Vehicle Technologies Program: Goals, Strategies, and Top Accomplishments

Chevy Volt plug-in hybrid electric vehicle. Courtesy of Wieck Media Services

The U.S. economy and the American way of life rely on transportation—especially the nation's vast fleet of cars, trucks, and buses. And this transportation depends almost entirely on oil. In 2009, the movement of goods and people in the United States consumed 13 million barrels of oil per day, representing 70% of total U.S. oil consumption and more than twice the amount of crude oil produced domestically. This oil dependence makes the nation vulnerable to supply disruptions and economically harmful price shocks, while petroleum-powered transportation generates air pollution and one third of U.S. greenhouse gas emissions. Reducing transportation's dependence on oil is vital for achieving U.S. economic and environmental goals.

The U.S. Department of Energy's (DOE) Vehicle Technologies Program (VTP) is meeting this transportation challenge with an integrated portfolio of advanced vehicle and fuel research, development, demonstration, and deployment activities. VTP accomplishes this work in collaboration with industry leaders, national laboratories, universities, state and local governments, and other stakeholders—harnessing a vast resource of expertise to help technologies developed in the laboratory make the transition to commercially successful products.

Ultimately, the widespread commercialization of advanced vehicle and fuel technologies will reduce U.S. oil consumption, strengthen the economy, and reduce air pollution and greenhouse gas emissions. VTP's approach to achieving this vision is described below through the goals, strategies, and top accomplishments for each of its subprograms: Hybrid Electric Systems; Advanced Combustion Engines; Fuels and Lubricants; Materials Technologies; and Outreach, Deployment, and Analysis (including Clean Cities).

Key Goals

- **Hybrid Electric Systems:** Reduce the production cost of high-energy, high-power batteries from $1,200/kWh in 2008 to $300/kWh by 2014, enabling cost-competitive market entry of plug-in hybrid electric vehicles.
- **Advanced Combustion Engines:** Develop engine technologies that increase the fuel economy of passenger vehicles by 25%–40% and commercial vehicles by 20% by 2015.
- **Fuels and Lubricants:** Identify which components of fuels and lubricants have the most significant effects on tailpipe and evaporative emissions by 2014.
- **Materials Technologies:** Validate a cost-effective 50% weight reduction in passenger-vehicle body and chassis systems by 2015.
- **Outreach, Deployment, and Analysis:** Leverage Clean Cities partnerships to reduce U.S. petroleum consumption by 2.5 billion gallons per year by 2020.

Hybrid Electric Systems

Widespread use of advanced electric-drive vehicles—including hybrid electric vehicles (HEVs), electric vehicles (EVs), and plug-in hybrid electric vehicles (PHEVs)—could revolutionize U.S. transportation and dramatically reduce oil consumption. VTP is advancing the large-scale, cost-competitive production of the next generation of electric-drive vehicles through three complementary component- and system-level technology pathways:

1. Reduce the cost of electrochemical energy storage by developing lithium-ion batteries and other advanced energy-storage technologies that afford higher energy densities without sacrificing safety and performance.
2. Enable the use of advanced energy-storage technologies in vehicle systems by developing low-cost advanced power electronics and electric motor components.
3. Develop and validate models and simulation tools to predict the performance, fuel economy, and emissions of advanced conventional and electric-drive vehicle systems.

One key goal is to reduce the production cost of high-energy, high-power batteries from $1,200/kWh in 2008 to $300/kWh by 2014, enabling cost-competitive market entry of PHEVs. The following are some of VTP's top Hybrid Electric Systems accomplishments to date.

