U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

VEHICLE TECHNOLOGIES OFFICE

Commercial Technologies and Products Supported by the Vehicle Technologies Office

April 2017

Prepared by Pacific Northwest National Laboratory
for the U.S. Department of Energy Vehicle Technologies Office

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Batteries

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Advanced Battery Manufacturing Facilities and Equipment Program

Commercial Technology

As the U.S. transportation sector experiences advancements in hybrid electric vehicle technologies, new suppliers of battery materials will need to be identified to facilitate adoption of electric vehicles (EVs) in the short term and to help in supporting more complex EV systems thereafter. While lithium-ion batteries offer attractive benefits to energy storage, they are often expensive to manufacture and recycle, and are imported from foreign sources. Increased production of new advanced lead-based batteries could help meet DOE's cost goals in the near term.[1] These domestically produced batteries would offer a low-cost method of fostering growth in the EV industry while sustaining domestic jobs.

East Penn Manufacturing Company (EPM), with assistance from VTO and the American Recovery and Reinvestment Act, used a newly constructed, state-of-the-art battery manufacturing facility to produce advanced value regulated lead-acid batteries including the UltraBattery® product. This new 739,000 ft^2 automotive battery facility located in Lyon Station, Pennsylvania, alongside the company's other manufacturing facilities, is supported with vertically integrated self-sufficiencies and on-site recycling.

By the time the project was completed in December 2012, this facility produced over 2.9 million advanced value regulated lead-acid batteries annually, exceeding initial project projections of 2.8 million. The company has sold millions of these batteries, which have the potential to help save over 200 million gallons of petroleum in just a few years.[2] These batteries support the start-stop system in micro-hybrid EVs and other absorbent glass mat battery market needs. EPM continues to increase its capacity to meet rapidly growing customer demands.

The company created more than 276 direct permanent job positions, exceeding the projected 205 jobs, and hundreds of additional supporting jobs.



East Penn Manufacturing Company's Newest Automotive Manufacturing Facility in Lyon Station, Pennsylvania

[1] For more information: Vehicle Technologies Office: Batteries
[2] For more information: East Penn Manufacturing Co. 2012 AMR Presentation

Advanced Battery Manufacturing Facilities and Equipment Program



East Penn Manufacturing Company's Advanced Battery Manufacturing Line

Technology History

- Developed by East Penn Manufacturing Company.
- Continuing efforts to achieve widespread commercial integration.
- Completed in 2016.
- Received initial funding in 2009.

Applications

- Can be used to manufacture advanced batteries for hybrid electric vehicles and other transportation and energy storage applications.

Capabilities

- Two state-of-the-art battery oxide facilities for battery manufacturing and development.
- On-site EPA permitted lead smelter and refinery.

Benefits

Cost Savings

Reduces EV cost by offering domestically produced, less expensive, and highly recyclable advanced batteries.

Job Creation

Created more than 276 direct permanent job positions at East Penn Manufacturing Company, plus hundreds of other supporting jobs.

Contact Information:
Rick Greenly
Email: rgreenly@dekabatteries.com
Phone: (610) 682-6361x2537
East Penn Manufacturing Co., Inc.
Deka Road
Lyon Station, PA 19536
Website: www.eastpennmanufacturing.com

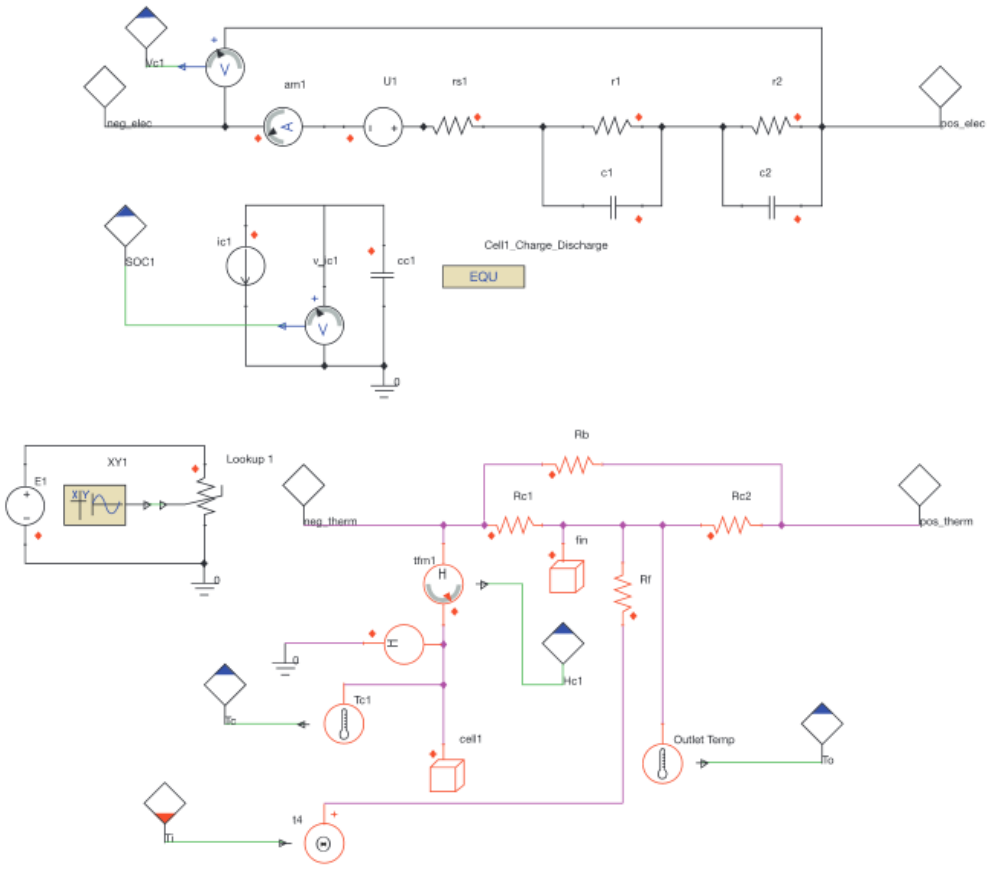
ANSYS Fluent: Computer-Aided Design Tool for Automotive Batteries (CAEBAT)

Commercial Technology

Adoption of electric vehicles (EVs) continues to increase as cheaper and more reliable technologies are developed for the EV industry. To foster further growth of the EV industry, DOE has targeted reduction in battery cost and weight as a primary goal for new vehicle technology development.[1] Currently, there are several methods of advanced battery development which often rely on extensive modeling from an assortment of design programs. These programs offer powerful design solutions but commonly are parts of standalone systems that could benefit from seamless integration. Seamless design programs could shorten development times of new batteries and help encourage adoption of EVs in the U.S.

General Motors Company LLC, with assistance from ANSYS, Inc., Esim LTD, the National Renewable Energy Laboratory (NREL); and VTO, have developed improvements to the ANSYS Fluent® software. The team successfully integrated disparate physical battery scales (electrodes, cell, pack, and full vehicle) and multiple physical phenomena (electrochemical, thermal, fluid, and structural) to generate software that provides effective simulations. In addition, the team blended established detailed 3-D field simulation technologies with full system-level simulations, allowing ANSYS Fluent® to automate both the construction and simulation of reduced order models. Future technology advancement at the pack level can be obtained through development of innovative reduced order models derived from cell-level models and validated by test and measurement. ANSYS Fluent® improves design cycles of new batteries and provides seamless design assistance for the entire design process.

ANSYS Fluent® is available through the ANSYS website and is compatible with other software included in the ANSYS Battery Design Tool suite. The tool offers the flexibility necessary to integrate work done in other existing applications and uses the expandable multi-scale multi-physics framework developed by NREL.

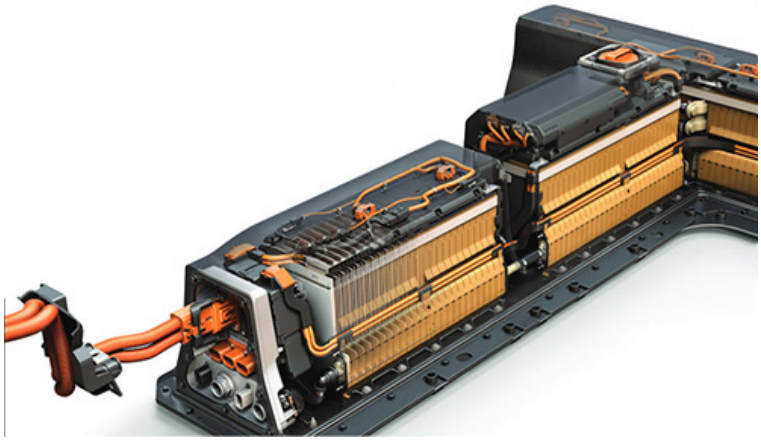


Simplorer Unit Model with Six-Parameter Electrical Circuit Model (Top) and Cell Cooling Channel Model (Bottom)

[1] Vehicle Technologies Office: Batteries, U.S. DOE, August 2015

ANSYS Fluent: Computer-Aided Design Tool for Automotive Batteries (CAEBAT)

Commercial Technology



2016 Chevy Bolt Battery, Designed using ANSYS Software

Technology History

- Developed by General Motors Company LLC, ANSYS, Inc., Esim LTD, and the National Renewable Energy Laboratory.
- Commercialized in 2015.
- Received initial funding in 2011.

Applications

Can be used to improve design cycle times for batteries.

Capabilities

- Performs cell level and pack level simulations.
- Offers linear time invariant system level reduced order model capability.
- Allows users to define their own models while using the ANSYS Fluent® battery framework.

Benefits

Cost Savings

Reduces development cost of advanced batteries by improving design cycle times and inter-model compatibility.

Efficiency

Allows users to create linear or non-linear user defined models for specific design goals.

Contact Information:
Dr. Taeyoung Han
Email: Taeyoung.Han@gm.com
Phone: (586) 986-1651
General Motors Company LLC
300 Renaissance Ctr.
Detroit, MI 48226
Website: www.gm.com/index.html

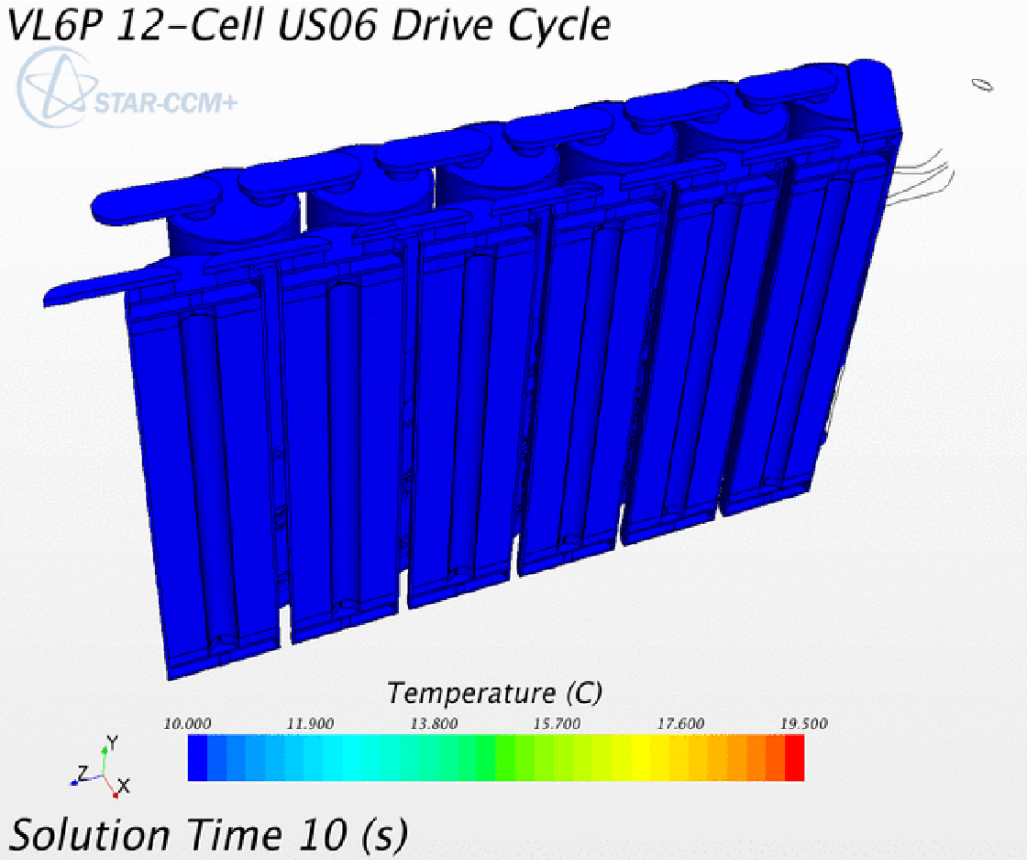
Computer-Aided Design Tools for Automotive Batteries

Commercial Technology

To reduce the use of imported fuel and transport sector emissions, DOE has emphasized the improvement of electric drive vehicle performance.[1] As part of this process, new batteries are being designed and tested to provide power for next generation electric vehicles. Battery modelling, design, and testing are necessary for the development of better systems, but traditional processes often extend design cycles and/or increase development costs. Improved modelling capabilities will reduce development cycles and the costs associated with validating new designs.

CD-adapco, a wholly owned subsidiary of Siemens PLM Software, with assistance from VTO and a team of partners, has developed new modelling capabilities for spirally-wound lithium-ion cell designs. This new modelling software was incorporated into Siemens' STAR-CCM+® software and Battery Design Studio™. The additions to STAR-CCM+® improve electrochemical, electrical, and thermal simulation modelling for both cylindrical and prismatic batteries. STAR-CCM+® is capable of simulating battery properties over a wide range of length scales using combined flow, thermal, and electrochemical simulation.

STAR-CCM+® and Battery Design Studio™ are available from Siemens and offer simulation support for module and pack level analysis. The software was validated using five cells from two manufacturers with at least one cell from each of the form factors including stacked, cylindrical, and prismatic wound electrodes.[2] The software is further supported by a database of modern electrolyte formulations that would be used in each battery type.

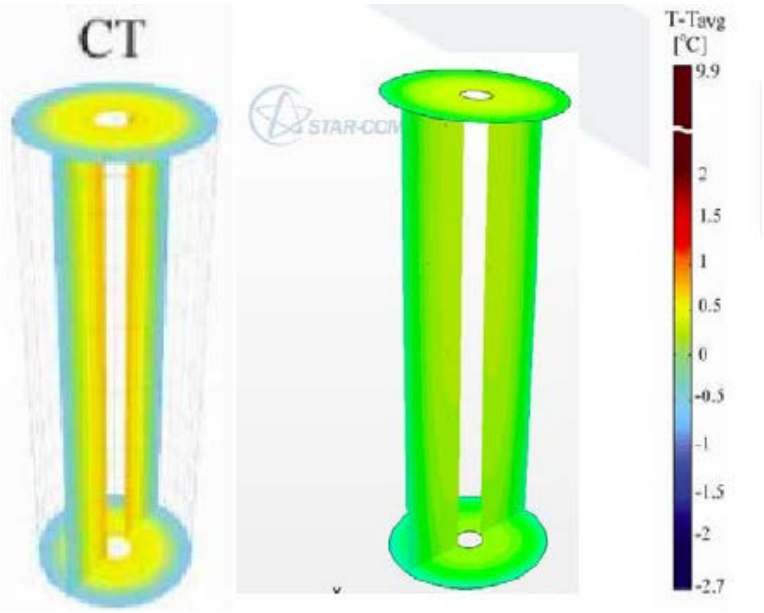


VLP 12-Cell US06 Drive Cycle Test

[1] For more information see: Computer-Aided Engineering for Electric-Drive Vehicle Batteries (CAEBAT)
[2] For more information see: 2014 Annual Merit Review, U.S. DOE, June 2017

Computer-Aided Design Tools for Automotive Batteries

Commercial Technology



Battery Core Temperature Model

Technology History

- Developed by CD-adapco (Siemens PLM Software), Battery Design LLC, Johnson Controls International PLC, A123 Systems Inc., the National Renewable Energy Laboratory, Idaho National Laboratory, and Oak Ridge National Laboratory.
- Commercialized in 2014.
- Received initial funding in 2011.

Applications

Can be used to assist with battery design and modelling.

Capabilities

- Offers adjustable modelling accuracy to allow users to run simulations at reduced accuracy when necessary.
- Offers an aging model, based on solid-electrolyte interphase growth, to use alongside standard battery modelling.
- Follows U.S. Advanced Battery Consortium procedure.
- Ability to be integrated into Siemens' Design Exploration platform, HEEDS® software to enable powerful automated design exploration capability while increasing productivity.

Benefits

Cost Savings

Reduces design cost by improving modelling performance and reducing design cycle time.

Efficiency

Supports modelling of major form factors using various common electrolytes from the same platform.

Contact Information:
Gaetan Damblanc
Email: gaetan.damblanc@siemens.com
Phone: +44 (207) 471-6246
CD-adapco
200 Shepherds Bush Road
London, United Kingdom, W67NL
Website: www.siemens.com/mdx

Expansion of Domestic Production of Lithium Carbonate and Lithium Hydroxide to Supply U.S. Battery Industry

Commercial Technology

The growing electric vehicle industry is turning to increasingly advanced batteries as a means of storing the energy needed to power advanced electric drive systems. For the most part, manufacturers are using lithium ion batteries because of their performance and durability. The scale of production needed to maintain battery availability has led heavy imports of lithium materials, as domestic production is relatively low. Expanded domestic production of these materials will increase U.S. energy independence and provide a low cost source of high-quality materials to U.S. manufacturers.

Rockwood Lithium (an Albemarle company), with assistance from VTO, BE&K Building Group, Jacobs Engineering Group, and the Nevada Bureau of Land Management, completed the enhancement of two domestic Rockwood Lithium production facilities. The group expanded Rockwood Lithium's facility in Kings Mountain, NC, and constructed a geothermal power facility at Rockwood Lithium's Silver Peak, NV facility. These plants produce lithium hydroxide and lithium carbonate, respectively.[1]

Rockwood Lithium's Kings Mountain plant installed a new LiOH unit as well as condensers to support the new unit. The geothermal plant installed at the Silver Peak facility was completed in 2013, and contributes to the 100,000 MT/year of potash and sodium chloride salts produced by the plant.



Kings Mountain Lithium Hydroxide Unit

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[1] For more information see: 2013 AMR, U.S. DOE, May 2013

Expansion of Domestic Production of Lithium Carbonate and Lithium Hydroxide to Supply U.S. Battery Industry

Commercial Technology



Silver Peak Production Plant

Technology History

- Rockwood Lithium (an Albemarle company), BE&K Building Group, Jacobs Engineering Group, and the Nevada Bureau of Land Management.
- Commercialized in 2010.
- Received initial funding in 2014.

Applications

Can be used to provide a source of high quality domestically produce lithium materials.

Capabilities

- Produces up to 6,000 MT lithium carbonate equivalent annually.
- Manages 5,500,000 tons of salts.

Benefits

Cost Reduction

Offers a low cost source of high quality lithium materials for reduced cost electric vehicle batteries.

Job Creation

Created more than 71 jobs in Silver Peak, Nevada and Kings Mountain, North Carolina.

Contact Information:
Contact Name
Email:
Phone: (###) ### ####
Company Name
Address
City, State Zip
Website:

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General Motors Lithium-Ion Battery Pack Manufacturing

Commercial Technology

Adoption of electric vehicles (EVs) continues to increase as cheaper and more reliable technologies are developed for the EV industry. To foster further growth of the EV industry, DOE has targeted reduction in battery cost and weight as a primary goal for new vehicle technology development.[1] Cost reductions for current EV batteries will rely on the evolution of EV battery technology, as well as the cultivation of new production capacity in domestic locations. Domestic production of EV batteries will create new jobs in the U.S. manufacturing and battery development sectors, while reducing energy consumption.

General Motors Company LLC (GM), with assistance from VTO and the American Recovery and Reinvestment Act and in collaboration with a team of university partners, established and subsequently expanded battery pack production facilities in Brownstown, Michigan. GM's facility is responsible for producing GM battery packs for GM's extended range electric vehicles (EREV) and hybrid electric vehicles. These battery packs are designed for high-volume production and will benefit from increased production capacity and reduced cost driven by both scale economies and large scale production techniques. Each of the battery family of batteries is also designed to maximize the use of common components to further reduce component costs and maximize the use of high-volume manufacturing techniques.

GM worked with several universities on continuous improvement activities and has validated production capability for multiple battery pack manufacturing programs. In 2010, the Brownstown facility began production with the 2011 model Chevrolet Volt battery pack. GM's work with universities focused on synchronizing the manufacturing and quality processes.

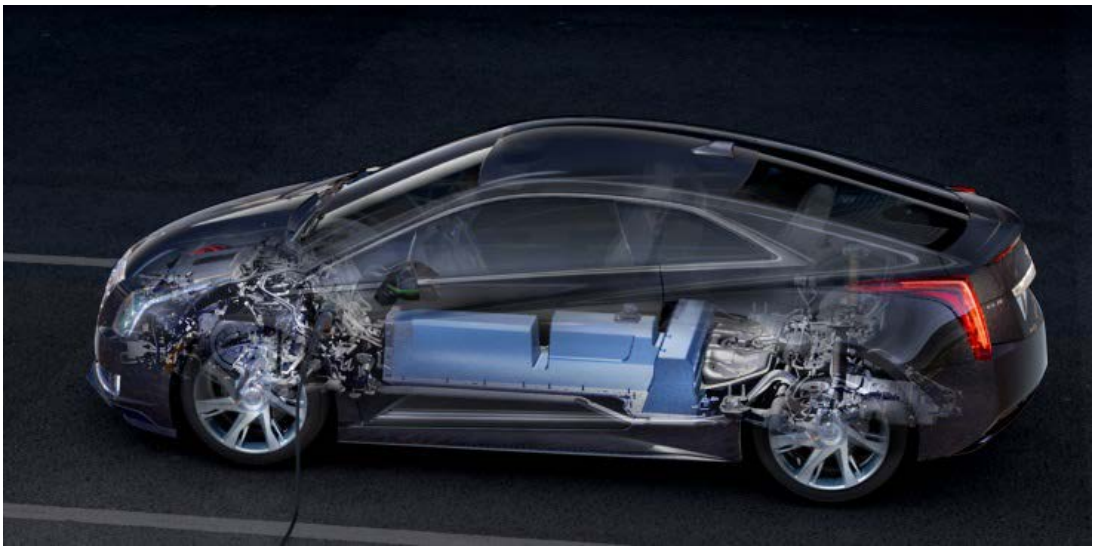


Brownstown Manufacturing Equipment

[1] Vehicle Technologies Office: Batteries, U.S. DOE, August 2015

General Motors Li-Ion Battery Pack Manufacturing

Commercial Technology



Model of General Motors Company LLC's EREV Battery Pack in the Cadillac ELR

Technology History

- Developed by General Motors Compnay LLC, Purdue University, University of Michigan, University of Texas, University of Wisconsin, University of Illinois, New York Institute of Technology, and Wayne State University.
- Commercialized in 2010.
- Received initial funding in 2009.

Applications

Manufacture and production of low cost EV and hybrid electric vehicle batteries.

Capabilities

- Provides a low cost domestic source of EV and hybrid electric vehicle batteries.
- Provides continuous improvement through academic partnerships.
- Enables future EV and hybrid electric vehicle battery improvement.

Benefits

Cost Savings

Reduces EV and hybrid electric vehicle battery cost through high volume production of multiple General Motors Company LLC battery families.

Job Creation

Has created approximately 100 full-time domestic jobs in the manufacturing sector.

Contact Information:
Linda Trumm
Email: Linda.Trumm@gm.com
Phone: (248) 240-8324
General Motors LLC
30200 Mound Rd. MS 480-111-L1W
Warren, MI 48092
Website: www.gm.com

Isothermal Battery Calorimeter Development

Commercial Technology

The automotive industry has turned to lithium-ion batteries as the energy storage technology needed to make electric-drive vehicles viable for a wider market. Problems related to hot climate operation and near-catastrophic issues with batteries catching fire dramatically illustrate how crucial the precise control of battery thermal properties is to ensure battery longevity and safety. Extreme temperatures lead to faster lithium-ion battery degradation and can trigger reactions that lead to thermal runaway. Faster degradation means replacing expensive batteries sooner, making the cost of ownership of electric vehicles (EVs) more expensive. The safety concerns connected to thermal runaway can also make EVs less appealing to potential buyers. The battery temperature must be controlled to prevent potential damage. Effective battery thermal management system design relies on knowing how much heat is generated while charging and discharging a battery. This information can be used to increase the power capabilities of the battery pack while limiting unwanted heat generation and transfer. Battery pack power can decrease by more than 17% because of problems with thermal management and the inter-connects between cells. The diagnostic abilities of isothermal battery calorimeter (IBC) technology can help minimize thermal control issues and maximize battery performance.

The National Renewable Energy Laboratory (NREL), with assistance from NETZSCH Instrument North America LLC and VTO, has developed IBCs for use in advanced battery development. These systems provide battery designers with a method of obtaining accurate measurements of cell heat output over the course of the entire charge/discharge cycle.[1] The systems also have the ability to differentiate between electrochemical or resistively generated heat. NREL's large-volume battery calorimeter can measure generation rates between 10 mW and 50W, while having a load measuring accuracy of ±1%. Measurements obtained by the IBCs can be used to compare new designs to industry standards, allowing designers to quickly determine design efficacy.

The IBC 284, which was recently patented, received a R&D 100 award in 2013, and is available from NETZSCH. The IBC 284 allows users to run cell and module size tests even with large format batteries. Pre-programmed testing software that is capable of testing batteries in the -30°C–+60°C range is distributed with the IBC 284 to allow users to perform "out-of-the-box" tests. Testing is performed in a completely submerged isothermal bath using heat sink bus bars and cables to ensure highly accurate measurements.

