

APPROXIMATELY 9,300 EMPLOYEES IN 19 COUNTRIES

MERITOR
RUN WITH THE BULL

*World Headquarters
Note: Leadership positions based on market data and management's estimate relative to independent, non-captive suppliers competing in the same addressable markets.

Specialty Business at Meritor

Bus & Coach

GILLIG
ELDORADO REV GROUP
PREVOST
MOTOR COACH INDUSTRIES
NOVABUS
NEW FLYER

Construction & Utility

DAIMLER
NAVISTAR
TEREX
PACCAR
OSHKOSH
GRADALL
AUTOCAR
GLOBAL ENVIRONMENTAL PRODUCTS
Lodal

Fire & Emergency

Pierce
SUTPHEN
Seagrave
rosenbauer
REV
HME AHRENS-FOX
E-ONE
SPARTAN
FERRARA
smeal
KME KOVATCH

Terminal Tractor

KALMAR OTTAWA
TICO
CAPACITY REV GROUP

Many Leading Electrification Markets

MERITOR
RUN WITH THE BULL

Our eMobility Vision

To be a recognized leader in providing advanced eMobility solutions for the global commercial vehicle and industrial markets

MERITOR
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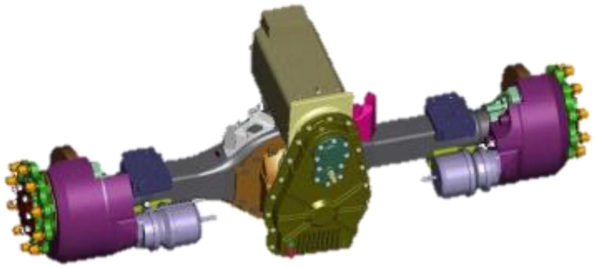
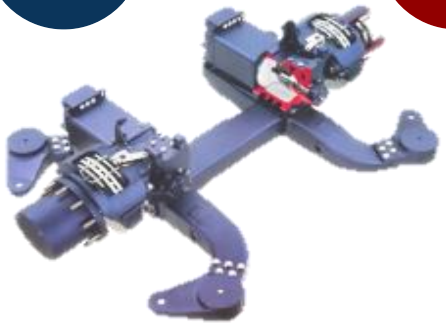
Long History in eMobility



RE-17-345 eAxle
Mercedes CITO
9m transit bus
600+ produced

1998

1999



Low Floor eAxle
12m low floor transit bus
Low volume production

2006

eCorner Module
7t delivery van
Demonstrator

EV Systems
Vehicle controls
Battery packs
e-Accessories

2012

Tri-Mode Hybrid Drive Unit
26-40t regional haul
SuperTruck demonstrator

2016+

MERITOR
BLUE HORIZON™

Efficiency

- High efficiency technologies that improve fuel economy

Connectivity

- Smart & connected products that monitor components real-time and predict future behavior

Electrification

- e-Solutions that enable best-in-class efficiency, packaging, and weight

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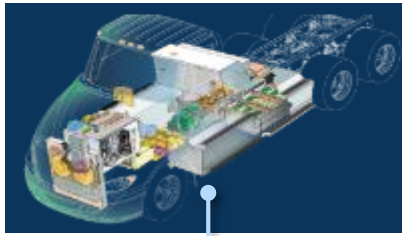
eMobility Strategy Overview

ECO Carriers (1)
- Designed for regen braking
- Specialized gear designs
- Quiet gears

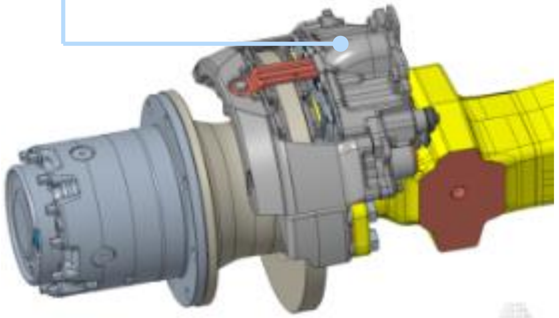
ECO Gearboxes
- Purpose-built
- Bolt-on motors
- Multi-stage



EV Systems
- Vehicle controls
- Electric powertrain
- Battery pack
- System integration

Evolution ⟷ Revolution

ECO Brakes
- Designed for lighter duty
- Thinner pads & rotor
- 25 lbs weight reduction per axle



eAxles
- eCarrier
- Motor & inverter
- Shifting controls
- ECO gearing

Strategy covers a spectrum of products from Evolution to Revolution

(1) - **ECO** = **E**lectric **CO**mpatible

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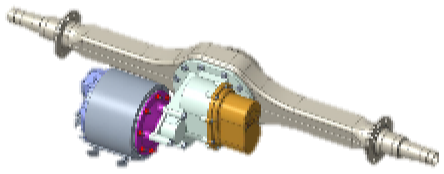
eAxle Platform Strategy Overview

10Xe

up to 130 kW (cont)

4-6t gvw trucks and vans

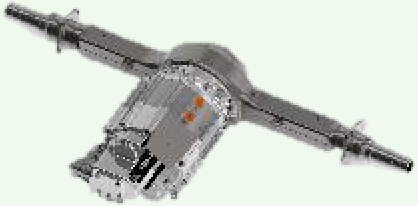


Future product, A-sample design to begin in 2021

12Xe

up to 180 kW (cont)

6-12t gvw light trucks and minibuses



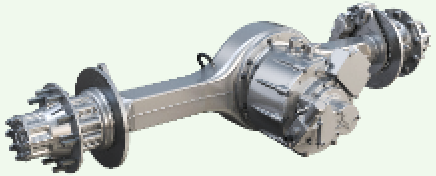
B-sample vehicle testing planned for 1Q20, SOP mid-2021

14Xe

up to 200 kW (cont)

9-26t gvw 4x2

26-40t gvw 6x4



B-sample vehicle testing currently underway, C-sample in mid-2020, SOP early 2021

17Xe

up to 400 kW (cont)

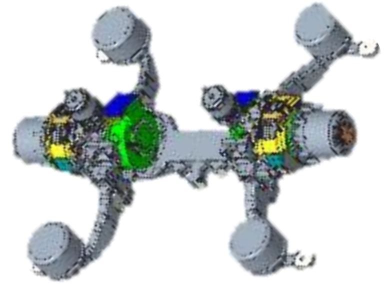
26-44t gcw
4x2 & 6x2 trucks

A-sample design under development, vehicle testing planned for late 2020

e-ULFA

up to 400 kW (cont)

15-26t gvw
low floor buses



Future product, A-sample design to complete in 2021

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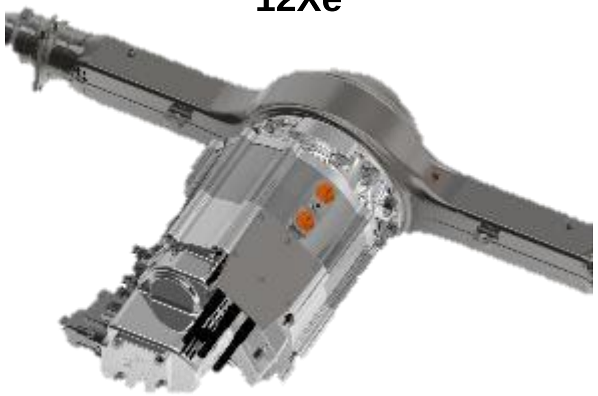
eAxle Design Philosophy

12Xe



14Xe

17Xe

3 Primary Design Principles

1) **Maximize integration**

   - *Minimizes weight and improves packaging*

2) **Maximize modularity**

   - *Widens application range to increase scale*

3) **Leverage existing Meritor components at scale**

   - *Reduces risk and product cost*

- Housings
- Bevel gears
- Differentials
- Shifting
- Planetaries

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12Xe / 14Xe eAxle Modularity

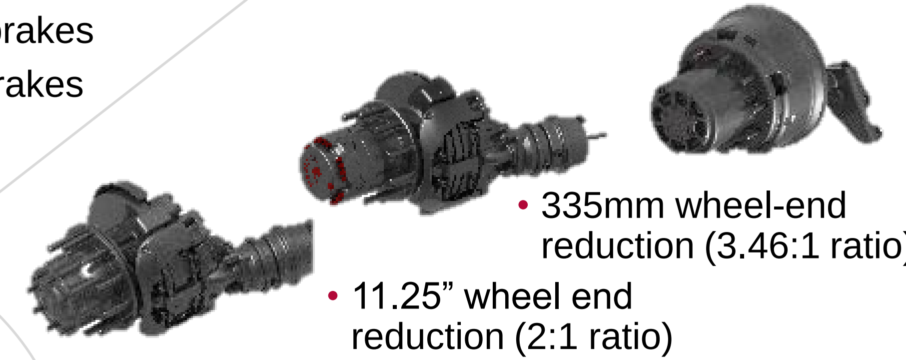
Housing

- Independent Suspension
- Fabricated housing
- Cast housing

Brakes

- Disc brakes
- Drum brakes
- ECO brakes

Wheel End



- 335mm wheel-end reduction (3.46:1 ratio)
- 11.25” wheel end reduction (2:1 ratio)
- Single reduction

eAxle

Electric Motor

- Continuous Power / Peak Torque
  - 130kW / 760Nm
  - 150kW / 1,000Nm
  - 180kW / 1,000Nm
  - 200kW / 1,100Nm

Gearing

- 390mm bevel (14Xe)
- 340mm bevel (12Xe)
- Wide range of ratios from 3.0 to 6.57:1

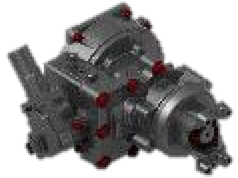
Transmission

Planetary (v3.0)

- 1-speed (2.67)
- 2-speed (2.67, 1)

Dual Countershaft (v4.0)

- 2-speed (5.6, 2.8)
- 3-speed (5.6, 2.8, 1.4)



- e-PTO

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Global Electric Vehicle Programs

3 PROGRAMS

- Urban bus

16 PROGRAMS

- Linehaul
- School bus
- Yard tractor
- Forklift
- Refuse
- MD Trucks

5 PROGRAMS

- Urban bus
- Urban delivery
- MD/HD Trucks
- Trailer

Meritor Content

CORE

- Front and rear suspensions
- Wheel ends
- Drum brakes
- Disc brakes
- Gear box

ELECTRIC

- eAxle
- Battery pack
- Single and dual motor
- Fuel cell and storage

Meritor intends to lead in the development electric drivetrains globally

MERITOR
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Thank You

MERITOR
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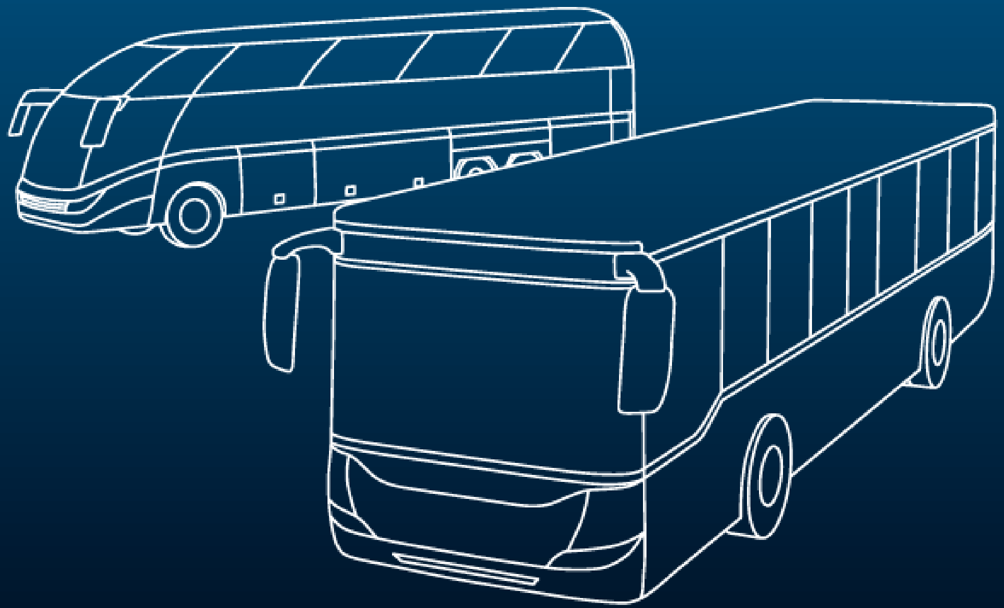
Transit Bus Component Tech Forum 2019: Electric Axle Panel

