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Task 3.12 - Small Power Systems

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1.0 INTRODUCTION

One of the overall goals of the U.S. Department of Energy (DOE) is the development of the technology necessary to provide for a secure, reliable, affordable, and environmentally sound source of energy. This technology is important to ensure economic stability and growth in the next century as well as to reduce current and minimize future environmental impacts associated with power generation in the United States and the world.

Throughout the world, coal will play an expanded role in the production of affordable energy necessary to meet the demands of economic development and growth. The development of more efficient and environmentally sound technology in the United States may present export market opportunities throughout the world. For coal to play a key role in the energy mix, it will be necessary to develop and commercialize technologies capable of producing electricity at significantly higher overall system efficiencies with minimum emissions. A number of demonstration projects addressing these needs for large utility plants are being performed under the Clean Coal Technology Program. A need also exists for smaller (500 kW - 20 MW) systems to satisfy the needs of remote-site markets. Many of these markets are in areas where a small increment of power is needed to meet demand and the installation of transmission lines to bring in the power is not practical or economical. Diesel engines have traditionally filled this market niche; however, some of the advanced power systems currently under development could provide power more economically and with reduced environmental risk. Innovative solutions to barrier issues, in some measure common to all advanced power system processes, can be developed and demonstrated more economically and effectively in small-scale systems. Examples are material issues, involving ceramic and refractory components, and operational issues unique to high-temperature pressurized systems.

2.0 OBJECTIVES

The programmatic goal in advanced power systems will be to develop small power systems in the range of 20 kW to 20 MW in cooperation with commercial vendors. These systems will be designed to incorporate the advanced technical capabilities of the EERC with the latest advancement in vendor-offered hardware and software.

Work during this program year has focused on two main technical issues. Pressurized fluid-bed combustion has been identified as one technology applicable to the small user's market. Work is focused on the development of sorbents for in-bed alkali, sulfur, and chlorine capture to reduce or eliminate problems on backend equipment. Tar production in the gasification of coal is deleterious to the operation of downstream equipment, including fuel cells, gas turbines, hot-gas filters, and pressure swing adsorption systems, all of which are candidate technologies for use in small power generation systems. Cracking of these tars into smaller hydrocarbons is the second technical issue addressed in this year's advanced power systems task. In addition to working to solve these technically related problems, existing and developing power systems are being surveyed and a technology option(s) chosen as the focus of further development.

The specific objectives of the three tasks are the following:

- To determine optimum sorbents and their range of effectiveness as in-bed sorbents for alkali, sulfur, and chlorine control during pressurized fluid-bed combustion.
- To determine the effective operating range of selected sorbents for cracking tars from gasification systems, measure the quality of the resultant gas, and determine the best advanced power systems to utilize this gas.
- To collect information from vendors, evaluate alternative design concepts, and select a practical and economic design for targeted development in upcoming years. A leading objective for the EERC will be to form strong business partnerships with equipment manufacturers who can commercialize the selected power system design.

3.0 ACCOMPLISHMENTS

The major effort focused on reviewing available and emerging technologies applicable for small or remote sites at capacities between 500 kW and 20 MW. A recent comprehensive study was completed by the Energy and Environmental Research Corporation (EER) for the Alaskan Division of Community and Regional Affairs (DCRA). The focus of this study was on the commercial availability of combustion systems integrated with power generation units. The focus of the effort during the past 6 months by the EERC has been on gasification technologies, including their integration with turbine generator sets, spark-ignited engines, diesel engines, and fuel cells. The intent was to complement the work performed on the combustion technologies to provide a comprehensive review of all available technologies applicable for small, remote applications. A brief summary of the study for DCRA is presented, along with a more detailed presentation of the review recently completed by the EERC. A topical report will be submitted that details the work performed at the EERC.

