EnerTech

ENVIRONMENTAL, ♦ INC.

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The following Final Report has been prepared in accordance with the reporting requirements of the DOE General Terms and Conditions for Research Grants, Section 9 of EnerTech's contract under this program. Please note that because of the timeliness of this Final Report, this Final Report also serves as the Quarterly Report for the quarter ended 12/31/96.

I. Project Aim

The aim of this project was to demonstrate the environmental and combustion performance advantages of a carbonized refuse derived fuel (RDF) slurry, produced from EnerTech's slurry carbonization process, using continuous pilot scale equipment and its suitability as an alternative fuel for utility and industrial boilers.

II. Slurry Carbonization Process Description

EnerTech's innovative slurry carbonization process will produce a homogeneous pumpable fuel from a bulky heterogeneous Municipal Solid Waste (MSW) or Refuse Derived Fuel (RDF). The product carbonized RDF slurry fuel can be pumped as a liquid and will have improved combustion characteristics, including an improved heating value which exceeds the heating value of the feed MSW or RDF. Slurry carbonization will extract chlorine and ash components, control moisture content of the product fuel, minimize excess air during combustion of the product fuel, and reduce air pollution control equipment requirements. The pumpable slurry fuel produced will be readily marketable because it will serve as an excellent feed for efficient combustion in a variety of boilers and gasifiers.

EnerTech's slurry carbonization process (please see Figure 1) will be used in conjunction with a resource recovery process that separates recyclable material from collected MSW through either dry or wet process technologies. The MSW remaining after resource recovery, often termed RDF, is a bulky, heterogeneous feed stock with a low heating value and a high chlorine content due to the presence of PVC plastic. It is because of these characteristics that RDF has a difficult time finding a market.

EnerTech's slurry carbonization process takes RDF and greatly improves its combustion characteristics, heating value, and handleability. The EnerTech technology will improve the characteristics of RDF by mixing RDF with water to form a pumpable slurry at 10-15 wt.% solids with a heating value of 700-1,200 Btu/lb. (wet or slurry basis) (STEP 1). EnerTech has demonstrated that processing RDF as a fluid slurry, instead of a bulky solid, will result in dramatic savings in operating and capital costs, and will simplify process control. The dilute 10-15 wt.% feed RDF slurry then will be pumped and pressurized above the saturated steam pressure to prevent the slurry from boiling when heated above its normal boiling

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point, and minimize system thermal energy inputs (STEP 2). Using heat exchangers, the temperature of the pumpable slurry will be raised to between 520 and 620°F (STEP 3). At this temperature and pressure, the heated slurry will flow to a reactor where it will molecularly rearrange by splitting off carbon dioxide gas from the solid RDF (STEP 4). This reaction is stopped short of RDF pyrolysis into hydrocarbon gases and liquids. Due to the carbonization reaction, the solid and polymer-like RDF molecules will be significantly reduced in size and improved in uniformity. In a separate, concurring reaction, the PVC content of the RDF will decompose to form soluble hydrochloric acid, which can be neutralized with alkalis and washed from the solid carbonized RDF product, along with other salts.

Figure 1 - Simplified Flow Diagram of EnerTech's Slurry Carbonization Process.

After partial cooling through the same set of heat exchangers, the carbonized RDF then will be dewatered, washed, and reconcentrated to approximately 50-55 wt.% solids, with a pumpable viscosity of 500 cP and a heating value of 7,400-8,200 Btu/lb (wet basis) (STEP 5). By Coal-Water-Mixture (CWM) standards, a slurry with these characteristics is considered an excellent fuel for combustion (STEP 7). Dissolved salts and acids are removed and recycled from the filtrate water which also is recycled to the feed slurry preparation (STEP 6).

