# Innovative Membrane Technologies for Reducing $NO_x$ Emissions and Preventing Transformer Failures


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### Environmental Problem

Nitrogen oxides ($NO_x$) lead to acid rain and contribute to unhealthy ground-level ozone and smog, often leading to severe respiratory problems among affected communities. Diesel engines produce unacceptably high levels of $NO_x$ at high loads, and $NO_x$ from nonroad diesel engines represents an increasing percentage of the environmental pollution in nonattainment regions (areas that do not meet primary environmental standards), where more than 90 million Americans live. Economical, easy-to-integrate solutions are needed to meet the $NO_x$ reduction goals of the Clean Air Act.

### SBIR Technology Solution

A promising new method of reducing $NO_x$ emissions involves the recycling of exhaust gas in a process called exhaust gas recycle (EGR). EGR sends captured exhaust gas back into the combustion chamber of the engine, thereby increasing fuel economy and reducing emissions: a 50 percent EGR leads to a 50 percent reduction in $NO_x$. There are some problems, however, associated with the process, including: (1) extra pumping and cooling of the EGR stream, (2) engine wear from recirculating engine soot, and (3) high feed-air water vapor levels. These issues can be avoided by the use of nitrogen-enriched air (NEA), which reduces the diesel combustion temperature and, in turn, the amount of $NO_x$ emitted in the engine exhaust. The $NO_x$ reductions achieved through NEA are similar to those accomplished through the EGR process, while simultaneously avoiding the pumping, cooling, wear and water vapor issues associated with EGR.

With support from EPA's SBIR Program, Compact Membrane Systems, Inc. (CMS), in cooperation with its commercialization partners, has developed stable fluoropolymer membranes to nitrogen enrich the turbocharged intake air to diesel engines. Cooled turbocharged air is processed by an NEA membrane to supply NEA to the diesel engine intake. NEA reduces the diesel combustion temperature; in turn, the amount of $NO_x$ produced and emitted in the engine exhaust is greatly reduced.

CMS membrane modules are designed for very high-flux, harsh operating conditions; stable performance; and production of NEA in the range of 79.5 percent up to 84 percent. As a result of EPA's SBIR funding and collaborations with downstream partners and commercial membrane manufacturers, CMS has made large advances in demonstrating and commercializing NEA membranes for $NO_x$ reduction in diesel engines, particularly for truck, generator, marine and locomotive platforms.

### Commercialization Success

Working with major industrial gas companies (e.g., Praxair and Air Liquide) and their membrane divisions (IMS and MEDAL), CMS has produced large, commercial-sized membrane modules. In collaboration with Caterpillar, these modules were operated successfully in excess of 1 million on-road miles on five Class 8 diesel trucks. Independent laboratory testing of the membrane systems showed them to have excellent fouling resistance to ingested dust and durability to an excess of 1 million pressurization cycles while operating at high temperature (85°C) and high pressure (30 psig). Caterpillar's tests over a broad cycle showed that the membranes exceeded the target $NO_x$ emission reduction of 50 percent. CMS' successful field demonstration with Caterpillar in combination with ongoing support from EPA's SBIR Program has led to additional opportunities that presently are under commercial/developmental evaluation. Low-speed marine diesel CMS membranes on Scandinavian ferries and ships have been tested and achieved the target 30 percent $NO_x$ reduction with less than 5 percent fuel penalty.

The retrofitting of installed emergency generators with CMS NEA membranes is being evaluated, and the membranes show promise for creating cost savings from peak electric power rates. Stand-alone membrane units driven by a vacuum pump have been developed, offering an alternative to retrofitting machinery with minimal or no downtime. These additional programs have successfully completed the feasibility phase.


