# ENVIRONMENTAL AND ECONOMIC ASPECTS OF RECYCLING LIVESTOCK WASTES– ALGAE PRODUCTION USING WASTE PRODUCTS

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Attention is now focused upon problems confronting our Nation in the area of environmental pollution. There is a close correlation between industrial and agricultural expansion and increases in population over the last few decades. There is also a pronounced association between increases in population and the magnitude of pollution problems. As an example, there is some concern about environmental pollution associated with power production which is rapidly expanding to meet the demands for electricity of an increasing population and industrial complex. Power production expansion is occurring largely in areas which already have high population densities.

The same trend holds true for the livestock industry. Expansion of this agricultural enterprise to include large confined feeding operations is potentially a pollution problem with respect to waste disposal and nitrate contamination of local water sources, especially in more heavily populated humid areas. This expansion has occurred to meet the demands for livestock products by increasing numbers of people. For example, 15.4 billion pounds of beef, 11.7 billion pounds of pork, and 5.3 billion pounds of poultry were consumed in the United States in 1960. In 1968 consumption increased to 22.0 billion pounds of beef, 13.3 billion pounds of pork, and 8.2 billion pounds of poultry. Projected consumption in 1980 is 36.2, 16.2, and 14.5 billion pounds, respectively [2]. So, it is evident that the livestock industry will most likely expand in concentrated units. From an environmental pollution viewpoint, such an expansion will have to be compatible with a rapid increase in population.

We will discuss herein the economic feasibility of simultaneously increasing food production and decreasing potential pollution problems by producing algae (a high protein feed source) from nutrients in waste disposal systems. This could convert a potential livestock waste pollutant into an economic resource while reducing fertilizers needed and other potential pollutants.

## WASTE DISPOSAL PROBLEM

The magnitude of waste disposal problems from confined feeding operations, as well as sources for nutrient elements, is illustrated in Table 1 [7].

Livestock wastes in the United States are in excess of a billion tons of fecal waste per year, including over 400 million tons of liquid effluent. Probably half of this waste is produced under concentrated conditions which in certain cases might cause problems in environmental pollution. Nutrient elements in this quantity of agricultural wastes could produce phenomenal quantities of algal protein through a recycling system.

In the past, manure disposal involved spreading on cropland, but with confined feeding operations, particularly in highly populated areas, land for this disposal is becoming limited and supplies concentrated, so it is essential that other disposal alternatives be evaluated. One system that has been proposed involves using nutrient elements contained in livestock wastes for algae production in a series of lagoons or ponds. Such a system integrated into a feedlot operation should reduce the accumulation of nitrates in ground water and also in nearby lakes and streams, thereby decreasing the potential for more acute eutrophication. The algae, or maybe other plants produced hydroponically, could be harvested and processed into a high protein feed source for livestock. With proper processing, algae may have some merit for human consumption.

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**TABLE 1. ORGANIC AND MAJOR FERTILIZER ELEMENTS IN THE COMPLETE ANIMAL EXCREMENT PER 1,000 POUNDS OF LIVE ANIMAL WEIGHT**

| | Hens | | Hogs | | Cattle | |
|---|---|---|---|---|---|---|
| | Lbs./day | Lbs./yr. | Lbs./day | Lbs./yr. | Lbs./day | Lbs./yr. |
| Wet manure | 56 | 32,200 | 70 | 22,400 | 64 | 20,600 |
| Total mineral matter | 3.9 | 1,400 | 1.8 | 600 | 2.1 | 800 |
| Organic matter | 12.2 | 4,400 | 9.4 | 3,400 | 8.2 | 3,000 |
| Nitrogen (N) | 0.93 | 333 | 0.50 | 185 | 0.38 | 138 |
| Phosphorus ($P_2O_5$) | 0.69 | 253 | 0.26 | 110 | 0.11 | 41 |
| Potassium ($K_2O$) | 0.34 | 118 | 0.48 | 172 | 0.31 | 112 |

## RESOURCE POTENTIAL OF POLLUTANT

The tremendous potential for production of protein using algae has been illustrated by Oswald and Golueke [6]. They produced 20 tons of algae (50 percent protein) per acre of pond with domestic sewage in large-scale pilot plants at Richmond, California. They reported that protein and energy yields from algae were much greater than from agronomic crops (Table 2). For the 283 million acres of traditional cropland shown in Table 2, less than 5 million acres would yield equivalent protein.

Beall discussed systems, including greenhouse-poultry-algae operations, that could be conducted to utilize waste heat near nuclear steam generating plants [1]. He estimated yields of $1.5 \times 10^6$ pounds of algae per year from a 50-acre culture and valued the algae at three to five cents a pound if incorporated into fish or animal feeds. Such an operation could be even more impressive if credited with an economic value for treating waste sewage or utilizing waste heat from steam plant effluent.

