The Potential of Urban Organic Waste Utilization as Neo Carbon Food

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Abstract. Majority of the urban society has a problem with their organic waste. One alternative urban waste utilization as food production can be obtained by producing Single Cell Protein (SCP) through Neo-Carbon Food (NCF). NCF is a single cell production based on microorganisms using CO₂ emissions and urban organic waste as the main raw material for hydrogen oxidizing bacterial growth. NCF are potential because contain high protein, requiring less land and water, reducing pollutions and the GHG emissions. So, NCF can decrease GHG emissions to overcome climate change and also as sustainable food.

Keywords: GHG, neo-carbon food, single cell protein, sustainable food, urban organic waste

1. Introduction

Nowadays, nearly 55% of the World population lives in urban areas, and it is expected that the number will increase up to 66% by 2030 [1]. As the city grows, new problems arise (e.g., traffic congestion, waste management, pollution, and GHG emissions. A greenhouse gas (GHG) is any gas in the atmosphere which absorbs and re-emits heat, and thereby keeps the planet’s atmosphere warmer than it otherwise would be. The main GHGs in the Earth’s atmosphere are water vapour, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and ozone [2]. CO₂ gas is the largest contributor of GHG emissions, which is 77% [3]. One of the causes of GHG emission is waste production.

The production of wastes especially the urban organic waste remains a major source of concern as it has always been since pre historic period. The urban organic waste produced as a result of various agricultural operations. It includes manures and other wastes from farms, harvest waste, fertilizer run-off from fields, and pesticides [4]. Though the waste enters the environment it will contribute a significant to overall greenhouse gas (GHG) emissions, This waste is also an energy source and protein source because this urban organic waste contains carbon, hydrogen and nitrogen [5]. Organic wastes such as fruit and vegetables have biological and chemical potential in producing bioethanol [6,7], this bioethanol can be used as alternative liquid fuel for energy source [8].

Urban organic waste can also be used as a raw material for making Neo-Carbon Food. One of the urban organic wastes that can be used to make Neo-Carbon Food is tofu waste. Generally, solid waste tofu can be used for animal feed. Meanwhile, tofu waste in the form of liquid is discharged into the...
water, resulting in a detrimental effect on water quality, which results in a foul odor in the river or place around the tofu liquid waste disposal. The presence of liquid waste can give a negative value to an industrial activity. Tofu liquid waste can also provide a positive value if it can maximize the potential that exists in industrial wastewater as well as handling with the right technology [9].

The potential for the development of Neo-Carbon Food in developing countries like Indonesia is very possible to make by making several modifications in the manufacturing process. For example, like tofu waste which can be used as an energy source as well as a nitrogen source. The energy used for its production uses biogas from tofu solid waste, as well as tofu liquid waste as its nitrogen source. So, Neo-Carbon Food can decrease GHG emissions to overcome climate change and also as sustainable food.

2. Neo Carbon Food Concept

Neo-Carbon Food comes from the word "Neo" which means renewable and "Carbon" which is an element with an atomic number 12. Neo-Carbon Food is the result of biosynthesis that produces a single cell protein. In the manufacture of SCPs, in addition to microorganisms with strong ripple power, the composition of basic materials, as well as the process technology used greatly determines the quality of the products produced. The raw material for the manufacture of SCP must contain water, source N, source C and minerals [10]. Neo-Carbon Food is a future protein production that uses electricity and carbon dioxide as the main ingredients as a source of C for bacteria. This research was developed by VTT Technical Research Center of Finland Ltd. and Lappeenranta University of Technology LUT. This process is carried out using microbes. This technology allows safe food production without pesticides or agricultural land [11]. Neo-Carbon Food is processed through biosynthesis by electrolysis of water with the help of electricity so that the CO₂ occurs in the fusion reaction to C and O₂ and H₂O to H₂ and O₂.

Microbes that are used as SCP producers must have criteria that are not pathogenic, have good nutritional value, can be used as food or feed and do not contain toxic compounds [12]. Many types of microbes can produce SCP, one of which is a group of hydrogen oxidizing bacteria (eg. Cupriavidus necator, Rhodococcus opacus, and Hydrogenobacter thermophilus) capable of autotrophic growth by using hydrogen as a donor electron and oxygen as an electron acceptor to improve carbon dioxide to build their biomass. This bacterial biomass has a high protein content (50-83%), and can be used as a nutrient in humans and animals [13]. Overall growth and biomass production factors, the productivity of hydrogen oxidizing bacteria is also much faster and higher than the productivity of Cyanobacterium [6,7]. But this hydrogen oxidizing bacteria is still less frequent than Cyanobacterium.

