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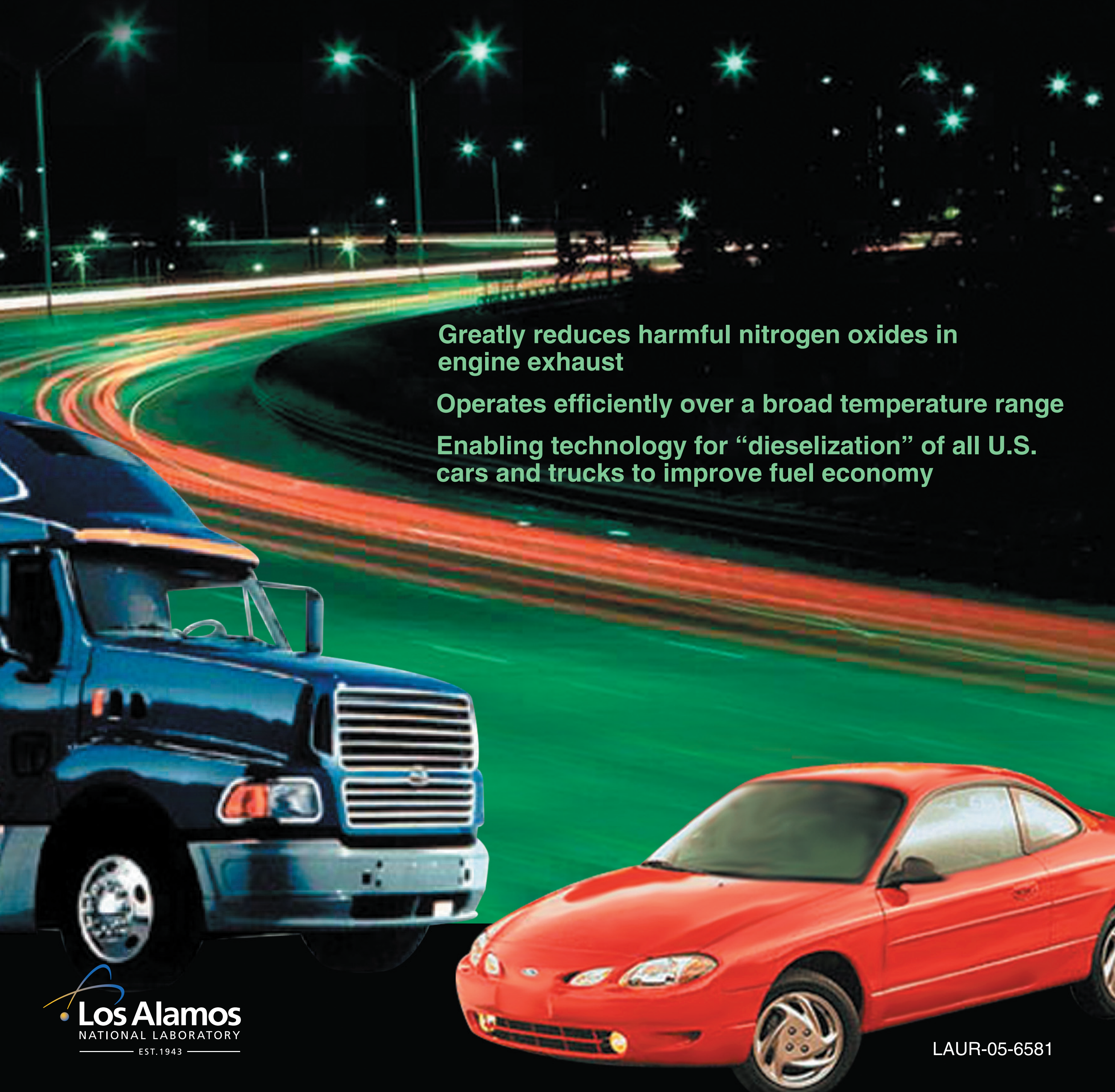
NO$_x$ HyCat

A New Catalytic System for Diesel Engines



- Greatly reduces harmful nitrogen oxides in engine exhaust
- Operates efficiently over a broad temperature range
- Enabling technology for “dieselization” of all U.S. cars and trucks to improve fuel economy

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NO_x HyCat: A New Catalytic System for Diesel Engines

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ABOUT THE COVER

The streaming headlights on a nighttime freeway, symbolic of the traffic carried day and night by U.S. roads, form the background for a heavy truck and a small passenger car. Those vehicles represent the two ends of the automotive spectrum that could benefit from an efficient catalytic system that reduces harmful nitrogen oxide (NO_x) emissions in diesel-engine exhaust. The NO_x HyCat is a catalytic NO_x-reduction system designed for diesel and other lean-burn engines. It can be used in 18-wheelers, which are already diesel powered but have no NO_x controls, and in light trucks, vans, SUVs, and passenger cars. The NO_x HyCat could allow "dieselization" of all U.S. cars and trucks, enabling substantial energy savings.

