TimberFish TECHNOLOGIES

Ecologically Integrated Agriculture

Introduction:

Ecologically Integrated Agriculture (EIA) is a new form of comprehensive agriculture that can greatly increase our food production and diversity while resolving environmental and food security issues. EIA does this by combining and connecting Confined Animal Feeding Operations (CAFOs); Feed Crop Production Systems; Grain, Fruit, and Vegetable Farming; Aquaculture; and Forestry with the TimberFish Technology (TFT).

Here the TFT expands and replaces existing manure and nutrient management practices while also including some aspects of industrial and municipal waste and wastewater treatment technologies. By integrating the different processes the wastes and byproducts from one system become desirable inputs to other systems. This results in increased material handling, storage, and transportation efficiencies, and the elimination of environmental problems.

The key metric to understand this technology is to follow the course of nitrogen as it enters, recycles around, and exits the system on a daily basis. The index we will use for the dairy is that one cow will excrete a total of one pound of nitrogen in feces and urine each day. In one year you get 365 pounds of manure nitrogen from one cow. The index we will use for TimberFish is based on 2,000 pounds of dry wood chips that can be sustainably harvested from one acre of forest each year. These 2,000 pounds of wood chips can convert one pound of nitrogen into a maximum of 50 pounds of fish. Thus in one year 365 acres of forest can be used to produce 18,250 pounds of fish from 365 pounds of nitrogen. This could be the 365 pounds of nitrogen you get from the manure from one cow during that year.

What is critical about this is that the forest will retain all of its carbon sequestering capacity. What is harvested for TimberFish is more than replaced by the normal growth in steady state forests. In the cases of new or rapidly growing forests they will still be adding to their total of carbon sequestration capacity, but at a slightly slower rate. Thus EIA provides a strong economic incentive for large scale new forest development, reforestation, and deforestation avoidance.

The benefits of EIA will be illustrated by comparing; a stand alone modern Dairy CAFO with on site feed crop production using land applied manure; and an EIA system which includes such a Dairy CAFO. Here is a summary of that comparison.

A 300 cow Dairy CAFO can produce 697,000 gallons of milk per year. At a $1.40 farm gate price for milk this earns $977,000 per year.

Connect this dairy to a TimberFish system in an EIA CAFO system so that all manure normally land applied to crop fields enters the TimberFish bioreactor. The dairy milk production and income remains the same but that is now supplemented by additional income streams as follows:

Annual values for a 300 cow dairy EIA - CAFO

Parameter	Units	result	Value	Basis for Value
Milk	gallons	697,000	$977,000	$1.40 per gallon
Fish	pounds	2,190,000	$10,950,000	$5.00 per pound
Energy	KWh	22,300,000	$2,230,000	$0.10 per KWh
C offset	acres	45,440	$408,000	$9.00 per acre/year
Corn	acres	570	$454,000	$4.50 per bushel

The Systems:

#1 A Dairy CAFO.

A typical Dairy CAFO comprises one or more free stall barns connected to a milking parlor. Manure, feces and urine, will be excreted by the animals onto barn alleys and walkways and flushed periodically into a storage lagoon with water recycled out of the storage lagoon. The lagoon water and solids will be periodically pumped out and land applied via spreading, spraying, or soil injection at appropriate times. These will be scheduled to optimize soil inclusion of the manure and avoid nitrogen loss to atmosphere or runoff in accordance with best management practices for the location and environment of the Dairy.

Assume that during the course of a year each cow will produce 54.8 pounds, or 6.37 gallons of milk per day (Microsoft Word - Dairy manure nutrient content and forms.doc (ucdavis.edu)). All of the nitrogen in this milk will come from the cow feed. The rest of the total amount of nitrogen in the cow feed will be excreted in the manure. Roughly half of the excreted nitrogen will be as ammonium nitrogen some of which can rapidly volatilize and be lost to the atmosphere. Good manure management practices can minimize this loss to 40 percent of the ammonium nitrogen as excreted (20 percent of the total nitrogen) so that 80 percent of the total excreted manure nitrogen can be incorporated into the soil. The UC Davis data for Central California indicates that 70 percent is a more realistic number for that area. We will use the 80 percent number in these calculations while realizing that in many cases this number is too high due to weather, runoff, and other factors.

