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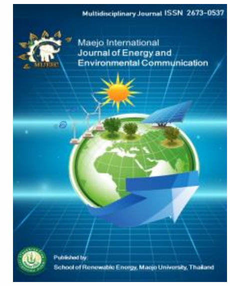


ARTICLE

# Evaluation of cattail characteristics as an invasive wetland plant and biomass usage management for biogas generation

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ABSTRACT

The fossil fuel-based linear economy has many severe drawbacks, including the need for energy security and the resulting environmental degradation. In a new cycle of the bio-economy that is becoming increasingly important, biomass waste has been used to generate energy while reducing pollution and greenhouse gas emissions. The growth of renewable energy will be substantial in the reduction of greenhouse gas emissions in order to achieve the ambitious goal of becoming carbon neutral by the mid-century. It appears that using anaerobic digestion technology to produce methane-rich biogas from biomass has a great deal of potential in this scenario. The cattail fresh and dry biomass substrate with pig wastes as inoculum was tested for biogas production. Cattail's highly complex lignocellulosic structures make it challenging to decompose as a biogas substrate. Alkaline pretreatment is one of the efficient tools in solubilizing lignin. As a result, chemical pretreatment of biomass (2 % sodium hydroxide) was a unique method for increasing biogas generation by reducing complex polymers of lignocellulosic materials into simpler molecules that microorganisms could digest. The fresh and dry biomass substrate added fermenter was produced with 57% and 60% methane, respectively.

## 1. Introduction

Biomass is organic, which means it is composed of material derived from living organisms such as plants and animals. Plants, wood, and garbage are the most frequent biomass materials utilized for energy. These are referred to as biomass feedstocks (Khammee et al., 2021). Plants absorb the sun's energy through photosynthesis and transform carbon dioxide and water into nutrients, resulting in biomass. The logic for biomass energy is simple (Vu et al., 2015; 2018). Trees and plants receive carbon dioxide from the atmosphere, isolate it through photosynthesis, and construct tree trunks, bark, and leaves. However, as the plant dies, much of the carbon is released back into the environment as carbon dioxide. Thus, they interfere with the carbon cycle by repurposing the stored energy rather than releasing it back into nature when using biomass as an energy source. As a result, these organisms' energy can be converted into usable energy. Biomass is presently the most significant global source of renewable energy, accounting for about

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half of global yearly primary energy consumption, and it has the potential to grow further in the generation of heat, power, and transportation fuels (Chuanchai et al., 2019; Saengsawang et al., 2020).

Biomass energy plants must establish and implement a biomass source plan that complies with the principles and can provide the facility for the duration of its operational life, considering competing for biomass demand in the sourcing area. Our reliance on fossil fuels has been reduced thanks to significantly converting to biomass energy (Unpaprom et al., 2015; 2017). Renewable energy sources are renewed regularly by natural processes. Renewable energy resources can be found in any part of the planet. However, access to these resources is determined by their availability and the expense of accessing them (Dussadee et al., 2017; Wannapokin et al., 2018). Although the use of biomass for energy generation may reduce GHG (Greenhouse gas) emissions, the favorable influence on other environmental components and economic benefits of biomass use is generally overlooked (Kaewdiew et al., 2019). Several studies have shown that large-scale biomass production or harvesting can lead to contamination and depletion of soil and water resources and significantly reduce biodiversity and the loss of traditional rural landscapes.

**Nomenclature and Abbreviation**

| | |
|---|---|
| $CH_4$ | Methane |
| $CO_2$ | Carbon dioxide |
| $O_2$ | Oxygen |
| $H_2S$ | Hydrogen sulphide |
| NaOH | Sodium hydroxide |
| GHG | Greenhouse gas |

