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APPLICATION OF VASCULAR AQUATIC PLANTS FOR POLLUTION REMOVAL, ENERGY AND FOOD PRODUCTION IN A BIOLOGICAL SYSTEM

By B. C. Wolverton
R. M. Barlow
R. C. McDonald

NASA
NATIONAL SPACE TECHNOLOGY LABORATORIES
BAY ST. LOUIS, MISSISSIPPI 39520

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B. C. Wolverton, R. M. Barlow and R. C. McDonald

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16. ABSTRACT
Vascular aquatic plants such as water hyacinths (Eichhornia crassipes) (Mart.) Solms and alligator weeds (Alternanthera philoxeroides) (Mart.) Griesb., when utilized in a controlled biological system (including a regular program of harvesting to achieve maximum growth and pollution removal efficiency) may represent a remarkably efficient and inexpensive filtration and disposal system for toxic materials and sewage released into waters near urban and industrial areas. The harvested and processed plant materials are sources of energy, fertilizer, animal feed, and human food. Such a system has industrial, municipal, and agricultural applications.

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B. C. Wolverton

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APPLICATION OF VASCULAR AQUATIC PLANTS FOR POLLUTION REMOVAL, ENERGY AND FOOD PRODUCTION IN A BIOLOGICAL SYSTEM

Vascular aquatic plants such as water hyacinths (Eichhornia crassipes) (Mart.) Solms and alligator weeds (Alternanthera philoxeroides) (Mart.) Griesb., common to tropical and subtropical regions of the world, appear to be among the most promising candidates for solving many of man's problems, including pollution removal, increased food, energy and fertilizer requirements. Vascular aquatic plants, when utilized in a controlled biological system including a regular program of harvesting to achieve maximum growth and pollution removal efficiency, may represent a remarkably efficient and inexpensive filtration and disposal system for toxic materials and sewage released into waters near urban and industrial areas. The NASA/National Space Technology Laboratories, as a result of searching for economical solutions to upgrading the effluent quality of its sewage and chemical waste treatment lagoons, began investigating the potentials of vascular aquatic plants for pollution control.

The fact that vascular plants can absorb, translocate and metabolize or concentrate various chemicals has been known for almost forty years (1). This ability, for example, has been used to great advantage by entomologists using systemic insecticides in controlling plant-eating insects (2). Also, the capability of vascular aquatic plants to assimilate nutrients and remove excess nitrates and phosphates from sewage effluents has been recognized for several years (3, 4, 5, 6, 7). The phenomenon involved in systemic uptake, translocation, concentration and/or metabolic breakdown of pesticides, and the vast potential vascular aquatic plants have in removing chemical pollutants from water systems are just beginning to be fully appreciated by environmental scientists. Interestingly, vascular aquatic plants, such as the water hyacinth in particular, have been the subject of considerable research concerning mineral and nutrient uptake, growth rates, and mechanical harvesting practices. Most of the research effort has been associated with control and eradication, since, in the natural state, water hyacinths are considered a major pest due to their tremendous growth rate and extreme hardiness.

These characteristics become desirable attributes when the plants are utilized in a controlled biological system for pollution removal. Research has also been done on developing useful products from plants harvested to clear waterways, including evaluation for animal feeds and human food and assessment of their nutrient content (8, 9, 10, 11, 12). No sustaining efforts to process and utilize the plants on a commercial basis are presently known. Due to the problems encountered in harvesting in the wild state and transportation to processing sites, economical utilization could not be achieved. Using a well designed system to increase harvesting efficiency and by locating the processing equipment on-site to eliminate logistics problems, an economical operation is entirely feasible.

LABORATORY INVESTIGATIONS

As a result of preliminary studies on utilization of vascular aquatic plants for pollution control, laboratory investigations were undertaken at NSTL to determine the pollution removal capabilities for various pollutants and nutrients.

It has been reported that under favorable conditions, one acre (0.40 hectare) of water hyacinths can produce over 534 pounds (240 Kg) of dry plant material per day, which is one of the greatest yields of organic matter ever reported (13). This same surface area of water hyacinths has the potential of removing over 3,500 pounds (1,591 Kg) of nitrogen and over 800 pounds (364 Kg) of phosphorus, annually, from sewage effluent; absorbing and metabolizing over 150 pounds (68 Kg) of phenol every seventy-two hours from water polluted with this chemical, in addition to removing over 120 grams of trace heavy metal contaminates every 24 hours (3, 5, 6, 14, 15, 16).