Once the manure is stabilized in the soil it will provide Plant Available Nitrogen (PAN) for feed crops grown on the land and used for feed in the Dairy. The nitrogen in the soil will exist in one of three forms; mineralized, mostly as ammonium ions; in non cellular organic compounds such as proteins, nucleic acids, urea, and similar nitrogen containing compounds; and cellular nitrogen, nitrogen that is bound up in living microorganisms, mostly bacteria.

Over time the nitrogen can recycle through the three forms depending on the many variables that impact the soil ecosystem. The nitrogen in the microorganisms is in the most stable form and least likely to be lost to the environment due to volatilization or runoff.

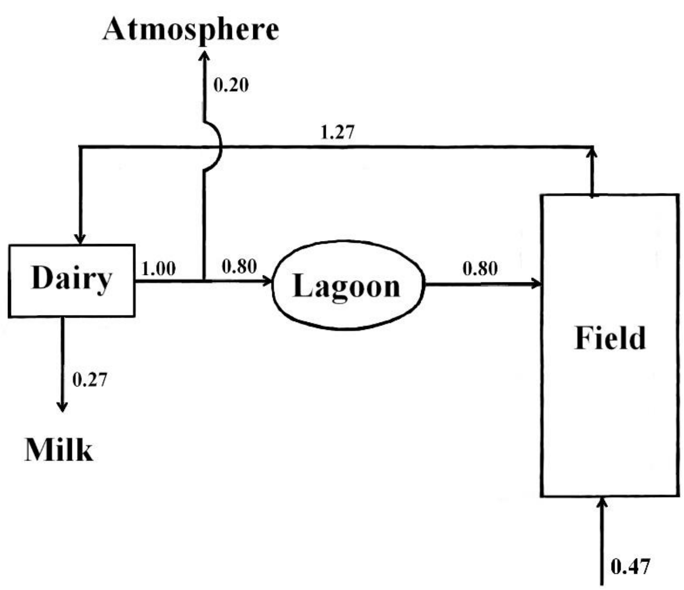
Plants can only utilize the nitrogen in its mineralized form so the other two forms act as storage reservoirs, preventing loss of the nitrogen to volatilization or runoff.

The recycling through the three forms allows for the plants to use the nitrogen as needed. In this manner all of the nitrogen can become PAN over time and as needed by the plants.

For our example we assume that 100 percent of the nitrogen stabilized in the soil will become PAN at some time. This is not strictly true since some nitrogen can be lost to heavy rains or extremely high temperatures, etc., but it is useful for our comparison and does not affect our conclusions.

The footprint for the CAFO Dairy will include the land for the buildings and infrastructure and the required crop acreage to produce the feed used to feed the cows. In the northern dairy states this tends to require 1 to 2 acres per cow per year. We will assume two acres per cow per year for this comparison. Thus a 100 cow Dairy CAFO might require 10 acres for buildings and infrastructure and 200 acres of cropland to produce feed for 100 cows over the year.

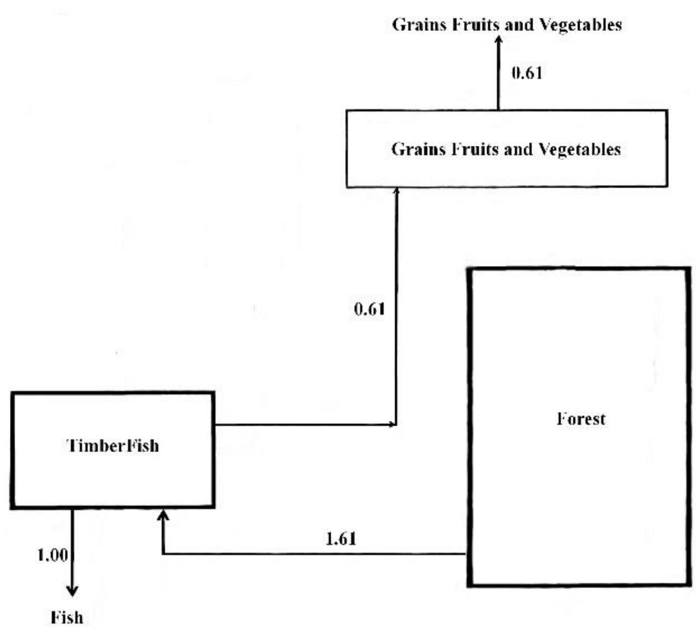
Fig 1 shows the nitrogen cycle in pounds for one dairy cow in one day.



