# Clean Water Harvest:

## A Case for Mechanical Removal of Water Hyacinth from Lake Okeechobee and Other Watersheds

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## Executive Summary:

Current methods for controlling water hyacinths in Lake Okeechobee and connecting waterways may have contributed significantly to the deterioration of water quality throughout South Florida. This observation is based upon a range of scientific research, anecdotal references, and historical records. This report provides a basis for assessing the positive and negative contributions of water hyacinth in the ecology of South Florida. Benefits of hyacinths range from nutrient removal to creation of fish habitat. In addition, utilization of water hyacinth for energy, biochar, and carbon sequestration is discussed. The report concludes that transformation of hyacinth into biochar, a sustainable soil amendment, may provide key incentives to offset the cost of mechanical water hyacinth control. At the same time, removal of hyacinth bio-mass from the watershed will work to restore and revitalize local waterways.

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# INTRODUCTION

Studies have shown that deterioration of water quality along the Caloosahatchee River can be explained primarily by two causes. First, farming runoff and back pumping into Lake Okeechobee cause a buildup of excess nutrients in lake water. When discharged down the Caloosahatchee, the nutrients promote algae blooms and kill fish. Second, uneven discharges of lake water through the Caloosahatchee river system cause unnatural changes in salinity that stressed the estuaries critical to aquatic life. This report argues that a third factor has also contributed significantly to the decline in water quality: chemical and biological control of Eichhornia crassipes, the water hyacinth.

Long before the sugar plantations, dairy farms, and urban runoff, water hyacinth was embedded in the South Florida ecosystem. As pollutants from agriculture and urbanization increased, the hyacinths quietly soaked it up. In the 1960’s surveys by the Army Corp of Engineers reported over 3000 acres of water hyacinths on Lake Okeechobee alone. By the time significant eradication efforts began in the early 1970’s, South Florida had millions of pounds in phosphorus and nitrogen sequestered within water hyacinths. Following treatment with chemical herbicides and biological controls, hyacinths decomposed and returned vast quantities of these nutrients back into the water.

One approach to solving the decomposition problem is to use mechanical harvesters to physically remove the hyacinth. This approach was used on a limited bases throughout the 1960's and earlier. However, due to inefficiencies and high operating costs, harvesters have largely been abandoned in favor of cheaper chemical and biological treatments. If some form of hyacinth utilization could offset harvester costs then the approach may again be viable.

Over the past century, researchers have actively studied uses for water hyacinth that include fodder for livestock, fish food, paper products, and basket making, to mention a few. However, the results were simply not economically sustainable or delivered an inferior product. This report evaluates two additional forms of water hyacinth utilization. The first is the potential for hyacinth biomass to be used in energy production. The second is the use of hyacinth in the production of a soil amendment known as "Terra Preta," or biochar.

# WATER HYACINTH IN SOUTH FLORIDA

In the past, one would hear stories of fishing guides spinning their boats in tight circles on Lake Okeechobee. The maneuver was used to clear holes in thick mats of water hyacinths that often dominated the shoreline. Once pushed aside, sun light shining through the opening would reveal a white sandy lake bottom - boiling with bream. In the Caloosahatchee River, thousands of blue crab traps stretched out from the banks; each caught two pounds per day or more. Unfortunately, along with the bountiful catches and the clear, clean water, there was an overabundance of hyacinths. They were in the locks, marinas, and under bridges and in nearly every fresh water tributary and creek. They are, however, intolerant of salt, and by the time the river emptied into the Gulf of Mexico, all of the hyacinths were gone.

Water hyacinth was originally introduced into the U.S. as an ornamental plant in 1884. Even today, its attractive purple flower makes it a desirable addition to water gardens throughout the northern regions of the United States. In regions with cold winter climates, water hyacinth has a shortened growing season and will die off each year.

In sub-tropical climates, however, water hyacinth is considered to be a "noxious weed." In Florida, water hyacinth is regulated as a Class I Prohibited Aquatic Plant. Under no circumstance is it permitted to possess, collect, transport, cultivate, or import water hyacinth. With a growth rate of up to 15% surface area per day, it has earned a reputation for being the "worlds worst weed." A complete list of states that regulate water hyacinth can be found at: www.plants.usda.gov.