3.1 Review of Small Combustion Systems

The EER contacted companies throughout the world who could supply small-scale, coal-fired power plant technology. A questionnaire was provided to each potential technology supplier. The evaluation of technologies, based on the answers to this questionnaire, revealed that fluidized-bed combustion and micronized coal combustion technologies were perhaps the best technologies for rural Alaskan applications. Eleven commercially available fluidized-bed combustion systems were evaluated as well as two micronized coal technologies. In addition, four developing technologies were evaluated. From the 17 technologies analyzed, EER concluded that the five best commercially available technologies are as follows:

• Cethar Vessels, Ltd.	Fluid bed
• Fuller Power Corporation	Micronized coal
• JWP Energy Products, Inc.	Fluid bed
• TCS, Inc.	Micronized coal
• Thermax Ltd.	Fluid bed

The five finalists were then contacted to provide cost estimates for specific sizes of their combustion systems. EER contacted Dresser–Rand to provide cost estimates for multistage steam turbine/power generation units to be integrated with the combustion systems. EER also provided the balance of plant cost estimate to provide an overall cost estimate for each system and size analyzed. The cost estimates were then used in conjunction with the questionnaire answers to determine the best candidate technology for power generation in Alaska.

The highest-ranked technology supplier, according to the EER study, was Cethar Vessels, Ltd., a fluidized-bed combustion company based in India. They have a relatively low-cost system and have built power plants in the 250-kW_e to 5-MW_e range. Of all of the suppliers, Cethar Vessels has installed the most units. Also, Cethar alone has integrated power generation systems with their small-scale combustion system. The Fuller Corporation MicroFuel System yielded a fairly low cost for the 5-MW_e units. The system would have been considered more seriously, but Fuller did not want to quote a smaller unit. However, in rural Alaska, most of the power generation needs are for plants smaller than 5-MW_e. The capital cost estimates for the five finalists ranged from \$1664/kW_e for a 5-MW_e system to \$7685/kW_e for a 200-kW system. The study did not report the cost of electricity (COE) for any of the systems studied.

More extensive studies have since been completed investigating the feasibility of fluid-bed combustion for power generation in Alaska. One study, completed by Gilbert-Commonwealth, looked at utilizing a Donlee Technologies FBC, with capabilities of cofiring municipal solid waste (MSW) along with coal. Initial studies indicated a relatively high COE of approximately \$0.40/kWh; however, further investigations are ongoing and likely to result in a significantly lower COE. Another fluid-bed system, designed by EER and The Will-Burt Company, utilizes a gas turbine rather that a steam turbine, yielding a COE as low at \$0.17/kWh. If a humidified gas turbine is used, the COE could be reduced to as low as \$0.11/kWh. These two systems will be studied in more detail as additional information becomes available.

3.2 Gasification Systems

The EERC is completing a detailed review of available and emerging gasification technologies coupled with either gas turbines, spark-ignited engines, diesel engines, or fuel cells. First-level capital cost and COE estimates have been made and compared to those for combustion systems. The conclusions and recommendations from that evaluation are presented in this section. Details of this study are being presented in a separate topical report to be issued in August 1995.

With respect to the objectives of this study, results are less conclusive than hoped. This is due specifically to the lack of reliable or predictable performance data and costs for integrated gasifier–engine or gasifier–fuel cell power systems. Performance and cost data for small coal-fired power systems, on the other hand, appear reasonably firm. Numerical comparisons are based on composites of rough cost data and some cautious assumptions.

The lack of reliable cost data for gasifiers in integrated systems is due to the substantial amount of gasifiers and costly engineering that would be required by providers or developers for these specific systems. The value of a number of similar, recent investigations is limited for this same reason. If more definitive results are desired, the specific vendors must be paid. An investigation to provide something approaching an EPRI TAG-1 cost estimate of a gasifier-MCFC system may cost $100,000 to $200,000 and substantially less for gasifier–engine systems.

For each kind of integrated system, request for proposals (RFPs) should be issued for two or more conceptual studies (to provide system designs and costs) to teams of developers/designers of specific gasifiers and fuel cells or engines.