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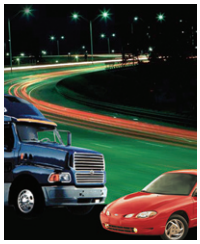


Executive Summary

NO_x HyCat: A New Catalytic System for Diesel Engines

Features

No catalytic system has yet been commercialized that can eliminate nitrogen oxides (NO_x) from the exhaust of vehicles powered by diesel and other lean-burn engines. The problem is temperature: a successful system must operate over the full range of temperatures found in vehicle exhaust: 150°C to more than 500°C, the low temperatures being the most problematic. Our NO_x HyCat is the first catalytic system to span that temperature range. The system includes a brand-new iron-containing zeolite catalyst that is augmented with cerium-manganese oxide, an oxidizer that produces a near-optimum ratio of NO_x components to speed up the catalytic reaction and enable the zeolite to operate efficiently as a low-temperature catalyst. We combine this new low-temperature catalyst with a conventional high-temperature catalyst in a “dual-bed” configuration that provides high rates of NO_x conversion over the broadest temperature range ever achieved.

Applications

The NO_x HyCat is the first NO_x-reduction system for diesel engines that can be used in vehicles:

- sedans,
- vans,
- SUVs,
- light and heavy trucks, and even
- locomotives.

Benefits

- Enables “dieselization” of U.S. vehicles to benefit from diesel’s 25% to 35% mpg advantage over gasoline engines.
- Allows diesel-powered vehicles to meet increasingly stringent EPA standards for the reduction of NO_x emissions.
- Operates efficiently from 113°C to as high as 600°C.
- Converts from 83% to greater than 98% of NO_x, depending on temperature.
- Includes no expensive precious metals and requires no complex engine controls.
- Is compatible with existing manufacturing techniques.

Overview

The thermal efficiency of diesel engines allows diesel-powered vehicles to get 25%–35% more miles per gallon than their gasoline-powered counterparts, so in Europe, where the price of fuel is high, diesel-powered cars are common. In the United States, however, diesel-powered vehicles are found mostly in the trucking industry. In fact, essentially all heavy trucks are powered by diesel. If more U.S. vehicles were diesel powered, the increased fuel economy could cut U.S. oil imports by as much as 25%.

But diesel has a significant pollution problem—particulates, for which filters are already available, and nitrogen oxides, which remain an unresolved issue. Collectively known as NO_x, nitrogen oxides are a common byproduct of internal combustion engines. Because NO_x contributes to smog, ground-level ozone, and acid rain, many nations are gradually strengthening their regulations about NO_x emissions. In the United States, the Environmental Protection Agency, through Clean Air Act amendments being phased in through 2007, will prohibit cars, SUVs, and light trucks (gasoline and diesel) from emitting more than 0.07 gram of NO_x per mile. That amounts to a greater-than-90% tightening of the NO_x belt for light diesel engines, which currently release about 1 gram of NO_x per mile. Similar NO_x reduction will be required of the heavy diesel engines used in the 18-wheelers that carry consumer goods across the country.

Unfortunately, there are no catalytic NO_x converters for diesel engines in vehicles. The catalytic converters for gasoline-powered vehicles require low-oxygen exhaust and so cannot be used with diesel engines. Gasoline-powered engines use just enough oxygen to burn the fuel (a stoichiometric ratio), resulting in little if any oxygen in the exhaust. Diesel engines are "lean-burn" engines; that is, they use a lean fuel-to-oxygen mixture and so have an oxygen-rich exhaust.

Lean-burn NO_x-abatement systems *do* exist but only for stationary applications—for power-plant emissions and for diesel engines that run equipment such as pipeline compressors or electric generators or that do load leveling for the generation of electricity during peak-use hours. These systems cannot be used in vehicles because their catalysts are not active enough over the full range of vehicular engine temperatures: 150°C during warm-up to more than 500°C during high-load excursions (e.g., high speeds, steep grades, heavy cargo loads). Some catalysts operate efficiently only above 350°C; others operate at as low as 290°C but because of thermal-stability problems cannot operate near 500°C.

NO_x HyCat was developed specifically for vehicles with lean-burn engines and can fulfill the most stringent NO_x-abatement requirements. It links a brand-new *hybrid* catalyst with another, already-existing catalyst in a "dual-bed" configuration that provides efficient NO_x abatement over the broadest temperature range so far: 113°C to more than 500°C.