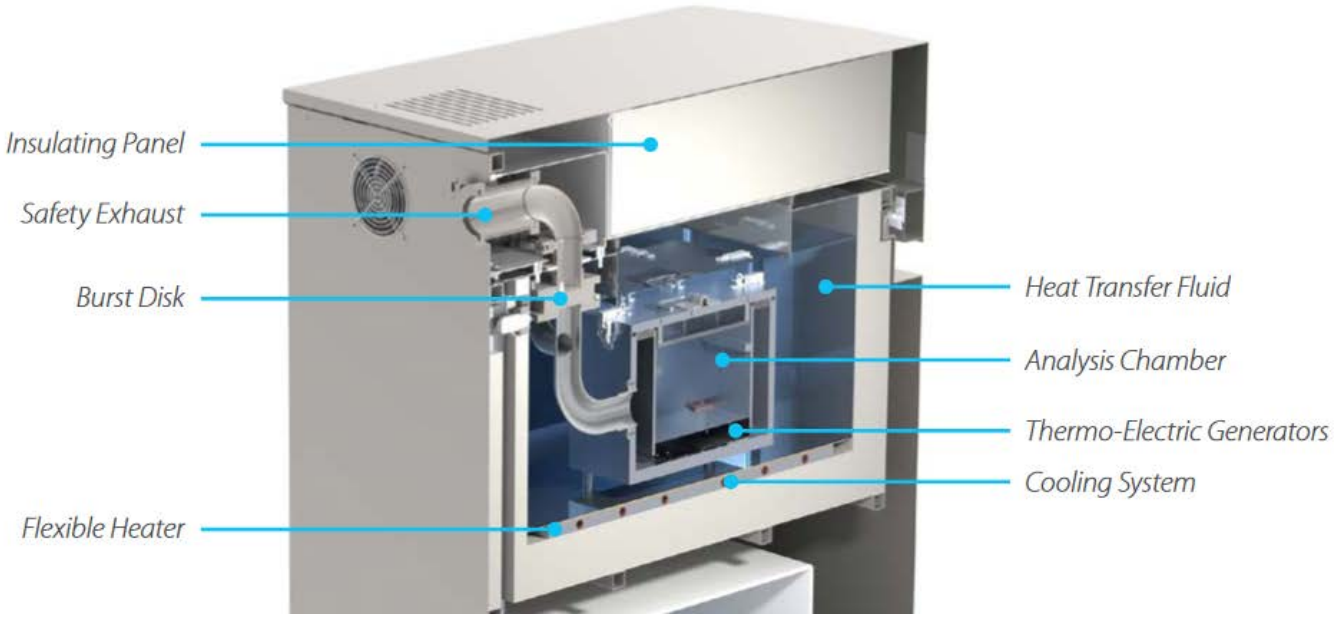


NETZSCH IBC 284

[1] Isothermal Battery Calorimeters, NREL, March 2015

Isothermal Battery Calorimeter Development

Commercial Technology



Cutaway of IBC Testing Chamber

Technology History

- Developed by the National Renewable Energy Laboratory and NETZSCH Instrument North America LLC.
- Commercialized in 2013.
- Received initial funding in 2005.

Applications

Can be used to obtain accurate heat generation data for battery cells, components, and packs under different modes of system operation, battery power profiles, and operating temperatures.

Benefits

Accuracy

Achieves 98% accuracy and can distinguish energy stored through waste heat regeneration for vehicle energy consumption estimations.

Cost Savings

Reduces overall EV cost by helping optimize battery performance and reduce battery failure rates.

Data Analysis

Compiles data for comparison against user defined models while maintaining a cell performance history for cell aging and cycling analysis.

Contact Information:
Matthew Keyser
Email: Matthew.Keyser@nrel.gov
Phone: (303) 275-3876
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
Website: www.nrel.gov/

Lithium-Ion Battery Cathode Materials Production Plant

Commercial Technology

The growing electric vehicles (EVs) industry is continually developing more advanced batteries to increase vehicle range and performance. New lithium-ion batteries have become less expensive while yielding better performance. Advancing EV technology and wider availability has enabled DOE to set goals to decrease the cost of EVs to facilitate further adoption.[1] To meet the demand for this increase in EV adoption, it will be necessary for domestic manufacturers to increase imports of battery cathode materials to maintain production levels. Relying on imported materials exposes the manufacturing industry to the risk of material shortfalls caused by political turmoil or other trade barriers. Domestic production of these materials could alleviate these concerns while creating sustainable domestic jobs in the U.S.

BASF Corporation (BASF), with assistance from VTO, has built a cathode materials manufacturing facility in Elyria, Ohio. BASF was selected as a licensed supplier of Argonne National Laboratory's nickel-cobalt-manganese cathode materials. The facility is presently manufacturing these advanced materials and the facility has the capacity to expand to meet market demand. The facility will not manufacture finished EV batteries, but has been recognized as a versatile cathode materials producer.

The new BASF facility is four stories tall and over 70,000 square feet. The plant is the largest advanced cathode material manufacturing facility in North America and is expected to have a positive impact on reducing the cost of EV batteries as DOE ramps up plans to increase nation-wide EV use. BASF's Elyria plant has been in operation since 2012.



BASF Corporation's Elyria, Ohio facility

[1] For more information see: About EV Everywhere

Lithium-Ion Battery Cathode Materials Production Plant

Commercial Technology

Technology History

- Developed by BASF Corporation.
- Commercial production began in 2012.
- Initially funded in 2010.

Applications

Can be used to manufacture advanced cathode materials used in the manufacture of lithium-ion batteries.

Capabilities

- Produces cathode materials for EVs, hybrid electric vehicles, and plug-in hybrid electric vehicles.
- Can produce precious metal catalysts.
- Produces Argonne National Laboratory-designed advanced nickel-cobalt-manganese materials.

Benefits

Job Creation

Created over 170 new sustainable jobs in Elyria, Ohio.

Manufacturability

Manufactures low-cost high performance cathode materials.

Sustainability

Produces nickel-cobalt-manganese materials for use in EV batteries.

Contact Information:
Cesar F Garcia
Email: cesar.f.garcia@basf.com
Phone: (732) 205- 7650
BASF Corporation
25 Middlesex/Essex Turnpike
Iselin, NJ 08830, USA
Website: www.basf.com

Lithium-Ion Battery Development (40kW Hybrid Electric Vehicle)

DOE's Vehicle Technologies Office (VTO) supports research, development, demonstration, and deployment of a broad portfolio of advanced transportation technologies that improve energy security by reducing dependence on foreign oil and greenhouse gas emissions. Reducing cost and improving the performance of technologies, such as advanced energy storage devices (batteries and ultracapacitors), is one of several areas that VTO funds research at the national laboratories, universities, and industry. To fund R&D of emerging energy storage technologies for automotive use, General Motors Company LLC, Ford Motor Company, and Fiat Chrysler Automobiles US LLC formed the United States Advanced Battery Consortium (USABC) in 1991. USABC's mission is to develop electrochemical energy storage technologies that support commercialization of electric drive vehicles.[1]

Johnson Controls International (JCI), with assistance from VTO and USABC, in the form of numerous grants awards and as part of the American Recovery and Reinvestment Act, developed advanced lithium-ion (li-ion) battery technologies for use in hybrid electric vehicles (HEVs), plug-in hybrid vehicles (PHEVs), and electric vehicles (EVs). Li-ion technology is cheaper, lighter, smaller, and more durable and powerful than similar nickel metal hydride batteries. JCI has been developing and investing in Li-ion research and manufacturing capability since the 1990s. More recently, as U.S. automakers catch up plan to compete globally (primarily Japan) in the EV/HEV/PHEV sector, JCI sped up their ability to supply li-ion batteries by collaborating with French manufacturer, Saft S.A. and by acquiring Delphi's battery business unit and German battery manufacturer, Varta AG. JCI's goal was to leverage their leading market leadership and industry relationships as a supplier to overtake companies supplying hybrid battery technology.

Since 2005, as interest in HEVs and PHEVs became more widespread, JCI was awarded several grants to improve lithium-ion battery power, abuse tolerance, and lifecycle as well as address the lack of domestic li-ion battery infrastructure. JCI won numerous contracts to supply lithium-ion battery technologies including, Mercedes-Benz (S400 & S300), Beijing Electric Vehicle Co., Chery Automobile Corp. and SAIC Motor Corp. (Chinese automakers), BMW (7 series hybrid), Ford Motor Company (Escape Hybrid & Transit Connect BEV van), General Motors Company LLC (Saturn Vue), Daimler-Chrysler (Dodge Sprinter van), Land Rover (Range Rover Hybrid sport), and a German electric boat engine (Torqeedo). In 2009, as part of a $300M ARRA investment to support the increasing demand for batteries, JCI built the first of two battery manufacturing plants, a li-ion facility in Holland, Michigan and an advanced battery facility in Toledo, Ohio. The underlying 40 kW lithium-ion battery called VLP6 was initially developed in partnership with SAFT SA and is still being improved, along with the new 48V micro hybrid battery technologies that combine advanced start-stop lead acid and lithium-ion battery technologies to increase vehicle fuel efficiency by as much as 15–20%. JCI continues to push lithium-ion technology development through collaboration and partnerships with universities, national laboratories and industry.



Johnson Controls International's Lithium Battery Cell and Pack Technology

[1] For more information see: 2015 DOE Quadrennial Technology Review - United States Advanced Battery Consortium

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Lithium Ion Battery Development (40kW Hybrid Electric Vehicle)

Commercial Technology



On-Vehicle Platform Examples of Johnson Control International's Lthiumi-Ion Battery

Technology History

- Developed by Johnson Controls International in partnership with Saft SA and U.S. Advanced Battery Consortium LLC
- Commercialized in 2004.
- Received initial funding in 2004 from U.S. Advanced Battery Consortium.

Applications

Can be used for transportation applications such as EVs, HEVs, and PHEVs, including hybrid battery systems, industrial battery applications, and energy storage applications in buildings.

Capabilities

- Provides smaller, lighter, 2-3 times more energy, and 50% higher energy density than NiMH based battery technologies.
- Constructed using a $LiNi_xCo_yAlzO_2$ cathode, low cost graphite anode, and an alkylcarbonate based $LiPF_6$ salt electrolyte.
- VL6P cylindrical cell provides 6.8Ah with 25Wh total power, with a long life for a low cost.
- Lithium-ion technology development has enabled investigation of other materials for future increases in performance and lower cost.

Benefits

Market Leadership

Johnson Controls International's investment, industry supplier relationships, and manufacturing presence in the U.S. and globally has placed them at the forefront of new battery technology development, manufacturing, and deployment.

Job Creation

Lithium-ion battery development and manufacturing capabilities has created hundreds of domestic jobs in the states of Michigan and Ohio.

Contact Information:
Michael Andrew
Email: Michael.G.Andrew@jci.com
Phone: (414) 524-1200
Johnson Controls, Inc.
5757 N. Green Bay Avenue
Milwaukee, WI 53201
Website: www.johnsoncontrols.com

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Lithium-Ion Battery Recycling Facilities

Advancing battery and electric drive technologies are spurring growth in the electric vehicle (EV) industry. DOE's "EV Everywhere" program aims at further reducing the cost of EVs to the point where they are no more expensive than a traditional gas-powered car.[1] Though EVs can represent clean modes of transportation, there have been concerns related to battery disposal and limits on domestic supply of advanced battery materials. Domestic supply of lithium carbonate is relatively low and though it is not currently economically attractive to recycle batteries for their lithium, mass adoption of EVs could result in increased materials cost or material shortages due to low domestic supply. In addition to this, other metals in batteries currently represent relatively expensive components and could benefit from expanded recycling facilities in the short term.

Retriev Technologies Inc. (Retriev), with assistance from VTO, expanded their existing recycling facility in Lancaster, Ohio through the addition of a 66,000 square foot facility to accommodate EV battery recycling. The new facility is responsible for the disassembly and recycling of lithium-ion hybrid electric vehicle (HEV) and EV batteries, in addition to their current capability of processing all NiCad, NiMH, and lead acid batteries. The operations are fully permitted to handle all battery types and operate under the oversight of a Resource Conservation and Recovery Act (RCRA) Part B permit that governs the treatment, storage, and disposal of all hazardous waste on-site. The facility currently hosts the company's large format battery recycling lines as a means of promoting sustainable HEV and EV battery manufacturing processes.

The Retriev process for recycling NiCad batteries is classified by the EPA as the best demonstrated available technology for cadmium recovery. The process uses low temperatures to remove cadmium from recycled batteries while yielding nickel rich iron—a component in stainless steel production.

Retriev's facility is also capable of "battery to battery recycling," meaning some recycled components are directly reusable in new batteries without remanufacturing.[2] As an example of this capability, Retriev's patented alkaline recycling process supplies manganese oxides from alkaline batteries back to Energizer to support their EcoAdvanced product line.



Retriev Technologies Inc.'s Battery Recycling Facility in Lancaster, Ohio

[1] For more information see: About EV Everywhere
[2] For more information see: Toxco AMR, U.S. DOE, May 2013

Lithium-Ion Battery Recycling Facilities



Retriev Technologies Inc.'s Recycling Process Lines

Technology History

- Developed by Retriev Technologies, Inc.
- Commercialized in 2015.
- Received initial funding in 2011.

Applications

Can recycle EV and hybrid batteries.

Capabilities

- Offers fully permitted recycling options for multiple battery chemistries.
- Offers an environmentally friendly method of battery disposal.
- Maintains a comprehensive database on all EV and HEV packs.

Benefits

Environment

Reutilizes and recovers materials via low environmental impact recycling, keeping battery materials out of landfills.

Job Creation

Creates sustainable domestic jobs in Ohio.

Scale

Able to process 4 million lbs/yr of EV and HEV battery packs with the ability to easily triple production within the existing footprint.

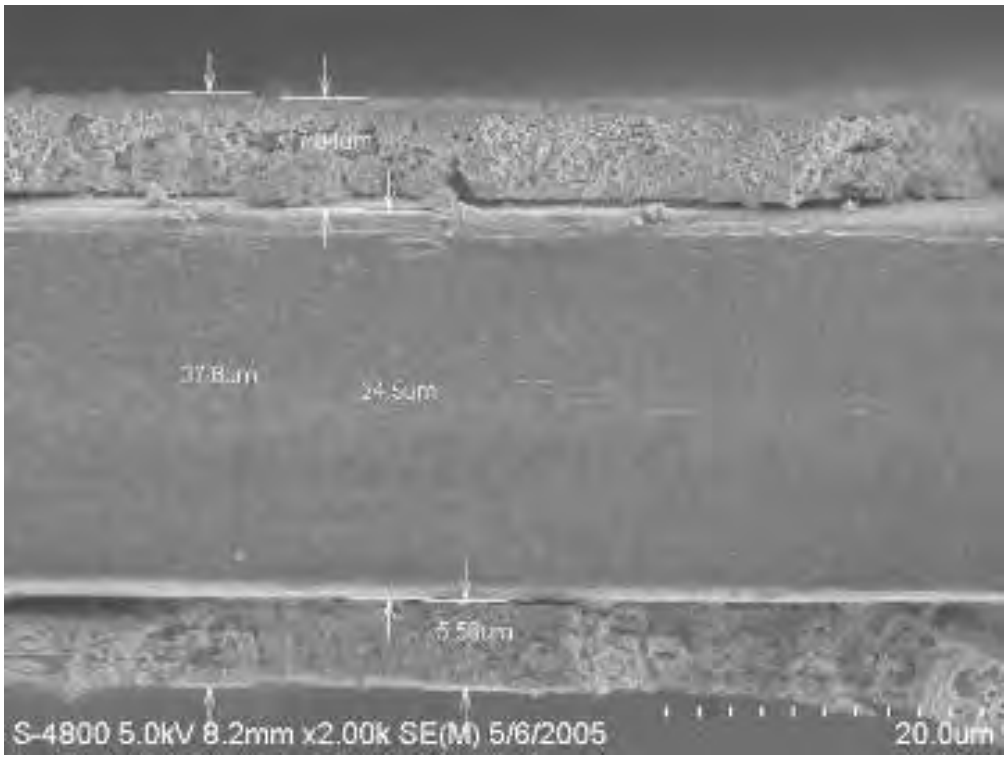
Contact Information:
Joseph Acker
Email: joeacker@retrievtech.com
Phone: (740) 653-6290
Retriev Technologies
265 Quarry Road Southeast
Lancaster, OH 43130
Website: www.retrievtech.com

Lithium-Ion Cell Manufacturing

Development of new electric drive systems could reduce emissions in the transportation sector to below 2013 levels by 2040.[1] To support this goal, DOE hopes to reduce cost, volume, and weight of batteries used for electric vehicles (EVs) while increasing power, energy and durability.[2] The cost component of improved battery production could be addressed through expansion of domestically produced batteries using advanced manufacturing systems. This domestic increase in battery production may lower battery costs to more favorable levels while offering the U.S. increased energy security.

LG Chem Michigan Inc., with support from VTO, has built a factory in Holland, Michigan to produce advanced lithium-ion batteries. The facility was completed in 2012 and steadily increased production to over 650 megawatt-hours, approximately 2 million cells, annually by 2016. The plant operates three manufacturing lines with two operating around the clock. A fourth is expected to come online to further increase the plant's production capacity in the near future. The advanced operations at the Holland facility allow high-quality batteries to be produced and have been shown to produce as little as two defects per million batteries.

The Holland facility produces batteries for several EVs and is capable of further expanding to accommodate a growing EV market. The scalable production system used by LG Chem Michigan Inc.'s facility allows the factory to scale up to 3 gigawatt-hours, approximately 9 million cells, annually without adding square footage to the existing facility.[3]



LG Chem Michigan Inc.'s SRS™ Separator

[1] Annual Energy Outlook 2015, U.S. Energy Information Administration, April 2015
[2] The Vehicle Technologies Office's Contribution, U.S. DOE, August 2015
[3] LG Chem Factory May Have Largest Battery Factory In US, GAS2, December 2015

Lithium-Ion Manufacturing



Cutaway of Battery Pack Produced by LG Chem Michigan Inc.

Technology History

- Developed by LG Chem Michigan Inc.
- Commercialized in 2013.
- Received initial funding in 2009.

Applications

Used to manufacture advanced power storage materials.

Capabilities

- Produces batteries incorporating a Safety Reinforced Separator™.
- Achieves low cost production of batteries.
- Offers 650 megawatt-hour production capacity annually.

Benefits

Cost Savings

Reduces manufacturing costs by using a highly vertically-integrated scalable production system.

Flexibility

Capable of adding additional production lines to accommodate new battery types without further construction.

Job Creation

Created more than 400 new jobs in Holland, Michigan.

Contact Information:
Karen Scudder
Email: Kolsen@lgchem.com
Phone: (616) 494-7196
LG Chem Michigan Inc.
1 LG Way
Holland, MI 49423
Website: www.lgchem.com

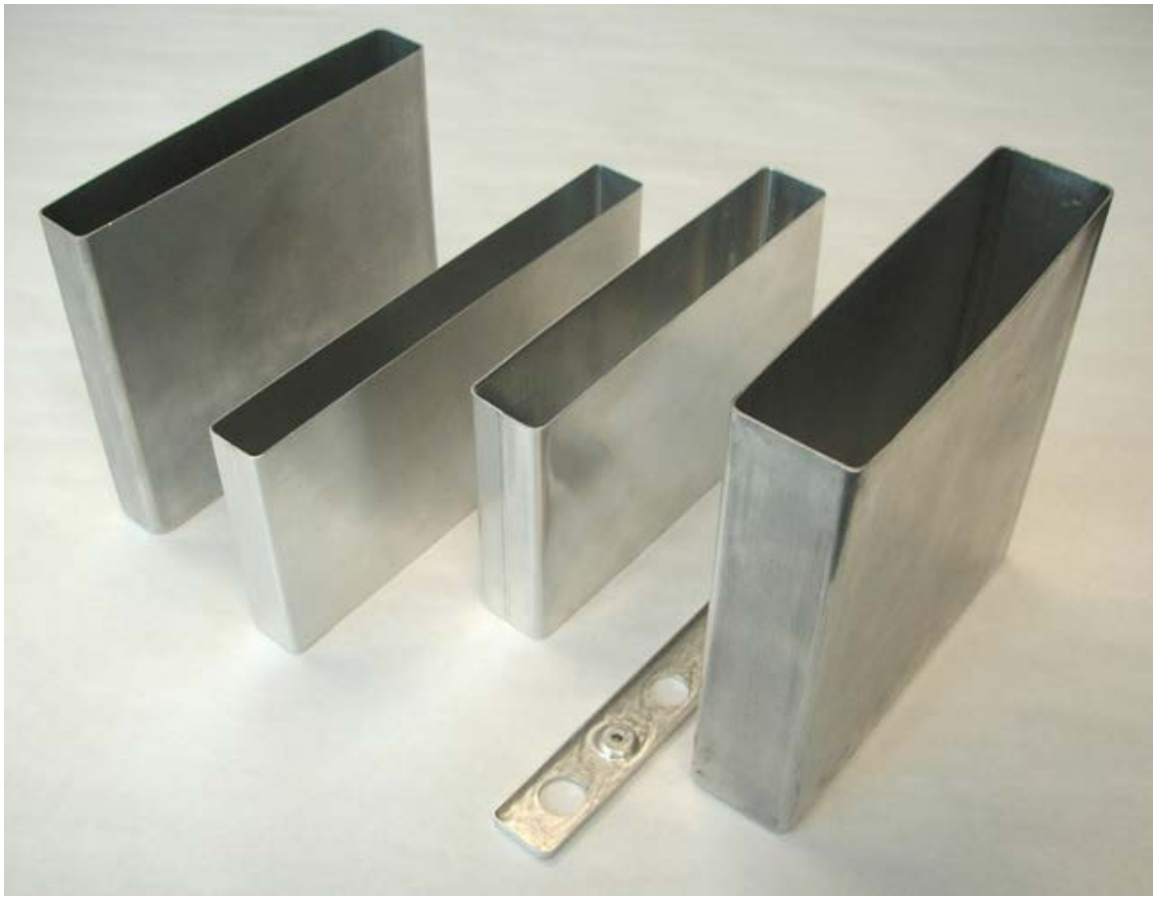
Manufacture of Advanced Battery Metal Containers and Components

Commercial Technology

Development of large format batteries is contributing to domestic market acceptance of advanced battery electric vehicles and plug-in hybrid electric vehicles. To support the integration of new batteries in consumer ready products, DOE has focused on reducing cost, volume, and weight. These reductions are to be accompanied with increases in power, energy, and durability.[1] Lighter weight batteries will increase electric vehicle performance but will need to retain their durability to avoid safety and quality issues. New domestic manufacturing capacity for batteries could help produce these advanced batteries and further encourage growth in the electric vehicle sector.

HTTM, LLC (HTTM), with assistance from VTO, project partners, and the American Recovery and Reinvestment Act, has developed new advanced battery cans and cover assemblies. These new materials are produced using new swaging, laser welding, helium leak testing, and in-house aqueous cleaning processes. HTTM's new battery containers are hermetically sealable and include a safety vent that is stamped into the can or cover using a process that was developed to allow adjustments to the burst pressure. As part of the container development process, HTTM developed a high precision digital probe for measuring pressure burst discs. This probe is used in conjunction with a burst tester to expedite verification testing of newly produced containers.

HTTM's advanced battery containers are available to original equipment manufacturers and can be tailored to specifications provided by manufacturing partners. HTTM's products are suitable for both automotive and stationary power applications, and have been used in three programs that were launched in 2013. High volume manufacturing began in 2013 and serves nine original equipment manufacturers.



HTTM LLC Inc.'s Battery Containers

[1] For more information: The Vehicle Technologies Office's Contribution, U.S. DOE, August 2015

Manufacture of Advanced Battery Metal Containers and Components

Commercial Technology



HTTM LLC's Burst Pressure Verification System

Technology History

- Developed by HTTM, LLC, Heitkamp & Thumman Group, Trans-Matic Manufacturing Co., and Karotech Inc.
- Commercialized in 2013.
- Received initial funding in 2010.

Applications

Can be used to manufacture advanced battery containers.

Capabilities

- Offers domestic large format metal battery containers and cover assemblies.
- Supports rapid prototyping techniques for the development of new designs.
- Offers in-house prototyping and production with the option to keep customer designs confidential.

Benefits

Cost Savings

Reduces manufacturing costs by implementing forming simulation software to optimize manufacturing processes and ensure new designs are "designed for manufacturability." (DFM).

Efficiency

Supports a high level of vertical integration in the design and manufacturing processes.

Flexibility

Allows rapid development of new battery designs through in-house tool design and manufacturing processes.

Contact Information:
Dan Moffa
Email: dan.moffa@ht-group.com
Phone: (203) 596-3329
HTTM, LLC
300 East 48th St.
Holland, MI 49423
Website: www.ht-group.com

Nanoengineered Ultracapacitor Material Surpasses the $/kW Threshold for Electric Drive Vehicle Use

Commercial Technology

Development of new electric drive systems could reduce emissions in the transportation sector to meet 2040 target levels.[1] To support these targets, DOE aims to reduce cost, volume, and weight of batteries used for electric vehicles while increasing power, energy, and durability.[2] New batteries developed in this effort will allow manufacturers to make lighter vehicles that offer better performance and improved durability. Part of this development process is producing new advanced materials that can be used to improve the performance of existing technologies. These materials could represent a low-cost method of reducing transportation related emissions in the short term.

EnerG2, with assistance from VTO and a team of industry partners, has constructed a manufacturing facility to produce materials for use in advanced energy storage solutions. The facility in Albany, Oregon, produces high quality carbon materials for use in both batteries and ultra-capacitors. The porous carbon materials produced by EnerG2 offer improved cycle life for their batteries and improved power density in their ultra-capacitors. EnerG2's ultra-capacitors use materials that achieve high levels of purity and can offer as low as 1/20th the level of impurities of other materials.

EnerG2 produces its materials using customized polymers that are tailored for each energy application (e.g. batteries, capacitors).[3] These materials represent a domestic source of high quality carbon materials for electric drive systems and are contributing to the reduction of electric vehicle costs. EnerG2 has begun producing advanced energy storage materials in 2012.



Kilns at EnerG2's Albany facility.

[1] Annual Energy Outlook 2015, U.S. Energy Information Administration, April 2015
[2] The Vehicle Technologies Office's Contribution, U.S. DOE, August 2015
[3] Polymer Chemistry Platform, EnerG2, 2014

Nanoengineered Ultracapacitor Material Surpasses the $/kW Threshold for Electric Drive Vehicle Use

Commercial Technology



EnerG2's Albany Facility

Technology History

- Developed by EnerG2 Technologies Inc., CH2M Hill Companies Ltd., Fisher & Sons Inc., Oregon Freeze Dry Foods, Inc., Harper International Corporation, Procedyne Corp.
- Commercialized in 2012.
- Received initial funding in 2010.

Applications

Can be used to manufacture advanced power storage materials.

Capabilities

- Offers domestic production of advanced storage materials.
- Achieves low cost production of high purity materials.
- Offers 60,000 electric drive vehicle production capacity annually

Benefits

Cost Savings

Reduces manufacturing costs by using polymer production techniques.

Flexibility

Supports production of materials that are specifically tailored for various products and their application.

Job Creation

Creates jobs in the Pacific Northwest.

Contact Information:
Dr. Aaron Feaver
Email: afeaver@energ2.com
Phone: (206) 547-0445
EnerG2 Technologies Inc.
3000 SW Calapooia Street
Albany, OR 97322
Website: www.energ2.com

Process Development and Scale up of Critical Battery Materials

Commercial Technology

As part of the EV Everywhere challenge, DOE has launched an effort to make domestic electric vehicles (EVs) as affordable and convenient to drive as their gas-powered counterparts.[1] This effort emphasizes the need for domestically produced batteries that offer reduced size and weight and improved performance characteristics. While lithium-ion batteries are capable of offering compelling performance improvements over older batteries, achieving EV performance comparable to gas vehicles can be cost prohibitive. New advanced batteries and production processes will need to be developed to further EV performance.

Argonne National Laboratory (ANL), with assistance from a team of partners and VTO, has developed 12 new battery materials for use in the next generation of domestic EVs.[2] These electrolyte materials were invented in ANL's Chemical Sciences and Engineering division and production scale-up at ANL's Materials Engineering Research Facility. The ANL-developed production process allows high purity material production at both reduced reaction time and temperature.[3] The improved production processes developed at also resulted in increased yield and reduction of waste materials.

The new battery materials are available through Sigma-Aldrich Corporation and Strem Chemicals, Inc. Strem Chemicals offers nine of the materials, while Sigma-Aldrich Corporation offers three. ANL has provided both manufacturers with technology transfer packages that include synthesis procedures, process information, and analytical and quality control data.