**TABLE 2. COMPARISON OF LAND USE FOR FOOD AND ANIMAL FEED PRODUCTION WITH CONVENTIONAL CROPS AND WITH ALGAE**

| Crop | Land Use Total Area (millions of acres) | Area of Micro-algae Culture Required for Equal Production (millions of acres): Total Free Energy Basis | Protein Basis |
|---|---|---|---|
| Corn | 82 | 4.1 | 1.67 |
| Hay | 69 | 3.2 | 1.00 |
| Wheat | 53 | 1.1 | 0.55 |
| Oats | 27 | 0.8 | 0.25 |
| Soybeans | 23 | 0.4 | 1.10 |
| Sorghum | 15 | 0.4 | 0.20 |
| Barley | 14 | 0.3 | 0.14 |
| Total | 283 | 10.3 | 4.91 |

Production of algae competes favorably with conventional uses of water in production of agronomic crops. Generally, one acre-foot of water produces about 288 pounds of protein with soybeans, 120 pounds of protein with corn, and 90 pounds of protein with wheat. The same quantity of water produces about 5,000 pounds of protein with algae culture (Table 3) [6].

Production of one gram of algae requires 0.4 gram carbon, 0.1 gram nitrogen, and 0.01 gram phosphorus, and certain amounts of secondary and micronutrients. Animal wastes should be an excellent source of nutrients for algae. In addition to nitrogen, phosphorus, and potassium contained in animal wastes (Table 1), considerable amounts of other elements essential for plant growth are also present (Table 4) [7].

TABLE 3. COMPARISON OF WATER USE FOR PROTEIN PRODUCTION WITH AGRONOMIC CROPS AND WITH ALGAE

| Crop | Annual Protein Yield, lbs./acre | Annual Consumptive Water Use, Acre-feet per acre | Lbs. of Protein per acre-foot |
|---|---|---|---|
| Soybean | 576 | 2.0 | 288 |
| Corn | 240 | 2.0 | 120 |
| Wheat | 135 | 1.5 | 90 |
| Algae | 20,000 | 4.0 | 5,000 |

TABLE 4. POUNDS OF SECONDARY AND MINOR ELEMENTS IN 1,000 GALLONS OF FRESH ANIMAL MANURES

| Manure | Calcium | Magnesium | Sulfur | Iron | Zinc | Boron | Copper |
|---|---|---|---|---|---|---|---|
| Hen | 300.0 | 24.0 | 26.0 | 3.9 | 0.75 | 0.50 | 0.12 |
| Hog | 47.0 | 6.6 | 12.0 | 2.3 | 0.50 | 0.35 | 0.13 |
| Cattle | 17.0 | 8.7 | 5.8 | 0.33 | 0.12 | 0.12 | 0.04 |

## COMPARATIVE PRODUCT VALUE

Prospects look favorable that the expected need for plant proteins, as well as the vitamins and minerals, can be met rather economically by the culture of new plants and animals such as algae, yeast, and fish (Table 5).

If these new farming operations prove commercially feasible, good quality protein, along with vitamins and minerals, should become more available to poor elements of our population, especially the children, and also to the poverty-stricken in less developed countries.

Mattoni, et al., also showed algae to be an excellent protein source when compared with soybeans, corn, and sugarcane (Table 6) [4].

From 1960-66, feeding trials were conducted at the University of California (Davis) to evaluate the use of algae as an animal feed. A pelletized mixture of barley and algae (10% algae in mixture) with small quantities of vitamin $B_{12}$ was as efficient as barley and fish meal for swine production. Rations containing 10 percent algae were rated excellent for sheep production. In studies with cattle, it was found that ruminants digested algae more readily than nonruminants.

Other aquatic plants may have a potential for livestock feed. Martin analyzed three locations in Pickwick Reservoir in 1966 and found Najas, a rooted submerged species, to contain from 16.0 to 20.0 percent protein and rather high concentrations of other elements (Table 7) [3]. Yields of over 600 pounds per acre-foot were observed under existing stream conditions. Such yields might be multiplied in solutions enriched with livestock wastes.

## ESTIMATED PRODUCTION COSTS

It was estimated that algae production on domestic sewage at Lancaster, California, would recover about 1.2 billion gallons and produce about 2,400 tons of algae (40-50% protein) annually. The esti-

**TABLE 5. ESTIMATED MARGINAL COST FOR PROTEIN PRODUCTION [5]**

| | | Anticipated Cost of Protein (per lb.) | Investment Required (Annual ton) |
|---|---|---|---|
| Fish farms | | $ .40-1.00 | $ 1,000-2,500 |
| Cane Juice: | Food yeast | .35- .50 | 600-1,200 |
| | Fatty yeast | .70-1.00 | 1,200-2,000 |
| Chlorella | | .10- .20 | 300- 600 |
| Blue-green algae | | .05- .15 | 300- 600 |