There are other beneficial reasons besides the speed of growth to use oxidizing hydrogen bacteria for biomass production. This bacterium has a high protein content and one product of the oxidation of hydrogen is water. Hydrogen oxidation occurs, when oxidizing bacteria use hydrogen to grow substances. The bacterial protein content varies between 60-70%. There have been several experiments, in which bacterial biomass is fed to farms and furry animals. Such experiments were carried out at the biophysical institute at the Russian science academy. The result is that the use of bacterial biomass as a feed is beneficial for 25-50% of the animal protein diet. The result depends on the species and age of the animal [14]. This experiment shows that there is the potential to use these bacteria as feed use [15]. It is this high protein that bases why it is used to oxidize hydrogen to produce single cell proteins (SCP), because the need for protein in the global community is increasing.

One species of hydrogen oxidizing bacteria is the Cupriavidus necator. This species is commonly used in studies that focus on cell growth [16]. This microbial stoichiometry is used as a reference for calculating the needs of carbon dioxide, nitrogen, and hydrogen per kg of biomass produced. Stoichiometry for Cupriavidus necator is as follows [17]:

$$21.36 \text{H}_2 + 6.21 \text{O}_2 + 4.09 \text{CO}_2 + 0.76 \text{NH}_3 \rightarrow C_{4.00}H_{7.13}O_{1.96}N_{0.76} + 18.7 \text{H}_2\text{O}$$

One kilogram of Cupriavidus necator requires about 1850 grams of carbon dioxide, 220 grams of hydrogen, 1020 grams of oxygen is needed [18]. Hydrogen and oxygen can be supplied to bacteria by conducting electrolysis directly in the bioreactor, where bacteria are bred. In situ water electrolysis
allows the efficient use of hydrogen and oxygen by bacteria, because the transfer of the gas mass is better to the aqueous solution, than in the case of an external gas supply. Also combustible mixtures in the reactor headroom can be avoided to some extent. In addition to H2 and O2, CO2 and nutrients needed for growth are supplied to reactors such as nitrogen, vitamins and minerals [13].

One of the most important growth conditions is pH. The pH used can even affect the product formed. For example, if pH is lowered, alcohol production may increase [19]. Optimal pH varies, when using different organisms, for *Cupriavidus necator* the optimal pH is in the range 6.7–6.9 with optimal temperature of 30°C [20]. This bacterium belongs to the mesophilic bacteria because it grows at a temperature of 30–40°C [21].

![Figure 1. Scheme of Neo-Carbon Food Production [13]](image)

An electricity-to-biomass efficiency of 54% has been achieved by applying in situ water electrolysis, which would correspond to approximately 10% solar-to-biomass efficiency (assuming 18% efficiency for photovoltaic). For comparison, the annual average efficiency of crops do not typically exceed 1%, and efficiencies during the growing seasons can reach only 3.5–4.3%. By applying direct air capture (DAC) of CO2 by adsorption/desorption process with in situ water electrolysis, bacterial protein can be produced basically only from electricity, air water and some nutrients. The scheme of this concept is illustrated in Figure 1. [13]. The reason why DAC is used as part of the biomass production process, is that it offers a solution to produce high purity carbon dioxide with possibility to reduce the concentration of CO2 from atmosphere without specific location. Other reason is that, it can be used sustainable, if renewable energy source is used to power the process [22]. Besides using DAC we can use CCS (Carbon Capture and Storage) as the alternative [23].

When calculating the impacts and energy consumption, the assumption is made so that, all the electrical energy used to produce biomass is produced from renewable sources. The sources are wind and solar energies. The process is assumed to function so, that all the gasses produced for biomass production are used right away. The gasses needed for biomass production can be stored, if there is so much oversupply that the process cannot handle all the material produced, but storage needs energy and materials and thus increases the energy need, GWP and land use [24].

