Research Performance Progress Report (RPPR) for DOE/EERE

Final Report for DE-EE0003986

Project Title: "Next Generation Refrigeration Lubricants for Low Global Warming Potential/Low Ozone Depleting Refrigeration and Air Conditioning Systems"

Covering Period: August 3, 2010 to September 30, 2013

Approved Project Period: August 3, 2010 to September 30, 2013

Submission Date: December 31, 2013

Recipient: Chemtura Corporation
199 Benson Road
Middlebury, CT 06770

Website (if available) www.Chemtura.com

Award Number: DE-EE0003986

Working Partners:

Cost-Sharing Partners:

PI: **Cyril Migdal**
Technical Director, Petroleum Additives
Phone: 203-714-8721
Fax:
Email: Cyril.migdal@chemtura.com

Submitted by: **Edward T. Hessell**
Technical Manager, Refrigeration Lubricants
Phone: 203-714-8674
Fax:
Email: ed.hessell@chemtura.com

DOE Project Team:

DOE Contracting Officer	Leon Fabick
DOE Project Officer	Michael Wofsey
Project Engineer	

Signature Date

Project Background, Justification and Objective: It is internationally recognized that ozone depletion and global warming are two processes that can, and have, had a significant impact on environmental change. One of the major contributors to these industrially generated environmental problems has been the emission of halocarbon gases used in many applications; but most often associated with refrigeration. Although the work of the last two decades has led to tremendous reductions in the manufacture, use and emission of the most dangerous classes of halocarbon refrigerants (chlorofluorocarbons and hydrochlorofluorocarbons) that impacted the ozone layer, the predominant replacement refrigerants (hydrofluorocarbons; HFCs) still contribute to Global Warming. In fact, despite the fact that the percentage of emissions of HFCs is relatively small (about 1%) of the total emission of "greenhouse gases", the global warming impact of the HFCs is 600 to 3000 times greater than carbon dioxide. Thus even small emissions of HFCs can create a significant contribution to GWP impact. One fact that greatly assisted the transition from CFCs to HFCs is that there was no requirement for drastic modification of equipment. The HFCs were similar to CFC/HCFCs in being thermally stable, non-flammable and operated at similar pressures. In fact, one of the major changes with implementing HFC technology was a requirement for new lubricants (change from mineral oil to synthetics such as polyol esters, polyalkylene glycols, polyvinyl ethers). Polyol esters by far the most popular synthetic lubricants used in stationary HFC-based refrigeration equipment. But because of the recent global focus on addressing global warming, the industries that use HFCs are already considering replacements that have significantly lower or negligible GWP. One of the big unanswered questions will be if these new technologies will require new synthetic lubricants.

There are many options for replacing the current HFC refrigerants with next generation low GWP alternatives. But unlike the conversion from CFCs/HCFCs to HFCs, many of the best new alternative refrigerants operate at higher pressure, are flammable and less chemically stable. So this presents unique design challenges to adopt these refrigerants in commercial equipment so they are safe and operate at the same energy efficiency as previous HFC systems. In fact, there are many new refrigerants and/or refrigeration cycle designs that promise to be dramatic improvements in energy efficiency in select application areas.

The most predominant refrigeration technology used today involves the repeated compression/condensation and expansion of a gas. This process takes advantage of the heat gain and loss of a condensable gas upon going from liquid to gaseous states and back to liquid. In order to compress the gas from low to high pressure a pump (or more specifically a compressor) is required. The compressor has moving parts such as bearings and sliding metal surfaces that must be lubricated and cooled. The objective of this project was to develop synthetic refrigeration lubricant technologies specifically optimized to provide long compressor/system service life and improved energy efficiency to equipment that use environmentally benign low GWP refrigerants. Examples of low GWP refrigerants that meet the definition of environmentally benign and were approved for inclusion within the scope of this grant include HFCs with GWP < 700 (ex. R-32), HFC/HFO refrigerant blends such as mixtures of R-32 and hydrofluoroolefins (R-1234yf and R-1234ze) with GWP < 600, natural refrigerants such as hydrocarbon refrigerants R-290 (propane) and R-744 (carbon dioxide). The basic strategy and outline of the project is documented in the DOE approved Project Management Plan (PMP); a copy of which is included with the submission of this report. The PMP contains (4) major sections. The first two objectives focus on creating, characterizing and evaluating the lubricants both alone and with refrigerant vs. those of current commercial refrigeration lubricants in various bench tests and refrigeration equipment components and systems. This also includes evaluations of energy efficiency improvement either at the component or full system level. The last two involve the development of the technology into a commercially viable product as well as all the steps required to commercialize one or more embodiments of the technology. The basic objectives are as follows:

- Advanced synthetic lubricant synthesis, characterization and bench test evaluations with and without refrigerant.
- High pressure advanced bench tests as well as system component (compressor, heat exchanger) evaluation of the lubricants in the presence of refrigerants. Also included would be OEM sponsored or independent contract lab full system compressor life testing and full system calorimeter tests to assess energy efficiency.
- Process development and scale up of commercially viable process for the ester technology.
- Commercialization of one or more embodiments of the synthetic lubricant technology.

Background: The scope of the project encompassed a number of different sub-projects that are most easily categorized in terms of the various classes of low GWP refrigerants that are either under consideration for commercialization, or have already been designated as commercially viable technology for one or more applications in refrigeration. It should be noted that the term “refrigeration” as defined in this report refers to any process for transferring heat energy between one or more isolated environments using a condensable or compressible gas. A diverse sampling of examples includes traditional refrigeration and freezing, air conditioning, heat pumps, heat pump hot water heaters and industrial cooling operations. The DOE grant has supported individual lubricant development projects involving advanced ester technology for:

1) Carbon Dioxide
2) Hydrocarbon refrigerants (with emphasis on R-290).
3) Low GWP HFC or blends with HFO refrigerants (R-32 and low GWP R-410A “equivalents”)
4) New applications for high efficiency HFC refrigerants (R-410A).
5) Low GWP replacements for R-134a in commercial/industrial refrigeration (R-1234ze)

Each refrigerant requires a synthetic lubricant with a unique set of performance properties.
It is important to note that during the course of this project, any given sub-project may be at a different stage of the PMP. So some projects were in the early stages with activities primarily in Task 2 while other projects were closer to commercialization with a concentration of activities in stages 4 and 5. We also recognize that, although in our idealized stage gate system we strived to finalize activities in one stage before advancing to the next, in reality it is common for us to be executing activities in two or more stages in parallel. But we always look to the stage gate PMP as a guide in order to ensure that we at the very least acknowledge the incompletion of a lower stage activity before moving ahead to subsequent stages as well as make sure that we are not forgetting critical components required for the commercial success of the project. In the end, some of the sub-projects were completed and resulted in commercial products during the official period of the grant, while some projects initiated during the period of the grant continue on with 100% support of Chemtura Corporation, as the evaluations and final approvals of products with original equipment manufacturers in next generation equipment is a multi-year process. Commercial embodiments of these projects will be realized in 2014-2015.

Summary of Significant Accomplishments:
The majority of this final report will focus on the latter full system energy efficiency tests of various embodiments of the advanced synthetic ester technology that was the subject of the grant proposal (PMP

section 3.3.3, Phase 3). It is these results that are the most important to the objectives of the grant. The results of the tests will be compared to our initial grant proposal predictions of improvements in energy efficiency that might be derived by optimizing the properties of the lubricant to any particular low GWP refrigerant.

Protection of Confidential Data:
A significant portion of the detailed data and results generated under the grant is considered confidential. Such data submitted as part of the final report that must be maintained as either Chemtura specific confidential information, or must be protected as part of an NDA with a customer or research partner, is provided separately as "DE-EE0003986 Final Technical Report Appendix_Limited Rights Data.pdf".

Status:

Task 1.0 - Project Management Plan

Completed and updated accordingly as necessary for contract extensions.

Task 2.0 – Synthesis and Bench Tests

The details of this work has been detailed in previous quarterly progress reports. No additional information will be provided in the final report.

2.1 Initial "range finding" design of experiment synthesis of candidate materials using Chemtura patented process technology.

Detailed in monthly progress reports.

2.2 Characterization of material physical properties.

Select examples of products that have been successfully commercialized or are in final approval trials at various OEMs are detailed in Table 1 of the Appendix document. Tables 2-4 of the Appendix contain summary tables of the physical properties of a number of experimental candidates that were identified at various ISO viscosity grades for select applications.

2.3 Conduct compatibility with current HFC's and next generation refrigerants.

Select examples of the miscibility of lubricants developed for several applications are detailed in Figures 1-4 of the Appendix.

2.4 Synthesis of New Candidates based upon outcome of initial bench testing

Nothing to report

2.5 Evaluation of lubricant candidates alone versus current technology in lubricity, load carrying, and friction and wear tests.