NO_x HyCat uses the same chemical process that is used for NO_x abatement in stationary diesel engines—selective catalytic reduction (SCR). SCR mixes NO_x with an ammonia source (most likely, urea) and passes the mixture through a catalyst, where an ammonia-NO_x reaction converts the NO_x to nitrogen and water. The highest rates of SCR occur with a 1:1 ratio of nitric oxide and nitrogen dioxide, but NO_x from vehicles has approximately a 9:1 ratio of those oxides. Lowering the ratio requires oxidizing some of the nitric oxide to nitrogen dioxide, which is particularly difficult to do at low temperatures. We achieve ratios close to the optimum 1:1, even at low temperatures, with a new catalyst design—an iron-containing zeolite that is augmented with a cerium-manganese oxide. The iron converts the NO_x during the SCR process; the cerium-manganese oxide oxidizes about 50% of the nitric oxide to nitrogen dioxide, enabling a faster rate of SCR. (The exact oxidation percentage depends on engine exhaust temperature.) It is this dual functionality—NO_x conversion *and* oxidation—that makes the new design a *hybrid* SCR catalyst (see Fig. 1).

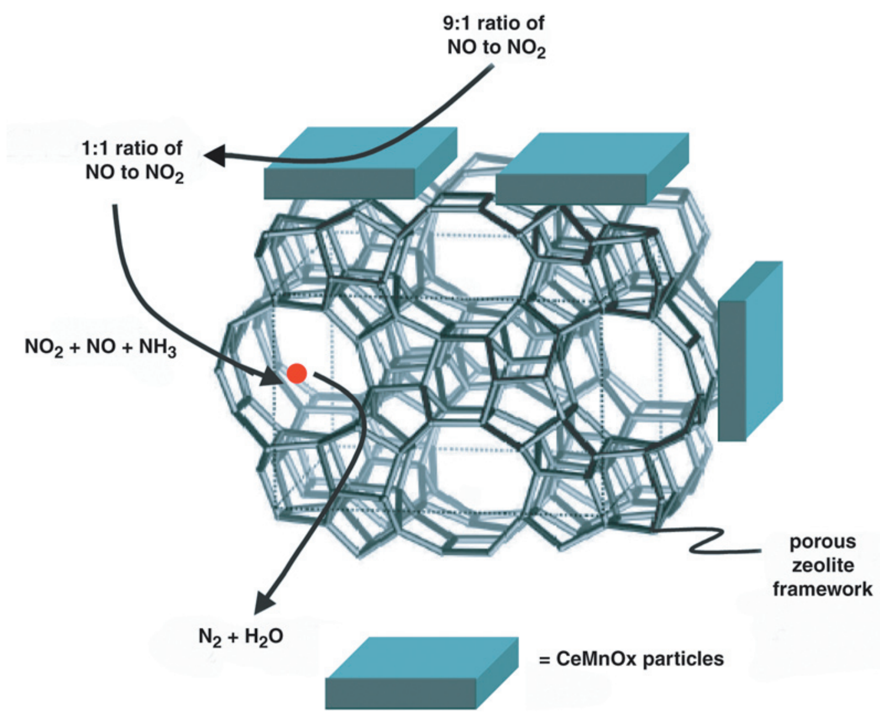


Figure 1. A representative portion (about one-thousandth) of the zeolite crystallite found in our new hybrid catalyst. At low temperatures, cerium-manganese oxide particles adhering to the exterior of the crystallite efficiently oxidize enough nitric oxide to nitrogen dioxide to produce an NO:NO_2 ratio as close to 1:1 as temperatures allow. The nitric oxide and nitrogen dioxide mix with ammonia, and that mixture diffuses through the porous zeolite's framework, where the ammonia in the mixture causes a reductive chemical reaction at the iron sites (represented here by a single red dot) in the catalyst. The reaction with iron converts NO_x mixed with ammonia to nitrogen and water.

Our new hybrid converts from 80% to more than 98% of the NO_x at engine temperatures ranging from 113°C to 350°C. Above 350°C, however, it becomes so active that it oxidizes the urea-produced ammonia along with the nitric oxide, thus eliminating the reductant needed for NO_x conversion. To counter this effect, the NO_x HyCat has a "dual-bed" configuration in which the new hybrid catalyst works in tandem with a second catalyst that we position just upstream (see Fig. 2). The upstream catalyst is a *conventional* iron-containing zeolite SCR catalyst, that is, one without the cerium-manganese oxide. It operates efficiently above 350°C but is fairly inactive below that temperature, for example, when the engine is warming up or running under low-load conditions. In the dual-bed configuration, the NO_x-containing exhaust gas and ammonia pass relatively unchanged through the upstream catalyst at low temperatures to be converted efficiently by the hybrid catalyst. As the engine's temperature rises above 350°C, the upstream catalyst becomes active, converting nearly all of the NO_x before the exhaust reaches the hybrid. In both cases, the resultant nitrogen and water (in the form of steam) are released as exhaust. This tandem system, the NO_x HyCat, provides unprecedented NO_x reduction—a maximum of more than 98%—spanning a temperature range never before possible (see Fig. 3, p. 8).

