APPENDIX I

# POTENTIAL APPLICATIONS FOR UTILIZATION OF WASTE HEAT FROM K- AND C-REACTOR COOLING WATER DISCHARGES

During the public comment period on the draft environmental impact statement (EIS) for alternative cooling water systems at the Savannah River Plant (SRP), the U.S. Department of Energy (DOE) received several comments that requested consideration of other alternatives for use of the cooling water effluents from K- and C-Reactors. These comments did not identify specific alternatives (i.e., concepts with specific functions and features) for the effluents, but rather suggested that DOE consider the use of the cooling water or the contained thermal energy in agricultural or aquacultural applications or in the production of ethanol.

This appendix discusses earlier waste heat utilization studies conducted at the Savannah River Plant, and assesses the general alternatives identified during the public comment period (irrigation, soil warming, greenhouse heating, aquaculture, and ethanol production).

## I.1 K- AND C-REACTOR COOLING WATER DISCHARGES

K- and C-Reactor each discharge approximately 11.3 cubic meters of reactor cooling water per second at an average temperature of between 70°C and 77°C. These discharges are not continuous; periods of reactor operation depend on production runs and on required maintenance shutdowns of 1 to 2 months, which generally occur during the summer. The chemical quality of the cooling water is similar to that of the Savannah River; however, the cooling water from both reactors contains tritium, a radioactive isotope of hydrogen, resulting from small process water leaks in the reactor heat exchanger.

## I.2 PREVIOUS STUDIES

DOE has funded or performed several studies that evaluated the potential for utilization of waste heat generated at SRP. In 1978, the South Carolina Energy Research Institute (SCERI) prepared a report entitled Low Level Waste Heat Utilization Project, Savannah River Plant, Preliminary Analysis. This study considered a number of potential waste heat utilization projects, including agricultural and aquacultural uses, industrial applications, and direct power generation. It evaluated five agricultural options - soil warming, biomass production, greenhouse heating, anaerobic digestion of animal wastes, and space heating of poultry brooding houses. After the evaluations, the researchers did not consider any of these options to be independently viable as a major user of SRP waste heat. Of the nine aquatic species evaluated for potential commercial culture using SRP waste heat, the report considered the culture of freshwater prawns and channel catfish to offer the most promise as an end user in an energy cascade system. Of the direct power generation options considered, a Rankine cycle system appeared to be the most viable.

In 1982, Clemson University's College of Agricultural Sciences and College of Forest and Recreation Resources prepared a report entitled Feedstock Options for Ethanol Production at the Savannah River Plant (Cross et al., 1982). This report provided DOE with information to judge the short- and long-term potentials for feedstock alternatives for onsite ethanol conversion.

In 1983, Arthur D. Little, Inc. (ADL), under contract to E.I du Pont de Nemours and Company (Du Pont), prepared the SRP Cogeneration Study, which evaluated the feasibility of various methods of cogeneration (i.e., the recovery and utilization of heat from the reactor effluents) as a means of reducing SRP thermal impacts. The ADL investigation utilized the previous studies conducted on this issue with appropriate updates of technologies and costs (ADL, 1983). The cogeneration options evaluated included the generation of electricity using Rankine cycle systems, the generation of process steam for the SRP using heat pumps, onsite industrial applications (direct uses and/or temperature augmentation using heat pumps), onsite agricultural and aquacultural applications, and hot water delivery to offsite users. ADL evaluated each of the applications with respect to technical, economic, institutional, and environmental feasibility. The environmental evaluations included an assessment of the ability of the cogeneration options to meet the proposed 32.2°/2.8°C thermal standard for SRP streams. This standard requires that the temperature of plant effluents entering a natural stream not exceed 32.2°C, and that plant effluents cause no more than a 2.8°C temperature increase above the natural stream temperature.

ADL evaluated the onsite applications both as standalone strategies and as precooler strategies. The standalone evaluations examined the cost/benefit associated with adding a cogeneration system to the existing once-through reactor cooling system. The precooler evaluations assumed that the once-through system would be augmented by mechanical-draft cooling towers, and examined the cost/benefit of using cogeneration to precool the reactor effluent before it enters the cooling towers.

Based on a detailed review of the ADL work and on an independent assessment of cogeneration, the Savannah River Laboratory (Roggenkamp, 1983) concluded that none of the standalone strategies would provide sufficient temperature reduction to satisfy the 32.2°/2.8°C thermal standard for SRP streams year-round. The precooler strategies were not considered feasible for reasons specific to each application, as discussed below.

Technically, Rankine cycle systems could generate as much as 37 to 46 megawatts of electricity at each reactor. However, while the 12°C temperature reduction would permit the use of smaller cooling towers, the delivered electricity costs would be 2 to 3 times higher than the costs for the current system of purchased electricity.

The only technically viable heat pump application identified in the studies would result in a decrease in reactor cooling water effluent temperatures of only 0.6°C. In addition, this application would be uneconomical.

Onsite industrial, agricultural and aquacultural applications, and heated effluent delivery to offsite users would not be feasible because of poor economics and many institutional barriers.

The institutional problems associated with industries locating to the SRP area to obtain low-cost heat from the reactor effluent would be virtually insurmountable. ADL cited the problems encountered by the Tennessee Valley Authority in attracting industries to use the waste heat from its Watts Bar Nuclear Power Plant.