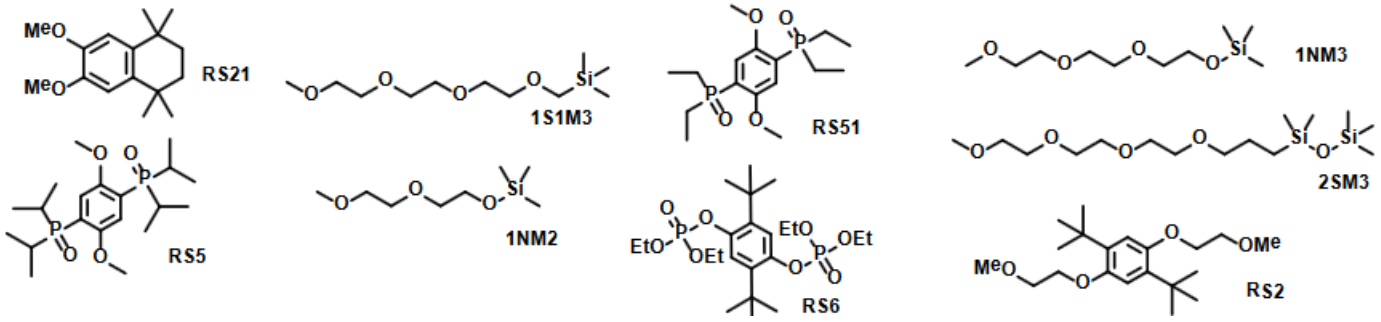


Argonne National Laboratory's Materials Engineering Research Facility

[1] For More Information: About EV Everywhere
[2] For More Information: Electrolyte Materials Available for Sampling
[3] A matter of scale, Nature Nanotechnology 11, 733 (2016)http://www.anl.gov/articles/lithium-ion-battery-electrolyte-material-scale

Process Development and Scale up of Critical Battery Materials

Commercial Technology



Argonne National Laboratory-Developed Advanced Battery Materials

Technology History

- Developed by Argonne National Laboratory.
- Commercialized in 2015.
- Received initial funding 2010.

Applications

Can be used in high performance battery applications.

Capabilities

- Offers high purity yields of >99.95%.
- Reduces waste by up to 97% for some materials.
- Offers high reproducibility.

Benefits

Cost Savings

Reduces cost associated with advanced battery development by improving batch yields, reducing process time, and minimizing waste.

Efficiency

Increases batch size to more than 3 kg for some materials, while maintaining purity and reproducibility.

Contact Information:
Gregory Krumdick
Email: GKrumdick@anl.gov
Phone: (630) 252-3952
Argonne National Laboratory
9700 S. Cass Avenue
Lemont, IL 60439
Website: www.anl.gov

Combustion Engines

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NOx Control and Measurement Technology for Heavy-Duty Diesel Engines 36
On-Board Engine Exhaust Particulate Matter Sensor for Homogeneous Charge Compression Ignition and Conventional Diesel Engines 38
Volvo SuperTruck: Powertrain Technologies for Efficiency Improvement 40

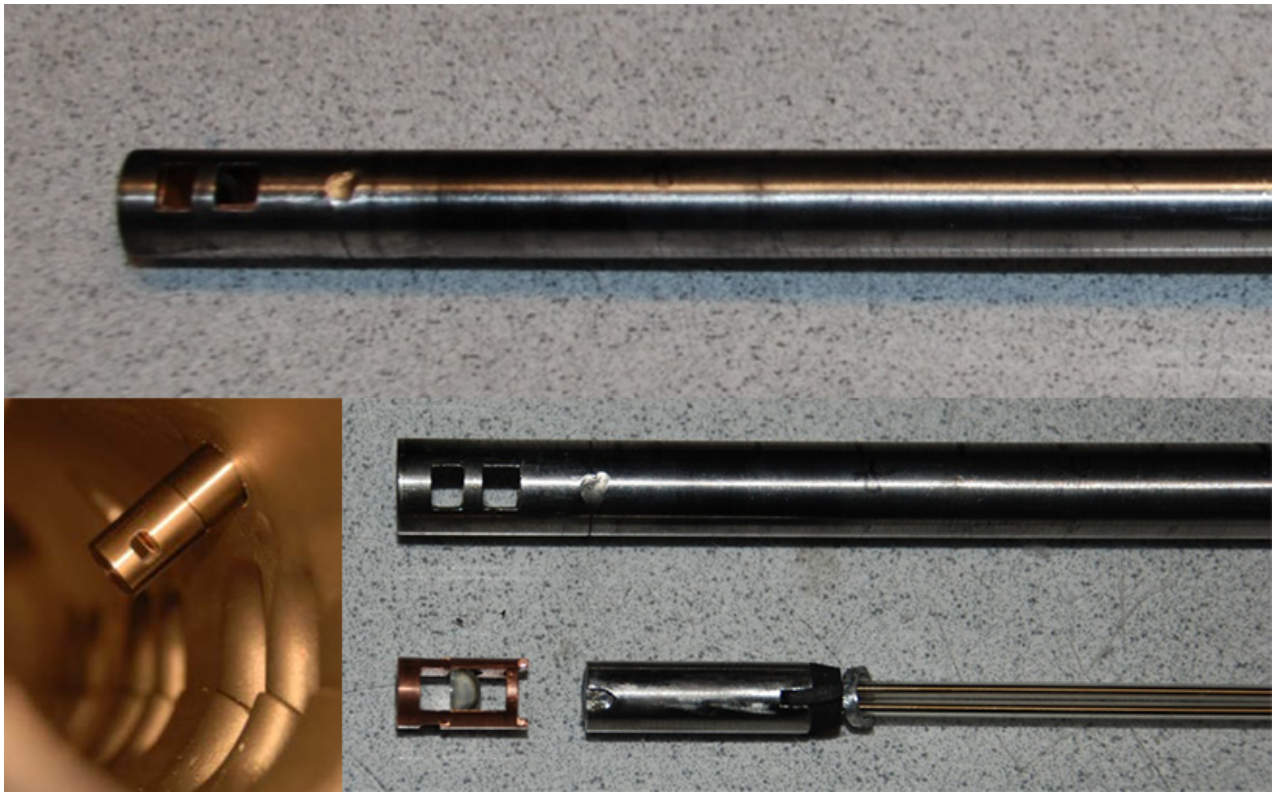
Characterization and Reduction of Combustion Variations

Commercial Technology

Advancement of combustion engines has been selected by DOE as a method of improving performance and near term reduction of emissions in the U.S. transportation sector.[1] Multi-cylinder engine combustion intake charge fluctuations negatively impact efforts to advance current engine designs. Specifically, cylinder-to-cylinder and cycle-to-cycle combustion variations limit overall engine efficiency, durability, and performance. Improvements to current understanding of engine fluctuations could result in a more robust domestic advanced engine portfolio.

Oak Ridge National Laboratory in collaboration with Cummins, Inc., and with assistance from VTO, has developed a multi-species exhaust-gas-recirculation (EGR) Probe to assist with engine intake characterization. The instrument allows near-crank-angle-resolved (5kHz, 1.2 CAD [crank angle degrees] at 1k RPM) simultaneous measurement of H_2O and CO_2 concentrations, as well as temperature and pressure transients from four separate probes. The probe-based instrument can be used in a broad range of applications throughout advanced, well-packaged engine systems with minimal modifications to the base engine hardware. Only a single, ca. 3/8-in outer diameter, access port is required to accommodate and locate each probe via a compression fitting with non-swaging ferrule. By translating the probe within the engine system, spatiotemporal parameter distributions can be mapped and correlated with engine operating conditions.

The EGR Probe has been applied to assess parameter and combustion uniformity associated with specific hardware designs and configurations, combustion modes, and control strategies. It has been applied to assess, verify, and improve numerical design and other modeling tools. Using its ability to measure internal and external EGR via combustion-residual-backflow measurements, the instrument has been applied to develop a measurement-based real-time model for predicting cylinder-charge parameters, and their cylinder- and cycle-specific fluctuations. The Cummins Inc.-Oak Ridge National Laboratory team has implemented the EGR Probe in several joint measurement campaigns including the Cummins Inc., SuperTruck program, and continues to apply this and other Cooperative Research and Development Agreement-developed diagnostics for advancing next-generation engine designs for achieving advanced efficiency, durability, cost, and performance.

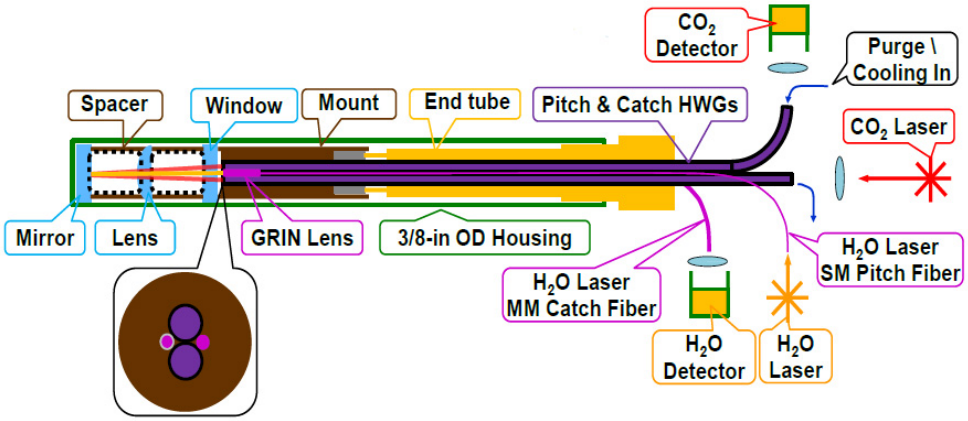


Multi-Species EGR Probe

[1] "Advanced Combustion Engines", U.S. DOE, May 2016

Characterization and Reduction of Combustion Variations

Commercial Technology



Schematic of the EGR Probe

Technology History

- EGR Probe developed by Oak Ridge National Laboratory and Cummins Inc., in a DOE-sponsored Cooperative Research and Development Agreement.
- Commercialized in 2016.
- Initially funded in 2013.

Applications

- Can be used to identify and assess engine performance fluctuations.

Capabilities

- Simultaneous CO_2, H_2O, temperature, and pressure measurements provide parameters relevant to engine system design.
- Fast measurements resolve cycle-specific, cylinder-specific, and intra-valve-event transients.
- Probe-based instrument allows broad application to advanced-packaged engine systems, requiring minimal modification to the base hardware.
- Simultaneous measurements from up to four separate probes and individual probe translation for spatial mapping.
- Instrument is expandable to incorporate additional relevant species such as CO and CH_4.

Benefits

Cost Savings

Reduces costs associated with engine maintenance by improving engine design and durability.

Efficiency

Allows four real-time probes to be used for simultaneous multi-location data gathering for reduced cost analysis.

Flexibility

Other species may be added to the primary measurement capabilities including CO and CH_4. The instrument can also drive line-of-sight hardware for primary specie and O_2 measurements.

Contact Information:
Bill Partridge
Email: partridgewp@ornl.gov
Phone: (865) 946-1234
Oak Ridge National Laboratory
1 Bethel Valley Rd,
Oak Ridge, TN 37831
Website: www.ornl.gov

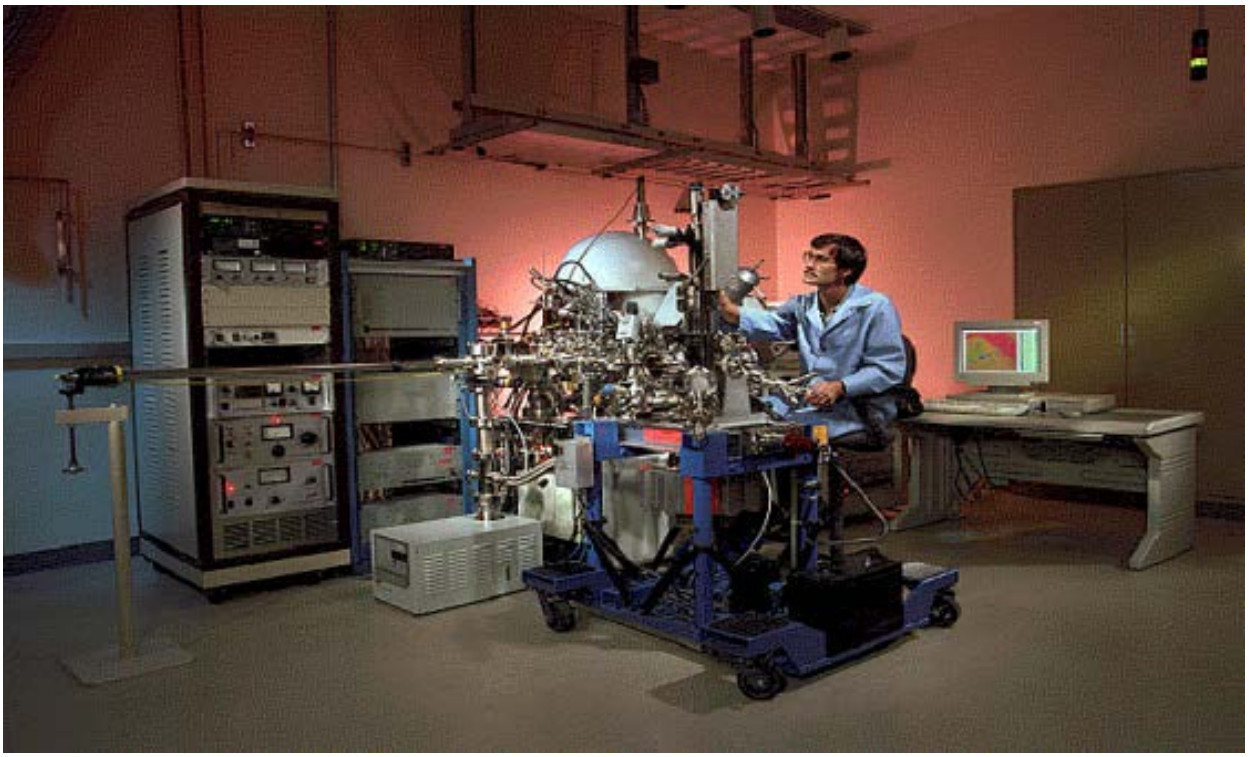
Enhanced High and Low Temperature Performance of NOx Reduction Materials

Commercial Technology

In an effort to meet DOE's future fuel economy goals, original equipment manufacturers are pursuing lean combustion strategies that make use of low engine temperatures.[1] As these technologies become available, they must meet stringent emissions requirements before they are viable for deployment in the U.S. To date, there are few catalytic after treatment technologies that have been designed with low temperature treatment in mind, which limits implementation into new engine designs. To counter this issue, DOE's U.S. Drive Partnership has set a goal to reduce emissions below 150ºC by 90% with several programs already funded under this goal in an attempt to reduce emissions concerns and spur new engine development.

Pacific Northwest National Laboratory (PNNL), with assistance from Cummins Inc., Johnson Matthey, and VTO, has developed new emission reduction materials that exhibit adequate performance in both low and high temperature operations. Characterization and performance test work was performed by PNNL using in-house and Johnson Matthey produced catalyst materials to down select candidates for further research. Several copper loaded catalysts were identified that offered favorable operating temperature windows. Various lean NOx trap and selective catalytic reduction (SCR) catalysts were tested to provide thermal degradation data for future wo This work benefitted existing Cummins Inc., products and helped increase understanding of catalyst properties and refine performanc

Upon completion of their work, PNNL transferred the remaining catalyst work to the Cross-Cut Lean Exhaust Emissions Reduction Simulations (CLEERS) project. PNNL and its collaborators were able to generate copper-cyclohexylammonium salt (Cu/CHA) catalyst preparation guidelines to optimize catalyst performance. The team also identified key limiting factors in fast SCR catalysts with Fe/zeolites. Modeling and optimization work continues with the CLEERS team and is focused on further improvement of CHA-based SCR catalysts. In 2015, Cummins Inc., incorporated SCR in their engine exhaust after treatment systems.

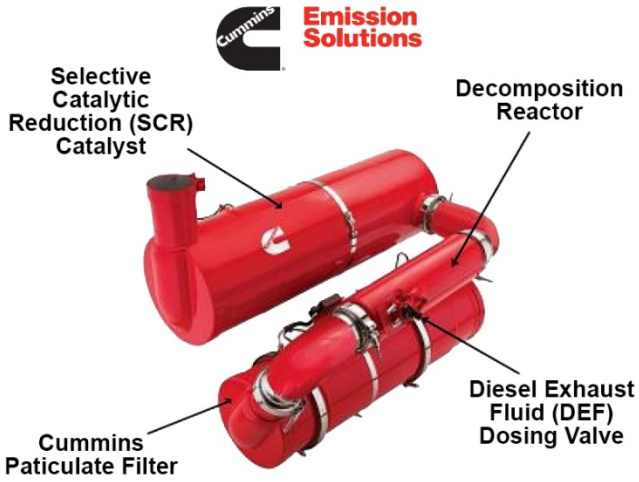


Testing done at Pacific Northwest National Laboratory's Institute for Integrated Catalysis.[2]

[1] USDRIVE ACEC Tech Team Low Temperature Protocol, CLEERS, August 2015
[2] For more information: http://iic.pnnl.gov/

Enhanced High and Low Temperature Performance of NOx Reduction Materials

Commercial Technology



Cummins Inc., SCR Catalyst Based Engine Exhaust Aftertreatment System

Technology History

- Developed by Pacific Northwest National Laboratory, Cummins, Inc., and Johnson Matthey.
- Commercialized in 2015.
- Initially funded in 2009.

Applications

Can be used for low and high temperature catalyst development.

Capabilities

- Offers catalyst performance metrics for lean NOx trap and selective catalytic reduction catalysts, including estimations of optimal copper loading for various catalysts.
- Identifies selective catalytic reduction catalyst materials with low "light-off" temperatures and increase NH_4NO_3 resistance.
- Provides catalyst preparation guidelines.

Benefits

Catalyst Development

Offers groundwork for further catalyst development by providing design and preparation recommendations.

Environment

Achieves acceptable performance in both low and high operating temperature ranges.

Contact Information:
Dr. Feng Gao
Email: Feng.Gao@pnnl.gov
Phone: (509) 371-7164
Pacific Northwest National Laboratory
902 Battelle Blvd,
Richland, WA 99354
Website: www.pnnl.gov

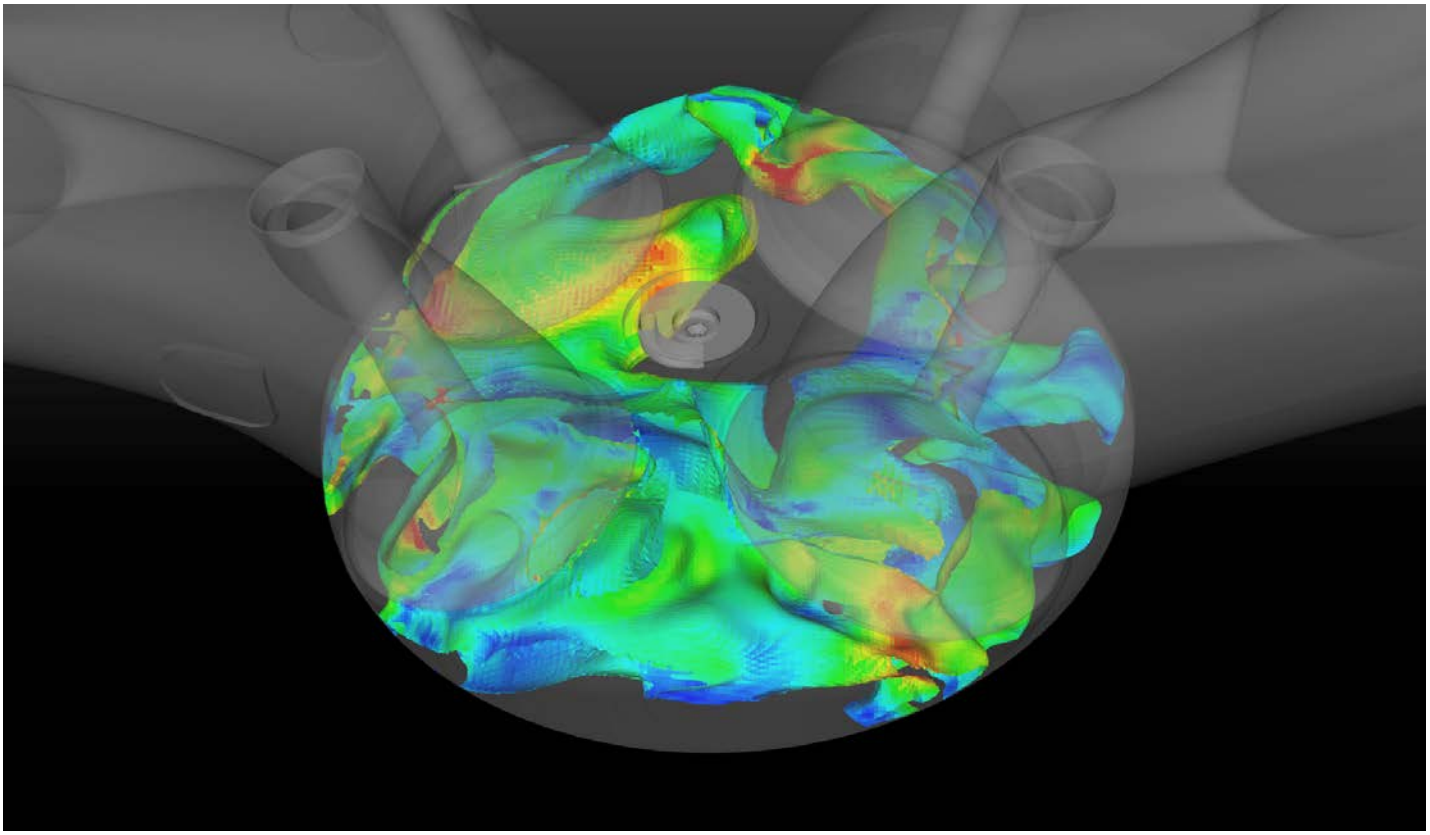
Improved Solvers for Advanced Engine Combustion Simulation Enabling High Efficiency Clean Combustion

Commercial Technology

With the transportation sector accounting for nearly three quarters of the petroleum consumed annually in the U.S., continued investment in the development of new combustion engines remains vital to decreasing carbon emissions and reliance on foreign energy sources.[1] DOE has identified efficiency and emissions as the primary targets for cost effective improvement in engine performance in the short term.[2] Designing advanced combustion engines relies on knowledge of the operational characteristics over many operating regimes and extensive testing before new advanced engines can be produced. Some of this testing can be replaced by computer modeling, but existing software lacks enough detail to accurately predict control, efficiency, and emissions over the range of operating conditions necessary when developing new engine designs. Improved modeling software can aid the development of new, advanced engines by closing this gap.

Lawrence Livermore National Laboratory (LLNL), with assistance from VTO, has developed a software package targeted at enabling more detailed combustion simulations. The software, which the authors have dubbed Zero Order Reaction Kinetics (Zero-RK), is a chemistry solver package that performs calculations 4-15 times faster than other commercially available chemistry packages for large fuel mechanisms with more than a thousand chemical species. As a result, Zero-RK allows for 10 times as much chemical detail in engine design simulations for the same cost. To increase industry impact, LLNL has licensed Zero-RK to Convergent Science Inc., to deliver a five-fold increase in speed over their Sage chemistry model in their ConvergeCFD™ package.

Zero-RK was awarded a 2015 R&D 100 award in the software and services category. Recent improvements to the software have focused on user demands to accelerate more complex chemistry models, which are needed to resolve detailed soot formation processes and multi-channel pressure dependent reactions. Additional VTO-funded research is underway at LLNL to develop Zero-RK algorithms suitable for acceleration by general purpose graphics processing units that are now commonly found on the world's largest supercomputers.

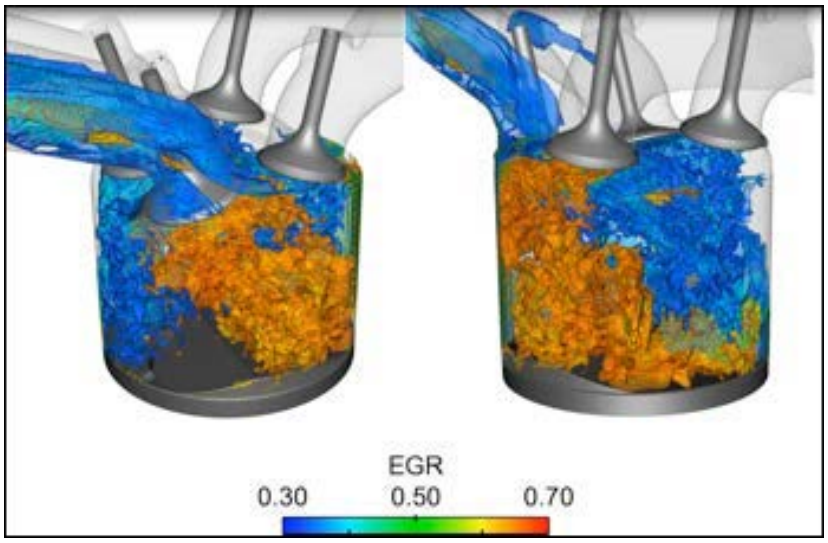


ConvergeCFD™ simulation of flame propagation using a detailed gasoline chemistry model accelerated by the Zero-RK plugin.

[1] "Benefits and Considerations of Electricity as a Vehicle Fuel", U.S. DOE, May 2016
[2] Advanced Combustion Engines", U.S. VTO, May 2016

Improved Solvers for Advanced Engine Combustion Simulation Enabling High Efficiency Clean Combustion

Commercial Technology



Homogeneous Charge Compression Ignition Transition Model

Technology History

- Developed by Lawrence Livermore National Laboratory and tested through partnerships with Cummins Inc., General Motors Company, Convergent Sciences Inc., NVIDIA, and several national laboratories and universities.[1]
- Commercialized through licensing in 2015.
- Initially funded in 2012.

Applications

Can be used to model detailed fuel chemistry for realistic transportation fuels for engine combustion.

Capabilities

- Near linear scaling of the computational cost with fuel mechanism size.
- Four-fifteen times faster than commercial packages for realistic transportation fuel models with more than a thousand species.
- Accelerated reaction models available for complex soot formation and multi-channel pressure dependent reactions.

Benefits

Environment

Provides more accurate chemistry models needed to aid in the design of kinetically controlled engine modes under investigation by VTO for high efficiency clean combustion operation.

Flexibility

Allows users to model complex chemical reaction networks as a standalone analysis or coupled with Computational Fluid Dynamics.

Contact Information:
Dr. Matthew McNenly
Email: mcnenly@llnl.gov
Phone: (925) 424-6418
Lawrence Livermore National Laboratory
7000 East Ave,
Livermore, CA 94550
Website: www.llnl.gov

[1] For a full list see: 2016 Annual Merit Review

NOx Control and Measurement Technology for Heavy-Duty Diesel Engines

New efficiency regulations for heavy duty vehicles are part of an effort to reduce fuel consumption in the transportation sector while improving performance and reducing emissions. To achieve the levels of efficiency required for these new heavy duty vehicles engine designers must carefully integrate engine-catalyst-control systems. Such integration requires broad and detailed knowledge of catalyst performance and reactions under varying operating conditions, ageing mechanisms, and practical strategies for through-life catalyst control. Via enabling such knowledge, greater understanding of catalyst performance and operation could improve domestic engine designs and reduce current barriers to realizing advanced performance.

