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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 impact 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 (20-kW to 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 that are 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.

Because of their size, small communities are faced with a variety of problems that make the construction and operation of community-wide managed waste and wastewater cleanup, reuse, and/or disposal a difficult undertaking. Many communities in rural America have been losing population as a result of migration to large urban areas. Concurrently, federal and state regulations pertaining to waste disposal and water supply treatment have become more stringent. Small communities must provide the same degree of treatment that is now provided by large communities. Another effect of their size is the lack of economies of scale that are possible with the construction of waste and wastewater treatment facilities for larger communities. In addition, the economic base of smaller communities is often not large enough to support the added burden of more sophisticated treatment facilities, further stressing the resources of these rural communities. In many cases, the smaller communities have a lower per capita income, a residential tax base with few commercial or industrial entities, and difficulties in arranging financing become of low bond ratings (1). In many cases, the small community has limited economic resources and experience to manage wastewater treatment facilities. Problems are often experienced in design, contracting, inadequate construction supervision, project management, billing, accounting, budgeting, and maintenance (2). Overcoming these problems makes the implementation of treatment facilities in the United States a major undertaking. Low-maintenance solutions must be developed to provide proper water and waste treatment for small communities.

In many developing countries, waste disposal and water treatment capabilities are often not available to the general population outside the larger urban centers. In many cases, this is due to a lack of infrastructure to support these capabilities. Access to required power supplies is extremely limited, and power generation capabilities are nonexistent. Of particular concern is the increasing occurrences of outbreaks of infectious diseases within the last 30 years in these areas. As these occurrences have become more frequent, concern has increased over the potential for transmission of these diseases to other countries. At least partially, the trend for increasing infectious disease occurrences has been attributed to human-induced environmental stress and the lack of even the most rudimentary control techniques in many areas of the world. It is now becoming evident that the best method for controlling infectious disease is through the development and implementation of preventive measures and containment capabilities.

During the past 15 years, interest in small treatment systems has been overshadowed by design, construction, and operation of large regional systems. Small systems were often designed and constructed as small-scale models of large plants. As a consequence, many are operationally energy- and resource-intensive. Greater attention needs to be focused on the design, operation, and maintenance of individual on-site systems. Decentralized technologies can reduce construction costs, minimize operation and maintenance costs, lower energy consumption, and drop infrastructure requirements as compared to the centralized options. These technologies are especially important in areas where centralized options are not possible.

The health and pollution hazards, including groundwater contamination, caused by the use of such systems warrant special attention and represent an area of need not only in the United States, but worldwide. In many cases although effective treatment methods exist to provide safe drinking water and disposal of wastes, the impediments to implementing optimal technologies may be lack of sophistication and funds. Some small systems do not have access to skilled technicians, good support services, or the economies of scale available to larger systems.

2.0 OBJECTIVES

The programmatic goal in advanced power systems is to develop small integrated waste treatment, water purification, and 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 Energy & Environmental Research Center (EERC) with the latest advancement in vendor-offered hardware and software. The primary objective for the work to be performed under this subtask is to develop a commercialization plan for small power systems, evaluate alternative design concepts, and select practical and economical designs for targeted development in upcoming years. A leading objective for the EERC will be to continue to form strong business partnerships with equipment manufacturers who can commercialize the selected power system and treatment design(s).

FY95 activities were focused on collecting information from vendors and evaluating alternative design concepts. This year's activities began with the process of selecting one or more designs for targeted development. Once the design(s) are selected, specific technical requirements will be defined that will be the subject of focused studies to overcome technical barriers to achieving a clean, cost-effective generating system. During this program year, the technical barriers limiting the use of the selected technology in the small power system market will be identified. A plan will be devised to overcome these barriers.

Also during this program year, strong business partnerships will be developed between the EERC, Morgantown Energy Technology Center (METC), and equipment manufacturers who can commercialize the selected power system(s). A plan will be created for rapid development leading to commercialization. This may involve integration of this task with other research activities currently ongoing at the EERC and METC.

3.0 THE INTEGRATED MODULAR SUPPORT SYSTEM CONCEPT

The solution to the energy, water, and waste treatment needs of the small community involves the use of integrated energy and environmental technology modules to meet the specific needs of each community. This modular approach uses new and existing technologies to provide waste disposal, water supply purification, wastewater treatment, and power generation capabilities on a scale appropriate to the situation. Integration of specific modules allows the total needs of the community to be met. In some cases, a specific technology such as fluid-bed combustion can be used to solve several problems. Fluid-bed combustion can be used to dispose of agricultural, industrial, and municipal solid wastes and sludges while utilizing these carbon sources for the production of energy or heat. The use of integrated, multifunctional modules increases flexibility, mobility, efficiency, and cost-effectiveness.

Several components must be considered in selecting wastewater treatment and water purification technology, the main consideration being the ability of the process to destroy microorganisms. In addition to their biological disinfection capabilities, these technologies must require relatively low maintenance, be modular and transportable, and be relatively cost-effective. Community size and geographical constraints must also be taken into account in selecting a technology. There are several treatment options that can be used alone or in a treatment series to solve one or several problems. These option include ultraviolet radiation, ozonation, reverse osmosis, filtration, chemical treatment, and distillation. Also, these systems can be designed to address a variety of water disposal situations, from well-drawn water to wastewater and industrial process water. The benefits that may be realized by this approach include a potential for economic development, protection of the environment, improvement of health for community members, job creation, and a general improvement in the quality of life.

