

# Technology Brief

## Keeping the Heat on Cold-Start Emissions

### NREL's Insulated Catalytic Converter Slashes Automotive Air Pollution

The catalytic converter on your car does a great job of eliminating hydrocarbons and other pollutants—once it is hot. But its effectiveness is greatly limited for the first minute or two that it takes to reach its operating temperature of about 300°C. Between 60% and 80% of the toxic air emissions from automobiles occur during this "cold-start" period. NREL researchers and catalytic converter

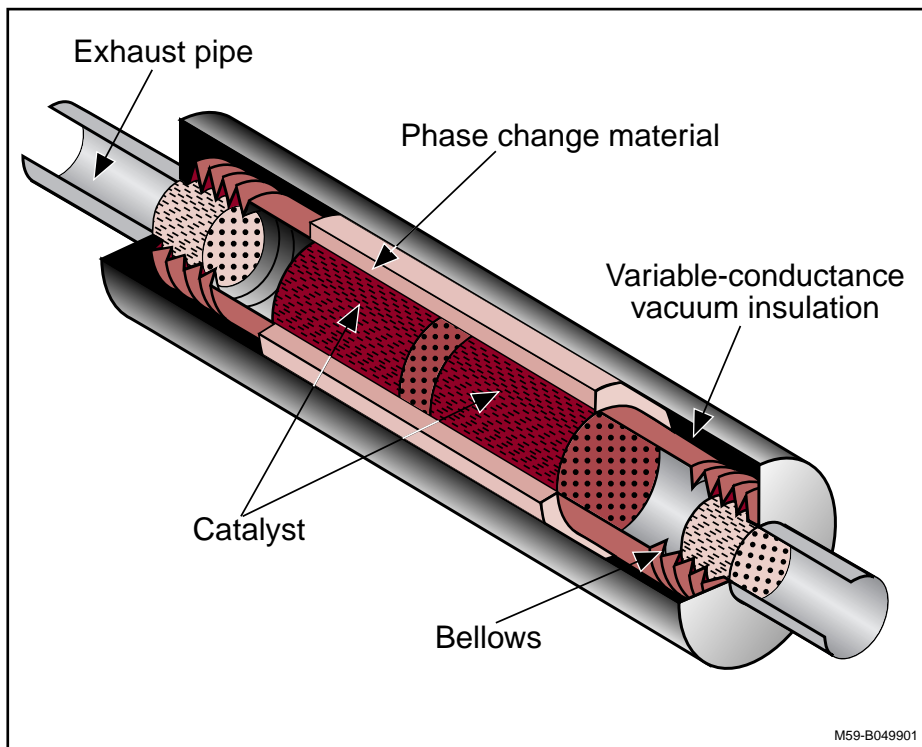
manufacturer Benteler Industries, Inc., however, have solved the problem of cold-start emissions with a unique passive system that keeps the converter hot from one automotive trip to the next.

Recently recognized by the prestigious *DISCOVER Magazine Awards* for Technological Innovation, the NREL-developed and patented

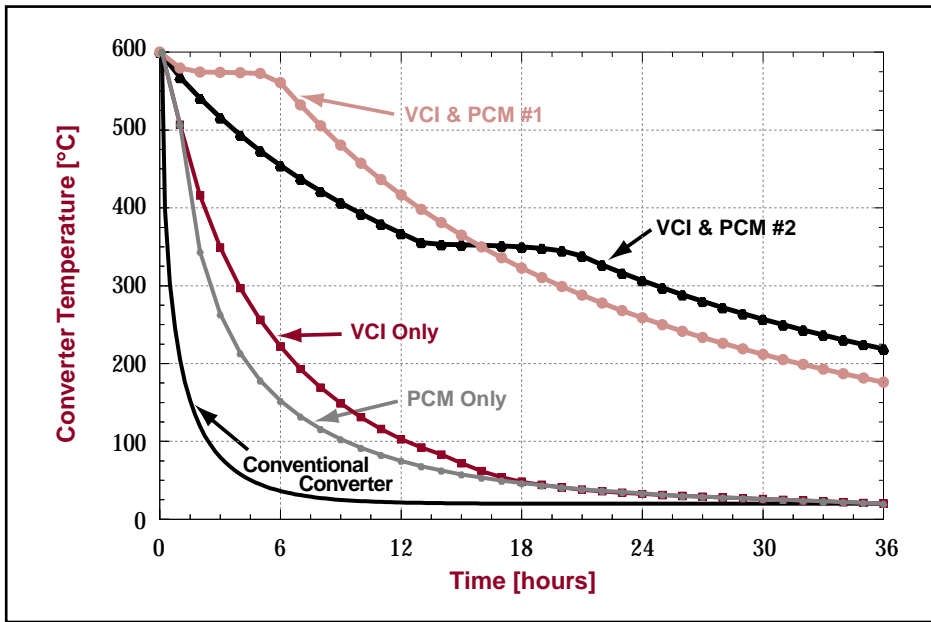
variable-conductance-insulation (VCI) catalytic converter stays hot enough to be immediately effective for the next trip 98% of the time. Standard testing showed that the VCI converter also reduces toxic emissions during operation to dramatically reduce automotive pollution. Total hydrocarbon emissions were reduced by 84% and total carbon monoxide emissions by 91%. Even greater emission reductions were obtained with an ethanol-fueled (85% ethanol/15% gasoline) vehicle.