The ADL study concluded that onsite agricultural and aquacultural uses of the waste heat were not feasible. Features of these applications leading to poor economics are the relatively low duty cycle (heat generally not needed except in winter) and the relatively low value of the output. Also, the study determined that, unless very large land areas are employed, these applications would produce little impact in terms of waste heat utilization. The relatively frequent outages of the reactors also would cause difficulties with respect to winter kill unless backup systems were provided. In addition, Federal legislation [21 USC 321(s) and 342(a)(7)] expressly forbids the adulteration of food or food products with any radioactive substance. SRP reactor cooling water contains tritium as a result of small process water leaks in the reactor heat exchangers. While discharges of this radioactive material are well within applicable regulatory limits for water quality, the legislation regarding food and food products sets no lower threshold limit, precluding the use of this water for direct contact use in agriculture or aquaculture.

The study also concluded that it would be uneconomical to pipe reactor cooling water effluent offsite for district heating or industrial applications.

## I.3 POTENTIAL AGRICULTURAL APPLICATIONS

### I.3.1 IRRIGATION

This potential application for the utilization of SRP waste heat would entail delivery, via a closed pipeline or open canals, of reactor cooling water effluent to offsite users for direct contact irrigation of agricultural crops.

In the six-county area surrounding the SRP, agriculture accounts for approximately 21 percent of the total land use (DOE, 1984). The results of the 1980 census of population (Bureau of the Census 1982a,b) indicate that fewer than 2 percent of the population in the six-county area were employed in the category of agriculture, forestry, and fishing, a 2-percent decrease from 1970. Agricultural land in the six-county area is undergoing a transition from smaller operators to larger consolidated farms, especially in the rural areas of Allendale, Bamberg, and Barnwell Counties (DOE, 1984).

Although the conservation of water resources is considered a national priority and recent drought conditions in the southeastern United States have generally indicated the importance of the availability of adequate water supplies, DOE is not aware of specific agricultural needs or requirements for diversion of existing water resources for use in the irrigation of local crops. No uses of the Savannah River for irrigation have been identified in either South Carolina or Georgia (Du Pont, 1982).

Even if a specific need was identified for local use of the SRP reactor cooling water for irrigation purposes and recognizing the legal barrier for such uses for food crops described above, various environmental, technical, and economic difficulties exist; these are discussed below.

The estimated temperature of the cooling water delivered from K- and C-Reactors to an offsite location would be between 52° and 75°C. Before it could be used for irrigation, this water would have to be cooled to about 32.2°C to avoid damage to crops. In the summer, when irrigation is needed and the ambient Savannah River temperature is approximately 26°C, an estimated 156 cubic meters per second of local water (or seven times the amount of cooling water delivered from K- and C-Reactors) would be required to dilute and thus cool the discharge water from both reactors to 32.2°C. This quantity is equal to the 7-day, 10-year low flow (159 cubic meters per second) of the Savannah River near the SRP. If such quantities of local water were available, the K- and C-Reactor discharges probably would not be needed for irrigation; because this amount of local surface-water use is not considered feasible, a cooling system (i.e., once-through or recirculating cooling tower) would still be necessary to cool reactor cooling water sufficiently for irrigation use. In addition, during those periods when irrigation water would not be required, some alternative mechanism of cooling water disposal (and cooling to meet regulatory requirements) would be necessary.

The offsite agricultural user(s) would be responsible for meeting all construction and operational permit requirements for offsite irrigation systems. Major issues of concern from a regulatory point of view relate to large volume translocation of a riverine water resource to the groundwater table and the potential permit requirements of transporting surface water from one basin to another (for example, interbasin transfer from the Savannah River basin to the Salkehatchie River basin near Allendale, South Carolina).

To deliver heated water from K- and C-Reactors to a potential user(s) at the SRP boundary line, DOE would have to construct either open canals or an underground pipeline. Consideration was given to the use of open cement-lined canals with gravity flow, similar to those constructed to carry cooling water from the P- and R-Reactors to Par Pond. However, this alternative was considered less attractive than the closed pipeline option for both technical and economic reasons. Several stream valleys and ridge lines would have to be crossed between the reactors and the SRP eastern and western boundary lines. Gravity flow canals could only be used from a ridge line to the next stream valley, from which a closed pipeline and a pumping station would be required to move the water to the next ridge line.

Water flow in a canal would be by gravity, whereas the pipeline would be under pressure from the pumps. Therefore, the pipeline could use a shorter, straight path and follow the existing ground elevation to avoid deep excavations and fills. A canal would have to meander along the contours, requiring a longer route and greater expense. The canal would also produce a larger potential area of disturbance than the pipeline and, accordingly, would have a greater potential environmental impact.

A pipeline system would require the following:

- A pumping station at each reactor with underground reinforced concrete pits approximately 20 meters deep, each containing 10 pumps capable of pumping 2.3 cubic meters per second.

- Associated control buildings, valves, electrical substations and switchyards, and access and security facilities.

- Underground pipelines from each reactor area to the SRP boundary. Each pipe would be about 2.5 meters in diameter. Both pipes would be combined into one about 3.7 meters in diameter where the lines converge. The system would have drain and air valves at low and high points in the pipes, similar to those in existing wastewater pipelines.

