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Comprehensive Study on the Supply Chain of Vacuum Thermal Cracking System for Sustainable Development: A Case of Waste-to-Energy and Resource Recovery.

Ho-Hsiang Lin *

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Abstract

The purpose of this study is to explore the possibility of applying a new technology, vacuum heating technology, to waste-to-energy and resources, and to explore the completeness and feasibility of its supply chain system. First, we'll take a closer look at the implications of vacuum heating technology and its past experience. Second, we will explore ways to convert waste into energy and resources, with a focus on the potential of this technology for sustainable development. Taking Taiwan as a case study, the results of this study show that the vacuum thermal decomposition system can be successfully applied to the recycling and reuse process of agricultural waste, and then generate a generator built into the system, and use the thermal structure to form the final production process. This not only results in the generation of four high-value goods, but also significantly increases the value of the entire system. From a sustainability perspective, such systems have the potential to have a positive impact and can play a positive role in promoting clean energy and resource recycling. However, in the process of promotion, there are still some challenges in supply chain management and the promotion of raw material markets. Successful promotion relies on the efforts of the operator, including active participation in the establishment and promotion of the supply chain, to ensure the viability and sustainability of the system. This study provides insight into the potential of vacuum heating technology in the field of waste treatment and energy recovery and provides a preliminary discussion of the feasibility study.

Keywords: Waste Energy Recovery, Resource Recovery, Vacuum Pyrolysis System, Supply Chain Management, Sustainable Development

*Corresponding; Researcher, Yung Chun Technology Co. Ltd. Taiwan, E-mail: hohsianglin23388@gmail.com

Introduction

Background

The main reason for the gradual increase in global temperature has been due to the global climate change caused by greenhouse gas emissions from combustion (Short & Neckles, 1999). To tackle this challenge, countries around the world actively promote energy conservation and carbon reduction measures and set goals in the direction of carbon footprint and minimum carbon emissions of various industrial processes (Huisingh et al.,2015).

In addition to reducing unnecessary resource consumption, we also need to focus on ways to effectively recycle and reuse waste and its environmental impact. This issue should be considered seriously, while we come up with feasible solutions, and think about how to effectively recycle waste. This is an important topic that requires in-depth investigations.

At present, the world is facing the problem of garbage disposal, with mountainous garbage being dumped over places, and agricultural waste is also causing a waste of resources during their treatment processes. Meanwhile, additional external energy may be needed for such treatment. This not only leads to the unnecessary waste of resources but also exacerbates the energy shortage we are facing, forming a double burden on society.

To improve this situation, we need to think about more efficient waste disposal methods, especially for agriculture to maximize resource recovery and reduce dependence on external energy sources. Such measures can not only alleviate the pressure of waste disposal but also help to mitigate energy shortages and provide a substantial contribution to the sustainable development of society.

Current Situation and Problem Presentation

Environmental experts and academics are urgently looking for new technologies to solve the combined challenges of environmental protection and energy. According to Taiwan's Environmental Protection Agency, in 2022, Taiwan's general waste reached 11.8 million tons, of which about 47.09 million tons were general waste, 6.57 million tons were recyclable waste, and another 4 million tons were food waste. These are available resources that we need to use effectively to protect the planet (MOE, 2024).

This study focuses on the application of a new technology, a vacuum pyrolysis system. This system can make the disposal of Taiwan's garbage a non-toxic and harmless process, generating 250 GWh of green electricity capacity per year. According to the Council of Agriculture, agricultural waste has a huge potential resource in Taiwan, can this agricultural waste also generate more green electricity?.

The operation of the vacuum pyrolysis system includes the reuse of waste and agricultural waste, reducing pollution sources, achieving carbon reduction effects, and promoting the generation of green electricity. This will translate the negative effects of the entire industrial production into positive ones while maximizing the value of the waste itself. By operating such a system, we can not only solve environmental and energy problems but also contribute to the sustainable use of resources (Parku et al., 2020).