In addition, aquatic biomass has long been cultivated and used in the industrial sector as a source of chemicals, a human food source, and a livestock feed source. The need to move away from first-generation biofuels (biodiesel and bioethanol derived from edible biomass) and toward non-food sources that can be grown without arable land has sparked interest in its usage as a biofuel source (Dussadee et al., 2016; Sittisom et al., 2019). Marine biomass can be cultivated in bioreactors to produce a range of fuels such as bio-oil, biodiesel, bioalcohol, and biohydrogen, among other things, or it can be grown in saline water or fresh wastewater (from municipalities or industrial processes). Biogas can be made from the residual biomass left over after liquid fuel extraction (Ramaraj and Unpaprom, 2016; Ramaraj et al., 2016a,b,c,d). They are gaining in favor since they are photosynthetic renewable resources with a high lipid content and a faster rate of development than terrestrial plants; they can also grow in salt, making them unsuitable for agricultural use (Ramaraj and Dussadee, 2015). However, while the lipid content of microalgae varies by strain on a dry cellular weight basis, some microalgal strains have been found to have a lipid content as high (Nithin et al., 2020). To influence their behavior and processes, physical stress or genetic engineering can be applied. They can produce biogas as well. When taken into account, aquatic biomass has the potential to become a fascinating and widespread energy source.

Wetland systems have recently grown in popularity for the purification of small amounts of wastewater due to their high efficacy in eliminating contaminants from wastewater. According to the study's findings, planned wetland systems can be used not only for very effective wastewater treatment, flood control, biodiversity, water filtering, and carbon storage are just a few of the many ecological services provided by wetlands. Wetland invasion by monotypic dominating plants can change soils' physicochemical and biological features, affecting methane emissions. They are also major emitters of methane, a potent greenhouse gas with global warming potential. However, also, for biomass formation for use in renewable energy production. The biomass produced by managing tree-less environments such as wetlands, wet meadows, and buffer strips has emerged as a promising biogas generation option. The biomass of fluviogenous wetlands, primarily Phragmites australis, Phalaris arundinacea, *Carex* sp., and *Typha* spp., is mowed in enormous quantities annually and has grown been recommended as an exciting alternative to energy crops for agricultural biogas plants, should be given special attention.

Eight promising wetland species were identified and yield experiments and nutrient requirement investigations were conducted on them. The species included three cattails (*Typha* latifolia L., Typha *angustifolia* L., Typha × *glauca* Godr.), common reed (*Phragmites australis* (Cav.) Trin. ex Steudel), sedge (*Carex atherodes* Spreng.), bulrush (*Scirpus fluviatilis* (Torr.) Gray), bur-reed (*Sparganium eurycarpum* Engelm.) and cordgrass (*Spartina pectinata* Link). The cattails (*Typha* spp.) appear to be the most promising candidates for a wetland bio-energy system (Dubbe et al. 1988). However, cattail is also being evaluated for usage as biomass crops due to their high yields and productivity. Cattail has a high growth rate and high biomass yield. In addition, it is a type of plant that generates the material lignocellulose. Lignocellulose is a common biopolymer that contains much organic material and is regarded as one of the essential biomass resources for biogas production (Unpaprom et al., 2019; Van Tran et al., 2020). The use of lignocellulosic biomass for biogas production via anaerobic digestion, on the other hand, has not been generally embraced due to the plant cell wall's complex structure, which makes it resistant to microbial attack. Therefore, before burning, pretreating resistant lignocellulosic biomass is required to get significant biogas production in the AD process. The study aimed to examine the biogas and methane production of wetland plant species, cattail.

## 2. Methodology

The cattail plant was used in this study. The fresh material was crushed into small particles by a grinding machine and stored in the freezer at four degrees Celcius for further use; inoculum (pig manure and wastewater) was obtained from the Energy Research Center, Maejo University, Thailand. Crushed cattail was soaked in 2% sodium hydroxide (NaOH) for alkali pretreatment for three days. The residual alkali remaining in alkali pretreated biomass could help prevent a drop in pH during the acidogenesis step. The entire experimental process and methodology were adopted from Chuanchai et al. (2019). Biochemical analysis data were not presented in this article. This preliminary experimental work was mainly focused on characteristics of invasive wetland plant (cattail), biomass usage management, and biogas production.

Fresh and dried cattail biomass was used in this study as a monodigestion. The experiments were carried out with a 5 L working volume. The percentages of cattail and inoculum inside the fermenter were 10% total solids biomass and 5% inoculum, respectively. For anaerobic conditions maintaining, the fermenters were sealed and closed using brass valves. Plastic cylinders were used to store and quantify the biogas that had accumulated (500 ml). For 36 days, the fermenters were kept at room temperature, between 30 and 34 degrees Celsius. During the fermentation period, the fermenters were manually mixed three times a day. A portable gas analyzer was used to determine the concentration of biogas, which included methane ($CH_4$), carbon dioxide ($CO_2$), hydrogen sulfide ($H_2S$), and oxygen ($O_2$) (Biogas 5000, UK). All the experiments were accomplished with triplicate conditions.