In this Figure the cow will eat forage crops from the field that contain 1.27 pounds of nitrogen in one day. The cow will produce 6.37 gallons of milk that contain 0.27 pounds of nitrogen, and will excrete 1.00 pounds of nitrogen in fresh manure. Of this, 0.20 pounds will be volatilized to atmosphere and the remaining 0.80 pounds of nitrogen will be stored in a lagoon. This nitrogen will be transferred to the field, incorporated in the soil as Plant Available Nitrogen, and eventually returned to the dairy cow as part of the 1.27 pounds of nitrogen required for another day's future feed. This will also require that 0.47 pounds of additional nitrogen be added to the field growing forage to feed the cows. Usually this is in the form of inorganic nitrogen fertilizer.

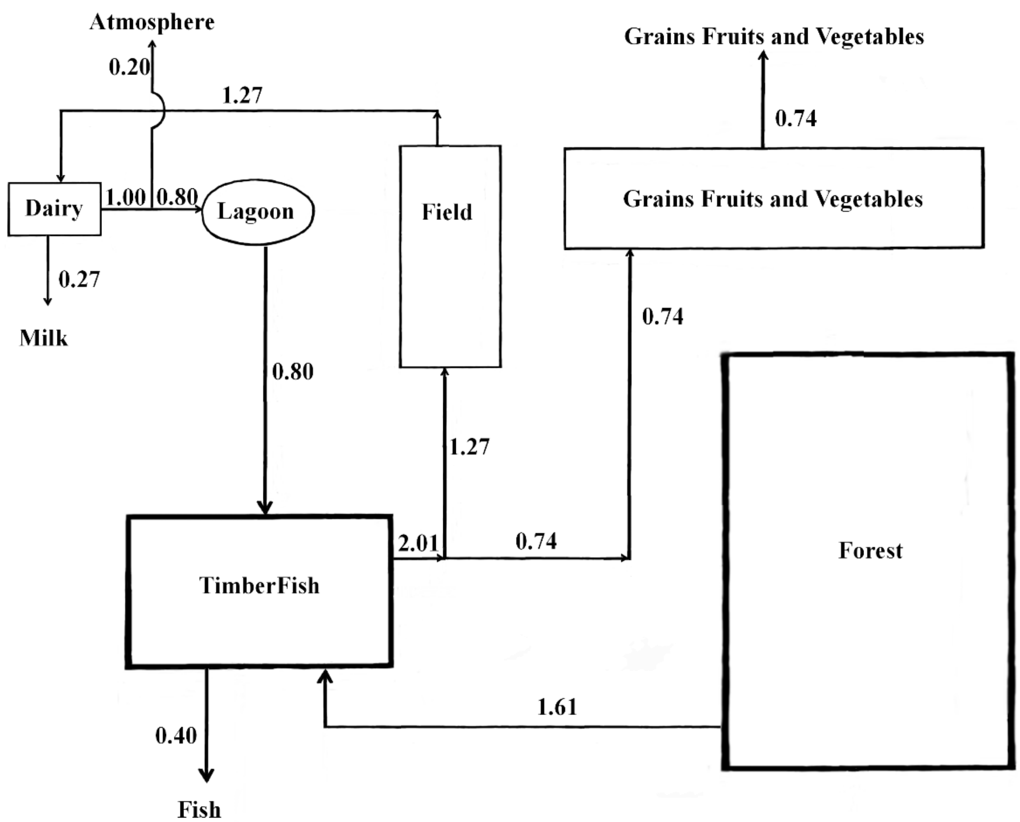
#2. An EIA – Dairy CAFO.