Jumpstarted the U.S. Electric-Drive Industry

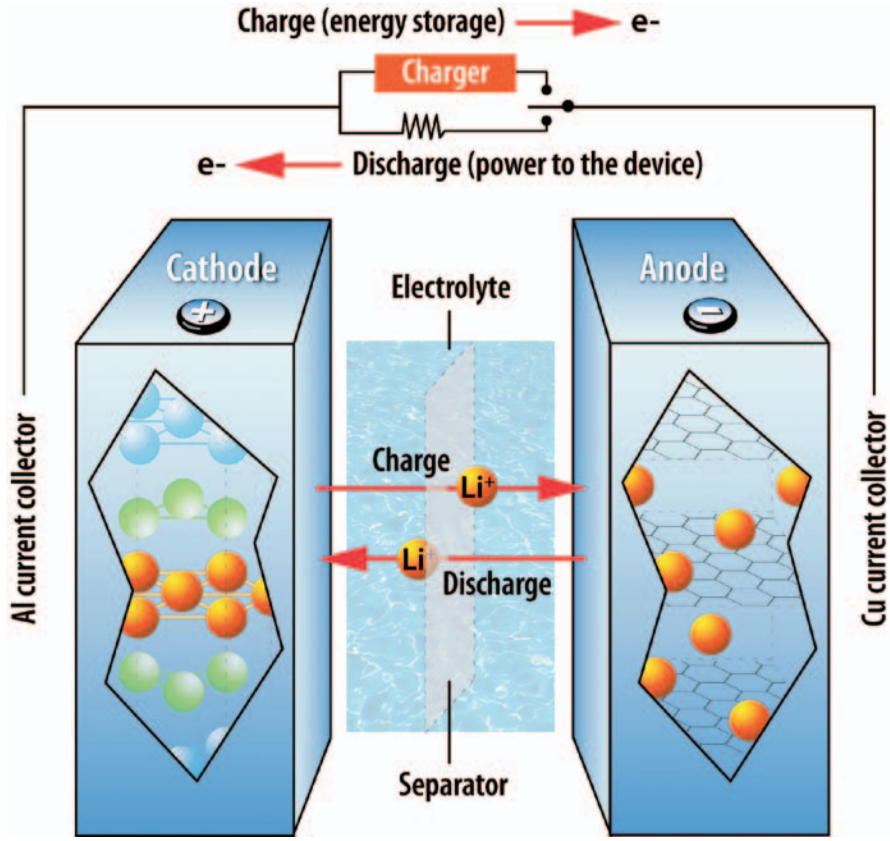
VTP awarded $2.4 billion in funds from the American Recovery and Reinvestment Act of 2009 to new battery and electric-drive component manufacturing and vehicle deployment projects. These include battery and power electronics manufacturing facilities, PHEV and EV demonstration projects, and education projects. As the largest single investment in these technologies, the awards will jumpstart the nation's electric-drive manufacturing capacity and deploy more than 13,000 vehicles and nearly 23,000 Level 2 charging stations in residential, commercial, and public locations nationwide.

Developed Today's HEV and PHEV Batteries

VTP-sponsored research and development (R&D) resulted in the state-of-the-art nickel-metal-hydride batteries used in all of today's HEVs. VTP also supported Johnson Controls-Saft in developing the first lithium-ion battery incorporated into a production HEV. In addition, General Motors (GM) chose lithium-manganese-spinel battery technology—developed by Compact Power/LG Chem with VTP support—for its Chevy Volt PHEV.

Created World-Class Modeling Tools

In 1999, VTP supported the development of the Powertrain Systems Analysis Toolkit (PSAT), which enables dynamic analysis of vehicle performance and efficiency to support detailed design, development, and validation of vehicle components and systems. PSAT became the primary vehicle model for all VTP activities in addition to winning major awards and being used by more than 130 companies worldwide. In 2010, PSAT evolved into an even more advanced tool, Autonomie, with significantly expanded component and vehicle modeling, testing, and evaluation capabilities.