The electricity can be produced by renewable sources and thus this application is used in the process. It is estimated that globally around 4% of hydrogen is produced via water electrolysis. The advantages of using water electrolysis are highly dynamic modes operation, compact stack design, high unit power densities, high capacities, satisfying gas purity levels, wide partial load ranges with high enough efficiencies and low investment costs. The technology is already in use, but there is still room for improvements. Currently a lot of research is done to make this technology more efficient [25]. When
using conventional electricity, the costs needed are more expensive than using electricity from renewable energy.

When planning to produce biomass from microbes in aquatic solution, the culture harvesting and drying are important unit process. There exists a couple of technologies for culture harvesting. Some usable technologies for harvesting are chemical flocculation, bio-flocculation, electro-flocculation, flotation, filtration and centrifugation. However, these harvesting technologies are not usually sufficient alone due to remaining liquid after these processes. Quite often drying process after culture harvesting is needed. Some technologies for drying are solar drying, convective drying, spray drying and freeze-drying [26].

The concept is still in research stage, but in the future, it may provide a solution to environmental impacts of conventional agriculture, such as greenhouse gases, fresh water use, land use, and pollution caused by fertilizers and pesticides. Optimization of electrode materials, cultivation medium and conditions, bioreactor construction, and process modelling and control are under research by the authors [13].

3. Neo-Carbon Food Potential as Sustainable Food

The use of microorganisms to produce single cell proteins have very fast growth rate; their biomass doubling time is typically 20-120 minutes, while e.g. soybean has doubling time 1–2 weeks. Due to high conversion efficiency and fast growth, bacterial protein production requires significantly less water and land area compared to the conventional protein sources [13].

The need of the land will also increase to grow food commodities. Land needs for this growth also affect the need for fertilizers and pesticides. Global fertilizer consumption is expected to increase by 50% in 2050 to maintain the required increase in food production capacity [27]. The use of Neo-Carbon Food can reduce the need for fertilizers and pesticides because the process of processing Neo-Carbon Food does not require pesticides and fertilizers, but what is needed is nutrition, vitamins and minerals for the growth of microorganisms that are far less than conventional protein production.

The demand for water is ought to continue rising in the future. The agriculture is the main reason why water is consumed so much. The irrigation uses approximately 70% of the global water consumption and thus the lack of water affects greatly to food production [28]. Because food production plays such a huge role on water consumption in the world, we should find solutions for more sustainable water use in that sector. Especially, when there is a talk about upcoming water crisis [29]. In addition, the energy needed to produce proteins use conventional way is greater than using microorganisms [22–27].

Neo-Carbon Food obtained from the results of Nygren, et al. [13] which is single cell protein powder containing 54% protein, 1% fat, 18% carbohydrate, 8% inorganic ingredients and 19% other ingredients [11]. This research has entered the pilot plant stage by using a 20 L reactor and producing 10 grams per hour. This protein content is quite high when compared to meat with 20% protein, 3.5% milk, 25% cheese, soybeans 35-40% [28,29]. The raw material used for the production of Neo-Carbon Food also uses CO₂ which is one of the gases that contributes the most in GHG emissions [3].

4. Potential Development of Neo-Carbon Food in Indonesia

Research on Neo-Carbon Food in Indonesia is still rare. However, there have been many studies on microorganism-based single cell proteins (SCP), because this single cell protein can be used as a substitute for animal and vegetable proteins. Making these single cell proteins (SCP) requires a bioreactor, substrate and microorganism, so SCP requires some energy to produce it.

Renewable energy in Indonesia is relatively small. Nygren et al. [13] using energy from solar and wind panels, in Indonesia such energy sources are still rarely used so the use of biogas can be used as an alternative energy source. Besides being able to reduce waste, it can also produce energy and reduce GHG emissions. At present the source of biogas raw material is available abundantly and has not been fully utilized [30]. The use of biogas in Indonesia as an alternative energy source allows it to be applied, along with the increasing price of fuel oil and it’s scarcity [31].

The energy needed to produce 1 kg of Neo-Carbon Food is around 13,523 kWh [31–35]. Based on the basic electricity rates from PLN in 2019, the electricity costs for the industry are Rp. 97-1115 / kWh. So for 1 kg of Neo-Carbon Food, it requires production costs (from electricity sources) of Rp. 13,482-
15,078 when using electricity from PLN. When using electricity from renewable energy, the cost of electricity used can be lower.