To effectively remove nutrients and other chemicals from waste effluents, water hyacinths must be harvested at intervals which allow for maximum biomass production. One acre (0.40 hectare) of water hyacinths has the potential of producing over 70 tons (63.5 metric) of dry plant material annually, when grown in a desirable nutrient media such as domestic sewage effluent under proper climatic conditions (13). This large volume of biomass has the potential of producing over one million cubic feet of bio-gas through anaerobic decomposition with 70 tons (63.5 metric tons) of residual high grade fertilizer being produced as a by-product (17, 18, 19). Water hyacinths also have a dry weight nutrient content similar to that of many agricultural crops (8). The nutrient content varies with water fertility and stage of plant growth.

Figure 1, 2 and 3 summarizes the laboratory investigations on the pollution removal capabilities of water hyacinths and alligator weeds. Experiments were conducted using plant controls free of pollutants and pollutant controls free of plants. Aqueous samples were taken at 1, 3, 6, and 24 hour intervals for heavy metals; and for nutrient removal analyses, samples were taken at seven-day and fourteen-day intervals (5, 14, 15, 16).

APPLICATIONS

Two of the most pressing problems facing the United States and other industrial nations today are rapid depletion of vital natural resources and environmental pollution. One important factor in the rise of the United States to its present high industrial level has been an abundance of fossil fuel resources. Presently, coal, oil, and large reservoirs of underground natural gas are all produced through natural decomposition of pre-historic forms of life. Modern society is depleting these resources at an alarming rate. Renewable sources must be developed within the near future.

As we deplete our natural resources, we are also polluting and contaminating our environment at ever increasing rates. Fortunately, the minerals and nutrients contaminating and polluting our water systems can potentially be recovered, utilizing natural biological processes.

Based on laboratory results with vascular aquatic plants and the preliminary results of field tests being conducted under a NASA, Office of Applications - sponsored program at the National Space Technology Laboratories, Bay St. Louis, Mississippi, some innovative applications now appear possible. A system of vascular aquatic plant filled lagoons appears possible for removal of chemical pollutants with the harvested plants being converted to bio-gas and extraction of heavy metals from the sludge. Since no toxic levels of heavy metals have been found in plants grown in domestic sewage (samples taken from the City of Bay St. Louis, Mississippi, sewage lagoon), the harvested plants are potential sources of animal feed, human food and fertilizer.

Figure 4 conceptually illustrates a biological system for removal of chemical and sewage pollutants from waste waters, utilizing either water hyacinths or alligator weeds as a biological filtration system in a zig-zag canal-type lagoon. Mature plants harvested to promote optimum growth rate and removal of pollutants and contaminants become a valuable source of raw material for conversion to useful products.

Figure 5 displays some of the processing alternatives and products that may be derived from the harvested biomass.

Figure 6 conceives a potentially self-sufficient agricultural homestead through the installation of a vascular aquatic plant filtration system and ancilliary processing equipment to produce energy, fertilizer and feeds.

FIELD DEMONSTRATIONS AND CONTINUING EFFORTS

Field demonstrations, utilizing a chemical waste lagoon and a municipal sewage lagoon are in process. The primary objective of the field tests is to demonstrate the pollution removal effectiveness of vascular aquatic plants. Figure 7 shows the zig-zag canal type lagoon at NSTL during the construction phase. This lagoon is now being utilized to evaluate the removal of pollutants from chemical wastes.

Efforts are continuing toward the development and demonstration of harvesting equipment. The planned harvesting scheme is to gather, remove from the water, and chop the harvested water hyacinths into approximately one inch (2.5 cm) pieces. From this point the plant material will be delivered to the selected processing equipment. The harvesting equipment is designed to process at a rate of 15 to 20 tons (13.6 to 18 metric tons) per hour.

Processing equipment, including scaled-up laboratory models of bio-gas generating units, is being developed. This equipment will be operated to gather data for sizing a pilot plant for field test and evaluation. Investigations of methods for processing the residual sludge from the bio-gas units into fertilizers will be conducted, including evaluation of the chemical and nutritive content.