A pipeline could follow several routes from K- and C-Reactors to the SRP boundary. The closest point on the boundary to either reactor is along the Savannah River. However, no practical use exists for heated water in this area because it consists almost exclusively of wetlands. The route to a usable offsite area with the shortest total length of pipe (Figure I-1) would start at a new K-Reactor pump station and follow the existing 115-kilovolt transmission line and control cable between K- and C-Reactors for about 4.5 kilometers. A 0.5-kilometer pipeline would run from the new C-Reactor pumphouse to connect to that pipeline just north of Road 3. From this connection, a larger combined pipe would follow the existing South Carolina Electric and Gas (SCE&G) Company transmission line to the intersection of Roads 2 and C. From this point, the pipe could either continue along the transmission line or run parallel to Road C to the SRP boundary near Jackson, South Carolina. The length of the large pipe would be about 13 kilometers, and the total length of pipe would be about 18 kilometers.

A second possible route (Figure I-2) would have the small pipes run from each reactor to a junction at the intersection of Roads B and C near L-Reactor. From the new pumphouse at C-Reactor, the pipe would follow the C-Area railroad to Road C, and then parallel Road C to the junction; this pipe would be about 8.5 kilometers long. The pipe from K-Reactor would run parallel to Road B for about 5.5 kilometers. From this junction, a larger pipe could follow two routes to the boundary. The shorter route (Route 2-A) would turn south, cross Myers Branch and the Seaboard Coast Line Railroad, and run approximately parallel to the SCE&G transmission line for about 10.5 kilometers to a point on the SRP boundary near the northwest corner of Allendale County. This point is near a ridge line that bisects the area between SRP and Lower Three Runs Creek. The large pipe could also continue (Route 2-B) from the junction 14 kilometers along Road B to the SRP boundary east of Par Pond. This point is near a ridge line that runs south through part of Barnwell County and most of Allendale County between Lower Three Runs Creek and the Salkehatchie River. The total lengths of pipe for Routes 1 and 2 are 24.5 and 28 kilometers, respectively.

Although the route to Jackson is the shortest, the pumps at each reactor would have to be larger than those required for the other routes because the pipeline would reach its lowest point where it crosses Upper Three Runs Creek; the system would have to pump water upgrade to the boundary. Stream crossings on the other routes are at higher elevations.

Depending on the pipeline route selected, 1200- to 1800-horsepower motors would power the pumps. The rating for each pump would be 1.1 cubic meters per second and the required power supply per pump would range between 0.995 and 1.5 kilowatts. Because each pumping station would require 10 operating and