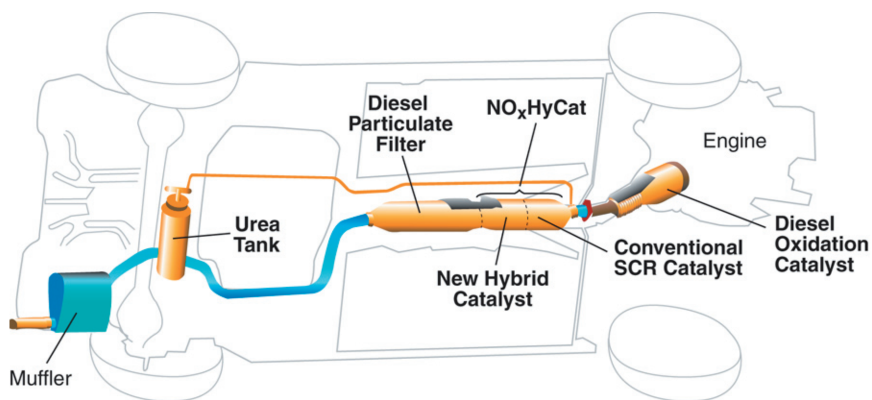
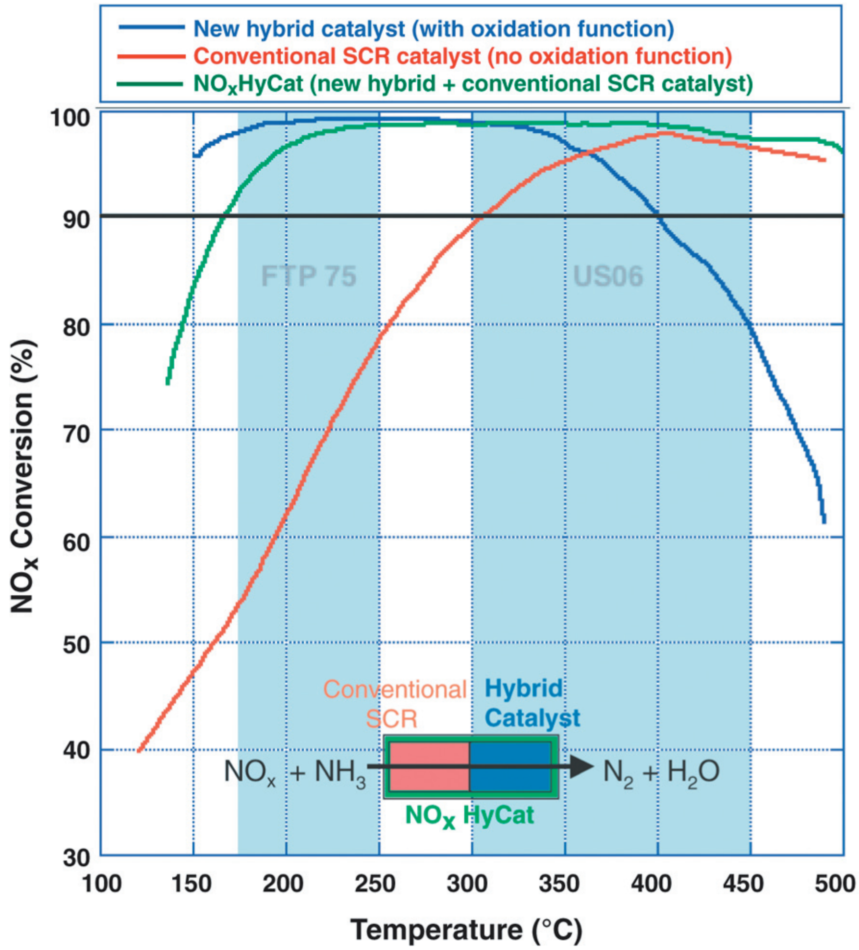


Figure 2. An artist's rendition of the NO_x HyCat dual-bed configuration in a car's undercarriage, interacting with the rest of the emissions-control system. The blue line represents the path taken by engine exhaust. NO_x in the exhaust, mixed with ammonia from an onboard urea supply (between the back wheels), first contacts the portion of the NO_x HyCat that is a conventional SCR catalyst (right, upstream). When the exhaust is at 350°C and above, the conventional catalyst—a *high-temperature* catalyst—converts the NO_x before it reaches the NO_x HyCat's downstream section occupied by our new hybrid catalyst—a *low-temperature* catalyst. At exhaust temperatures below 350°C, the conventional SCR catalyst is relatively inactive, so the exhaust passes through it relatively unchanged and is converted by the hybrid. The diesel oxidation catalyst—upstream from the catalytic system, just behind the engine—oxidizes unburned and partly burned hydrocarbons to carbon dioxide. The filter downstream from the NO_x HyCat captures particulates.