## 3. Results and Discussion

### *3.1. Cattail (Typha spp.) characteristics: structure, habitat, and distribution*

Cattail is a perennial aquatic herb that grows up to 3 meters tall and has blooms on a slender stem. The staminate (male) flowers are positioned above the pistillate (female) flowers in a cylindrical inflorescence made up of minute flowers crowded together into spikes. The staminate flowers are reddish to blackish-brown in color and range in length from 7 to 13 cm, while the dark brown pistillate blooms are 2.5 to 20 cm long. Creeping lateral rhizomes, also known as underground stems, grow up to 70 cm long and 0.5-3 cm wide from the base of the plant's leaves. The plant's grayish-green leaves are flat, linear, and long, and they frequently overtop blooming spikes (Grace and Harrison, 1986; Motivans and Apfelbaum, 1987; Mitich, 2000; Stevens and Hoag, 2000).

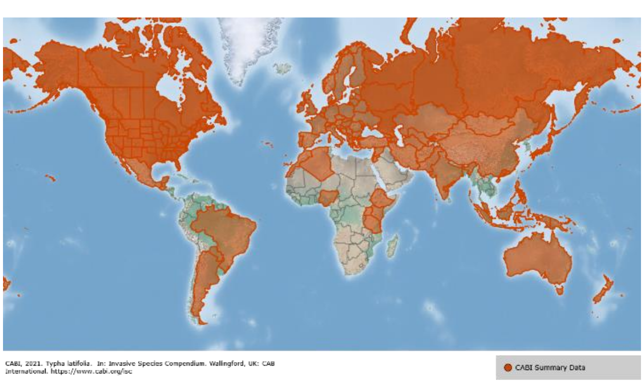


**Figure 1** Cattails global distribution (Source: CABI, datasheet 54297).

*Typha spp*., or cattail, is a common and invasive natural aquatic plant found throughout the world's aquatic ecosystems. In addition to their global distribution displayed in Figure 1. Cattail also has the advantage of being a cosmopolitan species, with natural populations ranging throughout all the continents, except for Antarctica, Africa, and Oceania. At least seven African countries have cattail in them. Six countries (Australia, Indonesia, Malaysia, New Zealand, Papua New Guinea, the Philippines) and the United States report the species was established as a non-native species (CABI, 2021)

Cattail's capability to quickly reproduce in locations where it is natural, and its extended life span pose a threat to non-native areas. Cattail has several regional names in English and other languages, but broadleaf cattail seems to be the most widely used one in the literature. Cattail plant types are aquatic, herbaceous, perennial, seed propagated and vegetatively propagated (Baldwin and Cannon, 2007). The young to the mature stage of the cattails plant is illustrated in Figure 2(A-D).

Taxonomy details the following:

Domain: Eukaryota
Kingdom: Plantae
Phylum: Spermatophyta
Subphylum: Angiospermae
Class: Monocotyledonae
Order: Typhales
Family: Typhaceae
Genus: Typha
Species: *Typha latifolia*, and other species

### *3.2. Methane emission management and biomass utilization*

Cattail invasion has an impact on $CH_4$ emissions from wetland ecosystems. Part of the reason plants helps to reduce $CH_4$ emissions from wetlands is that they provide carbon substrates for the methanogen population's anaerobic respiration. Microbial communities obtain labile carbon from biomass turnover and root exudation, and multiple studies have discovered that increased cattail biomass output results in increased $CH_4$ emissions. Parenchymatous cattail tissues are spongey and aerenchymatous, and they act as a conduit for $CH_4$ created in underlying anoxic sediment to bypass oxidized surface sediments and waters, increasing $CH_4$ emissions, in addition to supplying an abundance of carbon substrates. As cattail was present in manmade wetlands, $CH_4$ emissions were more significant when compared to controls that were not vegetated (McInerney and Helton 2016). $CH_4$ emissions mediated by cattails were responsible for more than half of the total $CH_4$ emissions from a dense Cattail pond's littoral zone. At night, cattail acts as a capacitor, accumulating carbon monoxide and releasing it during the daytime. In a marsh with a high concentration of cattails, daytime $CH_4$ emissions are two times higher than midnight emissions (Windham-Myers et al., 2018).

