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# Utilization of Rice Straw Waste as a Source of Bioenergy: A Review

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## Abstract

The rice straw waste is a byproduct of rice processing and is a plentiful natural resource in Indonesia. It has been utilized as a renewable energy source to decrease reliance on fossil fuels and tackle worldwide energy concerns. Rice straw waste contains various organic compounds, such as 36.6% cellulose, 25.3% hemicellulose, and 14.3% lignin. These compounds can be converted into various types of bioenergy, such as bioethanol, biogas, biomass, and bioelectricity through fermentation and pyrolysis processes. Rice straw waste has significant potential as a raw material in bioethanol production, biogas and bio-oil. rice straw waste also has the potential to produce bio-oil through the pyrolysis process. Tiny organisms, like bacteria and fungi, have a crucial part in the creation of bioethanol, biogas, and bio-oil. These microscopic organisms will be used in the process of fermentation, decomposition, or other biochemical reactions to convert rice straw waste into the desired renewable energy source. In the production of bioethanol, the use of enzymes such as amylase or cellulase may be required to break down the raw materials into simpler components that can be converted through the fermentation process into bioethanol. The process of producing biogas involves utilizing an anaerobic digester, which is a controlled environment devoid of oxygen. In this environment, microorganisms decompose the organic material found in rice straw waste and generate biogas. The methods used in the production of bioenergy (bioethanol, biogas and bio-oil) from straw waste may vary depending on the context and available technology.

**Keywords:** Bioenergy, Fossil Fuels, Biogas, Bioethanol, Bio-oil

## Introduction

Rice straw waste is seen as a promising source of renewable biomass for generating bioenergy. It is a byproduct of rice processing and is readily available in Indonesia, making it a plentiful natural resource Rice straw waste has been developed as an alternative bioenergy source that can reduce dependence on fossil fuels and help address global energy issues [1]. According to data from the Badan Pusat Statistik (BPS), the total production of rice in Indonesia reached 54.75 million tons in 2022 [2]. This figure represents the total production of rice in every region of Indonesia, as seen in Figure 1. From this total, it is estimated that 25-30% of rice straw waste is produced, or about 10.95-16.425 million tons [3].

Fig 1. shows the tremendous potential for utilizing rice straw waste as a source of bioenergy in Indonesia. In addition to its abundance, rice straw waste also contains content that can be utilized as bioenergy feedstock. Rice straw waste contains various organic compounds, such as 36.6% cellulose, 25.3% hemicellulose, and 14.3% lignin [3]. These compounds can be converted into various types of bioenergy, such as bioethanol, biogas, biomass, and bioelectricity through fermentation and pyrolysis processes [4]. The Indonesian government acknowledges the potential of rice straw waste as a bioenergy source. This is evident through their policy to promote the use of new and renewable energy in the National New and Renewable Energy Program (EBT) [38].

The utilization of rice straw waste as a bioenergy source can contribute to the reduction of greenhouse gas emissions and organic waste in Indonesia. [5]. However, there are challenges to overcome when utilizing rice straw waste as a bioenergy source, specifically the high lignin content present in the waste. This poses difficulties in breaking down the biomass into fermentable sugars required for bioethanol production [6]. In addition, improper utilization of rice straw waste, such as burning it in open fields, can cause environmental problems and emit significant amounts of greenhouse gases [7]. Furthermore, there are concerns regarding the potential adverse effects associated with the use of bioenergy, including excessive land utilization and environmental impacts [8]. Therefore, conducting research on the exploitation of rice straw waste as a bioenergy source becomes crucial in order to enhance the efficiency of natural resource utilization and mitigate detrimental environmental effects. This review aims to offer an encompassing perspective on the potential, composition, and utilization of rice straw waste as a valuable bioenergy resource.

