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FACTSHEET: DUCKWEED AS BIOMASS

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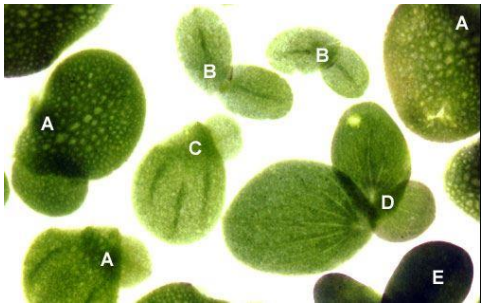
Duckweed is one the smallest, fastest growing plants in the world; it can be grown in nearly all geographic locations and altitudes on water, although is unsustainable and dormant in extremely cold temperatures and hot temperatures, because of freezing water and lack of water respectively. Thirty-seven different species of duckweed have been identified, several of which are now being examined for its bioenergy use and a source for protein.

How is it grown? Duckweed can flourish in any natural made body of water, manmade ponds, greenhouses, high-tech aquaponic farms, and even fish tanks. The growth of duckweed is only limited by nutrient availability and density dependent factors.; water temperature, air temperature, humidity, carbon dioxide levels in the ambient atmosphere, pH, and nutrient levels all can affect its growth rate. Although duckweed is naturally occurring, it additionally has been cultivated in aquaponic facilities, where all conditions are controlled to efficiently produce the feedstock.[1]



Duckweed possesses versatile qualities; it varies not only in uses and nutritional composition, but also in size. This plant may grow to be less than 1mm or up to 20mm.[2]

WHAT ROLE DOES DUCKWEED PLAY?

In order to both minimize the pollution from and dependency on fossil fuels, duckweed is being researched and utilized as a new source of renewable and sustainable biomass for feedstocks.

- **National Institute of Health (NIH)** supports duckweed research on the regulation of specific gene expression and biosynthesis of its nutrients. [3]

- **NASA** is researching the use of duckweeds in advanced life support systems for human space exploration.[4]

- **USDA** supports basic plant research on duckweed and its role as an alternative remedy for waste[5]

- **EPA** is currently exploring the use of duckweed to detoxify contaminated water sources.[6]

- **U.S. Geological Survey Biological Resources Division (BRD)** support work with duckweed in wetlands and waste treatment facilities.[7]

Duckweed can effectively absorb contaminants like nitrogen, phosphorus, heavy metals, and carbon dioxide from the air, but may also be fed fertilizers, compost, manure, or gray water from sewage facilities. Duckweed may be harvested in ponds nearby plant nurseries or farms, that have fertilizer runoff, with a motorized pond skimmer. Or, even in more suburban areas where nitrogen and phosphorus emissions and lawn fertilizer run-off are more prevalent.

Under optimal conditions, duckweed may double its body mass in less than 48 hours. The duckweed can then be harvested, processed, and harnessed for its numerous uses.

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& **Corresponding author:** Gal Hochman, Email: gal.hochman@rutgers.edu. The authors thank NIFA award # 2016-670023-24751, the USDA Office of Energy Policy and New Uses by cooperative agreement #58-0111-15-007, Department of Agricultural, Food, and Resource Economics, and the Rutgers Energy Institute for financial support.

