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(54) **Title:** SUSTAINABLE WASTE MANAGEMENT SYSTEM OF BIO-CIRCULAR TECHNOLOGY INVOLVING A MICROBIAL CONSORTIUM

(57) **Abstract:** The invention relates to an integrated, holistic, and cyclical waste treatment system for processing solid (12), liquid (16), and gaseous (18) waste streams of organic and inorganic origin. The system (10) primarily ferments solid waste (12) with a selected microbial consortium liquid (14), producing an amorphous solid product (31) and hydrogen-rich gas (32) in a thermo-chemical reactor (30). This solid product (31) is fed into the wastewater treatment unit (40) and the carbon capture unit (50) for processing liquid and gas waste respectively, resulting in a valuable intermediate solid product (55) that synergistically enables production of hydrogen-rich gas (62) and nanoparticles (61) in an inert reactor (60). The entire system (10) operates on zero-emission, zero-waste principles, provides higher gas/energy output than traditional waste energy technologies, and generates value-added products and nanomaterials for various industrial applications.

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DESCRIPTION

SUSTAINABLE WASTE MANAGEMENT SYSTEM OF BIO-CIRCULAR TECHNOLOGY INVOLVING A MICROBIAL CONSORTIUM

TECHNICAL FIELD

The present invention relates to waste treatment and management processes and energy production, in order to provide a sustainable and ecological structure to re-establish air-water-soil balance. The invention particularly relates to an integrated, holistic, and cyclical system and process operating under a zero waste - zero emissions principle, for the treatment of solid, liquid, and gaseous waste of organic and inorganic origin while simultaneously generating hydrogen-rich gas, clean water, clean air (decarbonization) and environmentally and economically beneficial nano materials as outputs from the waste materials.

BACKGROUND OF THE INVENTION

Waste management has become a significant global challenge due to the ever-increasing amounts of waste generated by human activities and industrial processes, as well as the non-integrated nature of current waste management processes.

Conventional waste treatment methods, are often focused on addressing specific types of waste materials and are generally limited in their ability to treat a wide range of waste sources. Landfills, incineration, composting, and conventional waste-to-energy (WTE) technologies have been widely used to manage solid waste. However, these methods can have significant environmental impacts, such as greenhouse gas emissions, air pollution, the generation of toxic byproducts and inadequate resource recovery, contributing to climate change and threatening the whole living beings. Additionally, these methods often require extensive pre-processing of waste materials and are energy-intensive.

In the case of liquid and gaseous waste treatment, technologies like biological and chemical treatment processes, adsorption, and membrane filtration have been applied. However, these methods can be expensive, require high energy input, and generate secondary waste products that require further treatment or disposal.

Several prior art technologies have attempted to address the problem of waste management and resource recovery. For instance, anaerobic digestion (AD) is a widely employed technology for treating organic waste materials, such as food waste, agricultural waste, and sewage sludge. AD harnesses the activities of a diverse group of microorganisms to decompose organic matter and produce biogas, which primarily consists of methane and carbon dioxide. While AD is effective in treating organic waste and generating biogas, it is not suitable for handling inorganic waste materials and may not efficiently convert waste into valuable products.

Thermochemical processes, such as pyrolysis and gasification, have also been explored for waste treatment and resource recovery. Pyrolysis involves the thermal decomposition of waste materials in an inert atmosphere without oxygen, producing solid char, liquid oil, and gaseous products. Gasification, on the other hand, involves the partial oxidation of waste materials under high temperatures to produce synthesis gas, or syngas, which mainly consists of hydrogen and carbon monoxide. Although these thermochemical processes can handle a wide range of waste materials, including organic and inorganic waste, their efficiency and the quality of the products produced can be highly variable, depending on the input waste composition and process parameters. While they offers a promising alternative to traditional waste management methods, these processes often involve high temperatures, lengthy processing times, produce non-beneficial and environmentally harmful outputs, and require energy-intensive and costly operations.

Several studies and patents are available on the use of microorganisms for waste treatment and resource recovery, including US 5,464,539 A for instance, which discloses a method for producing hydrogen gas from organic waste materials using microorganisms. Likewise, WO 2015/188245 A1, describes embodiments for the use of microbial consortia for the treatment of waste materials. However, these prior art technologies typically focus on the biological decomposition of organic waste materials and do not address the challenges associated with the treatment of inorganic waste materials and the efficient recovery of valuable products.

Furthermore, the prior art technologies may not be robust enough to handle toxic or recalcitrant waste materials, as many microorganisms are sensitive to environmental stressors, such as high concentrations of heavy metals, toxic chemicals, and extreme pH levels.

In any case, it is unlikely to see a conventional process utilizing successfully a new generation green and circular biotechnology that decomposes all types of organic and inorganic wastes irrespective of states thereof, i.e. in the solid, liquid and/or gas form, and promising valuable products therefrom, as well.

Therefore, there exists a growing need for more efficient and environmentally friendly waste treatment methods that can process efficiently various types of waste materials while producing valuable products. Such methods should minimize harmful emissions, reduce energy consumption, and generate useful byproducts that can be used in various applications. Moreover, the ideal waste treatment solution should be modular, integrated, and adaptable to different waste streams and operating conditions and create a circular green ecological life and economy.

BRIEF DESCRIPTION OF THE INVENTION

The present invention refers to a waste treatment and management system for the processing of solid, liquid, and gaseous waste streams of organic and inorganic origin, and to valuable intermediate products obtained therefrom.

The primary object of the present invention is provide an integrated waste treatment system that effectively converts all solid-liquid-gas wastes of organic and inorganic origin into valuable products, while also operating under a zero-emission and zero-waste principle.

Another important object of the invention is to provide an integrated, efficient and sustainable process of the waste treatment and management combining microbial fermentation, thermo-chemical reactions, and carbon capture technologies while simultaneously generating hydrogen-rich gas, clean water, decarbonization and environmentally and economically beneficial and valuable outputs, nano materials from the waste materials.

A further object of the invention is to provide a waste treatment system that produces significantly more gas/energy output than conventional waste-to-energy (WTE) technologies, while also effectively capturing and removing both inorganic and organic contaminants from the waste stream.

Yet, another object of the invention is to provide a novel and effective solution for waste management and resource recovery that can be advantageously and cost effectively customized and scaled to fit the needs of various industries, contributing to the development of a new generation green and circular biotechnology, circular life, circular economy and a more sustainable future.

In order to achieve the said objects of the invention, there is provided an integrated waste treatment and management system for the processing of solid, liquid, and gaseous waste streams of organic and inorganic origin, comprising the following processing units and steps :

- Mixing solid waste of any type, organic and inorganic origin with an aqueous microbial polymeric consortium and fermenting the waste mixture at a fermentation unit under controlled conditions for a short period of time;

  wherein the said controlled conditions of fermentation involve an aerobic environment, solid particle size of maximum 5cm, preferably 1-3 cm, mixing-fermentation duration of maximum 15 *min, preferably 7-10 min., regardless of pressure and PH, a temperature range of 25 to 45°C, moisture content of up to 80% and ambient humidity levels of 50 to 70%,*

wherein said microbial polymeric consortium fluid comprises a first group comprising mainly Pseudomonas and Bacillus species, a second group comprising at least two of Cyanobacteria, Rhodococcus, Mycobacterium and Actinomycetes species, and a third group comprising at least two of Clostridium, Methanobacterium and Acidithiobacillus species; the distribution ratio ranges of the groups in the total relative to each other are preferably 10-20%, 20-40% and 50-70%, respectively, the weight ratio of the said consortium liquid is at most 2%, preferably 0.3%-1.5%, and more preferably 0.5%-0.8% of the total waste mixture amount.