This concept revolves around packaged systems, each a proven technology, integrated in such a manner as to take advantage of the synergistic effects that the treatment and power generation modules offer to each other. Technologies that are easy to install and operate are particularly appropriate for use in package plants. These treatment plants are factory-designed to implement effective methodologies in the more restricted conditions typical of remote applications. The "packaged plant" and modularity of the units is meant to address the financial, operational, regulatory, and installation limitations that hamper small water and waste treatment ability to deliver safe waste and comply with current disposal standards.

The ultimate disposal of the solid and semisolid residuals (sludge) and concentration contaminants removed by treatment has been and continues to be one to the most difficult and expensive problems in the field of wastewater engineering. Recent legislation banning the ocean discharge of sludge has eliminated one disposal option used by some large coastal cities. Because of the concerns about air and groundwater pollution, the disposal of sludge by incineration and by the application on land or in landfills offers an attractive alternative. Land application of sludge is used extensively as a means of disposal, as a means of reclaiming marginal land for productive use, and as a means of utilizing the nutrient content in the sludges. However, landfilling and land application of sludge are becoming more strictly regulated, and landfill sites for the disposal of sludge are more difficult to locate. Landfilling and land application are also poor choices when infectious diseases are a concern.

The integration of the power system with the water and waste treatment facilities offers a solution to the problem of sludge disposal. The fluid-bed combustor offers a means to destroy the pathogens that cause serious health problems in some communities and greatly reduces the volume of material for final disposal. The integration of the power generation module with waste disposal, wastewater treatment, and water purification is depicted in Figure 1. The synergistic effects of integrating these modules can be clearly seen. For example, the power generation system can provide steam, heat, and/or electricity to any of the other modules while excepting the sludges generated from the various treatment processes as its fuel. Having a use for the low-level heat that is produced from the power generation system helps improve its overall efficiency and thereby reduces the overall cost of electricity to the consumer. Likewise, having the ability to route difficult-to-dispose-of sludges to the power generation system, rather than to a costly landfill or to a site for further treatment, can significantly reduce the cost of the treatment option.

The overall function of the integrated modular support system (IMSS) is to supply cheap and efficient power and water and waste treatment for domestic and industrial use. This is essential to sustain any community. A very attractive benefit of the IMSS is to provide the opportunity for economic development. If properly designed, the IMSS should produce a relatively inexpensive source of steam, heat, electricity, and water and an established and convenient method of dealing with the by-products produced from new economic developments. These developments not only benefit the community in the traditional manner, but will also help reduce the overall cost of power and treatment to the individual resident.

4.0 POWER GENERATION

Although a number of options exist for producing power at a small scale, the fluid-bed combustor (FBC) is the preferred option for the IMSS because of its ability to handle solid wastes and sludges that may be otherwise difficult to dispose of. Small FBCs have been designed with a number of attractive features, including a modular design, low maintenance, ease of operation, fuel flexibility, low-cost SO_2 control, low NO_x emissions, and the ability to produce hot water, steam, and electric power (Rankine or Brayton). One particular system currently being demonstrated by the Will-Burt Company is used as an example. Other, similar, systems could be made available from other vendors.

Although the Will-Burt system can operate either as a Rankine (steam) or Brayton (hot-air) cycle, for use in the IMSS, the preferred mode of operation is as a Brayton cycle. With this option, filtered flue gas at 1550°F is used to heat compressed air. The hot flue gas flows through a tube-and-shell heat exchanger to heat the compressed air the hot-air turbine to 1450°F. The compressed strongly dependent on the degree of sintering. Further, the ash conductivity exhibits