Figure 3. Used separately, our new hybrid catalyst (blue) provides very efficient NO_x conversion at low temperatures as compared with a conventional SCR catalyst (red). The full NO_x HyCat (green) reduces NO_x over the broadest temperature range because it combines the new hybrid with a conventional catalyst (inset). In fact, during the tests, we obtained single data points (not given here) showing that the NO_x HyCat performed effectively at as low as 113°C and as high as 600°C.

The conventional SCR catalyst's NO_x conversion rate shown here is similar to that of the best currently available technology. The shaded regions of the plot indicate temperature ranges for the two drive cycles used in emissions testing and certification: FTP 75 for stop-and-go urban driving and US06 for extended high-speed freeway or long-distance driving. The heavy black line at 90% marks the efficiency required for a system to pass future EPA emissions tests.



By deliberately coupling a highly active oxidation material—the cerium-manganese oxide—with an SCR catalyst to create a hybrid for low-temperature conversion and then coupling that hybrid with a conventional SCR catalyst for high-temperature conversion, we have created a composite system with none of the engine-temperature limitations inherent in other lean-burn NO_x-conversion systems. The NO_x HyCat could therefore be the answer to one of the most-important engineering challenges—NO_x-emission control—that must be met if diesels are to play a greater role in the U.S. automotive industry and in improving U.S. energy efficiency.

To learn how we designed our new hybrid catalyst, see "Strategy for Discovering a New Catalyst" in the Appendix.

Competition

Like the NO_x HyCat, the competing technologies named here are for lean-burn engines and are being developed to meet future EPA emissions requirements.

Conventional SCR Catalytic Systems. All SCR systems reduce NO_x to nitrogen and water through the use of ammonia as the reductant. Common systems in use today for the emissions from power plants are manufactured by Engelhard (a zeolite-based SCR catalyst, ZNX, and a vanadium-based SCR catalyst, VNX), Argillon (the $SINO_x$ emissions control catalysts), and Johnson Matthey Catalysts (various SCR catalysts). We have chosen the Engelhard ZNX catalyst for the comparison matrix because it is representative of this class of catalyst. Engelhard's VNX catalyst is inappropriate for vehicular applications because it cannot convert enough NO_x and contains a volatile vanadium component that evaporates at the upper end of the temperature range.

Lean-NO_x Trap (LNT). Not yet commercially available, the LNT is being developed by several companies that make catalytic systems for environmentally hazardous emissions, for example, Delphi (Delphi Diesel NO_x Trap). In place of the SCR process, the LNT relies on a three-way catalyst like the catalyst currently used with stoichiometric gasoline engines but modified with the addition of barium oxide to adsorb—"trap"—NO_x from lean-burn engine exhaust. In fact, at low temperatures, the LNT traps only the nitrogen dioxide portion of NO_x; the nitric oxide is not trapped and passes through the catalyst. At around 250°C, the LNT begins to efficiently oxidize nitric oxide to nitrogen dioxide, improving the overall efficiency of the LNT. When the trap is saturated, it is regenerated with 1–2 seconds of "rich" engine operation in which extra fuel is burned, resulting in low or no oxygen in the exhaust, and the nitrogen dioxide is reduced by the three-way catalyst, producing nitrogen, water, and carbon dioxide. After regeneration, the engine is returned to lean-burn operation.

Lean-NO_x Catalyst (LNC). The LNC operates similarly to the SCR catalyst but uses a different NO_x reductant: a mix of unburned hydrocarbons from the fuel tank injected into the exhaust stream just upstream from the LNC. The hydrocarbons are slowly converted on the catalyst into other chemical species that reduce nitric oxide and nitrogen dioxide to nitrogen, water, and carbon dioxide. The exact chemical pathways and species involved are still unknown. Academic researchers, several companies, and national laboratories are involved in research to discover useful LNCs.