For near-term (pre-2000) installations in small or remote communities, coal-fired steam power systems are generally the optimum choice, if an economical supply of coal is available. Otherwise, the size, reliability, and projected cost of alternative biomass fuels must be very carefully evaluated. It should be kept in mind that "waste" biomass fuels are only "free" in the absence of present economic use for them. The lower limit of available coal-fired steam systems is 500 kW. The average overall conversion efficiency for all the combustion systems reviewed in this study is only around 20%.

Most coal-fired steam systems can probably be modified to run on coal and biomass or biomass alone. Biomass combustion systems, with gas turbines, though far less developed than coal-fired systems, are available or under development for as low as 300 kW.

Any feasibility studies, undertaken with an intent to build a demonstration plant must be very site-specific, with the fuel supply economics being the decisive factor.

Of the alternative power systems considered in detail in this study, integrated systems consisting of relatively simple, cheap gasifiers with pilot-fueled engine generator sets are immediately feasible and appear ready for small commercial-scale demonstration. Some design effort is still needed to maximize the amount of rejected heat from the engine that can be returned to the gasifier for maximum overall efficiency, which may reach 45%. COE production ($/kWh) of such systems appears to be comparable to the upper limits of COEs for coal-fired steam systems. A minor cost factor is the cost of diesel fuel, which supplies about 5% of the total energy input. Such systems can be assembled in capacities down to as low as only 40 kW, compared with 300–500 kW for any alternatives.

Optimum combinations of gasifier and engine have yet to be identified by a joint effort of gasifier and engine providers. Only one such combination (1 MW) has been demonstrated, in Italy.

Spark-ignited gas engines can also be used in combination with gasifiers, but have the disadvantages of lower efficiencies and complete dependence on the gasifier. The pilot-fueled diesel system offers the emergency fallback feature of being able to run on diesel fuel alone, albeit expensively, in case the fuel does not get delivered or the gasifier breaks down.

The high overall conversion efficiencies of gasifier–engine systems or gasifier–fuel cell systems, compared with combustion systems, are essential to offset their higher capital costs. Therefore, meticulous system design for maximum waste heat recovery is the essential aspect of specific future design efforts.

Integrated systems consisting of more sophisticated gasifiers with molten carbonate fuel cells (MCFCs) can probably provide electric power at overall efficiencies exceeding 55%. High-temperature (1100°F) exhaust heat can be readily recovered and returned to a gasifier in enough quantity to make combustionless gasification possible, allowing 100% gasifier efficiencies. No such systems, on any scale, have yet been built, however. The two U.S. developers of MCFCs predict commercial units to be available by 1998, in 1- and 2.8-MW capacities, at capital costs of about $1500/kW, and running on natural gas.

The most important factor on overall system efficiency is the cold-gas efficiency of the selected gasifier. Effectiveness of heat recovery is next in influence.

The cost of gasifier–fuel cell systems remains uncertain because of the need for specific designs of gasifiers to operate in this mode and the cost of still unproven gas cleaning and heat recovery components. The only responsible cost estimate for a single gasifier for use with an MCFC, that could be built and delivered now, is not competitive with the gasifier–engine alternatives reviewed in this study. It includes large contingency factors to cover tar cracking, sulfur capture, filtration, gas scrubbing and heat recovery components, of a complexity not yet defined. More "aggressive" cost projections, for future, mass-producible units, appear quite comparable but will require substantial component design development. This supports the above recommendation of more detailed studies of specific systems.

Of the possible gasifiers and molten carbonate fuel cells reviewed, the following specific combinations stand out as being compatible and worthy of further consideration.

The MCFC design by Energy Research Corporation, with internal methane reforming, requires as much methane as possible for maximum efficiency and is therefore well suited to use the high-Btu gases produced by indirectly heated gasifiers, offered by Batelle/FERCO or MTCI/ThermoChem. The minimum scale for such a system will be roughly 2.1 MW.