- Subjecting said fermented mixture to heat treatment so as to have a moisture content of at most 20%,

- Feeding the fermented mixture into a thermo-chemical reactor to undergo a series of bio-chemical and pyrolysis reactions,

  wherein the said reactions involve thermal depolymerization, lignin pyrolysis, cellulose pyrolysis and, enzymatic reactions, organic substances are decomposed and inorganic molecules are provided to form reduction and oxidation reactions with the catalyst effect of the said consortium liquid enzymes, and there exists no aqueous media reactions such as hydrolysis,

  wherein operating parameters of the reactor involve temperatures of 100 to 700°C, pressures of 1 to 12 atm and residence times ranging from 0.5 to 2.5 hours,

- Obtaining preferably an amorphous solid product and a hydrogen-rich gas containing at least 35% H_2 (in mole quantities) from the thermo-chemical reactor.

  wherein said hydrogen-rich gas corresponds to 40-55% by weight of the total amount fed to the reactor, the amorphous solid product to 35-50%, and the reactor liquid to 3-12%,,

  wherein the amorphous solid product is fed separately to the carbon capture unit for the processing of all kinds of gaseous wastes (flue gases) of organic and inorganic origin, and to the waste water treatment unit for the processing of all kinds of liquid wastes

  wherein the amorphous solid product is fed separately, in the subsequent process stages, to the carbon capture unit for the treatment of all kinds of gaseous wastes (flue gases) of organic and inorganic origin, and to the waste water treatment unit for the processing of all kinds of liquid wastes.

The amorphous solid product (31) obtained through thermochemical processes according to the invention is a regular and homogeneous product with a high carbon content, a wide surface area and highly porous structure, and the number of active centers thereof is very high. The composition of the amorphous solid product (31) may vary depending on the input materials and the operating conditions of the reactor (30), but typically consists of the following:

- Organic Components (89% - 91%): A significant portion of this content consists of amorphous and graphitized carbon forms. This carbon fraction may include various carbon-based compounds derived from organic materials such as tar residues.
- Inorganic Components (6% - 8%): Typically, it may include components such as SiO_2, Fe_2O_3, Al_2O_3 and CaO. Of these components, SiO_2 is present in a concentration range of 2-4%, while others are generally found in a range of 1-2%.
- Other Components (0,5% - 2%): This category includes components with lower concentrations such as Na_2O, MgO, SO_3, Cl, K_2O and TiO_2. Each of these components is present in a concentration range of 0,1-1%.

According to the invention, the process also comprises the following steps:

- Feeding any kind of organic and/or inorganic liquid waste along with the amorphous solid product, special salts, and, if necessary, the flue gas exiting the thermochemical reactor to a wastewater treatment unit to produce deionized clean water and a second solid product.
- Feeding any kind of organic and/or inorganic flue gases (gaseous waste) along with the amorphous solid product, and, if necessary, the flue gas from the thermochemical reactor (and other reactors in the system) to a carbon capture unit to remove gaseous pollutants and generate a third solid product.
- Feeding the valuable solid product obtained by the simple physical mixture of the second and third solid products into an inert reactor under specific conditions to produce additional hydrogen-rich gas and nano powders.

The nano-powders so obtained can be utilized for various applications, such as composite materials, additives and surface coatings to obtain new generation materials.

The process according to the invention provides a new generation green and circular biotechnology that decomposes all types of organic and inorganic wastes in a sequential and holistic reaction chain, utilizing a new consortium of microorganisms with a variety of functional structures, to discover, adsorb, decompose and ionize all organic and inorganic wastes – in solid, liquid or gas form.

The reaction chain of the process according to the invention recovers efficiently essential products such as hydrogen-rich gas, carbon capture, deionized clean water and invaluable intermediate products, by combining unexpectedly and advantageously the benefits of the microbial decomposition with thermochemical processes such as pyrolysis and bio-reactions along with waste preprocessing, mixing, fermentation, moisture reduction, carbon capture, wastewater treatment, and utilization of the produced hydrogen-rich gas, and valuable solid materials.

These and other aspects, structural and characteristic features, advantages, and embodiments of the present invention will become more apparent from, and will be understood more clearly by reference to the following detailed description, examples, and associated figures.

BRIEF DESCRIPTION OF THE DRAWINGS:

Figure 1: Flowchart of the integrated waste treatment process, illustrating the various process steps and units according to the invention.

EXPLANATION OF REFERENCES IN FIGURES

10 Integrated waste treatment and management system

- 12 Solid waste
- 14 Microbial consortium liquid
- 16 Wastewater
- 18 Flue gases

20 Mixing and fermentation unit

- 21 Fermented mixture

30 Thermo-chemical reactor

- 31 Amorphous solid product
- 32 Hydrogen rich gas

40 Wastewater treatment unit

- 41 Second solid product
- 42 Deionized clean water

50 Carbon capture unit

- 51 Third solid product

55 Valuable solid product

60 Inert reactor

- 61 Nano-powders
- 62 Hydrogen rich gas

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 illustrates a simplified process flowchart for the integrated waste treatment and management system (10) of the present invention. The system (10) includes several process steps and units that can receive and process various types of waste, including solid, liquid, and gas forms of organic and inorganic origin (12,16,18). The solid waste (12), which has been reduced to specific particle sizes, is initially treated with a microbial consortium liquid (14) to ensure efficient outcomes in subsequent processing steps. The primary components of the system are as follows:

Microbial Fermentation Unit (20): The system (10) utilizes a microbial polymeric consortium (14) to treat and break down solid waste (12) previously reduced to particle sizes of preferably less than 3 cm. The waste (12) is mixed with the microbial consortium liquid (14) under controlled conditions, particularly at specific moisture levels, to produce a biomass-like product (fermented mixture) (21) with a maximum moisture content of 20%.

Thermo-Chemical Reactor (30): The fermented mixture (21) is fed into a thermo-chemical reactor (30), where it undergoes a predetermined set of bio-chemical and pyrolysis reactions. These reactions occur at specific time intervals, temperature-pressure ranges, electromagnetic field effects, and mixing rates. Some of the key reactions involved in this process are thermal depolymerization, pyrolysis, lignin pyrolysis, and cellulose pyrolysis, facilitated by enzymes and other catalysts present in the microbial consortium liquid (14). The reactor (30) yields an amorphous solid product (31) and a hydrogen-rich gas (32) containing at least 35% H_2, in mole fraction, which is used as an energy source for the reactor and other processes in the system, and the excess amount can be evaluated as an alternative energy source (converting it into electricity or blending it with natural gas).

Wastewater Treatment Unit (40): The solid product (31) obtained from the thermo-chemical reactor (30) is used in the wastewater treatment unit (40), where it interacts with wastewater (16) and special salts under controlled conditions. The flue gas (32) coming out of the thermochemical reactor (30) is also used as needed to optimize the treatment process. The unit (40) treats wastewater (16) and generates deionized clean water (42) and a second solid product (41), the latter of which is utilized in the system. Conventional resins can be employed, if required, following the passage of wastewater through filters treated with amorphous solid application.

Carbon Capture Unit (50): The solid product (31) from the thermo-chemical reactor (30) is also introduced into a carbon capture unit (50), to treat flue gases (18), along with the flue gas coming out of the thermochemical reactor (32). This process cleans the flue gases and captures both inorganic and organic contaminants, producing a second solid product (51), which can be further utilized in the system (10). The carbon capture unit (50) contributes to the system's zero-emission operation.

Inert Reactor (60): The valuable solid product (55), obtained by the physical mixture of the second and third solid products (51,41) from the carbon capture and wastewater treatment units (50, 40) is fed into an inert reactor (60) at predetermined temperature-pressure ranges and specific reaction conditions, where it undergoes various chemical reactions, reduction and oxidation reactions, to generate additional hydrogen-rich gas (62) and nano-powders (61).

These nano-powders (61) so obtained can be utilized to obtain new generation materials in various applications such as composite materials, additives, and surface coatings.

Overall, the integrated waste treatment system (10) allows for the treatment of various waste streams (12, 16, 18) and easy adaptability to different operating conditions with a sustainable and environmentally friendly solution. While producing energy and valuable products, it operates under a zero-emission and zero-waste principle, ensuring that no harmful emissions or waste products are generated. This innovative approach presents significant advantages over conventional waste treatment technologies, addressing the growing demand for efficient and eco-friendly waste treatment solutions.

<u>The microbial consortium liquid (14</u>

This is a microbial polymeric consortium (14) containing carefully selected microorganisms such as bacteria and fungi, with a variety of enzymes and nutrients, working together to discover, adsorb, decompose and ionize all organic and inorganic wastes in solid, liquid or gaseous form.

The mother culture has been engineered to survive all kinds of hazardous and toxic environments through selection and adaptation, and the said microbial consortium fluid (14) along with the enzymes thereof facilitates the separation, purification and nanoscale process of elements with lower energy by lowering the molecular structures and the bonding (activation) energies of the compounds and accelerates the process with its catalytic effect.