For an EIA system we can take the Dairy CAFO described in #1 and add a TimberFish system and an associated forest, woodlot, or other plant based cellulosic production system such as hybrid willow or switchgrass. The TimberFish system will include an aerated bioreactor, a Recycling Aquaculture System (RAS), and a variety of woodchip handling, water treatment, and invertebrate growth subsystems. The nitrogen cycle for a typical TimberFish system is illustrated in Figure 2.



Here one pound of nitrogen is combined with 2,000 pounds of dry weight woodchips from a forest to produce 50 pounds of fish. Each fish on a wet weight basis contains 0.02 pounds of nitrogen. 2,000 pounds of wood chips can be harvested from one acre of forest per year, and will contain 0.08 percent nitrogen on a dry weight basis or 1.61 pounds of nitrogen per acre per year. The nitrogen not used for fish production will be combined with the residual wood chips and applied as an organic fertilizer to crop land used for growing grains, fruits, and vegetables. A TimberFish system processing 2,000 pounds per day of wood chips into fish will operate with a hydraulic retention time of about 50 days and will discharge one gallon per minute of tertiary treatment water quality effluent.

This TimberFish system, which uses one pound of nitrogen to produce 50 pounds of fish per acre per year, can be combined with one CAFO dairy cow which excretes one pound of nitrogen per day, to generate an EIA CAFO as follows. This is illustrated in Figure 3. This nitrogen flow path is what was used to generate the financial numbers presented in the Introduction. It is noted here that nitrogen allocation into fish is a process variable with a maximum value of one pound of nitrogen per 2,000 pounds of wood harvested from one acre in one year. Fig 3 shows nitrogen allocation into fish of 0.4 pounds of nitrogen per 2,000 pounds of wood harvested from one acre in one year. It shows how effective the technology is even when operating at reduced fish production capacity. Here is Figure 3.



Here is how this all works.

The TimberFish bioreactor will receive the CAFO lagoon manure that the CAFO would normally land apply and incorporate into the soil in the forage field. Thus the amount of nitrogen entering the bioreactor would be the same as that land applied by the CAFO. As soon as it enters the bioreactor it will be assimilated into a microbial biomass. This will occur because the abundant and excessive carbon source from the wood chips and excess oxygen availability will promote rapid growth with nitrogen being the rate limiting reactant. Hence rapid nitrogen assimilation into the microbial biomass.

Once the nitrogen is in the microbial biomass it will remain there until it is returned to the forage field, or until that biomass is consumed by other organisms such as invertebrates or fish. There part of the nitrogen will be incorporated into the invertebrate or fish and the rest will be excreted back into the bioreactor where it will be rapidly reincorporated back into the microbial biomass.

An independent field trial at the Freshwater Institute documented a 30 percent reduction in feed conversion ratio (See FWI TimberFish Final Report). That data indicates that the first time a nitrogen atom from the manure was eaten by a fish, 30 percent of that manure nitrogen ended up in the final product animal, the fish. To get there it first cycled through a microbe and probably through an invertebrate.

The remaining 70 percent of that manure nitrogen went back to the bioreactor where it was reincorporated into the microbial biomass. If a nitrogen atom in this remaining 70 percent was subsequently again eaten by a fish, 30 percent of the remaining 70 percent would be retained in the fish.

So start with 100 pounds of manure nitrogen entering the bioreactor. The first fish consumption cycle would convert 30 pounds of the original 100 pounds of manure nitrogen into fish. The remaining 70 pounds of manure nitrogen would go back to the bioreactor and be converted into more microbial biomass. If that new biomass went through a second fish consumption cycle, 30 percent of that remaining nitrogen (21 pounds) would be converted into fish. Thus two fish consumption cycles would convert half of the original manure nitrogen into fish nitrogen.