The pressurized MCFC design by M-C Power, with external methane reforming for use with natural gas, requires a gas containing as much H_2 and CO as possible, and no methane, and is, therefore, well-suited to the gases produced by the directly heated, pressurized gasifiers offered by IGT/Tempella. The minimum scale for such a system will be about 1 MW.

Solid oxide fuel cells (SOFCs) are more forgiving of gas compositions and the inevitable pollutants, but appear further from commercial deployment than MCFCs and are not covered by this study. They should, however, be included in future studies or comparisons, if an SOFC manufacturer, teamed with a gasifier developer, is interested in participation.

In preliminary investigations (including this one) or projections for integrated systems with gasifiers, the problem of gas cleaning appears to be receiving inadequate attention and must be addressed as part of the system studies proposed above. Major gasifier developers in the United States (Batelle and IGT) have programs in this area. There is room for further, small-scale R&D in the following areas, if specific novel process steps can be identified.

- Tars can be nearly avoided by extremely high-temperature gasification or, possibly, by stratified downflow gasifiers, which have been used with engines.

- The "tar" (condensible organics) in product gas from different gasifiers varies widely and is not readily predictable. Tars can be eliminated from the gas stream by hot catalytic cracking or by chilling, scrubbing, and reheating, both of which are expensive and have relative merits and disadvantages. Extended tests with small MCFCs should be done to better establish the limits of tolerance for different categories of tar components, differentiated mainly by molecular weight or boiling point. If at all possible, such studies should be done on real product gases from pilot-scale gasifiers, to the extent that extended runs can be financed for multiple objectives.

- Hydrogen sulfide (H_2S) in the product gas, at levels above 1 ppm (part per million, or 0.0001%) is very harmful to fuel cells, although it presents no problem to engines. Because the H_2S content of product gases from biomass gasification is insignificant for most other applications and below the limits of detection for the usual means of gas analyses, it is generally not reported in the biomass gasification literature. It can be effectively removed from the product gas by using a zinc oxide (ZnO) sorbent step. A possible best case result of this study may be a gasifier selection for which the product H_2S level is below 1 ppm, which must be confirmed experimentally.

- A problem parallel to that of H_2S will arise with regard to the chlorine content of product gas from some of the plastics in refuse-derived fuel (RDF) or MSW gasifier feed and possibly also with lead and or mercury. In selecting specific sites and fuels for conceptual studies or demonstration projects with gasifier–MCFC systems, the use of MSW should be avoided, eliminating one increment of complexity.

There are two approaches to gas cleaning. One is chilling and wet scrubbing, which is a proven technology, buts incurs a wastewater treatment/disposal problem. For MCFC applications, the gas must be reheated to at least 1100°F, so that the heat recovery system will be fairly complex. For the engine application, product gas must be cooled to ambient in any case.

The other gas-cleaning approach is to maintain temperature, through tar cracking, H_2S capture and filtration, simplifying heat recovery but requiring more speculative, emerging technology. Even for gas engine applications, with gas cooled to ambient, this approach is recommended by the developers of the one demonstrated system.

While the original scope of this study presumes small and remote communities, the proximate justification for the alternative power systems discussed is a high cost of electric power from conventional coal-fired power plants. Compared with typical U.S. electric power costs, those in much of Europe are also high enough to trigger interest in biomass power, where commercial demonstrations are indeed more numerous and advanced than in the United States. Therefore, in addition to underdeveloped nations, the European market should be considered for development of these technologies.

4.0 FUTURE PLANS

Based on the results of the recently completed study, one or two practical and economic designs will be selected for further development in the upcoming year. Developmental activities will be identified and a plan devised to address remaining issues with the selected technologies. A commercialization plan for the selected technologies will also be developed during the next 6 months. R&D efforts in support of the remote power systems are also planned, specifically in the areas of sorbents for alkali capture in pressurized fluid-bed combustion systems and sorbents for cracking tars in gasification systems.

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