The microbial consortium is a robust and adaptable community of microorganisms that have been selectively enriched and adapted through a series of controlled laboratory and field-scale experiments. These microorganisms exhibit enhanced tolerance and metabolic capabilities, allowing them to thrive and perform their functions effectively in various challenging and toxic environments. The microbial consortium consists of a diverse array of microorganisms with a variety of functional traits, which can be organized into numerous distinct functional categories based on their roles in the decomposition and ionization of waste materials. These functional categories encompass a wide range of metabolic pathways, enzyme production, and detoxification mechanisms, which collectively contribute to the overall performance of the community in waste treatment.

According to the invention, discoverer group of microorganisms comprise the species of *pseudomonas* and *bacillus,* which are responsible for identifying and attaching to the waste materials, initiating the decomposition process. They can produce enzymes, such as proteases, lipases, and cellulases, which facilitate the breakdown of complex organic molecules into simpler compounds. Particularly, it is preferred in this group *pseudomonas aeruginosa, bacillus licheniformis, bacillus subtilis, hydrogenobacter, acidithiobacillus, methanospirillum,* and *ralstonia metallidurans*.

Adsorber group of microorganisms comprise at least two of the species of *cyanobacteria, rhodococcus, mycobacterium* and *actinomycetes*. These microorganisms have the ability to adsorb heavy metals and other toxic compounds, thereby detoxifying the waste materials and protecting the community from harmful substances. Particularly, it is preferred *cyanobacteria, mycobacterium, rhodopseudomonas, rhodobacter, rhodococcus erythropolis azotobacter vinelandii* and *chloroflexus*.

Decomposer/ionizer group of microorganisms comprise at least two of the species of clostridium, methanobacterium and acidithiobacillus. These microorganisms are responsible for the complete decomposition and ionization of organic and inorganic waste materials, producing valuable products such as hydrogen and hydrocarbons. Particularly, it is preferred *clostridium acetobutylicum, cellulomonas fimi, desulfovibrio vulgaris, geobacter sulfurreducens, methanogenic archaea, methanosarcina barkeri* and *shewanella*.

These functional categorizations are based on the primary roles of the microorganisms within the microbial consortium. However, it should be noted that many of these microorganisms can exhibit multiple functions, contributing to the overall efficiency and adaptability of the community. These microorganisms have been selected based on their ability to survive and thrive in various waste environments, as well as their unique biochemical and physical properties that enable them to efficiently decompose and ionize organic and inorganic wastes- by creating a unique synergy together as a consortium- including but not limited to sewage, garbage leachate, animal-vegetable-plant waste, mining/petrochemical wastes, process wastewater, industrial waste, plastic waste, pharmaceutical and chemical wastes, flue gases, battery/accumulator waste, and contaminated/toxic water.

A preferred example of the member microorganisms of the microbial consortium (14) that exhibits a synergistic effect in the waste pre-treatment according to the invention, is characterized by the following distribution ratios among the microorganism members, excluding the liquid:

- 1st Group: *Pseudomonas* and *Bacillus* species, comprising 10-20% of the total distribution,
- 2nd Group: *Cyanobacteria, Rhodococcus, Mycobacterium* and *Actinomycetes* species, comprising 20-40% of the total distribution,
- 3rd Group: *Clostridium, Methanobacterium* and *Acidithiobacillus* species, comprising 50-70% of the total distribution

Accordingly, the concentrations of each group within the feed consortium liquid (14), in this example, are preferably 1-2x10^8 CFU/mL, 2-4x10^8 CFU/mL and 5-7x10^8 CFU/mL, respectively. It is preferred that each species within the consortium contributes to the total concentration by forming colonies in a range of at least 0.3x10^8 CFU (colony-forming units). The concentration is selected to provide an effective inoculum while minimizing the amount of liquid required.

The microbial consortium liquid (14) is a carefully formulated mixture of the cultured microorganisms, suspended in a nutrient-rich medium, such as conventional municipal sewages, with abundance of carbon, nitrogen, phosphorus, sulfur, and trace elements, required for the growth and metabolic activities of the microbial consortium.

<u>Solid Waste Pre-treatment</u>

The first step in the integrated waste treatment process (10) involves the pre-treatment of solid waste materials (12) according to the conventional approaches (not illustrated in the figure). These waste materials (12) can include municipal solid waste, industrial waste, agricultural waste, and other sources of organic and inorganic waste. The pre-treatment process involves shredding, grinding, and dewatering as well as removing large debris and contaminants in order to reduce the moisture content and particle size, typically ranging from 1 to 3 cm in size. This step increases the surface area of the waste materials (12), allowing for better interaction with the microbial consortium (14) during the fermentation process (20). The pre-treatment process can be carried out using mechanical methods, such as crushers, grinders, or shredders, with adjustable settings to control the particle size

<u>Mixing & Fermentation Unit (20)</u>

The solid waste particles (12) is fed, along with the said microbial consortium liquid (14), to a mixer and fermentation unit (20), where they are fermented, readying a homogenous mixture for the thermo-chemical reactor by mixing through a suitable conventional mixer. During fermentation, the hydrolytic and fermentative bacteria in the microbial consortium (14) break down complex organic waste into simpler compounds, while acidophilic bacteria and archaea extract metals from inorganic waste materials. It is equipped with conventional temperature and pH control systems to maintain optimal conditions for microbial activity.

Considering that the waste mixture in the mixer and fermentation unit (20) has a total volume of 10,000 L, the recommended liquid amount (14) would be a maximum 2%, preferably 0,5%-0,8%, of the total waste mixture volume, which is 80 L in this example. This ensures that the microorganisms are present in a sufficient concentration to efficiently initiate the fermentation and decomposition processes..

The mixing and fermentation process is conducted under controlled conditions, independent of pressure and PH, such as temperatures ranging from 25 to 45°C, humidity levels of at most 80%, and moisture levels between 50 and 70%. The fermentation can last at most 15 minutes, preferably 7-10 minutes depending on the composition of the waste material and the desired degree of degradation. During the fermentation process, the microbial consortium liquid (14) enables the reduction of activation energies of molecule structures and compounds. In other words, the microorganisms in the consortium release their enzymes which act as biocatalysts to reduce the activation energy required to break down the waste materials through various metabolic pathways in the thermo-chemical reactor, such as glycolysis, the Krebs cycle, and the electron transport chain. The waste materials are converted into simpler compounds, such as organic acids, alcohols, and gases (e.g., carbon dioxide and hydrogen). The resulting fermented mixture is a biomass-like substance (21) with a maximum moisture content of 20%, which is then fed into the thermo-chemical reactor (30).

Thermo-Chemical Reactor (30)

Once the fermentation process (20) is complete, the mixture (21) is fed into a thermo-chemical reactor (30), which may be a pyrolysis reactor, torrefaction reactor, or bio-chemical reactor. Each type of reactor has its unique advantages and disadvantages, and the choice of reactor will depend on the specific needs of the process. Pyrolysis reactors, for example, are used to convert biomass into biochar, while torrefaction reactors are used to convert biomass into a product that is more suitable for combustion. Bio-chemical reactors, on the other hand, are used to convert biomass into biogas.

The thermo-chemical reactor (30) is designed to carry out a series of bio-chemical and pyrolysis reactions on the fermented waste materials (21). These reactions occur at specific time intervals, temperature-pressure ranges, electromagnetic field effects, and mixing rates. The reactor typically consists of multiple stages, with each stage optimized for a specific reaction or set of reactions. Some of the key reactions that take place in the thermo-chemical reactor (30) may include acidogenesis, acetogenesis, methanogenesis, and pyrolysis.

The specific reactions that occur during pyrolysis, for instance, can be highly dependent on the nature of the waste materials being processed, the pyrolysis conditions (such as temperature and residence time), and the presence of any catalysts or additives. These reactions are also often complex and involve a series of intermediate steps, and may vary depending on the specific microorganisms involved in the process. The temperature and pressure conditions within the reactor (30) can vary depending on the specific reactions taking place. For example, pyrolysis can occur at temperatures between 400 and 700°C and pressures between 1 and 10 atm, preferably lower than 5 atm. Residence time ranges from 0.5 to 2,5 hours. The electromagnetic field effects and mixing rates within the reactor can also be adjusted to optimize the various reactions.