Research Objectives

The main objectives of this study are as follows:

A. Discuss the technology of the vacuum pyrolysis system

B. Understand the main content of the vacuum pyrolysis system supply chain

C. Discuss possible problems in the supply chain of the vacuum pyrolysis system

D. Understand the impact of vacuum pyrolysis system on sustainable development

Research Questions

In this study, the following two research questions will be explored:

A. Whether the vacuum pyrolysis system supply chain is viable

B. Can the vacuum pyrolysis system supply chain have a positive impact on sustainable development?

Contribution to the Study

Due to global environmental change and climate warming, energy conservation and carbon reduction have become issues that environmental scientists are actively solving. The purpose of this study is to explore whether it's practical and feasible to use a vacuum pyrolysis system for waste-to-energy recovery. If it can be proved that this system has significant energy saving and carbon reduction benefits in practical application, it will have a positive and far-reaching impact on solving the problem of environmental pollution

Literature Review

Vacuum pyrolysis system

A vacuum pyrolysis system is a technology for chemical cracking at high temperatures and under vacuum conditions. It is typically applied to the treatment of organic substances, including municipal waste, biological resources, or fossil fuels, to produce useful products, such as energy or chemical feedstocks (Barth et al., 2004).

In addition, the vacuum pyrolysis system is also an organic synthesis technology, which breaks down organic substances into monomers and oligomers by heating them to high temperatures under vacuum conditions. This technique can be applied to the manufacture of nanoparticles, zirconia, and oxides. For example, a vacuum pyrolysis furnace can be used as a thermal cleaning system to remove organic polymer plastics and residual black carbon from heat-resistant metal parts under vacuum conditions using the principles of hot melting, pyrolysis, and oxidative carbon removal.

Technical content of vacuum pyrolysis system

In a vacuum pyrolysis system, the substance is subjected to high-temperature treatment in a vacuum environment, which helps to prevent the presence of oxygen and thus avoid complete combustion. Normally, high temperatures and vacuum cause organic matter to decompose into gases, liquids, and solid products.

These products can be further used to generate electricity, produce fuels, make chemical feedstocks, or other products.

Table 1 The main technical contents of the vacuum pyrolysis system

serial number	Technical content	description
1	High-temperature treatment	The system uses high temperatures, often above hundreds of degrees Celsius, to prompt the decomposition of organic matter into simpler molecules or monomers.
2	Vacuum conditions	Cracking in a high vacuum, i.e. decompression operation, helps to prevent the presence of oxygen and thus complete combustion for specific chemical transformations.
3	Organic matter decomposes	Organic substances are decomposed into monomers, oligomers or gases in a high-temperature and high-vacuum environment. This makes it possible to recover useful chemicals from waste or biological resources.
4	Energy recovery	The system is able to use the heat or gas generated during the cracking process for energy recovery, improving the energy efficiency of the system.

How to use a vacuum pyrolysis system to treat waste and recover energy

Waste-to-energy technologies, including incineration, biomass utilization, methane gasification, etc (Hameed et al., 2021). Vacuum pyrolysis systems have a wide range of applications, including waste treatment, energy recovery, and the chemical industry. One of the advantages of this technology is its ability to handle multiple types of raw materials while reducing the need for finite natural resources, helping to promote environmental sustainability.

In terms of manufacturing, vacuum pyrolysis systems are widely used to produce products such as nanoparticles, zirconia, and oxides (Tsai et al., 2004). At the same time, in the industrial field, its application as a thermal cleaning system enables it to effectively remove organic polymer plastics and residual black carbon from heat-resistant metal parts.

In addition, vacuum pyrolysis systems are not only used to manufacture nanoparticles, zirconia, and oxides but are also used in thermal cleaning, using the principles of hot melting, pyrolysis, and oxidative carbon removal under vacuum conditions to remove organic polymer plastics and residual black carbon from heat-resistant metal parts. In terms of waste treatment, pyrolysis technology can convert waste into energy such as oil and gas. For example, waste plastics can be converted into products such as fuel oil, gas, and solid charcoal after thermal cracking. In addition, pyrolysis technology can also be used to treat waste rubber, waste rubber tires, waste wood, etc.

Supply chain management.

What is supply chain management?