III. Project Objectives and Results

The overall objective of this project was to begin EnerTech's pilot plant program to demonstrate the Company's technology, which produces clean energy from municipal solid waste (MSW). From the data generated in the research, EnerTech conducted preliminary engineering design work as well as detailed economic studies for the first commercial unit. The specific objectives of this project and results of research completed under this project were:

1) To establish the rheological behavior of the raw and carbonized RDF slurry - Viscosity measurements of the raw and carbonized RDF slurry were completed with a Haake® Rotoviscometer RV-100 at a decreasing shear rate of 100 Hz. The solids loading of the raw RDF slurry was determined to be approximately 9.1 wt.% total solids at 500 cP. In comparison, the solids loading of the carbonized RDF slurry ranged between 43.3 to 50.1 wt.% total solids depending upon the conditions of slurry carbonization. The slurry carbonization treatment improved the rheology of the RDF slurry over 375%.

2) To evaluate the effect of pilot scale slurry carbonization on the chemical and physical properties of the RDF slurry - Continuous pilot scale slurry carbonization experiments were completed with the Energy & Environmental Research Corporation's 625 lb/hr hot-water-drying pilot plant, with samples of the raw and carbonized RDF slurry sampled for analysis. Depending upon reactor conditions, the slurry carbonization treatment removed approximately 67 to 72% (wt.% and dry basis) of the raw RDF oxygen as carbon dioxide gas, and improved the heating value of the carbonized RDF 64 to 88% (HHV and dry basis). In addition, over 98% of the raw RDF chlorine was decomposed and removed from the carbonized RDF product as chloride salts.

3) To establish the operating continuity and optimum operating conditions of pilot scale slurry carbonization - Several modifications were completed to the slurry carbonization pilot plant equipment to improve pilot plant operational reliability, system performance, and characteristics of the carbonized slurry. Statistical screening experiments then were completed with the pilot plant in which the reactor temperature, reactor residence time, plastic content of the raw RDF, and chlorine content of the feed RDF were modified. Samples of the feed and product streams were taken from each campaign and test period, and laboratory analyzed to determine yields and chemical properties versus operating conditions. Optimal slurry carbonization conditions appear to be between 550 and 620°F with a residence time of 5 to 20 minutes.

4) To characterize the gas and water effluents produced from pilot scale slurry carbonization - Samples of the carbonization gas and filtrate were sampled and analyzed for organic, ash, trace metals, and chlorine content. The carbonization gas was composed of approximately 95 wt.% CO₂, with lesser amounts of CO, CH₄, H₂, and light organic gases. The water filtrate contained significant soluble organic compounds which were highly oxygenated, and the majority of the chlorine and other soluble ash components of the raw RDF.

5) To characterize the fuel potential of the carbonized slurry and the flue gas/ash produced from pilot scale atmospheric combustion of the carbonized slurry - Continuous pilot scale combustion experiments were completed with the carbonized RDF slurry fuel in the Energy and Environmental Research Corporation's 800,000 Btu/hr Boiler Simulation Facility. Table 1 summarizes the emissions determined from this combustion experiment and compares it to the New Source Performance Standard (NSPS) for Municipal Waste Combustors (MWC), promulgated December 19, 1995.

	Carb. RDF Slurry		Municipal Waste Combustion	
	Emissions	Control Technology	1995 NSPS	Required Control Technology
Carbon Dioxide (CO ₂), vol. %	11.1	----	----	
Carbon Monoxide (CO), ppmv	59	None	50-150	Good Combustion Practice
Nitrogen Oxides (NO _x), ppmv	132	None	150	SCR or SNCR
Sulfur Dioxide (SO ₂), ppmv	71	None	30	Acid Scrubber
Hydrochloric Acid (HCl), ppmv	6	None	25	Acid Scrubber
Total PCDD/PCDF, mg/dscm	0.38	None	13	Activated Carbon Injection
Mercury (Hg), mg/dscm	0.0066	None	0.08	Activated Carbon Injection
Cadmium (Cd), mg/dscm	0.0017	ESP	0.01	Baghouse or ESP
Lead (Pb), mg/dscm	0.0346	ESP	0.1	Baghouse or ESP
Particulate Matter (PM), mg/dscm	31.2	ESP	15	Baghouse or ESP

*All emissions corrected to 7% O₂, dry basis

Table 1 - Summary of Emissions From Combustion of the Carbonized Slurry and Comparison to MWC NSPS.