Lithium-ion battery schematic. Courtesy of Argonne National Laboratory

Advanced Combustion Engines

Although internal combustion engines have been used for more than a century, increasing engine efficiency is still one of the most cost-effective approaches to reducing vehicle petroleum consumption and emissions. Integrating advanced engines with HEV and PHEV technologies provides even greater benefits. VTP's strategies for improving internal combustion engines focus on four complementary technology pathways:

1. Increase the efficiency of internal combustion engines for gasoline and diesel passenger vehicles.

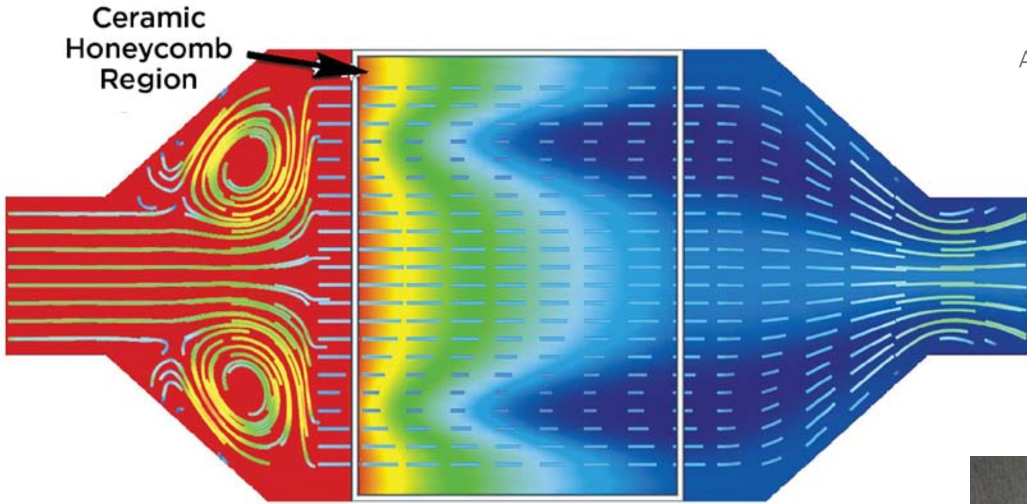
2. Increase the efficiency of internal combustion engines for commercial vehicles.

3. Develop new combustion approaches that are more efficient than diesel combustion and produce near-zero emissions.

Johnson Controls-Saft lithium-ion battery. Courtesy of Johnson Controls-Saft

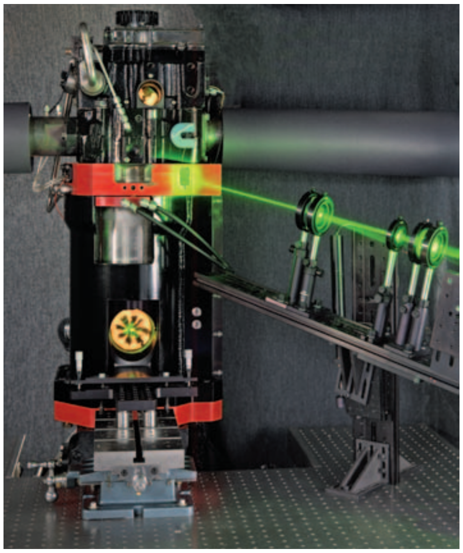
4. Recover waste-heat energy from the engine's exhaust to achieve a 10% or greater efficiency improvement.

One key goal is to develop, by 2015, engine technologies that increase the fuel economy of passenger vehicles by 25% (for gasoline vehicles) to 40% (for diesel vehicles) and commercial vehicles by 20%



Analysis of a catalytic converter during cold starting. Courtesy of Oak Ridge National Laboratory

Advanced laser diagnostics of combustion in a modified Cummins engine. Courtesy of Sandia National Laboratories



compared with 2010 baseline vehicles. A further goal is to increase commercial engine efficiency by 30% by 2018, with demonstrations in commercial vehicle platforms. The following are some of VTP's top Advanced Combustion Engine accomplishments to date.

Reaped a 60-Fold Return on Commercial Engine R&D Investments

VTP-sponsored R&D enabled engine manufacturers to improve diesel engine efficiency by 5% since 2002. To date, this has saved 2.4 billion gallons of diesel fuel worth more than $7.6 billion—more than 60 times VTP's $123 million investment in commercial engine R&D from 1999 to 2007. The R&D also enabled engines to meet 2007 regulations requiring a 90% reduction in particulate matter (PM) emissions and a more than 50% reduction in nitrogen oxides (NO_X) emissions compared with the previous standards.