Despite their seasonal and environmental vulnerability, Cattails are found in various biomes due to their high resilience. As a result, cattail are being considered for bioenergy crops. Cattail is a perennial macrophyte capable of producing enormous amounts of biomass and multiplying. Cattail plants can produce 200,000 seeds per flowering head, 32, and these are relatively simple to collect and process. A single inflorescence could theoretically provide enough seed to establish a stand approximately (Bansal et al., 2019). For example, cattail varieties of ecological biomass can be harvested to supply material inputs for industry while also resolving environmental concerns. Combining numerous environmental advantages with economic profits will boost the profitability of environmental management and the sustainability of new bioeconomics - economic systems in which the raw material for industry is harvested plant material or biomass.


**Figure 2** Cattails plant (young to the mature stage: A-D)

A typical practice in managing cattails is the removal of the biomass from the plants, and recent research and reviews have looked into the possibilities of utilizing this biomass as a source of biofuel. In recent research on a cattail, management has revealed several advantages over other biomass sources, including the fact that it grows in wetland habitats that are not suitable for conventional agriculture. In addition, it is quickly renewable; it is a C-neutral resource; it does not necessitate tillage or replanting; harvesting cattail can improve wetland habitats (Svedarsky et al., 2016). In addition, cattail biomass byproducts can be used in ethanol production right away if they are harvested fresh (Rahman et al., 2015). More importantly, the extraction of plant biomass from surface-water retention systems (e.g., cattail) provided additional money for landowners through a variety of revenue streams, in addition to providing a biofuel feedstock and reducing downstream nutrient loading (Berry et al. 2017).

Bioenergy could be possible to attain future energy demands while also reducing GHG emissions. This is evident in Europe, where biomass has been utilized to replace coal for many years. Renewable and sustainable energy sources are becoming increasingly important (Chu et al., 2021). Plants can provide bioenergy that is more environmentally friendly. In poor countries, the future of wood charcoal is still dubious. Cleaner-emitting heat, energy, and combined heat and power are produced by newer high-efficiency biomass technology. Plants accumulate $CO_2$ during growth and release it after combustion, unlike coal. Reducing GHG emissions and exchanging carbon offset credits to improve the Recycled economy, timber, sawdust, and agricultural leftovers are used. The range of sustainable biomass feedstocks for bioenergy and biofuels, on the other hand, has to be expanded (Hall et al., 2018). To turn biomass into a cost-effective biopower and fuel source, sustainable biomass supplies will be necessary. Carbon offset markets and products can improve their cost-benefit analyses. A market protocol for avoided GHGs exists in Alberta. They are finding new biomass feedstocks, such as cattail and reeds, used for environmental restoration and have significant environmental and economic benefits. Several ecological benefits have increased economic sustainability. Cattails are an important bioenergy and biomaterials source. Wetland and urban ditches can be used to export cattail biomass. Therefore, the ongoing food vs. fuel debate and worldwide concerns about bioenergy and biofuels are addressed. Food crops are used to make these fuels. This lessens the global need for food and feed (Keyport et al., 2019).

### *3.3. Cattail lignocellulosic biomass and biogas production*

Organic molecules are digested by mixed consortia of synergistic microorganisms in the absence of oxygen, resulting in the generation of $CH_4$ and $CO_2$ as byproducts. Biological processes in which organic compounds are digested by mixed consortia of synergistic microbes, resulting in the generation of $CH_4$, $CO_2$, and other byproducts, are referred to as anaerobic digestion (Nong et al., 2020a,b,c). By using a one-step approach that incorporates all four necessary metabolic processes, it is possible to complete anaerobic digestion in a single vessel and in a single stage. The utilization of a two-stage process in which hydrolysis and acidogenesis are separated from acetogenesis and methanogenesis in two or more vessels is an alternate strategy that should be investigated (Van Tran et al., 2019). Hydrolytic bacteria develop faster than methanogens, which grow more slowly and require a pH of 6.8–7.6 to survive and thrive. Methanogens, on the other hand, grow slowly and require a pH of 6.8–7.6 in order to thrive.