Keith Rubenacker | Application Engineering | TUN

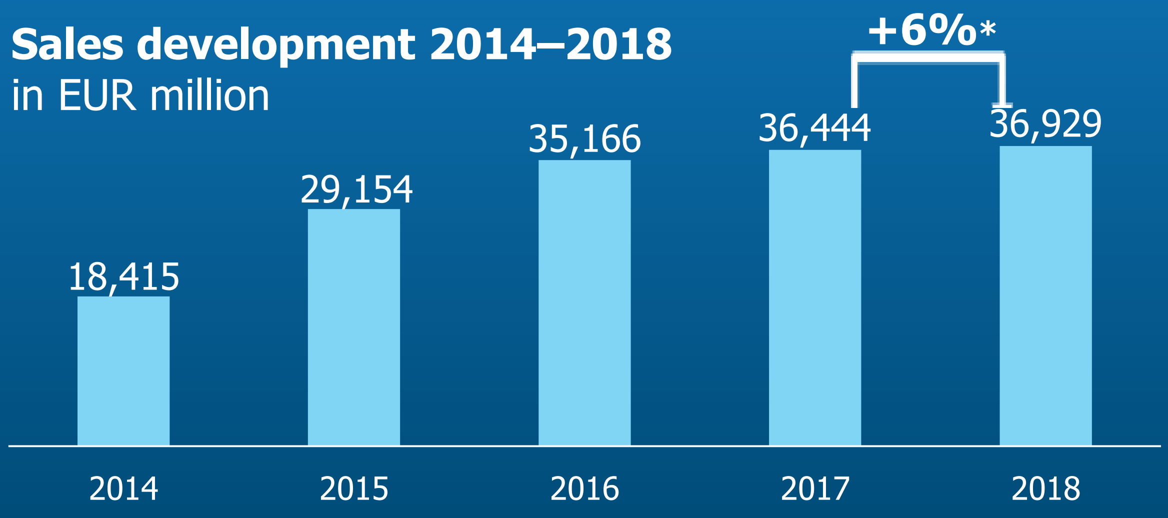


Keith Rubenacker – Application Engineering Manager

- Contact Info: Keith.Rubenacker@zf.com, (847)-478-6836
- 2019: Responsible for Transmission, Axle, and eMobility Technology for NA Bus and Coach
- 1994 – 1997: GM Institute Engineering Coop with ZFVH – Application Engineering NA Bus
- 1998 – 2001: Application Engineer NA Bus – Ecomat (Transit Bus)
- 2002 – 2003: Application Engineer NA Bus – Ecomat (Transit Bus) & ASTronic (Coach/Crane)
- 2004 – 2016: Application Engineering Manager / Application Engineer ASTronic (Coach/Crane)
- 2016 – 2019: Application Engineering Manager / Application Engineer EcoLife/CeTrax (Bus & Coach)

ZF – A Growing Company

Sales development 2014–2018
in EUR million



* Organic growth 2018.

Employees 2018 (end of the year)			
Europe	86,388	of which in Germany	50,800
North America	36,762		
South America	5,509		
Asia-Pacific	19,376		
Africa	934		
Total	**148,969**	of which Research & Development	17,100

ZF Shapes the Future in Four Technology Domains

T Division - Commercial Vehicle Technology

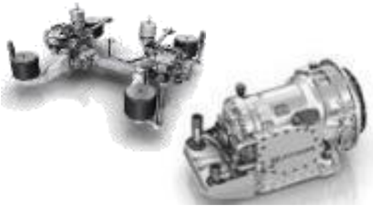
TC
CV Chassis Technology
Chassis Modules
Damper Technology

TE
CV Steering Systems
Steering Systems

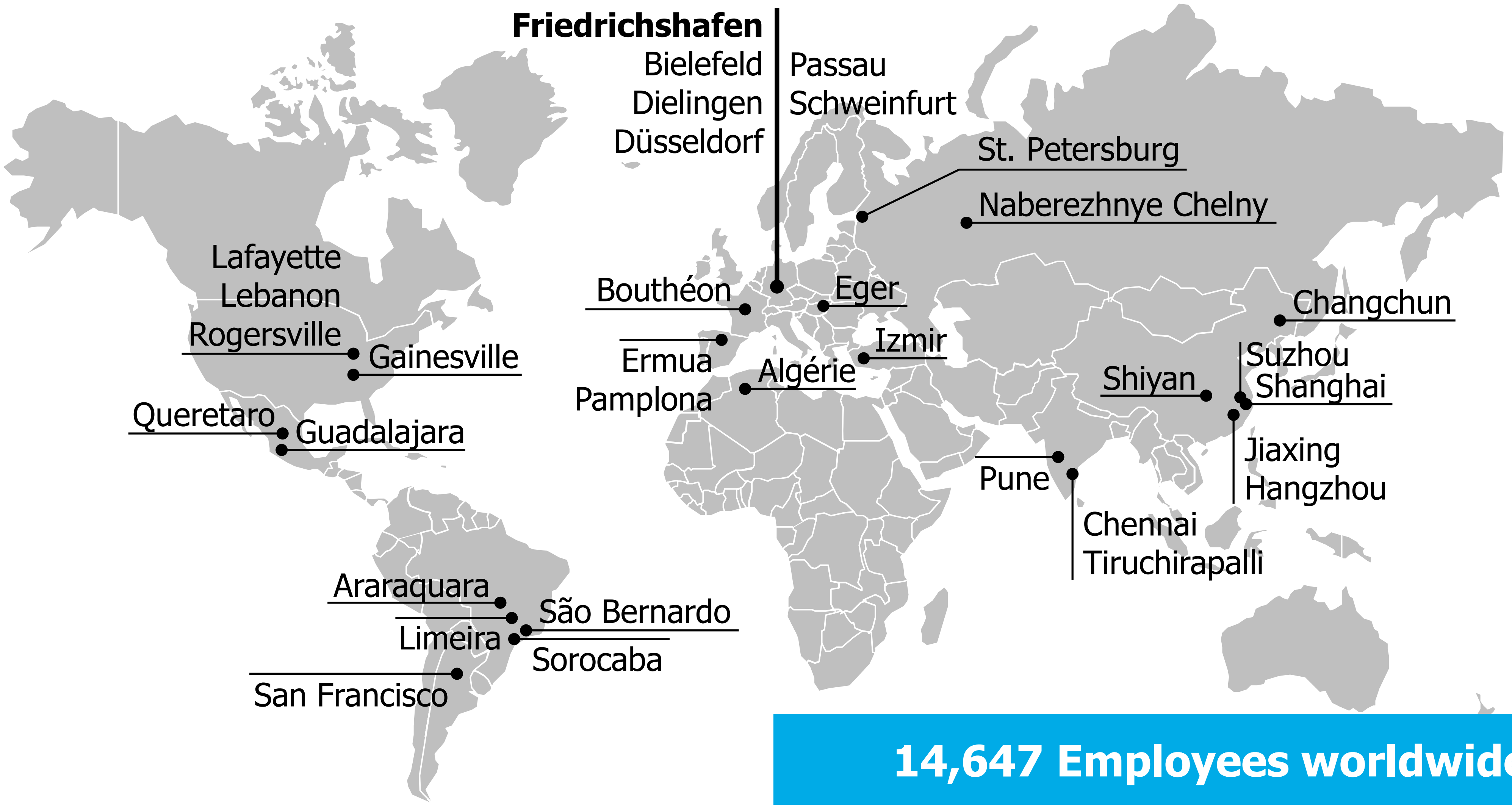
TN
CV Powertrain Modules
Clutches & Systems

TT
Truck & Van Driveline Technology
Transmissions

TU
Axle & Transmission Systems for Buses & Coaches
Axles & Transmissions



Commercial Vehicle Division
More Than 30 Locations Worldwide

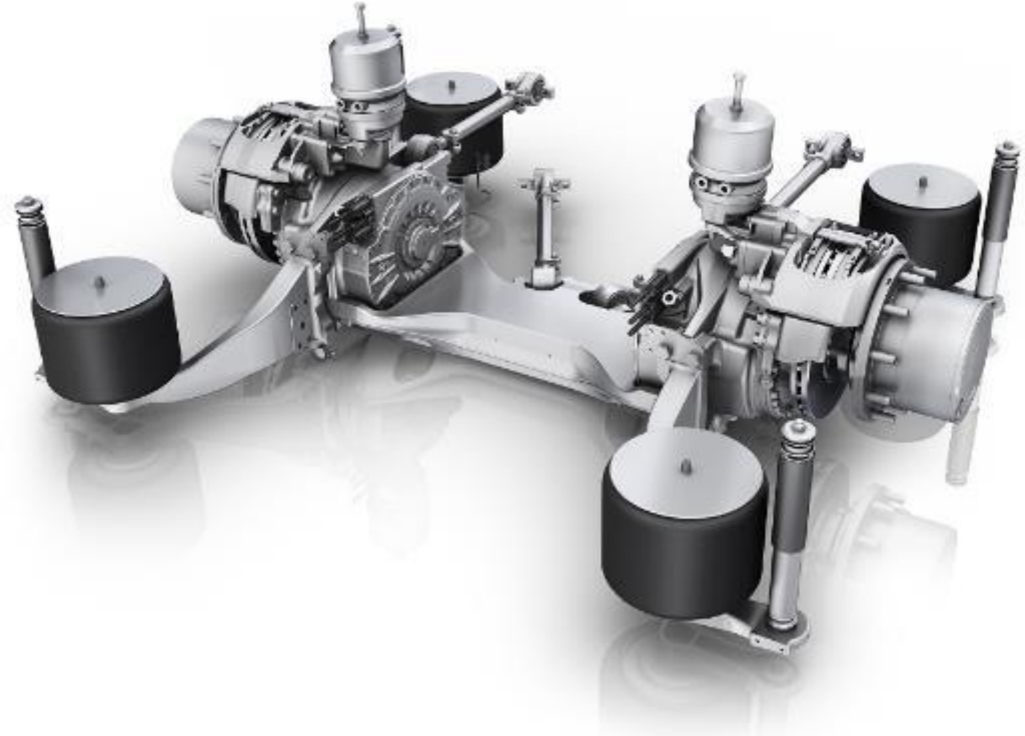


14,647 Employees worldwide

Electric Drive Solutions for City Buses
Products

Electric central drive
CeTrax

Electric portal axle
AxTrax AVE



AxTrax AVE and CeTrax – Two Supplementary Electric Drive Systems

Electric portal axle AxTrax AVE

- Extensive barrier-free standing area in the rear (Solo / Artic bus)
- Particularly fast entry and exit
- Low-floor artic buses could utilize a single driven center axle (puller) or even two driven axles.

Central drive CeTrax

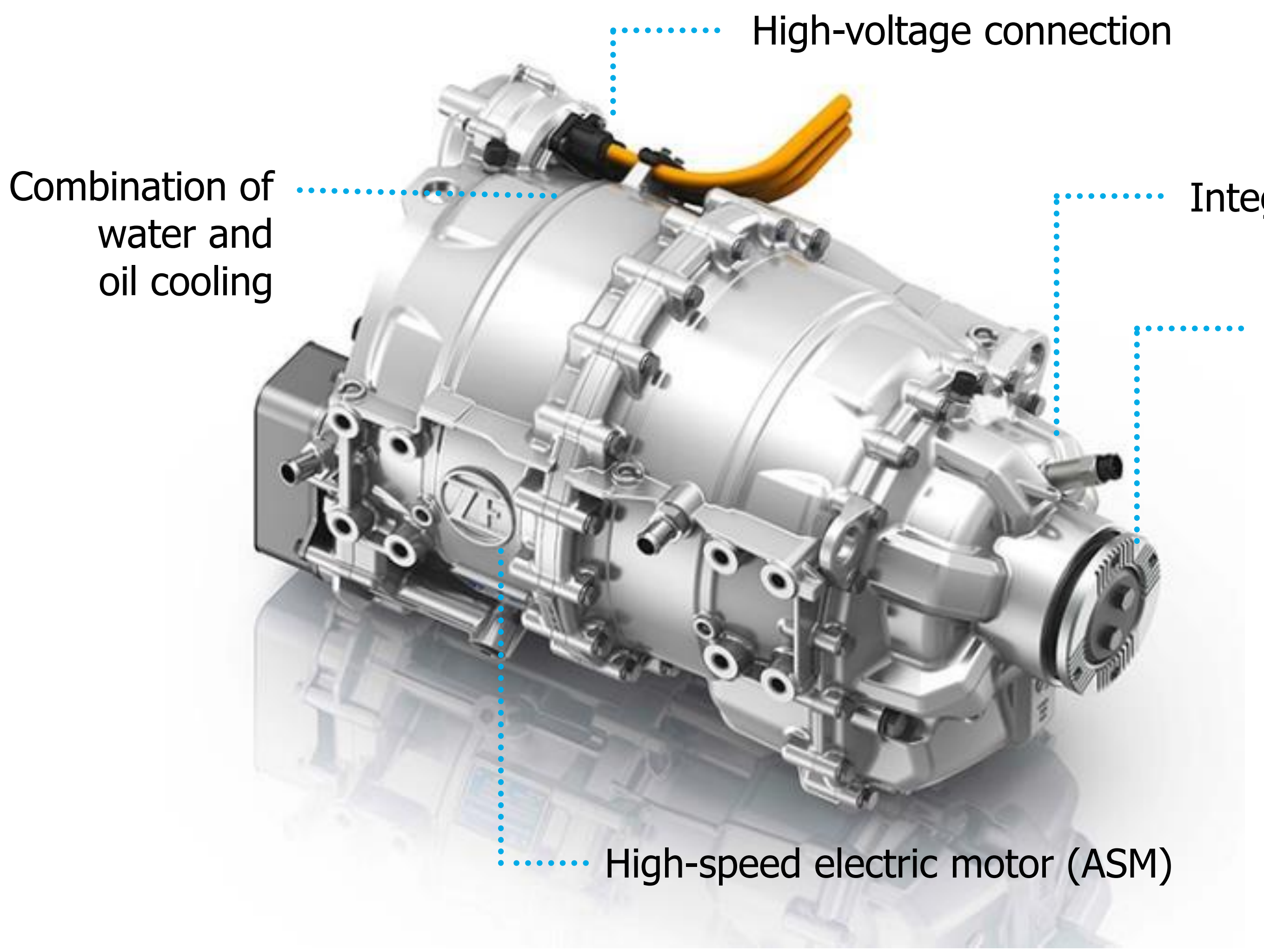
- Installation in conventional bus chassis possible
- Combinable with common driven axles and ratios
- Application of proven components from EcoLife city bus transmission