In the pyrolysis reactor, for instance, both thermal and chemical reactions occur, leading to the breakdown of waste materials into simpler compounds and the formation of valuable products. Some of the possible reactions that occur within the pyrolysis reactor include:

- Thermal decomposition: $C_nH_mO_m \rightarrow nC + mH_2 + xCO + yCO_2 + zH_2O$
- Steam reforming: $C_nH_m + nH_2O \rightarrow nCO + (m/2 + n)H_2$
- Water-gas shift reaction: $CO + H_2O \rightarrow CO_2 + H_2$
- Methanation: $CO + 3H_2 \rightarrow CH_4 + H_2O$
- Hydrocracking: $C_nH_m + xH_2 \rightarrow yC_{n/2}H_{m/2}$

The thermo-chemical reactor (30) yields an amorphous solid product (31) and a hydrogen-rich gas (32) containing at least 35% H_2 (in mole quantity). While the said gas (32) can be used as an energy source for the reactor and other processes in the system, the surplus can be considered as an alternative energy source. The amorphous solid product (31) can be advantageously utilized as a feedstock into wastewater treatment (40) and carbon capture (50) units, separately.

According to a preferred embodiment of the integrated waste treatment system (10), the thermo-chemical reactor operates under a series of at least five bio-chemical and pyrolysis reactions at predetermined time intervals, temperature-pressure ranges, electromagnetic field effects, and mixing rates in order to yield valuable initial amorphous solid product (31) as per the invention, such that:

- The first reaction stage occurs at a temperature range of 100-300°C, pressure range of 1-2 atm, and mixing speed of 10-20 rpm, particularly after achieving absolute dryness at 120°C. Thermal decomposition of certain light organic compounds can take place during this stage.

- The second stage takes place at a temperature range of 300-400°C, pressure range of 2-4 atm, and mixing speed of 20-30 rpm. Thermal depolymerization occurs during this stage, breaking down complex organic compounds into simpler ones.

- The third stage occurs at a temperature range of 400-500°C, pressure range of 4-6 atm, and mixing speed of 30-40 rpm. This stage involves cellulose and lignin pyrolysis, producing hydrogen and carbon monoxide. Additionally, reduction processes of inorganic compounds begin.

- The fourth stage occurs at a temperature range of 500-600°C, pressure range of 6-8 atm, and mixing speed of 40-50 rpm. In this stage, reduction and oxidation reactions increase, converting carbon monoxide and water into hydrogen and carbon dioxide.

- The fifth stage occurs at a temperature range of 600-700°C, pressure range of 8-10 atm, and mixing speed of 50-60 rpm. Gasification reactions accelerate during this stage, producing volatile gases, hydrogen-rich gas, and an amorphous solid product containing coal-like and inorganic components. Along with this stage, the amorphous solid product (31), whose physicochemical properties are enhanced by applied electromagnetic field effects, undergoes final cooling and stabilization in order to be made suitable for use in subsequent processing stages, namely at wastewater treatment and carbon capture units.

The products obtained from the reactor (30) comprise the following: hydrogen-rich gas (32) (approximately 45-55% of the total input quantity fed into the reactor), amorphous solid product (31) (approximately 35-45% of the quantity), and thermochemical reactor liquid (approximately 5-10% of the quantity).

The amorphous solid product (31) obtained, unlike typical waste in traditional technologies, is a valuable material produced according to the invention and has specific content and properties. Its key features include high carbon content, large surface area, highly porous structure, multi-center nature, regular and homogeneous structure.

Based on the analysis results from Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS), non-limiting examples of the chemical analysis values for the content of the amorphous solid material (31) are as follows:

Analysis	% C	% SiO_2	% CaO	% Fe_2O_3	% Al_2O_3	% K_2O	% MgO	% Na_2O	% SO_3	% TiO_2	% Cl
1	91,38	2,86	1,36	1,14	1,11	0,76	0,64	0,34	0,24	0,09	0,08
2	89,92	3,66	1,26	1,5	1,27	0,88	0,73	0,37	0,24	0,1	0,08
3	89,74	3,51	1,39	1,49	1,29	0,9	0,79	0,35	0,31	0,14	0.09

Wastewater Treatment Unit (40)

The wastewater treatment unit receives a portion of the amorphous solid product (31) and uses it to treat wastewater (16) from various sources, such as municipal, industrial, and agricultural wastewater as well as all liquid waste generated during the waste treatment process. This treatment process may include physical and chemical methods, such as high-pressure mixing, ion-exchange resins, and membrane filtration. The synergistic gain achieved in this process is due to the utilization and evaluation of the critical amorphous solid product (31), which is crucial according to the invention.

The said amorphous solid product (31) is applied to the wastewater treatment unit (40) at a dosage range of 1-30 g/L, serving as a reactive adsorbent and catalyst for the degradation of organic contaminants and facilitating the transformation of toxic and recalcitrant compounds into simpler, non-toxic substances

Special salts, such as coagulants or flocculants, are added to the wastewater to promote the aggregation of suspended particles, making them easier to separate from the water. Examples of these salts include aluminum sulfate, ferric chloride, polyacrylamide and polyaluminum chloride, applied at a dosage range of 0,5-5 mg/L as Al or Fe, which promote coagulation and flocculation processes, enhancing the removal of suspended and colloidal particles from the wastewater. If necessary, flue gas from the thermo-chemical reactor (30) or other types can also be introduced into the wastewater treatment unit (40) which used to maintain a reducing environment in the treatment process, promoting the conversion of contaminants, such as nitrates and sulfates, into less harmful forms, such as nitrogen gas and elemental sulfur, and to optimize the treatment process, particularly in cases where the pH level of the wastewater is above 7.

The treatment process occurs under controlled conditions, which can include temperatures ranging from 10 and 150°C, pressure ranging from 1 to 6 atm, pH ranging from 1-14, and a hydraulic retention time of 5-10 minutes to remove suspended solids, dissolved organic and inorganic contaminants, and pathogens from the wastewater. As a result, the treated water quality indicators meet the related standards.

The wastewater treatment unit generates deionized clean water (42), which can be used for various applications, such as drinking, irrigation, industrial processes, or discharged safely into the environment since it meets regulatory requirements. The wastewater treatment unit (40) also produces a second solid product (41) that will be combined later with the solid product (51) exiting the carbon capture unit (50) and thus be further processed in the inert reactor (60).

Carbon Capture Unit (50)

The carbon capture unit (50) receives another portion of the amorphous solid product (31) and uses it to treat flue gases (18) from various sources, such as power plants, industrial processes, and combustion engines. The carbon capture unit (50) can also receive the flue gas (32) produced by the thermo-chemical reactor (30).

The carbon capture unit (50) consists of multiple stages, each designed to carry out specific chemical and physical processes, such as adsorption, absorption, and chemical reactions, to capture both inorganic and organic contaminants present in the flue gases (18). The unit (50) operates under specific temperature and pressure conditions, which can range from 40-100°C, a pressure range of 1-10 bar, and a gas residence time of 0.5-5 seconds, facilitating the transformation of gaseous contaminants into stable solid compounds..

By treating the flue gases (18) with the amorphous solid product (31) and the gas (32) from the thermo-chemical reactor (30), the carbon capture unit (50) can efficiently remove contaminants, such as carbon dioxide, sulfur dioxide, nitrogen oxides, and volatile organic compounds. The treated flue gases can then be released into the atmosphere, while the second solid product (51) is further processed in the inert reactor (60).

In order to achieve the said results, in the carbon capture unit (50), the hydrogen-rich gas is introduced at a flow rate of 1-10 L/min per cubic meter of flue gas and a multi-stage scrubbing process is implemented using alkaline solution or amines within a concentration range of 0.1-1 M.

<u>Inert Reactor (60)</u>

The valuable solid product (55) obtained by mixing the solid products (51, 41) obtained from the carbon capture and wastewater treatment units (50, 40) is introduced into the inert reactor (60), which operates under predetermined temperature-pressure ranges and specific reaction conditions. The temperature conditions within the reactor can vary between 700 and 1200°C, while the pressure can range from 10 to 25 atm.

In the inert reactor (60), the valuable solid product (55) undergoes a series of chemical reactions, possibly including redox reactions, gasification, and other thermal or catalytic processes. These reactions produce additional hydrogen-rich gas (62) and nano-powders (61). The hydrogen-rich gas (62) can be utilized for energy production or other applications, while the nano-powders (61) can be utilized for various applications, such as graphite (63) production, and, through a high pressure inert reactor (70) and molding (71) operations, polyethylene plastic (72) nano composite materials (73) as well as insulation raw materials.