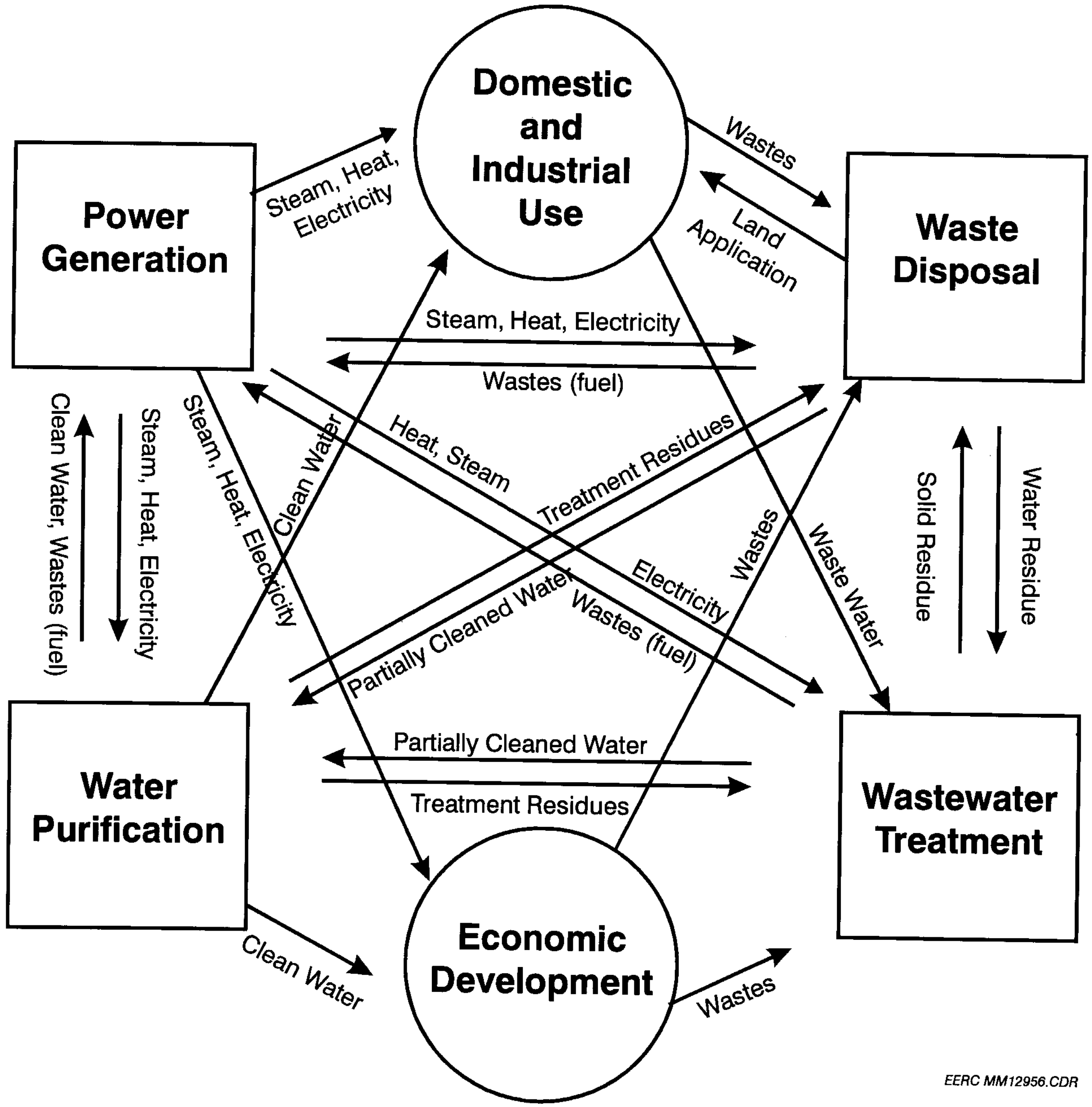


Figure 1. Schematic of the integrated modular support system.

hysteresis: once heated to a point where sintering occurs, the ash on cooling has a higher thermal conductivity than the original unsintered ash strongly dependent on the degree of sintering. Further, the ash conductivity exhibits hysteresis: once heated to a point where sintering occurs, the ash on cooling has a higher thermal conductivity than the original unsintered ash (925°-1125°F) then enters the combustor wind box to supply combustion air for the fluidized bed. Hot flue gas from the heat exchanger then passes through a heat exchanger to provide hot water-glycol for district heating. Steam or hot air could also be produced.

The attractiveness of this process is that high thermal efficiencies can be realized. The efficiency of the process can be tailored to meet the power/district heat/industrial requirements of a rural community or an industrial facility. An analysis was completed by Will-Burt and the Energy and Environmental Research Corporation (EER) for applying the FBC Brayton cycle to provide electric power and district heating needs for the community of McGrath, Alaska. The plant was sized for an average net power load of 537.5 MW_e and a base load heating requirement of approximately 2.7 MMBtu/hr. For the McGrath case, the gross thermal efficiency of fuel to electricity was 22.8%, with a net efficiency of 20.1%. This efficiency was set to satisfy the base load district heating requirement. The total gross operating cost of the system was 25.1 cents/kWh. A credit of 7.1 cents/kWh was taken for the district heat sales, with the resulting cost of electricity estimated to be 18 cents/kWh. Further reductions in the cost of electricity could be realized for systems requiring a larger electric demand and/or the capability of utilizing additional low-level heat. A lower-cost fuel would also reduce this cost ($60/ton coal was used for the McGrath study).

5.0 OPTIONS FOR SMALL WASTEWATER MANAGEMENT SYSTEMS

Small wastewater management systems vary in size from systems designed to serve individual residents with a flow of 50 to 500 gal/day to systems capable of handling up to 100,000 gal/day. The type of system(s) recommended will vary with a number of factors, one of which is existing infrastructure. One important element of infrastructure is whether the community has a sewer system or not. Wastewater from individual dwellings and other community facilities in unsewered locations may be managed by on-site treatment and disposal facilities. Often, because the individual lots are too small to accommodate an individual on-site system or the soils and underlying strata are unsuitable, small cluster, or community, systems are installed. These systems typically consist of 1) a collection system to convey the wastewater away from each residence or establishment, 2) some form of treatment, and 3) an effluent disposal system. The principal wastewater management options available for clusters of home and small communities are reported in Table 1.