Supply chain management is a management approach that aims to coordinate and optimize the flow of materials, information, and capital across multiple businesses (Cox,1999). It includes the effective management of material (product) flows, information flows, and capital flows. The main goal of supply chain management is to ensure that the right products are delivered to the right place at the right time, in the right quantity, in the right quality, and in the right condition. Through supply chain management, companies can improve production efficiency, reduce costs, and improve product quality, thereby enhancing their competitiveness.

Building a waste-to-energy vacuum pyrolysis system is challenging. From sourcing waste as a feedstock to establishing superior engineering know-how, to effectively marketing finished products, including energy and activated carbon, the entire process needs to be well coordinated (Cao et al., 2001). Therefore, when discussing how to build such a waste-to-energy vacuum pyrolysis system, we first need to carefully analyze its supply chain.

How is the supply chain of a vacuum pyrolysis system composed?

Here are some of the major parts that may make up the vacuum pyrolysis system supply chain:

The supply chain of a vacuum pyrolysis system consists of multiple parts that work together to ensure that the system operates smoothly and efficiently. Below are some of the major parts that may make up the vacuum pyrolysis system supply chain:

Table 2 The main segments of the vacuum pyrolysis system supply chain

serial number	Supply chain components	description
1	Raw material supply	This includes obtaining the waste or organic matter required by the pyrolysis system as a feedstock. Ensuring a reliable and stable supply of raw materials is the cornerstone of a successful supply chain.
2	Engineering & Manufacturing	Including the design, manufacture and technical support of vacuum pyrolysis system. Expertise is required to ensure the effectiveness and safety of the system.

Table 2 (Continued)

serial number	Supply chain components	description
3	Equipment Vendors	Provide all kinds of equipment and technical equipment required for vacuum pyrolysis system, such as pyrolysis furnace, vacuum device, control system, etc. The choice of partner is critical to the functioning of the system.
4	Technical Support & Services	Provide technical support and services required for system installation, commissioning, maintenance, and upgrades. It helps to ensure the long-term stable operation of the system.
5	Energy recovery and utilization	Treat the energy generated by the system to enable the recovery and efficient use of energy, such as power generation or supply to other industrial processes.
6	Marketing and sales of finished products	Bring system-manufactured finished products (such as energy and activated carbon) to market, market and sell them to ensure that the value of the finished product is fully realized.
7	Environmental Compliance & Regulation	Comply with relevant environmental regulations and regulatory standards to ensure that the operation of the vacuum pyrolysis system meets regulatory requirements and contributes to environmental sustainability.

This table collates the different parts of the vacuum pyrolysis system supply chain, as well as the main parts of each part, which together form the supply chain of the vacuum pyrolysis system, and the effective collaboration of each part is the key to achieving the efficient operation and sustainable development of the system.

Sustainable development

What is the significance of sustainable development?

Sustainable development is a development model that aims to meet the needs of the present without compromising the needs of future generations. In 2015, the United Nations announced the Sustainable Development Goals (SDGs) by 2030. There are 17 core goals, extending to 169 targets and 230 indicators, guiding global efforts to achieve sustainable development. These goals include, but are not limited to, 12 areas, including poverty eradication, climate change mitigation, and the promotion of gender equality. The United Nations expects that by 2030, the world will be able to achieve these goals and promote sustainable development (Persaud & Dagher, 2021). The following are the 17 core goals of the SDGs:

Table 3 United Nations 2030 Sustainable Development Goals

serial number	target	Specific projects
1	Eradication of poverty	Achieve economic and social development on a global scale and ensure equal economic opportunities for all
2	End hunger, achieve food security, improve nutrition and promote sustainable agriculture	Achieve food security, improve agricultural production and ensure adequate nutrition for people
3	Ensuring health and promoting well-being for all ages	Improve global health and ensure that everyone has access to timely and equitable health care
4	Ensure that education is inclusive, equitable and of high quality, and promote learning	Promote global education and ensure access to quality education for all
5	Achieve gender equality and empower women	Eliminate all forms of gender discrimination and promote women's rights to participate in social, economic and political affairs
6	Ensure access to water and sanitation for all and its sustainable management	Ensure access to safe drinking water and basic sanitation for all, and achieve sustainable water management
7	Ensure access to affordable, reliable, sustainable and modern energy for all	Promote global access to energy and promote the use of renewable energy
8	Promote inclusive and sustainable economic growth so that everyone has a good job	Promote global economic development and achieve full employment and economic growth
9	Build resilient infrastructure, promote inclusive and sustainable industries, and accelerate innovation	Develop global infrastructure and promote industrial upgrading and innovative development
10	Reducing inequality within and between countries	Reducing economic and social inequalities across regions and populations