In the inert reactor (60), the following reaction sequences, for example, take place:

- The first reaction stage occurs at a temperature range of 700-800°C, a pressure range of 10-13 atm, and a mixing rate of 60-75 rpm, where residual organic and inorganic components undergo high-temperature decomposition reactions, such as the thermal decomposition of calcium carbonate ($CaCO_3 \rightarrow CaO + CO_2$).
- The second reaction stage, at a temperature range of 800-900°C, a pressure range of 13-16 atm, and a mixing rate of 75-90 rpm, involves the formation of a solid product from the residual components, such as the formation of calcium silicate from the reaction of calcium oxide and silicon dioxide ($CaO + SiO_2 \rightarrow CaSiO_3$), which results in an amorphous, glass-like solid product.
- The third reaction stage takes place at a temperature range of 900-1000°C, a pressure range of 16-19 atm, and a mixing rate of 90-105 rpm, during which the solid product is cooled and stabilized, allowing its properties to be preserved for further processing.
- The fourth reaction stage occurs at a temperature range of 1000-1100°C, a pressure range of 19-22 atm, and a mixing rate of 105-120 rpm, where electromagnetic field effects are applied to the solid product to enhance its physicochemical properties, such as improving its mechanical strength or altering its surface chemistry for better performance in subsequent processes.
- The fifth reaction stage, at a temperature range of 1100-1200°C, a pressure range of 22-35 atm, and a mixing rate of 120-140 rpm, involves the final cooling and stabilization of the solid product before further utilization as nano-powders. This stage ensures that the solid product maintains its desirable properties and is suitable for the subsequent treatment processes.

As a result of the aforesaid reaction sequences, a valuable solid product (61) according to the invention can be obtained in the form of nano-powder.

The modular and integrated design of the waste treatment system allows for the treatment of various waste streams and easy adaptability to different operating conditions. The combination of microbial fermentation, thermo-chemical reactions, waste water treatment and carbon capture processes enables the efficient treatment of solid, liquid, and gaseous waste materials while minimizing harmful emissions. The zero-emission and zero-waste principle ensures that no harmful byproducts are generated, and waste materials are converted into valuable products, such as hydrogen-rich gas, clean water, and nano-powders.

In summary, the integrated waste treatment system described herein offers a holistic and environmentally friendly approach to treating solid, liquid, and gaseous waste materials of organic and inorganic origin. The system leverages the power of microbial fermentation, thermo-chemical reactions, carbon capture, and inert reactor processes to convert waste materials into valuable products. The zero-emission, zero-waste principle ensures that harmful byproducts are minimized or eliminated, providing an efficient and sustainable waste treatment solution.

Moreover, the system's ability to produce hydrogen-rich gas with a calorific value of between 3000 to 5000 kcal/kg presents an attractive energy source that can be utilized in various applications. The integrated waste treatment system can generate more gas/energy output compared to conventional waste-to-energy (WTE) technologies. This energy efficiency, coupled with the system's ability to treat various waste streams simultaneously, sets it apart from traditional waste treatment methods.

Overall, the invention provides a comprehensive waste treatment solution that addresses the challenges of modern waste management while contributing to a sustainable, circular economy. By transforming waste materials into valuable resources, the integrated waste treatment system not only minimizes environmental impact but also creates opportunities for new markets and industries.

<u>Test & Examples</u>

Example 1: Laboratory-Scale Solid Waste Conversion Tests

Four comparative tests were conducted at the laboratory scale to determine the efficiency of the microbial consortium application in waste treatment. These tests involved the processing of various solid wastes of organic and inorganic compounds in thermo-chemical reactors to determine the proportions converted into solid, gas, and liquid forms. The test results are given in the table below.

Table 1. Solid waste processing

	Mixing and Fermentation Unit			Input to Reactor After Drying (Kg)	Output from Reactor		
Solid Waste	OSB Sludge (Kg)	Factory Waste (Kg)	Microbial Consortium Liquid (Lt)		Solid (Kg)	Gas (Kg)	Liquid (Kg)
Chromate chrome sludge	20	2,5	0,5	8,85	4	4,5	0,35
Oxyvit process sludge	20	3	0,5	4,95	2,4	2,3	0,25
Chromium-contaminated soil	24	2	0,5	9,35	4	4,7	0,69

In these tests, the microbial consortium liquid (14) was mixed with approximately 2% of the total solid waste amount (12) and fermented for approximately 7 minutes. The fermentation process (20) was conducted under mesophilic conditions with temperatures ranging from 30 to 40°C, moisture content ranging from 55 to 60%, and ambient humidity levels ranging from 60 to 65%. The moisture content of the mixture (21) was reduced to below 20% after fermentation and drying, and it was then fed into the bio-reactor (30) as an input along with the valuable solid product (31) obtained according to the invention. The process resulted in the production of hydrogen-rich gas (32) and a small amount of liquid product.

Overall, approximately 35-48% of the input material was converted into solid output, 46-51% into gas output, and only 4-7% was identified as liquid output. These data demonstrate that the waste materials subjected to pre-treatment with the microbial consortium liquid were effectively gasified in the biological reactor, resulting in significant amounts of solid and liquid product outputs. Minor variations in output ratios were observed depending on the type of processed material.

Additionally, tests were conducted at Ege University in accordance with ASTM D7833-20 standard. For example, gas samples from the process where the chromate chrome waste mentioned above was treated were analyzed for their content, and the higher heating values of the gases were calculated using the mol ratios of the relevant components. The BS EN ISO 6976:2016 Standard method was used for calorific value calculations, and the respective results are reported in the table below. Notably, the production of gas containing 39% hydrogen represents a significant achievement.

Table 2. Gas composition obtained using Gas Chromatography method

Compound, % mole	Test 1	Test 2	Average
Methane	9,80	10,19	9.99
Ethane	1,80	1,86	1.83
Ethylene	3,60	3,73	3.66
Propane	0,11	0,11	0.11
Propylene	0,85	0,88	0.87
Acetylene	0,02	0,02	0.02
1-Butene	0,02	0,02	0.02
Iso-butylene	0,06	0,06	0.06
Trans-2-butene	0,01	0,01	0.01
1,3-Butadiene	0,05	0,05	0.05
CO	15,43	15,42	15.42
N_2	12,87	12,93	12.90
CO	14,16	14,13	14.14
H_2	39,00	39,00	39.00

Calorific Values	Mass-Based Higher Heating Value	Volume-Based Higher Heating Value
Current	18,34 Mj/kg 4384,8 kcal/kg	14,61 Mj/m^3 3491 kcal/m^3
CO_2 removed	28,70 Mj/kg 6858,5 kcal/kg	17,67 Mj/m^3 4224 kcal/m^3
CO_2 + CO removed	37,81 Mj/kg 9037,8 kcal/kg	18,84 Mj/m^3 4503,9 kcal/m^3
CO_2 + CO + N_2 removed	70,02 Mj/kg 16734,9 kcal/kg	21,98 Mj/m^3 5255 kcal/m^3

Example 2: Industrial Wastewater Treatment and Water Recycling

A poly-ionization followed by resin deionization process was applied for the treatment of 100,000 liters of wastewater containing various high-level pollutants in an industrial facility. Initial analyses revealed that the raw leachate contained high concentrations of heavy metals, organic pollutants, and suspended solids. Particularly, the concentrations of iron, calcium, magnesium, and sodium were found to be significantly high. The conductivity value was 35 mS/cm, TSS value was 777,5 mg/L, COD value was 9.225 mg/L, and TKN value was 3.119 mg/L.

As indicated in the table below, following the implementation of the process according to the invention, which involves the inclusion of the amorphous solid (31) obtained from the thermochemical reactor (20) into the wastewater, a poly-ionization and deionization process were applied. It can be observed that the quantities of many pollutants have significantly reduced, indicating their successful removal.