Commercially available prefabricated treatment plants, package plants, are considered for use in the IMSS. Although most package plants are available for capacity up to 1,000,000 gal/day, they are used most commonly for flows in the range of 10,000 to 250,000 gal/day. Properly sized, operated, and maintained, these plants can usually provide satisfactory treatment for small wastewater flows. A number of operational issues are encountered with these package plants, due mainly to the high variability of the load common in small remote communities. The major design and operational issues that affect the performance of package plants include the following:

- Hydraulic shock loads—the large variations in flow from small communities, accentuated by the use of oversized pumps for wastewater
- Very large fluctuations in both flow and BOD (biological oxygen demand) loading
- Very small flows that make the design of self-cleansing conduits and channels difficult
- Adequate or positive sludge return, requiring provisions for a recirculation rate of up to 3:1 for extended aeration systems to meet all normal conditions
- Adequate provision for scum and grease removal from final clarifier
- Dentrification in final clarifier, with resultant solids carryover
- Inadequate removal and improper provision for handling and disposing of waste sludge

TABLE 1

Wastewater Management Options for Clusters of Homes and Small Community Systems (3)

Source of Wastewater[1]	Wastewater Collection	Wastewater Treatment	Wastewater Disposal
• Individual Residences • Public facilities • Commercial establishments	• Conventional gravity-flow sewers • Small-diameter variable-slope gravity-flow sewers (with septic tanks or without septic tanks • Vacuum sewers	• Primary treatment – large septic tank, Imhoff tank, and variations • Secondary treatment – aerobic/anaerobic unit, activated sludge system(s), sequencing batch reactor, aerated lagoons, recirculating granular-medium filter, oxidation ditch, oxidation ponds, land treatment, constructed wetlands, trickling filter	• Surface water discharge • Constructed wetlands • Spray irrigation • Reuse • Combinations of the above

[1] Many residences, public facilities, and commercial establishments may be equipped with flow reduction devices and appliances.

- Adequate control of mixed liquor suspended solids in the aeration tank
- Adequate antifoaming measures
- Large and rapid temperature change
- Adequate control of air supply rate
- Adequate design under organic and solids loadings, which can cause poor treatment performance and odor problems

Although the above factors are related more specifically to package plants employing biological treatment, many of the factors also apply to package plants employing physical/chemical treatment.

The most common types of package plants include extended aeration, contact stabilization, sequencing batch reactors, rotating biological contactor, and physical/chemical. The types of systems currently being given the most consideration for the IMSS include reverse osmosis, zonation, physical filtration, ultraviolet radiation disinfecting, chemical treatment, and distillation. The type of treatment system implemented will vary according to the needs of each individual community.

6.0 APPROACH

The role of the EERC in the development and demonstration of the IMSS is the conception, planning, and evaluation of the IMSS with assistance in the design, construction, operation, and maintenance of the system. This process involves a number of integrated steps, and the outcome will vary depending upon the community being considered for installation of the IMSS. The three main elements to be considered are the development/selection of the package modules (treatment technologies) to be recommended, implementing the IMSS system, and helping to arrange financing for the system. Each of these is discussed briefly below.

6.1 Selection of Packaged Modules

Selection of the individual modules and their integration into a packaged plant design is the most critical aspect of this process. A number of major elements must be considered if the IMSS is to be successful, including the following:

- Needs of the owner of the facility
- Past experience
- Regulatory agency requirements
- Process analysis and selection
- Compatibility with existing facilities
- Cost considerations
- Environmental considerations
- Other important considerations such as equipment, personnel, and energy

A factor often overlooked in the selection of a treatment process is the needs of the owner of the facility. Owner needs may take the form of limitations of cost and the ability to pay for the project, operating capabilities where existing staff will be utilized, process preferences based upon personal experience, concerns about using proven processes or equipment and not experimenting, and considerations about possible environmental impacts. Owner needs are especially important in small communities where there is no past history of construction and operation of treatment systems. For projects both large and small, it is important for the design engineer and the owner to reach an understanding about their mutual goals and objectives so that the needs of the owner are satisfied and the selected treatment process fulfills the basic purposes for its selection (i.e., meeting waste discharge regulations in the most cost-effective manner and mitigating adverse environmental impacts).

Increased emphasis is being placed on treatment plant performance and reliability in order to meet consistently more stringent wastewater discharge standards. Past experience in the design and operation of wastewater treatment systems is important in process selection, so that the capabilities and limitations of various processes and their support systems can be assessed realistically. Information about performance, maintenance problems, ease or difficulty of control, and adaptability to changing conditions can be obtained from operating systems. The EERC will work closely with one or more vendors to capture this past experience.

For each site, the requirements of the regulatory agencies, including those having jurisdiction for public health, air quality, and solid waste management, have to be carefully investigated. These requirements will be reviewed carefully for each site, and the state planning or regulatory agency will be involved in the early stages of a project to ensure conformance with the requirements.