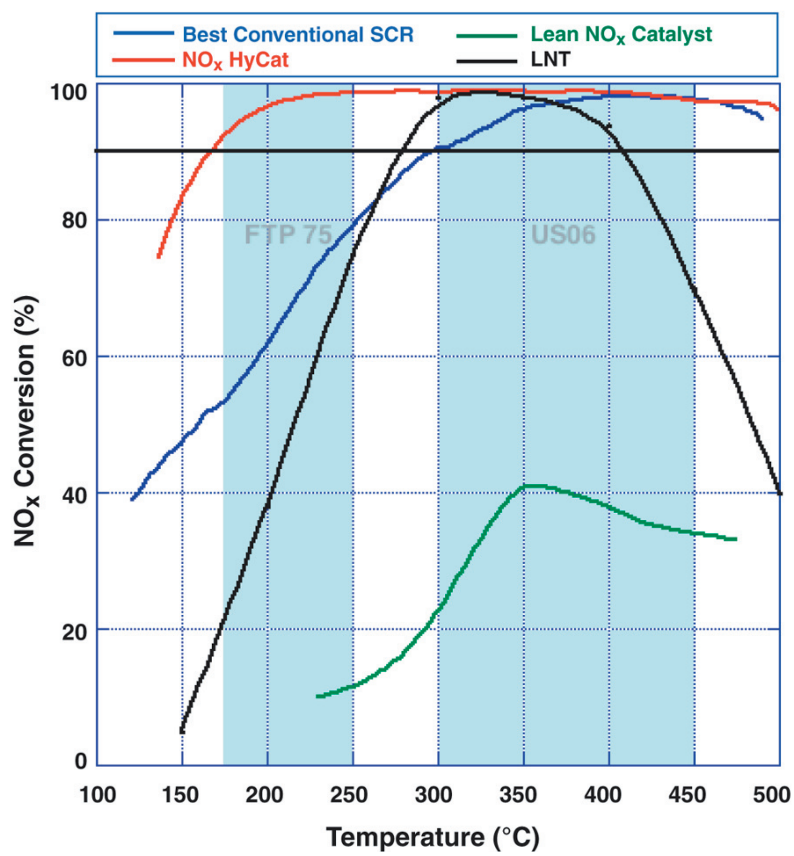
Comparison matrix

Parameters	NO_x HyCat	Conventional SCR Catalysts	Lean NO_x Trap (LNT)	Lean NO_x Catalyst (LNC)	Comments
NO_x Conversion:					NO_x HyCat offers excellent activity at low, middle, and high temperatures. Its superiority is seen especially at the lower temperatures. The difficulty of converting NO_x at low temperatures has been the main stumbling block to providing efficient NO_x abatement in lean-burn vehicles. The NO_x HyCat provides it.
150°C–250°C	83% to >98%	45% to 80%	10% to 75%	10%	
250°C–350°C	>98%	80% to 95%	75% to >98%	10% to 40%	
350°C–500°C	>98% to 96%	95% to >98%	>98% to 40%	40% to 35%	
Catalyst Cost (estimated)					Conventional SCR catalysts usually contain only inexpensive base metals such as iron and manganese, as does the NO_x HyCat. LNTs contain a substantial amount of precious metal—platinum and rhodium—appreciably increasing their cost. Some LNCs also contain precious metals—platinum and palladium—but costs are still unknown as the technology is too far from practical application.
2-L engine	\$50	\$50	\$175	N/A	
6-L engine	\$150	\$150	\$560	N/A	
Fuel Consumption by Catalyst	0%	0%	5%–10%	4%–8%	Both LNTs and LNCs use hydrocarbons as the reductant and so burn a percentage of the fuel for the catalytic process itself. For the LNT, fuel usage increases during the few seconds in which the engine is switched to rich operation for releasing the adsorbed NO_2 (denitration) and removing the barium sulfate (desulfaction) that builds up on the catalyst. LNT fuel usage in a fleet of 1 million cars could add up to \$200 million a year in extra energy costs. Neither the NO_x HyCat and nor conventional SCR catalysts use fuel for the catalytic process; both use ammonia as the reductant.
Sulfur Tolerance	Good to excellent	Good to excellent	Poor, but improving	Good, depending on composition	LNTs are especially vulnerable to sulfur poisoning. Barium sulfate builds up on the catalyst—the result of sulfur in the fuel reacting with the barium oxide in the LNT. The built-up barium sulfate reduces the LNT's NO_x-trapping capacity, and the sulfate must be removed through a separate desulfation process at high temperatures (generated by burning additional fuel), which is deleterious to LNT lifetime.
Steam Tolerance	Good to excellent	Good to excellent	Good to excellent	Poor	For LNCs, there is a loss of activity in the presence of water because water out-competes NO_x for reaction sites on the catalyst. LNCs containing silver catalysts are less sensitive to water than are LNCs made of of cobalt or iron zeolites, but they still have a limited temperature range of useful operation.
Vulnerability to Hydrocarbon Poisoning	Only temporary	Below ~250°C	Below ~250°C	Below 350°C, depending on composition	The NO_x HyCat is self-cleaning. It oxidizes the hydrocarbon poisons rapidly when the operating temperature exceeds 225°C, so hydrocarbon poisoning is temporary. For LNCs, an injected mix of hydrocarbons serves as the NO_x reductant, so although some compositions—for example, LNCs composed of cobalt or silver zeolites—effectively oxidize hydrocarbons above 350°C, they burn up needed reductant if they are too efficient.

Advantages

Superior Activity (NO_x conversion rate) over a Broad Temperature Range. Depending on the type of vehicle (sedan, SUV, van, truck), drive cycle (startup to sustained driving), and driving conditions (steep grades, heavy cargo loads), engine exhaust can range from 150°C to more than 500°C. To be used in vehicles, a NO_x-reduction technology must maintain high activity over that entire temperature range.