In general, it was determined that the advanced polyol ester lubricants had superior frictional properties to traditional POE lubricants while still providing good miscibility with the refrigerant. This has been detailed in previously submitted quarterly reports. The lubricity properties of the lubricants were measured using the Mini-Traction Machine (manufactured by PCS Instruments, UK). A graph and equations outlining the contact geometry and term definitions is shown in Figure 5 of the Appendix. Graphs illustrating the improvement in frictional properties of the advanced esters vs. traditional POEs are presented in Figures 6 and 7 in the Appendix.

One important note is that the lubricity advantages identified in the bench MTM testing could not be replicated in compressor tests. A compressor energy consumption study conducted using a 3 ton reciprocating compressor designed for trans-critical R-744 showed no difference in energy consumption as a function of lubricant type and/or ISO viscosity grade (80, 68, 55) under a number of normal and extreme operating conditions. This was attributed to the fact that the compressor was overdesigned to work with the lesser performing lubricant. Regardless, the compressor tests were instrumental in demonstrating "no harm" results for the advanced ester lubricants in a compressor (see Section 3.3.1).

2.6 Identify best balance of lubricity/load carrying and miscibility for a particular refrigerant.

Nothing to report

2.7 Define technical barriers and key research issues

Complete for all embodiments supported by the grant.

2.8 Manufacturing vision of routes

Documented processes in place for all leading candidates listed in Table 1 of the Appendix. commercial or in developmental phase.

2.9 Raw material costs and availability

Complete.

2.10 Check volume/price variables – first pass sensitivity

Complete. Pricing well established for commercial embodiments of the technology. Indicative pricing for developmental products in line with customer expectations.

2.11 Plan and execute CDA/Non-analysis agreement with customers for sampling plan.

Complete for all aspects of the project. A total of 12 NDAs were established to support joint information sharing or development under the grant. The principle NDAs were with compressor manufacturers, but there were also NDAs with refrigerant manufacturers, heat exchanger manufacturers, and system builders. The NDA covering the design and execution of the final system COP and energy efficiency tests involved four(4) different parties (system builder, compressor manufacturer, contract laboratory and Chemtura Corporation). A refrigerant manufacturer participated by establishing a separate NDA specifically with the contract laboratory that did the tests.

2.12 Toxicology and chemical regulatory status review. Determine estimate of costs and timetable for global regulatory compliance.

Complete

2.13 Plan regulatory objectives (product registration plan)

Complete. But this aspect will be continually rechecked as commercialization of various embodiments becomes imminent. Chemical regulatory for each region of the world is a dynamic process.

2.14 Analyze Competitive Landscape

Complete for R-744, R-410A, R-290, low GWP R-410A equivalents and R-32.

2.15 Creation of preliminary documentation to allow customer sampling for select developmental products:

Complete for all candidates in Table 1 of the Appendix

1) Experimental Product Designation

   Complete

2) Technical Data sheet.

   Complete

3) Material Safety Data Sheet

   Complete

4) Miscellaneous technical charts and documents.

   Complete for most developmental embodiments of the technology.

   Ongoing for some.

2.16 Stage Gate Review 1 (decision point). Specific criteria:

1) Did the candidate lubricants display a significant performance improvement over current technologies in laboratory bench tests? If not, did the bench test data provide strong direction concerning what new materials will display improvements?
   Several candidates developed which demonstrate significant improvement in properties vs. current synthetic lubricant technologies.
2) Have suitable customers been signed up to assist with further program stages?
   Yes. Working closely with a minimum of 3 major compressor OEMs to evaluate and/or qualify products in specific applications.
3) Are plans for Task 3 in place?
   Yes. Task 3 activities in progress.
4) Does competitive analysis suggest proceeding with development?
   Yes.

Task 3.0 - Advanced Testing

3.1 Conduct physical property data on lubricant/refrigerant mixtures as a function of temperature and pressure (Daniel Charts/data)(either internal or contract laboratory).

Complete for all embodiments supported by the grant.

3.2 Work with OEMs to conduct initial evaluations of candidates in compressors and full systems.

This is the major activity originally supported under the agreement that continues now fully supported by Chemtura. Candidate developmental lubricants continue to progress in compressor OEM accelerated reliability and performance tests. Highlights of progress towards commercial approval at customers are:

a. Successful approval and initial sales of a POE lubricant for R-32 at a major US OEM.
b. Continued approval tests beyond the period of the grant of several candidates for R-32 at other major US and European compressor manufacturers.
c. Anticipated finalization of approval for an and advanced POE in an R-290 application at a major US OEM.
d. Marketing launch of a product for trans-critical R-744 in collaboration with a major US based global supplier of finished lubricants for refrigeration.