For low-floor bus concepts

Quelle: www.wikimedia.org / Lord Alpha

For all bus types

Electric Central Drive CeTrax
Product Description



Control unit
EST 54

Inverter
ACH65L50

Electric Central Drive CeTrax Technical Data

Powertrain		
Traction motor	Performance (max. / 30 min.)	300 / 200 kW [1)]
	Motor/Output Speed (max.)	8,500 / 2,500 rpm
	Technology	Induction motor
Transmission stage (integrated)		1-gear; i = 3.36
Output torque (max / 30 min.)		4,500 / 2,170 Nm [1)]
Inverter (ACH65L50)		
Voltage DC (nominal / range)		650 / 580 - 750 V
Current AC (max. / continuous)		530 / 375 A_{rms}
System		
Gross vehicle weight (max.)		29 t [2)]
Weight		approx. 295 kg [3)]
Control unit		EST 54
Protection class		IP6K9K [4)]

Prototype available

SOP 2020

Advanced engineering

Volume production development

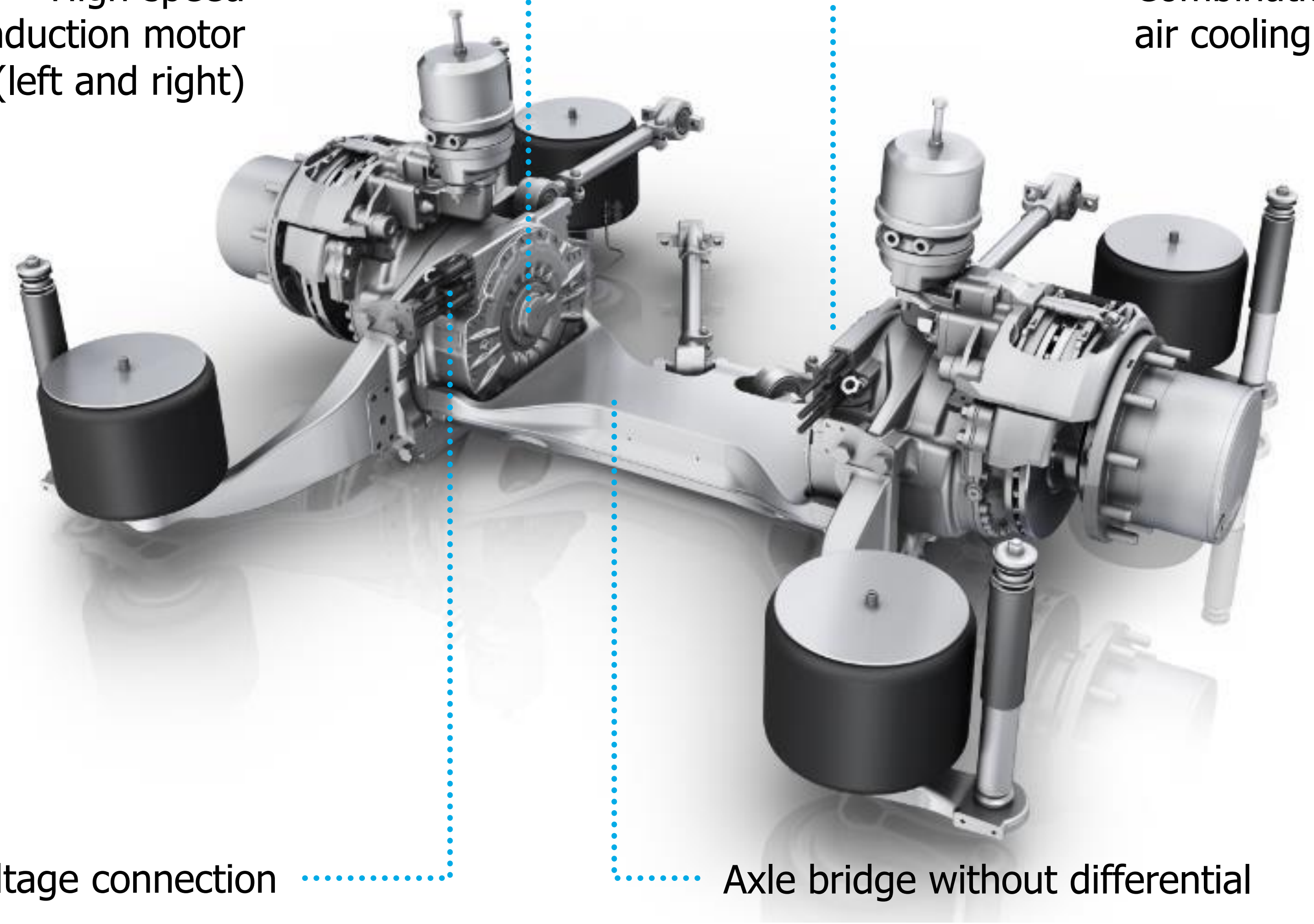
[1)] In accordance with ECE-R85

[2)] Higher vehicles weights possible upon request, application examples see notes

[3)] System weight:
Electric drive (traction motor + transmission) + inverter + EST 54

[4)] Upon request

Electric Portal Axle AxTrax AVE
Product Description



Electric Portal Axle AxTrax AVE
Technical Data

Powertrain		
Traction motor	Performance (max. / 30 Min)	2 x 125 / 2 x 87 kW [1]
	Speed (max.)	11,000 rpm
	Technology	Induction motor
Transmission stage (integrated)		1-gear; i = 22.66 [2]
Output torque (max. / 30 Min)		22,000 / 6,480 Nm [1]
Inverter (2 x ACH6530)		
Voltage DC (nominal / range)		650 / 580 – 750 V
Current AC (max. / continuous)		2 x 340 / 2 x 250 A_{rms}
System		
Gross vehicle weight (max.)		29 t [3]
Weight		approx. 1,250 kg [4]
Control unit		EST 54
Protection class		IP6K9K

SOP AVE 130 since 2017
SOP AVE 130 system Q1 2020

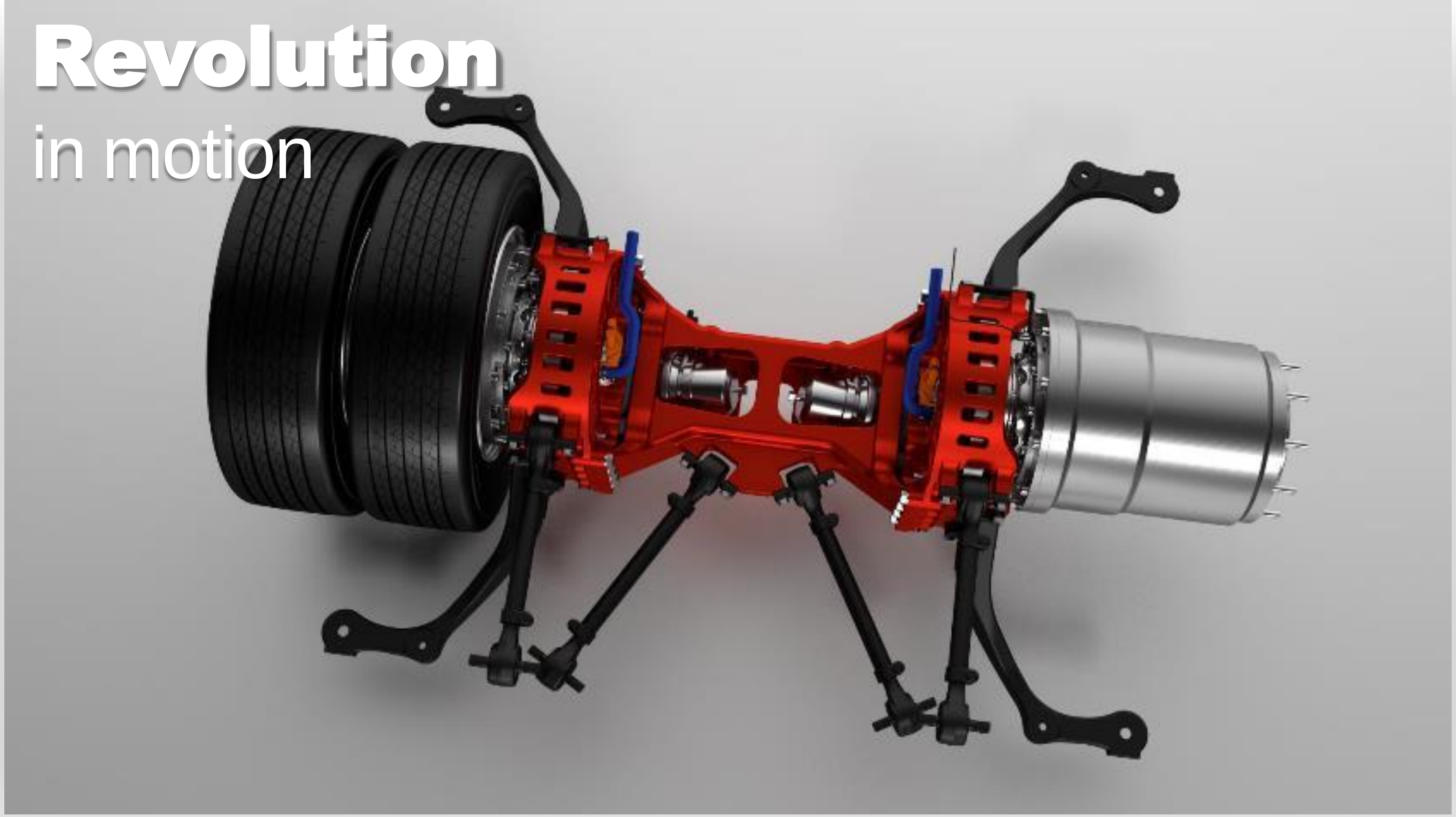
Advanced engineering
Volume production development

1) In accordance with ECE-R85, with i = 22.66, for axle system with both electric motors
2) Further transmission ratio i = 17.80
3) Higher vehicle weights with several axles possible, permissible axle load = 13 t, application examples see notes
4) System weight:
Axle + 2 traction motors incl. planetary stage + 2 inverters + EST 54