Animal feed processing will be accomplished by reducing the moisture content of the freshly chopped plant material to approximately that of well cured forage. A solar dryer will be evaluated for curing the plant material. Several feed formulations will be produced and evaluated in a beef cattle feeding program.

Several other processing possibilities are also being investigated on a limited scale. Laboratory studies are being initiated to develop methods for metal extraction from sludges containing heavy metals. Laboratory processes for converting harvested plant material (free of toxic substances) into human food will be undertaken to produce protein supplements, cereals or flour/meals.

Based on field tests to demonstrate pollution removal and to demonstrate the processing of harvested plants into usable products, a comprehensive economic assessment will be conducted including capital investment requirements, operating costs and potential sales of products to offset operating costs.

Chemical and Metal Pollutants	LABORATORY EXPERIMENTS			FIELD POTENTIAL	
	Dry Plant Weight (grams)	Contact Time (hours)	Quantity-Removed, Absorbed, or Metabolized	Area	Quantity-Removed, Absorbed or Metabolized
Cadmium*	1	24	0.67 mg	Acre 0.4 Hectare	0.355 lb ** 0.161 Kg **
Lead*	1	24	0.176mg	Acre 0.4 Hectare	0.093 lb ** 0.042 Kg **
Mercury*	1	24	0.150mg	Acre 0.4 Hectare	0.079 lb ** 0.036 Kg **
Nickel*	1	24	0.50 mg	Acre 0.4 Hectare	0.265 lb ** 0.120 Kg **
Silver*	1	24	0.65 mg	Acre 0.4 Hectare	0.344 lb ** 0.156 Kg **
Cobalt*	1	24	0.57 mg	Acre 0.4 Hectare	0.302 lb ** 0.137 Kg **
Strontium*	1	24	0.54 mg	Acre 0.4 Hectare	0.286 lb ** 0.130 Kg **
Phenols	1	72	36 mg	Acre 0.4 Hectare	19.1 lb ** 8.640 Kg **

* Ionized form

** Based on removal of mature plants every 24 hours

Figure 1. Capability of Water Hyacinths to Remove Various Pollutants From Waters Polluted With These Substances

Metal Pollutants (ionized form)	LABORATORY EXPERIMENTS			FIELD POTENTIAL	
	Dry Plant Weight (grams)	Contact Time (hours)	Quantity-Removed, Absorbed, or Metabolized	Area	Quantity-Removed, Absorbed, or Metabolized
Lead	1	24	0.10 mg	Acre 0.4 Hectare	0.053 lb * 0.024 Kg *
Mercury	1	24	0.15 mg	Acre 0.4 Hectare	0.079 lb * 0.036 Kg *
Silver	1	24	0.44 mg	Acre 0.4 Hectare	0.233 lb * 0.106 Kg *
Cobalt	1	24	0.13 mg	Acre 0.4 Hectare	0.069 lb * 0.031 Kg *
Strontium	1	24	0.16 mg	Acre 0.4 Hectare	0.085 lb * 0.038 Kg *

* Based on the removal of mature plants every 24 hours.

 Figure 2. Capability of Alligator Weeds to Remove Various Heavy Metals From Waters Polluted With These Metals

TYPE OF PLANT/ MEASUREMENTS TAKEN	INFLUENT				EFFLUENT			
	7-Day Exposure		14-Day Exposure		7-Day Exposure		14-Day Exposure	
	Reduction w/Plants	Reduction Control (Free of Plants)	Reduction w/Plants	Reduction Control (Free of Plants)	Reduction w/Plants	Reduction Control (Free of Plants)	Reduction w/Plants	Reduction Control (Free of Plants)
WATER HYACINTHS								
- Total Kjeldahl Nitrogen	92%	18%	-	-	75%	13%	89%	15%
- Total Phosphorus	60%	13%	-	-	87%	11%	99%	25%
- Total Suspended Solids	-	-	-	-	75%	15%	77%	12%
- BOD_5	97%	61%	-	-	77%	6%	-	-
- pH	Increased From 7.05 to 7.35	Increased From 7.05 to 7.75	-	-	-	-	Decreased From 8.80 to 7.20	Decreased From 8.80 to 8.20
ALLIGATOR WEEDS								
- Total Kjeldahl Nitrogen	97%	18%	97%	14%	61%	10%	76%	14%
- Total Phosphorus	50%	13%	78%	35%	44%	15%	62%	41%
- Total Suspended Solids	-	-	-	-	94%	48%	98%	60%
- BOD_5	92%	68%	97%	65%	-	-	-	-
- pH	-	-	Increased From 7.1 to 7.4	Increased From 7.1 to 8.25	-	-	Decreased From 8.9 to 7.2	Decreased From 8.9 to 8.35