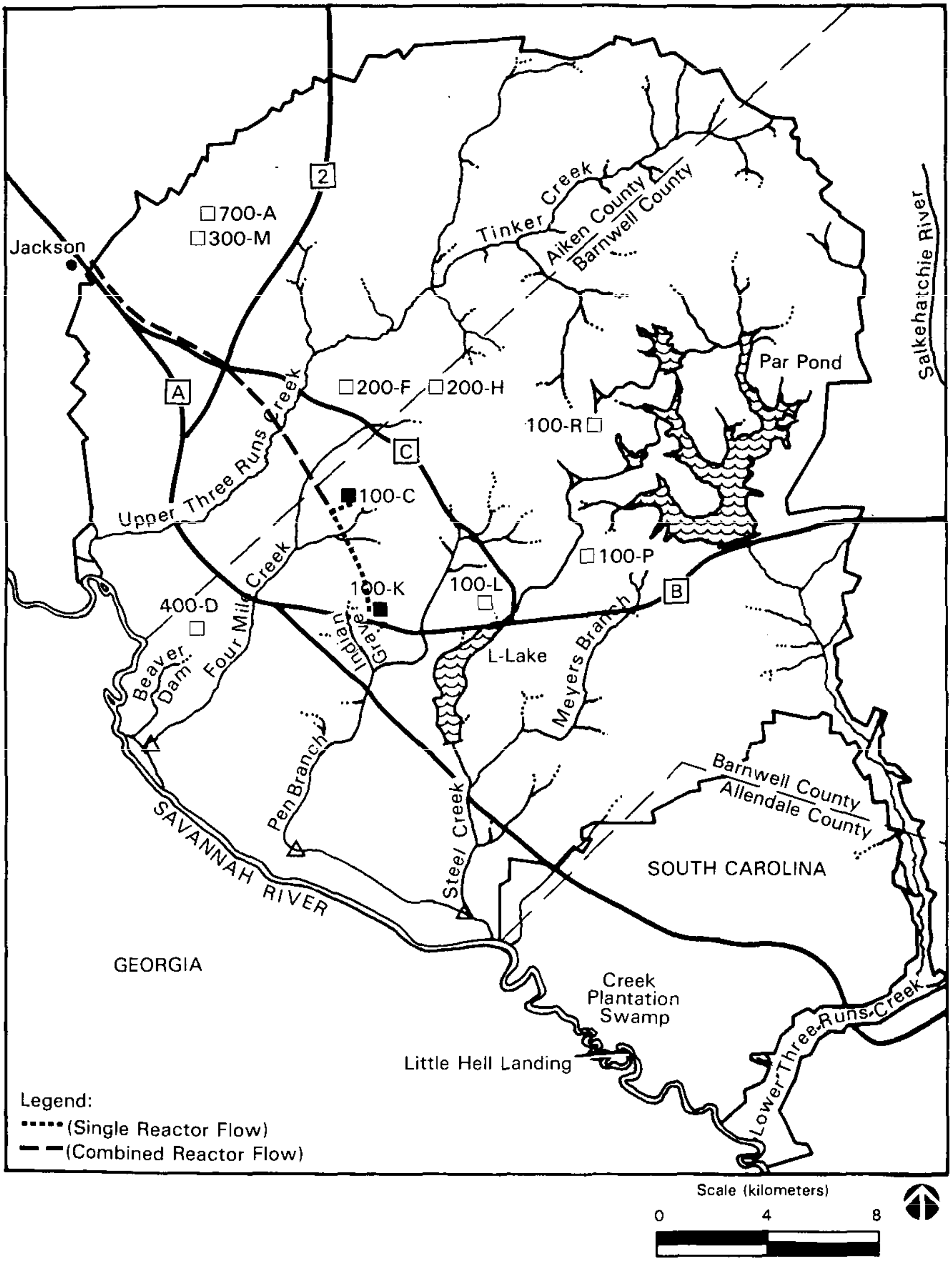


Figure I-1. Proposed Pipeline Route 1 (West)

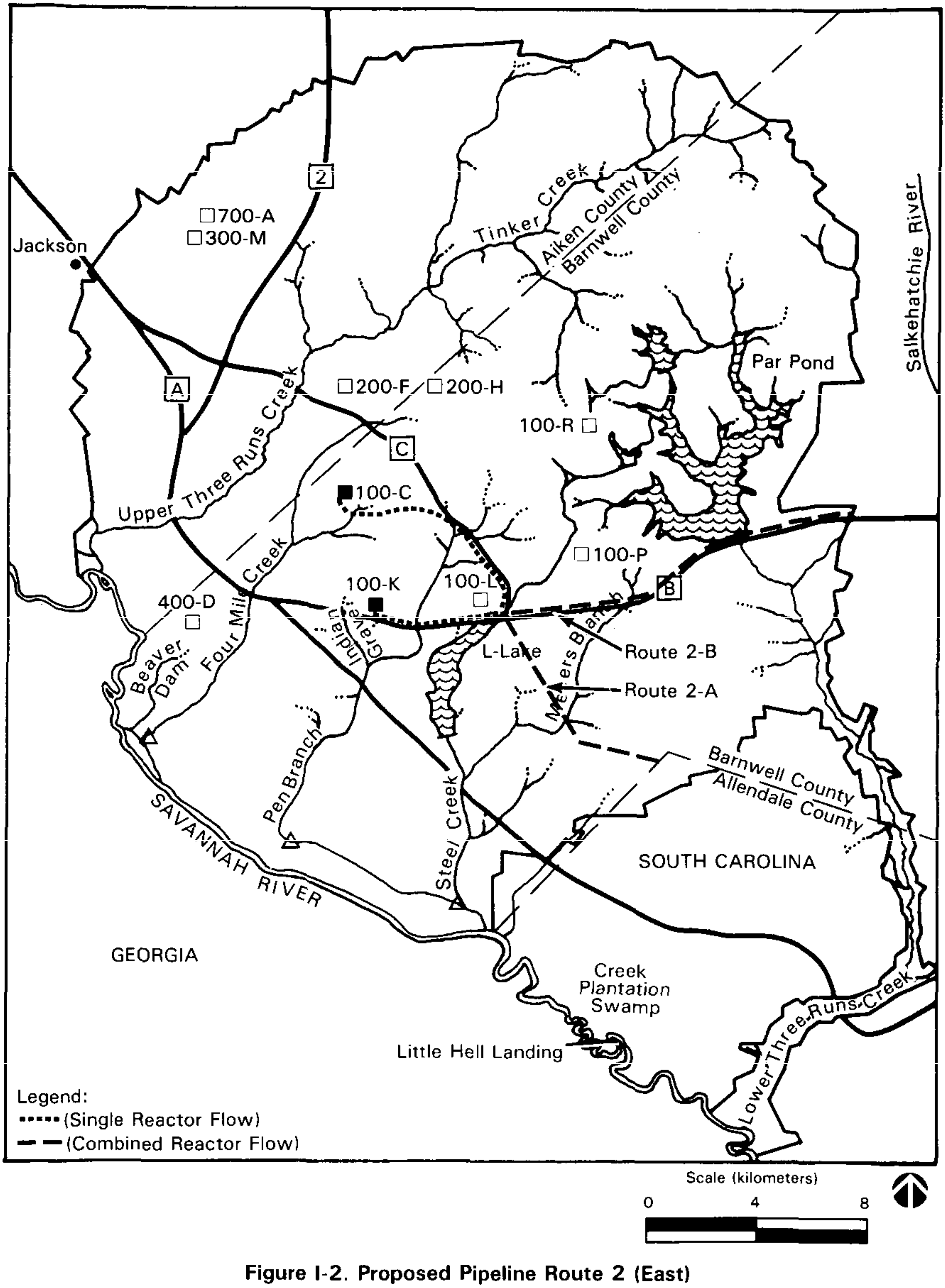


**Figure I-2. Proposed Pipeline Route 2 (East)**

5 redundant pumps, DOE would have to construct an electrical power substation and special transmission lines. The estimated total DOE construction costs for pumping stations and pipelines range between $188 and $215 million, and the estimated annual operating costs would be approximately $18 million (Table I-1).