Process analysis and selection is one of the most challenging aspects of treatment plant design and will be critical to the success of the IMSS. Both theoretical knowledge and practical experience are necessary in the consideration and evaluation of process alternatives. The principal elements of process analysis include 1) development of the process flow diagram, 2) establishment of processing design criteria and sizing treatment units, 3) preparation of solids balances, 4) evaluation of the hydraulic requirements (hydraulic profile), and 5) site layout considerations. The EERC will establish teaming arrangements to ensure these needs are met.

An important consideration not to be overlooked in the expansion and upgrading of existing wastewater treatment facilities is compatibility with existing process units. The introduction of a new operation or process into an existing facility represents new operating requirements and additional training of personnel for the proper operation and maintenance of the new unit. Often, equipment furnished by the same manufacturer as the existing installation may permit fewer spare parts to be kept on hand, provided the equipment has a good record of service. The amount of existing equipment is expected to vary considerably with each site.

Of major significance in the selection and design of alternative wastewater treatment facilities, especially to the client, is the question of cost—not only initial construction costs but also annual operation and maintenance costs. The cost for the IMSS has been evaluated as a complete package and compared to alternatives for providing the same services in a more conventional manner.

The environmental impacts of the IMSS are as important as cost considerations, if not more so. The protocol for evaluation of environmental impacts is set forth in the National Environmental Policy Act (NEPA) of 1969 (42 USC 4321-4347 as amended). Environmental evaluations should focus on social, technical, ecological, economic, political, legal, and institutional (STEEPLI) criteria. The NEPA regulations ensure that the probable environmental effects are identified, that a reasonable number of alternative actions and their environmental impacts are considered, that the environmental information is available for public understanding and scrutiny, and that the public and governmental agencies participate as a part of the decision process. All pertinent regulations and the inherent protection afforded must be disclosed in an Environmental Impact Statement (EIS). NEPA neither prohibits nor permits any action, but requires full disclosure of environmental information and public participation in the decision-making process. The EERC can play a significant role.

The selection of a power generation and treatment process should consider not only the amount of operating and maintenance personnel needed, but also the skills required. The simpler and less complex the process, the fewer highly skilled people are needed. For example, an aerated lagoon treatment system will require fewer highly skilled personnel than an activated sludge plant. Where facilities are being added to an existing treatment plant, capabilities of the existing personnel should be evaluated so that the new facilities can be added without causing major staffing problems and the need for extensive retraining. The IMSS will strive toward the simple design.

Some of the more complex processes require high levels of automatic controls utilizing electronic instruments and devices. Proper instrumentation and controls can save labor and even allow some of the small plants to operate unattended. However, complex instrumentation and control systems may require the on-staff services of highly skilled instrumentation technicians. Instrumentation specialists may be difficult to recruit and maintain on staff because of the high demand for well-qualified technicians. The extent and complexity of the control systems and the staffing levels required have to be evaluated carefully.

Concern over the rate of consumption of natural resources and energy has increased in recent years as shortages have occurred and worldwide demands have increased. Because the operation of wastewater management facilities depends on energy resources to a large extent, it is important to appraise the requirements realistically. Their high energy demand is also a strong driving force behind the integration of power generation and treatment options.

6.2 Implementation of the IMSS

A program for the implementation on IMSS has several major steps, usually consisting of 1) facilities planning, 2) design, 3) value engineering, 4) construction, and 5) start-up and operation. Most major projects having a construction cost over $10 million follow all steps. Smaller projects (less than $10 million) may not include the value-engineering step, although some simplified form of value engineering is highly desirable. One of the concepts of the IMSS is to provide a customized package system where many of these functions have been performed on a generic basis, thereby reducing the "soft" costs for any specific site.

A facilities plan is a document established to analyze systematically the technical, economic, environmental, and financial factors necessary to select a cost-effective wastewater management plan. The facilities plan itself may include an environmental impact assessment; on major projects, the environmental assessment is usually a separate document. The scope of the facilities plan includes 1) defining the problem; 2) identifying design year needs (usually at least 20 years); 3) defining, developing, and analyzing alternative treatment and disposal systems; 4) selecting a plan; and 5) outlining an implementation plan including financial arrangements and a schedule for design and construction. The ultimate objective of a facility plan is a well-defined, cost-effective, and environmentally sound project capable of being implemented and being acceptable to taxpayers and regulatory authorities. Facility plans could be developed to fit many communities in a given region, allowing this cost to be distributed among many potential users.

Following facilities planning, the approach generally used for designing a facility consists of conceptual design, preliminary design, special studies, and final design. The conceptual design is used to finalize the preliminary design criteria used in the facilities plan, to establish preliminary facilities layouts, and to define the necessary field investigations required, such as surveys and geotechnical studies. The preliminary design is an expansion of the conceptual design and defines fully the facilities to be included in the project so that final design can proceed. Special studies may include field studies or testing necessary for the development of design criteria. The final design involves the production of detailed contract plans and specifications used to bid for and build the project. Mitigation measurers may also be included in the design to reduce or lessen unavoidable environmental impacts. Generic designs will be tailored to each community at a fraction of the cost of a full design.

Value engineering (VE) is an intensive review of a project in which a specialized cost control technique is used to identify unnecessarily high costs in a project. The purpose of the VE analysis is to obtain the best project at the least cost without sacrificing quality or reliability. This will be performed for the generic systems developed so that the packages offered to individual communities represent the least-cost option.