Under a cooperative research and development agreement and license with NREL, Benteler Industries, Inc., of Grand Rapids, Michigan, is commercializing VCI technology for catalytic converters for automotive use. This innovative technology may be part of your next car—and we may all breathe easier because of it. The NREL/Benteler converter easily meets the California hydrocarbon standard for ultra-low-emission vehicles (ULEVs)—a major challenge for automakers. In fact, using ethanol, the VCI converter beats the ULEV standards so handily that it would likely meet revised "equivalent-zero-emission-vehicle" standards that California is now considering.

NREL researchers combined three technological innovations to solve the problem of cold-start emissions: highly effective compact vacuum insulation to hold in the heat;



This cut-away drawing of the VCI catalytic converter shows the vacuum insulation, phase change material, and bellows that make possible its extraordinary heat retention. The variable insulation automatically "turns off" above a certain temperature, allowing the converter to shed heat and keep from getting too hot.



The combination of variable-conductance insulation (VCI) and phase-change material (PCM) allows the VCI converter to remain at operating temperature for a full 24 hours after the engine is turned off. This makes the catalyst effective immediately for the next trip, solving the problem of cold-start emissions. Note how different PCMs "plateau" at different temperature allowing for optimal designs for different converters.

phase-change material (PCM) to absorb, store, and then release the heat when needed; and variable-conductance insulation that prevents overheating by automatically "turning off" the insulation whenever necessary.

### Compact Vacuum Insulation

The remarkable heat-retention capability of the NREL converter technology starts with compact vacuum insulation, a previous NREL invention that produces highly effective insulation by permanently sealing a vacuum between two layers of metal. Layers of copper foil within the vacuum block radiant heat loss. Compact vacuum insulation provides insulating values as high as R-100<sup>1</sup> per inch of insulation (even simple designs with inexpensive materials provide R-25 to R-40 per inch), making it an exceptional material for refrigerators, freezers, high-temperature batteries, or any application that needs effective insulation in a limited space.

A shell of one-half-inch-thick (13-mm) compact vacuum insulation provides

the insulation needed for the VCI converter without substantially increasing converter size. Combined with bellows and porous ceramic endshields to prevent heat loss at the inlet and outlet, the converter loses only one-tenth as much heat as a conventional converter.

Most converters reach full effectiveness between 250°C and 350°C and are typically operating at about 600°C at the end of a trip. Conventional converters then cool from 600°C to 300°C in less than 30 minutes. After 24 hours, the VCI converter will not yet have dropped below 300°C. This is 48 times as long as a conventional converter—long enough to cover the period between trips 98% of the time, according to a recent study by the U.S. Environmental Protection Agency. When the car is started again, the converter is already hot and effective in controlling emissions.

### Phase-Change Heat Storage

A second component of the VCI converter technology is the use of PCMs for heat storage. All materials

release heat when they solidify (freeze) and absorb heat when they melt. PCMs such as metal alloys and eutectic salt mixtures, however, store very large amounts of heat. The VCI converter has a layer of approximately one-half inch (13 mm) of PCM between the catalytic converter and the vacuum insulation shell. While the engine and converter are running hot, the PCM melts, absorbing and storing large amounts of heat. After the engine is turned off and the converter starts to cool, the PCM solidifies, releasing that heat.

The PCM—selected to be compatible with the converter operating temperature—also helps keep the converter at a more uniform temperature during operation. This reduces the stress on the converter and may provide the added benefit of extending its service lifetime.

### Variable Conductance Insulation

With insulation good enough to keep the converter temperature greater than 300°C for 24 hours after the engine is turned off, what keeps the converter from overheating while the engine is running at high speed? NREL has answered this challenge with a third innovation—variable-conductance insulation. Certain compounds of hydrogen and metals release their hydrogen above a particular temperature and then reabsorb hydrogen below that temperature. Because hydrogen gas is a good heat conductor, releasing it into a vacuum "turns off" the insulation provided by the vacuum. The VCI catalytic converter has a small amount of metal hydride within the vacuum envelope. As the converter approaches its maximum safe temperature (about 900°C), the hydride releases its hydrogen, allowing excess heat to escape. As the converter cools back down, it reabsorbs the hydrogen, thus reestablishing the vacuum.

