Fiscal Year 2005 Secretary of Defense
US Army Environmental Awards Nomination

CO_2 Cooling Development Team
Communications-Electronics RD&E Center

Environmental Excellence in Weapons Systems Acquisition

Sustaining the Environment for a Secure Future

INTRODUCTION

During the 1990s, the Army made the optimization of its Environment Control Units (ECU) a priority among its research and development (R&D) efforts. An ECU resembles a window air conditioner and provides space heating and cooling for both equipment and personnel. The Environmental Systems and Fuel Cell Branch of the Communications-Electronics Research Development and Engineering Center (CERDEC) leads the development of these ECUs. The optimization of the Army's ECUs was undertaken in response to implementation of the Montreal Protocol International Treaty and amendments to the Clean Air Act. Both of these initiatives were designed to reduce and eventually eliminate worldwide dependence on ozone-depleting and greenhouse gases.

During the same time period, Army program managers were identifying the need to provide protective armoring to its fleet of tactical vehicles. Armoring vehicles required sophisticated air conditioning for operations in extreme climate conditions, where both efficiency and effectiveness of these units takes on even greater importance. Tactical vehicles were outfitted with a hydrofluorocarbon (HFC) R134a refrigerant – the same refrigerant presently used in automotive air conditioning (AC) systems. However, HFCs have been shown to be a dangerous greenhouse gas, and the signing and ratification by many countries of the Kyoto Protocol has led to a search for alternatives to fluorocarbon refrigerants; legislation has already been proposed in the European Union that will effectively ban the use of R134a for use in automotive AC in new vehicle types beginning in 2011.

An Army standard ECU modified to use CO_2 as the sole refrigerant.

These environmental concerns led to the development of prototype AC systems using naturally occurring carbon dioxide (CO_2) as the sole refrigerant. The advantages of using CO_2 instead of R134a are many (see Figure 1 below).

Figure 1. CO_2 vs. HFC R134a

Refrigerant	Global Warming Potential	Cost	Logistics	Performance
Carbon Dioxide (CO_2)	1	Approximately $.30/lb.	No need for EPA-required refrigerant recovery & recycling equipment and special training	When compared with R134a, the use of CO_2 presents a 25 to 50 percent improvement in capacity, a lower evaporator outlet temperature of 10 to 20°F, and achieved a 50 to 100 percent reduction in temperature pull-down time.
HFC R134a	1,300	Approximately $4.00/lb.	Costly recovery and recycling machines are required by Clean Air Act	

CO_2 provides a number of advantages over the currently used R134a refrigerant.

In 2003, as the Army's prime information technologies and integrated systems center responsible for equipping the war fighter with the latest technology innovations, CERDEC had already formed the CO_2 Cooling Development Team to be at the forefront of this technology. CERDEC fabricated and tested the world's first full-scale unitary CO_2 cooling unit in 2001. In late 2003, the team sought a way to broaden the use of this technology to an Army platform with a more critical and immediate application to the war fighter. Through discussions with the National Automotive Center and the Program Manager, Tactical Vehicles, an M1114 Up-Armored HMMWV (High-Mobility Multipurpose Wheeled Vehicle) was acquired for the fabrication of a prototype vehicle using a CO_2 cooling system. With an appropriation in the FY 2004 Defense Budget in place, the CO_2 Cooling Team began its efforts to integrate this technology into the M1114 HMMWV.

> "Reduce the impact of refrigerant release on the environment and improve HMMWV air conditioning performance."
>
> *- Senator Herb Kohl (D-WI), identifying the two goals of the CO_2 Cooling Program*

BACKGROUND

Recognizing the need to bring together the nation's foremost authorities on CO_2 cooling technology, the CO_2 Cooling Team represented the successful collaboration of Army, industry and academia experts. This team not only developed and tested the technology, but also applied it directly to the war fighter.

The CO_2 Cooling Development Team consists of the following individuals:

- Mr. John Manzione – Special Projects Officer, US Army CERDEC;
- Mr. John Dolney – Special Projects Officer, Project Manager for Tactical Vehicles (PM TV);
- Dr. Stephen Memory – Manager, Global HVAC Technology, Modine Manufacturing Company;
- Mr. Samuel Collier – Manager, Advanced Systems Development & Technology, Modine Manufacturing Company; and
- Dr. Pega Hrnjak – Co-Director of the Air Conditioning and Refrigeration Center, Director University of Illinois – Urbana Champaign (UIUC).