Thank you

Transit Bus Component Forum

Edwin Shaw – North American Business Development Manager



Who is e-Traction

History of e-Traction

2019 Acquired by the Evergrande Group

2016 Joined TANHAS Group & TeT founding

2015 Inauguration of e-Traction China Office

2013 Winner BusWorld Innovation Label 2013

2012 DHDC becomes majority shareholder

2012 License for European market granted to Ziehl-Abegg

2009 First pilot with city buses in daily operation (Whisper Apeldoorn)

2002 First pilot project (full electric forklift)

2001 First family of patents for direct drive, in-wheel motors granted

1981 Company founded

Headquarters in Apeldoorn, the Netherlands

Appr. 45 employees

1,100 sqm production facility

600 sqm office space

100 sqm test facility

Introduction

恒大集团
EVERGRANDE GROUP

National Electric Vehicle Sweden
NEVS

CAR EVE

Koenigsegg

PROTEAN

SAAB

e-Traction®
revolution in motion

Joint Venture Partners

MAGNA

AVL

BENTELER
makes it happen

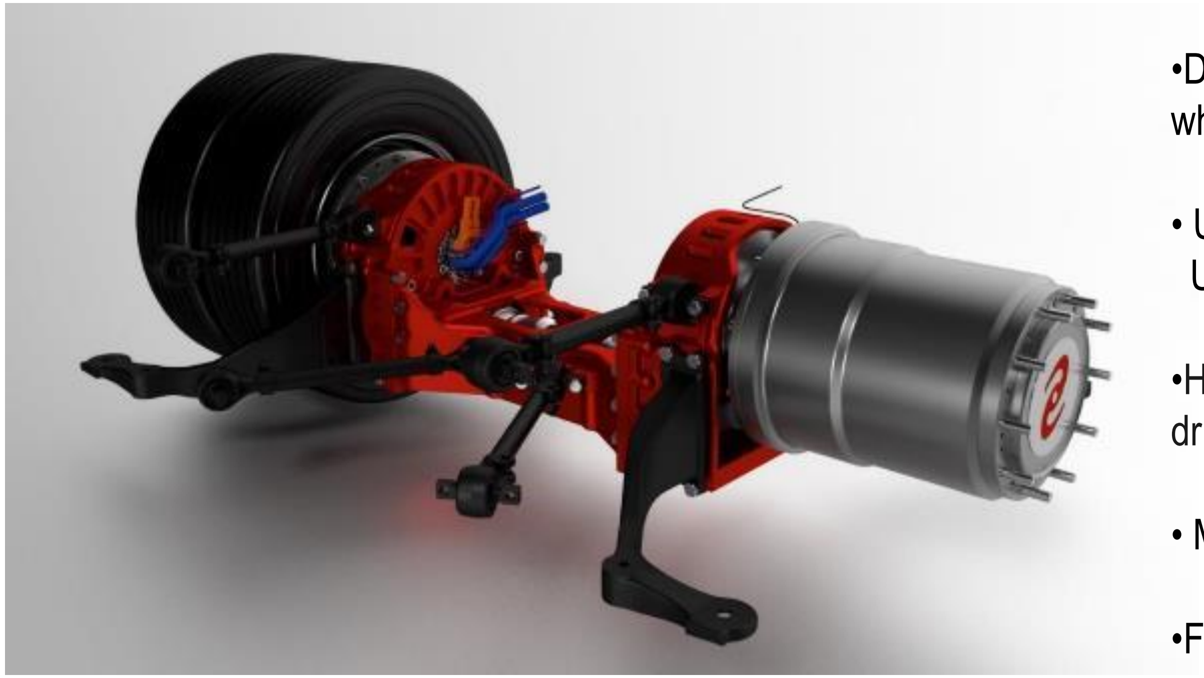
hofer
powertrain

FEV

EDAG

automotive engineering
iav

TheMotion 2.0 - The NEXT Generation - electric powertrain

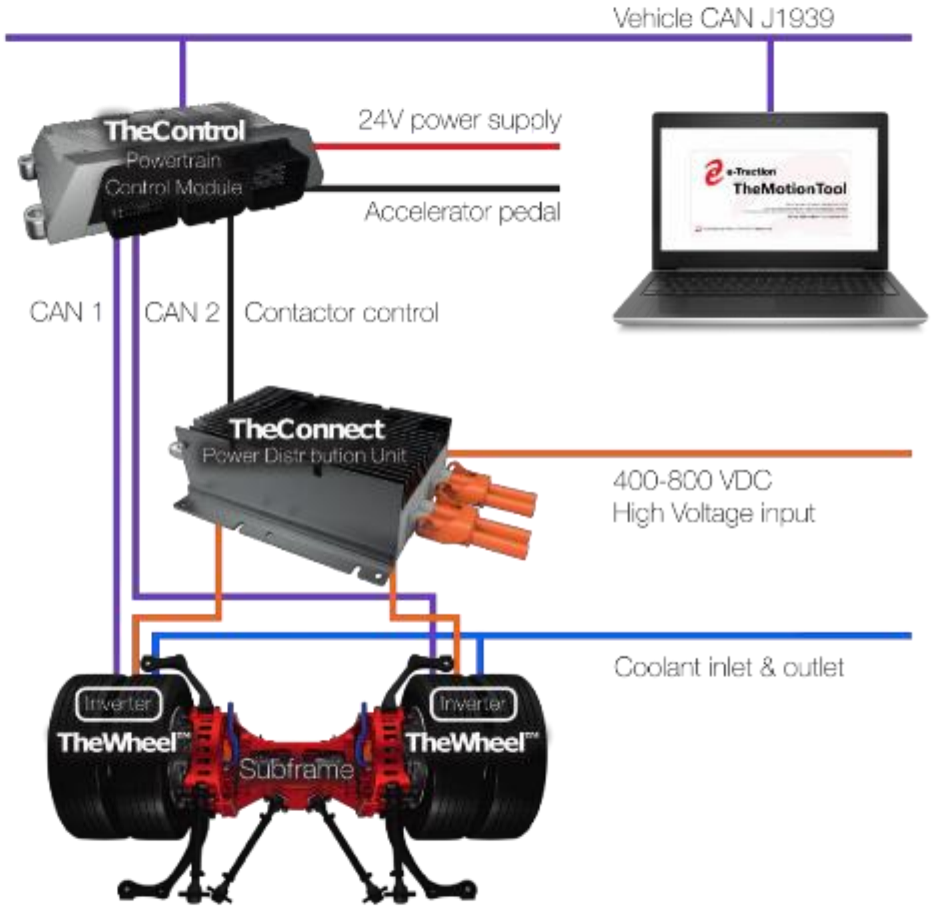


- Zero Emission
- Direct Drive - 94% efficiency from battery to wheel
- Up to 20% more mileage per charge = Up to 20% reduced battery size
- High peak torque of up to 20 kNm per driven axle
- Minimal maintenance – fit and forget
- Full automotive compliance and a wide scope of applications, including retrofit and fitting for both 12- and 18-metre buses and heavy goods vehicles

Lowest TCO in the market

1 Introduction

The Motion 2.0 System



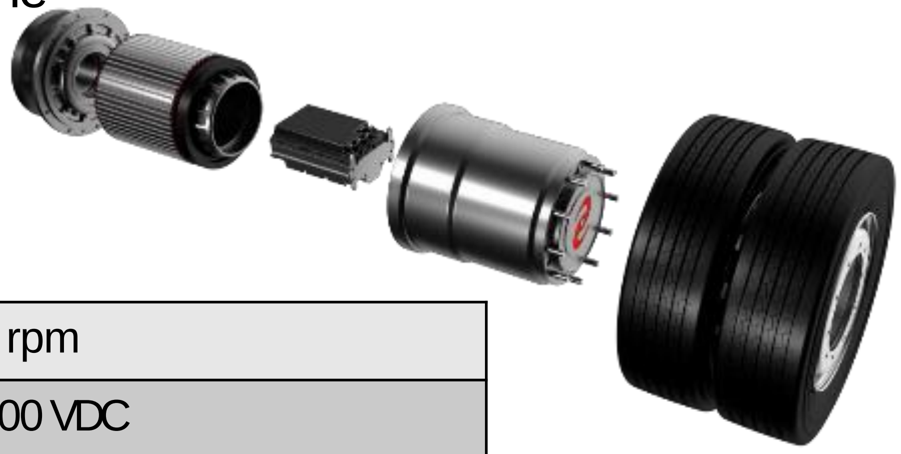
- No energy consuming gears and differential
- Electric Differential
- Low noise, high driving comfort
- Designed according to Functional Safety (ISO26262) principles
- Independently controlled wheels enable redundancy
- Small footprint gives optimum space utilisation
- Smart Control features
- Easy Integration

A complete system offering

TheWheelTM

- Integrated Power Inverter
- Liquid cooled
- IP6K9K

High efficiency direct drive
Permanent magnet synchronous machine
Integrated inverter
No gears
Twin-tire solution
Low noise

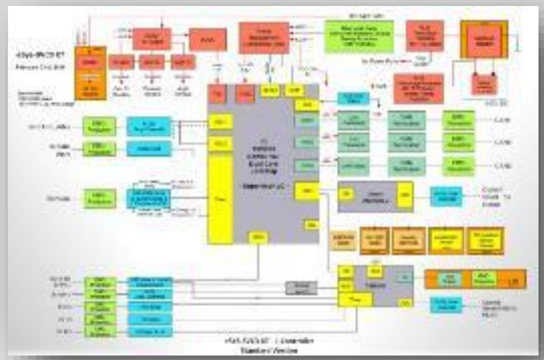


Operating speed range	0 – 500 rpm
Voltage range	400 – 800 VDC
Maximum torque	10.000 Nm (per wheel)
Continuous torque	3.900 Nm
Maximum power	204 kW (per wheel)
Continuous power	126 kW

PCM

Powertrain Control Module

- Responsible for all driveline related functionality such as:
  - Torque Control of in-wheel motors (max.8)
  - Cruise control
  - Electric differential
  - Retarder functionality
  - Seamless integration with braking systems
  - Optimal brake blending strategy
  - Extensive diagnostic capabilities
  - Detection and control of safety hazards
- Flexible software by calibration/configuration
- Robustness for automotive environment



TheMotionTool

TheMotionTool

- Software tool for all components in TheMotion system
  - Diagnostics activities
  - Software download
  - Calibration of parameters
  - Execution of test procedures
  - Execution of EOL procedures
- UDS-compliant communication over J1939 CANbus
- Role-based authentication and authorization
- Generic platform for existing and future products
- Compliant to industry standards and protocols

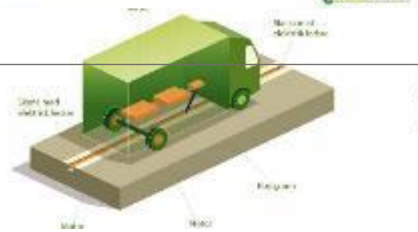
Double Decker Applications

Double Decker Applications

Signature Projects - New Energy Vehicles - TCO positive

City of Munster, Germany
- Urban & Region Transport
- Highly efficient
- Zero Emission
- Fast Charging (500kW)
- Wind, Solar, Hydrogen

Stockholm, Sweden
- Distribution
- BEV
- Conductive charging
- Electric Road



Signature Projects - New Energy Vehicles - TCO positive

RET:
Rotterdamse
Elektrische
Tram

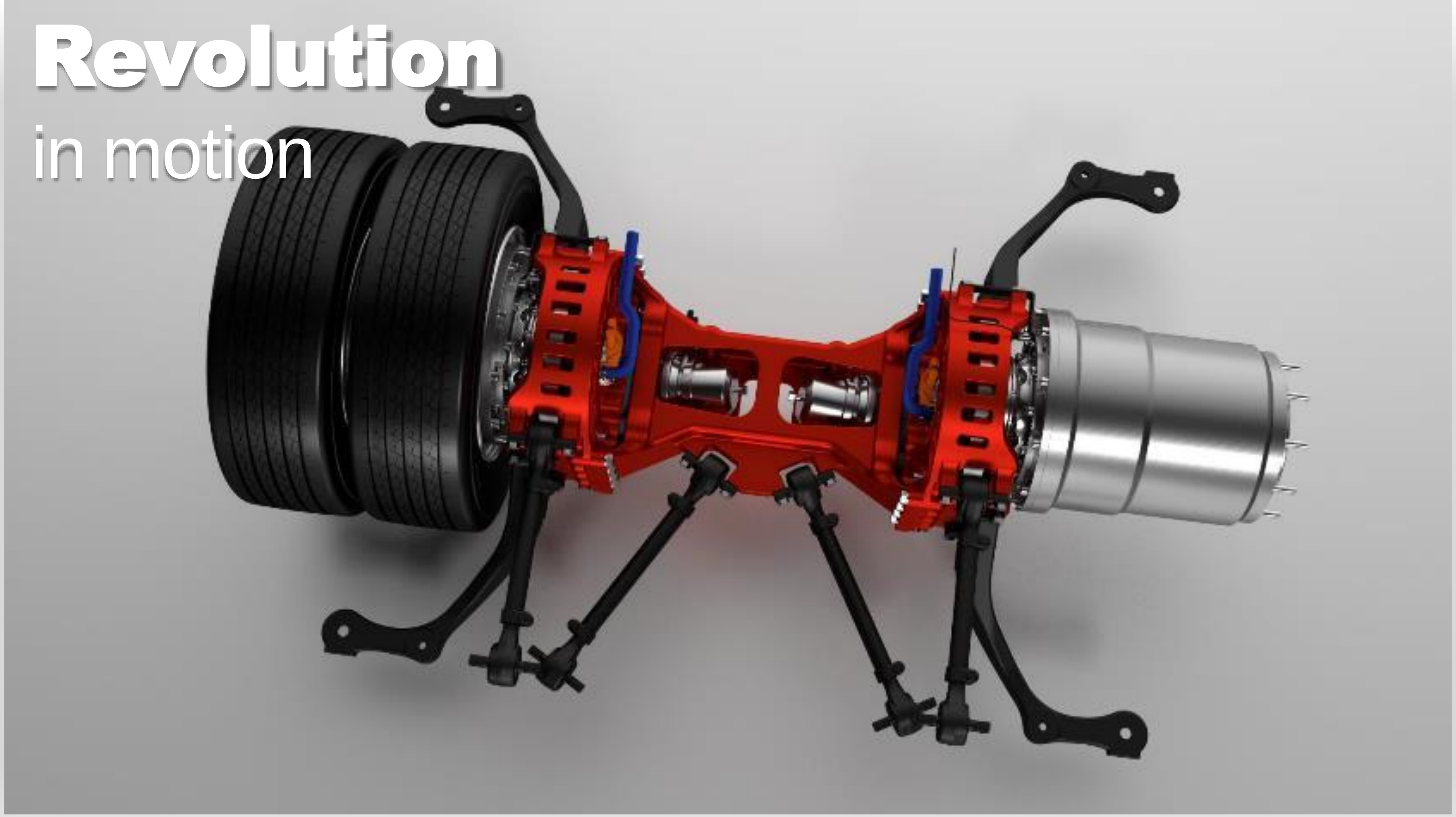
First
Generation
Installed in
2009

The Motion
2.0 Installed
Jan 2019

Transit Bus Component Forum

e-Traction®

Edwin Shaw – North American Business Development Manager



11:30 a.m. – 12:30 p.m.