Oak Ridge National Laboratory (ORNL), with assistance from VTO and in collaboration with Cummins Inc., has developed and applied several diagnostics to characterize catalyst performance, including a spatially resolved capillary inlet mass spectrometer called SpaciMS. The SpaciMS measures intra-catalyst transient species distributions, and enables detailed insights regarding the transient distributed network and sequence of reactions throughout a catalyst. In addition, the ORNL-Cummins Inc., team partnered with the Cross-Cut Lean Exhaust Emissions Reduction Simulations group, Chalmers, Politecnico di Milano, and the Prague University of Chemistry and Technology to study a wide range of catalyst performance issues. These issues include ageing impacts on various catalyst functions, variations in spatiotemporal performance with reaction conditions (catalyst kinematics and reactions measured instantaneously as a function of time and space), N_2O formation and SCR reaction mechanisms, and NH_3 formation, utilization and storage. [1]

The insights from intra-catalyst spatiotemporally resolved studies have broad basic and practical applicability for advancing catalyst technologies. The basic insights are useful for understanding how catalysts function and developing associated models for improving analysis-led design. Reduced forms of such models are applicable for enabling advanced control and are being used by project partners for the development of new engines. Knowledge of the evolving spatiotemporal relationships between various catalyst reactions and species assists in the development of practical strategies for implementing advanced control, such as determining which relationships can be controlled and the sensors required to provide feedback. Advanced diagnostics can be used to demonstrate advanced control strategies and quantify associated efficiency gains, even before required commercial on-engine sensors exist. The diagnostics and insights from the DOE-sponsored ORNL-Cummins Inc., team's Cooperative Research and Development Agreement enable faster and lower-cost development of engine systems with advanced efficiency, durability, and emissions.



Cummins 2007 6.7L Engine-Catalyst System, Developed Using SpaciMS

[1] "NOx Control and Measurement Technology for Heavy-Duty Diesel Engines", ORNL, February 2005

NO_x Control and Measurement Technology for Heavy-Duty Diesel Engines

Commercial Technology

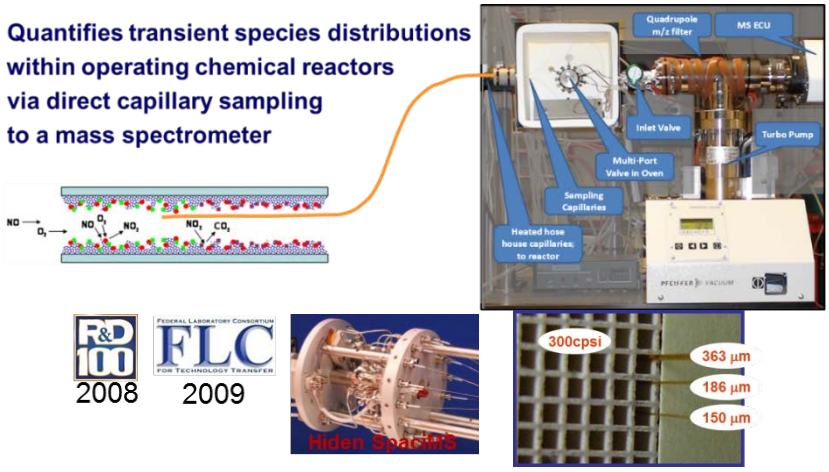


Diagram of the Oak Ridge National Laboratory-Cummins Inc., Test Setup (Top) and the commercial Hiden SpaciMS (Bottom)

Technology History

- SpaciMS developed by Oak Ridge National Laboratory and Cummins Inc.
- Commercialized in 2006 by Hiden Analytical.
- Initially funded in 1998.

Applications

Can be used to study confined-space chemical reactors including automotive catalyst, fuel cells, engine intake/exhaust manifold gas dynamics, non-thermal plasma reactors, and fuel reformers.

Capabilities

- Offers intra-catalyst measurements and mapping capability.
- Achieves in-operando measurement of transient distributed chemistry within operating catalysts.
- Tunable inlet system enables matching tradeoff between temporal resolution and invasive nature to application needs.
- Provides spatial resolution via individual capillary translation and/or switching between capillaries throughout a catalyst.
- Provides data and insights to enable improved through-life engine-catalyst system performance and efficiency.

Benefits

Cost Savings

Offers development cost savings through improved design and control models for faster and lower-cost analysis-led design of advanced engine-catalyst systems and insights for implementing advanced-control strategies.

Environment

SpaciMS applications provide data and insights for improved design, modeling, and control of automotive catalyst systems, which improves performance, and reduces emissions and environmental impact.

Performance

Improved understanding of catalyst mechanisms, reactions, and modelling enables advanced efficiency, durability, cost, and performance in future engine systems.

Contact Information:
Bill Partridge
Email: partridgewp@ornl.gov
Phone: (865) 946-1234
Oak Ridge National Laboratory
1 Bethel Valley Rd,
Oak Ridge, TN 37831
Website: www.ornl.gov/

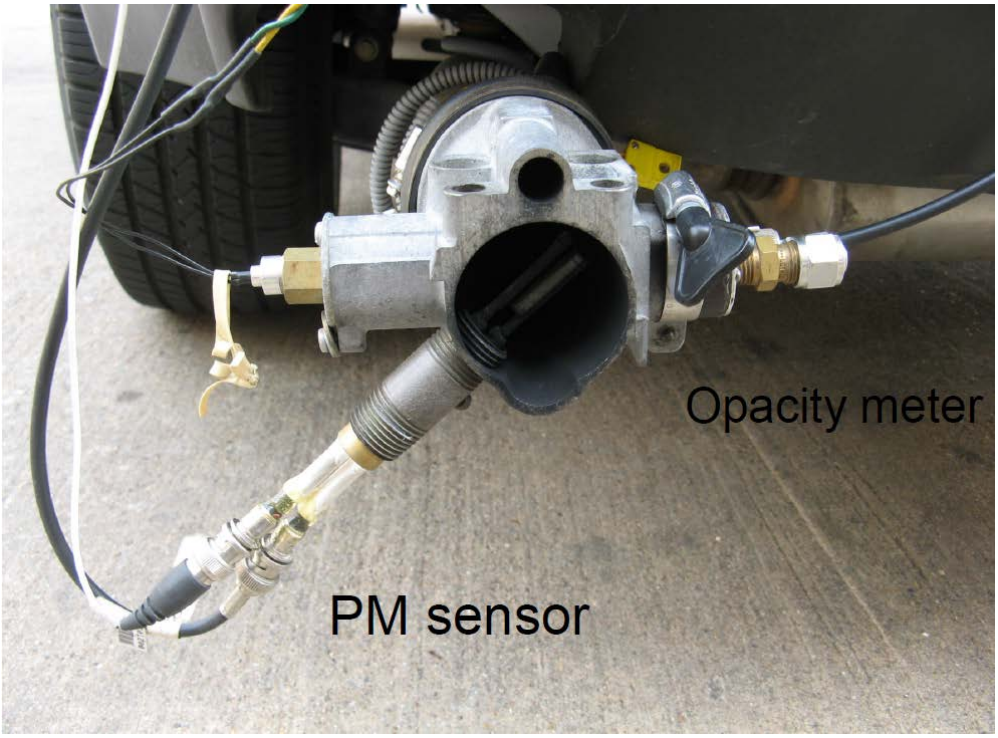
On-Board Engine Exhaust Particulate Matter Sensor for Homogeneous Charge Compression Ignition and Conventional Diesel Engines

Commercial Technology

In an effort to improve domestic fleet efficiency and reduce emissions, DOE has mandated that current propulsion technologies must be improved. While electric systems offer enticing reductions to vehicle emissions, current combustions systems are often lower in cost and provide superior range. As a result, improving current engines represents a cost-effective method of curbing emissions in the short term.[1] To further reduce emissions by diesel vehicles, manufacturers are working to introduce aftermarket treatments that can complement engine improvements. Development of new advanced after treatments could substantially reduce vehicle emissions.

The University of Texas at Austin, with assistance from VTO, EmiSense Technologies, LLC, and Cummins Engine Company, has developed PMTrac®, a low cost and accurate on-board particulate matter sensor for use with diesel vehicles. PMTrac® can be mounted to a vehicle and is used to identify particulate concentration levels in exhaust both upstream and downstream of a diesel particulate filter. The advanced electrostatic sensor is concentrically symmetrical to minimize orientation effects, is optimized to reduce sensor noise from vibration, and offers better durability. PMTrac® is not affected from buildup of ash and other contaminants that can build up on resistive accumulative sensors causing measurement drift and incorrect readings or fault indicators. EmiSense Technologies, LLC's electrostatic sensor uses an electrostatic field to direct particulate matter through the sensor and the resulting charge transfer to provide a real-time signal. The accumulation of ash or contaminants does not affect the electrostatic field or charge transfer and has no effect on the measurement process. Data gathered from testing found acceptable sensor resolution down to 3 mg/m^3 soot mass concentration, good correlation between multiple sensors, and agreed well with laboratory standard measurements of particle size.

PMTrac® is available through EmiSense Technologies, LLC, and is used to detect particulate filter failure. The sensor is capable of detecting particulates down to 20 µm and as large as 10 µm. The sensor has a real-time response in the 200-500 millisecond range.[2]



Particulate Matter Sensor Test Platform Installation

[1] "Advanced Combustion Engines", U.S. VTO, May 2015
[2] EMA OBD Workshop: "The State of Soot Sensing", EmiSense Technologies, LLC, May 2013

On-Board Engine Exhaust Particulate Matter Sensor for Homogeneous Charge Compression Ignition and Conventional Diesel Engines

Commercial Technology



EmiSense Technologies, LLC PMTrac® Sensor

Technology History

- Developed by the University of Texas at Austin, EmiSense Technologies, LLC, Ceramatec, Inc., and CoorsTek, Inc.
- Available through EmiSense Technologies, LLC
- Commercialized in 2016.
- Initially funded in 2006.

Applications

Can be used to monitor and control diesel engine emissions.

Capabilities

- Detects particulate filter failure.
- Achieves response times down to 200 milliseconds.

Benefits

Cost Savings

Offers low cost sensing capability using by using low cost materials through signal amplification.

Durability

Achieves sensor lifetime tolerance of contaminants on the electrode surface.

Resolution

Achieves high resolution through field-directed accumulation of soot.

Contact Information:
Patrick Thompson
Email: pt@emisense.com
Phone: (949) 436-0318
CoorsTek Sensors, LLC
2453 Riverside Pkwy,
Grand Junction, CO 81505
Website: www.coorsteksensors.com

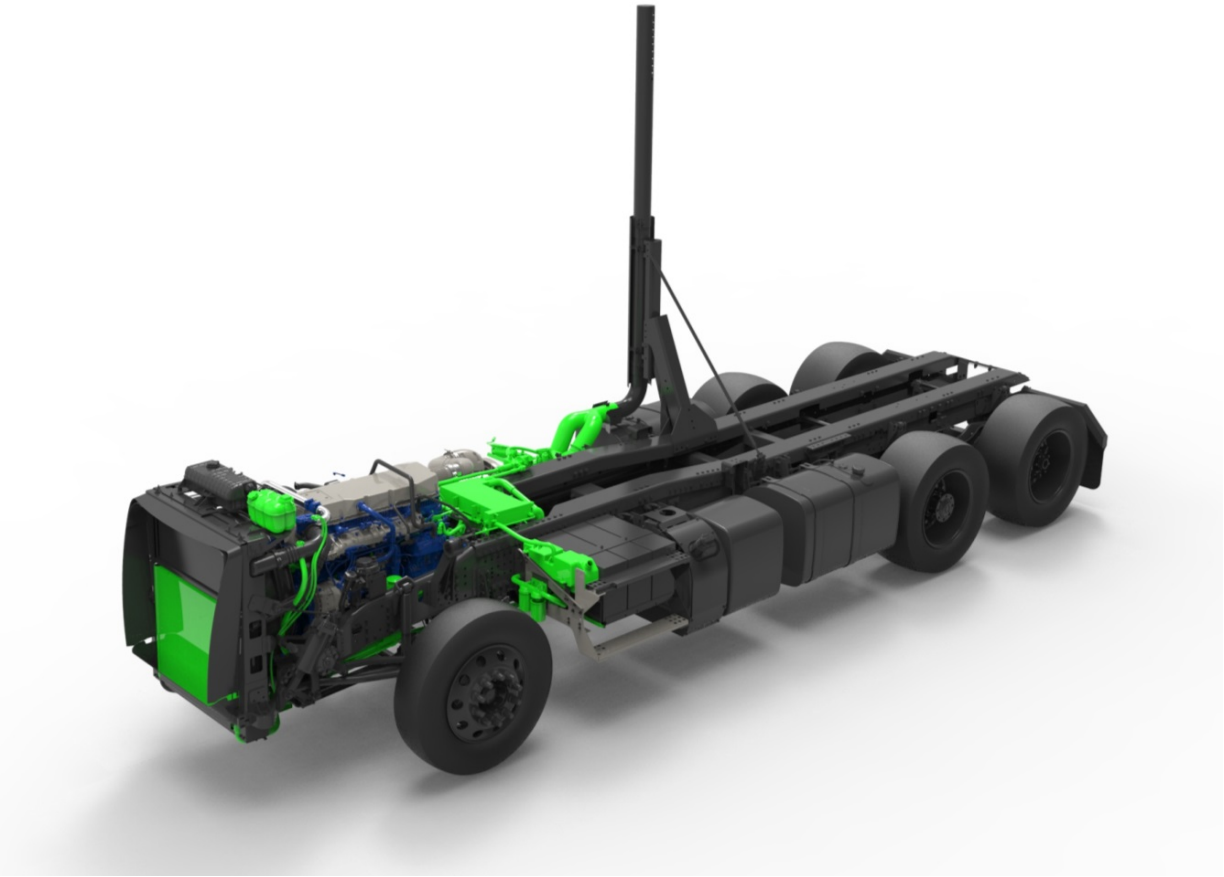
Volvo SuperTruck: Powertrain Technologies for Efficiency Improvement

Commercial Technology

Heavy duty vehicles (HDVs) represent an area of interest for performance improvement in the near term. Current predictions estimate that HDVs are expected to account for 7.3 quadrillion BTU in fuel use by 2040, as a result of industrial growth. Diesel accounts for up to 87% of this energy which results in increased emissions by HDVs.[1] To ensure HDVs meet emissions requirements, several improvements need to be made to engine, powertrain, and shipping efficiency.

The Volvo Group (Volvo), with assistance from VTO and several industry partners, collaborated to complete the Volvo SuperTruck program. This program performed extensive modeling of new engine technologies and powertrain designs. Volvo's goal of 55% brake thermal efficiency in an HDV engine has been met, as well as realizing the goal of achieving 50% brake thermal efficiency, using a broad combination of advanced powertrain components including a waste heat recovery system. Volvo's engine and its components have undergone system testing equivalent to over 1.5 million miles. The advanced powertrain products in combination with vehicle improvements such as aerodynamics and light-weighting technology have achieved an 88% freight efficiency improvement in the prototype demonstrator chassis.

Several technologies resulting from this development program are in production and are available through Volvo and its affiliates. Vehicle improvements to aerodynamics inspired by SuperTruck, such as a new bumper and fairings, have been implemented in production, along with trailer aerodynamic treatments. Powertrain component improvements realized in serial production from SuperTruck include a proprietary piston design, a new fuel injection system, turbocompounding technology, aftertreatment improvements, down-speeding technology, and several others. These developments were incorporated in Volvo's new enhanced D11 and D13 engines.



Model of Volvo's New SuperTruck Powertrain Components

[1] 2016 Annual Energy Outlook, Energy Information Administration, April 2016

Volvo SuperTruck: Powertrain Technologies for Efficiency Improvement



Volvo SuperTruck Vehicle

Technology History

- Developed by the Volvo Group, Grote Enterprises, LLC, Pennsylvania State University, Ridge Corporation, and Freight Wing, Inc.
- Commercialized in 2016.
- Initially funded in 2011.

Applications

Can be used to improve fuel economy and freight efficiency in HDVs.

Capabilities

- Offers engine performance of 50% brake thermal efficiency.
- Improves freight efficiency by 88%.

Benefits

Cost Savings

Offers lower operating costs to customers through more efficient operation.

Environment

Reduces environmental impacts of the domestic HDV fleet by reducing fuel consumed for freight handling.

Contact Information:
John Gibble
Email: John.Gibble@Volvo.com
Phone: (301) 790-6769
Volvo Group North America
2900 K Street, NW, House of Sweden,
Washington, DC 20007
Website: **www.volvo.com**

Electric Drive Systems

Advanced Thermal Interface Materials for Power Electronics 44
Cost-Effective, Compact, Light-Weight, and Scalable High Temperature Inverter 46
Low-Cost, High Temperature, High Ripple Current DC Bus Capacitors 48
Low-Cost U.S. Manufacturing of Power Electronics for Electric Drive Vehicles 50
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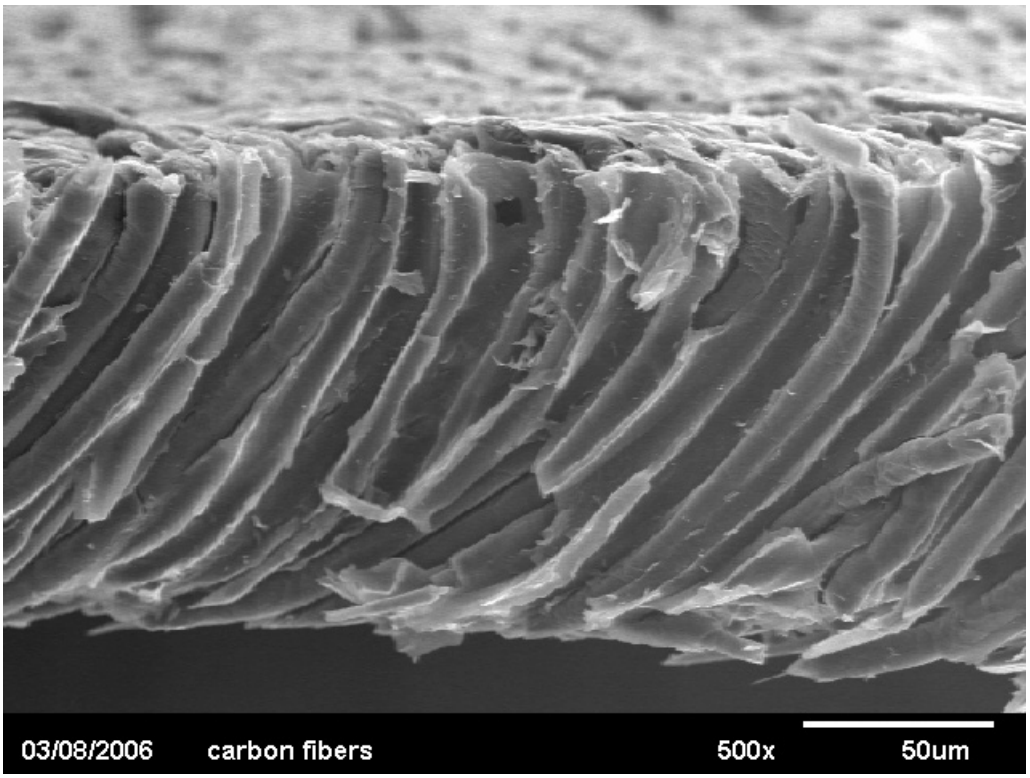
Advanced Thermal Interface Materials for Power Electronics

Commercial Technology

Traditional thermal interface materials (TIMs) such as greases, gels, and phase-change materials can often be bottlenecks to heat removal in power electronics packaging configurations. For TIMs such as grease, thermal resistance can be up to 35 mm^2K/W for bond line thicknesses of 100 µm. Bonded interface materials (BIMs), such as solder, sintered silver, and thermoplastics with embedded carbon fibers offer the potential for thermal resistances on the order of 5 mm^2K/W for the same thickness. This has resulted in significant interest in BIMs for power electronics packaging applications. Using improved TIMs/BIMs enables the dissipation of high heat fluxes while keeping the temperature of components within limits. The ability to dissipate high heat fluxes enables a reduction in component size, weight, volume and cost. High-performance, low-cost power electronics will be an enabler to wider market penetration of cost-effective, energy-efficient electric-drive vehicles.[1]

The National Renewable Energy Laboratory, with funding from VTO, collaborated with Btech Corporation (now ADA Technologies, Inc.) to improve TIMs for use in power electronics applications. The team characterized the thermal, reliability, and structural aspects of thermoplastics as interface materials and found that introduction of vapor-grown carbon fibers increased performance of the material for power electronics packaging and thermal management applications. Btech Corporation's HM-2 thermoplastic was demonstrated to have four times less resistance at 100 microns thickness, compared to standard commercial greases. Collaboration between National Renewable Energy Laboratory and Btech Corporation helped improve Btech Corporation's HM-2 material and characterize its performance under various conditions.

The new TIM generation, HM-3, is currently available from ADA Technologies Inc., and improves on HM-2's heat transfer performance. ADA Technologies' new QiFlo™ Thermal Management Products also incorporate technology that benefitted from HM-2 development work and are offered as thermal grease, film, pad, gap filler, and adhesive materials. Following completion, the results of this research were transferred to several industrial partners (e.g., Delphi, General Motors Company LLC, Ford Motor Company, Semikron, and UQM Technologies Inc.). Additionally, an extensive database was generated based on the results of materials characterization and is being used to assist with future development of advanced thermal interface materials.



HM-2 Carbon Fibers in Polyamide Matrix

[1] For more information see: EV Everywhere

Advanced Thermal Interface Materials for Power Electronics

Commercial Technology



ADA Technologies Inc.'s QiFlo™ Thermal Management Material

Technology History

- Developed by the National Renewable Energy Laboratory and Btech Corporation (now ADA Technologies, Inc.).
- Commercialized in 2010.
- Received initial funding in 2006.

Applications

Can be used to improve heat transfer in (power) electronics packaging and thermal management systems.

Capabilities

- Reduces thermal resistance by more than 400% compared to commercial greases.
- Offers very good reliability.
- Supports future bonded interface research.

Benefits

Flexibility

Low pressure (< 100 psi) and low temperature (160°C) synthesis of the bonded interface material.

Reliability

Improves heat transfer in power electronics and can extend product life and performance.

Contact Information:
Dr. Sayangdev Naha
Email: sayann@adatech.com
Phone: (303) 874- 8275
ADA Technologies Inc.
8100 Shaffer Parkway Suite 130
Littleton, CO 80127
Website: www.adatech.com

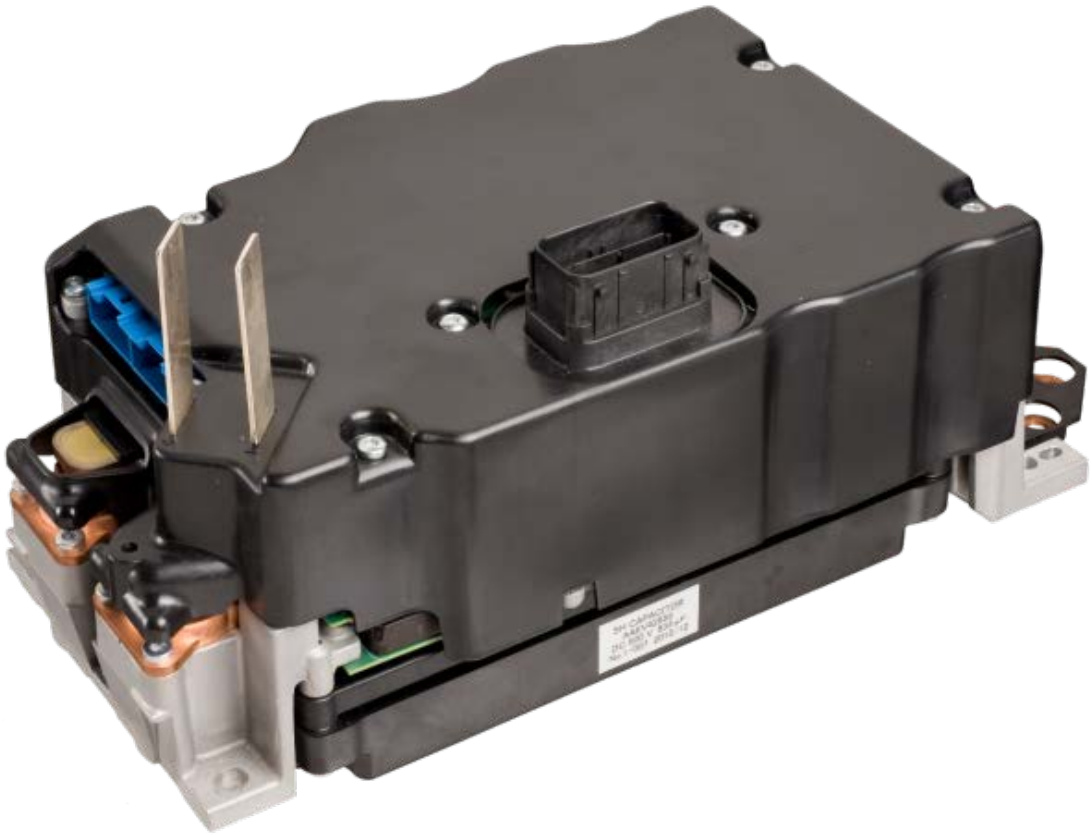
Cost-Effective, Compact, Light-Weight, and Scalable High Temperature Inverter

Commercial Technology

Electric drive systems (EDSs) used in modern electric vehicles (EVs) are becoming increasingly advanced to improve performance characteristics and spur adoption in the U.S. to support DOE's EV-Everywhere Grand Challenge Goal. DOE has indicated that development of new systems that reduce weight, cost, and volume while improving performance and reliability is needed.[1] A part of improving EV performance relates to simplifying the cooling systems used in new EDSs. This can be done, but often leads to increases in cost and size while reducing performance. An inverter that offered a durable and effective coolant system without negatively impacting performance could further DOE's EV-Everywhere goal and improve EV adoption in the U.S.

Delphi Automotive Systems, LLC, with assistance from a team of partners and VTO, developed a dual-side cooled power semiconductor package for use in advanced EDS assemblies. Each semiconductor package contains an insulated gate bipolar transistor and a diode with topside metallization co- packaged between metallized ceramic substrates, allowing dual-side cooling. This approach eliminates the need for wirebonds, reducing potential for failure.[2] This format allows the semiconductor package to offer improved inverter capabilities and durability while maintaining a small footprint. The package's small size allows extensive system layout flexibility while reducing cost for original equipment manufacturer vehicle platforms.

The dual side cooled semiconductor package is a key component in General Motors Company LLC's traction power inverter module used on the second-generation Chevrolet Volt. These key technologies contributed to the traction power inverter module's increased capabilities, while improving the reliability and performance of the second-generation Chevrolet Volt and achieving the DOE's goal of reducing weight, cost, and volume.