Table 3. Wastewater Treatment

COMPONENTS	UNIT	RAW WASTE LEAK WATER	RESIN OUTPUT (DE-IONIZED WATER)
Cadmium	mg/l	0,005	<0,003
Total Chromium	mg/l	1,67	<0,004
Copper	mg/l	0,069	<0,005
Nickel	mg/l	0,95	<0,009
Lead	mg/l	0,035	<0,014
Aluminum	mg/l	2,53	0,21
Iron	mg/l	42,5	0,99
Calcium	mg/l	92,9	0,99
Magnesium	mg/l	182,1	0,28
Sodium	mg/l	2.319	0,93
Conductivity	-	35 mS/cm	<15 µS/cm
TSS (Total Suspended Solids)	mg/l	777,5	<4,4
COD (Chemical Oxygen Demand)	mg/l	9.225	30
BOD (Biological Oxygen Demand)	mg/l	4.900	-
TKN (Total Kjeldahl Nitrogen)	mg/l	3.119	<5
Arsenic	mg/l	0,16	<0,004
Manganese	mg/l	<0,001	<0,005
pH	-	7,92	5,34

In the light of the data above, it is apparent that the concentrations of metals (Cadmium, Chromium, Copper, Nickel, Lead, Aluminum, Iron, Calcium, Magnesium, Sodium) are very low in the resin output, indicating that the resin treatment effectively removes metal ions. Additionally, the concentrations of chemical and biological oxygen demand (COD and BOD) and total Kjeldahl nitrogen (TKN) in the wastewater have significantly decreased in the resin output. This indicates that the wastewater treatment process effectively removes organic pollution, as well.

Example 3: Carbon Capture Unit Test

As previously mentioned, the carbon capture unit (50) effectively captures pollutants such as carbon dioxide, sulfur dioxide, nitrogen oxides, and volatile organic compounds from the waste flue gases (18) using the amorphous solid product (31) and gas (32) produced by the thermochemical reactor. The following table presents the results of gas chromatography analysis conducted by Ege University, following ASTM D7833-20, showing the gas components and their percentage composition.

Table 4. Gas Treatment Results

Component	Flue Gas (%)	Outlet Gas (%)
Acetylene	0,01	0
CO_2	12,84	0,34
N_2	80,75	75,61
CO	1,22	0
H_2	0,29	0

When comparing the values of input flue gas with the outlet gas, it can be seen that the CO_2 content decreases to 0.34 mol in the outlet, indicating a reduction of approximately 97.35% due to the effect of the amorphous solid product (31). Similarly, the CO_2 and H_2 contents in the input flue gas, which were 1.22% and 0.29% mol, respectively, are completely captured in the outlet due to the effect of the amorphous solid product (31).

Example 4: Nano-particles and Value-added Products - PIR Insulation Block Test

In this example, a PIR poliol formulation of 10 kg at a temperature of 24-25°C was taken into a mixing vessel. Then, 1.5 kg of valuable nano-particles (61) obtained from the output of the inert reactor (60) according to the process described in the invention was added to the mixture and homogeneously mixed with the aid of a manual mixer. Subsequently, 20 kg of 100% polymerized MDI isocyanate (PMDI) at the same temperature was added to the homogeneous mixture and manually mixed for 25 seconds before transferring to the mold. The water quantity used for adjusting the hydroxyl index was 80 grams. After observing the cream time (40-50 s), the mold was closed and the block was allowed to cure. After a waiting period of 4.5 hours at 40-42°C, the mold was opened, and sample sections were taken from the bottom, top, and middle parts of the PIR insulation block with a density of 55.4 kg/m³ and a volume of 0.52 m³ (61.5 cm x 202 cm x 42 cm) for testing. Different measurements, such as string time (260-285 s), take-free time (450-480 s), and hardness time (approximately 600 s), were also recorded.

The analysis revealed that the cell structure and reaction distribution occurred homogeneously throughout the block. The hardness perception of the block was almost equal in the bottom and top sections. The results indicated the positive impact of the additive (61) according to the invention, for example, the cream time (the time elapsed for the polymerization reaction to start) was reduced by approximately 5-6 seconds, and the isocyanate settling caused by the effect of gravity during polymerization rise was minimized. In this test, although the ratio of the additive (61) according to the invention was kept at a maximum of 5% known in the polyurethane industry, it was observed that it had minimal effect on viscosity. This contributed to a homogeneous mixture and stable cell density. The burning performance of the sample exhibited an unprecedented performance by preventing the spread of carbon layer formation and oxidation into the cells.

Table 5. PIR Insulation Block Test Analysis Results

According to TS EN 1604 Method - Dimensional Stability Test at -20°C (%) / Average 0.15		ng to TS EN 1604 Method - Dimensional Stability Test at +70°C (%) / Average 0.21	
Length Change (%)	0,16	Length Change (%)	0,23
Width Change (%)	0,15	Width Change (%)	0,21
Thickness Change (%)	0,14	Thickness Change (%)	0,20
Compression Strength Test Value	410 kpa	Foam Dimensions (length x width x height)	5 x5x5 cm
Test Result (kPA) :	410 kpa	Phase Separation	None
Density (kg/m³) - Average of Bottom, Middle, and Top Sections of the Block		55,9 kg / m³	
Initial Thermal Conductivity (Thermal Coefficient) NF EN 12667		0,021 w m.k	
Closed Cell Content– ISO 4590		%97	
Water Absorption– ISO 2896 -99		%2,4	
Water Vapor Permeability– ISO 12572/01		32 gr/m²	
Operating Temperature		-100 + 200 °C	
Fire Reaction Test - ASTM E84-21A; Flame Spread Index		CLASS A; 11 (Highly Successful)	

The values of dimensional stability test results indicate a positive performance well above the expected values (2-3% under pressure) in original polyurethane insulation materials at the relevant densities. The close ratios of width-thickness and length changes at -20°C and +70°C demonstrate the degree of success in homogenization. While the expected thermal conductivity values for the 55-60 density range in original polyisocyanurate products are in the range of 0.026-0.028 W/m·K, the performed test on the casting sample yielded a thermal conductivity coefficient value of 0.021 W/m·K, which is exceptionally high. Achieving this value eliminates the need for using special hydrofluorocarbon gases and other auxiliary agents at optimum levels in the 35-40 density range required for original polyurethane products.

The higher value obtained in this test is an indication that the used additive (61) is distributed in a reactive manner to provide thermal conductivity in all parameters (cream time, gel time, release time). The closed cell content and water absorption values are within the expected reference ranges. As a result, the insulation value is positive, indicating that it can be easily used for superior insulation in specific applications within the density range of 55-60. The test sample was classified as a CLASS A material in terms of fire test-response behavior according to ASTM E84 Standard, and the Flame Spread Index (FSI) value was measured as 11. This indicates its excellent non-flammability and suggests that the additive powder (61) according to the invention can be a substitute for existing products in various sectors that require superior flame resistance.

These examples demonstrate the effectiveness of the integrated waste treatment system with specific process parameters, values, ranges, and conditions across various waste treatment challenges, energy production, and value-added product, and that the system operates cyclically with zero emission zero waste principle without leaving any waste behind and acts against all waste groups (solid, liquid, gas, organic, inorganic) holistically.

Monitoring and Control:

A comprehensive monitoring and control system is in place to ensure the optimal performance of the integrated waste treatment process according to the invention. This includes real-time monitoring of key process parameters, such as temperature, pH, conductivity, dissolved oxygen, amount of CO2 and nutrient concentrations, as well as the use of advanced analytics and machine learning algorithms to optimize process control and maximize treatment efficiency, all of which are known from the prior art.

Industrial Applicability

Waste management system of bio-circular technology involving an microbial consortium according the invention has the capability to provide solutions to all solid-liquid-gas wastes of organic and inorganic origin, and work with a zero waste principle. Moreover, it is able to decompose inorganic solid wastes and inorganic waste liquids, obtaining hydrogen-rich gas during the decomposition process via reduction and oxidation reactions.

The technology produces much more gas/energy output than conventional waste-to-energy technologies while decomposing both organic and inorganic solid, liquid and flue gases together in a single integrated process.

The technology is differentiated from conventional waste technologies by its ability to offer holistic and integrated solutions to waste problems, to be cyclical, to find solutions to inorganic solid wastes, to recover more than 95% of the water it cleans, and by operating under the principle of zero emissions, solving the emission problem in the most environmentally friendly and economical way with modular carbon capture processing.