In addition, carbon burnout/conversion of the carbonized RDF slurry was determined to be 99.9+% and combustion ash was determined to be non-hazardous using the Toxicity Characteristics and Leaching Procedure

(TCLP). In general, emissions from combustion of the carbonized RDF slurry were comparable to significantly lower than the current NSPS for MWC, with fewer air pollution control systems required.

6) To establish the operating continuity and optimum operating conditions for pilot scale combustion of the carbonized slurry fuel - Statistical screening experiments also were completed with the carbonized slurry and combustion pilot plant in which firing rates, excess air levels, air splits, preheat temperatures, swirl number, and atomization air levels were modified. Flue gas and ash emissions were determined from each campaign and test period. Optimal combustion conditions appear to be between 1700 and 2200°F with excess air levels of approximately 20%.

7) To perform detailed engineering and economic estimates of a commercial scale process - Engineering and economic estimates of a commercial scale slurry carbonization process were determined from computer simulations using the SpeedUp™ software marketed by Aspen. Wet resource recovery and 100% filtrate water treatment and recycling were included in the process simulations and estimates. An integrated slurry carbonization facility was estimated to cost approximately \$95,000/TPD of received MSW capacity, with a cost of MSW disposal below \$30 per ton (not including capital debt service and depreciation). Based upon the heating value of the raw MSW, net electricity generation efficiency was estimated to be approximately 19.7% (including parasitic consumption) when the carbonized slurry was cofired in a pulverized coal boiler.

8) Reports - Financial and technical reports were submitted as required by the Federal Assistance Recording Checklist, Form EIA-459A.

All objectives for this project were met or exceeded with the research completed under this program.

IV. Current Status of Commercialization of Slurry Carbonization - What the Future Holds

EnerTech has aggressively embarked upon a campaign to commercialize its process of slurry carbonization. These efforts have yielded positive results. Currently, commercialization efforts have focused on the MSW application. EnerTech has identified four major markets to concentrate its efforts. With each major market EnerTech's goal is to:

- a) Find a large company or a consortium of companies to license the basic technology;
- b) With its licensee(s), demonstrate the technology on a 25 TPD or larger scale utilizing EnerTech's basic design and the detailed design generated by the licensee(s) or other EnerTech licensees;
- c) With its licensee(s), build commercial units; and
- d) EnerTech's role thereafter will be primarily licensor, equipment supplier, and engineer support.

The four major markets mentioned above for the MSW application of slurry carbonization are: 1) United States and North America; 2) Japan, China, Malaysia, Indonesia, Thailand, Vietnam, and the Philippines; 3) Korea, Taiwan, India, and other Asia; and 4) Europe.

Currently, the United States is EnerTech's primary marketing thrust. As part of its due diligence in determining the feasibility of the MSW application in the United States, EnerTech hired two outside consultant firms (*please note that the cost of these firms was borne by EnerTech, no DOE funds were used for these studies*). The two firms hired were M.L. Payton Consultants (MLP) of Houston, Texas and Environmental Business International (EBI) of Fremont, California. These studies would provide greater details to the market assessment performed by NCAT Development Corporation for the Department of Energy under this program. The NCAT report concluded:

"Based on the primary and secondary research performed for this assessment, it appears that the subject invention has a strong likelihood of penetrating the MSW equipment market."

The primary task for MLP, who specializes in detailed surveys, was to canvas the ultimate customer to determine if there would be a demand for slurry carbonization. EBI is well entrenched in the MSW industry and their goal was to utilize their industry knowledge and contacts, couple that information base with the results from the MLP survey, and determine if there was an immediate market for the technology in the U.S. If there was a demand for slurry carbonization in the MSW industry, then EBI was to help determine a strategy for implementation.