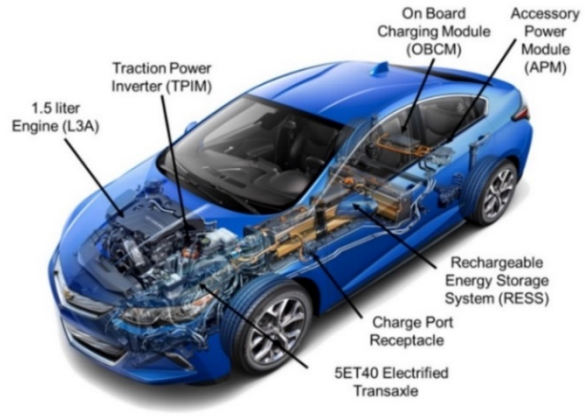


Delphi Automotive Systems LLC's Traction Drive Inverter

[1] For more information: Electric Drive Systems Research and Development
[2] For more information: Power Dense and Robust Traction Power Inverter for the Second-Generation

Cost-Effective, Compact, Light-Weight, and Scalable High Temperature Inverter

Commercial Technology



2nd Generation Chevrolet Volt Power Electronics Component Layout

Technology History

- Developed by Delphi Automotive Systems, LLC, and partners on the DOE program including Dow Corning Corp., GeneSiC Semiconductor, General Electric Company, Argonne National Laboratory, the National Renewable Energy Laboratory, and Oak Ridge National Laboratory
- Commercialized in 2015.
- Received initial funding 2008.

Applications

- Can be used as a high temperature inverter.

Capabilities

- Contains 40% less mass compared to the first generation traction power inverter module.
- Has 30% smaller volume than the first generation traction power inverter module.
- A 43% increase in system gravimetric power density compared to the first generation traction power inverter module.
- Offers dual side cooled capability.

Benefits

Cost Savings

Reduces silicon area, which reduces the traction power inverter module size and complexity, allowing manufacturers more layout flexibility while reducing cost

Durability

Achieves longer product life and better thermal performance through the use of compatible coefficient of thermal expansion materials and solderable interconnects.

Efficiency

Provides a silicon insulated-gate bipolar transistor and diode solution with dual side cooling, which improves system efficiency.

Contact Information:
Ralph Taylor
Email: ralph.s.taylor@delphi.com
Phone: (765) 451-3884
Delphi Automotive System, LLC
2501 East Lincoln Road, MC CTC1E
Kokomo, IN 46904
Website: www.delphi.com

Low-Cost, High Temperature, High Ripple Current DC Bus Capacitors

Commercial Technology

In an effort to bring to market electric vehicles that are as affordable and convenient as gasoline powered vehicles by 2022, DOE has set goals to improve vehicle electric drive systems. Improvements to cost, weight, volume, performance, efficiency, and reliability will all be necessary for current systems to meet DOE's 2022 goals.[1] The ability for capacitors to handle higher ripple currents has often relied on the implementation of systems that simply add a bank of capacitors to achieve the desired current rating. This method, while functional, inhibits thermal management and reduces performance. A new method of inverter development has resulted in a low-cost product with increased performance.

SB Electronics, Inc. (SBE), with assistance from VTO in the form of Small Business Innovation Research grants, has developed an advanced capacitor system for use in inverters. The Power Ring Film Capacitor™ is a disk-like DC link capacitor designed specifically for use in hybrid electric vehicles, plug-in hybrid electric vehicles, fuel cells, and battery electric vehicle systems. The Power Ring Film Capacitor™ is typically used in the 250V–1500V DC range with ripple currents ranging from 40–500 Amps at 5–20 kHz. Power Ring Film Capacitors™ are designed to handle greater ripple currents than standard format capacitors and can be used in groups when needed. The system design reduces the number of capacitors necessary to achieve the same performance which reduces the overall footprint, weight, and the cost by more than 50% in some cases.

SBE offers its Power Ring Film Capacitor™ as part of their Power Ring Module™ which is a vertically integrated surface mount assembly offering high power density with favorable equivalent series inductance and/or equivalent series resistance. The module includes a shared cooling system that uses a 105 °C internal combustion engine coolant to further improve module performance and reduce cost. SBE offers its Power Ring Module ™ as a drop in replacement, modification to an existing design, or as a solution for a completely new design. The Power Ring Film Capacitor™ has been available since 2009.



SB Electronics Inc.'s Power Ring Module™

[1] "Electric Drive Systems Research and Development", U.S. DOE, 2014

Low Cost, High Temperature, High Ripple Current DC Bus Capacitors

Commercial Technology



SB Electronics Inc.'s DC Link Capacitor

Technology History

- Developed by SB Electronics, Inc.
- Commercialized in 2009.
- Funded in 2007.

Applications

Can be used in advanced inverter manufacturing for electric drive systems.

Capabilities

- Achieves equivalent series inductance as low as 10nH.
- Reduces voltage overshoot.
- Achieves over 20,000 operating hours.[1]

Benefits

Cost Savings

Reduces cost by using polypropylene film and internal combustion engine coolant to reduce overall unit cost and improve performance at moderate temperatures.

Durability

Offers a durable alternative to standard capacitors, achieving over 20,000 hours of operation at 100kW using a 1,000µF capacitor.

Efficiency

Provides an efficient capacitor solution for inverters that benefit from very low equivalent series inductance and removes the need to provide extra capacitance as a safety net against current handling survival.

Contact Information:
Dr. Michael Brubaker
Email: michaelb@sbelectronics.com
Phone: (802) 661-3471
SB Electronics Inc.
81 Parker Road
Barre, VT 05641-9106
Website: www.sbelectronics.com

[1] For more information see: Power Ring Technology

Low-Cost U.S. Manufacturing of Power Electronics for Electric Drive Vehicles

Commercial Technology

To improve domestic acceptance of electric vehicles (EVs) and reduce reliance on foreign oil, DOE created the EV Everywhere program.[1] As EV adoption rates are strongly tied to EV price and performance, it is advantageous to implement new programs to reduce the price of EV systems while improving overall quality and performance. To achieve this goal, DOE has partnered with domestic original equipment manufacturers to facilitate the development and production of domestic sources of low cost advanced EV components.

In collaboration with DOE, Delphi Automotive Systems, LLC (Delphi) completed development of the Engineering Lab Building (ELB), an advanced testing and validation facility, and a manufacturing facility called Kokomo Morgan Street (KMS), in Kokomo, Indiana capable of volume production of power electronics products for electric drive vehicles (EDVs). These efforts were funded through a cost share grant via the American Recovery and Reinvestment Act. Delphi's work increased the scale of U.S. production for commercial state-of-the-art power electronics products that enable efficient conversion, storage, and control of electrical power for vehicle propulsion, as well as electrically driven vehicle accessory loads, such as air-conditioning and power steering. The products produced in this new facility include components such as, traction inverters, DC/DC converters, on-board chargers, hybrid and battery management controllers, and integrated systems, such as combined inverter and DC/DC converters and electrical power management systems. Delphi enabled scale-up of its U.S. production capability from about 3,000 units to over 250,000 units annually, a sizeable step toward the full-scale volume production needed to minimize cost. The ELB facility provides Delphi with dynamics, environmental, and electromagnetic compatibility testing services. ELB's equipment is accredited by the American Association for Laboratory Accreditation and performs device under test performance monitoring. The facilities' component testing capabilities contribute to reducing Delphi's component failure rate to single digit ppm.

The new facilities allow Delphi to leverage more than 30 years of electric drive manufacturing experience to research, validate, and manufacture new electric drive systems. Additionally, the Delphi Champion Technical Center's capabilities allow Delphi to compete globally by reducing the cost of EV components, while providing a domestic source of inverters, converters, chargers, controllers, and energy storage systems to automotive manufacturers. The facility also acts as a pathway for Delphi to continue development of other DOE funded projects and provides Delphi with a commercialization path for newly developed products.[2]

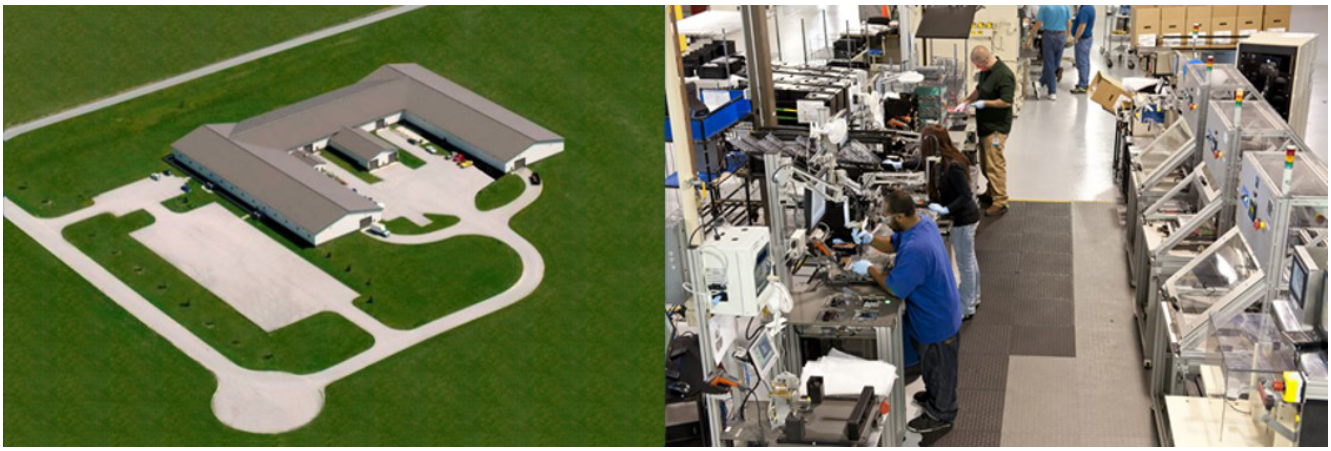
As a result of this project, Delphi is the leading U.S. manufacturer of automotive power electronics. To assure that Delphi's Kokomo power electronics engineering and manufacturing stay globally competitive as a supplier to the electric drive vehicle market, Delphi will continue to scale-up production in Kokomo, to further reduce its combined production and engineering cost per unit of production. This additional effort and investment is targeting a capability of approximately 325K units/year in 2017.



Delphi Engineering Lab Building Kokomo Technology Center, Indiana

[1] For more information: About EV Everywhere
[2] Low-Cost U.S. Manufacturing of Power Electronics for Electric Drive Vehicles, Delphi Automotive PLC, May 2013

Low-Cost U.S. Manufacturing of Power Electronics for Electric Drive Vehicles



Delphi Kokomo Morgan Street Production Facility

Technology History

- Developed by Delphi Automotive Systems, LLC.
- Production began in late 2012.
- First funded in 2009.

Applications

Supports the research, validation, and manufacturing process for new EV components.

Capabilities

- Produces more than 250,000 automotive components per year.
- Offers U.S. based remanufacturing services.
- Offers dynamics, environmental, and electromagnetic compatibility testing.
- Offers development and validation testing of power electronics components.

Benefits

Cost Savings

Reduces cost of EV components by providing a domestic source and streamlining the development and manufacturing processes.

Job Creation

Contributed to the creation of more than 250 domestic jobs with the potential to reach 300. The plant operated at approximately 75% capacity at year-end 2016.

Quality

Delphi Automotive Systems, LLC is an ISO/TS16949 quality certified U.S. power electronics production facility.

Contact Information:
Monty B. Hayes
Email: monty.b.hayes@delphi.com
Phone: (248)-451-3734
Delphi Automotive, LLC
2151 E Lincoln Road, MC CTC1E
Kokomo, IN 46902
Website: www.delphi.com

U.S. Electric Drive Manufacturing Center

To improve domestic acceptance of electric vehicles (EVs) and reduce reliance on foreign oil, DOE created the EV Everywhere program.[1] A primary goal of the EV Everywhere program is to reduce the cost of electric drive components while improving efficiency and performance. To support this goal, DOE has partnered with several original equipment manufacturers OEMs to produce new domestic sources for advanced EV components. Providing a domestic source of low cost electric drive systems will drive down the cost of new EVs, reduce reliance on foreign fuels, and provide jobs for local economies.

General Motors Company LLC (GM), with assistance from VTO, has built a new electric motor building (e-Motor expansion) and installed electric drive production capability in an existing GM facility in White Marsh, Maryland. This facility represents an expansion that provides electric drive components for the Chevy Spark, with plans for production of other electric drive components that will be installed in other GM products. The e-Motor expansion at White Marsh began production in early 2013, and completed production of over 700 electric drive components before the end of Q1 2013. This 110,500 ft^2 expansion brought the total work force at the plant to just under 300 employees.[2]

The White Marsh facility incorporates advanced manufacturing methods to deliver high quality products at reduced cost. More than 20 automated manufacturing units enable GM to offer the new Spark for just over $25,000.[3] The facility also benefits from a solar electric grid which can produce more than 1.7 megawatts, which supplies over 6% of the facility's power requirements. GM's dedication to building an advanced environmentally friendly manufacturing center has earned the White Marsh facility silver status in the U.S. Green Building Council's LEED program.[4]



Electric Drive Manufacturing Equipment Installed at White Marsh, Maryland

[1] For more information: About EV Everywhere
[2] For more information: Baltimore Operations
[3] General Motors unveils its new electric motor in White Marsh, The Baltimore Sun, April 2013
[4] GM ramps up hiring for White Marsh plant ahead of Chevrolet Spark EV sales in Maryland, Baltimore Business Journal, May 2015

U.S. Electric Drive Manufacturing Center



White Marsh Manufacturing Facility

Technology History

- Developed by General Motors Company LLC.
- Began production in 2013.
- Initially funded in 2010.

Applications

Supports the production of low cost advanced electric drive systems.

Capabilities

- Capacity to produce up to 40,000 electric drive units per year.
- U.S. based manufacturing capability.

Benefits

Cost Savings

Reduces the cost of EV components by providing a domestic source and streamlining the development and manufacturing processes.

Environment

Recycles 90% of the waste generated onsite and produces 6% of the power used in manufacturing with an on-site solar grid.

Job Creation

Contributed to the creation of more than 250 U.S. jobs.

Contact Information:
Charles Gough
Email: charles.gough@gm.com
Phone: (248) 904-5950
General Motors LLC
850 Glenwood
Pontiac, MI 48340-2920
Internal Mail Code: 483-710-210
Website: www.gm.com

Fuels and Lubricants

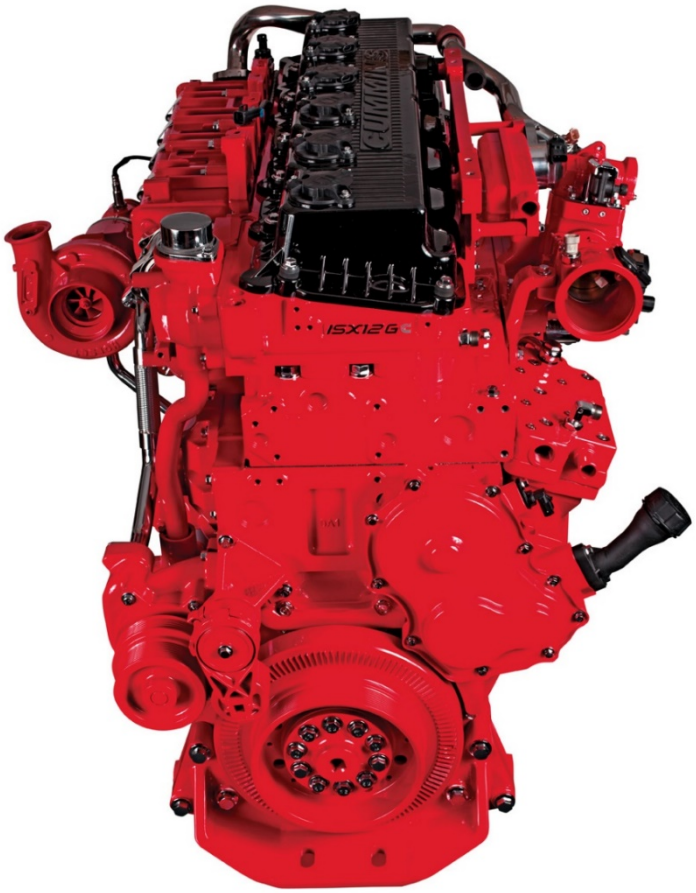
ISX12 G: Cummins Westport 12L NG Engine..... 56

ISX12 G: Cummins Westport 12L NG Engine

Development of new renewable fuel capable vehicles is a primary goal of the VTO program, with focus varying between several renewable energy sources.[1] Though electric vehicles (EVs) represent the majority of new advanced vehicle platforms, EVs are not always the most attractive solution for renewable vehicle needs. In the case of heavy duty vehicles, EVs can replace some units but may not offer the power necessary to replace large combustion engines. An alternate low emission solution will be necessary for the higher weight applications.

Cummins Westport Inc. (CWI), with assistance from VTO, additional funding from the California Energy Commission and support from the National Renewable Energy Laboratory, has developed the ISX12 G engine. This natural gas powered engine addresses the lack of low emission engines in the 12 liter regime and offers the ability to run on compressed natural gas, liquefied natural gas, or renewable natural gas. The ISX12 G benefits from the same stoichiometric, cooled exhaust gas recirculation combustion technology with spark ignition and three-way catalyst after treatment system as the CWI's ISL G engine. The ISX12 G operates with 25% lower NOx emissions than the 2015 EPA NOx limit. The engine offers this low emission performance without the use of an active particulate filter or selective catalytic reduction catalyst.

CWI's ISX12 G became available in 2013 for heavy duty vehicles. The ISX12 G offers high performance as well as reduced emissions and is capable of producing 400 hp with a peak torque of 1450 lb-ft at 1200 rpm. The engine also offers optional engine braking up to 240 hp and has 700 lb-ft of clutch engagement torque. A cooled exhaust gas recirculation system allows the engine to further increase its performance by precooling exhaust prior to mixing with intake air and fuel.[2]



ISX12 G Engine

[1] For more information: Advanced Combustion Engines
[2] The Natural Choice. ISX12 G Heavy-Duty Natural Gas Truck Engine, Cummins Westport Inc., March 2015

ISX12 G: Cummins Westport 12L NG Engine



Examples of Cummins Wesport Inc.'s ISX12 G engine on vehicle.

Technology History

- Developed by Cummins Westport Inc., with support from the National Renewable Energy Laboratory.
- Commercialized in 2013.
- Received initial funding 2011.

Applications

Can be used for low emission heavy duty vehicles—refuse truck, regional haul truck and tractor, and vocational applications.

Capabilities

- Reduces NOx emissions to 25% lower than EPA regulations.
- Offers up to 400 hp.
- Available peak torque of 1,450 lb-ft.

Benefits

Emissions

Achieves emissions reductions to 25% less than EPA standards using the advanced three-way catalyst after treatment system without the need for active particulate filters or selective catalytic reduction systems.

Performance

Offers front and rear-engine power take-off options to provide additional application flexibility.

Contact Information:
Brad Zigler
Email: Brad.Zigler@nrel.gov
Phone: (303) 275-4267
National Renewable Energy Laboratory
15013 Denver W Pkwy,
Golden, CO 80401
Website: www.nrel.gov/

Lightweighting

Aluminum Formability Extension through Superior Blank Processing 60
Carbon Fiber Technology Facility 62
On-line Weld Quality Non-Destructive Evaluation and Control with Infrared Thermography 64
Plasma Oxidation for Lower Cost Carbon Fiber 66
Structural Automotive Components from Composite Materials 68

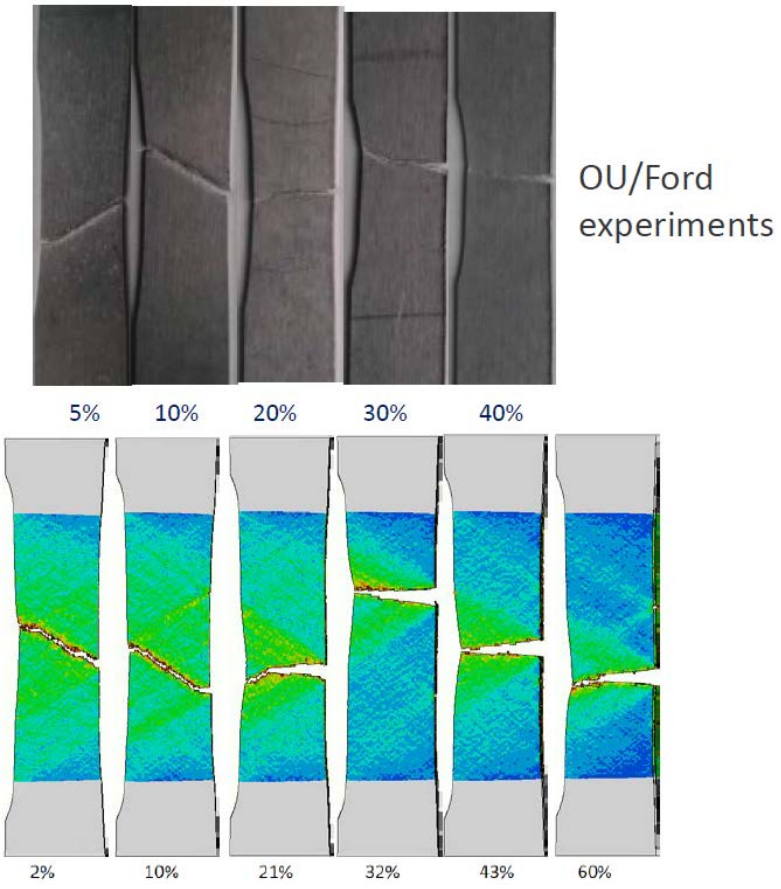
Aluminum Formability Extension through Superior Blank Processing

Commercial Technology

As the U.S. shifts toward more environmentally responsible transportation technologies, vehicle lightweighting is gaining more attention as a means of improving vehicle performance and reducing emissions in the short term. DOE has indicated that lightweighting could prove to be an effective means of improving fuel economy by increasing fuel economy by up to 8% with a 10% reduction in weight.[1] Manufacturers have turned to aluminum as one of the candidates capable of producing quality lightweight components. However, aluminum suffers from some manufacturing issues with today's infrastructure and can have reduced formability at room temperature—up to 50%—resulting in poor blanking, piercing, and trimming performance. A means of manufacturing aluminum components with high formability could benefit domestic manufacturers and would help reduce domestic emissions.

Pacific Northwest National Laboratory, with assistance from Ford Motor Company, Oakland University, and VTO, has developed new aluminum manufacturing processes to improve aluminum formability. The process improves on current blanking, piercing, and trimming operations by using a predictive model to help quantify edge condition and trimming relationships. The model is used to enhance coupon formability and accounts for edge stretchability and coupon hole-expansion. Using the model-based processes from this research, room temperature formability was improved by up to 50% and hole-expansion prediction capability was demonstrated to be within 90% of experimental values.

The model and process parameters developed by Pacific Northwest National Laboratory are now in use at Ford Motor Company. Ford Motor Company capitalizes on these techniques to facilitate production of aluminum components that are difficult to produce using standard manufacturing practices. In addition to improving formability performance, the model can be used to guide and shorten development cycles for new aluminum components.

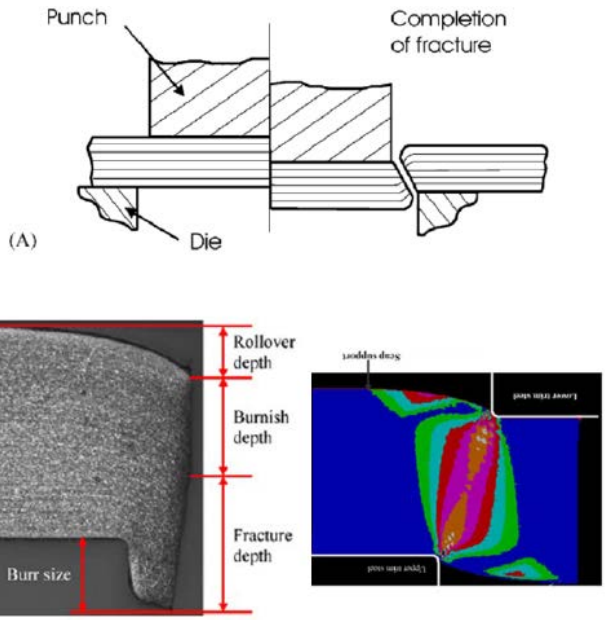


Comparison of model results to trimming results with scrap support.

[1] Vehicle Technologies Office: Lightweight Materials for Cars and Trucks, U.S. DOE, 2014

Aluminum Formability Extension through Superior Blank Processing

Commercial Technology



Comparison of Model Experimental Results for Rollover and Burring

Technology History

- Developed by Pacific Northwest National Laboratory, Ford Motor Company, and Oakland University.
- First commercial deployment by Ford Motor Company in 2015.
- Received initial funding 2011.

Applications

Can be used to manufacture aluminum components.

Capabilities

- Improves aluminum part blanking, piercing, and trimming operations.
- Provides modeling of trimming-to-edge characteristics and burr geometry prediction with greater than 90% accuracy.
- Predicts hole-expansion failure strain in aluminum components within 90% of measured values.

Benefits

Cost Savings

Reduces cost by optimizing aluminum forming techniques and component manufacturability.

Efficiency

Allows rapid development of new components through modeling and improves room temperature formability by 50%.

Contact Information:
Dr. Xin Sun
Email: Xin.Sun@pnnl.gov
Phone: (509) 372-6489
Pacific Northwest National Laboratory
902 Battelle Blvd,
Richland, WA 99354
Website: www.pnnl.gov

Carbon Fiber Technology Facility

Commercial Technology

In 2014, the transportation sector used nearly three quarters of the petroleum consumed by the U.S.[1] In an effort to reduce reliance on fossil fuels and reduce greenhouse emissions, DOE is supporting the development of new lightweight materials for vehicle manufacturing. Carbon fiber represents a promising material that can be used to produce many parts of light duty vehicles while benefiting from weight reductions. Heavy adoption of composite vehicles could reduce vehicle weight, fuel consumption, and increase performance. However, current carbon fiber production costs are often as high as $15/lb; the automotive industry viability target is around $7/lb. To increase the adoption of new lightweight composites, the production cost of carbon fiber must be reduced.

Oak Ridge National Laboratory, with assistance from VTO, has built the carbon fiber technology facility (CFTF) to reduce carbon fiber costs and assist with materials development. CFTF is a 42,000 ft^2 facility that offers a highly instrumented line for fiber development and technology demonstration. The facility's 390 foot-long processing line can produce up to 25 tons of carbon fiber per year and can be set up for custom configuration runs. This flexibility offers the ability for partners to validate conversion of their alternative carbon fiber precursors at near-production volumes.[2]

The CFTF has developed a manufacturing process for low cost carbon fiber utilizing a low cost commercially available multipurpose use commodity textile-based polyacrylonitrile precursor material. The approach allows for high volume throughput, demonstrating a reduction in the energy consumed during the manufacturing process. Mechanical properties, 400-500 ksi tensile strength and 32-40 msi tensile modulus, have been achieved that are equal to or exceeding commercially available industrial grade carbon fiber, making the low cost carbon fiber a prime candidate for a multitude of automotive applications. The combination of the manufacturing energy reduction, high volume throughput, and low cost commodity precursor enables a cost reduction making the product viable for the automotive industry. Oak Ridge National Laboratory is partnering with original equipment manufacturers to allow licensees to use the lab for medium volume production of new carbon fiber materials for both testing and manufacturing purposes.