Networking Lunch

With

Dr. Giorgio Rizzoni, The Ohio State University

CALSTART

Transformational Technologies Reshaping Transportation – An Academia Perspective

GIORGIO RIZZONI

The Ford Motor Company Chair in Electromechanical Systems
Professor, Mechanical and Aerospace and Electrical and Computer Engineering
Director, Center for Automotive Research

Qadeer Ahmed, Mukilan Arasu, Pradeep Oruganti

The Ohio State University

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

CAR OVERVIEW

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

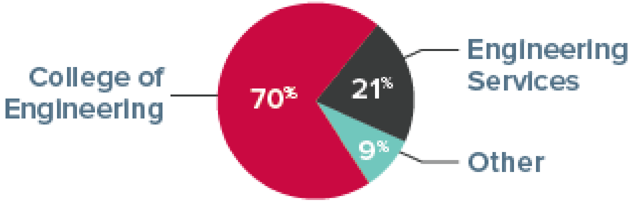
OUR TEAM

35 visiting scholars

43 research and administrative staff

49 CAR-affilliated faculty

OPERATING BUDGET - $1.9M annually



RESEARCH

Total:
$11.3M

Industry: $4.2M

Federal: $5.6M

State: $1.4M

STUDENTS

178 students in 2019

A 19% increase since 2018

EXPERIENTIAL LEARNING

7 vehicle project teams

10 on-site labs

45 miles to TRC: North America's largest proving ground

MEMBERSHIP CONSORTIUM

16 consortium members

80 percent of funds invested in exploratory research grants

39 students actively engaged in exploratory research projects

SERVICES

Engineering Services

- Emissions testing
- Battery testing
- Powertrain performance

Distance Education

- Summer School
- Seminars
- Certificate Programs

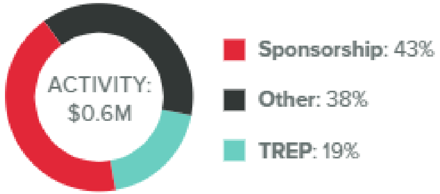
$952K in expenditures

OUR STUDENTS

MOTORSPORTS

MOTORSPORTS AT OHIO STATE

Baja Buckeyes • Buckeye Current • EcoCAR Venturi Buckeye Bullet • Formula Buckeyes Supermileage • Underwater Robotics



UNDERGRADUATES AND GRADUATES

62 undergraduate students

116 graduate students

35 female

13 different countries

INTERNSHIPS

10 CAR students at **8** different partner organizations

Cummins • Delphi • FCA • FEV • Ford • TuSimple • Samsung • Nagoya University

STUDENTS

84 domestic

94 international

77 graduate and PhD students have graduated inn the past 5 years prepared and ready to enter the workforce

CAMP CAR

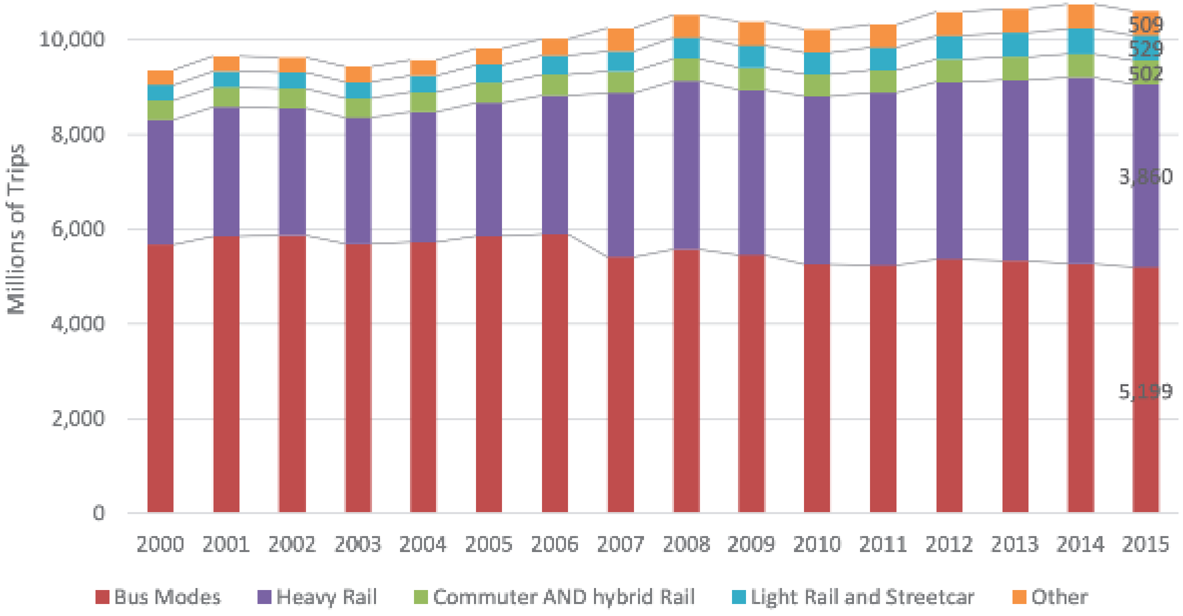
Educated 20 high school students about automotive engineering and mobility

CAR INTERNSHIP PROGRAM

Mentored 13 high school and college students in different areas of automotive engineering

Commercial Vehicles in the US Economy: Transit

Transit Ridership by Mode



Transit Spending in Private Sector

$35.8 billion in 2015 (source: APTA)

Passenger Load:

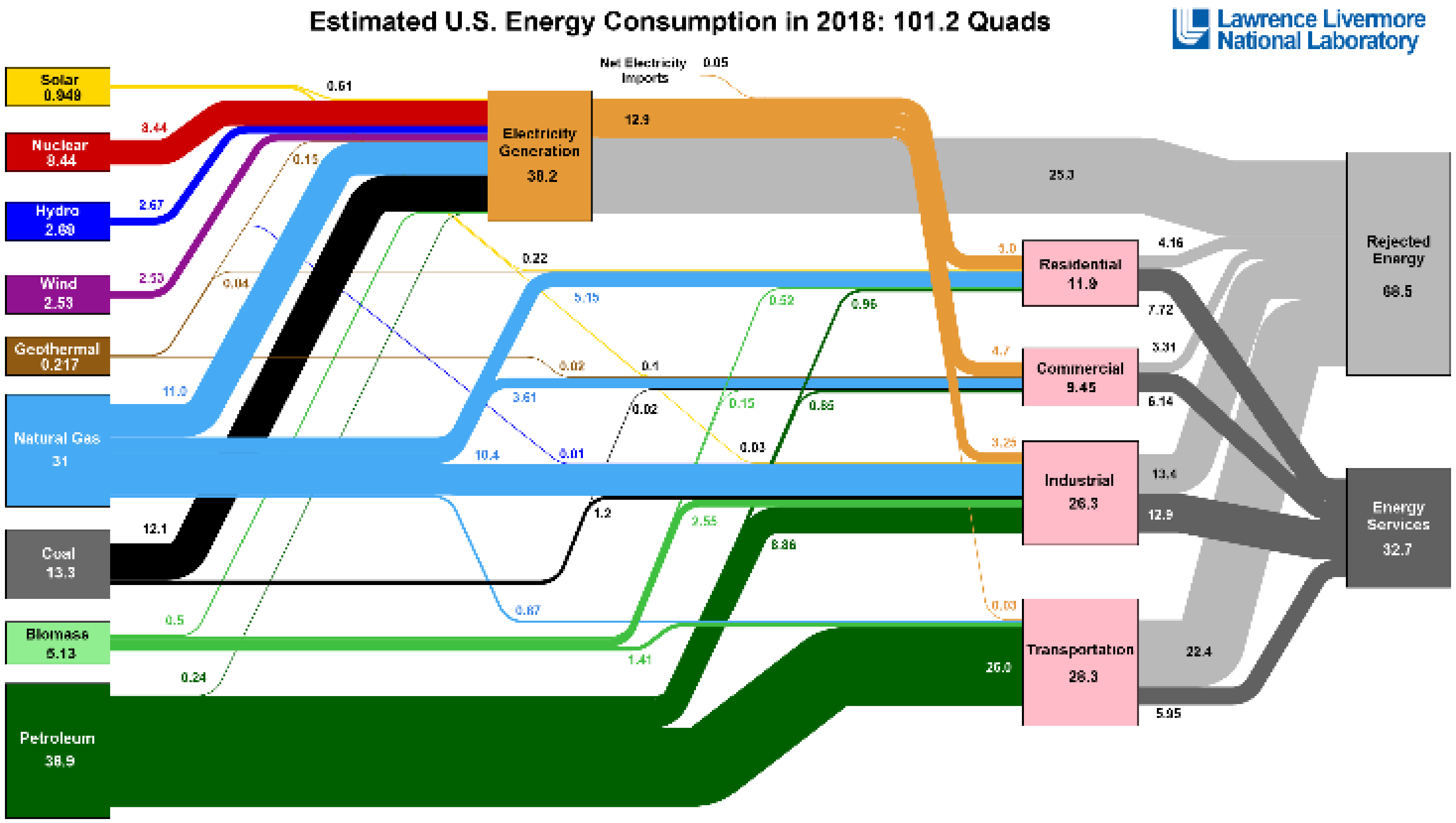
49% of all (unlinked) passenger trips were made by buses in 2015. (APTA)

Employment:

687,000 bus drivers employed in 2016 (Bureau of Labor Statistics)

Source: American Public Transportation Association (APTA), 2017 Public Transportation Fact Book
https://www.apta.com/wp-content/uploads/2017-APTA-Fact-Book.pdf.

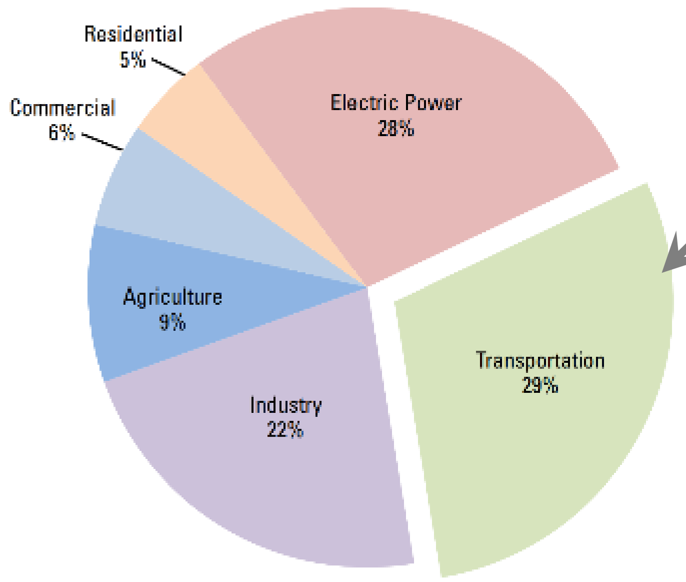
ENERGY EFFICIENCY



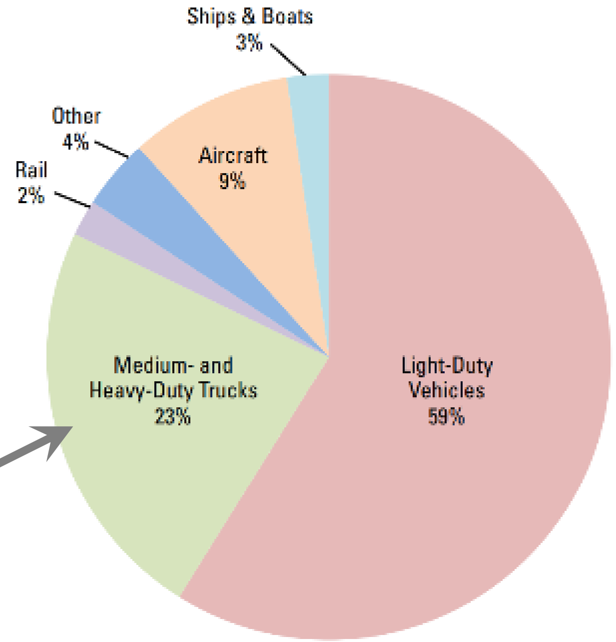
92% of all U.S. transportation powered by petroleum

Source: Lawrence Livermore National Laboratory (LLNL) - *Energy Flow Charts* 2019
https://flowcharts.llnl.gov/commodities/energy.

US Greenhouse Gas Emissions (2017)



Transportation accounts for 29% of US GHG emissions



M&HD vehicles account for 23% of US GHG emissions from Transportation

Source: US EPA Office of Transportation, *Fast Facts: US Transportation Sector Greenhouse Gas Emissions 1990-2017,* https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions.

Approaches to CO2 reduction:

- The following approaches will be discussed in more detail:
- Alternative Fuels
- Electrification
- Vehicle-level Efficiency Technologies
- ADAS Technologies

Alternative Fuels

Power vehicles by fuels produced from non-fossil fuel sources and less carbonaceous fuels.

- **Bio-diesel and Ethanol:**
  - Synthesized from plant sources: Vegetable oil, Corn
  - Waste organic material: Used cooking oil and animal fat

- **Natural Gas and Bio-CNG**:
  - Bio-CNG produced from processing of organic matter.
  - NG is important in transit bus and city truck fleets.