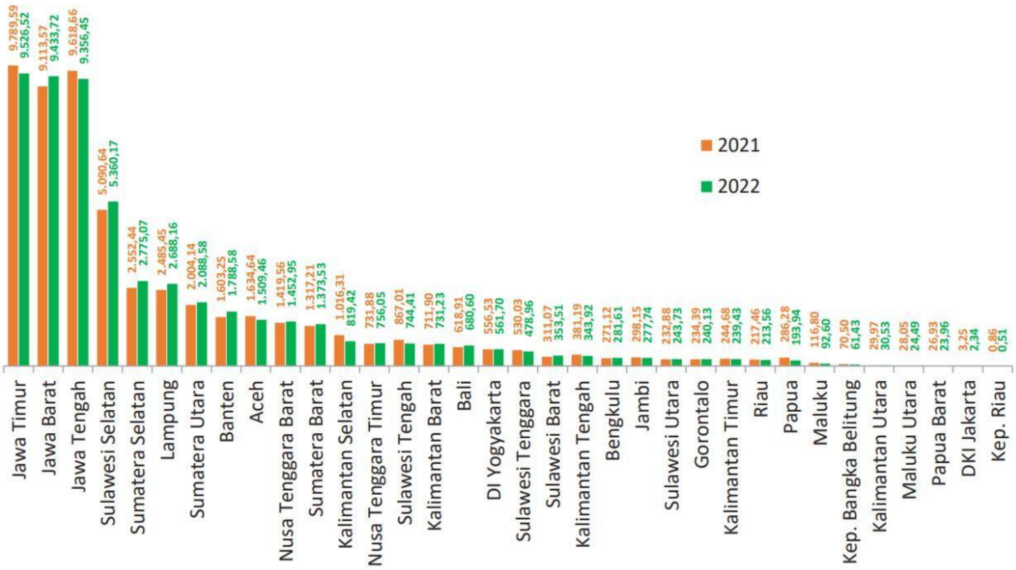


Figure 1. Data on Rice Production Quantity in Each Region of Indonesia
(Badan Pusat Statistik 2023)

## Materials and methods

The wastes are one of the renewable biomass raw materials that have great potential in producing bioenergy. The grass is the remains of the stems and leaves that remain after the harvest of grass and the processing of grass. In Indonesia, Pudding is available in abundant amounts because pudding is one of the main plants that are widely cultivated in the country.

The use of raw materials for rice straw bioenergy biomass to have important benefits. First, this will help reduce dependence on fossil energy sources that will not be renewed, such as petroleum and natural gas [9]. By utilizing rice straw as a bioenergy source, we have the potential to mitigate greenhouse gas emissions and minimize the adverse environmental impacts. In addition, processing straw to rice bioenergy can also provide economic benefits. By using this huge agricultural waste, farmers can get an additional income through the sale to plant rice straw bioenergy. It may help improve the welfare of farmers and reduce unemployment in the agricultural sector.

### 2.1 Materials

For waste paddy straw: in this journal, primary focus will be given to rice straw waste as raw material that will be discussed. The leaves are the remains of the plant, which are left behind after the harvest, like a tree, leafs, and the stalks that are not used for human consumption. Rice straw waste has significant potential as a raw material in bioethanol production, biogas, and bio-oil. In the context of bioethanol production, rice straw waste can be converted into bioethanol through a series of processes. Firstly, raw materials of rice straw are processed using enzymes such as amylase or cellulose to decipher the cellulose polymer into simple sugar. Sugar can then be fermented by certain microorganisms, like saccharomyces cerevisiae, become ethanol [9].

In addition, rice straw waste can also be used in biogas production through an anaerobic fermentation process. In an anaerobic digester, microorganisms break down the organic matter contained in rice straw waste and produce biogas as a by-product. Biogas, which contains methane ($CH_4$) and carbon dioxide ($CO_2$), acts as an environmentally sustainable energy source that can be utilized in an eco-friendly way. [10].

Furthermore, rice straw waste also has the potential to produce bio-oil through the pyrolysis process. Pyrolysis is a thermal process that utilizes high temperatures to convert rice straw waste into a liquid rich in organic compounds. This liquid, known as bio-oil, shows great potential as a renewable energy source and a valuable resource in the chemical industry, due to its ability to be produced without air or oxygen. [11]. Thus, rice straw waste has great potential in the production of bioethanol, biogas and bio-oil, so that proper management of this waste can provide significant economic and environmental benefits.

Microorganisms: Microscopic organisms, such as bacteria and fungi, play a vital role in the production of bioethanol, biogas, and bio-oil, making a significant contribution to their manufacturing processes. [12]. These microscopic organisms will be used in the process of fermentation, decomposition, or other biochemical reactions to convert rice straw waste into the desired renewable energy source.