Figure 3. Final Filtration of Sewage Utilizing Water Hyacinths and Alligator Weeds

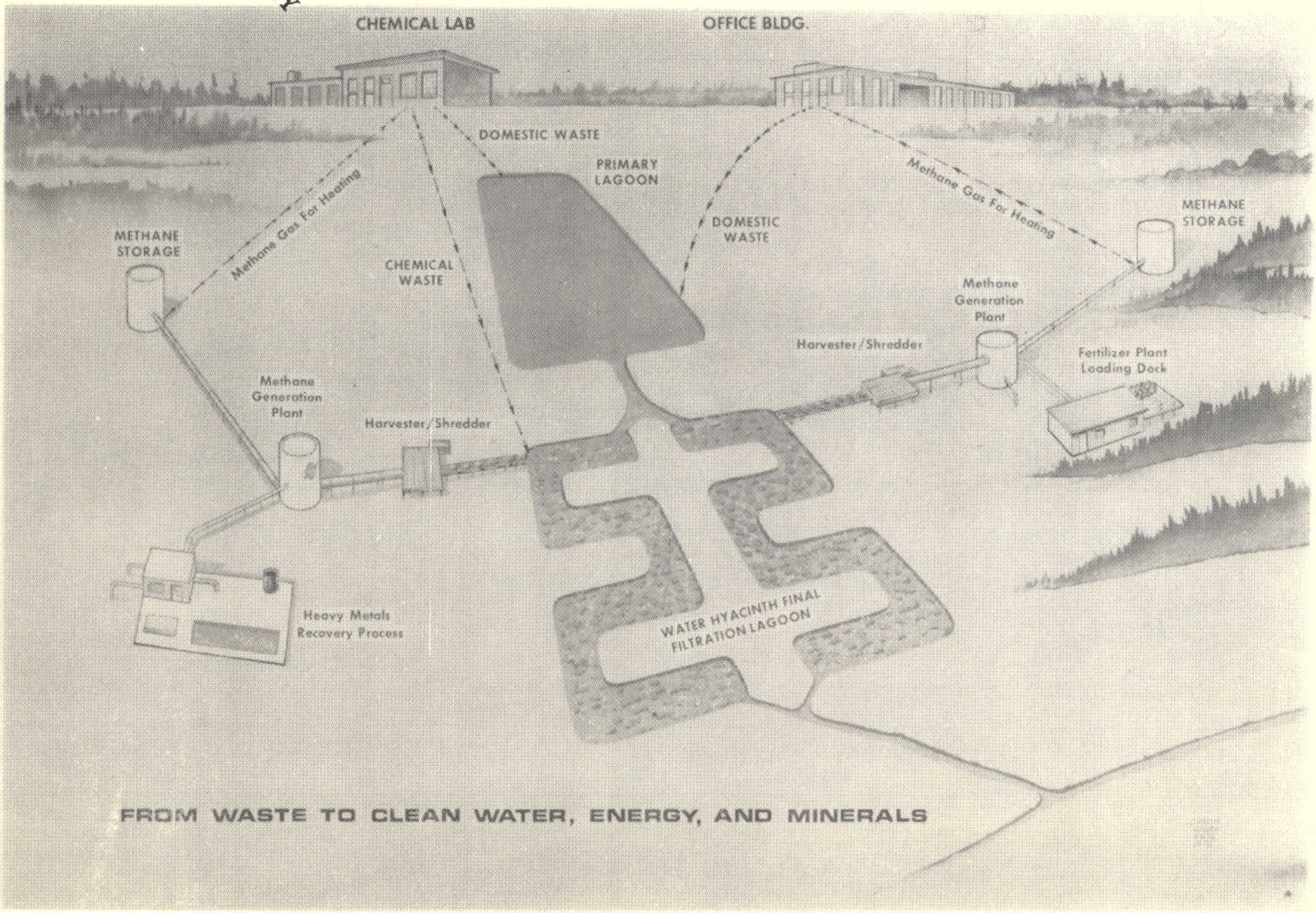

Figure 4. NASA Aquatic Plant Filtration System Concept