In all of these cycles the rapid and complete conversion of nitrogen into a microbial biomass would be driven by the excess availability of carbon. The resulting aerobic reactions would supply the energy needed for the synthesis of the microbial biomass. But this will only occur if there is a lot more carbon available than what is present in the raw manure feed to the system.

In one day the fresh manure from a lactating dairy cow will contain 20 pounds of total solids, 17 pounds of volatile solids, and 1 pound of nitrogen, all on a dry weight basis (I used the ASAE D384.2 MAR2005 Table 1.b data). But to convert nitrogen into fish using the TimberFish system will require 1,000 pounds of volatile solids to fix one pound of nitrogen into fish. Since fish are about 2 percent nitrogen on a wet weight basis this would result in 50 pounds of fish (wet weight) per 1,000 pounds of volatile solids (dry weight). The 17 pounds of volatile solids (dry weight) from the manure itself doesn't come close to satisfying this demand.

In this example we consider the bioconvertible volatile solids to be the cellulose and hemicellulose in the plant material. Since lignin is usually less than 30 percent of the volatile solids in wood we will only use half of the total volatile solids to produce fish. Thus it will require one ton or 2,000 pounds of dry weight wood chips to produce the 50 pounds of wet weight fish from one pound of original manure nitrogen. 2,000 pounds of dry weight wood chips per cow per day.

1,000 pounds of these wood chips will be utilized to provide the energy to drive the TimberFish biological processes. The remaining 1,000 pounds can be combined with the remaining microbial biomass to produce a potting soil, organic fertilizer, soil amendment, or landscaping material, or it could be separated from the residual microbial biomass and dried for a renewable energy source. In this analysis we will assume that 70 percent will be used for renewable energy and 30 percent will be returned to the crop fields along with the microbial biomass as a source of nitrogen and organic material for good soil health.

The 700 pounds of the remaining 1,000 pounds of residual wood chips used for renewable energy could be easily separated from the residual microbial biomass and dried for use in a steam turbine. This is because the microbial degradation of the cellulosic part of the wood chips leaves a lignin and hemicellulosic remainder with less microbe binding ability than raw wood. Hence easy cleaning and drying.

This clean dry residual wood chip will have an energy content of about 11,000 BTUs per pound dry weight. This is in contrast to raw wood which will have a BTU value of about 8,000 per pound dry weight. Thus the 11,000 BTUs in the 1,000 pounds of residual wood chips are theoretically equivalent to about 3,000 KWhr (Kilo Watt Hour) or 14,700 Hphr (Horsepower hour). Actual obtainable conversion rates will be much lower but will still be significant. We will use 70 percent of the remaining residual wood chips and a conversion rate for a steam turbine of 25 percent for the residual wood chip. This would compare with 33 percent for coal. Alternatively, the residual wood chip could be burned directly for heat, converted into pellets for pellet stoves, or pyrolyzed into a combustible gas or liquid biofuel.

In the North East part of the US, a mature steady state forest of mixed hardwoods can produce 9,700 to 17,600 pounds of green biomass, net respiration in the living trees, per acre per year. If 3,000 to 7,000 pounds of this green woody biomass was harvested and used to grow fish, there would still be 6,700 to 10,600 pounds of new forest biomass added each year to that previously sequestered in the forest.

So we can obtain the 2,000 pounds of dry weight wood chips required per cow per day from one acre of forested land. Commercially this can be done for $50 per ton in a manner that does not impair the sustainability, natural habitat, biodiversity and aesthetics of our native forests. Harvesting can be done at times that do not interfere with nesting and mating cycles. It also can be done in a manner that has minimal impact on the forest floor, thereby reducing erosion and runoff. What this all means is that a large area of forest will be required to drive the EIA – CAFO process. Sequestering this area as a forest preserve could qualify it for carbon offset funding as an additional source of income for the farm.