Enzymes: In the production of bioethanol, the use of enzymes such as amylase or cellulase may be required to break down the raw materials into simpler components that can be converted through the fermentation process into bioethanol [13].

Anaerobic digester: The production of biogas entails the utilization of an anaerobic digester, a controlled environment devoid of oxygen. In this oxygen-free setting, microorganisms have the capacity to decompose the organic constituents found in rice straw waste and generate biogas [6].

Equipment or analytical instruments: In compiling journals, it may be necessary to use analytical tools or instruments to obtain the required data and information. Some examples of these tools include spectrophotometers, gas chromatographs, thermometers, pH meters, or other equipment suitable for research purposes.

### 2.2 Methods

The methods used in the production of bioenergy (bioethanol, biogas and bio-oil) from straw waste may vary depending on the context and available technology. However, there are several common methods used in converting straw waste into bioenergy. The methods used in the production of bioethanol, biogas, and bio-oil are as follows:

#### 2.2.1 Production of Bioethanol

**Simultaneous Saccharification and Fermentation (SSF) Method**

The process of Simultaneous Saccharification and Fermentation (SSF) involves the simultaneous use of hydrolysis and fermentation processes in a single container or reactor to produce bioethanol [10]. In this method, hydrolysis can be carried out chemically or biologically. Chemical hydrolysis generally uses acids such as HCl, while biological hydrolysis uses enzymes [11]. Enzymes have the ability to activate other compounds specifically and can increase the speed of chemical reactions that will last a long time if enzymes are not used [12]. The enzymes used must match the polysaccharides to be hydrolyzed. Hence, in order to convert the cellulose and starch in rice straw into simpler sugars, enzymes such as cellulase and amylase or acidic substances are introduced into the mixture of straw and water.

The process of this technique [14][17][18] starts by combining rice straw with water, along with enzymes (cellulase and amylase) or acidic substances to decompose the cellulose and starch in the straw into basic sugars. The mixture is then heated to a certain temperature to accelerate hydrolysis. After the hydrolysis is complete, yeast or *saccharomyces cerevisiae* is added to the mixture to ferment the sugar into ethanol. Both hydrolysis and fermentation processes were conducted together in a single reactor. After the fermentation is complete, the mixture is separated using a distillation apparatus to separate the ethanol from the mixture. Ethanol is then further processed to produce bioethanol which is ready for use. The SSF method offers the benefit of combining hydrolysis and fermentation processes in a single reactor, resulting in time and cost savings [13][14]. This technique can also enhance the effectiveness of bioethanol production from rice straw.

**Separated Hydrolysis and Fermentation (SHF) Method**

In contrast to the SSF method, Separated Hydrolysis and Fermentation (SHF) is a method for making bioethanol which is carried out by separating the hydrolysis and fermentation stages [15]. However, the hydrolysis carried out in this method is still the same as SSF which can be carried out chemically or biologically [16]. Stages [10][17] Separated Hydrolysis and Fermentation (SHF) in the manufacture of bioethanol from rice straw begins with the hydrolysis stage, which is heating rice straw with acidic compounds such as sulfuric acid or enzymes to hydrolyze polysaccharides into simple sugars. After that, the fermentation stage is carried out by adding yeast to a mixture of simple sugars and water to produce ethanol. The SHF method requires a longer time than the Simultaneous Saccharification and Fermentation (SSF) method, but can produce ethanol with a higher concentration [18].

### 2.2.2 Production of Biogas

**Method by Adding Rumen Fluid and Cow Manure**

Microorganisms found in the rumen fluid and cow manure can aid in the anaerobic fermentation process and enhance the production of biogas [23]. The described in this method [24], begins by combining rice straw with rumen fluid and cow dung in an anaerobic batch reactor. Additionally, the microorganisms present in the rumen fluid and cow dung will decompose the organic material in the rice straw into more basic organic compounds, such as amino acids and volatile fatty acids (VFA). In addition, methanogenic bacteria will convert VFA into methane and carbon dioxide. The methane gas produced will be captured in the reactor and can be utilized as an alternative source of energy.