MLP surveyed over 550 municipal waste authorities - the ultimate customer. The survey included a detailed description of slurry carbonization with diagrams and an eight page survey form. Of the total amount of surveys mailed, 20% participated covering 39 states. Of those responding, over 70% were professionals with more than five years experience in the MSW industry. The final MLP report was dated August 1996 and excerpts from the survey results are below:

- a) Only 26% of the respondents reacted negatively to the process. This is very positive considering the MSW industry is very reluctant in accepting new technologies.
- b) Only 2% of the respondents had ever heard of EnerTech's slurry carbonization.
- c) Only 8% of the respondents considered slurry carbonization as a combustion technology.
- d) The most positive aspects of the process, according to the respondents, were the economics, production of a fuel product, and receiving all waste at a central site.
- e) Of those surveyed, 53% had tipping fees less than \$35 per ton.
- f) 51% of the respondents believed that landfill space will not become limited in their area for at least the next five years.
- g) The most negative aspects of the process were that it was an unproved technology, the economics of the process (for those with tipping fees less than the tipping fees required by slurry carbonization), and the fact that many respondents were unfamiliar with the technology.
- h) 87% responded that before they would consider any waste disposal technology, they would have to see commercial units in operation.
- i) The most important factors in evaluating whether to purchase a technology were capital cost, operation cost, and simplicity of operations.
- j) 35% of the respondents expected tipping fees to rise at a rate of at least 5% per year for the next ten years.
- k) 47% of the respondents were receptive to new technologies and 17% respondents expected to install a technology as an alternative to landfilling within the next 3-5 years.

Referring to the excerpts above, the survey uncovered five key elements with respect to the future success of slurry carbonization in the United States:

1. The technology is relatively unknown, but upon first introduction, it was positively received by the industry (*excerpts a-d above*);

2. Landfilling will remain the primary method of MSW disposal for the foreseeable future and there will be some markets in which EnerTech will not be able to compete because of cost (*excerpts e-f above*);
3. For those markets in which slurry carbonization can compete economically, before a decision could be made to utilize the process, the potential customer would have to see a working unit. Therefore, the technology will have to be demonstrated in the United States (*excerpts g-h above*);
4. The primary factor in accepting any technology is economics of which EnerTech can compete in some markets. In addition, many experts believe the basic cost structure of waste disposal will rise over the long term. This will be an advantage for slurry carbonization because it would not be subject to future regulations as much as current technologies would be, thereby making fixed costs more predictable at the rate of inflation (*excerpts i-j above*); and
5. The technology has great opportunity, however, on a market by market basis. Currently, municipalities are seeking new technologies (*excerpt k above*).

The EBI report, which was issued in November 1996, concluded that the slurry carbonization process should be able to find a lucrative market niche in the United States. *EBI believes that 2-3 plants under construction within five years is an attainable goal.*

EBI recommends a consortium-based approach for implementing the technology. Possibly a core group of companies with a unique partner for each project so that local companies and local contacts could be utilized. Each consortium member would have a core strength needed for successful implementation of the technology (i.e. engineering, operations, power, etc.).

Per EBI, the current trend for MSW disposal will be the mega landfill (receiving over 10,000 tons per day at a greatly reduced cost) which will stabilize tipping fees in many areas of the country. This trend, however, is expected to be a short-term phenomenon (about 5 years), but in the near-term it will make it very difficult for other technologies to compete economically.

To take into account the threat of the mega landfill, a systematic approach in locating suitable sites for slurry carbonization plants should be employed. First, areas currently subject, or in the future subject, to the mega landfill would be filtered out. Next, areas with tipping fees greater than \$50 per ton, smaller capacities (less than 500 TPD), and/or long hauls would be selected. Of those selected candidates, those which have a qualified user of the carbonized slurry fuel near a potential EnerTech site would be considered as a prime candidate. From a cursory search, with the above criteria, about 8% of the MSW market could currently qualify.

Through the definition of a suitable candidate from EBI's systematic approach, there is a large enough market for the technology to establish several commercial generations. If these generations are successful, then the technology could gain a strong foothold in the MSW industry, especially if the trend of the mega landfill subsides.

V. The Plan and Prognosis

A. The Market

As revealed by the market studies, the key criteria for success will be cost and slurry carbonization will have to compete on a cost basis. Based on engineering studies under this program, it appears that the

technology can compete on a cost basis. Please see Table 2 for comparison of slurry carbonization costs to major alternatives.