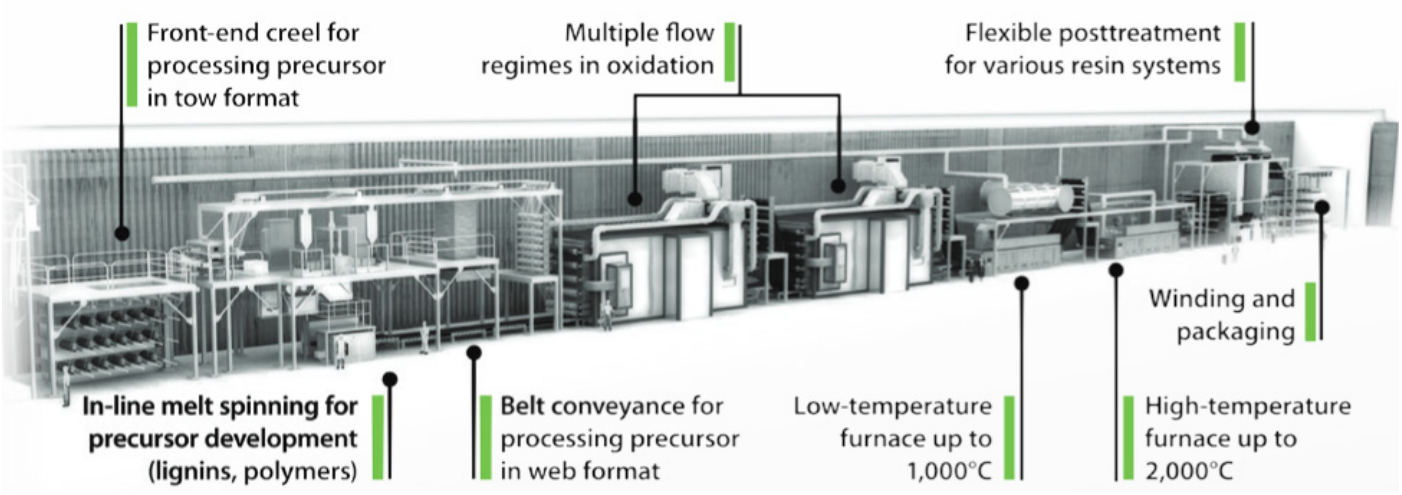


Diagram of Oak Ridge National Laboratory's Conventional Carbon Fiber Production Line

[1] "Benefits and Considerations of Electricity as a Vehicle Fuel", U.S. DOE, May 2016
[2] Carbon Fiber Technology Facility, ORNL, 2015

Carbon Fiber Technology Facility



Carbon fiber produced at Oak Ridge National Laboratory's Carbon Fiber Technology Center.

Technology History

- Developed by Oak Ridge National Laboratory.
- Commercialized in 2015 via licensing.
- Funded in 2010.

Applications

Can be used to manufacture carbon fiber materials.

Capabilities

- Can produce up to 115 tons of composite materials per year.
- Allows partners to test new composites at near production volumes.
- Provides a training system and educational internships for carbon fiber workforces.

Benefits

Environment

Provides lightweight high performance materials to reduce fuel consumption and emissions from vehicles.

Training

Provides carbon fiber related education and training for re-tooling and developing new workforces.

Contact Information:
Dr. Ron Ott
Email: ottr@ornl.gov
Phone: (865) 574-5172
Oak Ridge National Laboratory
1 Bethel Valley Rd,
Oak Ridge, TN 3783
Website: www.ornl.gov

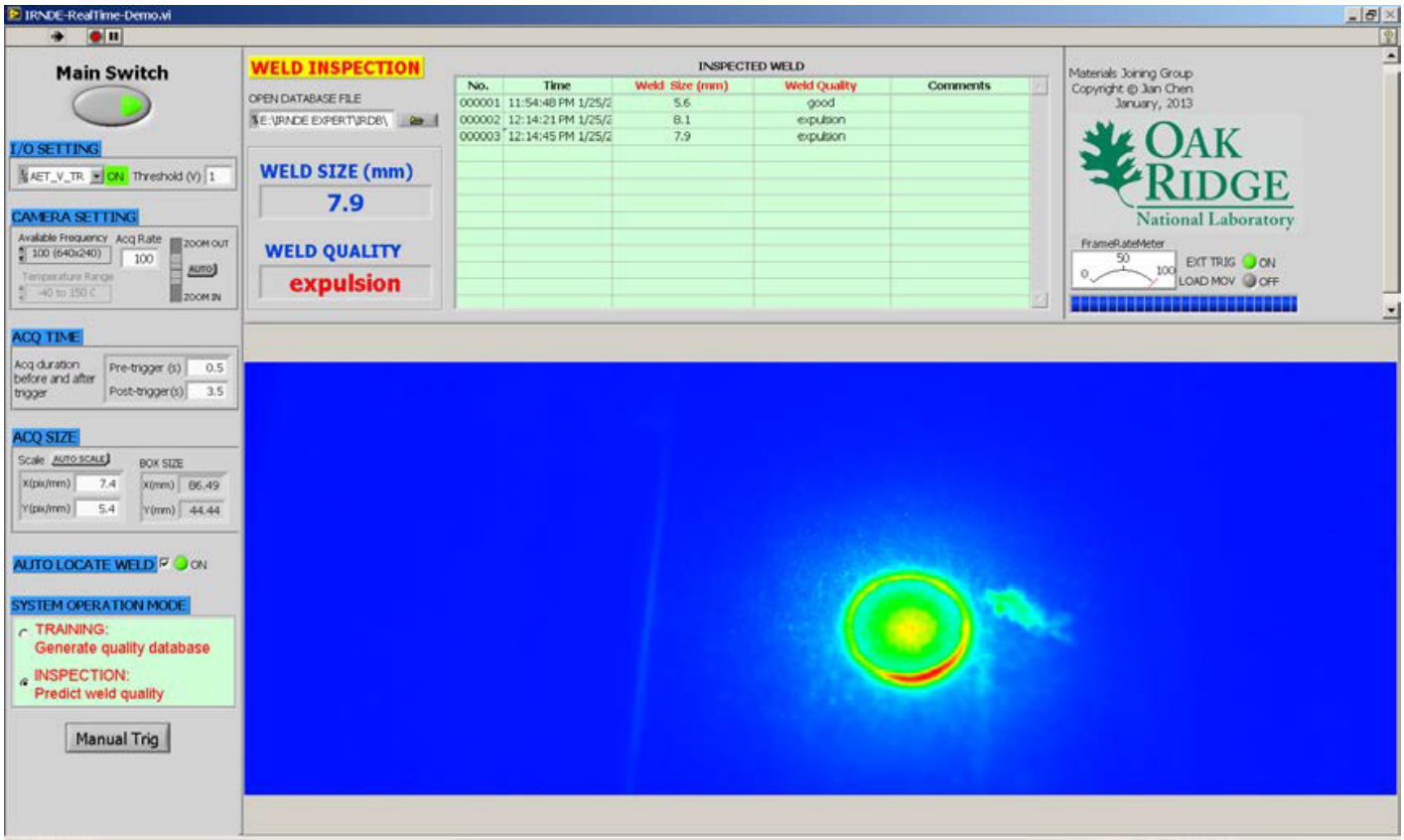
On-line Weld Quality Non-Destructive Evaluation and Control with Infrared Thermography

Commercial Technology

Increasing fuel efficiency in U.S. vehicles is a major goal for DOE with the expected average fuel economy to be 37 mpg in 2040.[1] Vehicle weight is a major area of interest, as reducing vehicle weight can improve the fuel economy of new and existing propulsion technologies. New high strength steel and aluminum components offer compelling weight reductions and can often be used in existing manufacturing lines. However, the welds used to join these new materials must be checked to ensure they are of satisfactory quality. To date, this has been a time consuming and labor intensive task as it involves destroying a random selection of welds for evaluation. A new non-destructive evaluation technique is needed to improve inspection quality and reduce production costs.

Oak Ridge National Laboratory (ORNL), with assistance from VTO and a team of industry collaborators, developed a software package that is capable of evaluating welds in real time. The Weld Quality Analysis Software (WQAS) uses thermography to identify weld quality. The process was developed to use an inexpensive infrared (IR) camera and the heat generated from the welding process to correlate IR signals with quality. The software has shown the ability to recognize many types of weld failures and can do so for most auto body parts using ORNL's weld quality database. The in-line nature of WQAS allows the setup to be used in high volume mass production environments without losing evaluation quality.

The WQAS system has a variable setup and can be used with a range of available IR cameras to meet the desired cost point. The system can also be used as a post-weld non-destructive evaluation if needed. ORNL received an R&D 100 award in 2015 as recognition of their WQAS system's performance.

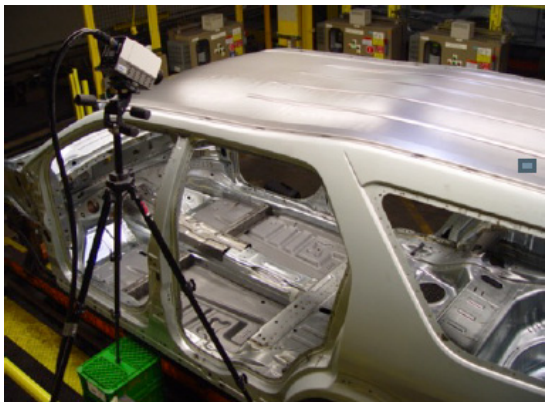


Oak Ridge National Laboratory's Weld Quality Analysis Software.

[1] Annual Energy Outlook 2015, Energy Information Administration, April 2015

On-line Weld Quality Non-Destructive Evaluation and Controlith Infrared Thermography

Commercial Technology



In-Line Manufacturing Set-up of Infrared Weld Monitoring Camera for *Weld Quality Analysis Software*

Technology History

- Developed by Oak Ridge National Laboratory, Fiat Chrysler Automobiles US LLC, Ford Motor Company, General Motors Company LLC, ArcelorMittal, AET Integration Inc., AMD NDE Steering Committee, Auto/steel Partenership (A/SP) Joining Team, Cosma International, and Eagle Bend Manufacturing.
- Available from Oak Ridge National Laboratory since 2016.
- Initially funded in 2008

Applications

Can be used to inspect weld quality.

Capabilities

- Evaluates welds without destroying the sample.
- Assesses weld quality without removal from the assembly line.
- Achieves evaluation times of ~1.5–3 seconds.

Benefits

Cost Savings

Inspects welds without destroying the sample leading to less waste and reduced labor requirements.

Efficiency

Offers in-line, real-time inspection which can inspect all parts rather than just a random selection.

Flexibility

Enables increased use of high strength materials without sacrificing inspection thoroughness.

Contact Information:
Zhili Feng
Email: fengz@ornl.gov
Phone: (865) 576-3797
Oak Ridge National Laboratory
1 Bethel Valley Rd,
Oak Ridge, TN 37831
Website: www.ornl.gov

Plasma Oxidation for Lower Cost Carbon Fiber

Commercial Technology

In the U.S. almost 70% of the petroleum consumed is used in the transportation sector.[1] In a recently completed vehicle design and build project, DOE's VTO was able to show that for every 10% weight reduction of a passenger car, a corresponding 9% increase in fuel efficiency is achieved.[2] High strength steel, aluminum alloys, magnesium alloys, and composites all offer individual benefits over traditional materials, but also introduce additional challenges. Carbon fiber composites have the potential to reduce the mass of automotive components by up to 60% while achieving equivalent or better performance, safety, and durability. Currently the greatest obstacle for the introduction of carbon fiber composites is the cost of the fiber. The fiber cost is about half attributable to the raw material and half attributable to the processing of material. The bottleneck in the manufacturing process is an 80-120 oxidative stabilization which is time, energy, and capital investment intensive. Conventional oxidation is a slow thermal process that typically consumes more than 80% of the processing time in a conventional carbon fiber conversion line. All subsequent steps are measured in seconds, not minutes.

Supported by VTO, Oak Ridge National Laboratory and RMX Technologies, LLC have developed a new method for oxidative stabilization which reduces manufacturing costs by 20% while using 75% less energy in the oxidation stage and producing carbon fiber three times faster than conventional methods. The new method is called plasma oxidation. The plasma oxidation process dramatically increases the conversion line throughput and appreciably lowers the fiber cost while reducing the line footprint by up to 30%. That new technology has been licensed to 4M Industrial Oxidation, LLC, and is being commercialized in partnership with C.A. Litzler Co., Inc., a leading manufacturer of oxidation ovens. The technology and oven design were also named as a 2016 finalist for an R&D 100 award.



Plasma Oxidation Oven

[1] Transportation Energy Data Book 2014 – Consumption of Petroleum by End-Use Sector, Tables 1.4, 1.7, 1.11, 1.12, 1.13.
[2] "Multi-Material Lightweight Vehicles", Skszek, T., Conklin, J., Wagner, D., Zaluzec, M., VTO Annual Merit Review, Washington, DC., 11 June 2015.

Plasma Oxidation for Lower Cost Carbon Fiber

Commercial Technology



Oxidized Polyacrylonitrile (PAN) Precursor Output from Low-Power Runs

Technology History

- Developed by Oak Ridge National Laboratory and RMX Technologies, LLC.
- Licensed and being used by 4M Industrial Oxidation, LLC and C.A. Litzler Co., Inc.
- Commercialized in 2016.
- Initially funded in 2004.

Applications

Rapid production of both carbon fibers and flame retardant material.

Capabilities

- Achieves processing speeds 66% faster than standard methods.
- Reduces energy consumption by up to 75% per pound of materials produced.
- Achieves three times faster mass throughput than standard methods.
- Reduces carbon fiber processing line footprint by up to 66%.
- Reduces carbon fiber production costs by up to 20%.

Benefits

Durability

Results in a carbon fiber with 20-30% increase in strength[1].

Efficiency

Increases carbon fiber availability by reducing cost and reducing energy requirements of the carbon fiber production process.

Environment

Reduces CO_2 emissions from vehicles by increasing fuel efficiency.

Contact Information:
Dave Warren
Email: warrencd@ornl.gov
Phone: (865) 574-9693
Oak Ridge National Laboratory
P.O. Box 2009, M/S 8050
Oak Ridge, TN 37831
Website: www.ornl.gov

[1] Lee, et al. Efficient preparation of carbon fibers using plasma assisted stabilization. Carbon, 55, 361 (2013).

Structural Automotive Components from Composite Materials

Commercial Technology

Reduction of vehicle mass is often a difficult proposition because of strict safety parameters for passenger vehicles and the performance expectations of consumers. Despite this, DOE has indicated that reducing vehicle weight is one of the primary methods of reducing vehicle emissions in the short term.[1] To meet DOE's expectations, while maintaining safety levels, manufacturers are turning to several lightweight commercially available alternatives to traditional steel parts. However, these components often rely on expensive substitutes that can lead to cost increases that are undesirable to both manufacturers and consumers. Development of low-cost components that satisfy new lightweighting guidelines could help reduce emissions and improve consumer acceptance of advanced vehicle parts.

The Automotive Composites Consortium, with assistance from Ford Motor Company, Oak Ridge National Laboratory, VTO, and a team of industrial and academic partners has developed new lightweight components for passenger vehicles. Two structures were developed by the partnership, including a structural composite underbody and a lightweight composite seat. In addition to these component designs, the group also developed the processes required to mass produce the parts. The advanced manufacturing process developed by the partnership is capable of fabricating the components necessary for 100,000 vehicles per year. Automotive Composites Consortium's advanced seat design benefited from the testing of 22 different prototype designs and achieved a final weight reduction of 23% compared to conventional seats.

A glass fabric/vinyl ester sheet molding compound with a low density core was designed for use in component production for lightweight underbodies. This material was selected over carbon fiber as it offered significantly lower cost while maintaining excellent performance. The new design results in an overall mass savings of 11.5 kg with components that offer a savings of up to $5 per kg saved. The seat manufacturing materials used glass-polypropylene direct long fiber injection (dlift) resulted in a total mass reduction of over 5 kg per seat structure.

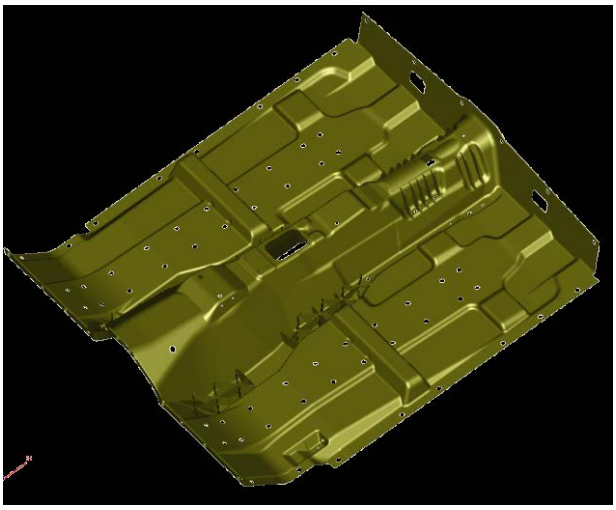


Automotive Composites Consortium's Composite Materials Seat

[1] "Lightweight Materials for Cars and Trucks", U.S. DOE

Structural Automotive Components from Composite Materials

Commercial Technology



Model of Automotive Composites Consortium's Structural Composite Underbody

Technology History

- Developed by the Automotive Composites Consortium (General Motors Company LLC, Ford Motor Company, Fiat Chrysler Automobiles) with collaboration from MultiMatic, Inc., Continental Structural Plastics, Century Tool and Gage, Oak Ridge National Laboratory, the University of Massachusetts Lowell, and IBIS Associates and Camanoe Associates.
- Commercialized in 2013.
- First funded in 2006.

Applications

Can be used to reduce vehicle weight.

Capabilities

- Achieves 23% reduction in component weight.
- Achieves a 2.5 min fabrication cycle for vehicle underbodies and cycle times as low as 60 seconds for seats.
- Offers weld bonding assembly compatibility.

Benefits

Cost Savings

Reduces cost of underbody and seating in vehicles by using less material mass and efficient design and fabrication methods.

Durability

Offers increased durability through the use of a high strength composite materials.

Efficiency

Provides a light weight, low-cost, alternative to traditional steel components that can be produced at commercially viable levels.

Contact Information:
Anthony Coppola
Email: anthony.coppola@gm.com
Phone: (586) 641-7669
General Motors Company
P.O. BOX 33170
Detroit, MI 48232-5170
Website: www.gm.com

Materials

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SiNANOde™: Innovative Cell Materials and Design for 300 Mile Range Electric Vehicles 74
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Saft America Factory of the Future

Continued growth of electric vehicles (EVs) in the U.S. could help reduce current domestic fuel consumption. With the transportation sector accounting for more than 70% of the fuel used domestically, this could drastically reduce U.S. use of foreign oil, reduce emissions, and improve the economy.[1] However domestic production of lithium is currently relatively low, forcing manufactures to rely on materials that are imported from foreign sources. To achieve a relatively self-sustaining EV infrastructure, domestic production of lithium for batteries must be increased.

Saft America, Inc. (Saft), with assistance from VTO, has established a lithium materials manufacturing facility in Jacksonville, Florida. The facility, which opened in 2011, produces advanced lithium-ion batteries for EVs and other applications. At a massive 235,000 ft^2, Saft's factory could produce up to 370 megawatt hours of battery power every year. This would be enough to supply 37,000 new EVs annually.[2] The increased capacity provided by this factory is expected to further decrease battery costs in the U.S., possibly down to half of the 2013 average cost.

The Jacksonville facility, which is now Saft's headquarters, has created jobs for more than 300 people—31% of whom are veterans—and is contributing to an expected growth of 600 indirect jobs in the region.[3] The factory's manufacturing lines use advanced techniques to improve efficiency and ensure the facility is competitive with foreign manufacturers. Saft's production capacity has allowed it to perform well domestically and expand its market outside the U.S.

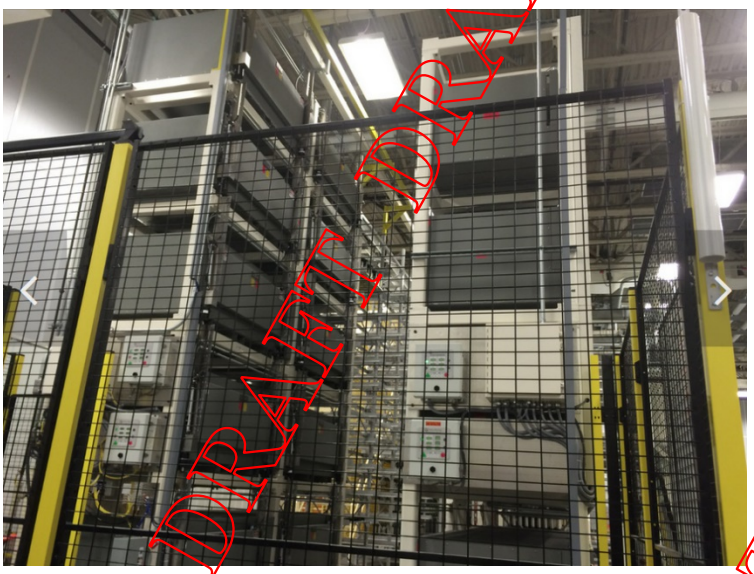


Saft America Inc.'s Battery Inspection Area

[1] "Annual Energy Outlook 2015", U.S. Energy information Administration, April 2015
[2] "Saft America Advanced Batteries Plant Celebrates Grand Opening in Jacksonville", U.S. DOE, September 2011
[3] "Obama touts Saft as stimulus success during Jacksonville visit", Jacksonville Business Journal, February 2016

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Saft America Factory of the Future



Saft America's Charging Racks

Technology History

- Developed by Saft America, Inc.
- Began commercial production in 2011.
- Received initial funding in 2009.

Applications

Can be used to produce EV battery systems.

Capabilities

- Offers a source of domestic battery production.
- Achieves a production levels suitable for supporting more than 35,000 EVs.
- Offers EV materials at costs competitive with foreign manufacturers.

Benefits

Cost Savings

Reduces EV material cost by offering a semi-automated domestic production process for lithium-ion batteries.

Grid Stability

Provides containerized batteries that can be used to stabilize electrical grids with high renewable penetration.

Job Creation

Stimulates the economy by generating over 300 U.S. jobs.

Contact Information:
Saft America
Email: lithiumsales@saftbatteries.com
Phone: (904) 861-1501
Saft America, Inc.
13575 Waterworks Street
Jacksonville, FL 32221
Website: www.saftbatteries.com/

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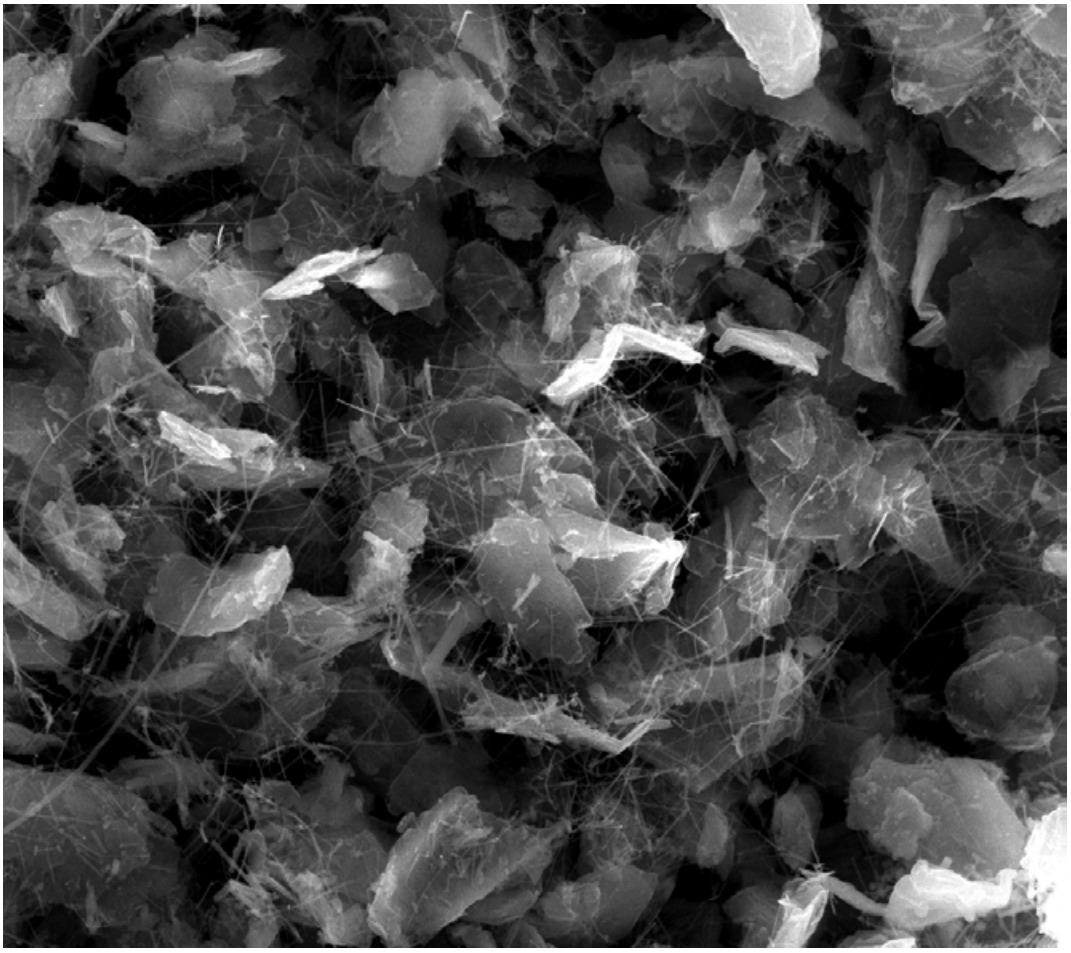
SiNANOde™: Innovative Cell Materials and Design for 300 Mile Range Electric Vehicles

Commercial Technology

Development of new advanced batteries is one of the driving forces for the reduction of electric vehicle (EV) cost and mass-adoption of EVs. As a result, one of DOE's goals is to reduce battery cost and weight while improving performance and durability.[1] While advancements in battery design have resulted in improvements to current battery technology, new materials will need to be developed to further reduce cost and improve performance. These new materials could result in batteries that offer increased performance (compared to combustion engines) and promote further adoption of EVs domestically.

OneD™ Material, LLC, with assistance from VTO and collaboration with A123 Systems, LLC, LG Chem Power Inc., the University of California Berkeley, and several national laboratories, has developed the SiNANOde™—a silicone nanowire anode. SiNANOde™ was developed along with a Mn-rich cathode as part of a high-performance cathode pouch cell. The SiNANOde™ has demonstrated improved volumetric energy density and capacity retention after life cycle testing. Additionally, the Si nanowire used in SiNANOde™ remains fully functional after depth of discharge cycling and cell swell testing has shown that OneD Material's pouch cell is much reduced (< 14%).[2]

SiNANOde™ is available from EaglePicher Technologies, LLC for advanced battery applications.[3] EaglePicher Technologies, LLC is offering the raw anode material other than the pouch cell. OneD™ Material, LLC has further developed its production process to significantly reduce the cost of SiNANOde™ material and improved its cycle life in pouch cells.