Table I-1. Costs for Closed Pipeline to Carry K- and C-Reactor Cooling Water Offsite

| Item | West pipeline (Figure I-1) | East pipeline (Figure I-2) |
|---|---|---|
| Length of route (kilometers) | 24.5 | 28 |
| Capital costs ($ million) | | |
| Pipeline | 44 | 64 |
| Pumps and accessories, installed | 92 | 92 |
| Contractor operations and profit | 27 | 31 |
| Design | 25 | 28 |
| Total capital costs ($ million) | 188 | 215 |
| Operating costs per year ($ million) | | |
| Power (at $.06/kWh) | 13 | 13 |
| Operations and maintenance | 5 | 5 |
| Total operating costs per year ($ million) | 18 | 18 |

DOE estimates that it would require about 12 to 15 months to design the pipeline, and about 24 months to construct the shortest system or 32 months to construct the longest route. The workforce is estimated to be 25 personnel for operations and 15 for maintenance.

### I.3.2 SOIL WARMING

Warming of crop soils to higher temperatures during the cooler months has been tested experimentally as a method of increasing agricultural productivity. SCERI (1978), in its assessment of potential applications at SRP, reported on soil warming experiments that produced a variety of effects on growing crops: longer growing seasons, higher quality vegetables, and sometimes significant increases in yields. However, artificial warming of the soil has also been found to cause substantial reductions in yields of some crops. A system using waste heat to provide soil warming would include the following necessary components:

- The availability of land suitable for crop production

- Sufficient labor, management, and equipment to produce a crop
- An extensive system of buried pipelines for the transfer of heat to the soil
- An irrigation system to alleviate the increased evapotranspiration caused by higher soil temperatures

Temperatures higher than 32.2°C have been found to decrease crop growth significantly. Some crops have a critical temperature limit as low as 13°C (Ontario Department of Agriculture and Food, 1978). Thus, the use of K- and C-Reactor discharges for soil warming, given an estimated delivery range between 52°C and 75°C, would require a method to lower the temperature before the cooling water could be used for soil warming.

The SCERI (1978) assessment determined that a volume of 21.5 cubic meters per second of water at a temperature of 32.2°C, distributed through a subsurface pipeline, would warm and maintain the soil temperature of a 1000-acre field during early spring. This would allow an approximate 5.6°C reduction in the temperature of the cooling water. Using a combined reactor cooling water effluent volume of 22.6 cubic meters per second at a maximum discharge temperature of 75°C, an estimated additional 50 cubic meters per second of local ambient surface water (at a March ambient Savannah River temperature of 13°C) would be required to provide 32.2°C effluent water for soil warming. Based on SCERI calculations of water distribution, approximately 3395 acres of agricultural land could be warmed using this method. However, the quantity of additional local surface water required to cool the reactor effluent to meet soil warming needs is approximately one sixth of the average annual Savannah River stream flow (295 cubic meters per second) near the SRP.

Reactor operations at the Savannah River Plant would have a significant effect on the supply of heated water available for soil warming. DOE cannot ensure a continuous supply of heated water due to frequent reloading and maintenance activities at the reactors; thus, system users would have to depend on other means for warming the soil when the supply of cooling water from the reactors was not available.

Because soil warming for agricultural purposes is required only during the coldest portions of the year, this method of heat dissipation would not be feasible during the warm seasons. For this reason and because of the need to cool reactor effluents to levels acceptable to plant growth requirements while using only reasonable volumes of local surface waters, the soil warming application would not preclude the need for cooling towers at the SRP.

Based on its assessment of the soil warming application, SCERI (1978) concluded that the potential limited benefits of soil warming do not justify the costs for such a system. Soil warming is useful for, at most, 6 months per year and the use of SRP waste heat is not replacing (and conserving) another energy source because soil warming is not practiced commercially. Estimated costs to the user for installation of the soil warming equipment are $5000 per acre for what is only an experimental system. The small profit margin for crops that do well on large acreages makes the additional soil warming investment economically unsound for large farms.

In addition to the costs associated with the soil warming equipment and agricultural production, the user would be responsible for all National Pollutant Discharge Elimination System (NPDES) permit requirements for the ultimate disposal of the reactor cooling water effluent after use in the soil warming application.

The estimated costs of the DOE delivery of K- and C-Reactor cooling water to the offsite user location would be the same as those discussed for irrigation. The estimated total construction costs for pumping stations and pipelines for soil warming range between $188 and $215 million, and the estimated annual operating costs for these delivery systems would be approximately $18 million. These costs would be in addition to the DOE costs for construction and operation of the anticipated cooling towers for K- and C-Reactors.

### I.3.3 GREENHOUSE HEATING

SCERI (1978) determined that, of the five potential applications it evaluated for the utilization of SRP waste heat, greenhouse heating appeared to be the best prospect. However, as with the other options, SCERI concluded that this application could not be a major use of the waste heat, but it could be incorporated into an industrial/agricultural park as one of the last recipients in an energy cascade. Based on its review of the greenhouse application, ADL (1983) concluded that "some greenhouse operations might be possible and could represent an interesting demonstration activity. However, the presence of low cost heat is not likely to be a sufficient incentive to attract any truly commercial activities."

SCERI (1978) cited a report (Boyd et al., 1977) on an experimental greenhouse facility in Minnesota that used cooling water waste heat from a powerplant of Northern States Power Company for both heating and cooling purposes. This greenhouse has been used for the successful production of tomatoes, lettuce, and roses during the winter.