**CMS' online transformer monitoring system, which monitors dissolved gases in transformer oil to protect against catastrophic transformer failure.**

In a joint development program with potential customers, CMS applied the gas permeable properties of its fluoropolymer membranes to a completely different problem from $NO_x$ engine emissions. The company customized its membrane system to "sniff out" potential catastrophic transformer failures in near real time using dissolved gas analysis (DGA) of the transformer oil. The power industry terms these transformer failures, which occur despite routine maintenance, "extraordinary events," and they have crippled electrical transmission systems without warning. Before CMS developed the online transformer monitoring systems, transformers only could be tested by periodic manual sampling with offsite analysis. The online systems monitor transformer health continuously and automatically trigger an alarm when a transformer malfunctions. During the last 12 years, the company has sold thousands of systems commercially. They are integral to Arizona Public Service's Transformer Oil Analysis and Notification (TOAN) system, which won the prestigious Edison Award in 2008 from the Edison Electric Institute. Use of these systems reduces the likelihood of power outages, lowers maintenance costs for transformers and extends transformer life.

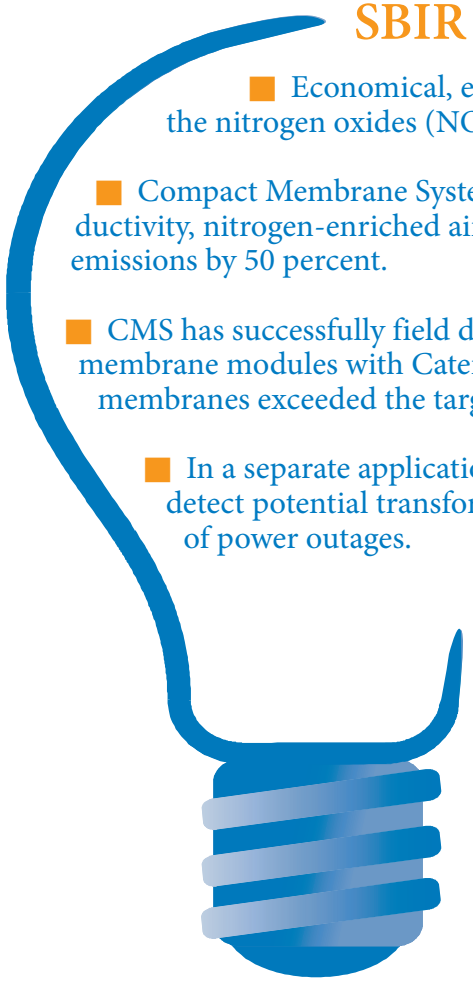
## Company History

CMS was founded in 1993, based on membrane technology acquired from E.I. DuPont. CMS is located in Wilmington, Delaware. CMS' focus is on the research, development and commercialization of membranes and thin films composed of fluorinated polymers with exceptional gas transport properties and chemical resistance. The firm holds numerous patents for its technology.

In 1998, 2000 and 2007, CMS received the Tibbetts Award as an Outstanding Small Business in the State of Delaware. This award is given by the U.S. Small Business Administration to firms judged to exemplify the best in small business innovation and research. The company's goal is to become, in combination with its partners, the world market leader of amorphous perfluoropolymer membranes for gas transport (including NEA).

Although CMS products are focused on perfluoropolymers, the company serves a broad range of markets that can utilize the unique features of CMS membranes. The California Air Board certified CMS' membrane cartridge to capture escaping gasoline vapors at pumps and tank vents and return the gasoline to underground storage tanks.

## SBIR Impact



- Economical, easy-to-integrate solutions are needed to meet the nitrogen oxides ($NO_x$) reduction goals of the Clean Air Act.
- Compact Membrane Systems, Inc. (CMS) demonstrated that a high-productivity, nitrogen-enriched air membrane reduced diesel engine $NO_x$ emissions by 50 percent.
- CMS has successfully field demonstrated commercial-sized membrane modules with Caterpillar. In these on-road tests, the membranes exceeded the target $NO_x$ reduction of 50 percent.
- In a separate application, CMS has used its membrane technology to detect potential transformer failures—thereby reducing the likelihood of power outages.