Because of its extraordinarily fast growth and highly invasive nature, in 1899 the United States Rivers and Harbors Act authorized the removal of water hyacinth from all navigable waterways. Three years later, the act was amended to call for the extermination of water hyacinth by any means. Due to the lack of safe and effective chemical herbicides, control efforts were largely limited to mechanical removal. Since these methods were costly, mechanical controls were generally reserved for maintaining navigation and infrastructure. However, by the 1970’s, new herbicides and biological controls allowed for large scale eradication programs.

# COMMON COMPLAINTS

Most of the common complaints about water hyacinths have been thoroughly researched and are well documented elsewhere. Although not the focus of this report, for completeness, several common issues are summarized below:

- **Invasive Nature**
  Water hyacinths have an extraordinary capacity for growth. Under ideal conditions, the plant can double in mass every 13 days. Although hyacinth can grow from seed, typically plants will reproduce vegetatively.

- **Navigation Hazard**
  Uncontrolled, water hyacinths can choke waterways and prevent access to marinas, fishing areas, and flood control and agricultural infrastructure.

- **Oxygen Depletion**
  Water hyacinth mats induce reductions in dissolved oxygen in sub-hyacinth water by blocking photosynthesis in the water column. In addition, the decaying leaves and roots increase the biochemical oxygen demand.

- **Reduced Biological Diversity**
  The density of water hyacinth communities can displace indigenous aquatic plants thereby negatively impacting fish and animal wildlife.

- **Disease and Pests**
  As is the case for many plant species, water hyacinths provide an ideal breeding ground for mosquito larva and other insects. In addition, the plant provides a habitat for parasite hosts such as snails.

- **Economic Costs**
  Numerous developing countries have reported economic hardships related to water hyacinth outbreaks. These accounts are centered around loss of fishing habitat and access to fresh water. Although these issues are not as immediate in the United States, the cost of controlling hyacinth can be a burden to local governments.

- **Water loss**
  Water hyacinths evapotranspirate water up to 8x the rate from a free water surface at the same temperature.

# ECOLOGICAL IMPACT

Prior to the 1970's, mechanical harvesters were extensively used to remove water hyacinth from infested waterways. Throughout this period, records show relatively high water quality in Lake Okeechobee and other waterways despite intensive agricultural activity in the region. As hyacinth eradication efforts intensified, emphasis shifted away from mechanical harvesting toward use of chemical and biological controls. As a result, from the 1970's forward, dramatic declines in both water quality and fish catches were observed.

The extraordinary ability of water hyacinth to transform and absorb agricultural pollutants is well documented, and they are sometimes used for tertiary water treatment. Additionally, historical records, and eyewitness accounts, indicate that fish and other aquatic species can thrive in the presence of water hyacinth, provided that the hyacinths cover only a modest fraction of an aquatic ecosystem.

## Water Quality

Water hyacinth can remove more than 19 lbs/ac/day of nitrogen and 7 lbs/ac/day of phosphorus from sewage treatment lagoons (Popenoe, H., 1976.). Like a sponge, water hyacinth appears to soak up and retain a wide range of excess nutrients and pollutants. It is generally agreed that reduction of these excess nutrients are key in maintaining water quality.

Although much research was conducted decades ago, the ability of water hyacinths to clean water is reflected in current studies as well. Recently, a study conducted by Hydromentia, Inc., for the South Florida Water Management District (SFWMD), achieved an averaged nitrogen removal rate of 313 g-N/m2-year using cultivated water hyacinths (Hydromentia, 2005). This roughly equates to 1.2 MT (2646 lbs) of nitrogen per acre. Additionally, in it's own review of Nitrogen Reduction Technologies, SFWMD found that water hyacinths "exhibited substantial DON removal " (dissolved organic nitrogen) when compared with other removal technologies (Morales, R., 2008).

| Element | Amount Recovered (kg/ha/day) |
|---|---|
| Nitrogen | 22 - 44 |
| Phosphorus | 8 - 14 |
| Potassium | 22 - 44 |
| Calcium | 11 - 22 |
| Magnesium | 2 - 4 |
| Sodium | 18 - 34 |

**Table 1:** Recovery of elements from water hyacinth under ideal conditions (Popenoe, H., et al, 1976. pg 117).

## Phosphorus Concentration in Lake Okeechobee

In 1986, a water hyacinth infestation on Lake Okeechobee grew to an estimated 2,000 acres. Initially, the outbreak was controlled using herbicides. Then, in July of 1986, Governor Bob Graham issued a lake-wide herbicide moratorium. By the time the moratorium was lifted, five months later, the infestation had grown to over 8,000 acres. It is interesting to note that the lowest concentration of phosphorus recorded for the lake, since 1979, occurred during the hyacinth infestation (figure 1). Although not conclusive, this observation suggests a strong correlation between the growth of water hyacinth and lake wide concentration of phosphorus.