Dry dead wood from forests will still contain small amounts of nitrogen, usually 0.03 to 0.50 percent. We will estimate this as 0.08 percent on a dry weight basis. Thus 2,000 pounds of dry wood will contain 1.61 pounds of nitrogen. This will be a significant source of nitrogen to the TimberFish system because of the relatively large amount of wood that is required to produce fish.

Figure 3 incorporated the Figure 1 nitrogen cycle for one dairy cow in one day, and assumes that 2,000 pounds of dry wood with 0.08 percent nitrogen, dry weight, will be harvested from an acre of forest each day. However, in this case the 0.80 pounds of nitrogen that left the lagoon for the field in the Dairy case, now is diverted to the TimberFish system. There 0.40 pounds of nitrogen is bioconverted into 20 pounds of fish. The remaining 0.40 pounds of manure nitrogen is combined with the residual 1.61 pounds of nitrogen obtained from the wood from the forest, and land applied as 1.27 pounds of nitrogen to the CAFO field and 0.74 pounds of nitrogen to the Grain Fruit and Vegetable field (in this example a corn field).

This balances the TimberFish CAFO loop and completes the Ecologically Integrated Agriculture by adding in the grains, fruits and vegetables that comprise the rest of our diet. In Fig 3 there is no need for the addition of external nitrogen from inorganic fertilizers because of the nitrogen obtained from the wood from the forest. Forests can fix some nitrogen and they do receive nitrogen from rainfall in the form of ammonium and nitrate ions. This dynamic will need to be monitored and if not in balance with the rest of the EIA system it can be remedied. One way to do this would be to add a clean but relatively high nitrogen waste stream to the bioreactor. This could come from a distillery or other food or beverage producer or processor.

The excess nitrogen from the bioreactor that is not needed to balance the CAFO field production would go to a Grain Fruit or Vegetable field as a slow release organic fertilizer. In this and the forage field application all the nitrogen would be bound up in the microbial biomass and thus would be plant available nitrogen that a crop could access when needed. There is a wide variety of crops that could be grown in the non CAFO fields, gardens, or orchards, but we arbitrarily choose corn for this example.

Current corn production runs about 177 bushels per acre pre year. A bushel weighs about 56 pounds and contains 0.8 pounds of nitrogen. Thus 177 bushels of corn would contain about 142 pounds of nitrogen. This accounts for about two thirds of the total nitrogen content of the corn plant prior to harvesting so 71 pounds of nitrogen will be returned to the field as part of the corn stover. Thus 142 pounds of nitrogen needs to be added to each acre of corn to produce next years crop. At 0.74 pounds nitrogen per day it will take about 192 days per acre of corn. This equates to about 1.9 acres of corn field per cow per year in addition to the 2 acres of field that the CAFO uses to grow the forage feed for each cow per year. This produces 336 bushels of corn per cow per year that is in addition to the forage crop used to feed the cows. Consequently the 336 bushels of corn can be sold into market.

Summarizing:

Start with a modern Dairy CAFO with 100 lactating Holstein dairy cows weighing 1,350 pounds each. This is connected to a TimberFish system as part of an EIA – CAFO system. Over the course of the year the following daily averages will apply.

The 100 cows combined will produce 637 gallons (5,480 pounds) of milk per day.

Also, each day 80 pounds of manure nitrogen will enter the TimberFish bioreactor and be converted almost immediately into a microbial biomass. A two fish consumption cycle TimberFish system will produce fish from 40 pounds of the manure nitrogen at a rate of 50 pounds fish per pound of manure nitrogen. The remaining 40 pounds of manure nitrogen that entered the bioreactor will be contained in a microbial biomass that is equivalent or better than commercially available organic nitrogen fertilizer.

This remaining 40 pounds of nitrogen will be combined with the 161 pounds of nitrogen from the 2,000 pounds per day of harvested forest wood and will be distributed as 127 pounds of nitrogen to the forage crop field of the CAFO and 74 pounds of nitrogen to the fields, gardens, or orchards used for grain, fruit, and vegetable production.

Total production of wet weight fish, 2,000 pounds per day.