POSITION DESCRIPTION

The team collaborated to design, fabricate and test an innovative, high-performance and environmentally responsible cooling system on the most critical tactical wheeled vehicle in the US Army inventory, the M1114 Up-Armored HMMWV.

- Mr. John Manzione formed the team and was assigned as the Contracting Officer's Technical Representative (COTR) for the contract with Modine Manufacturing Company. Mr. Manzione was responsible for daily management of the contract, budget and overall program direction. Mr. Manzione was selected as the COTR because he was and is the Army's prime expert for identifying and developing new cooling technologies for Army systems.
- Mr. John Dolney is assigned to the Project Manager's Office for Tactical Vehicles within the Program Executive Office (PEO) for Combat Support & Combat Service Support. Mr. Dolney provided the prototype M1114 HMMWV for testing on an Army platform. As the Special Projects Officer for PM TV, Mr. Dolney ensures that the latest technologies (including the CO_2 Cooling technology) can be applied directly to benefit the war fighter. During the CO_2 development process, he provided general design guidance and direction from a platform/user perspective.
- Dr. Stephen Memory and his team are responsible for exploring new technology opportunities to advance Modine Manufacturing's business development. For the past two years, Dr. Memory's team has been focused on spreading the CO_2 technology across industries.
- Mr. Samuel Collier led a team focused on integrating the CO_2 technology into mobile vehicles. Mr. Collier's team was instrumental in applying the CO_2 system to the M1114 HMMWV without modifying the current configuration of the vehicle.
- Dr. Pega Hrnjak and his team were contracted by Modine to perform all of the academic research and breadboard modeling necessary to prove the value and viability of the CO_2 technology. Dr. Hrnjak manages all of the labs that produced the scientific knowledge testing and guided the integration of the system into real-world applications.

AWARDS AND SERVICES

The primary reason for the CO_2 Cooling Team's success over the last two years lies within the knowledge and expertise of the team members. Individually, these five experts are some of the most respected professionals in the industry. Together, they have formed one of the most successful R&D teams found in the Army today.

Each member of the team is a valued leader within various professional organizations known throughout the air conditioning industry. Direct affiliations with organizations such as the American Society of Heating, Refrigerating & Air Conditioning Engineers, Society of Automotive Engineers, the Air Conditioning and Refrigeration Center at UIUC and the Mobile Air Conditioning Society have enabled a successful transfer of knowledge and experience.

Mr. Manzione was specifically recognized for his outstanding work on the CO_2 Cooling Team by the Army Materiel Command (AMC). From January 2003 through January 2004, Mr. Manzione was AMC's

"Engineer of the Year." During that same time, he was also one of the National Society of Professional Engineers' "Top Ten Federal Engineers."

Perhaps most significantly, the CO_2 Cooling Team was named a charter member of the Mobile Air Conditioning Climate Change Partnership with the US Environmental Protection Agency (EPA). Partners represent a growing team of corporate, government and environmental leaders working together to rapidly improve the energy efficiency of vehicle air conditioning systems.

Between them, Mr. Collier, Dr. Memory and their Modine teams have been awarded 14 US patents on both CO_2 system and component technology, with eight more patent applications pending. They have also authored and presented eight papers on CO_2 technology at various conferences and technical seminars.

Dr. Hrnjak is a distinguished and world-renowned member of academia with credentials as a research and teaching professor, consultant to industry, co-author of college textbooks, dozens of professional peer-reviewed journal articles and international conference papers. He has authored over 100 total publications on refrigeration science, many specific to the emerging CO_2 technology. Dr. Hrnjak is a Fellow in the American Society of Heating Refrigeration and Air-conditioning Engineers and Editor of the ASHRAE Research Journal.

"One remarkable benefit of the Army project is that DoD is seen worldwide as concerned about climate protection and on the cutting edge of new technology. Participation in global projects and conferences had the effect of training foreign researchers and government authorities to appreciate the unique circumstances of military combat vehicles."

- Stephen O. Andersen, Ph.D.
Director of Strategic Climate Projects, EPA

ACCOMPLISHMENTS

Weapon System Acquisition Program Summary
Over the past two years, the CO_2 Cooling Team has made great strides toward improving the CO_2 technology while increasing industry awareness of the need to identify an alternative to the environmentally harmful R134a refrigerant. Once the M1114 HMMWV test vehicle was obtained from the PM LTV, the team was directed to integrate the CO_2 technology into the test vehicle within the same space and weight limitations as the baseline R134a cooling system. This was done to ensure compatibility with the current fleet of HMMWVs.