3.3 Conduct component or full system testing at contract test lab to demonstrate energy efficiency relative to current technologies.

3.3.1 <u>Phase 1. Component Testing: Compressor Energy Consumption Tests</u>

Complete. Compressor efficiency and reliability tests were conducted on a reciprocating 3 ton compressor designed for use in trans-critical R-744 applications. The application requires a CO2 miscible lubricant. The compressors were run with lubricants of different viscosity under four different sets of conditions. One of the conditions was chosen at the center of the operating window for the compressor. Three other sets of conditions were chosen at the edge of the operating window. The results showed no difference in energy consumption of the compressor as a function of either lubricant viscosity or lubricant type (advanced vs. traditional POE). However, the important outcome of the tests was that the new lubricants showed “no harm” in compressor testing. The complete details of the testing are included in the Appendix submitted as “limited rights data” as a .pdf of a PowerPoint presentation format “**DE EE0003986 CO2_Dura_Report_6-26-12.pdf**”.

3.3.2 <u>Phase 2. Component Testing: Heat Exchange Efficiency Testing</u>

Complete. Effectiveness and Pressure Drop were studied in a micro-channel heat exchanger using R-410A and R-32 refrigerants and POE lubricants having various solubility/miscibility with each refrigerant. The general compatibility of the lubricants with the refrigerant are shown in Table A.

Table A. Miscibility of ISO 32 POE Lubricants with R-410A and R-32

POE Lubricant	R-410A	R-32
1	Miscible	Miscible
2	Miscible	Not Miscible
3	Not Miscible	Not Miscible

The heat exchanger used for the study would be typical of that used in newer residential AC/Heat Pump systems. The overall conclusion of this work suggests that there was little observable difference in heat exchanger effectiveness (expressed as a percentage of theoretical) for a given

refrigerant as a function of lubricant miscibility/solubility. However, larger pressure drops were observed with less soluble lubricants than with more soluble lubricants.
Refrigerant distribution in the micro-channel heat exchanger was studied as a function of oil concentration in the refrigerant (1% and 5%) and the flow rate through the HX. Infrared thermal imaging spectroscopy was used to map the distribution of the liquid refrigerant in the HX. The colors of each pixel in the digital image could be converted to a value that was used to derive an overall distribution factor. Factors in all cases were greater than 0.85. The overall conclusion of this study suggests that the lubricant properties can have a significant impact on refrigerant distribution in the HX. Lubricants miscible with the refrigerant over the entire range of relative concentrations give a more even distribution as a function of mass flow rate. The consistency of the distribution decreases with increasing flow rate at equivalent load. Thus all lubricants showed good distribution with R-410A at low concentration in the refrigerant (1%). However, the lubricant immiscible with R-410A showed an uneven distribution at 5% lubricant and high flow rate. Similarly, the single lubricant miscible with R-32 showed better distribution than the 2 immiscible lubricants showed radical heat exchanger distribution at higher concentrations and flow rates. The details of the heat exchanger study are submitted as "Limited Rights Data" in a separate report titled "**DE EE0003986 Heat Exchanger Testing.pdf**"

3.3.3 Phase 3. Full System Testing

The objective of these tests was to determine and isolate any energy efficiency improvements in a full system that can be attributed solely to the advanced ester lubricants that are the subject of the grant. The test protocol used was that of AHRI 210/240. A 3 ton stationary packaged residential AC/Heat Pump system provided by a US OEM system manufacturer was used for the tests. The system contained a 3 ton scroll compressor. The system was designed for R-410A, however, some soft optimization of conditions was made to better accommodate the lower GWP refrigerants (R-32 and Honeywell's L-41). Tests were carried out under 4 conditions of cooling and 2 conditions of heating. Compressor energy consumption, system capacity, EER and SEER were determined for a total of 13 refrigerant/lubricant pairs. The details of the tests are included in the report "**DE-EE0003986 Full System Tests.pdf**", submitted as limited rights data as a separate document.
In general, R-32 outperformed R-410A, followed by L-41. But statistically significant differences could be identified for various lubricants with a given refrigerant. Most important, there was a noticeable increase in cooling capacity for the advanced esters over traditional esters in tests with R-32 refrigerant (slide 13). This may be in part due to the optimized miscibility of the advanced esters vs. traditional lubricants that, although compatible with R-410A, are immiscible with R-32. Independent measurement of the outdoor unit power consumption, which is dominated by compressor electrical power consumption, indicated no direct reduction of the power consumption involving the advanced esters with R-32 refrigerant (slide 15). But regardless, an improvement in EER was observed in all tests involving R-32 and the advanced ester lubricants (slide 16). SEER ratings for the advanced ester lubricants with R-32 were also higher than those from corresponding tests with traditional POEs. The highest SEER was for the R-32/HXL-8840 refrigerant/lubricant combination. HXL-8840 is a high lubricity, R-32 miscible advanced ester.