### 2.2.3 Production of Bio-oil

**Pyrolysis Method**

Pyrolysis is a chemical process in which organic matter is decomposed through heat, without the presence of air or oxygen [19]. The biomass pyrolysis process typically occurs within a temperature range of 300°C to 600°C [9]. The outcome of this pyrolysis procedure is influenced by various factors, such as the temperature and rate at which it is heated [20]. The process of pyrolysis starts by heating rice straw at high temperatures without oxygen. This heat transforms the organic material in the rice straw into gases and liquids. The gas that is produced is then utilized as a source of energy to heat the remaining rice straw. The liquid that is obtained is known as bio-oil and can be employed as an alternative fuel. Bio-oil derived from the pyrolysis of biomass has a significant amount of energy and can be used as a replacement for fossil fuels [19].

## Results and discussion

### Characteristics of Rice Straw

### Bio-oil

The hydrolysis process is a crucial stage in the generation of bioethanol from rice straw, which is rich in lignocellulosic material [21]. During hydrolysis, the lignocellulose in rice straw is broken down into simple sugars through the application of specific enzymes or chemical reagents. These sugars can then be fermented by microorganisms to produce ethanol. In a study conducted by [22], rice straw was subjected to hydrolysis using cellulase enzymes to produce glucose, which was subsequently fermented into bioethanol through the saccharification and simultaneous fermentation (SSF) process. Additionally, other studies have explored the acid delignification SSF method and the separate hydrolysis and fermentation (SHF) method for bioethanol production from rice straw [17]. By combining hydrolysis processes with both aerobic and anaerobic fermentation, rice straw can be effectively utilized as a sustainable feedstock for bioethanol production.

Rice straw can also serve as an organic material in the production of biogas through an anaerobic fermentation process involving microorganisms in a biogas reactor [17]. This fermentation process decomposes the organic matter in rice straw, resulting in the production of methane ($CH_4$) and carbon dioxide ($CO_2$) as by-products [23]. Various studies have demonstrated that biogas production from rice straw can be enhanced through pretreatment methods such as the use of sodium carbonate [24] or by using various other pre-treatment methods [13]. In several studies, rice straw is mixed with other organic materials such as kitchen waste and pig manure to increase biogas production [25].

Rice straw can be used as an organic material in bioelectric production through an anaerobic fermentation process by microorganisms in a biogas reactor [26]. The bioelectric production process involves the use of microorganisms in a biogas reactor to directly generate electricity through anaerobic fermentation. These microorganisms decompose the organic matter in rice straw and produce electrons, which can be captured through electrodes in the reactor. The bioelectric production process is similar to biogas production, but with a focus on collecting electrons as electrical energi.

Rice straw can be utilized as a raw material in the production of bio-oil, a liquid fuel derived from biomass sources such as rice straw, agricultural waste, or other biomass materials. The production process of bio-oil involves pyrolysis, which is the thermal decomposition of biomass at high temperatures in the absence of air [22]. After undergoing this process, bio-oil derived from rice straw can be used as an alternative fuel to replace fossil fuels in various applications, including heating, power generation, and industrial machinery [21]. The utilization of bio-oil helps reduce dependence on fossil energy sources and contributes to lower greenhouse gas emissions [27]. In a study conducted by Maguyon-Detras et al. (2020), the potential of rice straw as a raw material for bio-oil production through pyrolysis was tested. They use a pyrolysis process with a biomass-fired reactor to produce bio-oil. The results showed that rice straw can produce bio-oil with a relatively high energy content and properties similar to fossil fuels [28].

### Technical Review of Utilization of Rice Straw to Become Bio-Oil

The utilization of rice straw as a raw material for bio-oil production has attracted significant attention as part of the efforts to develop a sustainable renewable energy source. Several studies have been conducted to explore the potential of rice straw in producing bio-oil, yielding promising results

Key factors investigated include the bio-oil yield achievable from rice straw. Chen et al. (2017) found that pyrolysis of rice straw at temperatures ranging from 500 to 600°C can yield bio-oil in the range of 40-50% [22]. These findings highlight the significant potential of rice straw as a feedstock for bio-oil production. However, it is important to note that bio-oil yields may vary depending on the processing method, operating conditions, and characteristics of the rice straw used.