Cattail is a typical lignocellulosic aquatic plant with a high output of lignocellulosic material. Lignocellulose feedstock (cattail), which is a natural product, has a limited ability to be fully exploited due to the intricate interactions that exist between the constituents of the feedstock (cellulose, hemicellulose, lignin). The fact that lignocellulosic cellulose composition varies depending on where it comes from and its slow degradability pose significant barriers to the expansion of biofuel production. These two factors, combined with the fact that lignocellulosic cellulose composition varies depending on where it comes from, pose significant barriers to the expansion of biofuel production. In the pretreatment of lignocellulose feedstock, high temperatures and the use of potentially hazardous chemicals are frequently employed, making it an energy-intensive process that necessitates the use of potentially hazardous chemicals as well as high temperatures (Wannapokin et al., 2019). In this study 2 % sodium hydroxide was used as chemical pretreatment, applied with fresh and dry cattail biomass. Biogas composition, yield of fresh and dry biomass cattail with inoculum shown in Table 1. During anaerobic digestion, the pretreated cattail was broken into two components: sugars and proteins, which were subsequently converted into volatile fatty acids (VFAs) by pig waste infected bacteria, and products such as lignin, which were difficult for microorganisms to utilize. Following the mass balance of the digested products, the products in the reactor were divided into four sections: undigested sugars and proteins; VFAs; biogas; and the mass required for microbial development and maintenance.

Because hydrolysis is the only step involved in anaerobic digestion of lignocellulosic materials, the amounts of sugars and proteins present in the liquid may be disregarded entirely. The fact that all of the fermentations were carried out under the same conditions may have led to overlooking the differences in the mass utilized for rumen microbe formation and maintenance across all of the investigations. As a result, for the sake of simplicity, the products formed might be defined as the sum of volatile organic compounds (VOCs) and biogas produced during anaerobic digestion (Ramaraj and Unpaprom, 2016; Ramaraj et al., 2016a,b,c,d). The results demonstrate that the breakdown of the crystalline and physical structure of cattail caused by chemical pretreatment improves its anaerobic digestibility. Fresh cattail provided highest methane content (61 %) and biogas yield (7,571ml) compared to dry biomass methane content (57%) and biogas volume (7,025ml). Biomass made of lignocellulosic material has recently gained appeal as a great source of renewable and environmentally friendly energy.

**Table 1** Biogas composition, yield of fresh and dry biomass cattail with inoculum.

| Gas composition/ time | Fresh biomass with inoculum | | | | | Dry biomass with inoculum | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 |
| $CH_4$ (%) | 6 | 24 | 44 | 56 | 61 | 5 | 20 | 42 | 52 | 57 |
| $CO_2$ (%) | 61 | 59 | 43 | 40 | 34.8 | 64 | 59.8 | 42.5 | 35 | 33 |
| $O_2$ (%) | 28 | 6 | 4 | 1 | 0.1 | 30 | 7 | 5.2 | 3.7 | 1.09 |
| $H_2S$ (ppm) | 62 | 49 | 35 | 32 | 26 | 64 | 50 | 42 | 39 | 35 |
| **Total biogas (ml)** | | | | | 7,571 | | | | | 7,025 |

Comparing anaerobic digestion to other techniques of waste disposal such as landfilling and composting, it is a more environmentally friendly approach of dealing with cellulosic wastes (Nong et al. 2020d). Although cellulose and hemicellulose are the most biodegradable components of biowaste, they form rigid complexes with lignin that hinder biodegradation, particularly under anaerobic conditions. In this work, it was demonstrated that chemical pretreatment is a simple and effective method of increasing cattail anaerobic conversion. This pretreatment resulted in significant hemicellulose solubilization, a significant reduction in cellulose crystallinity, wax and lignin breakdown, as well as increases in the rate of production and yield of the finished product. The results of this study suggest that microwave irradiation pretreatment of lignocellulosic wastes could be used to improve the anaerobic digestion of these wastes.

## 4. Conclusion

A significant proof of concept, this research study demonstrates how to collect plants or biological material, such as cattail, to absorb nutrients that would otherwise flow into streams and contribute to eutrophication. It is the purpose of this study to investigate the mechanisms of pretreatment for optimizing the anaerobic digestion of cattail by pig waste microorganisms and fresh/dry biomass utilizing in the fermentation conditions of cattail. According to the findings of this study, cattail has the ability to pre-process lignocellulosic substrates for use in energy and platform chemical synthesis, and further research into cattail's biotechnological applications is required.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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