Made Diesel as Clean as Gasoline for Passenger Vehicles

VTP-sponsored research demonstrated the ability of diesel passenger vehicles with advanced aftertreatment to meet stringent U.S. Environmental Protection Agency (EPA) emissions standards, spurring the current reintroduction of highly efficient diesel vehicles into the passenger vehicle market. Cummins partnered with VTP to develop diesel engine technologies that meet the 50-state 2010 emissions standards while boosting vehicle fuel economy by 30% over comparable gasoline-powered vehicles. The advanced Cummins engine is available on 2010 Dodge pickup trucks.

Fuels and Lubricants

Advanced vehicles require advanced fuels and lubricants. VTP uses two complementary strategies to develop cleaner, greener fuels and lubricants for the vehicles of today and tomorrow:

1. Develop nonconventional fuels and lubricants that maximize engine efficiency and minimize emissions.
2. Test the impacts of nonconventional fuels and lubricants on vehicle engines, emission-control systems, fueling infrastructure, and human health.

One key goal is to identify which components of fuels and lubricants have the most significant effects on tailpipe and evaporative emissions by 2014. The following are some of VTP's top Fuels and Lubricants accomplishments to date.

Evaluated Intermediate Ethanol Blends

Reaching 36 billion gallons of annual renewable fuel consumption by 2022— as outlined by the Energy Independence and Security Act of 2007—likely will require vehicles to use intermediate ethanol blends such as E15 (15% ethanol, 85% gasoline). VTP played a major role in EPA's October 2010 decision to permit E15 for model year 2007 and newer vehicles. Before intermediate blends could be approved for use, their effects on the performance and emissions of vehicles and small non-road engines designed to run on gasoline with 0%–10% ethanol had to be determined. VTP was the primary source of information about the impact of intermediate blends, with research focusing on emissions, fuel economy, and vehicle driveability.

Performed Research Resulting in Market Shift to Ultra-low Sulfur Diesel (ULSD)

VTP led a government-industry collaboration in demonstrating that the sulfur content of diesel fuel had to be greatly reduced to enable the use of advanced emission-reducing aftertreatment systems. Diesel vehicles require the use of advanced aftertreatment systems, such as lean-NO_X catalysts, to meet stringent emissions standards. VTP-sponsored research led EPA to require that all highway diesel fuel contain a maximum of 15-ppm sulfur. Before this ruling went into effect in 2006, diesel fuel for on-road use contained an average of 350-ppm sulfur, with a legal maximum of 500 ppm.

Instilled Confidence in Biodiesel Fuel Quality

In response to problems with the quality of U.S. biodiesel arising in 2005, VTP partnered with the National Biodiesel Board to improve ASTM (an international standards organization) biodiesel fuel specifications and ensure that suppliers adhere to the specifications. Surveys of marketed biodiesel conducted by VTP in 2005 and 2007 showed a large improvement in compliance with the ASTM standard over this period, including more consistent biodiesel concentration and reduced levels of impurities. The fuel-quality improvement resulted in increased willingness among engine manufacturers to endorse biodiesel use in their engines.

Materials Technologies

One way to improve a vehicle's efficiency is to make it lighter. Another way is to power it with high-efficiency propulsion technologies. Advanced materials play a key role in both these approaches. VTP is leading the development of high-performance, cost-effective materials—and the processes needed to manufacture them—to make advanced vehicles more efficient and affordable. These efforts focus on three complementary strategies:

1. Reduce the weight of body and chassis components through use of advanced materials.

2. Develop advanced engine and powertrain materials able to withstand high pressures and temperatures that enable more efficient propulsion systems.

3. Develop low-cost materials for electric motors and drivetrain components.

One key goal is to validate a cost-effective 50% weight reduction in passenger-vehicle body and chassis systems by 2015. The following are some of VTP's top Materials Technologies accomplishments to date.