The Pennsylvania Power and Light Company (PPL) has established a greenhouse complex at its Montour Steam Electric Station (a coal-fired powerplant in east central Pennsylvania) to deliver heat to greenhouse operators (PPL, 1982). PPL uses the discharge from the plant's cooling towers rather than directly from the condensers because the greenhouse operators could not process water warmer than 45°C. Based on a flow rate of 0.022 cubic meter per second of 37.8°C cooling water (annual average) per acre of greenhouse, this system, as presently operating, has the capacity to supply 34 or 17 acres of greenhouses with or without pump assistance, respectively. At the time of the report, 13 greenhouse acres were under cultivation. This application utilizes approximately 1 percent of the plant's cooling water with an approximate 5.6°C reduction (to 32.2°C) in cooling water temperature for return to the plant.

The PPL greenhouses employ an underfloor heating system and an overhead (air heater) system. Each greenhouse operator had to install full-capacity gas- or oil-fired backup heating systems and self-draining pipes to ensure the maintenance of suitable temperatures in the greenhouse during powerplant outages and extremely cold periods.

If the PPL figures are used as a basis for estimating the amount of greenhouse area necessary to lower the temperature of the cooling water discharges from K- and C-Reactors without cooling towers and still meet a discharge temperature of 32.2°C, 30.2 cubic meters per second of local surface water at ambient Savannah River temperature in January (approximately 10°C) for dilution/cooling and 2402 acres (not including associated equipment and access areas) of greenhouses would be required.

PPL estimates that its 34-acre greenhouse cost $35,650 per acre to construct and that the annual heating cost (annual charge for the pipeline) is about $13,290 per acre (PPL, 1982). The SCERI (1978) study at SRP estimated the capital costs of greenhouse construction at $43,560 per acre, with an annual energy cost of $7675 per greenhouse acre.

Based on an estimate of 2402 acres of greenhouses needed to dissipate the waste heat from K- and C-Reactor discharges without a cooling tower and meet a 32.2°C discharge temperature, greenhouse construction costs (excluding costs for the delivery of cooling water from the reactors) would range between $86 and $105 million; annual energy costs would range between $18 and $32 million.

When the heat in the water used for greenhouse heating is not dissipated to required levels, discharge of this water would require a cooling system, such as a cooling tower, to meet South Carolina water-quality standards.

## I.4 POTENTIAL AQUACULTURAL APPLICATIONS

### I.4.1 PRAWN PRODUCTION

The SCERI (1978) report found that, for biological, technical, and economic reasons, the freshwater prawn (Macrobrachium rosenbergii) was the only crustacean with commercial culture potential at the SRP. However, because no commercial prawn farms of the type envisioned exist, the SCERI report concluded that extensive pilot-scale testing and research would be required to determine the extent of this economic potential.

The SCERI study determined that the greatest potential for commercially successful prawn farming in the local area would result from the use of a combination of very intensive indoor and outdoor culture systems. A production plan was proposed for a controlled-environment pilot operation that would utilize indoor tanks for the brood-stock, hatchery, and nursery phases and outdoor ponds for the production phase, during which juvenile prawns would be grown to marketable size. The local climate is such that prawn culture can occur outdoors only during the warmer months of the year. Thus, the cooling water from K- and C-Reactors could contribute heat to an aquaculture operation during the colder months. The low-level waste heat from SRP reactor cooling water could be used to maintain water temperatures in a range favorable to prawn growth (26-30°C), making year-round production possible. However, the presence of tritium in the reactor cooling water precludes direct contact with the prawn culture medium [21 USC 321(s) and 342(a)(7)]; therefore, waste heat could only be used indirectly, through a heat-exchange system, to heat the culture water. This would necessitate the local availability of large volumes of high-quality water (uncontaminated with biocides from agricultural uses, industrial wastes, etc.) for the culture medium. In addition, the commercial feasibility of using SRP waste heat for prawn production would depend on the cost of the heat-exchange system best suited for large-scale production, which could be determined only through pilot-scale testing.

Water temperatures higher than 33°C are detrimental to prawn growth; accordingly, during the warmer periods of the year, the use of outdoor ponds for heat dissipation would be negligible. (Intensive indoor tank culture would allow year-round use, but would require only relatively small volumes of reactor cooling water for tank warming.) Conversely, a continuous supply of heated cooling water would have to be provided to the prawn farm during the colder months. Any significant interruptions in this flow could result in the complete loss of the prawn crop. Therefore, a backup heating system would be required to ensure controlled maintenance of suitable temperatures during periods of reactor shutdown.

The SCERI report concluded that the potentially most feasible and economically successful system for prawn production using SRP waste heat would be with intensive management techniques using small (1/4-acre) ponds and maintaining high densities of individuals in the ponds. The estimated potential production from such intensively managed units ranges from about 6000 to 8100 kilograms of whole prawns per acre per year. The type of system envisioned by the SCERI studies would use 10 to 100 acres of growout ponds plus associated hatchery and nursery facilities. SCERI assumed that circulation of SRP heated water would be required for 8 months of the year. During the coldest periods, SCERI estimated that a maximum volume of 0.022 cubic meter per second of 38°C reactor cooling water effluent (assuming that pond water could be heated 14° to 17°C via the heat exchangers) would be required for heating each 1/4-acre pond. Considering the maximum prawn farm size suggested by SCERI of 100 acres, pond heating during the coldest portion of the year would be able to utilize only 8.8 cubic meters per second (39 percent) of the total cooling water effluent from K- and C-Reactors. Some other form of cooling of the effluent would be required for the remaining volume (13.8 cubic meters per second) to meet regulatory requirements. Also, SCERI determined that additional cooling of the reactor effluent (to reduce the temperature to 38°C) would be required before passage through the culture system heat exchangers for maintenance of suitable temperatures in the ponds.

