[PLEASE NOTE: All information you submit is public information. These forms will be posted on the materials sub-program website.]

ADMINISTRATIVE INFORMATION

1. Project Name: Advanced thermoelectric Materials for Efficient Waste Heat Recovery in Process Industries

2. **Lead Organization:** PPG Industries, Inc.
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3. **Principal Investigator:** John Connors, PPG Inc.
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4. **Project Partners:** ALCHAS, Inc., Bart Marvin, 419 537-9081, marvinb@alchasinc.com
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Owens-Illinois, Tom Dankert, 419 247-7804 Thomas.Dankert@us.o-i.com
Pacific Northwest National Laboratory, Moe Khaleel
Michigan Technological University, John Johnson

5. **Date Project Initiated:** March 29, 2004

6. **Expected Completion Date:** September 30, 2007

PROJECT RATIONALE AND STRATEGY

7. **Project Objective:** The overall objective of this project is to integrate advanced thermoelectric (TE) materials into a power generation device that can convert waste heat from an industrial process to electrical power with an efficiency of 20 %. This performance will be achieved with improved TE materials fabricated by depositing nanostructure films that are characterized by a dimensionless figure-of-merit (ZT) greater than 2.0 over the temperature range of 100ºC to 600ºC.

8. **Technical Barrier(s) Being Addressed:** In order to develop a viable approach to conversion of waste heat to electrical power two key challenges must be met successfully: efficient recovery of thermal energy from a waste heat stream; and, scale-up fabrication processes for efficient TE materials. These two challenges must be overcome in order for electrical power to be generated from waste heat from industrial processes in an economic manner.

9. **Project Pathway:** The overall approach involves two major pathways, namely: demonstration of thermoelectric generation of power from waste heat in one or more of the industrial partner's plants; and the development of high ZT materials and approaches to produce the TE materials economically. Demonstration of TE power generation from waste heat involves work at PNNL with a Test Bed to acquire important heat transfer parameters

and TE generator (TEG) characteristics, and incorporating TEGs in PPG and other industries for generation of power. Current technology TEGs will be utilized to gain experience with coupling units to waste heat streams early in the program. As new materials are developed, prototype TEGs will be fabricated and tested, first at PNNL, and secondly, at industrial partner sites.

10. **Critical Metrics:**
    - Development of thermoelectric materials with ZT $\geq$ 2.0 from 100ºC to 600ºC that can be produced economically
    - Development of approach to capture high percentage of process waste heat for use in a thermoelectric conversion system
    - Generation of electrical power from process waste heat at an industrial partner site with an efficiency of 20 %

PROJECT PLANS AND PROGRESS

11. **Past Accomplishments:** A Test Bed for evaluating thermoelectric generators under conditions that simulate those presented in the waste heat streams in industry was completed. A system was fabricated that uses natural gas combustion and a blower to deliver up to 2 Million BTU/hr (585 kW) with a flow rate of 1000 SCFM. This Test Bed is being used to evaluate the thermal and electrical performance of a current technology, PbTe TEG. This TEG is constructed with thermoelements placed around a tubular gas passage. The information is being exchanged with PPG and other industrial partners for planning an in-plant demonstration of thermoelectric conversion of waste heat to electrical power. In preparation of conducting an in-plant demonstration, PNNL personnel and members from industrial partners met at the PPG Meadville glass plant to evaluate potential locations for a slip stream. Efforts are underway to carry out the demonstration at PPG. Significant progress was made in the area of advanced TE materials. After evaluating boron-carbide and silicon-germanium material systems, efforts concentrated on sputtered nanostructures of Ag/PbTe. Films with very good electrical properties were obtained.

12. **Future Plans:** (Please describe the specific dates, milestones, deliverables, and activities of all partners (i.e., who is doing what) for the life of this project, with particular emphasis on FY06. PLEASE NOTE: This information is used by DOE throughout the year for funding actions and to respond to Congressional inquiries. Failure to provide the requested information may delay funding actions.)

Date	Milestone/Deliverable	Partner Activities
4/05	Test Bed Completed at PNNL	Demonstration evaluated by PPG, ALCHAS, OI and DOE
9/05	PPG Completes Study of Condensates	All consider effect on heat transfer
9/05	Demonstration of 6% TEG at PPG	PNNL and PPG install and test TEG/ ALCHAS provides engineering drawings
3/06	ZT=2 Materials developed for 100ºC-600ºC	PNNL develops materials using magnetron sputtering/ Define scale-up approach
3/06	Define heat exchange approach for efficient waste heat recovery	All partners participate in determining approach
6/06	Demonstration of 10% TEG at PPG	PNNL and PPG install and test TEG/ ALCHAS provides engineering drawings
3/07	Approach to avoiding problems with condensates determined	All partners contribute

6/07	Demonstration of advanced 20% TEG at PPG	PNNL and PPG install and test TEG/ ALCHAS provides engineering drawings
9/07	Detailed economic analysis completed	All partners contribute

13. **Project Changes:** There were two significant changes in the program relative to original planning. After interacting with industrial partners, PNNL personnel determined that construction of a Test Bed for evaluating thermoelectric generators under conditions that represent those encountered in industry was very important. In addition, gaining early experience concerning heat transfer would be beneficial for modeling purposes and would increase the probability of a successful in-plant test later in 20005. Thus, a current technology PbTe TEG was purchased for studies to be conducted with the PNNL test bed. Secondly, early studies of potential advanced thermoelectric materials indicated that nanostructure films based on $AgSbTe_2$, PbTe and related materials offered more potential for practical applications than multi-layered films based on boron-carbide (BC) and silicon-germanium (SiGe). Whereas the BC and SiGe films have to be deposited onto very thin single crystal silicon to provide good performance, films based on PbTe and related materials can be deposited on essentially any substrate. The advanced materials effort is concentrating on sputtered mixtures of Ag, PbTe, $AgSbTe_2$ and other compounds.

14. **Commercialization Potential, Plans, and Activities:** The end-use for the technology being developed is the generation of electrical power. The amount of process heat that is wasted in the glass, steel, aluminum and chemical industries exceeds 100 TBTU/yr and may be approaching a Quad/yr. In a typical plant, the waste heat available is on the order of 60 Million BTU/hr, or 17.6 MW. With efficient capture of thermal energy and production of electrical power with thermoelectric generators, prospects for producing electrical power below the cost of power supplied by the grid are very good. Three key objectives of this program are to: (1) Demonstrate the production of electrical power from waste heat in an industrial-partner plant with a converter efficiency of 20%; (2) Develop efficient thermoelectric materials that can be produced economically; (3) Develop technology that clearly demonstrates that waste heat can be recovered efficiently. If these objectives are achieved, it is clear that industries such as those represented by the industrial partners would be motivated to utilize the technology being developed in this program to produce a significant fraction of their required electrical power.

15. **Patents, Publications, Presentations:** (Please list number and reference, if applicable. If more than 10, please list only 10 most recent.)

    None

<u>PLEASE NOTE</u>: Items one through 15 should not exceed four pages in total length.