Commercialized Advanced Material Components

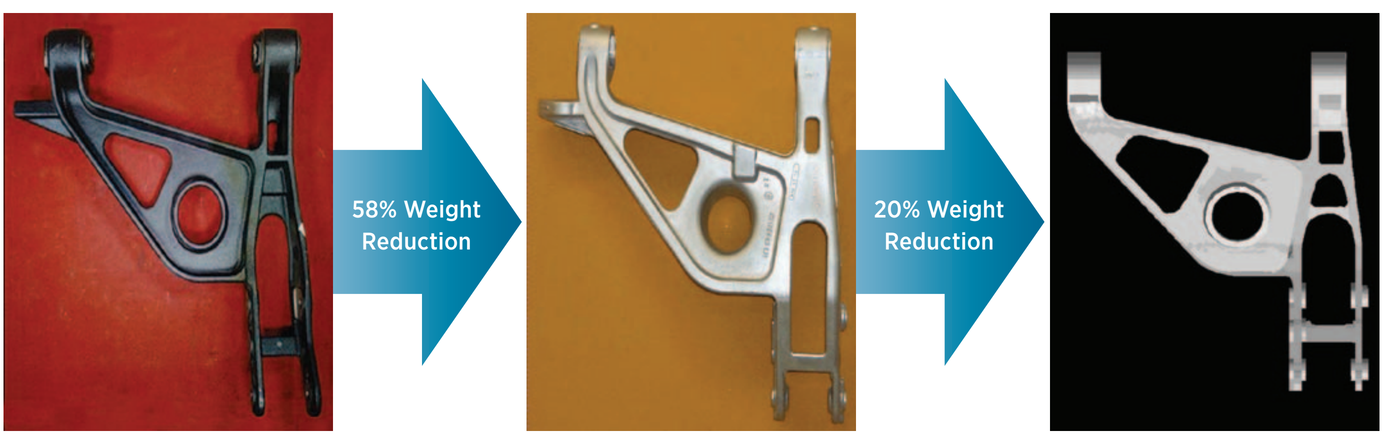
VTP collaborated with GM and Kaiser Aluminum to develop what would become GM's "Quick Plastic Forming" process for manufacturing door components, lift gates, and various other components. GM's use of this process to replace steel with aluminum components has produced per-part weight reductions of 35%. In addition, a joint project between VTP and U.S. automakers overcame several barriers to the introduction of lightweight magnesium components, resulting in a magnesium engine cradle for the Chevy Corvette Z06 that is nearly 60% lighter than a steel cradle and 35% lighter than an aluminum cradle.

Ultra-low sulfur diesel fueling pump label. Courtesy of American Petroleum Institute

Developed Materials Required for Clean Diesel Engines

As detailed above, VTP research led to the commercial introduction of ULSD in 2006. ULSD enables the use of the advanced aftertreatment devices that cut emissions from high-efficiency "clean diesel" vehicles, but its reduced lubricity creates reliability concerns for some fuel-system components. To address these concerns, VTP coordinated development of improved zirconia-ceramic fuel injector components, which resist the wear ULSD causes on injectors made of traditional materials. Cummins, an engine manufacturer and project partner, subsequently introduced zirconia-based timing, metering, and pumping plungers in the fuel injectors of its mid-range diesel engines.

Example of weight reduction through component design optimized for lightweight materials. Three photos courtesy of U.S. Department of Energy