- **Hydrogen**:
  - Produced from electrolysis of water, powered by the grid or a renewable source.
  - Strong interest in Fuel Cell EVs fueled by H_2, but infrastructure challenges remain.

https://afdc.energy.gov/

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

Electrification

An electric powertrain is more efficient than conventional powertrains over a wider operating range and can additionally recover energy by regenerative braking.

Electrified vehicles have become more cost-competitive due to improvements in:

- Battery technology:
  - Costs have dropped dramatically:
    200-300 $/kWh in 2019 from $1000 in 2010.
  - Capacity and durability have also improved

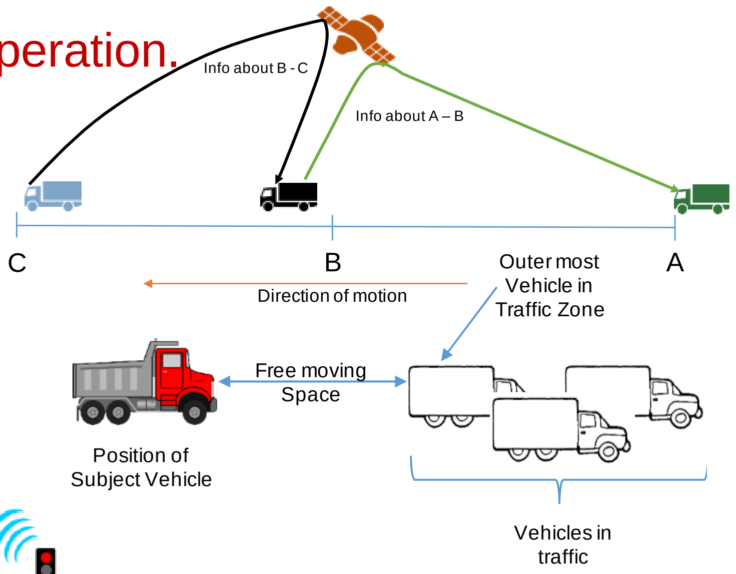
- Charging infrastructure:
  - Fast charging for shorter range applications are already available.
  - On-the-fly charging for longer range applications are under development.

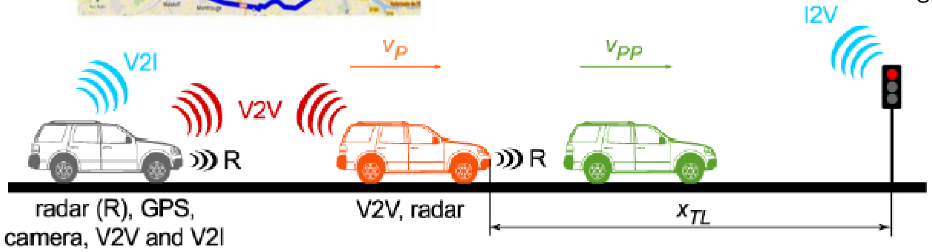
Advanced Driver-Assistance Systems (ADAS)

- Use route preview to vary speed and powertrain operation.

Route, Road features, Environment

Traffic signs
Traffic lights
Weather
Road curvature
Traffic density
Road grade





V2V and V2I information

Source: B. Hegde, "Look-Ahead Energy Management Strategies for Hybrid Vehicles," PhD Dissertation, Ohio State University, 2018.

Smart Cities: SMART Columbus Operating System

Source: Smart Columbus, https://smart.columbus.gov/

SMART Columbus Operating System

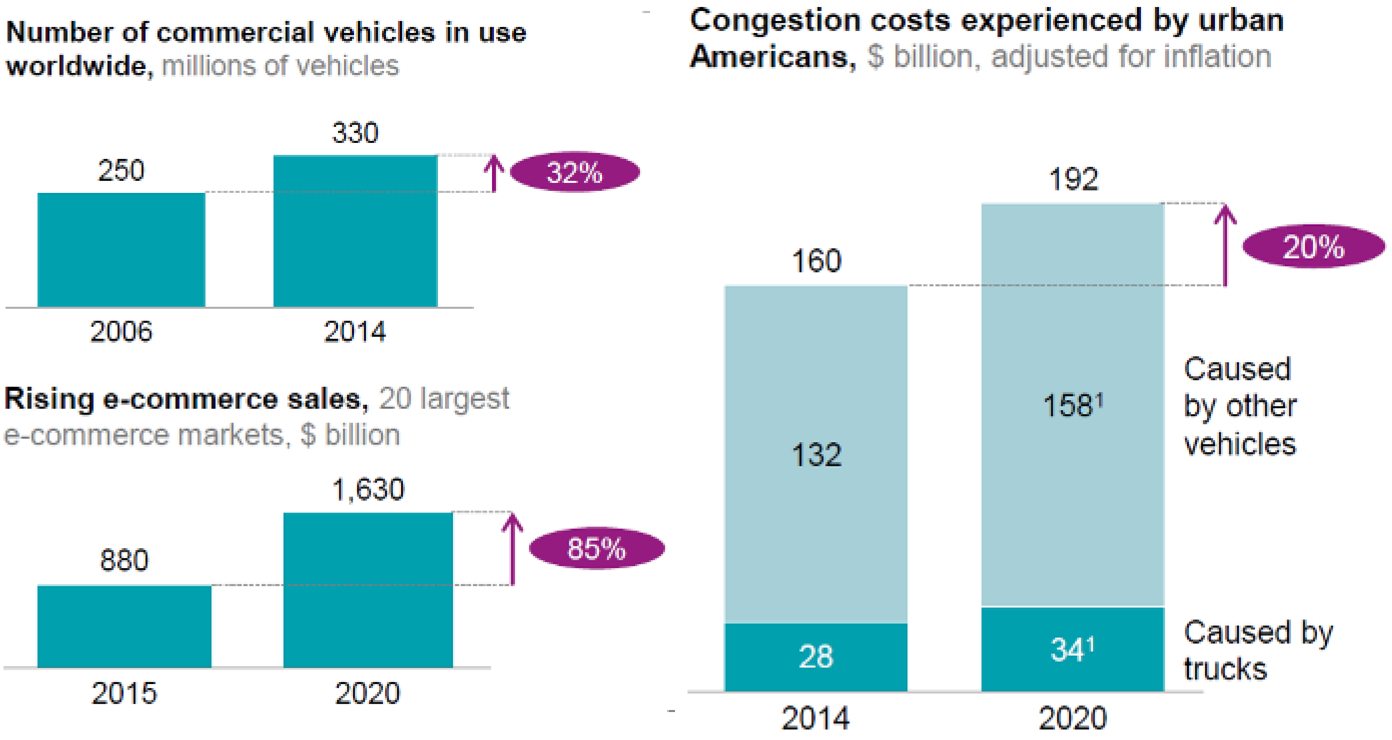
Source: Smart Columbus, https://smart.columbus.gov/

Urban Logistics & Mobility: SMART Columbus

The SMART Columbus Program is working on a number of fronts to make transportation within the city of Columbus cleaner and more efficient.

Source: Smart Columbus, https://smart.columbus.gov/

Urban Transportation



The number of commercial vehicles on the road is increasing, especially driven by the rise of e-commerce.

Traffic congestion is also increasing in urban US.

Source: McKinsey Center for Business and Environment, "An integrated perspective on the future of mobility, part 2: Transforming Urban Delivery," McKinsey & Company, 2017.

Urban Transit and Logistics Simulation: a case study

The efforts in this initiative are focused on **creating and deploying** an urban logistics framework that enables in the **simulation, validation and discovery** of **existing and new technologies and businesses**

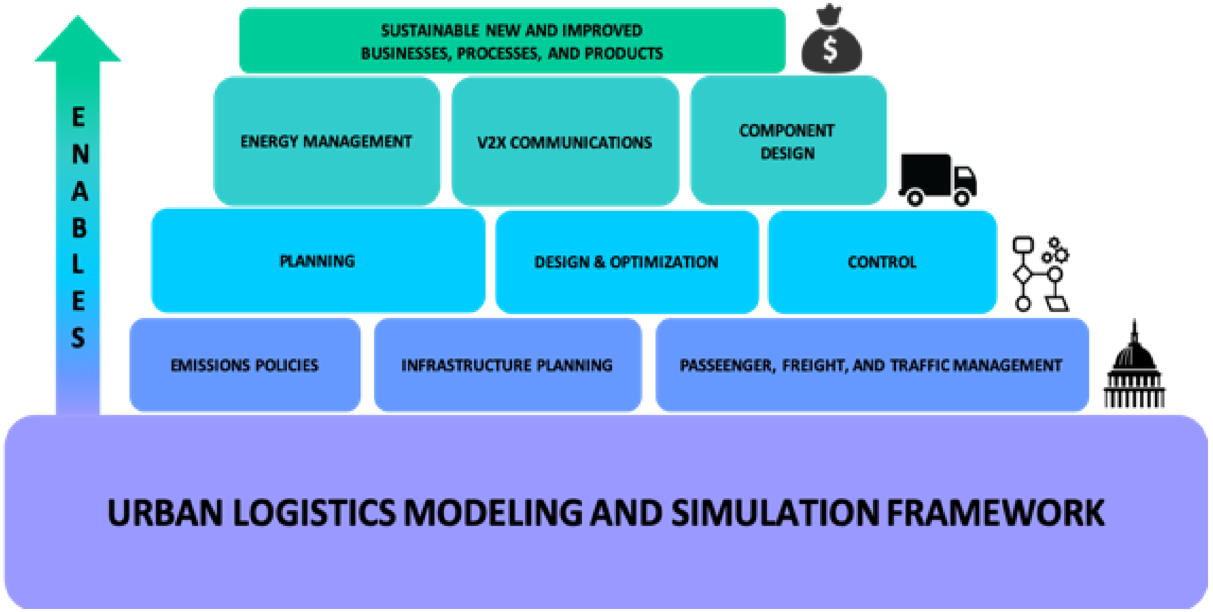
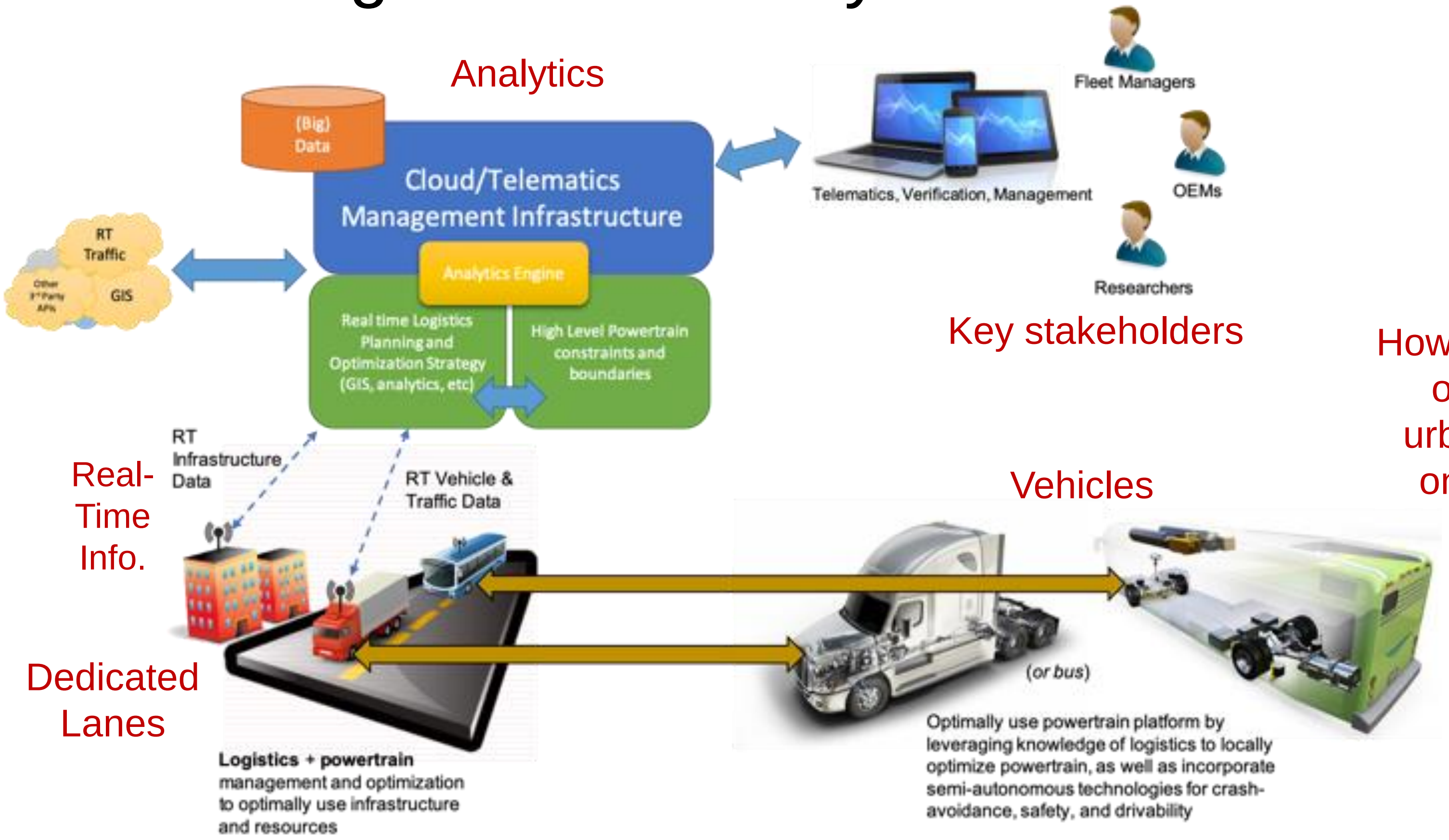


Image courtesy of: B.J. Yurkovich, R. Mishalani, A. Carrel, The Ohio State University

Urban Logistics & Mobility



How to optimize operation of transit buses and urban delivery vehicles on dedicated routes?