Additionally, it is able to use all solid-liquid-gas waste generally as raw materials that existing conventional waste technologies leave as waste during processing, decompose with a series of integrated bio-chemical and physical reactions, and therefore, no chemicals are used in the integrated waste treatment and management system – on the contrary, chemical wastes are utilized as raw materials during the processing stage. The technology solves waste problems in the most environmentally friendly way, transforming waste into an asset, and paying for itself in a short time with both direct and indirect revenues, turning the waste treatment into a profitable business.

Furthermore, the present invention proposes a new green city model, in which central and complementary integrated and modular new bio-circular processes according to the invention are established in optimum urban locations with local authorities. This approach aims to achieve clean soil, zero waste, and clean air, which will be green and sustainable.

Additionally, the model solves wastewater and carbon emission problems of all private and public facilities in the city, by establishing the Wastewater Treatment Process and Carbon Capture Process respectively.

The outputs of the Bio-Circular Technology according to the invention include zero waste-zero emissions, hydrogen-rich gas, carbon capture, deionized clean water, nano powders, and so much more. This integrated and comprehensive system can be distinguished from the conventional approaches as the more powerful and cleaner hydrogen-rich gas producing biotechnology, and is a stronger bio-degrader, decomposer, solvent, poly-ionizer, and bond breaker.

While certain examples and embodiments of the present invention have been described so far, it is obvious that various changes, modifications, and adaptations can be made by those skilled in the art without departing from the spirit and scope of the invention. For example, the process conditions, such as temperature, pressure, humidity, and moisture levels, can be adjusted within the fermentation unit (20), the thermo-chemical reactor (30), the wastewater treatment unit (40), the carbon capture unit (50), and the inert reactor (60), depending on the specific waste stream (12, 16 and/or 18) and desired treatment outcomes. This flexibility allows for the optimization of the integrated waste treatment system for various waste types and contaminants. Besides, different types of salts or additives can be used in the wastewater treatment unit (40) and the carbon capture unit (50) to enhance the removal of suspended particles, contaminants, or pollutants. These additives can include natural or synthetic coagulants, flocculants, adsorbents, or catalysts, depending on the specific waste stream and treatment objectives.

Furthermore, the integrated waste treatment system (10) can be scaled up or down to accommodate different waste processing capacities, ranging from small-scale, decentralized installations to large-scale, centralized facilities. This scalability allows for the implementation of the system in various settings, such as rural communities, urban areas, or industrial complexes.

Therefore, with the attached claims, it is ensured that such changes and modifications are included in the scope of protection without departing from the scope and integrity of the invention.

CLAIMS

1. An integrated waste treatment process (10) for processing and converting organic and inorganic waste into valuable products, comprising the following steps:

   - mixing all types of organic and/or inorganic solid waste particles (12) with microbial polymeric consortium fluid (14) and fermenting the resulting mixture for a short period in a fermentation unit (20) under controlled conditions;

     wherein the controlled conditions are an aerobic environment, with maximum solid particle size of 5 cm, maximum mixing-fermentation period of 15 minutes, temperature range of 25 to 45°C, and maximum moisture content of 80%;

     wherein the microbial polymeric consortium fluid (14) essentially consists of a first group containing *Pseudomonas* and *Bacillus* species, a second group containing at least two species selected from *Cyanobacteria*, *Rhodococcus*, *Mycobacterium*, and *Actinomycetes*, and a third group containing at least two species selected from *Clostridium*, *Methanobacterium*, and *Acidithiobacillus*;

     wherein the weight ratio of the said consortium fluid (14) corresponds to a maximum of 2% of the total waste mixture (12, 14);

   - subjecting the fermented mixture to thermal treatment with a moisture content of up to 20%;

   - feeding the resulting fermented mixture (21) to a thermochemical reactor (30) for bio-chemical and pyrolysis reactions;

     wherein the operational parameters for the reactor include temperatures of 100 to 700°C, pressures of 1 to 10 atm, and residence times ranging from 0.5 to 2.5 hours;

   - obtaining hydrogen-rich gas (32) containing at least 35 mol% H_2 and amorphous solid product (31) from the thermochemical reactor (30);

     wherein the hydrogen-rich gas (32) corresponds to 40-55% by weight of the total fed amount (21), and the amorphous solid product (31) corresponds to 35-50% by weight;

     wherein the amorphous solid product (31) can be separately fed to a carbon capture unit (50) for processing gas waste (flue gases) (18) and to a wastewater treatment unit (40) for processing liquid waste (16).

2. An integrated waste treatment process according to claim 1, characterized in that the said bio-chemical and pyrolysis reactions in the thermochemical reactor (30) comprise depolymerization, lignin pyrolysis, cellulose pyrolysis, and enzymatic reactions occurring at temperatures below 700°C, for the breakdown of organic substances and reduction and oxidation reactions facilitated by the microbial consortium fluid enzymes (14).

3. An integrated waste treatment process according to claim 1, characterized in that the said amorphous solid product (31) comprises 89-91% organic compounds (carbon fraction), 6-8% inorganic compounds, particularly selected from SiO_2, Fe_2O_3, Al_2O_3, and CaO, and 0.5-2% other compounds of lower concentrations selected from Na_2O, MgO, SO_3, Cl, K_2O ve TiO_2.

4. An integrated waste treatment process according to claim 1, characterized in that the said first, second, and third groups constituting the microbial polymeric consortium fluid (14) have distribution ratios of 10-20%, 20-40%, and 50-70%, respectively, within the total content in relation to each other.

5. An integrated waste treatment process according to claim 1, further comprising the following steps:

- feeding any type of organic and/or inorganic liquid waste (16) to the wastewater treatment unit (40) along with the amorphous solid product (31), salts, and, if necessary, flue gas (32) from the thermochemical reactor to generate deionized clean water (42) and a second solid product (41);

- feeding any type of flue gases (18) to the carbon capture unit (50) along with the amorphous solid product (31) and, if desired, flue gas (32, 62) from the reactor to remove gaseous pollutants and produce a third solid product (51).

6. An integrated waste treatment process according to claim 5, further comprising the following process step:

- feeding the valuable solid product (55) obtained by the simple physical mixture of the said second and third solid products (41, 51) into an inert reactor (60) and producing additional hydrogen-rich gas (62) and nano powders (61).

7. An integrated waste treatment process according to claim 5, characterized in that the operational parameters of the wastewater treatment unit (40) comprise temperatures of 10 to 150°C, pressures of 1 to 6 atm, pH values of 1 to 14, and hydraulic retention times of 5 to 15 minutes, and the amorphous solid product (31) is applied in a dosage range of 1-30 g/L.

8. An integrated waste treatment process according to claim 5, characterized in that the salts applied to the wastewater treatment unit (40) are selected from aluminum sulfate, iron chloride, polyacrylamide, and polyaluminum chloride, and total dosage range of which is from 0.5 to 5 mg/L.

9. An integrated waste treatment process according to claim 5, characterized in that the carbon capture unit (50) operates at temperatures ranging from 40 to 100°C, pressures ranging from 1 to 10 bar, and gas residence times ranging from 0.5 to 5 seconds.

10. An integrated waste treatment process according to claim 5 or 9, characterized in that the carbon capture unit (50) is supplied with hydrogen-rich gas at a flow rate of 1-10 L/min per cubic meter of flue gas and subjected to a multi-stage washing process using alkaline solution or amines at concentrations ranging from 0.1 to 1 M.

11. An integrated waste treatment process according to claim 5, characterized in that the inert reactor (60) operates at temperatures ranging from 700 to 1200°C and pressures ranging from 10 to 25 atm.

12. An integrated waste treatment system for processing and converting organic and inorganic waste into valuable products, comprising:

– a fermentation unit (20) where all types of solid waste particles (12), initially reduced to a size of less than 5 cm, are fermented with microbial polymeric consortium fluid (14) via mixing under controlled conditions at a temperature range of 25 to 45°C for a maximum of 15 minutes and brought to a maximum moisture content of 20%;

wherein the microbial polymeric consortium fluid (14) essentially consists of a first group containing *Pseudomonas* and *Bacillus* species, a second group containing at least two species selected from *Cyanobacteria*, *Rhodococcus*, *Mycobacterium*, and *Actinomycetes*, and a third group containing at least two species selected from *Clostridium*, *Methanobacterium*, and *Acidithiobacillus*;

wherein the weight ratio of the said consortium fluid (14) corresponds to a maximum of 2% of the total waste mixture (12, 14);

– a thermochemical reactor (30) wherein the reduced-moisture fermented mixture (21) undergoes bio-chemical and pyrolysis reactions, comprising thermal depolymerization, lignin pyrolysis, cellulose pyrolysis, and enzymatic reactions, at temperatures ranging from 100 to 700°C, pressures ranging from 1 to 10 atm, and residence times ranging from 0.5 to 2.5 hours, resulting in obtaining hydrogen-rich gas (32) containing at least 35 mol% H_2 and an amorphous solid product (31);

wherein the hydrogen-rich gas (32) corresponds to 40-55% by weight of the total amount of the fermented mixture (21) fed to the reactor (30), and the amorphous solid product (31) corresponds to 35-50% by weight;

wherein the amorphous solid product (31) comprises 89-91% organic compounds (carbon fraction), 6-8% inorganic compounds, particularly selected from SiO_2, Fe_2O_3, Al_2O_3, and CaO, and 0.5-2% other compounds of lower concentrations selected from Na_2O, MgO, SO_3, Cl, K_2O ve TiO_2..