In addition to yield, the quality of bio-oil is a focal point of research. Bio-oil obtained from rice straw can exhibit various properties, including energy content, stability, viscosity, and chemical composition. Rice straw pretreatment has emerged as a commonly employed strategy to enhance the quality of bio-oil. Research conducted by *Wu et al.,* (2019) using pretreatment with oxalic acid and citric acid succeeded in reducing the levels of phenolic compounds in bio-oil and increasing its thermal stability [21]. Such pretreatment can reduce unwanted compounds in bio-oil and improve the desired characteristics for fuel applications.

The potential application of bio-oil produced from rice straw is very broad. Bio-oil can be used as liquid fuel directly or converted into other fuels such as biodiesel or synthetic fuels through advanced processing. Its utilization as an alternative fuel offers advantages in terms of reducing emissions of greenhouse gases and decreasing reliance on fossil energy sources. However, along with increasing the utilization of bio-oil, it is necessary to carry out further research regarding the technical, economic and environmental feasibility of using bio-oil in various applications.

Although the utilization of rice straw into bio-oil shows promising potential, there are still some challenges that need to be overcome. These challenges include processing efficiency, cost competitiveness, scaling up production, and potential environmental impacts associated with waste treatment. The development of bio-oil technology from rice straw requires ongoing research and development efforts to enhance both yield and quality of bio-oil, as well as to minimize environmental impacts related to waste treatment.

Overall, utilizing rice straw as a raw material for bio-oil production holds great promise in supporting the transition towards renewable and sustainable energy sources. However, it is essential to continue conducting further research, improving technological efficiency, and conducting comprehensive feasibility studies to ensure successful utilization of rice straw as a raw material for bio-oil production on a larger scale.

**Bio Gas**

Besides that, the principle of zero waste is an agricultural practice that is environmentally friendly and biogas is a gas mixture produced by methanogenic bacteria that occurs in materials that can decompose naturally under anaerobic conditions. In general, biogas from rice straw consists of 50% - 70% methane ($CH_4$), 30% - 40% carbon dioxide ($CO_2$), 5% - 10% hydrogen ($H_2$), and other gases in small quantities. Methane gas produced by fermenting rice straw will contribute to the calorific value contained in biogas, between 590 – 700 kcal per cubic meter. The main source of the calorific value of biogas comes from methane gas plus a little bit of $H_2$ and CO gas. While carbon dioxide and nitrogen gas have no contribution to the heating value. From the calorific value contained, biogas can be used as a source of energy in several daily activities.

**Review of Technical Aspects**

In general, biogas energy has the potential to be developed. Several reasons are first, the production of biogas from rice straw is supported by conditions that are conducive to the development of agriculture in Indonesia. Second, regulations in the energy sector such as increases in electricity rates, increases in prices for the utilization of LPG (Liquefied Petroleum Gas), premium, kerosene, diesel oil, diesel oil, and fuel oil has fostered the advancement of alternative energy sources that are cost-effective, renewable, and ecologically sound. Third, rising prices and scarcity of inorganic fertilizers in the market due to poor marketing distribution have caused farmers to turn to using organic fertilizers. Biogas itself is easy to implement in rural areas on a household scale as a multipurpose business.

The use of biogas in rural areas is for fuel for stoves, lighting, water heaters and other uses that support small industrial activities in rural areas. While the sludge output from the digester can be used for fertilizer or flowed into fish ponds. Biogas energy can be used optimally by integrating it and using it in productive activities. So that the use of biogas energy can have a wider impact and can increase productivity, efficiency and added value to products. Thus, through this agribusiness activity is expected to create jobs and stimulate the economy in rural areas. In addition to the great potential, the use of biogas energy with a biogas digester has many advantages, namely reducing the greenhouse gas effect, reducing unpleasant odors, preventing the spread of disease, generating heat and power (mechanical/electrical) and by-products in the form of compost. The use of rice straw in this way is economically very competitive as the cost of fuel oil and inorganic fertilizers experiences an upward tren, continuation.

Methane gas production depends on input conditions (rice straw), residence time, pH, temperature and toxicity. The digester temperature ranges from 25-27°C to produce biogas with a methane gas ($CH_4$) content of around 77%. Based on the calculation of biogas production, which is 6 $m^3$/day, while the results of measurements without load show a gas flow rate of 1.5 $m^3$/hour with a pressure of 490 mm$H_2O$ (greater than expected). The use of lighting lamps requires 0.23 $m^3$/hour of biogas with a pressure of 45 mm$H_2O$ and for a gas stove requires 0.30 $m^3$/hour of biogas with a pressure of 75 mm$H_2O$. starting materials and the BOD/COD ratio is 0.37 which is smaller than the normal BOD/COD liquid waste condition which is 0.5. Meanwhile the main elements N (1.82%), P (0.73%) and K (0.41%) did not show a significant difference compared to commercial compost (containing N (1.45%), P (1.10%) and K (1.10%).