Table 3 (Continued)

serial number	target	Specific projects
11	Build inclusive, safe, resilient and sustainable cities and villages	Develop urban and rural planning, improve the quality of the living environment, and achieve inclusive development of urban and rural areas
12	Promote a green economy and ensure sustainable consumption and production patterns	Promote sustainable consumption and production to achieve efficient use of resources and environmental protection
13	Develop mitigation and adaptation actions to address climate change and its impacts	Take effective measures to combat climate change and reduce its negative impacts
14	Conservation and sustainable use of marine ecosystems to ensure biodiversity and prevent degradation of the marine environment	Protect the marine ecosystem, prevent marine pollution, and ensure the sustainable use of marine resources
15	Conserve and sustainably use terrestrial ecosystems to ensure biodiversity and prevent land degradation	Protect terrestrial ecosystems, prevent land degradation and ensure ecological diversity
16	Promote peaceful and pluralistic societies, ensure judicial equality, and build a credible and inclusive system	Promote peace, justice and justice, and build an inclusive and pluralistic social system
17	Establish multiple partnerships to promote a sustainable vision	Strengthen global cooperation, build diversified partnerships, and achieve the common goal of sustainable development

The impact of vacuum pyrolysis systems to treat waste and recover energy on sustainable development.

Vacuum pyrolysis systems are used to treat waste and recover energy, which can have multiple positive impacts on sustainable development, some of which include: resource reuse, energy recovery, waste pollution reduction, climate change mitigation, technological innovation and employment opportunities, and compliance with sustainable development goals, as shown in the table below.

Table 4 The impact of vacuum pyrolysis system to treat waste and recover energy on sustainable development

serial number	Influence the project	description
1	Resource reuse	Vacuum pyrolysis systems are able to convert waste into useful products such as energy and activated carbon to maximize the reuse of resources and reduce the demand for natural resources.
2	Energy recovery	The system generates heat energy by pyrolyzing waste, which realizes energy recovery. It helps to reduce dependence on traditional energy sources and improve energy efficiency while reducing greenhouse gas emissions.
3	Reduce waste pollution	By turning waste into useful products, vacuum pyrolysis systems help reduce waste accumulation and environmental pollution. In line with the requirements of the Sustainable Development Goals on environmental protection and resource management.
4	Climate change mitigation	Through energy recovery and reduction of greenhouse gas emissions, vacuum pyrolysis systems help to mitigate the effects of climate change, in line with the requirements of the Sustainable Development Goals on climate action.
5	Technological innovation and employment opportunities	Promoting the application of vacuum pyrolysis technology may lead to technological innovation, while creating new jobs and promoting economic development.
6	In line with sustainable development goals	By addressing the twin challenges of waste treatment and energy recovery, vacuum pyrolysis systems contribute to the achievement of the United Nations 2030 Sustainable Development Goals, especially those on clean water and sanitation, sustainable cities and communities, and responsible production and consumption.

Research Methods

Literature Search

First, previous relevant studies and literature will be analyzed to understand the existing knowledge of the vacuum pyrolysis system supply chain and sustainable development and to establish the theoretical basis for the research.

Database Analysis

Secondly, this study will search for technical information related to the supply chain of vacuum pyrolysis systems from the existing database.

Case Studies

In this study, we will use a case study in Taiwan to analyze the possible benefits of the system.

Results and Discussion

Results and analysis of research data

Vacuum thermal, pyrolysis system

A typical vacuum pyrolysis system is applied in Taiwan, as shown in the figure below.