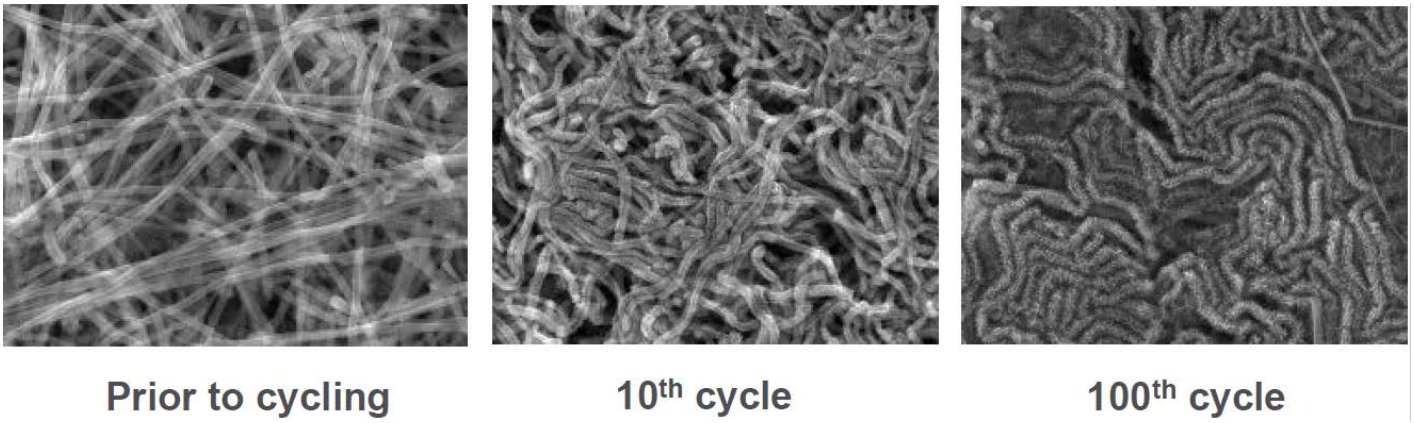


SiNANOde™ Powder Based on Carbon Substrate Powder

[1] For more information: Vehicle Technologies Office: Batteries
[2] For more information: Innovative Cell Materials and Design for 300 Mile Range EVs, U.S. DOE, June 2014
[3] EaglePicher Technologies™, LLC. Website: www.eaglepicher.com

SiNANOde™: Innovative Cell Materials and Design for 300 Mile Range Electric Vehicles

Commercial Technology



Si Nano-Wire After Depth of Discharge Testing

Technology History

- Developed by OneD™ Material, LLC, A123 Systems, LLC, LG Chem Power Inc., the University of California Berkeley, and several national laboratories.
- Commercialized in 2015.
- Available from EaglePicher Technologies™, LLC.[1]
- Received initial funding in 2011.

Applications

Can be used to manufacture high energy density batteries with long cycle lives.

Capabilities

- Offers anode capacities up to 1,600 mAh/g.
- Achieves 79% cell retention after 800 half-cell cycling @ T = 0.3ºC.
- Achieves reduced swelling with cell thickness increases of <14% after 300 cycles.
- Achieves volumetric energy density over 620 Wh/L @ V_{ave} = 3.7 V.

Benefits

Durability

Achieves 100% functionality after depth of discharge testing.

Efficiency

Offers increased energy densities for lighter weight EV battery components.

Contact Information:
Dr. Yimin Zhu
Email: yimin.zhu@onedmaterial.com
Phone: (650)766-7668
OneD™ Material, LLC
2625 Hanover Street
Palo Alto, CA, 94304
Website: www.onedmaterial.com

[1] EaglePicher Technologies™, LLC. Website: www.eaglepicher.com

Toda America Inc. Cathode Materials Production Facility

Commercial Technology

To reduce emissions caused by the U.S. transportation sector, DOE is emphasizing the need for the development of new electric vehicle (EV) technologies. This development is focusing on advanced batteries as a primary method of increasing growth in the industry and reducing costs.[1] With the industry expected to experience continued growth, new sources of battery materials will need to be identified to keep up with production requirements. Increased domestic production of battery materials will help drive down the cost of EVs and should be explored.

Toda America Inc., with assistance from Itochu Corporation, Argonne National Laboratory, the National Energy Technology Laboratory, VTO, and the American Recovery and Reinvestment Act, completed construction of a cathode materials production facility in Battle Creek, Michigan. The facility can produce 3,600 tons per year of cathode materials and distribute these materials to both the American and European markets. The facility is ISO 9001/14001 certified, offering a state-of-the-art domestic supply of advanced cathode materials. The lithium-ion cathode materials comprise $LiNiCoAlO_2$, $LiNiCoMnO_2$, and $LiMnO_2$ materials, including 2nd generation Argonne National Laboratory technology.

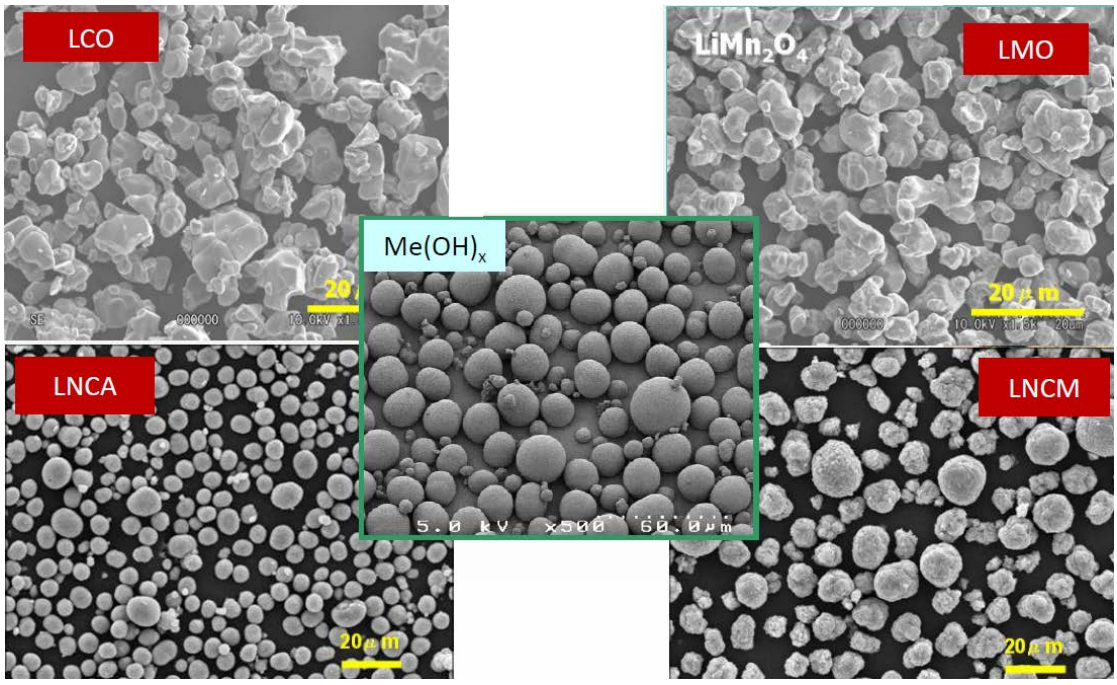
The Battle Creek plant began producing and shipping lithium-ion materials in 2011 for customer qualification and was fully commercialized by 2013. It continues to supply low cost advanced materials. The facility has created more than 40 permanent new jobs in the Battle Creek area, with the number expected to increase to around 60 employees when production reaches full capacity. In addition to expanding domestic EV battery production, the materials produced by Toda America Inc. will be useable in other advanced battery systems including wind and mobile usages.



Toda America Inc. Battle Creek Facility

[1] Vehicle Technologies Office: Batteries, U.S. DOE, August 2015

Toda America Inc. Cathode Materials Production Facility



Toda America Inc. Advanced Cathode Materials

Technology History

- Developed by Toda America Inc., Itochu Corporation, Argonne National Laboratory, and the National Energy Technology Laboratory.
- Commercialized in 2013.
- Received initial funding in 2010.

Applications

Can be used to produce advanced cathode materials.

Capabilities

- Produces $LiNiCoAlO_2$, $LiNiCoMnO_2$, and $LiMnO_2$ materials.
- Produces cathode materials at 3,600 tons per year.

Benefits

Cost Savings

Reduces cost of cathode materials by offering state-of-the-art domestic supply of material.

Job Creation

Creates more than 40 jobs in Battle Creek, Michigan.

Contact Information:
David Han
Email: dhan@turtlerockgroup.com
Phone: (734) 787-9855
Toda America, Inc.
4750 W Dickman Road
Battle Creek, MI 49037
Website: www.todaamerica.com

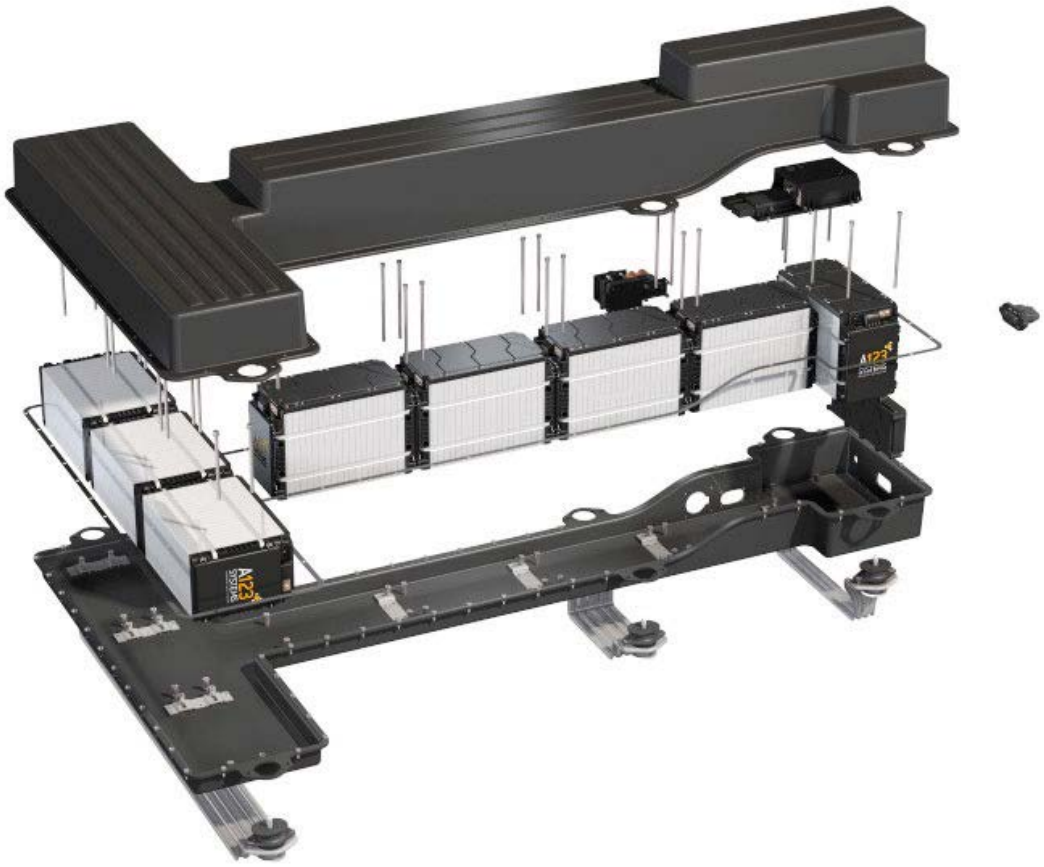
Vertically Integrated Mass Production of Automotive Class Lithium Ion Batteries

Commercial Technology

In an effort to reduce emissions generated by the domestic transportation sector and reduce reliance on foreign fuels, DOE has created the "EV Everywhere" program. The major thrust of this program is to increase the adoption of electric vehicles (EVs) in the U.S.[1] To accomplish this, battery cost and weight will be the focus for improvement in the short term. Battery cost is a primary contributor to overall vehicle cost and could positively affect EV adoption if it were improved. Cultivation of domestic sources of EV batteries could both improve production levels and create jobs. Therefore, domestic production should be pursued.

A123 Systems, LLC, with assistance from VTO as part of the American Recovery and Reinvestment Act and the U.S. Advanced Battery Consortium LLC, has built two facilities in the U.S. The production facilities, located in Livonia and Romulus, Michigan, support the production of EV batteries for more than 500,000 vehicles annually. These advanced, vertically integrated facilities perform different steps of the manufacturing process, but work in conjunction to produce EV batteries at reduced cost.

A123 Systems has been producing batteries at the Livonia, Michigan location since 2010. The Romulus facility began operations later that year. The manufacturing process is split between the two plants, the Livonia plant performs material production and cell assembly. The Romulus plant's site 1 performs cell coating with site 2 (performing high volume production of low risk steps in support of the Livonia plant.



A123 Systems Passenger Vehicle Battery System

[1] For more information see: About EV Everywhere

Vertically Integrated Mass Production of Automotive Class Lithium Ion Batteries

Commercial Technology



Production facility in Romulus, Michigan

Technology History

- Developed by A123 Systems LLC and U.S. Advanced Battery Consortium LLC.
- Commercialized in 2011.
- Received initial funding 2009.

Applications

Can produce low cost EV batteries.

Capabilities

- Provides a low cost domestic source of EV batteries.
- Achieves high volume production of low risk parts.
- Produces more than 500,000 batteries per year.

Benefits

Cost Savings

Reduces EV battery cost through vertical integration of the manufacturing process and high volume production of components.

Job Creation

Creates full-time jobs in Livonia and Romulus, Michigan.

Contact Information:
Jesus M. Alvarez, MPM
Email: Jalvarez@a123systems.com
Phone: (856) 904-8211
A123 Systems LLC
39000 Seven Mile Road
Livonia, MI 48152
Website: www.a123systems.com

U.S. Advanced Battery Consortium (USABC) 42V Start Stop Development Program

Commercial Technology

Improving electric vehicle (EV) adoption rates is a primary goal for DOE as it will help reduce U.S. domestic emissions and decrease U.S. dependence on foreign fuels.[1] To support this effort, it is important to develop EV technologies that offer similar or improved performance compared to internal combustion engine vehicles. To date, EVs have struggled to achieve internal combustion engine vehicle performance levels while maintaining a low unit cost. This can be attributed to the high cost of advanced power systems needed for high performance operation. Improved low cost components represent a way to improve vehicle performance and ultimately increase adoption.

Maxwell Technologies, Inc. (Maxwell), with assistance from VTO and the United States Advanced Battery Consortium, has developed improved ultracapacitors for use in advanced EVs. Development work performed by Maxwell was completed in 2006, and culminated in the development of eight new ultracapacitor designs. The Gen 6 design of the MC-2006-2 7V ultracapacitor, later became the K2-series ultracapacitor. The K2 2.7V series was launched in 2005, and has been used in over 1.5 million vehicles to date. This series was the first generation of ultracapacitor to be used in hybrid busses and still being used in over 25 thousand vehicles.

Maxwell's K2 2.85V 3400F ultracapacitor resulted from the Gen 8 design generated by this research. The K2 2.85V cell became available in 2014, and offers 17% more power and 23% more energy than the 2.7V/3000F cell.[2] In addition to increased power storage, the 2.85V cell provides increased vibrational resistance and shock immunity through the incorporation of Maxwell's DuraBlue™ Advanced Shock and Vibration Technology. The K2 2.85V ultracapacitor was recognized as one of EDN's Hot 100 Products of 2014.[3]



Maxwell Technologies Inc.'s K2 2.7V Series

[1] For more information: Vehicle Technologies Office-Batteries
[2] For more information: K2 2.85V/3400F Cell, Maxwell Technologies, Inc., 2016
[3] For more information: "Ultracap boasts 3400 farads, boosts transportation reliability", EDN Network, June 2014

U.S. Advanced Battery Consortium (USABC) 42V Start Stop Development Program



Maxwell Technologies Inc.'s 2.85V Ultracapacitor with DuraBlue™

Technology History

- Developed by Maxwell Technologies, Inc.
- Commercialized in 2006.
- Received initial funding in 2004.

Applications

Can be used in high performance EVs and other systems which require high quality power storage.

Capabilities

- Offers up to 1,000,000 duty cycles or 10-year DC life.
- Achieves up to 18kW/kg specific power.
- Offers up to 4Wh of storage.

Benefits

Cost Savings

Reduces EV energy storage costs by featuring a 60mm diameter cylindrical design, installation friendly threaded terminals, or optional weldable terminals.

Durability

Offers long cell life for use in high performance applications including fast response and backup power systems.

Contact Information:
Dr. Xiaomei Xi
Email: XXi@Maxwell.com
Phone: (858) 503-3305
Maxwell Technologies, Inc.
3888 Calle Fortunada
San Diego, CA, 92123
Website: www.maxwell.com

Vehicle Systems Simulation, Integration and Testing

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Advanced Vehicle Electrification and Transportation Sector Electrification

Further adoption of electric vehicles (EVs) represents an opportunity to reduce greenhouse gas emissions from the transportation sector, reduce reliance on foreign oil, and increase the number of highly-skilled jobs available in the U.S. EVs will be able to use renewable power for charging as more renewable sources become available, such as overnight charging from off-peak renewables that would otherwise not be used. Growing numbers of EVs have been added to the domestic market, offering electric ranges of more than 200 miles. However, common complaints of insufficient charging locations or long charging times are affecting adoption rates and represent one of the barriers to widespread use and growth of the EV industry. Understanding infrastructure installation issues is needed to expand the number of available charging locations, and decreased charging times will accelerate EV adoption.[1]

General Motors Company LLC (GM), with assistance from VTO and a team of industry partners, including nine utilities, installed over 300 charging stations to "kick-start" some of the first residential and public charging infrastructure. In some cases, issues with codes and standards were identified and resolved paving the way for more widespread charging infrastructure. The team also developed and tested a fast charging protocol to support the creation of a new industry SAE standard for use with GM, and other EV original equipment manufacturers. Development of standardized connection interfaces and communication standards was undertaken to align automakers and increase the consumer convenience and use of public vehicle charging stations. This project gathered data to further understand the impact of DC fast charging stations on the national electric grid. Overall, GM and its partners collected and analyzed vehicle and charging data for more than three years to facilitate the design and development of future EVs and charging stations. The consumer driving behavior data, analyzed by Idaho National Laboratory, was particularly invaluable in understanding the driving and charging behaviors of battery electric vehicle, extended range electric vehicle, and plug-in hybrid electric vehicle technologies. The data identified early insights into AC vs. DC infrastructure utilization, cost, and has been used to shape infrastructure projects nationally. The data also opened a critical dialog with key regulatory agencies about eVMT (electric vehicle miles travelled), and future regulations and guidance.

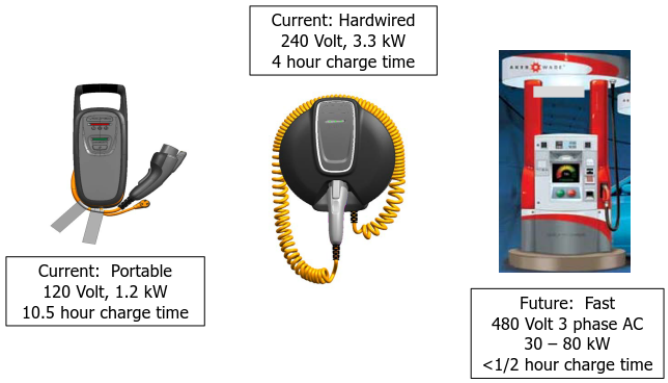
GM and its partners used project data to gain experience and consumer insights into the tradeoffs and commercialization impacts of AC Level 1 (120V) vs. AC Level 2 (240V) vs DC fast-charging systems. A new DC fast-charging station developed during the program, capable of charging a vehicle in under 30 minutes, was used to help guide and shape the SAE industry standard for DC fast-charging, and was used to further understand the impacts of fast charging on the electric grid. What was once considered the "future" is now a robust SAE industry standard with over 800 SAE DC fast-chargers across the U.S.



General Motors Company LLC's Smartphone Application by OnStar

[1] "New EPRI-NRDC Report Finds Widespread Adoption of Electric Transportation Could Curb Greenhouse Gas Emissions and Improve Air Quality", Electric Power Research Institute, September 2015

Advanced Vehicle Electrification and Transportation Sector Electrification



General Motors Company's Portable AC L1, Hardwired AC L2, and DC Fast-Charging Units

Technology History

- Developed by General Motors Company, Electric Power Research Institute, and nine major utility partners.
- Commercialized in 2013.
- Initially funded in 2010.

Applications

Can be used for utility demand response leveraging EV charging, to identify and address EV commercialization barriers, and to inform future infrastructure projects (including building codes).

Capabilities

- Achieved charging times of under 30 minutes.
- Standardized connection and communication interfaces for industry DC fast-charging.
- Demonstrated utility-to-EV smart charging and demand response.
- Offers charging reminders through text message and provides much other remote functionality.
- Demonstrated the re-purposing of EV batteries for secondary market stationary storage use.

Benefits

Adaptability

Offers charge scheduling to allow EV users to ensure charging occurs during off-peak hours.

Interactive Design

Allows charging and environmental controls to be accessed through the user's smartphone.

Job Creation

Stimulates the economy by assuring a more robust consumer market for EVs and charging infrastructure. Additional growth can be seen through the high-skill jobs, including domestic manufacturing, created by new transportation market demands.

Contact Information:
Britta Gross
Email: britta.gross@gm.com
Phone: (586) 596-0382
General Motors LLC
300 Renaissance Center
Detroit, MI 48265-3000
Website: www.gm.com

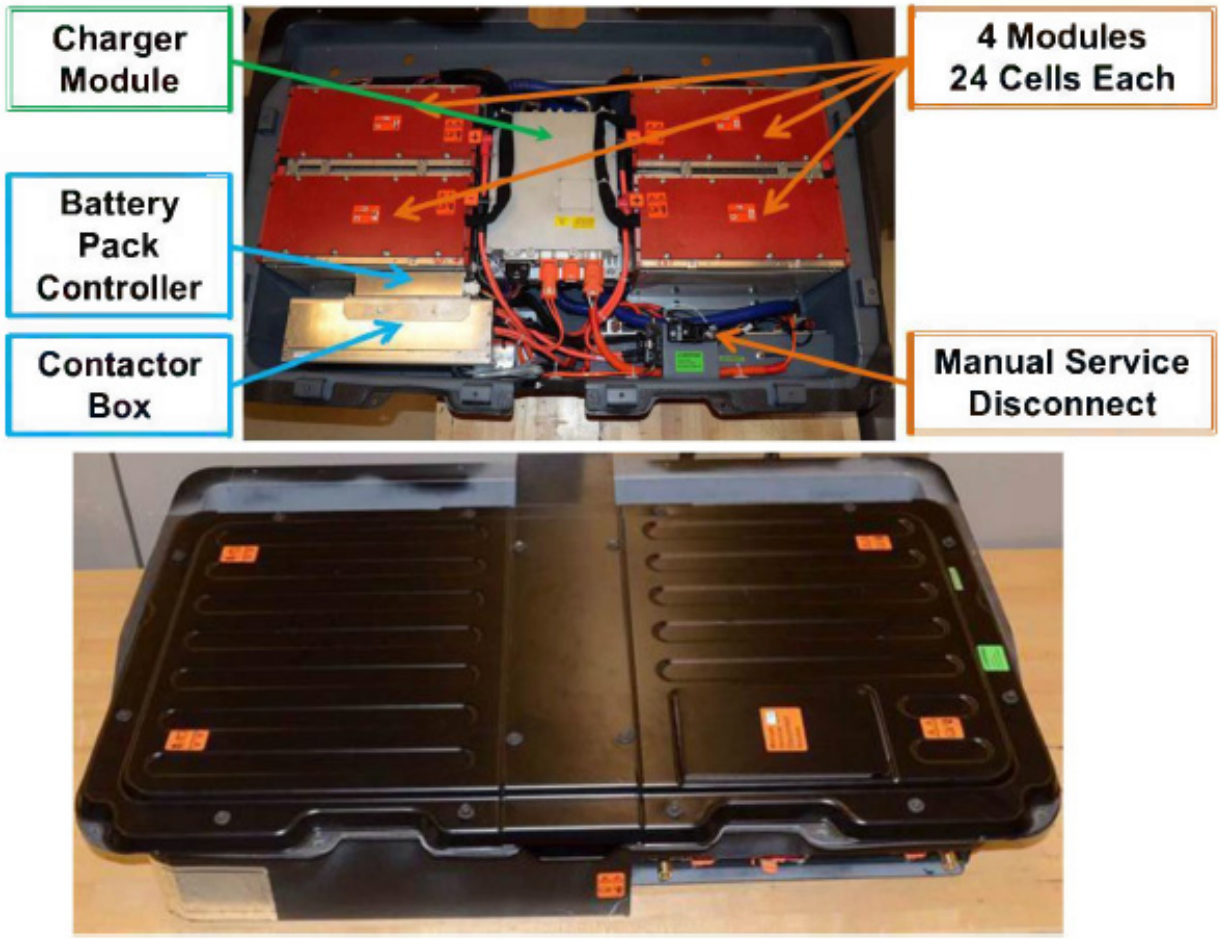
Advancing Plug-In Hybrid Technology and Flex Fuel Application on a Chrysler Mini-Van Plug-in Hybrid Electric Vehicle

Commercial Technology

The growing plug-in hybrid electric vehicle (PHEV) industry could benefit from increased understanding of component use and operating characteristics.[1] Though several electric propulsion systems are available, there is no standard model that can be used for "economy of scale" production. As a result, the cost of implementing electric drive systems is noticeably higher than conventional systems. In addition, various electric drive systems offer different performance standards when used in the various regions of U.S. and could benefit from more extensive performance characterization in different climates.

Fiat Chrysler Automobiles US LLC, with assistance from VTO and a team of partners, has completed an extensive project to characterize electric drive systems. The project was able to refine the specifications previously available for PHEV platforms and gathered the data necessary to scale-up system production to more commercially viable levels. A prototype was produced to demonstrate system performance in-line with customer behaviors and expectations. As a result of this demonstration, 25 advanced prototypes were produced for accelerated development and validation. These advanced prototypes were used to facilitate fleet testing by project partners in several locations throughout the U.S.

Fiat Chrysler Automobiles US LLC directly implemented the research completed during this project in the development of its 2017 Pacifica Hybrid, the first electric vehicle in its class. The charging system, high voltage battery system, and thermal system for the Pacifica Hybrid were all developed and refined with knowledge gained during the DOE project.