The use of cooling water from K- and C-Reactors for prawn production would require the delivery of this water via a pipeline to an offsite prawn producer(s). In addition to the costs associated with the delivery of the cooling water (estimated construction costs of between $188 and $215 million and estimated annual operating costs of about $18 million), cooling systems (once-through or recirculating cooling tower) would still be required to meet environmental standards during the warm season when the prawn producer(s) would not need the cooling water from the reactors.

### I.4.2 CATFISH PRODUCTION

The SCERI report (1978) examined raising such noncrustacean food organisms as clams, eels, and exotic fish such as tilapia. Due to the lack of literature on the potential environmental impacts for an inadvertent introduction of these species into the South Carolina environment, and due to specific technical difficulties with the culture of each species, SCERI eliminated most of these candidates from further consideration as potential aquaculture products. However, it did consider channel catfish (Ictalurus punctatus) culture as a potential application. Catfish farming is presently centered along the Mississippi River, particularly in Louisiana, Mississippi, and Arkansas, where the major portion of the product market also exists. In comparison to the freshwater prawn, the per pound value of catfish is lower and, while prawns are relatively disease-free, catfish are particularly susceptible to certain bacterial, viral, fungal, and algal diseases that often occur under culture conditions. Because these factors would greatly influence the economic feasibility of a commercial catfish operation using reactor waste heat, SCERI determined that the establishment of a research facility would be required to develop the technology of growing catfish in heated ponds and raceways and to develop strains that would be better able to cope with stressful environments and diseases.

Channel catfish have optimum growth and feed conversion at relatively high temperatures (28.9°-31.1°C). Using SRP waste heat, a catfish culture system could expand what would normally be 7 to 8 months of production in the southeastern United States to year-round production. However, the presence of tritium in the reactor cooling water precludes direct contact with the catfish culture medium [21 USC 321(s) and 342(a)(7)]; therefore, waste heat could only be used indirectly, through a heat-exchange system, to heat the culture water. This would necessitate the local availability of large volumes of high-quality water (uncontaminated with biocides from agricultural uses, industrial wastes, etc.) for the culture medium. In addition, the commercial feasibility of the use of SRP waste heat for catfish production would depend on the cost of the heat-exchange system best suited for large-scale production, which could be determined only through pilot-scale testing.

Optimum catfish production requires culture water temperatures of 28.9° to 31.1°C. Water temperatures must remain above 15.6°C if the fish are to continue to grow throughout the year; at temperatures greater than 32.2°C, the fish do not feed regularly. Accordingly, during the warm periods of the year, the use of outdoor ponds for reactor heat dissipation would be negligible. Conversely, a continual supply of heated cooling water would have to be provided to the catfish farm during the colder months; any significant interruptions in this flow could result in complete loss of the catfish crop. Therefore, a backup heating system would be required to ensure maintenance of suitable temperatures during periods of reactor shutdown.

Open ponds are the most common facilities used in catfish production, and their cost in relation to the volume of fish produced is less than that of other facilities such as cages and raceways. Cage culture accounts for only a small proportion of commercial production, used where the culture water is not readily seined (for collection of grown fish). Additional research is required before cage culture could be adopted on a wide scale. Raceways are generally used when only a small amount of land is available for farming. In pond culture, spawning and fry-rearing ponds are usually 1 acre in size, while the most profitable size for growing ponds appears to be 20 acres.

While the SCERI (1978) study did not quantify potential cooling water use or the degree of heat dissipation possible using a heat-exchange system with catfish production ponds, the limitations for waste heat utilization probably would be similar to those for prawn pond farming; that is, (1) that pond heating could utilize only a fraction of the cooling water available from K- and C-Reactors, and (2) that the volume of cooling water that could be utilized for pond heating would require some precooling prior to passage through the heat-exchange system. As with prawn farming, these limitations would necessitate an additional means of reactor effluent cooling to meet regulatory requirements and to make available a usable source of waste heat.

The SCERI study (1978) estimated that it could cost as much as $20,000 to construct a 20-acre pond. Construction of a 50-acre pond would require an estimated $60,000. Enclosing the hatcheries and brooding tanks could double the costs. In addition, SCERI estimated that annual operational costs could amount to more than $1 million for every 640 acres of ponds.

The use of cooling water from K- and C-Reactors for catfish production would require the delivery of the cooling water via a pipeline to an offsite producer(s). In addition to the costs associated with the delivery of this water (estimated construction costs of between $188 and $215 million and estimated annual operating costs of about $18 million), cooling systems (once-through or recirculating cooling tower) would still be needed to meet South Carolina water classification standards during the summer, when the catfish producer(s) would not need the cooling water from K- and C-Reactors.

## I.5 ETHANOL PRODUCTION

The technology for ethanol production is fully established; a considerable amount of development and market research has been completed during the past decade. The largest markets for ethanol would be as fuel for engines or as gasoline blending stock (gasohol). The market for gasohol currently exists. At present, however, this market in the United States cannot compete economically with the price of gasoline.

Even though gasohol marketing efforts during the past 10 years have diminished with the decrease of subsidy support from tax credits and the reduction of economic incentives with the fall in crude oil prices, there is still a potential for ethanol to help offset declining U.S. crude oil production. Due to its strong octane-enhancing properties, a barrel of alcohol displaces more than a barrel of crude oil.