Image courtesy of: B.J. Yurkovich, R. Mishalani, A. Carrel, The Ohio State University

CONCLUSION

The commercial vehicle industry is transforming.

- Key change agents include regulations and technology.

The transformation of the commercial vehicle industry will include:

- Enabling new business models, increase in productivity and efficiency
- Providing more eco-friendly solutions with reduced GHG and criteria emissions.
- Increased connectivity and the use of data to make smart decisions in smart infrastructure.
- Limited degrees of automation

Many challenges for a new generation of CVs – exciting times ahead for engineering.

Giorgio Rizzoni

Director, Center for Automotive Research
rizzoni.1@osu.edu
car.osu.edu

12:30 – 1:15 p.m.

Power Electronics:

Next Gen Inverters, Motors, DC/DC Converters, Fuel Cells, Chargers

Moderated by Steve Sokolsky

Daljit Bawa, Ballard

Thomas Orberger, Siemens

Steve Scott, EMP

BALLARD®

Fuel cell electric buses no compromise zero-emission transit

Transit Bus Component Technology Forum

Daljit Bawa Nov 07, 2019

BALLARD®

Fuel cells enhance the performance of electric buses.

250-300 miles Proven range

Significant reduction in vehicle weight
(carry more passengers)

Rapid refueling speeds
(6 to 10 minutes)

1:1 replacement of conventional vehicles

Fuel cell electric buses are available today for deployment

New Flyer Xelsior CHARGE H2 Battery/Fuel Cell Hybrid Electric Bus Specifications		
Size	40’	60’
Curb weight	32,240 lbs	49,900 lbs
Fuel cell power	85kW FCveloCity®-HD	85kW FCveloCity®-HD
Hydrogen storage	37.5 kg at 350 bar	60 kg at 350 bar
Range	300 miles	300 miles
Passenger load	82	125

El Dorado / BAE Axess Fuel Cell Bus Specifications	
Size	40’
Curb weight	34,800 lbs
Fuel cell power	85kW FCveloCity®-HD
Hydrogen storage	60 kg at 350 bar
Range	312 miles
Passenger load	57

FC buses went through FTA-Altoona testing and are on CARB HVIP list

BALLA BALLARD

Celebrating 40 Years

1979-2019

700 Employees

1,500 Patents & Applications

Publicly listed Company

24 years Nasdaq

26 years TSX

4 Strategic shareholders

WEICHAI

NISSHINBO

AngloAmerican

450 Transit **buses** in service

>2000 **Trucks** delivering goods

4 train projects on track

5 ships in development

12,000 **Forklifts** in operation

$80m **automobile** stack development program

Delivered **850MW** of **Fuel Cell** products

Produced **5 million MEAs**

KM

Passed **16 million km** of service for modules operating in buses

LIFETIME DURABILITY

>30,000hrs Operation for fuel cell stack in London **BUSES**

* In construction or commissioning phase

BALLARD®

Adoption barriers

- Technology awareness
- Total cost ownership
- Hydrogen infrastructure

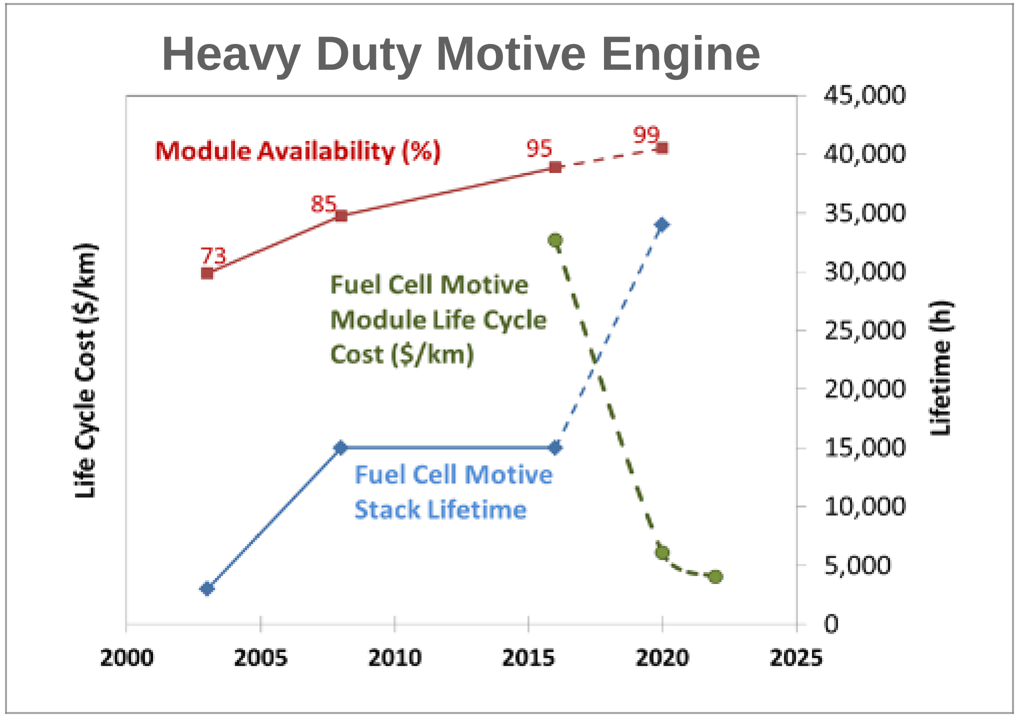
BALLARD®

Increase engagement with fleet operators to increase hydrogen mobility awareness.

Advance in Technology & Performances

- Functional improvements with each product iteration
  - Higher durability
  - Greater reliability
  - Lower cost

- 8th generation (~2020) will be cost competitive with battery powertrain and have lower operating cost than diesel bus
  - Lifecycle cost will be reduced by a factor of 5x



BALLARD

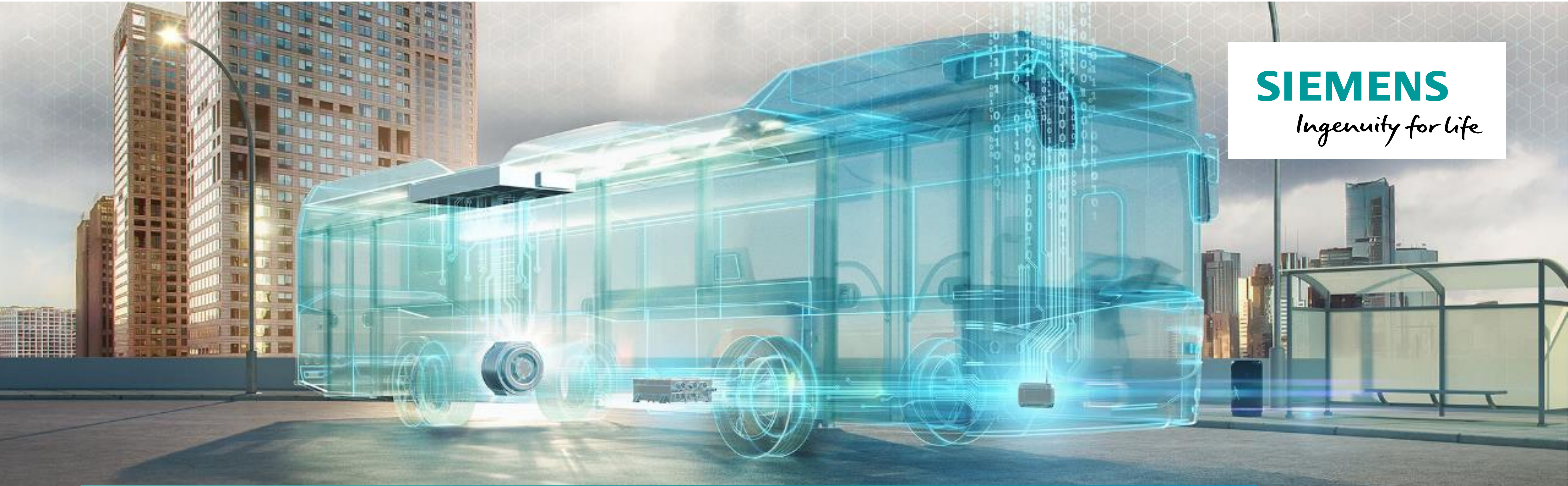
Offer simple and attractive H2 supply contract to fleet operators.

Summary

Fuel cell electric buses have been demonstrated and validated in actual service for many years

Fuel cell electric buses meet operation requirements of transit fleet today

Fuel cell and hydrogen reduce adoption risk for zero-emission bus fleet



SIEMENS
Ingenuity for life

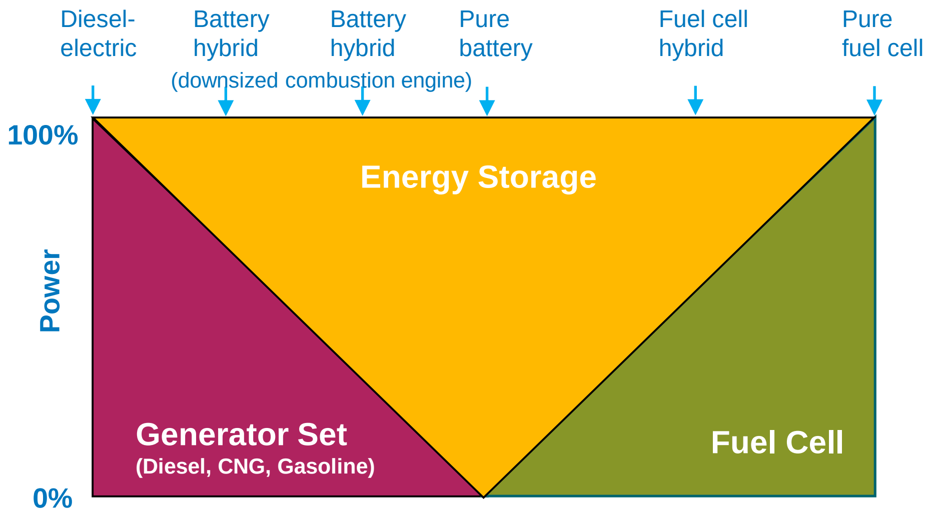
Powertrain Equipment for Transit Busses

Nov 7th , 2019

Transit Market Transition & Power Electronics Evolvement

SIEMENS
Ingenuity for life

Siemens 1985: “Bus , Truck & Personal vehicles will be electric” !



Power Train to be agnostic of Power Source & Energy Storage

1st Gen. Rail based (~ 1000 systems delivered)



2nd Gen Minorized Rail based (~ 9000 systems delivered)



3rd Automotive based (several hundred systems delivered)



ELFA I 1995- 2005

ELFA II 2004-2020

ELFA III 2019-

What is next ?
(Launch of Global ELFA III Power train platform)

SIEMENS
Ingenuity for life

- 30 % weight & size reduction in power electronics
- Plug an play cable connections
- Next generation CPU
- Improved torque accuracy
- Improved EMI
- Resolver operation
- VCU integrated in inverter
- Functional safety ISO 26262
- AUTOSAR software Architecture