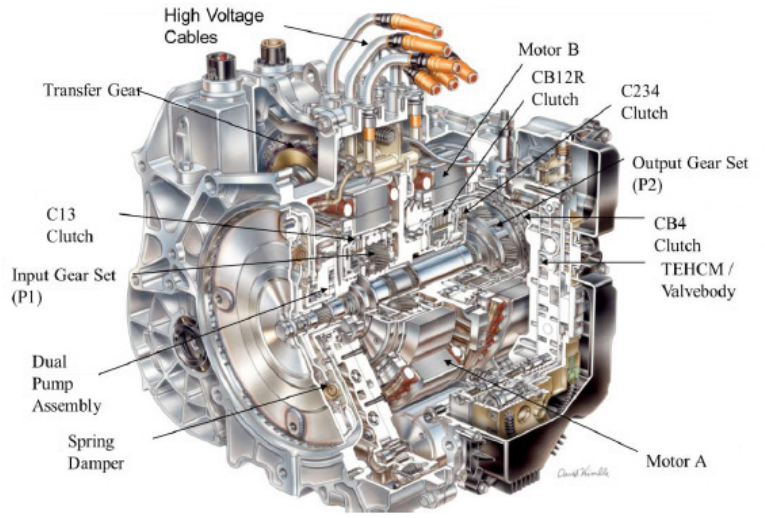


Fiat Chrysler Automobiles US LLC's Battery Pack and Internal Cutaway (top)

[1] For more information see: FCA US LLC Final Technical Report

Advancing Plug-In Hybrid Technology and Flex Fuel Application on a Chrysler Mini-Van Plug-in Hybrid Electric

Vehicle



Fiat Chrysler Automobiles US LLC''s 2-Mode Hybrid Transmission

Technology History

- Developed by Fiat Chrysler Automobiles US LLC, Electrovaya, Inc., and MAHLE Behr USA, Inc.
- Commercialized in 2016.
- Funded in 2009.

Applications

Knowledge gained can be used to increase reliability and decrease cost of PHEV systems.

Capabilities

- Demonstrates acceptable performance during multi region testing.
- Optimizes engine operation during charge-sustaining mode.
- Meets customer performance expectations.

Benefits

Cost Savings

Reduces cost by improving previous PHEV concept designs with real-time propulsion strategy optimization and energy storage system model refinement.

Durability

Operates in conditions ranging from -20°F to 125°F using a lithium-ion battery thermal management system.

Job Creation

Stimulates the economy by generating more than 70 full-time U.S. based high tech, green jobs.

Contact Information:
Abdullah Bazzi
Email: Abdullah.Bazzi@fcagroup.com
Phone: (248) 944-3093
FCA US LLC
800 Chrysler Drive
Auburn Hills, MI 48326
Website: www.fcausllc.com

Advancing Transportation through Vehicle Electrification – Ram 1500 Plug-in Hybrid Electric Vehicle

Commercial Technology

Electric light duty vehicles (LDVs) have experienced increased interest in recent years as they offer a solution to the heavy fuel consumption attributed to the transportation sector. LDV total miles traveled are expected to increase by 36% over 2013 values by 2040. Growth of the hybrid electric, plug in hybrid electric, and electric vehicle (EV) industries could reduce emissions and fuel consumption increases associated with increased LDV use.[1] However, battery performance in LDVs is not adequately proven in some environments. Lack of pertinent information has resulted in some reluctance by consumers to adopt EVs. Increased understanding of EV performance in extreme conditions could result in greater market acceptance and consumer adoption.

Fiat Chrysler Automobiles US LLC (FCA), with assistance from the VTO, as part of the American Reinvestment Recovery Act, and a team of industry partners have developed and tested new systems for use in EVs. As part of this testing, 140 pickup trucks were tested in diverse areas across the U.S. Drive cycles and consumer use patterns in these areas were used to ensure compatibility of the advanced equipment in the entire North American Free Trade Agreement region. Plug-in charging performance for these vehicles was monitored, resulting in verification of the battery models developed. The validated testing allowed for the redeployment of 34 newly retrofitted Ram 1500 plug-in hybrid electric vehicles (PHEV).

Ram 1500 PHEV pickup trucks developed by this project are available through FCA US and its deployment partners. The trucks are capable of reaching full charge in less than 4 hours and are able to use either 220V or 110V charging stations. Regenerative brakes, which capture kinetic energy for re-charging the battery, increase its maximum range to 655 miles using a full tank of gas while allowing a maximum pure electric range of 20 miles. The fleet performance results enabled FCA to develop components and sub-systems to support their PHEV powertrain architecture across multiple vehicle platforms, the first of which was commercialized in 2013.

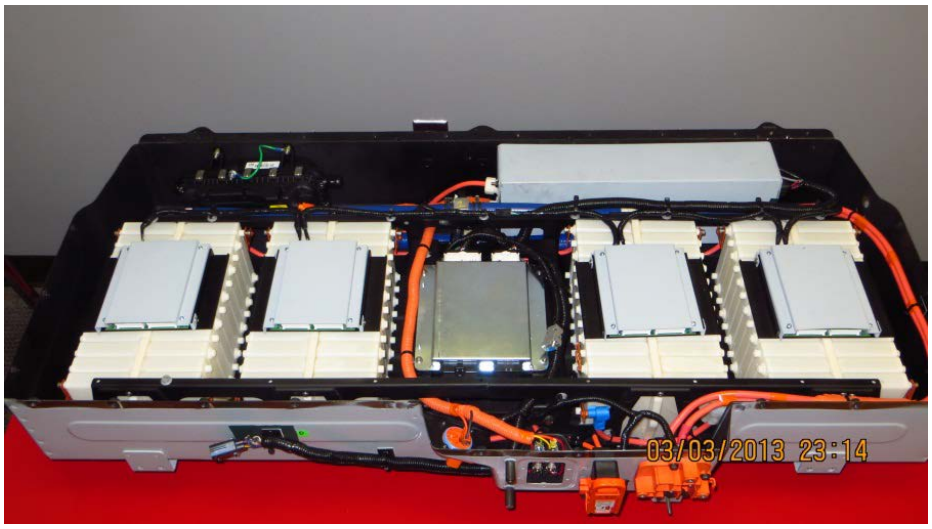


Fiat Chrysler Automobiles US LLC's RAM 1500 PHEV Demonstrator

[1] "2015 Annual Energy Outlook", U.S. Energy information Administration, April 2015

Advancing Transportation through Vehicle Electrification - Ram 1500 Plug-in Hybrid Electric Vehicles

Commercial Technology



Fiat Chrysler Automobiles US LLC's High Voltage Battery System

Technology History

- Developed by Fiat Chrysler Automobiles US LLC and project partners.
- Commercialized in 2013.
- Funded in 2009.

Applications

Can be used to manufacture PHEV trucks.

Capabilities

- Can produce 6.6 kW of continuous AC power via onboard auxiliary power panel.
- Achieves 399 horsepower and max gross combined weight of 12,100 lbs.
- Offers towing capacity up to 6,000 lbs.

Benefits

Cost Savings

Reduces fuel costs by offering a rating of 32 mpg at full charge and up to 20 miles of pure-electric range.

Efficiency

Achieves advanced fuel efficiency using dual-mode transmission (electric and hybrid-electric) and regenerative braking (passive electric recharging).

Job Creation

Stimulates the economy by creating domestic manufacturing and research jobs.

Contact Information:
Abdullah Bazzi
Email: Abdullah.Bazzi@fcagroup.com
Phone: (248) 944-3093
FCA US LLC
800 Chrysler Drive
Auburn Hills, MI 48326
Website: www.fcausllc.com

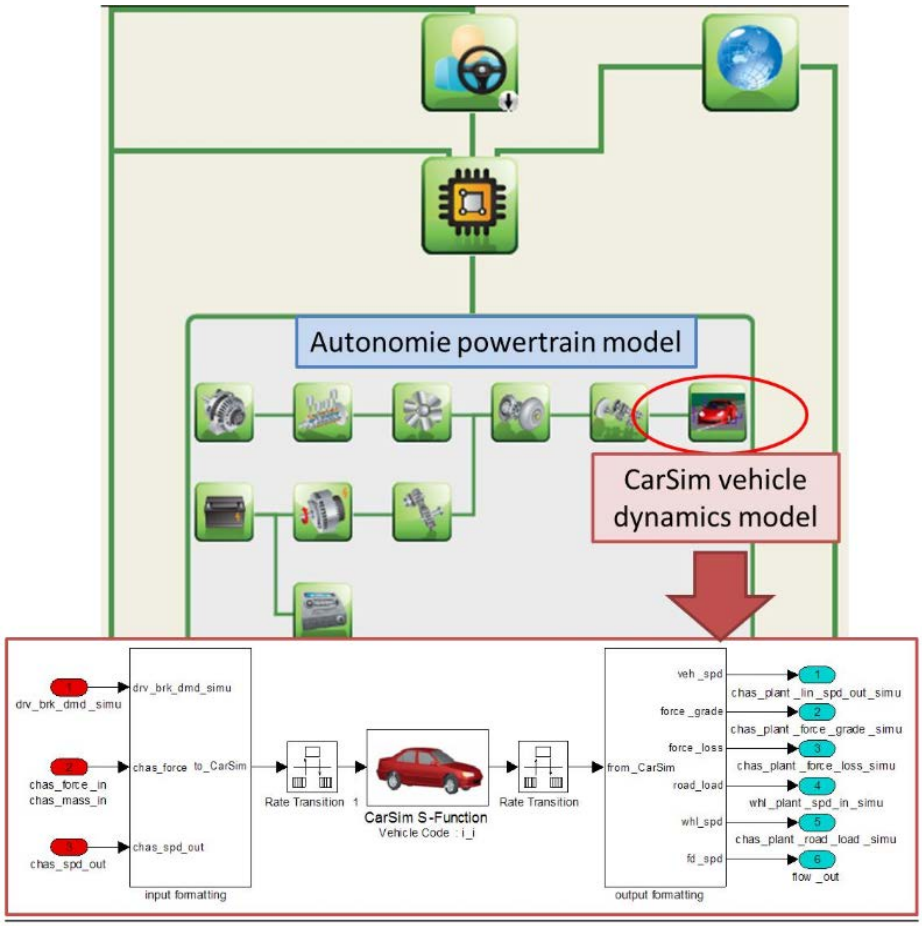
Autonomie Plug and Play Software Architecture

Commercial Technology

In recent years, vehicle technologies have become increasingly complex with the introduction of new powertrain configurations such as electric vehicles (EVs), new component technologies like advanced transmissions, and control strategies such as eco-routing. In addition, with increased focus on connectivity and automation, one cannot only consider the vehicle as a stand-alone element, but rather focus on the entire transportation system due to the numerous interactions with a vehicle and its environment.[1] New modeling systems could help expedite EV development and encourage domestic EV sector growth.

Argonne National Laboratory's System Modeling and Control group, with assistance from VTO and a team of partners, has developed a series of integrated tools and processes to quickly and efficiently evaluate the impact of advanced vehicle and transportation technologies from a mobility and energy point of view. Autonomie is a powerful and robust system simulation tool for vehicle energy consumption and performance analysis. Developed in collaboration with General Motors Company LLC, Autonomie is a MATLAB©-based software environment and framework for automotive control-system design, simulation, and analysis. Its application covers energy consumption and performance analysis throughout the entire vehicle development process by leveraging its Plug-and-Play Powertrain and Vehicle Model Architecture and Development Environment.

Autonomie can be used as an assessment tool in several areas of vehicle development. The tool provides insight into energy consumption and cost for technologies including impacts of component sizing, component technologies, powertrain configurations, vehicle level control, and energy impact at the transportation system level.



Vehicle built by Autonomie using the CarSim vehicle dynamics model.[2]

[1] For more information: "Vehicle Technologies Office: Integration, Validation and Testing Tools and Procedures"
[2] For more information: System Analysis Using Multiple Expert Tools, ANL, January 2011

Autonomie Plug and Play Software Architecture

Commercial Technology



Dynometer testing at Argonne National Laboratory's Advanced Powertrain Research Facility.

Technology History

- Developed by Argonne National Laboratory, General Motors Company LLC, MathWorks, Inc., Gamma Technology LLC, Siemens Product Lifecycle Management Software Inc., and Mechanical Simulation Corporation.
- Commercialized in 2011.
- Initially funded in 2007.

Applications

Can be used to assess the energy consumption and cost of multiple advanced powertrain technologies of EVs.

Capabilities

- Offers a complete set of turnkey EVs for a wide range of vehicle classes (light duty to heavy duty) and powertrain configurations (conventional, start-stop, hybrid electric vehicles, plug-in hybrid electric vehicles, battery electric vehicles, full hybrid electric vehicles, etc.).
- Offers validated low level and high level control algorithms from Argonne National Laboratory's Advanced Powertrain Research Facility dynamometer test data.
- Integrates third party tools for data management and plant, economic, environment and process modelling.
- Supports "industrialization" of models, processes, and post-processing through current standards.

Benefits

Customizable

All features are configurable and nonrestrictive to support plug-and-play integration of custom or proprietary models, architectures and processes for the end user, and to support future technology.

Efficiency

Autonomie provides the environment and standard framework to make an entire engineering organization more efficient through the reuse and sharing of models and methods, and by leveraging modeling and control experts across different areas.

User-friendly

Autonomie's graphical user interfaces allow users to rapidly select the specific model to be evaluated by the proper method. Graphical user interfaces also support the selection of processes, configuration, and database management for any data type.

Contact Information:
Aymeric Rousseau
Email: arousseau@anl.gov
Phone: (630) 252-7261
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439
Website: www.anl.gov/

Electric Vehicles - Smart Grid Interoperability Products

Commercial Technology

As the domestic transportation sector moves toward widespread use of electric vehicles (EVs), development of technology and standards for vehicle-grid connectivity and communication will be required to minimize the impact on the grid. However, differences in charging technologies and communication protocols could inhibit adoption of EVs and the achievement of DOE's goals for vehicle electrification. EV charging standards have been and are being developed by industry with the help of the national laboratories. As new technologies are developed standards will undergo further development, but it is apparent that the global automotive industry and developers of charging infrastructure could benefit from the early adoption of a universal communication standard.[1]

Argonne National Laboratory (ANL), with assistance from VTO, developed and operates the EV-Smart Grid Interoperability Center. The EV-Smart Grid Interoperability Center utilizes several ANL facilities, including the Advanced Powertrain Research Facility, a Vehicle-Grid Integration Lab, an Embedded Controls Lab, and the Smart Energy Plaza. These facilities support the development of technology and standards for the interface between plug-in vehicles and electric vehicle supply equipment, as well as vehicle integration with the key elements of smart grids (e.g., building systems, renewable energy, and grid storage).

ANL's EV-Smart Grid Interoperability Center successfully led the development of the SAE J2953 (interoperability) standards, as well as the equipment for compliance testing. The center went on to develop additional standards compliance tools including an SAE J1772 charge coupler compliance tool, a smart charge adaptor, and end use measurement devices in commercial form factors. To encourage the adoption of a universal communication standard, ANL developed the SpEC module for EV-electric vehicle safety equipment-grid communication.[2]



Argonne National Laboratory's SpEC Module and Charging Station

[1] "HARMONIZATION OF STANDARDS, TECHNOLOGY AND TESTING EV-Smart Grid Interoperability Centers in Europe and the U.S.", U.S. DOE and European Commission, February 2014

[2] For more information See: Argonne's SpEC Module

Electric Vehicles - Smart Grid Interoperability Products

Commercial Technology



Argonne National Laboratory's SpEC Module

Technology History

- Developed by Argonne National Laboratory and industry partners.
- Commercialized SpEC module in 2014.
- Initially funded in 2011.

Applications

- Communication controller for EV or electric vehicle safety equipment enabling:
  - DC Fast Charging (ISO/IEC 15118, DIN 70121, SAE J2847-2)
  - AC Smart Charging (ISO/IEC 15118, SEP 2.0)
- Plug- in electric vehicle or electric vehicle safety equipment emulation for testing.

Capabilities

- Offers internationally compatible charging capability.
- Easily integrate into any existing EV or electric vehicle safety equipment hardware platform.
- Enables DC fast charging which can add 60-80 miles of range in < 20 minutes.

Benefits

Cost Savings

Streamlines EV infrastructure and enables demand response control on individual charging stations during peak load periods to reduce the strain on the grid or the premise's demand charges.

Interoperability

Allows EVs to use any charging station that includes the SpEC module which enables interoperable DC charging.

Stability

Increases grid stability by allowing EV charging stations to interact with local electricity service providers.

Contact Information:
Jason Harper
Email: jharper@anl.gov
Phone: (630) 252-1032
Argonne National Laboratory
9700 Cass Ave,
Lemont, IL 60439
Website: www.anl.gov

Improved Heavy Vehicle Fuel Efficiency through Aerodynamics

Commercial Technology

To combat climate concerns and reduce fuel consumption, policy makers are enacting programs to improve vehicle efficiency in the United States. The transportation sector is estimated to use more than 70% of U.S. fuel intake, making it a prime candidate for efficiency programs that will help improve domestic air quality while reducing fuel imports.[1] Heavy duty vehicles (HDVs) are of particular interest, as class 7 and 8 vehicles are essential to the domestic shipping industry. These HDVs represent about 12% of domestic fuel use but have not benefited from the prevailing electric vehicle trend.[2] Instead, aerodynamics is viewed as an area that could be improved for most HDVs. Improvements in HDV aerodynamics could result in an estimated $1.2 billion per year savings in diesel alone, as well as a 42 million ton reduction in domestic fleet CO_2 emissions.

Lawrence Livermore National Laboratory, in collaboration with industry partners and with assistance from VTO, has developed a series of add on aerodynamic devices to improve HDV fuel economy. These add on devices have resulted in drag reductions up to 25% and have been adopted in 11 fleets in North America. As part of the research performed by Lawrence Livermore National Laboratory, tractor-trailer integration was evaluated as a means of further improving fuel economy. Integrated trailer research resulted in add-on devices that can further improve fuel economy by more than 20%.

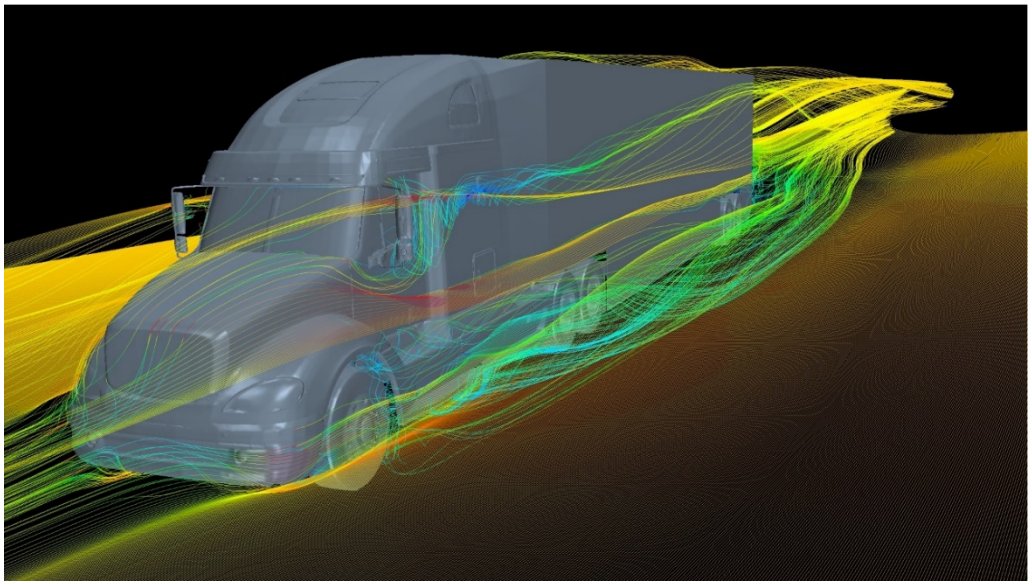
Further implementation of tractor-trailers was found to drastically reduce aerodynamic drag and resulted in a 40% reduction of fuel use. Developments based on generic speed form 2 testing were found to further reduce the pressure effects that result in parasitic drag. The research team is now working with the National Renewable Energy Laboratory to investigate the effects of platooning (having HDVs drive in groups) on drag.



Truck with Skirt and Add-On Tail Devices

[1] "Annual Energy Outlook 2015", U.S. Energy Information Administration, April 2015
[2] "LLNL 2016 AMR", U.S. DOE, June 2016

Improved Heavy Vehicle Fuel Efficienc through Aerodynmaics



Model of Truck with Aerodynamic Effects

Technology History

- Developed by Lawrence Livermore National Laboratory and tested in collaboration with several partners.
- Commercialized in 2015 and available from STEMCO Aerodynamics.
- Initially funded in 2009.

Applications

Can be used to improve fuel efficiency of class 7 and 8 trucks.

Capabilities

- Improves heavy vehicle fuel efficiency through the use of aerodynamics.
- Introduces integrated and highly aerodynamic shape designs.
- Demonstrates drag reduction with the proposed generic speed form shapes compared to the vehicles on the road.
- Potentially could reduce HDV domestic fuel use by up to 4.2 billion gallons of diesel per year.

Benefits

Efficiency

Increases HDV fuel efficiency by reducing the vehicle aerodynamic drag caused by pressure effects.

Environment

Reduces CO_2 emissions from HDVs by up to 42 million tons by increasing fuel efficiency.

Contact Information:
Kambiz Salari
Email: salari@llnl.gov
Phone: (925) 424-4635
Lawrence Livermore National Laboratory
7000 East Ave,
Livermore, CA 94550
Website: www.llnl.gov

Plug-In Hybrid Electric Vehicle Technology Advancement

Increasing electric vehicle (EV) adoption could reduce light duty vehicle emissions by up to 64% compared to current levels.[1] However, high technology costs pose a barrier to the mass-adoption of EVs. The new and highly advanced technology implemented in many EVs typically translates into a higher vehicle purchase cost that is seen as undesirable by consumers. Improved EV component and subsystem design optimizations that incorporate advanced lithium-ion battery technology and balance fuel economy, emissions, vehicle performance, and battery life trade-offs can lead to important cost reductions that could spur further adoption of EVs and lead to a cleaner domestic environment.

General Motors Company LLC, with assistance from VTO and a team of academic and industrial partners, completed the development of several new components for a plug-in hybrid electric vehicle (PHEV). The team developed new lithium-ion battery modules and thermal systems to increase the performance of PHEVs while reducing costs. This was done through heavy data collection and modeling from over 50 test vehicles and a cumulative drive distance of over 180,000 miles. Modeling allowed the team to develop more advanced charge depleting and charge sustaining functionality as well as validate cold weather performance even when using alcohol based fuels.

Three different battery modules were produced and down-selected to one concept based on the developed thermal design concepts. Further thermal testing measured module temperature, maximum and minimum cell temperature, and the heat capacity of the battery coolant. In addition to thermal system development and testing, key evaluations were made in areas that included the verification of the structural integrity of the module to vibration, module aging evaluation, module sealing evaluation, and a thermal cycling life assessment of the module sealing system. All the results are key to understanding the performance of lithium-ion battery and thermal systems over the expected working life and can be used in new advanced PHEVs. The vehicles developed under the program are compatible with industry-standard charging systems.



Plug-in Charging Station

[1] "New EPRI-NRDC Report Finds Widespread Adoption of Electric Transportation Could Curb Greenhouse Gas Emissions and Improve Air Quality", Electric Power Research Institute, September 2015

Plug-In Hybrid Electric Vehicle Technology Advancement



Plug-in Hybrid Demonstrator Vehicle

Technology History

- Developed by General Motors Company LLC, FEV, Inc., and the University of Michigan Advanced Battery Coalition for Drivetrains-Research.
- Incorporated in General Motors Company LLC commercial PHEV systems in 2013.
- Funded in 2008.

Applications

Battery module and thermal system designs can be applied to produce advanced EVs, including PHEVs.

Capabilities

- Produced significant technology improvements made in the vehicle build process.
- Offers PHEV performance that exceeded test specs in cold climates.
- Demonstrated the thermal performance, structural performance, and manufacturability of battery systems.
- Improved understanding of module aging and thermal cycling life performance of batteries and thermal systems.
- Reduces the cost of domestic PHEV production.

Benefits

Adaptability

Cold weather testing exceeded technical specifications using both gasoline and alcohol fuels.

Job Creation

Stimulates the economy by generating domestic manufacturing jobs.

Contact Information:
Britta Gross
Email: Britta.gross@gm.com
Phone: (586) 596-0382
General Motors LLC
300 Renaissance Center,
Detroit, MI 48265
Website: www.gm.com

Plug-In Hybrid Medium-Duty Trucks

The electric vehicles (EVs) sector is experiencing continued growth with domestic EVs expected to reduce emissions below 2013 levels by 2040 with corresponding a drop of 3.4 quadrillion Btu in gasoline consumption.[1] Class 1 vehicles account for the majority of EV sector growth with medium and heavy vehicles experiencing relatively less caused by lack of vehicle availability and poor market acceptance. A more mature medium class EV sector could reduce medium class vehicle fuel usage by up to 71% and warrants investigation.

The South Coast Air Quality Management District, with assistance from VTO and industry partners, has developed three plug-in hybrid electric vehicles capable of offering similar performance to current class 2-5 vehicles. An Odyne Class 6-8 truck was developed for use by partners and deployment by utilities. Also developed was a vehicle internal architecture (VIA) class 1 plug-in hybrid electric vehicle pickup truck and a VIA class 2 plug-in hybrid electric vehicle van. All the vehicles are capable of reaching full charge on a level 2 charger in less than seven hours and are Federal Motor Vehicle Safety Standards (FMVSS) compliant. Two hundred and ninety-six trucks and vans were deployed to 62 different fleets and 23 states, including Washington, DC.

As a result of this work, the VTRUX truck and van are now offered by Via Motors, Inc. The trucks, which began shipping in 2014, house a 150 kW onboard generator to power the motor, as well as provide 14.5 kW of export power at 60 Amps. VTRUX trucks are also available with a 50 kW of export power option with 1,000 lbs. of payload capacity.[2] Odyne Systems, LLC offers its modular conversion system for most class 6-8 trucks with Allison transmissions and received the 2015 Wisconsin Clean Cities Technology Award, adding to its multi-award portfolio.[3]



Via Motors Inc. VTRUX Truck

[1] Annual Energy Outlook 2015, U.S. Energy Information Administration, April 2015
[2] The World's First Extended-Range Electric Truck, Via Motors, Inc.
[3] Our Awards, Odyne Systems, LLC

Plug-In Hybrid Medium-Duty Trucks



Odyne Plug-In Hybrid Electric Vehicle Utility Vehicle

Technology History

- Developed by South Coast Air Quality Management District (SCAQMD), California Energy Commission, Electric Power Research Institute, Odyne Systems, LLC, VIA Motors, Inc., and Pathway Technologies, Inc.
- Commercialized in 2014.
- Funded in 2009.

Applications

Can be used to improve fuel efficiency of class 1-8 vehicles.

Capabilities

- Offers 40 miles of electric only driving.
- Achieves fuel economies up to 120 mpg.
- Improves fuel economy by up to 50%.
- Achieves motor torques up to 380 Nm.

Benefits

Cost Savings

Reduces vehicle fuel use while idling by up to 50%.

Efficiency

Allows up to 40 miles of pure electric range with an extended range of up to 400 miles at a maximum of 120 mpg.

Flexibility

Offers continuous performance even when in areas with no external power by charging onboard batteries with the combustion engine up to 50% state of charge.

Contact Information:
Joseph Impullitti
Email: jimpullitti@aqmd.gov
Phone: (909) 396-3249
South Coast Air Quality Management District
21865 Copley Drive
Diamond Bar, CA 91765
Website: www.aqmd.gov

Prepared by Pacific Northwest National Laboratory
for the U.S. Department of Energy
Vehicle Technologies Office

PNNL-SA-125835 | April 2017

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

VEHICLE TECHNOLOGIES OFFICE