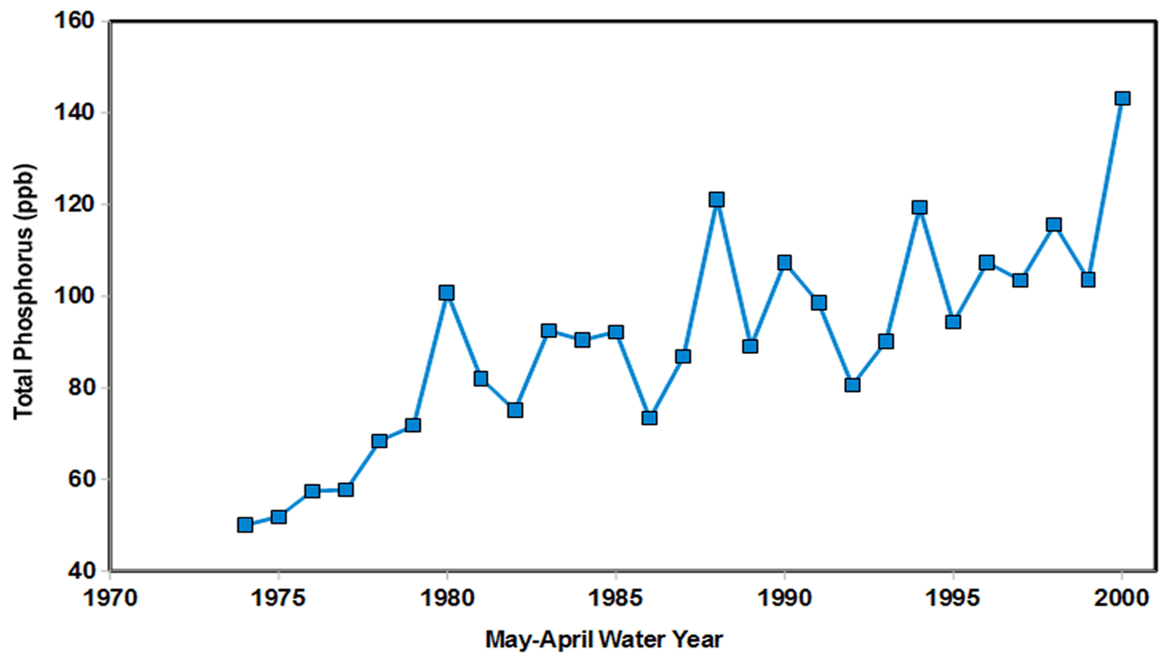


**Figure 1:** Phosphorus concentration in parts per billion for Lake Okeechobee from 1974 - 2000 *(source: graph was generated using phosphorus data obtained from SFWMD)*

### Cost of Nutrient Removal

The primary challenge in using hyacinths for purification is that the maximum benefit is only achieved by removing the plant. If the plant is allowed to die or decay in the water, it will release nutrients back into the water. In addition, the rotting vegetation will promote bacteria growth that, in turn, depletes oxygen. The following list is a rough estimate of what one mature acre of water hyacinth (40 dry tons) might leave behind as it dies and rots on the bottom of a river or lake:

- 13,000 lbs of methane gas
- 16,000 lbs $CO_2$
- 2,000 lbs of nitrogen
- 330 lbs of phosphorus
- nearly 25 tons of polluted sludge

…and will consume more than 6400 lbs of dissolved oxygen.

(*Estimated values extrapolated from various sources: Popenoe, H., 1976., Lawrence, J.M. 1970., Fedler et al, 2007., Little, E. C. S., 1979.*)

One analysis of harvesting costs on the St. Johns River found that clearing water hyacinth from one hectare can cost as much as $3,000/year (Sainty, G., 1985). This is equivalent to $1,200/acre/year. However, when compared to other forms of water treatment, hyacinth removal is far less expensive. For example, in a 2003 report from the SFWMD, the cost for removing phosphorus using alternative treatments ranged from $58 - $196 per pound (Johns, G., et al, 2003). By contrast, using the St. Johns River example, if one acre (yielding 40 dry tons of water hyacinth) were harvested only once at $1,200, the cost of phosphorus removal can be calculated between $4 - $9 per pound. This is roughly a 95% savings over alternative treatments.

