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

6. **Expected Completion Date:** 30 June, 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 approaching 20%. This performance will be achieved with improved TE materials fabricated by depositing nanostructure films with dimensionless figure of merit (ZT) approaching or exceeding 2.0 at temperatures between 250C and 700C.

8. **Technical Barrier(s) Being Addressed:**
There are two major technical barriers that must be addressed in order to convert industrial waste heat to electricity, and thereby dramatically improve industrial energy efficiency. First, a method must be developed to efficiently capture a significant fraction of the waste heat. Second, a method must be developed to efficiently convert the waste heat to electricity. Ideally, the solutions developed to overcome these barriers should be modular and easily adapted to many different industrial waste streams with a variety of temperatures, chemistries, and heat delivery rates.

9. **Project Pathway:**
The pathway to address the need for a method to efficiently capture a significant fraction of the waste heat is to develop and demonstrate a power-generating module that can recover waste heat from a real industrial exhaust stream. Such a module could be replicated many times and inserted in appropriate places in the exhaust stream to efficiently capture a large portion of the waste heat. For demonstration purposes, conventional thermoelectric technology will be used. The pathway to

address the need to efficiently convert the waste heat to electricity is to develop advanced materials with figure-of-merit ZT well above that of conventional bulk materials. These new materials will be evaluated by a thermoelectric generator manufacturer to evaluate their suitability for integration in a thermoelectric generator. An advanced material will be integrated into a thermoelectric generator for testing in a real industrial exhaust stream. These two barriers are being addressed in parallel.

10. **Critical Metrics:**
    - Development of thermoelectric materials with ZT>1.5 for temperatures of 250C and above, and demonstration of suitability for integration in thermoelectric generator
    - Demonstration of stable, low-maintenance waste heat recovery and electricity generation with conventional thermoelectric technology
    - Demonstration of stable, low-maintenance waste heat recovery and electricity generation with advanced thermoelectric technology
    - Attractive Net Present Value for waste heat recovery and electricity generation with advanced thermoelectric technology

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. This Test Bed was used to evaluate the thermal and electrical performance of a current technology, PbTe TEG that is envisioned for use in the industrial plant exhaust stream demonstration. The information gained was highly valuable in developing the current in-plant test strategy and identifying potential problems that could arise in the in-plant test. After evaluating boron carbide and silicon germanium thin film structures, PNNL discovered a new thin film material (germanium silver antimony telluride, or "GAST") with ZT of about 1.5 at 250C. PPG identified probable locations in the exhaust stream for an in-plant test of conventional technology, and characterized the chemistry of particulates deposited on cold surfaces placed in the exhaust stream.

12. **Future Plans:**

Date	Milestone/Deliverable	Partner Activities
8/06	Deliver prototype GAST thermoelements to thermoelectric generator manufacturer	PNNL develop process and fabricate thermoelements
11/06	Deliver final thermoelements to manufacturer for advanced device build	PNNL finalize process and fabricate thermoelements
11/06	In-plant test results for conventional thermoelectric generator technology	All partners develop test apparatus; PPG install and test apparatus with partner input
3/07	Strategy to mitigate impact of waste stream processes which reduce heat transfer (e.g. particulates)	PPG, O-I, John Johnson
6/07	Final system design proposal	All partners contribute
6/07	Final economic analysis	PNNL models; all partners contribute input

13. **Project Changes:**
    The PNNL test bed work on conventional technology demonstrated the importance and challenge of transferring sufficient heat to the thermoelectric generator to produce the generator's rated electrical

output. We concluded that we could not find an efficient way to use a simple slipstream from the main industrial exhaust to drive the thermoelectric generator. As a result, we have focused on alternative methods to collect the waste heat, including schemes involving thermoelectric generators mounted in the wall of the exhaust flue, and generators connected to sealed alkali vapor heat pipes. Secondly, early studies of potential advanced thermoelectric materials indicated that nanostructure films based on AgSbTe2, PbTe and related materials offered more potential for practical applications than multi-layered films based on boron-carbide (BC) and silicon germanium (SiGe). This realization led to the discovery of GAST material that we are currently pursuing for use in an advanced thermoelectric generator.

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 18 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 near 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 portion of their required electrical power.

15. **Patents, Publications, Presentations:**

Polcyn, A. “Opportunities for Waste Heat Recovery in a Glass Furnace”. Presented at Advanced Materials for Waste Heat Recovery in Process Heating Applications Workshop, IHEA-DOE Joint Conference, Indianapolis, IN, 1 November, 2005.