[1] Photo from Armstrong, W.P. "Duckweeds From Minnesota." *Palomar College*, W.P. Armstrong, 12 Mar. 2011, www2.palomar.edu/users/warmstrong/dckwdher2.htm.
[2] Lam, Eric. "Using Duckweed for Scalable Food Production: a Path Toward Domestication of the Lemnaceae" (2017) *Rutgers University*.
[3] Tobin, Elaine M., and David M. Kehoe. "Phytochrome Regulated Gene Expression." *Seminars in Cell Biology*, vol. 5, no. 5, 1994, pp. 335–346. University of California, Los Angeles, doi:10.1006/scel.1994.1040.
[4] Macelroy, R.D., et al. "NASA Technical Reports Server - The CELSS Research Program." *NASA*, NASA, 28 Nov. 1995, ntrs.nasa.gov/search.jsp?R=19910030116.
[5] Bergmann, BA., et al. "In Vitro Selection of Duckweed Geographical Isolates for Potential Use in Swine Lagoon Effluent Renovation." *Biosource Technology* Vol 73 pp. 13–20. *Department of Forestry, North Carolina State University*, doi: 10.1016/S0960-8524(99)00137-6
[6] Yamamoto, Yuri, et al. "Plant Improvement for Wastewater Remediation and Metabolic Engineering for New Plant Production." *North Carolina State Univeristy*, https://www.mobot.org/jwcross/duckweed/CRIS/0172393.txt
[7] Fedler, Clifford B. "Cost Effective Waste Treatment Through Aquatic Protein Production." *Texas Tech Univeristy, Texas Cooperative Fish and Wildlife Research Unit* https://www.mobot.org/jwcross/duckweed/USGS_abstracts.html#Fedler2

U.S. CONSUMPTION OF DUCKWEED

1. AQUACULTURE
- The water-dense duckweed is harvested using solid-handling pumps

2. WATER REMOVAL
- Duckweed is sent into a water removal system to be pre-dried

3. HEATING
- The dewatered biomass is then heated to 400 degrees Fahrenheit utilizing the waste heat from gasifiers

4. PUMPING
- A progressive cavity pump then moves the material to a drying screw.

5. DRYING
- Duckweed exits the drying screw and is pumped into a gasifier.

6. REACTION
- Material is heated to 1600 degrees Fahrenheit and begins to break down
- Resulting carbon biochar is separated and sent to gasifier for combustion, driving the reaction

7. HEAT RECOVERY
- A methane biogas is cooled and separated.

8. POWER
- The gases from the process are then recaptured and cooled.
- CO_2 rich gases are sent back to the greenhouse, where the cycle of growth begins again.

How is it processed? Ceres Energy Group (CEG Power and Gas) uses duckweed to generate biogas and electricity at their facility in Cape May, New Jersey by following **process** charted below on the left. [8]

Uses: Duckweed may be utilized at different stages of growth and processing for various needs:

A. Food

i. Chicken feed/fish food: Corn, for example, is normally used to feed livestock but remains low in protein; duckweed can supplement low-protein conventional feeds in a cost-effective manner. Similarly, it is used to feed fish like tilapia and carp. Fish, otherwise, may be placed in duckweed tanks to suppress certain pests, like mosquitos.[9]

ii. Human food: Poor populations in Laos, Thailand, Myanmar, India, Pakistan, Bangladesh survive on carbohydrate-rich foods which may be supplemented with duckweed as a protein or fat source. Depending on the strain of duckweed, human diets may be supplemented with different levels of carbohydrates, proteins, fats, minerals, carotenoids, and sterols. [10]

B. Energy

i. Pelletize for traditional boilers: In comparison to dense wood, pelletizing duckweed would require less energy; the pellets may be burned directly for energy or further processed into fuel.

ii. Feedstock for biogas: Upon drying and pelletizing the duckweed, the pellets can be used to produce a biogas; this gas is renewable in comparison to natural gas.

iii. After further processing, biofuel: Once converted into a gas, duckweed may be further processed into methanol, and then converted into gasoline. Due to the low cost of duckweed production and maintenance, duckweed-sourced biofuel may become very cost-competitive with existing oil refineries. [8]

C. Environment

i. Water contamination measure: The EPA currently uses a strain of duckweed, from the species *Lemena minor*, to identify the level of heavy metal contamination in water. Duckweed is also utilized as a sediment toxicity indicator to test the level of nutrients or contaminants in enriched or unenriched soils; this method provides an additional, natural method to test sediment toxicity.[11]

ii. Clean water: Duckweed's ability to uptake nitrogen and phosphorus makes it an efficient way to purify water and remove excess contaminants. Companies like BioTech Waste Management (BTWM) in Armidale, Australia are using duckweed technology to provide low-cost water treatment solutions to local areas.