## Fish Population

In the year 2000, a report from the United Nations Food and Agricultural Organization (FAO) indicated that aquatic plants can increase communities of desirable sport fish and improve overall productivity of lakes and ponds. The report further states that the presence of some invasive aquatic plants have led to multifold increases in fish stocks (Petr, T., 2000). Reports such as this, coupled with strong anecdotal evidence, suggests that water hyacinth, occurring over small areas, can have a positive affect on fish habitat.

It has been widely observed that water hyacinth, when covering large portions of a lake or river, can negatively impact fish population. In 1986, a hyacinth infestation on Lake Okeechobee grew to an estimated 8,000 acres. However, from the time the outbreak began, to when it was brought under maintenance control three years later, catch rates for crappie were well above normal (figure 2). The 1986 infestation, though very large (approx. 11 sq/mi), covered less than 2% of the Lake Okeechobee's surface area. Perhaps the data indicate that the percentage of surface area covered is a determining factor in the effect of hyacinth on fish populations.

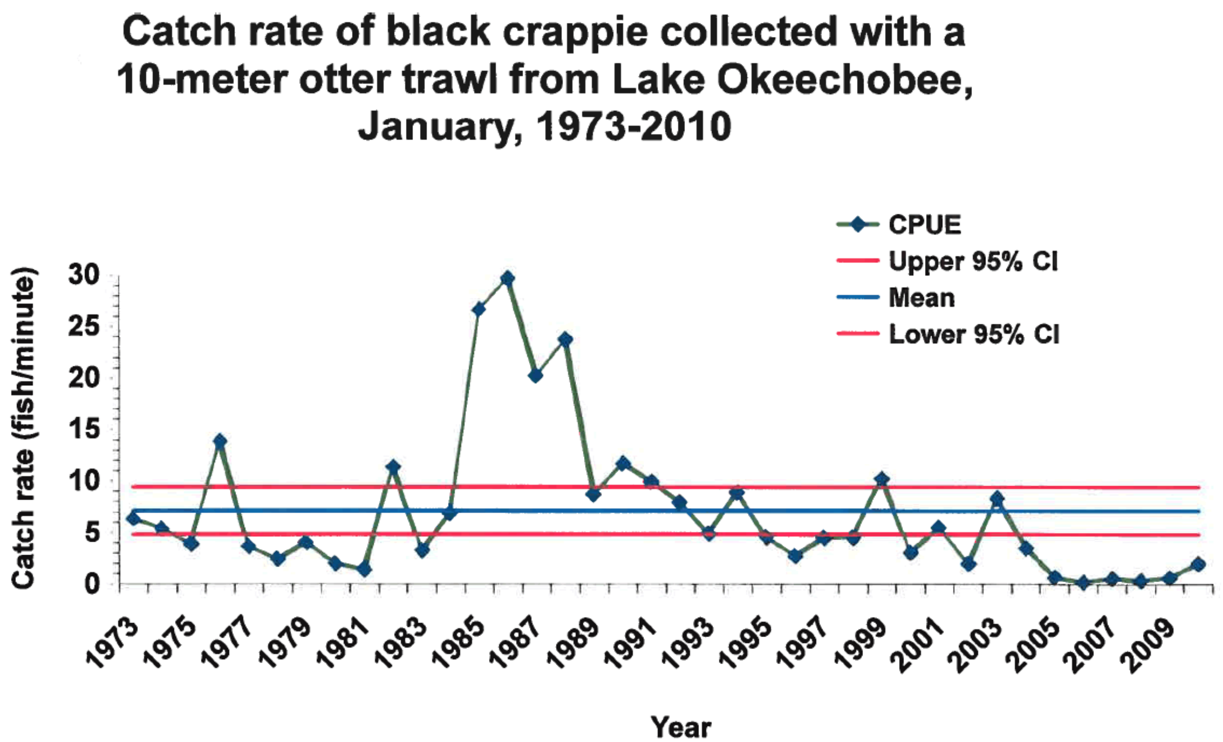


**Figure 2:** Catch rate of black crappie collected with a 10-meter otter trawl from Lake Okeechobee, January, 1973-2010*; (Source: Florida Fish & Wildlife Conservation Commission)*

# HYACINTH CONTROL METHODS

The tendency of water hyacinth to grow uncontrollably is, and always has been, the central argument for its eradication. Until the late 1960's, mechanical harvesting was the primary method for controlling plant growth. By the 1970's, however, emphasis began to shift away from mechanical harvesting toward increased use of chemical and biological controls.