Total return of manure nitrogen onto crop land as Plant Available Nitrogen fertilizer, 40 pounds per day.

The process will require 2,000 pounds of dry weight wood to bioconvert a pound of manure nitrogen into fish. Dry weight wood chips required per day 80,000 pounds or 40 dry tons per day. This will contain 161 pounds of nitrogen.

Since only half of the wood will actually be used for oxidation energy to drive the biological processes, there will be 40,000 pounds of residual wood chips available to combine with the residual microbial biomass for field crop application. If we were to use 70 percent of this to run a steam turbine to produce electricity (conversion efficiency rate of 25 percent) we would produce 21,000 KWh of electricity per day.

One acre of sustainable managed forest can produce 2,000 pounds of dry wood chips per year. Therefore 40 acres of forest will be needed each day to satisfy the 40 ton dry weight wood chip requirement per day. This means that 14,600 acres (23 square miles) of forest will be needed to run a 100 cow dairy EIA CAFO.

The footprint EIA CAFO 100 cow dairy

CAFO buildings and infrastructure	10 acres
CAFO feed crop acreage	200 acres
Grain, Fruit, Vegetable acerage	190 acres
TFT buildings and infrastructure	20 acres
Forest Preserve	23 square miles (14,600 acres)

Conclusions:

Using these numbers a 300 cow Dairy CAFO can produce 697,000 gallons of milk per year. At a $1.40 per gallon farm gate price for milk this earns $977,000 per year. Unfortunately, expenses often exceed income and the dairy must depend on subsidies to be profitable.

Connect this dairy to a TimberFish system so that all manure normally land applied to crop fields enters the TimberFish bioreactor. The dairy milk production and income remains the same but now the manure nitrogen will be combined with wood chips to produce 2,190,000 pounds of fish with a farm gate price of $5 per pound for annual farm gate revenue of $10,950,000. This will require wood chips from 71 square miles of forested land which can be sustainably harvested (20 percent of new biomass per year in steady state forests).

These forests could qualify for carbon offsets, and the residual wood chip, up to half of the total wood requirement, will have a significant renewable energy content. If we were to use 70 percent of this residual wood chip for producing electricity from a steam turbine we would get 22,300,000 KHh. At 10 cents per KWh this would generate $2,230,000 in revenue.

Similarly, the 71 square miles of forest would be 45,440 acres. With carbon offset prices running from $3 to $30 per acre per year this could generate an additional revenue of $136,320 to $1,363,200 per year. We used a rate of $9 per acre per year for revenue of $408,000 per year.

Finally the residual nitrogen not needed for fish production or forage crop filed replacement can be applied to 570 acres for grain, fruit, or vegetable production (in this example, corn). At 177 bushels of corn per acre per year and $4.50 per bushel this generates revenue of $454,000. This all provides an economic driver for forest sequestration, reforestation, and deforestation avoidance in accordance with the UN IPCC guidance for managing Climate Change.

Here is a summary of the annual values for a 300 cow dairy EIA - CAFO

Parameter	Units	result	Value	Basis for Value
Milk	gallons	697,000	$977,000	$1.40 per gallon
Fish	pounds	2,190,000	$10,950,000	$5.00 per pound
Energy	KWh	22,300,000	$2,230,000	$0.10 per KWh
C offset	acres	45,440	$408,000	$9.00 per acre/year
Corn	acres	570	$454,000	$4.50 per bushel

Final notes:

If 0.8 pounds of nitrogen are used to produce fish per cow per day, (instead of the 0.4 number used in this example) it would leave only 0.34 pounds of nitrogen to produce the corn. However, this would double the fish revenue to $21,900,000 per year but would decrease the corn revenue to $208,600 per year.

If the maximum of 1.00 pounds of nitrogen are used to produce fish per cow per day, (instead of the 0.4 number used in this example) it would leave only 0.14 pounds of nitrogen to produce the corn. This would increase the fish revenue to $27,375,000 per year but would decrease the corn revenue to $85,892 per year.