**Figure 2. Scheme of Neo-Carbon Food Production in Indonesia**

### 4.1. Urban Organic Waste

Urban organic waste is biodegradable part of households refuse, market waste, yard waste and animal and human waste. When waste is not managed properly it may cause serious health and environmental risks. The overall goal of municipal refuse management is to improve and safeguard the public health and welfare, reduce waste generation and increase resource recovery and re-use, and protect environmental qualities [36].

There are many resources from urban organic waste that can be used to produced the Single Cell Protein (SCP). For example, the horticulture waste such as vegetables and fruits from households refuse or market waste is a rich source of potentially valuable to produce the SCP. These waste contains water-soluble carbohydrates such as glucose, and water-insoluble ones such as pectin and cellulose. Carbohydrates can be used as a substrate for the SCP to grow because SCP can aerobically grow on lignin and sugar compounds [37]. Meanwhile total nitrogen level in this waste reach 2.22%. This nitrogen could be the source to produce the SCP. Another major issue associated with urban waste mismanagement is the greenhouse gas emission, which comprehends methane and nitrous oxide [38]. These gasses can be used as an energy source in biogas plant (Figure 2).

### 4.2. Tofu Waste

One of the organic wastes that can produce biogas is tofu waste. The tofu industry produces 20 million cubic meters of liquid waste per year and produces around 1 million tons of CO$_2$ equivalent. 80 percent of the tofu industry is on Java, thus emissions issued by tofu factories in Java reach 0.8 million tons of CO$_2$ equivalent [39].

Tofu industry waste is generally divided into two forms of waste, solid waste and liquid waste. The solid waste of the tofu processing plant is in the form of soybean cleaning (rock, soil, soybean skin, and other solid objects attached to soybeans) and the remaining soybean crude, while tofu liquid waste is produced from water used for soybean cleaning and during the processing of tofu. Tofu liquid waste is rich in protein, fat, and carbohydrates and high organic compounds. These organic compounds will produce methane (CH$_4$), carbon dioxide (CO$_2$), other gases, and water [39].

Solid waste from tofu can be used as an energy source in the bioreactor. Methane gas from tofu solid waste is used as an energy source. Bioreactor or often referred to as a bio digester, which is a dome-shaped gas-tight building that functions to capture methane gas from organic matter. The biogas reactor consists of a digester and a sink. This reactor can be filled continuously with wastewater from industrial tofu production. This reactor includes all the needs to produce methane through anaerobic processes [39].
The raw material for producing SCP must contain water, source N, source C and minerals [10]. Nitrogen can be obtained from tofu waste [40]. This tofu liquid waste which is usually immediately disposed after processing will undergo a process carried out by microorganisms (spontaneously) during disposal. This happens by hydrolyzing organic substances, such as proteins, carbohydrates, and fats which are still high in content [41], so tofu liquid waste can be used as a source of nitrogen for hydrogen-oxidizing microbes.

If all aspects; energy source (electricity), source C, source N obtained from the nature can be applied properly, then Neo-Carbon Food is economical. Neo-Carbon Food contains 54% protein, while meat only contains 20% protein [28,29]. Therefore, Neo-Carbon Food can be an alternative source of protein because of its higher protein content than meat.

This technology can be simplified and implemented in the village. The use of urban organic waste from local villages into biogas and also N sources for NCF can be done. Besides being able to empower local people, it is also source of protein. Even villages that are difficult to reach can also obtain high-protein food sources with independent production without go far to the city so they can produce new food sources through a waste to resource approach.

Based on the explanation above, the technology of Neo-Carbon Food production in Indonesia is still very possible to do by modifying several things such as the energy used and the source of N, vitamins and minerals needed by these SCP-producing. However, further research must be done to determine the optimization of Neo-Carbon Food production so that the results are more optimal and the process used is more effective.

5. Concluding Remark

Neo-Carbon Food could be implemented by using urban organic waste. A Holistic process in the utilization can take advantage of biogas as side process for the energy source. It may provide a solution for environmental impacts of organic waste, such as greenhouse gases, fresh water use, land use, and pollution. So, Neo-Carbon Food can decrease GHG emissions to overcome climate change and also as sustainable food.

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