Waste heat from K- and C-Reactors at 77°C could be used economically for ethanol production until it reaches 55°C; technically, it is possible to use this heat to a minimum of 32.2°C. The ethanol production process is a batch activity, during which cooling water must be supplied continuously. Because the production process could not always accept the waste heat, the ethanol facility would require a cooling water system to meet the South Carolina water-quality standards.

The Office of Technology Assessment (OTA) prepared a study to evaluate ethanol production potential (OTA, 1980). A slurry of biomass material (grains are preferred but other crops can be used) would be prepared at ambient temperature; it would be heated to about 90°C to promote enzyme development. The high-temperature enzyme addition accelerates the fermentation process. After fermentation, a mechanical separator would remove the solids, fibers, and particles from the slurry. Depending on the biomass source, the removed solids could be dried, caked, and used as animal feed. This drying operation would start at about 90°C and require a temperature higher than 100°C to be efficient; therefore it would not be a potential application for the waste heat from K- and C-Reactors because the cooling water temperatures are too low.

The use of the available waste heat for the major energy requirement (i.e., the distillation and purification operation) for this process would require a departure from the normal commercial practice - performance of the distillation at a partial vacuum pressure. This would lower the reboiler temperature requirement, but it would add significantly to the required capital costs. Of even greater concern, this departure would remove the process from a well-established commercial practice.

The OTA report (1980) concludes that a 38 to 189-million-liter-per-year process plant was the largest that should be built, due to the requirements for transporting the biomass material to the facility and for transporting the ethanol to market and the byproduct (the dried stillage) to a disposal point or a secondary market. The OTA report states that an acre of corn could produce 640 to 980 liters of ethanol per year in such a process. This report estimates that the ethanol production costs for a 189-million-liter-per-year plant would be about $0.32 per liter and that product delivery costs would be about $0.08 per liter, for a total product cost of $0.40 per liter. OTA further concluded that ethanol as an octane-boosting additive to gasoline would not be economical until crude oil prices ranged from $20 to $30 per barrel (in 1980 dollars). If the SRP waste heat were provided free to the producer, the savings realized would only be about $0.02 per liter, which would not be of great importance in a decision to build such a plant.

A variety of biomass feedstocks could be used in the process. The OTA (1980) and Rogers (1980) studies indicate that the best crops are corn or grain sorghums. Both of these grains produce a solid byproduct that is suitable for processing as an animal feed. Because the Savannah River Plant is not located in a major corn or grain growing area, crop transportation costs would be significant. Also, as indicated above, existing ethanol production facilities are operating at well below full capacity due to depressed crude oil prices.

Clemson University (Cross et al., 1982) studied the feasibility of using waste heat from SRP reactors and root crops such as sweet potatoes and Jerusalem artichokes as feedstock. The estimated production costs of ethanol using these crops ranged from $0.42 to $0.45 per liter, excluding the cost of the feedstock. This study indicated that further study along these lines would not be productive unless a significant cost-reduction breakthrough in harvesting or processing technology is achieved.

## I.6 SUMMARY

None of the potential applications for the utilization of SRP waste heat are considered substitutes for cooling water systems because of institutional, technical, and economic problems. Rather, such costs are considered additive to the construction and operation of cooling water systems for K- and C-Reactors. Reactor cooling water cannot be used directly on crops or other food products because of the presence of tritium in the cooling water discharges. This precludes direct contact use for irrigation of crops and as an aquacultural growth medium. Reactor effluent could be used indirectly in agriculture or aquaculture through the warming of crop soils or the heating of greenhouses or prawn or catfish culture ponds, requiring the use of expensive heat-exchange systems. Such agricultural and aquacultural applications are of seasonal value, required only during the coldest months of the year. Even during the period of use, these applications alone would not dissipate sufficient waste heat to meet State temperature discharge requirements. These potential applications, as well as an ethanol production facility, would require significantly greater capital costs (Table I-2) than recirculating or once-through cooling towers and would take several years to implement, even if commercial operators could be identified. For these reasons, the Department of Energy does not consider the agricultural, aquacultural, and ethanol production applications to be reasonable alternatives to the construction and operation of once-through or recirculating cooling towers for K- and C-Reactors.

Table I-2. Costs for Alternative Cooling Systems and Waste Heat Applications for K- and C-Reactors

| Alternative/application | Capital cost ($ million) | Annual operating cost ($ million) |
|---|---|---|
| Once-through cooling towers | $87 | $0.4 |
| Recirculating cooling towers | $190 | $2.4 |
| Irrigation[a] | $275-302 | $18.4 |
| Soil warming[a] | $275-302 | $18.4 |
| Greenhouses[b] | $86-105 | $18-32 |
| Aquaculture[a] | $280-324 | $4-6 |
| Ethanol production | $NP[c] | $NP |

a. Estimated costs include the costs for once-through cooling towers (because cooling water discharge temperatures are too high to be used during summer) and the costs for delivery of cooling water to the SRP boundary; they do not include costs of user irrigation, soil warming, or production systems (ponds).

b. Estimated costs do not include the costs of delivery of cooling water discharges or of the cooling system that might be required for discharge of the warm water from the greenhouse.

c. NP = Technology not practicable unless gasoline prices rise significantly or there is a cost reduction breakthrough in harvesting feedstock or processing technology. (Note: The estimated capital cost of an ethanol production facility would exceed several hundred million dollars).

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