Original Design - Iron
16 lb

Original Design - Aluminum
6.7 lb

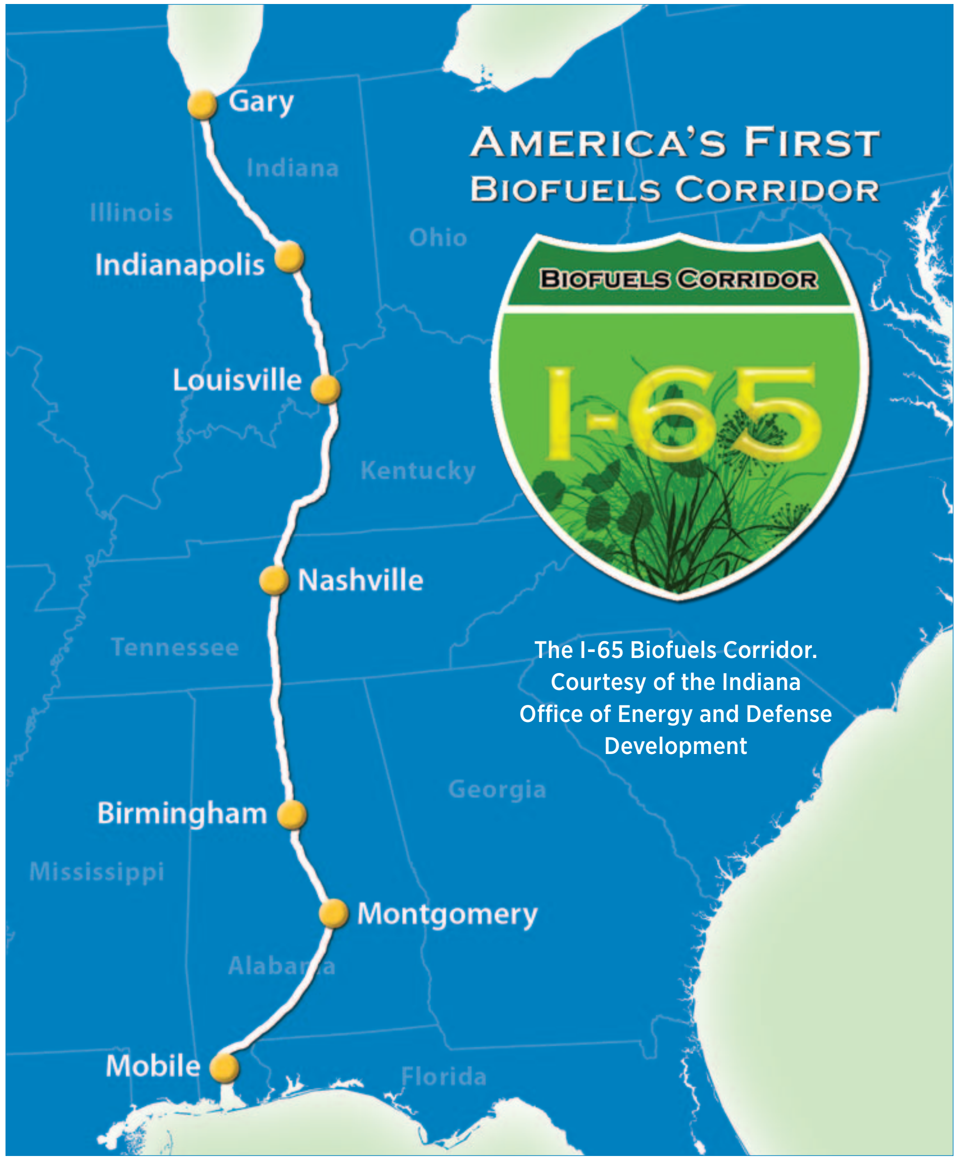
Optimized Design - Aluminum
5.4 lb

Outreach, Deployment, and Analysis

VTP complements its R&D with outreach, deployment, and analysis that accelerate the adoption and use of alternative fuels and advanced vehicles. Many of these efforts are part of VTP's Clean Cities program. Clean Cities partners with state and local organizations in the public and private sectors to reduce petroleum use through three strategies:

1. Replace petroleum with alternative and renewable fuels.
2. Reduce petroleum consumption by promoting smarter driving practices, idle reduction, and the use of more fuel-efficient vehicles and advanced technologies.
3. Eliminate petroleum use by encouraging the use of mass transit, trip elimination measures, and congestion mitigation.

Clean Cities' overall goal is to reduce U.S. petroleum use by 2.5 billion gallons per year by 2020. Below are some of VTP's top Clean Cities accomplishments, as well as a description of VTP's work to train the next generation of advanced transportation experts.