In areas like Iraq and Afghanistan, extreme heat conditions are sometimes more of a concern than enemy fire. Up-armoring of the HMMWV has increased Soldier safety but has placed a stronger emphasis on the need for more efficient cooling systems.

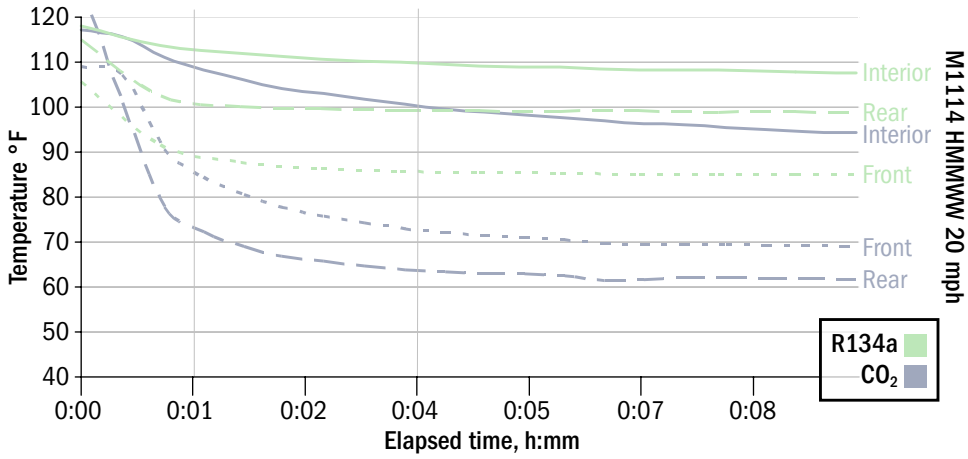
To meet this challenge while maintaining original program goals, the team created a comprehensive program management approach. Utilizing an integrated process team strategy ensured complete cooperation, synchronization and transparency among all partners. The team was split into functional working groups, each led by one of the team members. Through regular status meetings, progress reports, C/SSRs (Cost/Schedule Status Reports), Mr. Manzione was able to manage budget and program performance. He then met with the various industry, academic, federal and trade association partners to share intellectual capital and program breakthroughs.

Contracted partners worked under fixed-sum, cost-reimbursable contracts that allowed the team to show appropriate budget justification and return on investment. From the initial appropriation of $1.7 million in FY 2003 all the way through to FY 2005's appropriation of $3.6 million, this program management approach has continued to be a successful method of improving the CO_2 technology.

Technology Advancement
As of October 2003, the CO_2 tactical vehicle technology was considered to be at Technology Readiness Level 4, meaning initial breadboard testing had just commenced. Two years later, the CO_2 technology was classified as having reached

Technology Readiness Level 6, meaning the team had completed a full-scale prototype CO_2 cooling system on an authentic Up-Armored HMMWV. The prototype system had passed testing in both a high fidelity laboratory wind tunnel environment as well as a simulated operational environment at Yuma Proving Ground (see Figure 2). In June 2004, the HMMWV with the CO_2 air conditioning system and an identical HMMWV with an R134a air conditioning system were entered in the informal ride program at the Society of Automotive Engineers (SAE) Alternate Refrigerants Symposium. These informal rides are intended to simulate real world driving conditions.

Figure 2: System Testing Results



These tests show that the CO_2 cooling system delivered twice the cool-down performance of the R134a installed system in the armored HMMWV. In wind tunnel testing, at 120°F simulated ambient temperatures, the CO_2 Cooling System was producing air that was 40°F colder than ambient while the air produced by the R134a system was only 20°F below ambient. After just four minutes of operation, the CO_2 system had cooled the cabin by 20°F, doubling the 10°F achieved using the original R134a system.

The prototype CO_2 system, despite the constraining space limitations, was eight percent lighter in weight and 30 percent smaller in volume than the original R134a system. Space and weight claims for supporting subsystems are extremely critical on armored vehicles. Every pound saved and every square inch removed enables operators to carry additional mission-critical components and equipment.

"This new environmental control system will help keep the increasing proliferation of complex electronics cool while deployed on patrol with our war fighters. Not only does it improve cooling capacity 25 to 50 percent and reduce the vehicle cab temperature by another 10 to 20 degrees below the current system, its use of CO_2 eliminates complex maintenance requirements and the associated onerous logistics trail. Works better, cheaper and is more maintainable using common materials. It doesn't get much better than this."