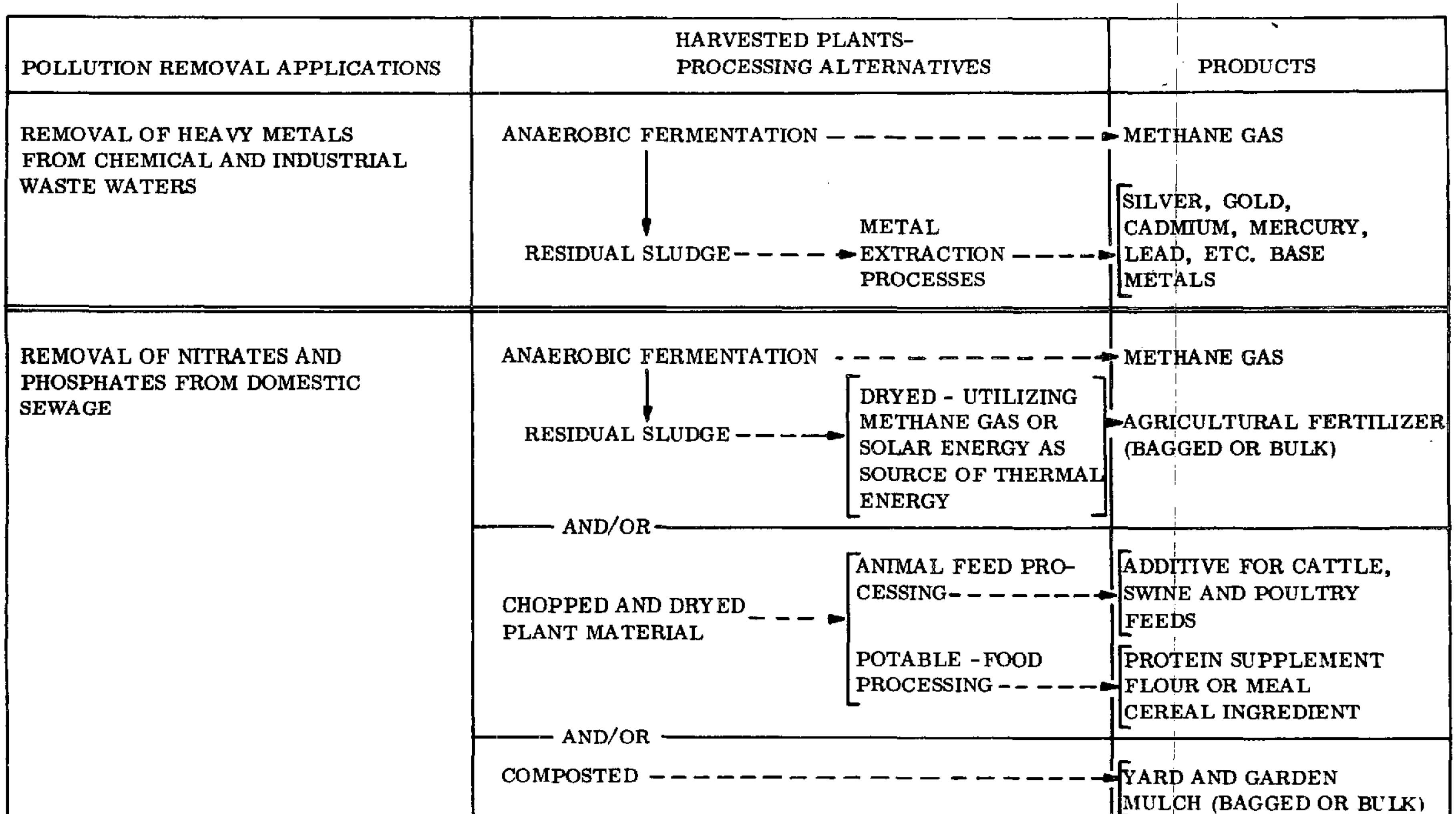

Figure 5. Processing Alternatives for Conversion of Vascular Aquatic Plants to Useful Products