The quality of the design plans and specifications are often measured by 1) ease of integration of new facilities into existing sites, 2) clarity of presentation that allows contractors to submit bids with small allowances for undefined or unforeseen conditions, 3) specification of high-quality materials of construction to ensure a long useful life of the facility, 4) timely completion of the work, and 5) a minimum of changes required during construction. The concept of the IMSS is to transport packaged systems to the site and simply connect them together. This will minimize the high costs associated with the construction phase and poor quality design plans and specifications.

Some of the principal concerns in wastewater engineering relate to the start-up, operation, and maintenance of treatment plants. The challenges facing the design engineer and the treatment plant operator include 1) providing, operating, and maintaining a treatment plant that consistently meets its performance requirements; 2) managing operation and maintenance costs within the required performance levels; 3) maintaining equipment to ensure proper operation and service; and 4) training operating personnel. Therefore, the design of the IMSS will be done with operations in mind. One of the principal tools to be supplied for the IMSS and used for plant startup, operation, and maintenance is the operations and maintenance (O&M) manual. The purpose of an O&M manual is to provide treatment system personnel with the proper understanding of recommended operating techniques and procedures and the references necessary to efficiently operate and maintain their facility.

6.3 Financing

The traditional funding sources for wastewater treatment plants have changed. The U.S. Government has provided grants for construction of treatment facilities for over 30 years. The 1987 Water Quality Act provided a 9-year transition program that phases out the construction grants program and phases in a state revolving loan fund program. This revolving loan program pays only a portion of the costs; the wastewater agencies have to provide the balance. Therefore, cities, towns, and small communities have to investigate their funding options carefully to determine what is the most economical financing method for them. Alternative financing methods that are used commonly include 1) long-term municipal debt financing (with or without federal or state grants or loans), 2) nondebt financing, 3) leasing, and 4) private financing (privatization). Because financing is becoming more integrally involved with wastewater treatment design, construction, and operation, options will need to be explored as the IMSS develops.

For projects with major capital expenditures, public agencies often use long-term debt to spread the cost of the project over a number of years. Long-term financing mechanisms include general obligation bonds, limited or special obligation bonds, revenue bonds, special assessment bonds, industrial development bonds, locally issued bonds, and small denomination bonds called "minibonds." Nondebt financing is a method of generating revenues from system charges and is sometimes called "pay-as-you-go" financing. The funds generated annually by rates or charges that are not used for operations and maintenance or for debt payments can be used to finance new construction. It is unlikely that many communities will have established funds using this method for finance on IMSS. Private sector ownership and operation may be an option for establishing IMSSs.

The overall result of privatization is a reduction in life-cycle cost, as much as 20% to 30% as compared to conventionally financed, constructed, and operated projects. Operating efficiencies may result under private operation by centralized administration, bulk ordering of chemicals and supplies, and sharing of key personnel among multiple facilities. Assurances in meeting effluent standards may be provided by the resources available from the private operator such as required management skills and trained operating personnel.

7.0 MARKET OPPORTUNITIES

Considering the power generation option alone, the current trend to deregulate the electric power industry provides the backdrop required for remote applications of power generation. Small gas turbines are currently considered the market leader for the small-size system (1 to 40 MW) and will be discussed first in the context of the continuously evolving electricity utility industry. It should be noted that while these systems are capable of cogeneration, they do not provide the other benefits of the IMSS. However, the benefits of the IMSS must be substantial enough to warrant the cost differential between the IMSS and the gas turbine.

With only modest transmission and distribution (T&D) benefits factored into the comparison, gas turbine cogeneration appears to offer long-term, sustainable economic benefits to the customer and the electric industry in the range of 1 to 40 MW. A number of regulatory, institutional, and market barriers need to be overcome for small gas turbines to be meaningfully deployed in the marketplace. Historically, industrial and commercial customers have not taken the initiative to pursue cogeneration on their own. They have allocated their limited staff and capital resources to their core business. The higher "soft" costs for small projects hurt the economics and make the third-party developers shy away from the lower end of the market. These soft costs include project development, financing, engineering, environmental compliance, fuel management, utility coordination, and project management. Mass market strategies that can reduce the high costs for financing, environmental compliance, development, engineering, and installation traditionally associated with industrial cogeneration need to be created.

Electric utility motivations can have a major effect on this market. If utilities continue to view on-site generation as a competitor, small power growth will likely be stunted. On the other hand, if utilities have sufficient incentives or opportunities to participate, the small power market could prosper. This could be through cogeneration project equity participation, a more economical T&D system, enhanced grid reliability and power quality, and demand-side management such as rate-based incentives. For the IMSS to compete in this environment, the synergistic effects of coupling power generation with the water and waste treatment needs to be substantial to allow direct competition with the gas turbine.

A recent assessment of the global market for FBC, coalbed methane, and coal-fired diesel engines was completed by Energy Resources International, Inc. (ERI). While it did not assess the implementation of combined power generation and waste and waste treatment, ERI did conclude that a significant market for remote power systems exists in a number of countries (4). Results from their qualitative assessment are summarized below.