**TABLE 6. PROTEIN YIELDS PER ACRE WITH VARIOUS CROPS AND ALGAE**

| Crop | Nitrogen % | Protein % | Dry Matter Yield per acre per yr. (lbs.) | Protein Yield per acre per yr. (lbs.) |
|---|---|---|---|---|
| Soybeans | 2.6 | 16.25 | 12,230 | 1,987 |
| Corn | 1.2 | 7.5 | 26,500 | 1,988 |
| Sugarcane | 0.285 | 1.78 | 111,579 | 2,879 |
| Algae (mixed) principally Scenedesmus | 8.19 | 51.2 | 100,000 | 51,200 |

**TABLE 7. YIELD AND NUTRIENT CONCENTRATION OF NAJAS COLLECTED FROM THREE LOCATIONS IN THE TENNESSEE RIVER**

| Location | Pounds of Oven-Dry Plant Material Per Acre-Foot of Water | Ca | Mg | K | Protein | P | Fe | Mn | Zn | Cu |
|---|---|---|---|---|---|---|---|---|---|---|
| Bruton Branch, Pickwick Lake | 744 | 1.2 | 0.39 | 6.2 | 16.0 | 0.36 | 0.56 | 0.82 | 0.004 | 0.0015 |
| Cane Creek, Pickwick Lake | 760 | 1.2 | 0.34 | 6.8 | 20.0 | 0.73 | 0.52 | 0.46 | 0.018 | 0.0074 |
| Town Creek, Wilson Lake | 623 | 1.0 | 0.32 | 3.7 | 19.4 | 0.32 | 1.30 | 2.00 | 0.010 | 0.0019 |

mated costs of a plant for this type production would be about $350,000 per year to operate and amortize, giving a production cost of $150 per ton for algae. Not included in these computations are the beneficial effects of recovering 1.2 billion gallons of water and avoiding the cost of a conventional sewage disposal system.

The economics of algae production from livestock wastes integrated into a feedlot operation have not been evaluated experimentally. Potential yields of algae with the nutrients in manure from a 1,000-capacity hog feedlot were estimated on the basis of data given in Table 1. During a one-year period, assuming the feedlot operated at maximum capacity, about 3 million pounds of manure, containing about 25,000 pounds of nitrogen and 7,000 pounds of phosphorus, would be produced. On the basis of carbon, nitrogen, and phosphorus requirements of algae, this quantity of manure has the potential (assuming 100% utilization of nutrients) for producing in excess of 300 tons of algae with nitrogen-fixing cultures and in excess of 100 tons with non-nitrogen-fixing cultures.

An estimated production cost for algae in an underdeveloped area was about $70 per ton (Table 8) [5]. This estimate included about $300 per hectare ($121.41 per acre) per year for nutrients and water which would not be included in an integrated feedlot-algae production system as the animal waste would be supplying the nutrients.

## RESEARCH NEEDS

Considerable research is needed on harvesting and processing of algae to make this an economically feasible operation. However, cost of production, harvesting, and processing would offset conventional costs of manure disposal. Methods for harvesting algae from domestic sewage have been investigated [6]. The algal suspension is concentrated, the re-

**TABLE 8. PROSPECTIVE ECONOMIC CHARACTERISTICS OF BLUE-GREEN ALGAE PRODUCTION**

Estimated for a Typical Location in an Underdeveloped Area

| | |
|---|---|
| Assumptions as to Yield | |
| 50 tons/hectare (45,000 lb./acre) dry wt., 90% of available minerals are utilized | |
| Capital Costs | |
| Land leveling (or shore installations) | $ 1,000/hectare |
| Pump-aeration units (50/hectare) | 10,000 |
| Piping and valves (300 m/hectare) | 2,000 |
| Frames, channels, repair jigs, etc. | 2,000 |
| Central facilities (pro-rated) | 1,000 |
| ($6,500 per acre) | $16,000/hectare |
| Operating Costs | |
| Labor (50 workers per 1,000 hectares, $1,000 annual wage) | $ 50/yr./hectare |
| Water and minerals | 200 |
| Power (at 1-2 ¢ per kwhr) | 300 |
| Plastics replacement and materials for repair | 150 |
| | $ 700/yr./hectare |
| Total Costs | |
| (10-yr. amortization, 8% interest on capital) | $ 3,500/yr./hectare* |
| | ($ 1,400/yr./acre) |
| | or about $70/ton |

*The product from such a plant is moist and very perishable, ready for some nearby food-processing unit. Dried product for storage will cost somewhat more.

sulting slurry dewatered and further concentrated, and the slurry dried for storage and handling.

While these estimates are of necessity tentative, they are subject to empirical tests. Some of the main elements of risk or uncertainty are (1) the development of an economical system of harvesting, processing, and marketing both from a private and social viewpoint, (2) maintaining a proper culture environment for maximum production, (3) disease and insect control, (4) weather, (5) producing a product that is palatable for livestock consumption, and (6) maintaining high levels of management skills.

The Tennessee Valley Authority proposes to begin empirical tests to determine the feasibility of an integrated livestock-algae producing system to utilize nutrients from livestock wastes and thermal energy from a nuclear power generating plant.

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