In much of the early literature, chemical control methods were viewed as unsafe and, therefore, less desirable. Today, however, attitudes toward the efficacy of chemical treatment has changed. Advancements in chemical controls, such as Glyphosate (used in the herbicide Roundup), have had great success in controlling water hyacinth outbreaks.

Since the early 1970's, biological control organisms have been effective in providing maintenance control of water hyacinth. Typically, the organisms will kill or weaken the plant before it can mature and spread throughout the ecosystem. The first approved biological control for water hyacinth was *Neochetina eichorniae*, the mottled water hyacinth weevil, released In 1972 by the U.S. Army Corps of Engineers. This was followed in 1974 by *Neochetina bruchi*, the chevroned water hyacinth weevil and, in 1977, *Sameodes albiguttalis*, the water hyacinth moth. Their presence did not, however, prevent the 1986 hyacinth outbreak on Lake Okeechobee. Recently (2010), the plant hopper, *Megamelus scutellaris*, was add to the list of biological control agents.

Mechanical removal, or harvesting, is typically more expensive than chemical or biological controls but has significant ecological advantages. First, pollutants absorbed by the plant, such as phosphorous and nitrogen, are eliminated from the watershed. Second, hyacinth propagation is reduced because seeds and reproductive capacity are removed. Additionally, to the extent that hyacinth removal reduces available nutrients, the growth rate of remaining vegetation is also reduced.

# ENERGY PRODUCTION

One acre of water hyacinth can produce approximately 40 to 80 dry tons of biomass annually (Fedler et al, 2007). This growth rate suggests that hyacinth would be an ideal feedstock for bio-energy production. However, with a moisture content near 95%, approximately 20 tons of hyacinth must be harvested for every one ton of usable biomass. Also, the sustainability of energy production is negatively affected by high transportation costs.

Converting water hyacinth to an energy source can be accomplished by the following three methods: conventional electricity, anaerobic digestion, and gasification. The first two options use well established technologies. However, they may lack the efficiency needed to make energy production economically viable. The third option, gasification, is still highly experimental in many of its various forms.

## Conventional Electricity

Burning water hyacinth to make electricity from steam is a readily available technology. Commercial wood-burning power plants are currently operating in the US. The 19 MW Lyonsdale Facility in New York state consumes an average of 700 tons of wood chips per day. This is approximately 36.8 tons per MW (mega watt). At this level of efficiency, the annual production of one square mile of hyacinth could supply enough cellulose to fuel a 2 to 4 MW generator. According to Florida Power and Light, one MW will power about 750 homes. However, this analysis does not account for the enormous energy requirements for transporting, processing, and drying the hyacinth.

## Anaerobic Digestion

Anaerobic digestion is a process that converts biomass into methane gas. However, the difficulty in recovering significant quantities of gas may make this process unsustainable. In one study, a sophisticated two-stage hyacinth digester was reported to yield 0.14 $ft^3$/lb/day . Given a processing time of 25 days and an energy content of 690 BTU/$ft^3$ (value for digester gas from engineeringtoolbox.com), a pound of water hyacinth would make 2415 BTU. By contrast, the average energy content of dry hyacinth is reported to be approximately 6792 BTU (Fedler et al, 2007). In addition, the land area required for the digesting apparatus as well as the processing time (about 20-30 days) casts doubt on the viability of this approach.

## Gasification

The most promising technology for converting water hyacinth to energy appears to be gasification. More than 100 years old, gasification is a process that essentially cooks a feedstock, in this case biomass, at very high heat (over 1200 °F) within an oxygen starved environment. This has the affect of liberating gases from the fuel without burning them. These gases, called synthesis gas or syngas, can be burned directly in gas turbine generators; at much higher efficiencies than conventional wood-burning power plants.

More recently, enhanced forms of the Fischer-Tropsch process are making it possible to convert syngas directly into liquid hydrocarbons. Sometimes referred to as thermochemical reforming, various fuels, such as mixed alcohols and diesel, can be produced. A recent NREL report predicted that by 2012 production of thermochemical ethanol will be competitive with ethanol fermented from corn.