13. An integrated waste treatment system according to claim 12, further comprising:

- a wastewater treatment unit (40) wherein any type of organic and/or inorganic liquid waste (16) is fed along with the amorphous solid product (31), salts, and, if necessary, flue gas (32) from the thermochemical reactor (30) to generate deionized clean water (42) and a second solid product (41);
- A carbon capture unit (50) wherein any type of flue gases (18) is fed along with the amorphous solid product (31) and, if desired, flue gas (32, 62) from the reactor, capturing/removing gaseous pollutants and producing a third solid product (51).

14. An integrated waste treatment system according to claim 13, characterized in that the operational parameters of the wastewater treatment unit (40) comprise temperatures ranging from 10 to 150°C, pressures ranging from 1 to 6 atm, pH values ranging from 1 to 14, and hydraulic retention times ranging from 5 to 15 minutes, and the amorphous solid product (31) is applied in a dosage range of 1-30 g/L.

15. An integrated waste treatment system according to claim 13, characterized in that the salts applied to the wastewater treatment unit (40) are selected from aluminum sulfate, iron chloride, polyacrylamide, and polyaluminum chloride, and total dosage range of which is from 0.5 to 5 mg/L.

16. An integrated waste treatment system according to claim 13, characterized in that the carbon capture unit (50) operates at temperatures ranging from 40 to 100°C, pressures ranging from 1 to 10 bar, and gas residence times ranging from 0.5 to 5 seconds.

17. An integrated waste treatment system according to claim 13, characterized in that the carbon capture unit (50) is supplied with hydrogen-rich gas at a flow rate of 1-10 L/min per cubic meter of flue gas and subjected to a multi-stage washing process using alkaline solution or amines at concentrations ranging from 0.1 to 1 M.

18. An integrated waste treatment system according to claim 13, characterized by further comprising an inert reactor (60) wherein the valuable solid product (55), obtained through the simple physical blending of the second and third solid products (41, 51), is fed, resulting in the production of additional hydrogen-rich gas (62) and nano powders (61), and the operational parameters of the inert reactor (60) comprise temperatures ranging from 700 to 1200°C and pressures ranging from 10 to 25 atm.

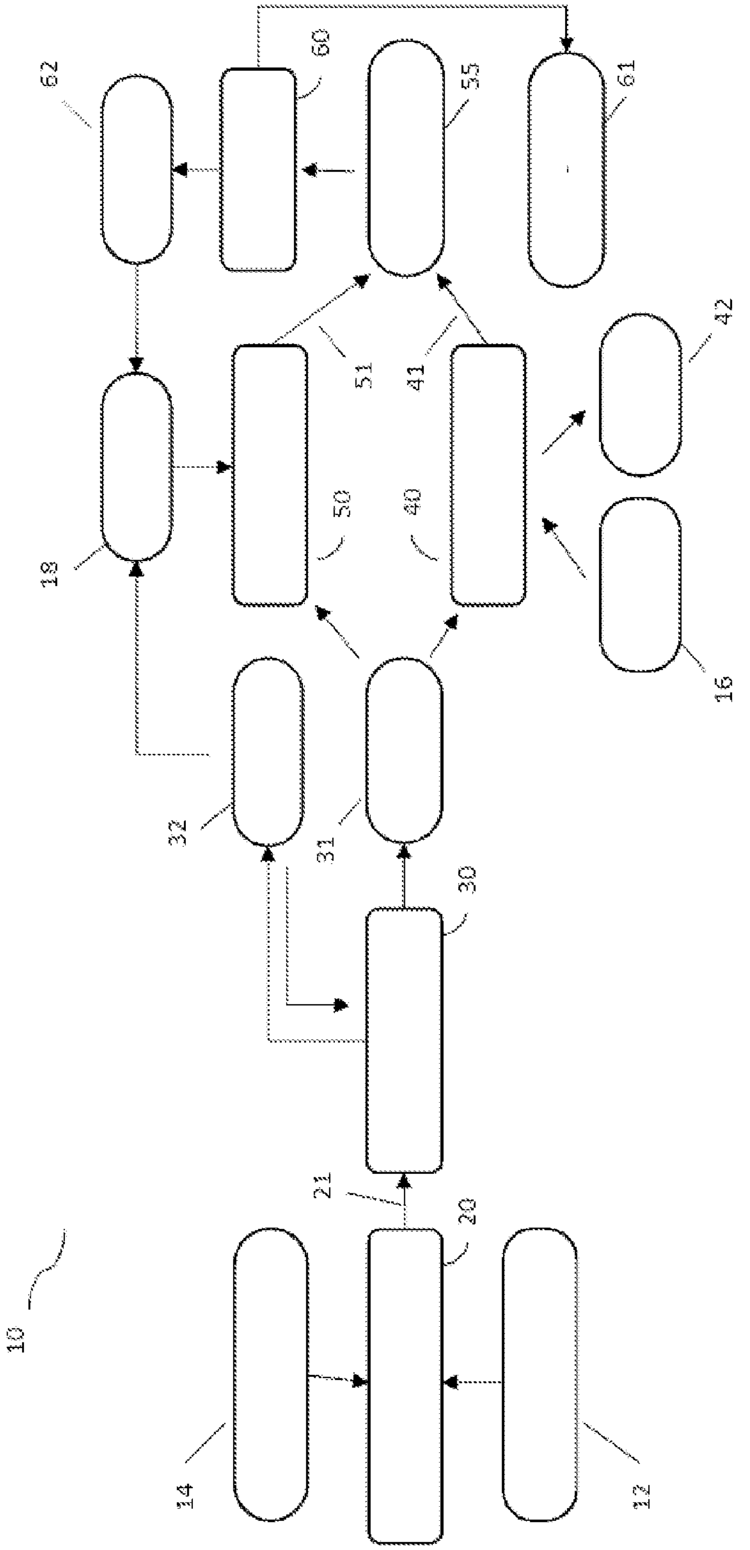

FIGURE 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/TR2023/050690

A. CLASSIFICATION OF SUBJECT MATTER

B09B 3/00 (2022.01)i; C12P 1/04 (2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B09B 3/00; C12P 1/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Turkish Patent Database

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO Abstract and Full text Databases

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 102808000 A (UNIV LIAONING SCI & TECH) 25 June 2014 (2014-06-25) Whole document	1-18
A	US 2012309066 A1 (A1)SIMPSON SEAN DENNIS [NZ]; FORSTER RICHARD LLEWELLYN SYDNEY [NZ]; OAKLEY SIMON DAVID [NZ]; COCKREM MICHAEL CHARLES MILNER [US]; KOEPKE MICHAEL [NZ]; LANZATECH NEW ZEALAND LTD [NZ] - (B2) LANZATECH NEW ZEALAND LTD [NZ]; SIMPSON SEAN DENNIS [NZ]; FORSTER RICHARD LLEWELLYN SYDNEY [NZ]; OAKLEY SIMON DAVID [NZ]; COCKREM MICHAEL CHARLES MILNER [US]; KOEPKE MICHAEL [NZ]06 December 2012 (2012-12-06) Whole document	1-18
A	WO 2011139804 A2 (SEQUESCO [US]; REED JOHN [US]; DYSON LISA [US]) 10 November 2011 (2011-11-10) Whole document	1-18

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
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Date of the actual completion of the international search	Date of mailing of the international search report
17 January 2024	**29 January 2024**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/TR2023/050690

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