Performance trends in heat pump mode were less significant. The overall conclusion was that both R-32 and L-41 performed better than R-410A. But it was difficult to draw any strong conclusions as to whether the advanced esters performed better than the traditional POEs.

3.4 Stage Gate Review 2. Specific criteria:

1) Did the candidate lubricants show demonstrated/measurable improvement in energy efficiency and/or service life relative to current lubricants in component and full system tests?
   Yes. Full results and conclusions to be included in the final report.
2) Have suitable customers given positive feedback and/or initial approval of the product for use to justify proceeding with further program stages?
   Yes. Several products either commercial or advancing in approvals at 5 OEMs.
3) Are plans for Task 4 in place?
   Components of Task 4 are either complete or progressing based on customer demand for the developmental products.
4) Does competitive analysis suggest proceeding with development?
   Yes.

Task 4.0 Process Development and Scale Up

4.1 Conduct bench scale process development.

4.1.1 Evaluate analytical equipment and develop methods for monitoring the progress of the reaction to ensure process reproducibility. Trial the methods at laboratory scale and then consider options for implementing at pilot plant and/or full manufacturing scale.

Complete

4.1.2 Evaluate various options for reducing cycle time to make the process more cost competitive. This would include an assessment of any needs for capital investment in the manufacturing equipment.

Complete

4.2 Transfer lab scale process to pilot plant (process transmittal).

Several pilot plant trials were conducted to support customer sampling and actual product sales. The inline reaction monitoring equipment was successfully transferred to our pilot plant reactor.

4.3 Do pilot plant trials for best candidates in select ISO viscosity grades.

Complete. Additional trials conducted as needed to supply product to prospective OEMs.

4.4 Prepare sufficient quantities of candidates for large scale OEM field trials.
Ongoing for four developmental products at three different OEMs.

4.5 Engineering, environmental and safety process description package.
To be completed prior to initial production scale batch

4.6 Preliminary PFD, P&ID, engineering designs, scale-up plans.
Complete.

4.7 Sampling of product to potential customers for final approval.

Ongoing at 5 OEMs. Additional OEMs being added to the list of companies that we are working with.

4.8 Raw material sourcing and pricing negotiated
Current embodiments of the technology use raw materials already approved and used by Chemtura for other types of products. The pricing and sourcing of the materials is reviewed and negotiated on a regular basis.

4.9 Product economics complete
As we approach commercialization, we routinely refine our calculations of the economics of various embodiments of the technology based on the most current data obtained from sample preparation at the laboratory and pilot plant scale as well as trends in raw material cost.

4.10 Registration of products on track
Complete for all countries where the products will be used. But this regulatory process for approval in various geographic areas is dynamic. So we must constantly review the status of our approvals to the latest versions of policies.

4.11 Preliminary technical package for capital expenditure
Complete.

4.12 Complete market plan
Initial plan complete. Periodic additions/modifications made to the plan as new market information becomes available or current information changes.

4.13 Develop competitive response plan
Documented competitive response plan is in place. Complete.

4.14 Legal review for freedom to operate
No barriers to marketing the lubricants have been identified. Complete, but regularly reviewed and updated.

4.15 Stage Gate Review 3.

1) Did the pilot plant trials produce lubricant that matched the properties and composition of the laboratory synthesized product?
   Yes. Details in batch sheets and Certificate of Analysis for each product.
2) Are details and resources in place to support full-scale commercialization?
   In place for some products. Still in progress for others.

Task 5.0 Process Development and Scale Up

5.1 Large scale life test compressor and system field trials by OEM for approval

This is the major time consuming step toward commercialization of a product. The time from initial evaluation by the OEM to final approval for purchase and first product order can range from 1.5-2.5 years. We have several candidates at various stages of approval and now have one embodiment of the lubricant technology fully approved at an OEM. But it will take some time for other opportunities to reach commercialization.