The developing countries with the greatest near-term market potential for coalbed methane recovery from active mines are Russia, Ukraine, South Africa, China, Poland, and India. Based on existing mining operations in these countries and assuming that 25%–35% of the coalbed methane released from these mines is recoverable, then 181 to 459 billion cubic feed per year could be available (in the near term) for consumption in the identified markets. Greater recovery rates at existing mines and the inclusion of recovery at new mines expands the potential market considerably. A more detailed assessment is required, however, to quantify this opportunity. To realize the near-term (and longer-term) market potential of coalbed methane requires the removal of particular market barriers: capital cost of projects; cost of installing coalbed methane systems; lack of clear legal authority (and precedent) regarding ownership of the resource; and lack of understanding in-country of the resource and its value.

The countries with the greatest market potential for small-scale FBCs; and coal-fired diesels (CFDs) are identified below by region:

- Africa: Zimbabwe, Morocco
- Asia: India, China, Pakistan, Indonesia, Vietnam, Philippines, and Thailand
- Central/East Europe: Poland, Bulgaria
- Middle East/Near East: Turkey

- Central/South America: Peru, Columbia, Chile

Each of these countries was rated as having high market potential for FBC and CFD technologies. The rationale for this rating includes the following:

- They are currently using coal for power generation and thereby have the coal infrastructure in-place.
- They are projected to realize high growth rates in demand (>6% per annum) and/or require investment in replacement capacity.
- They have a high percentage of rural population (>50%) and/or have isolated load centers due to topographical conditions.
- A small percentage of the rural population has access to the electric grid.
- The countries have policies to increase rural electrification and diversify their fuel sources (including reduced oil consumption by diesel generators).
- They have private power development incentives and/or privatization programs, either in-place or proposed.

While the amount of new/replacement generating capacity in these countries ranges from 400 MW (Zimbabwe) to 400 MW (China), there remains a viable market for FBC and CFD technologies in remote applications within each of the identified countries for the aforementioned reasons. A more detailed assessment of the current power system and load demand in these remote areas is required before a quantitative estimate of the market potential for these technologies can be derived.

The major barriers to deployment of these technologies are 1) competition with hydroelectric and natural gas technologies, which is prevalent in these countries because of resource availability; 2) capital availability, which is limited and generally requires external private power investors; and 3) lack of local information about the benefits of these technologies and their use in a microgrid.

8.0 REFERENCES

1. Flowers, J.E. "The Importance of Wastewater Facilities Planning in Small Communities," In *Small Alternative Wastewater Systems, Design Workshop Notes*; Developed under Grant No. T-901092-010, U.S. Environmental Protection Agency, 1983.

2. *Proceedings of National Conference on Less Costly Wastewater Treatment Systems for Small Communities*; Reston, VA, April 13–15, 1977; U.S. Environmental Protection Agency; Washington, DC, 1977.

3. Metcalf & Eddy, Inc. (Tchobanoglous, G.; Burton, F.L., revisors) *Wastewaster Engineering, Treatment, Disposal, and Reuse*; 3rd ed., McGraw-Hill: New York, 1991.

4. Siegel, J.S.; South, D.W. "Global Market Assessment of Coalbed Methane, Fluidized-Bed Combustion, and Coal-Fired Diesel Technologies in Remote Applications," prepared for the Energy & Environmental Research Center by Energy Resources International, Inc., Washington, DC, March 15, 1996.

FORM E1A-459E
(10/80)