- Col. Bob Mattes (USAF), Director, Comparative Testing Office, Defense Acquisition Challenge Program

Based in part on these results as well as the overall progress of the CO_2 technology, the CO_2 cooling system has already been written into industry planning documents for future blocks of the highly visible Future Combat System Program. CO_2 cooling systems are also being favorably considered for the future fleet of Light, Medium and Heavy Tactical Vehicles, which places the rapidly maturing CO_2 technology on a direct and definable path to Army fielding, concurrent with the anticipated arrival of the first commercial passenger vehicles from Europe and Asia.

In addition to current and planned Army applications, this technology has drawn the interest of the Department of Defense (DoD) and the other Services. The team has presented its findings to favorable audiences within the US Marine Corps, the Joint Logistics Commanders, the Corps of Engineers and the US Air Force. The CO_2 Cooling Team was also made a part of the Defense Acquisition Challenge Program. This program provides opportunities for both innovators and the DoD. For innovators, it means faster entry to the defense acquisition system. For the DoD Program Manager, it means increased technology insertions to improve systems. For the CO_2 Cooling Team, it means additional opportunities to get this technology to the war fighter quicker.

Education and Outreach

With an understanding that bolstering the industry awareness of the benefits of using CO_2 as a refrigerant is a key factor in the success of this technology, the members of the team are involved with worldwide outreach efforts, including participation in conferences, seminars, expositions and in the presentation of technical papers and reports.

Technical Papers on CO_2 Technology

- "Using CO_2 to Cool an Up-Armored M1114 HMMWV." Presented at the SAE Alternate Refrigerant Systems Symposium, Scottsdale, Ariz., June 2004.
- "Using R744 (CO_2) to Cool an Up-Armored M1114 HMMWV." Presented at the Vehicle Thermal Management Systems Conference and Exposition, Toronto, Canada, May 2005.

Presentations

- Keynote Speaker at a Mechanical Engineering Department Seminar at Virginia Polytechnic Institute and State University, August 2005.
- SAE Alternate Refrigerant Systems Symposium, Scottsdale, Ariz. July 2005 and June 2004.
- Verband Der Automobilindustrie E.V. (VDA) Winter Meeting, February 2005.
- Tactical Wheeled Vehicle Component Technology Demonstration (Yuma Rodeo), January 2005 and January 2004.
- DoD Comparative Technology Demonstration, November 2004.
- International Compressor Engineering Conference at Purdue University, July 2004.

The CO_2Cooling Team also enlisted the support of several industry and federal partners to take advantage of best practices and lessons learned that helped to ensure transferability and compliance. Working partnerships were formed with the following agencies and organizations:

- The US Army Research, Development and Engineering Command, The Program Executive Officer for Combat Support/Combat Service Support, The Assistant Secretary of the Army for Acquisition, Logistics and Technology, Program Manager, Light Tactical Vehicles and the US Air Force;
- The University of Illinois Air-Conditioning Research Center, the University of Maryland, Purdue University, the Norwegian University of Science and Technology, Georgia Tech and Virginia Polytechnic Institute and State University;
- Automakers, compressor and end item manufacturers, heat exchanger and other component suppliers and engineering prototype companies;
- The American Society of Heating, Refrigerating & Air Conditioning Engineers Air-Conditioning and Refrigeration Institute and SAE; and,
- The EPA, Department of Energy, National Institute of Standards & Technology and National Science Foundation.

CONCLUSION

Through its extensive public and private sector outreach, the CO_2 Cooling Team's efforts over the last two years have led directly to an increased awareness of this technology not only within DoD and academia, but also in the commercial auto industry. In two short years, the commercial auto industry has begun incorporating CO_2 into the cooling systems of new automobiles, the EPA has extolled the environmental advantages of using CO_2 instead of HFCs, and the Army is currently considering making it the standard cooling system on the future fleet of Tactical Vehicles. Less expensive, more efficient, non-toxic, environmentally friendly CO_2 is the future of air conditioning technology, and the CO_2 Cooling Team is sure to play a key role in helping the US military realize that future.

An Up-Armored M1114 HMMWV using the current Army standard cooling system appears on the left. The HMMWV on the right is outfitted with a cooling system using the CO_2 technology.

On the cover: An Up-Armored M1114 HMMWV outfitted with the more efficient, environmentally friendly CO_2 Cooling System.