5.2 Development of all documentation to support sale of product.

a. Final commercial designation.

   Complete

b. Technical Literature

   i. Technical data sheet

      Complete

   ii. MSDS in all required geographical location formats.

      Complete

   iii. Labels and approval of shipping containers.

      Complete

   iv. Technical customer presentations.

      Complete

5.3 Customer forecasts for product on a monthly schedule.

Too early for customers to provide accurate 2014 forecasts.

5.4 Resource requirements to run the manufacturing according to the forecasts

In place.

5.5 Process quality capabilities confirmed (SQC data)

Available for pilot plant trials. Will be generated over time for production batches.

5.6 Back-up manufacturing site program in place (toller identified or alternate Chemtura sites

Yes.

5.7 Obtain approval for any plant capital expenditure required

None required.

5.8 Competitive response plan in place

Yes

5.9 Complete registration of products and all regulatory compliance issues

Complete for major global geographic locations. Will be periodically reviewed to ensure compliance with changing regulations.

5.10 Complete technical literature

Complete for all embodiments of the technology currently being evaluated at potential customers.

5.11 Stage Gate Review – Final

Final stage gate review will be conducted when the first significant commercial order for a new product developed under the grant is received. Although we have some smaller volume sales of select new products, we understand that these are being utilized for field trials by the OEMs. We do not consider these full commercial sales.

Patents:

Details of patents related to the grant are summarized in form DOE F 2050_11.doc submitted separately as part of the final report. It is noted that a patent waiver was approved for this grant. A copy of the approval is submitted separately as "**Granted SOC 1591 2911-010.pdf**"

Property Certification:

Details are included in form "**DE EE0003986 Property Certification S-428B**".

Publications/Presentations/Travel:

Past Presentations

None.

Upcoming Presentations/Publications

1) Hessell, E.; Benanti, T.; Urrego, R. "*Polyol Ester Lubricants Designed for use with R-32 and Related Low GWP Refrigerant Blends*", ASHRAE Winter Conference 2014, New York, NY; January 21, 2014.
2) Hessell, E.; Benanti, T.; Urrego, R. "*Polyol Ester Lubricants Designed for use with R-32 and Related Low GWP Refrigerant Blends*" 22nd International Compressor Engineering Conference, Purdue University, July 14-17, 2014. (submitted).
3) Urrego, R.; Benanti, R.; Hessell, E. "*Solution Properties of Polyol Ester Lubricants Designed for use with R-32 and Related Low GWP Refrigerant Blends*" 15th International Refrigeration and Air Conditioning, Purdue University, July 14-17, 2014. (submitted).
4) Benanti, R.; Hessell, E.; Urrego, R.; Wujeck, S.; Elbel, S. '*Energy efficiency of a residential air conditioning system: Effects of refrigerant-lubricant combinations focusing on R-410A, R-32, and next generation lubricants*" 15th International Refrigeration and Air Conditioning, Purdue University, July 14-17, 2014. (submitted).
5) Wujeck, S.; Elbel, S.; Benanti, T.; Urrego, R.; Hessell, E. *Refrigerant and lubricant mass distribution in a convertible split system residential air-conditioner* 15th International Refrigeration and Air Conditioning, Purdue University, July 14-17, 2014. (submitted).
6) Wujeck, S.; Elbel, S.; Benanti, T.; Urrego, R.; Hessell, E. *Effect of lubricant-refrigerant mixture properties on compressor efficiencies* 15th International Refrigeration and Air Conditioning, Purdue University, July 14-17, 2014. (submitted).

Status Summary Tables:

The status of the project is “complete”. A final status and financial Excel Spreadsheet has been submitted with the Q3 2013 report, however; another copy is submitted as an attachment to the final report as “**DE-EE0003986 Final.xls**”.

List of Documents Submitted to Accompany the Final Report

1) DE-EE0003986 Final Technical Report Appendix_Limited Rights Data Supplement.pdf
2) DE-EE0003986 Final Research Progress Report and SF-424A.xls
3) DE-EE0003986 Patent Certification DOE F 2050_11.pdf
4) DE-EE0003986 Property Certification SF-428B.pdf
5) DE-EE0003986 CO2 Dura Report 6-26-12_final.pdf
6) DE-EE0003986 Heat Exchanger Testing.pdf
7) DE-EE0003986 Full System Tests.pdf
8) DE-EE0003986 Oil Retention Testing.pdf