Although it is believed that certain gasification techniques may be economically viable, this analysis does not calculate possible energy deficits due to high ash content. Having elevated ash content is typical of water hyacinth grown in eutrophic, or agriculturally polluted, water.

# BIOCHAR PRODUCTION

Biochar is a charcoal-based soil amendment that enhances the agricultural potential of sandy soils. The amended soil is often referred to as "Terra Preta" meaning “black earth”. Although the term "biochar" is relatively new, the idea of converting biomass into charcoal is thousands of years old. Recently, however, improved soil science, coupled with the demand for carbon sequestration, have greatly accelerated commercial interest and research into this product.

Currently, the International Biochar Initiative (IBI), formed by members of the World Soil Science Congress, lists noxious weeds as the number one desired source for biochar feedstock. In addition, according to the IBI, noxious weeds (like water hyacinth) are only one of three potential feedstocks that have no significant sustainability issues.

An acre of water hyacinth is expected to yield approximately 13 tons of biochar given an annual harvest of 40 dry tons/acre *. The current bulk wholesale price for biochar is around $500 per/ton, or $0.25/lb. Given this rate, biochar for just one acre of hyacinth would have a cash value of $6,500.

* Water hyacinth can produce approximately 40 to 80 dry tons of biomass annually (Fedler et al, 2007). Growth rates are based on a wide variety of water sources. The actual tons of hyacinth harvested per acre may be higher or lower depending upon plant maturity, available nutrients, and climate.

## Making Biochar

Biochar production can begin immediately following the harvesting of water hyacinth. The production process can be broadly defined in three steps: dewatering, pyrolysis, and charging.

### Dewatering

Ideally, biomass feedstock should have a moisture content near 10%. Hyacinth is about 95% water when harvested. Although some water can be removed by simply shaking the plant, much more can be removed using an industrial press; similar to those used in the citrus industry. This type of press uses an auger or screw to quickly and efficiently reduce water content to 60 to 65%. After initial processing, the semi-dry hyacinth is chopped and tumble dried using waste heat generated by the pyrolysis reactor.

### Pyrolysis

The process for transforming biomass into biochar is called slow pyrolysis. This process cooks the biomass at high heat (about 1000 °F), in an oxygen deprived atmosphere to prevent combustion. Slow pyrolysis thermochemically decomposes the biomass into three components: charcoal, bio-oil, and non-condensable gas. While the charcoal and bio-oil are both marketable products, the gas is typically used to fire the transformation process.

The amount of time required for processing, or residence time, can range from a few minutes to an hour or more. The quantity of each product generated is dependent upon reactor temperature and residence time. In general, higher temperatures require less time and produce superior charcoal. However, the trade-off is that less charcoal is produced; resulting in higher output of bio-oil and gas. Although final ratios are adjustable, slow pyrolysis is expected to yield 1/3 charcoal, 1/3 bio-oil, and 1/3 gas (Reed, 1988).

### Charging

Once created, biochar may need to be "charged" with nutrients. Initially, for the first year, crops grown in biochar often see little improvement until the "charging" is complete. Alternatively, fresh biochar can be treated in a nutrient-rich solution prior to use. However, water hyacinth grown in eutrophic or agriculturally polluted water may not need charging. Because of its high uptake of phosphorus, hyacinth should produce charcoal that is essentially pre-charged.

## Advantages of Pyrolysis

Converting water hyacinths into biochar has many key advantages over other methods of hyacinth utilization:

- **Reduction of mass**
  Slow pyrolysis can reduce the mass of harvested vegetation by up to 97%. In the past, the cost of transporting harvested vegetation severely undermined attempts to utilize water hyacinth in commercial products.

- **Potential for on-board processing**
  Currently, numerous efforts are underway throughout the biochar community to create portable slow pyrolysis reactors. Such apparatuses will greatly increase daily harvesting capacities by eliminating the need to offload harvested vegetation.
- **Clean, renewable fuel supply**
  Non-condensable gases and bio-oil generated during pyrolysis can be readily consumed by the harvesting equipment. This will reduce or eliminate the need for fossil fuel inputs.

- **Complete destruction of plant**
  All vegetative matter comprising the water hyacinth is destroyed by pyrolysis. No part of the plant remains.