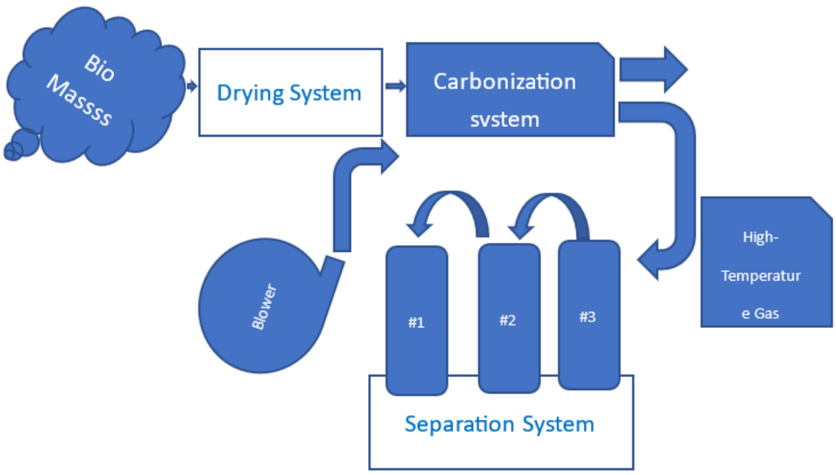

Figure 1 Typical Vacuum thermal pyrolysis system

The system in the above diagram includes the biomass feed section, drying system, carbonization system, high-temperature gas discharge, and separation system (Ju et al.,2018).

Waste-to-energy and resource reuse systems

The conversion of waste into energy and resource reuse is an important feature of the system. Due to the built-in self-circulating power generation mechanism, the system can provide the power required by the pyrolysis equipment (Bishoge et al., 2019).

In a typical system applicable to Taiwan, biomass waste is used as raw material to achieve a heat recovery rate of more than 70% at a high temperature of 900℃. The methane produced during the cracking process is recycled for power generation, while the carbonaceous residue from the final product is converted into activated carbon, which becomes a high-value commodity.

Such a system demonstrates innovation in environmental management, reducing dependence on natural resources through efficient heat recovery and resource reuse, while at the same time bringing substantial improvements to the ecological environment and energy efficiency.

During the pyrolysis process, the methane produced can be used to drive a generator to generate electricity. After vacuum cracking, bio-organic waste is converted into activated carbon, which can be reused, enabling the entire system to achieve the goal of a circular economy.

Figure 2 shows the entire system of using pyrolysis equipment for waste to energy and resource reuse.

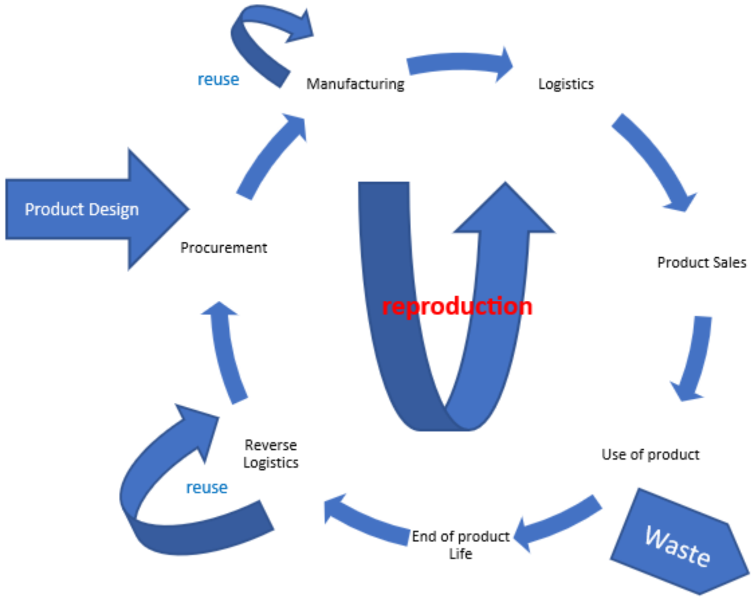

Figure 2 shows the entire system of using pyrolysis equipment for waste to energy and resource reuse

Discussion

Possible problems faced by the supply chain of vacuum pyrolysis system

Possible issues in the vacuum pyrolysis system supply chain include the following, as shown in the table below:

Table 5 Possible issues in the vacuum pyrolysis system supply chain

issue	description
The supply of raw materials is unstable	The supply of waste or organic substances as raw materials is subject to market fluctuations, regulatory changes, etc., which may lead to supply instability.
Technical equipment supply risk	The technical equipment required for the system may be dependent on a specific supplier, and its reliability, delivery time, and price fluctuations may affect the stability of the supply chain.
Cost pressures	Changes in the cost of technical equipment, raw materials and related services can have an impact on the economic performance of the supply chain, requiring effective cost management and risk control.
Technical support and maintenance challenges	Technical support and maintenance of the system is challenging, especially when it comes to resolving technical issues, providing real-time support, and ensuring the long-term operation of the system.