> **Mike Smith, CEO of CEG Power and Gas emphasizes, *"the only material we are producing outside of emissions is ash, but this is used as fertilizer for the next generation of duckweed."***

[8] Smith, Mike. "Our Power Services." *CEG Power*, CEG Power, 2012, cegpower.com/.
[9] Anderson, K.e., et al. "Duckweed as a Feed Ingredient in Laying Hen Diets and Its Effect on Egg Production and Composition." *International Journal of Poultry Science*, vol. 10, no. 1, Jan. 2011, pp. 4–7., doi:10.3923/ijps.2011.4.7.
[10] Appenroth, Klaus-J., et al. "Nutritional Value of Duckweeds (Lemnaceae) as Human Food." *Food Chemistry*, vol. 217, 2017, pp. 266–273., doi:10.1016/j.foodchem.2016.08.116.
[11] International Steering Committee on Duckweed Research and Applications. "Duckweed Forum." Jan. 2016.

Efficiently carbon neutral: Not only does duckweed remove carbon dioxide in the ambient atmosphere through photosynthesis, but it also consumes the carbon dioxide retuned to the water as part of the closed loop process.[13] As duckweed uptakes nutrients, it has a tendency to raise the pH level of the water; by using the carbon dioxide that we get from our stack gases, the pH is lowered and the cycle is continued. [12]

Costs: For duckweed producers like Smith at CEG Power and Gas, roughly three acres of water surface are needed to produce a megawatt of power. Compared against current installed green energy systems like solar and wind the cost of a duckweed plant is 20 to 25 percent cheaper to install and run. Smith estimates solar at about $3 installed per watt and duckweed at $2.50 per watt, considering operating costs and labor are similar.[13]

Energy Security: In 2013, British Petroleum (BP) published an Energy Outlook 2030 report[14], in which it predicts the world will require almost double its current energy supply by 2030 to sustain its economic and population growth; there is an increasing gap between GDP and energy consumption. Domestically-produced cost-effective biofuel will be pertinent for the conservation of energy, decline of fossil fuel use, and fulfillment of future energy needs.

The **problem with duckweed**, is that there is no consistent way to grow the biomass. Unlike our understanding of corn cultivation, our understanding of duckweed cultivation does not span nearly as extensively since little organized effort had been spent on its domestication; some scientists are beginning to systematically determine how to reliably grow duckweed in large quantities and on different scales. [12]

DUCKWEED VS. ALGAE

Despite high growth rates for duckweed and algae, both organisms differ in other properties[15]:

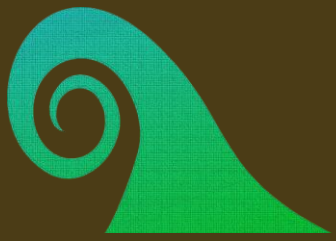
- Algae is a protist whilst duckweed is a plant, but both photosynthesize

- Duckweed is can be more easily gathered from the water due to their larger leaves

- Duckweed flourishes in many different climates and is composed of mainly proteins and starch

- Algae flourishes strictly in warm climates and is composed of mainly proteins and oil

- Both organisms have a high rate of nutrient uptake



[12] International Steering Committee on Duckweed Research and Applications. “Duckweed Forum.” Jan. 2016.
[13] Smith, Mike. “Our Power Services.” *CEG Power*, CEG Power, 2012, cegpower.com/.
[14] BP. “BP Energy Outlook 2030.” *British Petroleum*, Jan. 2013, pp. 1–86., https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2015/bp-energy-outlook-booklet_2013.pdf.
[15] Cheng, Jay J. "Growing Duckweed for Wastewater Treatment and Feed/Food Products" (2017) North Carolina State University.