- Siemens volume production
- Transition to Automotive

- Global Roll Out ELFA III in Transit

- Electrification with target OEM's

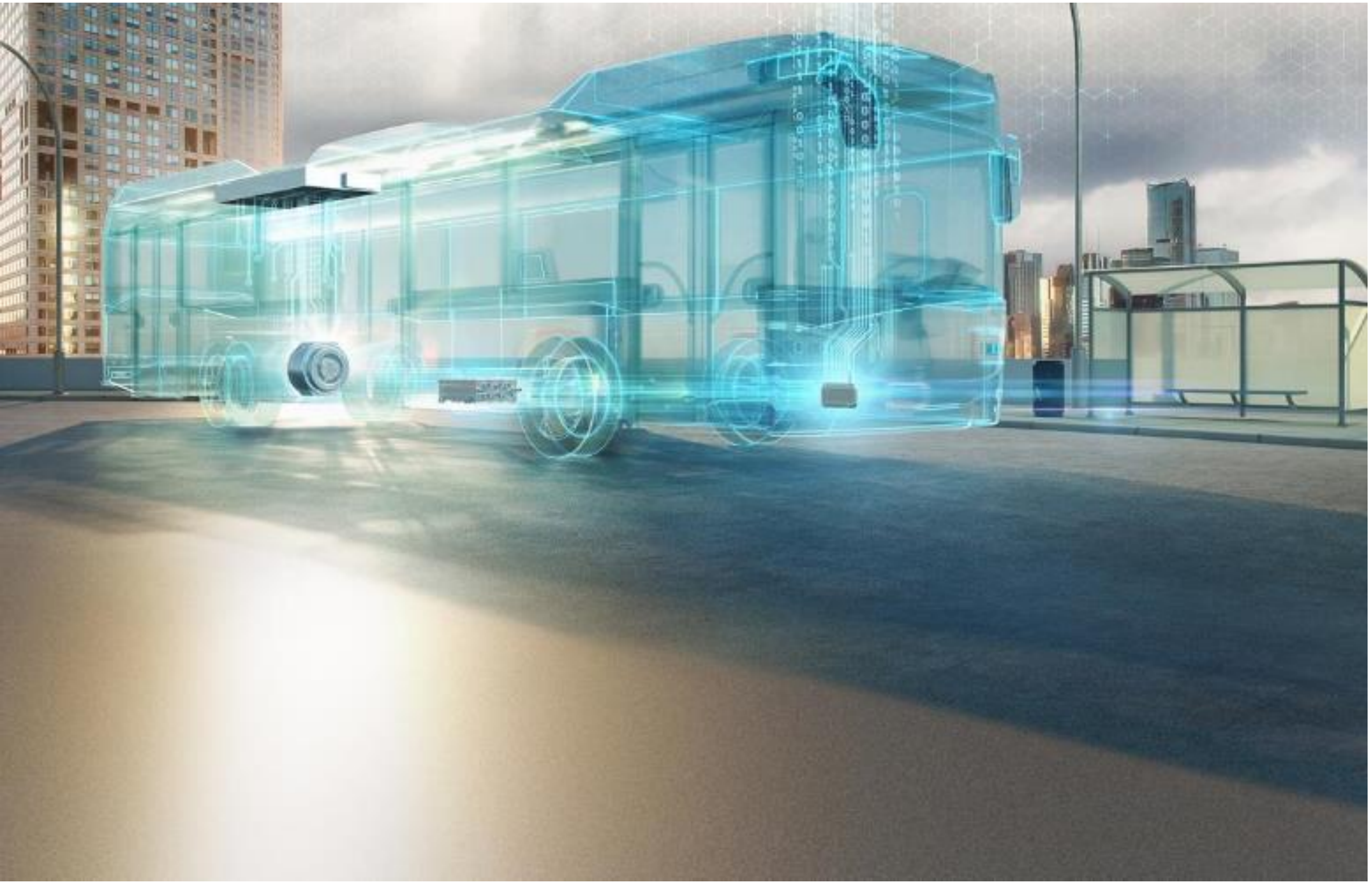
- Cost reduction through volume in China
- Local manufacturing and country specifics i.e. Buy America

- Continuous high invest e.g. electric axle, truck motor, high speed PEM machines.
- Cloud based applications

- Proliferation in Off-High applications

Contact

SIEMENS
Ingenuity for life



Thomas Orberger

Siemens CV

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EMPrecision™ | EMPredict™

EMP

POWERING THE FUTURE®

SMART FLOW®

WATER/OIL/AIR

Available in 12V, 24V, and 48V DC

Brushless DC Water Pumps

WP32

WP150

Brushless DC Electric Fans

11” and 15” available

Brushless DC Oil Pumps

OP40 & OP80

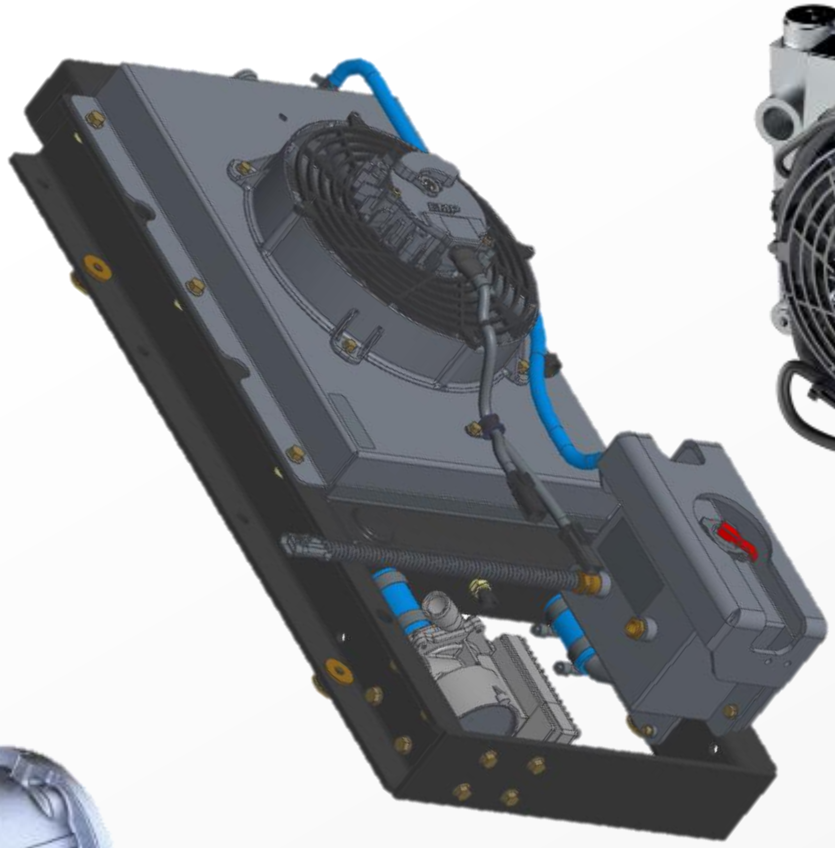
Cartridge Style

OP3530

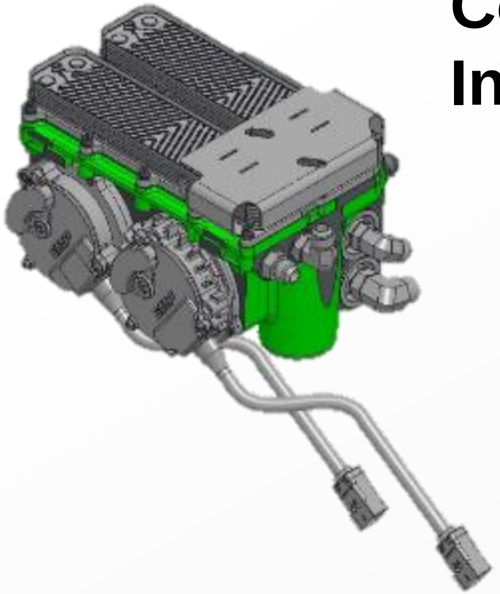
EMP
POWERING THE FUTURE®

COOLING SYSTEM INTEGRATION

Mini-Hybrid® Cooling Systems



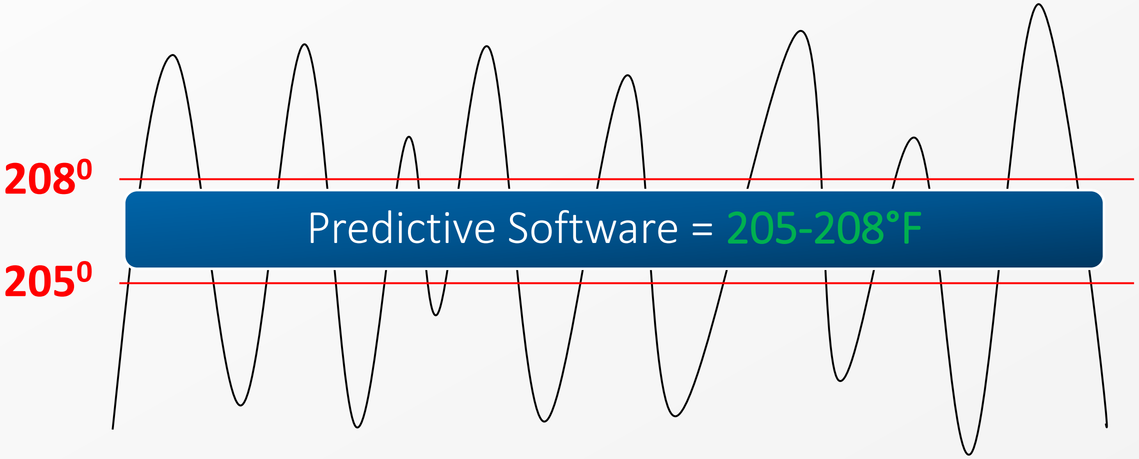
SmartFlow® Component Integration



TRANSIT INDUSTRY TODAY

EMP in the Transit Industry Today…

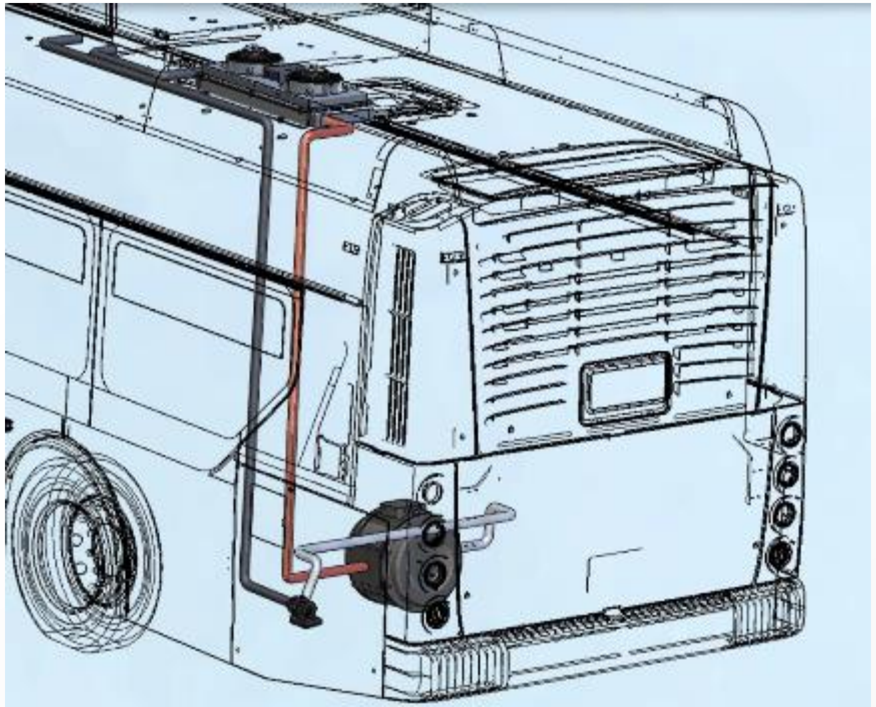
- Electrified Component & System Supplier
- Entered Transit Industry in 2007 with **Mini-Hybrid®** Cooling System
- Introduced Brushless Motor Smart Cooling Technology to the Industry
- Offer Varying Voltage Solutions: 12V/24V/48V
- Glycol, Oil, HVAC and Air Cooling
- Solutions Mounted in Various Locations
- No standard APTA specifications



EMP

POWERING THE FUTURE®

INDUSTRY HURDLES



INDUSTRY CHALLENGES & HURDLES...

- Variations of duty cycles – route specific vehicles
- Electrification support Infrastructure
- Industry wide specifications
- Numerous start-up companies
- Packaging Optimization - Integration responsibilities vary from OEM to OEM
- New engineering competencies – trained support workforce
- High investment cost
- Achieving economies of scale at current volumes and transferring technology to other industries

Thank You for your attention:

Steve Scott

EMP

Steve.Scott@emp-corp.com

www.emp-corp.com

1:15 – 2:00 p.m.

Energy Storage

Moderated by Marc Wiseman, Ricardo

Paul Beach, Octillion

Kyle Burak, BYD

Roy Schulde, AKASOL Inc.

AGENDA

8:30 – 8:45	**Welcome**
8:45 – 9:00	**Opening Remarks**
9:00 – 10:00	**Overview of LoNo Component Assessment Program and Standardized Testing**
10:00 – 10:45	**Electrified Thermal Cooling and Heating Systems**
10:45 – 11:30	**Electric Axles and Wheel Motors**
11:30 – 12:30	**Networking Lunch**
12:30 – 1:15	**Power Electronics: Next Gen Inverters, Motors, DC/DC Converters, Fuel Cells, Chargers**
1:15 – 2:00	**Energy Storage**
2:00 – 3:00	**Systems Integration Perspectives and Offerings**
3:00 – 4:00	**Closing Remarks and TRC Tour (Buses provided by COTA)**
4:00	**Adjourn**

CALSTART

2:00 – 3:00 p.m.

Systems Integration Perspectives and Offerings

Moderated by Fred Silver, CALSTART

Sherif Abou-Rayan, Cummins

Lucas Dehn, BAE

Mark Finnicum, SARTA

David Warren, New Flyer

Transit Bus Component TECHNOLOGY FORUM

3:00 – 4:00 p.m.

Closing Remarks and TRC Tour

Brett Roubinek, TRC

TRC Transportation Research Center Inc.

COTA

Buses provided by the
Central Ohio Transit Authority

CALSTART

THANK YOU FOR ATTENDING!

CALSTART