	EnerTech	Mass Burn	Resource Recovery
Capital Cost per TPD of capacity	\$95,000	\$128,700 - \$222,100	\$ 34,700 - \$121,600
Operating & Maintenance Costs without debt service and depreciation (per ton):	\$30.00	\$32.05-\$48.49	\$54.94

Table 2 - Summary of Capital and Operating Costs For Major Competitive Technologies.

Landfilling will always be the least expensive way to dispose of MSW when examining costs on an average basis. However, of the 209 million tons of MSW generated in the United States in 1995, 39% was disposed of through Mass Burn or Resource Recovery technologies. In addition, utilizing a micro-approach, there are many markets in the United States where the cost of landfilling exceeds \$50/ton. Therefore, EBI concluded that EnerTech's technology could compete on a cost basis in many markets in the U.S..

B. Steps Towards Commercialization

EnerTech will follow EBI's recommendation for implementation in the U.S.. During these efforts, EnerTech will be extremely mindful of the responses from the ultimate customer in the MLP survey. EnerTech planned steps towards commercialization are:

1) Develop a Consortium of Companies to Further Develop, Market, and Sell the Technology - EnerTech currently is seeking commercialization partners in the United States. EnerTech currently has signed an agreement with Mitsubishi International Corporation, a U.S. Company to help with the U.S. efforts. This agreement is an important first step towards U.S. commercialization, but other companies, with industry pertinent experience also are needed. *Those members of the U.S. Consortium will share in the success of the technology.*

2) Build a Demonstration in the United States - As revealed in the market assessment by NCAT Development Corp., EBI, and MLP, the technology must be demonstrated in the United States. EnerTech has accumulated enough design data to build a 25 TPD unit in the United States. A semi-commercial situation will be sought for this \$10-\$15 million project where the tipping fees and slurry fuel sales will offset costs. This first generation unit will address industry skepticism, allow future potential customers to visit, and will allow the U.S. Consortium to optimize the technology for future generations.

To pay for the cost of demonstration, EnerTech will be seeking investment from the Federal Government. In addition, Consortium members will be expected to invest in the first unit.

3) Find the Most Suitable Customers - As recommended by EBI, a great effort will be employed in seeking the optimum sites for commercial units. Criteria such as current disposal situation, tipping fees, competitive situation (far from mega landfills), user of the slurry fuel, and other important factors will be scrutinized and the most suitable candidates will be selected. From this list, marketing efforts will be focused.

4) Have Three Installations under Construction Within Five Years - Should the EnerTech succeed in locating suitable Consortium members, receive funding for the first unit, and properly execute the potential

customer selection process, the Company expects to meet the goal that EBI stated as attainable - two to three units under construction within five years.

C. Projections

Should EnerTech be successful and have three commercial units under construction within five years, EnerTech would aim to have a minimum of one unit sold per year thereafter. If this goal is met, and EnerTech sells twenty 500 ton per day units in a 20 year time frame, this would result in approximately \$1 billion in equipment and construction sales. In addition, should the EnerTech Consortium own and operate all of these units, by the twentieth year, the business would render over \$60 million in annual pretax profits per year to the Consortium. Is this goal attainable? *If the above projections were met, the EnerTech Consortium would have garnered only 1.6% of the 1995 market share of 209 million tons.* Please note that all amounts are expressed in 1996 dollars.

VI. The ERIP Program

EnerTech would like to thank the DOE for the opportunity of working with the ERIP program. The program provided an excellent service with the required workshop, the market assessment provided, and the continued hands-on approach of the inventions coordinator and other ERIP personnel. When EnerTech embarked upon this project in 1994, many people believed that the odds, as they are with any start-up company developing an innovative technology, were greatly against EnerTech. Now in 1997, EnerTech has greatly addressed much of the development risk and although there still remains significant hurdles for commercialization, the prognosis for success is very good. The ERIP program definitely played a role in this success with their investment in EnerTech and the process of slurry carbonization.

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