The accompanying figure indicates the relative performance of the competing lean-burn NO_x-abatement technologies versus the NO_x HyCat. As shown in the figure, performance at lower temperatures is the most problematic, and that is because the rate of NO_x conversion is directly affected by the ratio of nitric oxide to nitrogen dioxide in the exhaust. If neither the catalyst itself nor a diesel-oxidation catalyst added to the system can oxidize enough of the exhaust's nitric oxide to nitrogen dioxide quickly enough at lower temperatures, NO_x conversion will lag. The NO_x HyCat solves this problem with its hybrid SCR catalyst, which has its own superior oxidation function by virtue of the cerium-manganese oxide on the exterior of the zeolite crystallite.



Data on the LNT and LNC were taken from published literature on those technologies. Data on the NO_x HyCat, in comparison with a conventional SCR catalyst, were taken in a laboratory setting, using synthetic automobile exhaust, as prescribed by the auto industry. For more information about the tests, see "Testing the NO_x HyCat" in the Appendix.

As a result, NO_x HyCat is the first catalytic system with low-temperature NO_x conversion for lean-burn engines. This is especially crucial for vehicle applications because a large fraction of emissions occur during cold start. Also, as diesel engines become more efficient, realizing lower exhaust temperatures, activity below 225°C will become even more important. In addition, the NO_x HyCat's dual-bed configuration adds a second, high-temperature SCR catalyst and so enables high-efficiency NO_x conversion over the full temperature range found in vehicles. None of the competing technologies achieves as broad a range of activity. The LNCs discovered to date lag particularly far behind, operating too slowly or over too narrow a temperature range—or both. (They are also highly sensitive to water in the exhaust.) LNC research is still ongoing, but only a significant breakthrough will make the LNC competitive.

Appropriate Size for Vehicles. Conventional SCR systems could get the same high conversion as the NO_x HyCat if the catalyst could be made very large. For stationary applications (handling emissions from power plants or from the engines powering backup generators), "large" is not a problem; it is a very big problem for vehicular applications. To be used in a vehicle, a catalytic system has to achieve the necessary activity in a small size, and the NO_x HyCat does just that. Its superior activity at all temperatures allows it to be small enough for all types of vehicles. No other SCR NO_x-reduction system can do that. LNTs may be a little bigger than the NO_x HyCat but not large enough to preclude their use in vehicles. However, other concerns—low-temperature activity, durability, fuel penalty, and cost—put them at a disadvantage when compared with the NO_x HyCat.

Highly Durable—Resistent to Hydrocardon Poisoning and Tolerant of Both Sulfur and Steam. Hydrocarbon poisoning of a catalyst occurs when unburned hydrocarbons block the catalyst's reaction sites or chemically alter those sites, reducing or diminishing their reactivity. For commercially available SCR catalysts, LNTs, and LNCs, the diesel-oxidation catalysts used in conjunction with them do not fully oxidize hydrocarbons at low temperatures, leaving the catalysts susceptible to hydrocarbon poisoning at those low temperatures. Although the NO_x HyCat will probably also be accompanied by a diesel oxidation catalyst, it does not succumb to hydrocarbon poisoning because the hybrid's cerium-manganese oxide component effectively oxidizes unburned hydrocarbons (along with nitric oxide), converting them to carbon dioxide and water. Unburned hydrocarbons may begin adhering to the catalyst but are quickly oxidized and dispatched. In fact, the hybrid's ability to oxidize hydrocarbons may obviate the need for the diesel-oxidation catalyst in a NO_x HyCat-based SCR system.

The LNT is sensitive to sulfur in the fuel, which builds up on the trap as barium sulfate, reducing its storage capacity, and must be burned off (desulfated) at high temperatures. High-temperature desulfation shortens the LNT's lifetime. Steam (the water that results from combustion in the engine) causes a loss of activity in LNCs. The NO_x HyCat is tolerant of both sulfur and steam because its components do not react deleteriously with sulfur in the exhaust to form stable sulfates, as happens in the LNT. Water in the exhaust also does not interfere with the its NO_x reaction pathways, as it does with many LNCs. In addition, the NO_x HyCat provides a bonus: at higher temperatures, it converts any excess ammonia to nitrogen and water and is therefore potentially useful as a catalyst for preventing ammonia from slipping into the atmosphere from a vehicle's exhaust system. The EPA is concerned about "ammonia slip."

Compatible with Existing Manufacturing Techniques. The common way of producing an SCR catalyst is to deposit the catalytically active metal ions on a support structure, usually through aqueous-solution techniques. Our HyCat can be supported on the same ceramic honeycomb structures already in commercial use for other catalysts and may also be supported on other common structures (metal honeycombs, for example). Our hybrid catalyst can be deposited on a support structure, using an aqueous solution. Its compatibility with existing deposition techniques will keep manufacturing costs in line with current catalyst-production costs. And material costs are low because the NO_x HyCat uses only inexpensive base metals, cerium, and zeolite.