<sup>1</sup> English unit "R" Values: R-100 = 100 ft<sup>2</sup> hr °F/Btu = 17.6 m<sup>2</sup> K/W

## Meeting Automotive Industry Needs

Faced with increasingly strict emission standards, automakers have investigated a variety of approaches to reduce cold-start emissions. Efforts to heat the converter with electric resistance heaters, separate gasoline burners, or combustion of purposely over-rich exhaust gases have encountered difficulties, including cost, complexity, and durability. The automotive industry consensus seems to be that active systems such as these would be used only where passive systems were insufficient.

One passive system for heating the converter more quickly—placing it closer to the engine—is being adopted by several manufacturers. However, this offers only a partial solution because it reduces the cold-start period but does not eliminate it. "Close-coupled" systems such as this also pose significant overheating concerns both for the catalyst and for other vehicle components. Most of them will also require engine improvements or other measures to meet the more stringent emission standards.

The VCI converter is unique in that it provides a durable, easily incorporated system that surpasses the performance of any active system, without the added cost and complexity of active systems. Use of the VCI converter alone would allow automobile manufacturers to meet the emission standards they now face, including the challenging California ULEV standards for hydrocarbons. This also means that consumers will pay less and changes affecting vehicle performance will be avoided (when compared to other ways to meet emission standards).

## Cleaner Air, Now and in the Future

The NREL/Benteler VCI catalytic converter provides an easy, low-cost way for automobile manufacturers to reduce air pollution. As the table below shows, use of the VCI catalytic converter reduced levels of carbon monoxide and hydrocarbon emissions from a flexible-fueled (uses ethanol or gasoline) Ford to less than one-tenth and one-sixth, respectively, of the levels from a conventional converter.

Benteler Industries is currently developing the VCI converter for conventional automobile use, but the VCI converter can reduce air emissions for any vehicle or machinery with an internal combustion engine. It will be particularly useful in solving cold-start emission problems for alternative-vehicle technologies. Some alternative fuel vehicles will have cooler exhaust gas and many hybrid vehicle designs use the combustion engine intermittently.

This means that their engines will cycle on and off, and they could have numerous "cold starts" during the course of a trip—a potential pollution problem that the VCI converter can prevent.

Stored heat in excess of that needed by the catalytic converter could also be used for immediate heating of the passenger compartment—a side benefit that drivers in cold climates would greatly appreciate.

Internal combustion vehicles contribute between one-third and one-half of the carbon monoxide and hydrocarbon emissions in the United States. This contribution is even greater in most urban areas, where the most serious air quality problems are. With no sacrifice in vehicle performance or change in design, the NREL/Benteler VCI catalytic converter can eliminate at least half and perhaps even 80% to 90% of those emissions—a landmark contribution to public health.

### REGULATED EMISSIONS FROM A GASOLINE ENGINE Data in Grams of Pollutant Per Mile

	Conventional Converter	VCI Converter	ULEV Standards
<b>Nonmethane Hydrocarbons</b>	0.194	0.031	0.040*
<b>Carbon Monoxide</b>	1.463	0.131	1.700
<b>Oxides of Nitrogen</b>	0.135	0.066	0.200

VCI catalytic converter emissions from a flexible-fuel Ford Taurus compared to a conventional converter and to California standards for Ultra-Low-Emission Vehicles—tests conducted at the Southwest Research Institute using a federal test procedure cycle following a 24-hour cold-soak

\*The California standard is for reactivity-adjusted nonmethane organic compounds. The actual test was for nonmethane hydrocarbons (the federal standard), but the results clearly showed that the VCI converter would also meet the similar standard used by California.



NREL/Benteler prototype VCI catalytic converter mounted on a Ford Taurus for emissions tests at the Southwest Research Institute. After sitting cold for 24 hours, hydrocarbon emissions were 84% less and carbon monoxide emissions 91% less than with the car's conventional converter under a standard testing cycle.

## For More Information

General Information and other  
NREL Technology and  
Research Briefs:

Energy Efficiency and  
Renewable Energy  
Clearinghouse Hotline  
(800) 363-3732

Technical Information on this  
NREL Project:

Dave Benson, NREL  
(303) 384-6462

[bensond@tcplink.nrel.gov](mailto:bensond@tcplink.nrel.gov)

Steve Burch, NREL  
(303) 275-4392

[sburch@nrel.gov](mailto:sburch@nrel.gov)

John Biel

Benteler Industries, Inc.  
(616) 248-5536

NREL Business Information:

Center for Business Ventures  
(303) 275-3008  
[technology\\_transfer@nrel.gov](mailto:technology_transfer@nrel.gov)

## Patents and Publications

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The National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado 80401-3393, is a national laboratory of the U.S. Department of Energy (DOE), managed for DOE by Midwest Research Institute

Produced by the Communications Center for the Center for Business Ventures and the Center for Transportation Technologies and Systems  
NREL/MK-336-21116 5/96



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