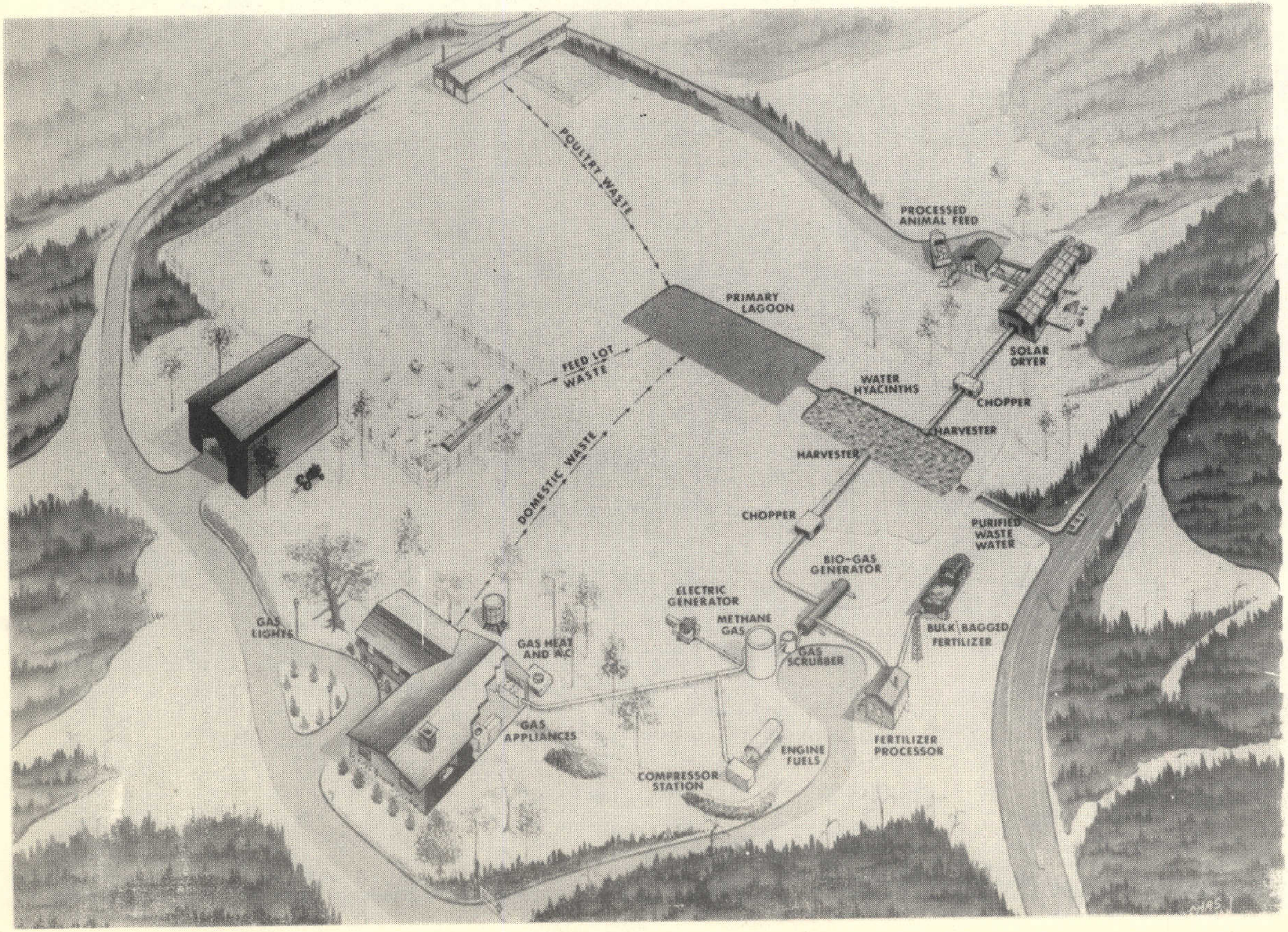

Figure 6. Agricultural Applications

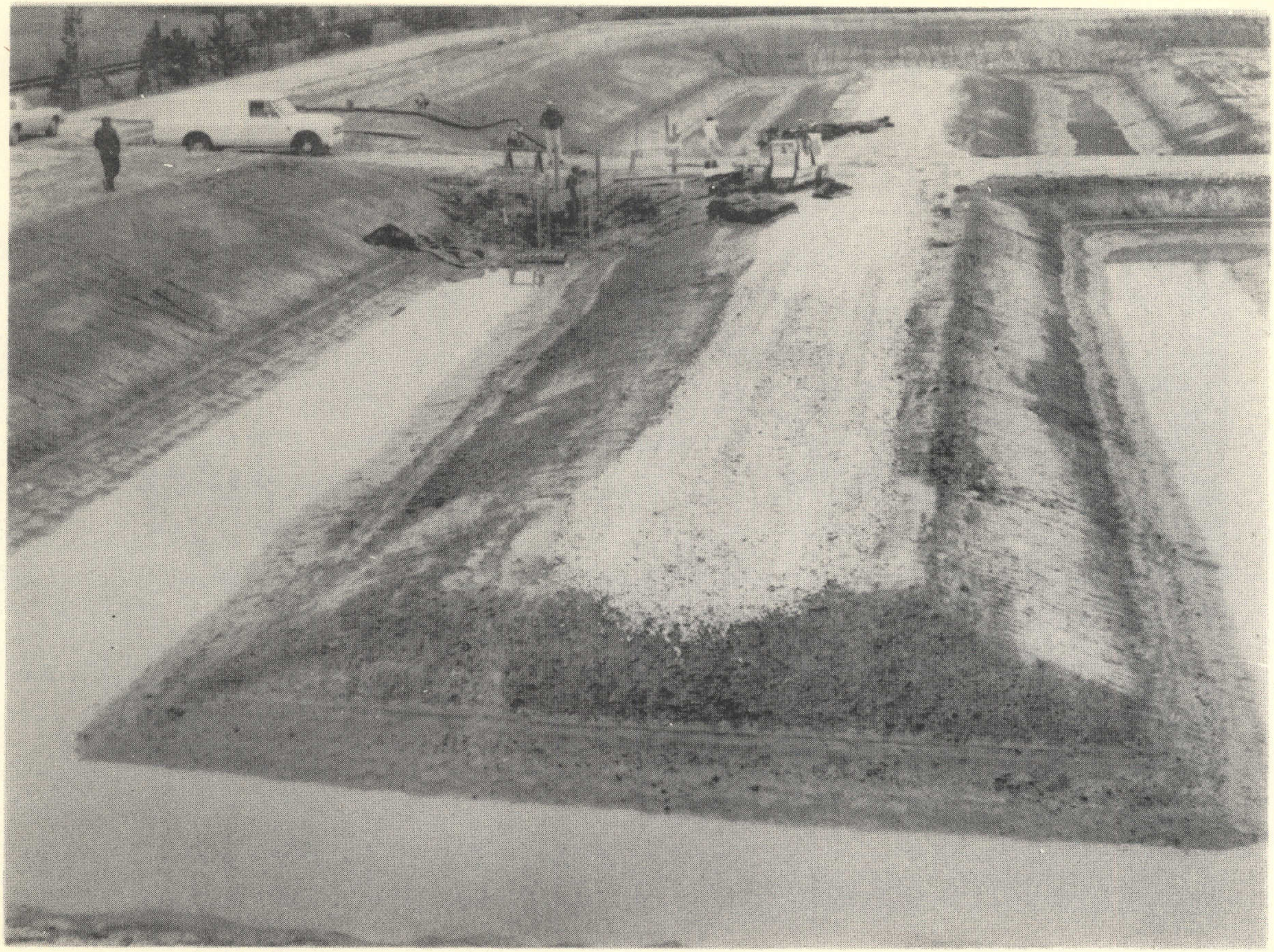

Figure 7. NSTL Zig-Zag Lagoon During Construction

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APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense of Atomic Energy Commission programs has been made by the NSTL Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Henry F. Auter

HENRY F. AUTER
Director, Applications Engineering
National Space Technology Laboratories