Cost-Effective. Both the LNT and the LNC use hydrocarbons (a percentage of the fuel) as the reductant for catalysis. By burning extra fuel, they lower fuel economy and raise vehicle operating costs. In addition, the LNT's cycle of lean burn to rich burn and back again requires complex—and expensive—engine controls. The LNT also includes the precious metals platinum and rhodium as the catalytically active materials, making the LNT an expensive technology. Assuming a fleet of 1 million new diesel vehicles of various engine displacements each year (about 10% of the U.S. market), Ford has estimated that LNTs could result in an annual fleet cost of over $400 million dollars in precious metals alone. Some LNCs will also include expensive precious metals.

The NO_x HyCat, like conventional SCR catalysts, is cost-effective because it uses no expensive diesel fuel for catalysis, contains no expensive precious metals, and requires no complex engine controls.

Primary applications

The NO_x HyCat is primarily for NO_x abatement with lean-burn engines in vehicles—sedans, vans, SUVs, light- and heavy-duty trucks, and even locomotives. It is the only SCR catalytic system appropriate for these vehicular applications and the leading candidate among all competitors, based on overall performance, durability, and cost.

Our hybrid SCR catalyst may also be separated from the full NO_x HyCat and used alone—a "single-bed" configuration. Used alone, the hybrid catalyst achieves the following NO_x-conversion activity: 92% to >98% at 150°C to 250°C, >98% to 95% at 250°C to 350°C, and 95% to 70% at 350°C to >500°C. Although its activity begins to fall off at high temperatures, the hybrid can be used for applications in which low-temperature activity is crucial but high-temperature (>350°C) operation is not as relevant. This might be the case for small diesel-powered automobiles designed for urban, low-speed use, for which the exhaust temperatures stay lower.

Other applications

The NO_x HyCat dual-bed configuration is also appropriate for stationary applications, controlling NO_x emissions from the following:

- Electric power plants (used on the stacks or on generators)
- Large, megawatt-scale diesel engines for backup power
- Large diesel engines for remote power generation (e.g., for pipeline compressors)

Summary

Decades of research worldwide have gone into developing a NO_x-emission-control catalyst for lean-burn engines. In addition to the obvious benefit of substantially reducing the emissions from existing lean-burn engines, such as diesel engines, implementation of NO_x HyCat technology can lead to large potential energy savings for the United States. Lean-burn engines are at least 30% more efficient than conventional gasoline engines. There are currently no commercial lean-burn NO_x-emission control systems for vehicles, so the large potential energy savings go unrealized. This is because there are no catalysts with the requisite activity (which influences the size of the "catalytic converter") and durability (the catalyst must maintain high activity over the lifetime of the vehicle) to meet increasingly stringent emissions standards both here and in Europe.

Our recent invention of the highly active and durable NO_x HyCat system will enable automobile manufacturers to cost-effectively meet increasingly more stringent emissions requirements and provide energy savings for U.S consumers. In addition, the NO_x HyCat can provide NO_x abatement for the existing diesel fleet—mainly medium-duty delivery trucks, farm vehicles, and heavy-duty trucks such as 18-wheelers. These vehicles currently contribute significantly to overall U.S. NO_x emissions but are indispensable trucks such as 18-wheelers. These vehicles currently contribute significantly to overall U.S. NO_x emissions but are indispensable because they move the bulk of U.S. durable goods and food to market. Also, very large diesel engines are being used more and more for generating electrical power in remote locations such as along pipelines and in oil fields. They are also being used for load leveling of the power used in urban areas. These stationary engines, as well as locomotive engines, will also come under more-stringent emissions-control requirements in the near future. NO_x HyCat technology will allow them to keep operating under the emissions-control standards of the future.

Most important, NO_x HyCat could allow more U.S. vehicles to be diesel powered, resulting in significant energy savings (recall that diesel engines are some 30% more fuel efficient than current gasoline engines). In 2004 the United States produced 11.6 million new passenger vehicles out of the worldwide production of 53 million. If progressively more U.S. vehicles in that impressive production were "dieselized" in the European fashion, it could reduce oil imports by an estimated 25%. Lean-burn NO_x-emission-control technology would thus enable the United States to take advantage of this tremendous energy savings in the near- to mid-term while future fuels are being developed as the next-generation energy sources.

Overseas, the European market for light-duty diesel engines in small automobiles is increasing quickly and is being driven by the higher European fuel costs. More than 50% of all cars sold in Europe are diesel and that number is increasing, even though Europeans have not yet been able to employ NO_x-emissions-control systems on the diesel engines powering those cars. So there is a large unmet *worldwide* need for durable, high-activity NO_x-emissions catalysts. It is a need the NO_x HyCat can fill.