**Bioethanol**

Bioethanol is ethanol derived from biological sources. Currently, bioethanol is produced from the first generation, the raw materials are sugar/sucrose or starch. This causes intense competition among producers of food sources and is suspected as one of the causes of rising food prices [29]. Bioethanol can also be produced from second generation raw materials: organic waste, wood and forestry waste, plantation waste, and agricultural waste [30]. Bioethanol is sourced from simple sugars, starch and cellulose. After going through the fermentation process, ethanol is produced. Agricultural waste, such as rice straw, which is abundant and relatively inexpensive in Indonesia, serves as a plentiful source of cellulose, making it an ideal raw material for bioethanol production that avoids competing with food and feed sources. Unfortunately, this valuable resource often goes to waste. [31].

The primary constituents of rice straw are as follows lignin, cellulose and hemicellulose, which are known as lignocellulosic materials [32]. As a component of carbohydrates, cellulose and also hemicellulose can be degraded by microorganisms (generally by *saccharomyces cerevisiae*), resulting in bioethanol [33]. Bioconversion of rice straw into bioethanol is carried out through several processes, starting with pretreatment, hydrolysis, and fermentation. Pretreatment can be carried out physically or mechanically, either by means of pressing and rapid evaporation (steam bursting), or chemically by soaking with lime or chemicals that can open the lignin barrier for a certain period of time. After the protective lignin is 'soft', the rice straw is ready to be hydrolyzed [34].

Hydrolysis can be done by two methods, acid hydrolysis or enzymatic hydrolysis. Acid hydrolysis is carried out by cooking straw diluted in sulfuric acid at high temperature and high pressure conditions [34]. Enzymatic hydrolysis uses hemicellulose enzymes which have the ability to break down cellulose into glucose [15]. The use of enzymes is more efficient in hydrolyzing cellulose, and can be combined with a fermentation process referred to as Simultaneous Saccharification & Fermentation (SSF). There is also a Separate Hydrolysis & Fermentation (SHF) method in which enzymatic saccharification is carried out before fermentation. Hydrolysis during SHF is completed in two stages. In the first stage, most of the hemicellulose and a small amount of cellulose will be broken down into its constituent sugars, while the second stage aims to break down the remaining cellulose that is not hydrolyzed. The second hydrolysis stage is expected to obtain large amounts of sugar. The hydrolyzate obtained is fermented by anaerobic fermentation using the yeast Saccharomyces cerevisiae to convert glucose into ethanol. In theory, when one molecule of glucose undergoes fermentation, it yields two molecules of ethanol and two molecules of $CO_2$. Consequently, it is estimated that one kilogram of glucose will generate approximately 0.51 kilograms of ethanol and 0.49 kilograms of $CO_2$. [35].

## Conclusions

The rice straw waste is a byproduct of rice processing and is a plentiful natural resource in Indonesia. Rice straw waste has been developed as an alternative bioenergy source that can reduce dependence on fossil fuels and help address global energy issues. The waste generated from rice straw contains valuable constituents that can be harnessed as raw materials for the production of bioenergy. It consists of various organic compounds, such as 36.6% cellulose, 25.3% hemicellulose, and 14.3% lignin. Through processes like fermentation and pyrolysis, these compounds can be transformed into different forms of bioenergy, including bioethanol, biogas, and bio-oil. The production of bioethanol can be carried out using SSF (Simultaneous Saccharification & Fermentation) and also SHF (Separate Hydrolysis & Fermentation) methods. Biogas can be produced by adding rumen fluid and cow dung, while bio-oil can be obtained through pyrolysis. Utilizing bio-oil as a substitute fuel offers advantages such as reducing greenhouse gas emissions and decreasing reliance on fossil fuel energy sources. The explanations provided clearly demonstrate that rice straw can be effectively employed as a sustainable bioenergy resource.

## Acknowledgements

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