Table 5 (Continued)

issue	description
Technical support and maintenance challenges	Technical support and maintenance of the system is challenging, especially when it comes to resolving technical issues, providing real-time support, and ensuring the long-term operation of the system.
Regulatory compliance risk	Changes in environmental regulations and regulatory standards can affect the compliance of systems and require constant adaptation and compliance with relevant regulations.
Difficulties in marketing and sales	Promoting and selling finished products manufactured by systems can face market acceptance, competitive pressures, and marketing challenges that require an effective marketing strategy.
Environmental and social responses	The heightened focus on environmental issues can create social and environmental pressures that require greater sustainability and environmental responsibility.
The speed of technological innovation	The rapidly evolving technology environment can make technology obsolete, and supply chains need to constantly keep up and adopt new technologies to stay competitive.

Whether the vacuum pyrolysis system supply chain is viable

To ensure the stable operation of the vacuum pyrolysis system supply chain, the operations team needs to have an effective supply chain management strategy, which includes risk assessment, partner relationship management, technology refresh, regulatory compliance monitoring, and marketing strategy.

Attempts to convert waste to energy using vacuum pyrolysis systems are feasible, and although there are several difficulties mentioned above, these problems can be solved by technology. Vacuum pyrolysis systems are not difficult to process waste-to-energy or resource-based technology, but achieving continuous operation requires consideration of many factors, such as risk assessment throughout the supply chain, management of partners, the ability to continuously update technology, and changing regulations.

The smooth operation of the entire supply chain can be largely decided by two driving forces: manufacturing and commercial. The manufacturing supply chain includes circular supply and resource recovery, while the commercial side includes product life extension, shared platforms, and product services.

Can the vacuum pyrolysis system supply chain have a positive impact on sustainable development?

This system has a clear positive impact on environmental sustainability. The advantage of the system is that it is in line with the trend of environmental protection, can realize the reuse of resources, and reduces the secondary damage to the environment. This achievement is due to the self-circulating energy characteristics of the system, which can provide the required electrical energy for the pyrolysis plant.

During the pyrolysis process, the methane produced can be effectively used for gas-fired power generation, further reducing the need for traditional energy sources. The carbonaceous residue can be used as high-value activated carbon, opening up more possibilities for commercial applications.

Overall, the contribution of this system to environmental protection cannot be ignored. It not only effectively reduces energy consumption, but also realizes the transformation of waste into valuable products, promoting the process of environmental sustainability.

Since 2022, all listed companies in Taiwan have been required to implement carbon inventory as a standard for social corporate responsibility (ESG). Waste is regarded as one of the main sources of carbon emissions, so if waste can be effectively disposed of, it is expected to achieve ESG goals and meet the company's social responsibility commitment.

Conclusions and Recommendations

Conclusions of the Study

From the above study, we have derived the following conclusions. Firstly, the vacuum cracking equipment system is an effective waste conversion technology, capable of reducing carbon emissions and achieving energy recovery. Therefore, it has the potential to reduce environmental impact and, at the same time, enhance resource utilization efficiency. Secondly, in terms of sustainable development goals, this technology can be an effective means to promote the development of a circular economy.

Recommendations of the Study

Here are suggestions for future research:

It is recommended that future researchers delve into the challenges faced by supply chain management in practical applications, particularly addressing issues related to promoting raw material markets and the roles of operators.

Provide recommendations for future supply chain system managers to ensure the sustainable operation of the system. This includes regularly monitoring technological advancements, conducting cost-benefit analyses, formulating corresponding policy support, and actively participating in social engagement strategies. These suggestions contribute to a deeper understanding of the challenges and opportunities of the vacuum cracking equipment system in practical applications. They also provide valuable guidance for future research and implementation.

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