- **Ready market**
  Both biochar and bio-oil are commodity products with established and growing world wide markets.

- **Carbon Sequestration**
  When used as a soil amendment, biochar is eligible to receive carbon credits.

# Energy Byproducts

Along with biochar, several other products are generated during pyrolysis of water hyacinths. Each has a specific value and function. None of the byproducts are waste.

## Bio-Oil

A significant byproduct in the production of biochar is bio-oil. Used as low-grade boiler fuel, bio-oil has a BTU content of approximately 8500 BTU/lb (Reed, 1988). The energy value per gallon of bio-oil is slightly better than that of methanol. However, its physical properties and limited shelf life (approximately six months) make it less desirable than equivalent petroleum-based products. Current research suggests a market value of about $1.00/gal (US) in bulk quantities.

Given an estimated annual yield of 40 dry tons per acre of water hyacinth, about 13 tons (26,000 lbs.) of bio-oil could be recovered from one acre of hyacinth (about 1/3 of dry weight). This is approximately 2,708 gallons of oil at 9.6 lbs/gal.

## Non-condensable Gas

As biomass cooks during pyrolysis, 2/3 of its components are driven off in the form of gas. When cooled, ½ of this gas will condense into bio-oil. The remaining gas will not condense. Non-condensable gas consists primarily of nitrogen ($N_2$) and carbon monoxide (CO) at concentrations near 50% and 25% respectively. Additional gases include hydrogen (H) near 15% and methane ($CH_4$) near 3.0%. The balance of gas is composed of $CO_2$ and $O_2$. Altogether, processing may generate as much as 13 tons/acre/year of non-condensable gas from water hyacinth. The precise amount and content of gas is dependent upon reactor temperature and feedstock residence time.

Although much of the gas is inert, levels of hydrogen and methane within the mixture are sufficient for combustion. It is estimated that the energy content of non-condensable gas will be close to 10,714,282 BTU/ton. This value is based on 300 BTU/$ft^3$ at a density of 0.056 lb/$ft^3$ (Reed,1988).

### Waste Heat

Heat from combustion of non-condensable gas may be used to dry biomass. This helps to reduce residence time for biomass in the reactor; increasing the efficiency of the process. Beginning with a preprocessed water content of 35%, approximately 1100 BTU/lb will dry hyacinth to 10-15%.

## Cash Value

The following list shows the estimated prices per quantity, in US dollars, for biochar and bio-oil. Quantities used are based on one acre of water hyacinth with a dry weight of 40 tons. In the table below, a portion of the bio-oil (5 tons) has been converted to gas to supply additional processing needs.

| tons/acre/year | Material Produced | Price/lb | Value |
|---|---|---|---|
| 13.2 | Biochar | $0.25 | $6,600 |
| 8 | Bio-oil | $0.10 | $1,600 |
| 18.8 | Non-condensable Gas | (consumed in process) | |

**Table 2:** Estimated cash value for water hyacinth products

# CONCLUSION

In recent years, without the necessity to dispose of harvested biomass, interest in water hyacinth utilization has declined. In addition, many environmental groups now actively oppose the commercial use of invasive plant species. Regardless, the control of water hyacinth remains an important priority of government and industry.

In order to offset the high cost of mechanically removing water hyacinth, some form of hyacinth utilization should be implemented. Although, it is believed that hyacinth may be useful in energy production, this analysis does not calculate possible energy deficits due to high ash content. Having elevated ash content is typical of hyacinth grown in eutrophic, or agriculturally polluted, water. In production of biochar, however, the minerals comprising the ash become a valuable supplement to the product. Therefore, it is envisioned that hyacinth biochar will have a commercial advantage over biochar made from lesser feedstock. In addition, oil and gas byproducts are available to be consumed during production, thereby eliminating the need for energy inputs.

Another key advantage of biochar is the potential to miniaturize production apparatus. When using hyacinth in energy production, large scale centralized facilities are required. The cost of the facilities are amortized over decades and require continuous significant supplies of feedstock. A portable biochar facility, on the other hand, could be located near the harvesting site. Since it does not require continuous operation, it can sit idle for periods of time when hyacinth collection is not needed. In other words, commercial hyacinth cultivation will not be required to sustain a biochar initiative.

As this report has shown, mechanical removal of water hyacinth has substantial environmental benefits. Although use of chemical and biological controls should continue, a preference for mechanical harvesting should be adopted by hyacinth control authorities.

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