The I-65 Biofuels Corridor. Courtesy of the Indiana Office of Energy and Defense Development

Displaced Nearly 3 Billion Gallons of Petroleum

Clean Cities coalitions have reduced petroleum consumption by nearly 3 billion gasoline gallon equivalents (GGE) since 1993 through local efforts like helping school districts run buses on biodiesel, working with truckers to install idle reduction equipment, and facilitating the adoption of alternative fuels by private and government fleets. Clean Cities efforts were responsible for more than 700,000 of the AFVs on the country's roads in 2009.

Created Alternative Fuel Corridors

Clean Cities helps place alternative fueling stations along major interstate corridors. Today's longest corridor keeps flexible fuel vehicle drivers always within one-quarter tank of an E85 (85% ethanol, 15% gasoline) station while traveling from the Great Lakes to the Gulf Coast along I-65. Other E85 corridors include the I-5 corridor in Oregon; the New York State Thruway; roads from Penn State University to Philadelphia; and the I-95/I-64 Crescent Corridor, in Maryland, Washington, D.C., and Virginia. Clean Cities has also helped California, Utah, and New York establish numerous natural gas stations along heavily traveled routes.

Brought the Fuel Economy Guide to Millions of Car Buyers

The Clean Cities/EPA *Fuel Economy Guide* and its companion Web site *www.fueleconomy.gov* help consumers purchase efficient cars and result in substantial petroleum displacement—saving an estimated 131 million gallons in 2009 alone. In a user-friendly format, the guide provides fuel economy and emissions ratings, energy impact scores, and carbon footprint information for all vehicles back to model year 1985, plus user-provided fuel economy statistics, calculators, and additional consumer tools. It also can be accessed from mobile phones and other handheld electronic devices.

Spearheaded a Major Increase in Alternative Fuel Transit Buses

For more than a decade, Clean Cities has helped deploy alternative fuel use in transit applications with great success. In 1996, only 4% of U.S. transit buses used alternative power. By 2008, nearly 30% used alternative power, mostly compressed or liquefied natural gas. Clean Cities coalitions brought more than half these alternative fuel and advanced buses to U.S. roads. The Natural Gas

One type of alternative fuel transit bus promoted by Clean Cities. Credit: Leslie Eudy

Transit Users Group, led by Clean Cities, provides assistance to transit agencies that are considering or already operating natural gas buses.

Students learning about advanced vehicle technologies as part of the EcoCAR engineering competition. Courtesy of EcoCAR

Trained the Next Generation of Engineers

VTP's university-based activities develop a workforce of talented, trained individuals to help build the future U.S. automotive industry. Through the Graduate Automotive Technology Education activity, VTP funds eight universities to support graduate fellowships and establish or enhance coursework toward graduate engineering degrees that focus on a critical automotive technology. Student competitions—sponsored by VTP with government, industry, and academic partners—have given more than 16,000 students hands-on experience in tackling advanced vehicle challenges. More than 1,000 student competitors have gone on to automotive-related careers in government, academia, and industry.

More Information

For more information about the Vehicle Technologies Program, contact Drew Ronneberg at *Drew.Ronneberg@ee.doe.gov*

Vehicle Technologies for a Better Future

In an advanced vehicle, each component is designed and optimized for superior individual performance. These components are then integrated in a way that maximizes the entire vehicle's performance. The same paradigm holds true for DOE's VTP. Each VTP subprogram focuses on specific goals, and the individual achievements are integrated to maximize the speed and scope of VTP's advanced transportation progress.

For example, a new battery technology enables the development of advanced electric-drive vehicles, which are designed and tested with powerful modeling tools, manufactured with government support, and deployed with the help of Clean Cities coalitions. Another R&D effort leads to the introduction of clean diesel passenger vehicles, another provides the ULSD needed to run them, and yet another creates engine materials that are more compatible with ULSD. These are just two of the many examples of VTP's successful integrated approach.

VTP activities range in scale from atoms to Class 8 tractor-trailers, and in maturity from exploratory concepts to the automobile dealership floor. Partners from industry, academia, national laboratories, and government lend their support. This integrated, collaborative strategy builds U.S. leadership in science and engineering while laying the necessary foundation of technologies—and domestic technology manufacturers—for advanced transportation that will strengthen the nation's economic and environmental prosperity.

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