U.S. DEPARTMENT OF ENERGY

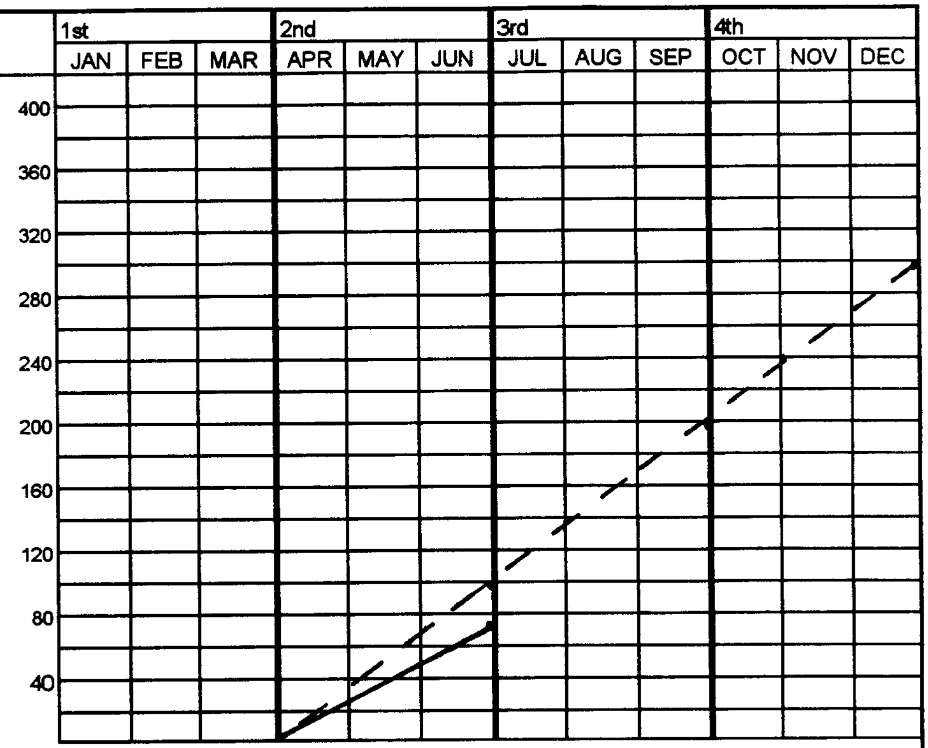
FEDERAL ASSISTANCE MANAGEMENT SUMMARY REPORT

FORM APPROVED
OMB NO. 1900 0127

1. Program/Project Identification No. DE-FC21-93MC30097	2. Program/Project Title TASK 3.0 ADVANCED POWER SYSTEMS	3. Reporting Period 4-1-96 through 6-30-96
4. Name and Address Energy & Environmental Research Center, University of North Dakota, PO Box 9018, Grand Forks, ND 58202-9018 (701) 777-5000		5. Program/Project Start Date 1-12-93
		6. Completion Date 12-31-97

7. FY 96/97 — 8. Months or Quarters: Quarters

9. Cost Status — a. Dollars Expressed In Thousands — b. Dollar Scale



10. Cost Chart

Fund Source		Quarter 1st	2nd	3rd	4th	Cum. to Date	Tot. Plan
DOE	P	0	100	100	100	100	300
	A	0	76			76	
	P						
	A						
	P						
	A						
	P						
	A						
Total P		0	100	100	100	100	300
Total A		0	76			76	
Variance		0	24			24	

P = Planned A = Actual

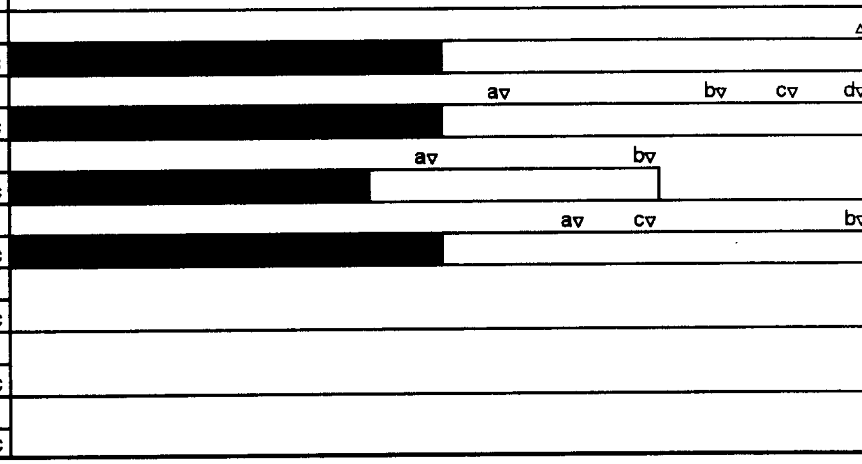
Total Planned Costs for Program/Project

$300

c. Cumulative Accrued Costs

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Planned			0			100			200			300
Actual			0			76						
Variance			0			24						

11. Major Milestone Status	Units Planned / Units Complete
3.12 Small Power Systems Commercialization Plan	P / C
3.15 Impacts of Low-NO_x Combustion on Fly Ash and Slagging	P / C
3.16 Low-Cost CWF for Entrained Flow Gasification	P / C
3.17 Hot-Gas Cleanup	P / C
	P / C
	P / C
	P / C



12. Remarks

Milestones have been pushed back because of a 4 -month delay in receiving DOE funding.

13. Signature of Recipient and Date

Michael D. Mann 7/31/96

14. Signature of DOE Reviewing Representative and Date

FORM E1A-459E
(10/80)

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Grand Forks, ND 58202-9018 (701) 777-5000

5. Program/Project Start Date: 1-12-93

6. Completion Date: 12-31-97

Milestone ID. No.	Description	Planned Completion Date	Actual Completion Date	Comments
Subtask 3.12	Small Power Systems Commercialization Plan			
	Develop commercialization plan	9/96		
Subtask 3.15	Impacts of Low-No_x Combustion on Fly Ash and Slagging			
a	Modification of CEPS for low-No_x combustion and ash deposition	3/96	7-96	delayed
b	Low-No_x fly ash generation and analysis	6/96	10-96	delayed
c	Low-No_x slagging tests and analysis	8/96	11-96	delayed
d	Submit draft topical report and article for publication	12/96		
Subtask 3.16	Low-Cost CWF for Entrained Flow Gasification			
a	Procure samples for vendors	4/96		
b	Technical evaluation for dewatering	9/96		
Subtask 3.17	Hot-Gas Cleanup			
a	Screening of PFBC sorbents	6/96		
b	Optimization of selected PFBC sorbents	12/96		
c	Optimize conditions for tar-cracking catalysts	9/96		

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Report Number (14) DOE/MC/30097--5707

Publ. Date (11) 199707

Sponsor Code (18) DOE/FE, XF

UC Category (19) UC-101, DOE/ER

DOE