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CES OxyNol™ - a proven waste-to-ethanol process

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Abstract

Traditional landfilling and incineration fall short of the public's demand for sustainable, affordable, and long term solutions to solid waste and sludge disposal. Masada OxyNol™ LLC ("Masada") is currently deploying its CES OxyNol™ waste-to-ethanol process that beneficially reuses or recycles up to 90 percent of delivered nonhazardous municipal solid waste ("MSW") and sewage sludge. Masada's first commercial facility in Middletown, New York USA is fully permitted and a groundbreaking is expected in October 2002.

A typical Masada OxyNol™ facility creates hundreds of new jobs and involves three main process areas, all of which are currently in commercial use today:

- Mixed waste materials recovery facility ("MRF") that separates recyclable materials from MSW and prepares a cellulosic feedstock.
- Acid hydrolysis converts cellulose to sugar and lignin residue, a renewable biomass solid fuel.
- Fermentation and distillation converts sugars to ethanol, a renewable fuel.

The CES OxyNol™ process is robust and permanently disposes of waste. Heavy metals are safely controlled and the process produces no hazardous waste or harmful air or water emissions. Masada's patented process is economically viable partly because of improved yields, reduced cost of materials of construction, and application of existing and proven processes.

Masada's CES OxyNol™ process offers an economically viable and environmentally sustainable alternative to burying, burning, or spreading raw waste. Local authorities benefit from economic development opportunities and a long term, sustainable solution to today's waste disposal problems.

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The need for a new, local waste disposal solution

Traditional landfilling, incineration, and sludge land application fall short of the public's demand for sustainable and affordable waste management solutions. Key societal trends demanding new solutions include: (i) local and sophisticated opposition to siting traditional disposal facilities; (ii) tightened environmental and land use rules forced small unregulated disposal sites to close, necessitating new larger disposal facilities located far from waste generators; and (iii) collection and processing of source separated recyclables are rendering most curbside recycling programs uneconomical.

When added together these established societal trends have resulted in dramatic increases in the total disposal cost for common non-hazardous wastes. While the real total cost of public sector waste disposal is sometimes difficult to ascertain, one can not deny a dramatic increases have taken place over the last 20 years.

Municipalities and local governmental authorities are on the front line of this problem since they are responsible - directly or indirectly - for providing the necessary public health service of solid waste and sludge disposal. Decreasing disposal choices, increased disposal costs, and tightening fiscal constraints are forcing municipalities to search for alternatives to traditional disposal options. Municipalities in the northeastern United States, Ireland, and Japan, to name a few, know well these challenges.

The private sector is not immune from these trends and has arguably profited by them. Vertically integrated waste disposal firms are multi-billion dollar entities. In the United States, the three largest waste companies accounted for 83.2 percent of the waste sectors revenues in 1999. Gynn [1]. Similar market concentrations exist in parts of Europe and Asia. Local independent waste collection firms are a dying breed because they are reliant on larger companies who control the location and cost of disposal.

Masada's CES OxyNol™ Process addresses a need

Masada is currently deploying a new paradigm for environmentally responsible MSW and sewage sludge management that addresses these issues and breaks the status quo in the waste industry. Masada's patented [2] and proprietary CES OxyNol™ waste-to-ethanol process provides opportunities to host authorities for local control of disposal options, long term guaranteed competitive disposal costs, and a new industry. A Masada OxyNol™ facility also provides a means to improve collection efficiency of source separated recycling programs by allowing co-collections of green waste, recyclables and solid waste that are then processed and separated in a central facility.

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Development history

Hydrolysis is the selective conversion (saccharification) of cellulose plant tissue into their constituent sugars. It is an old process and the first producing plant using plant fiber was built in the USA during WWI. New developments led to fuel alcohol plants in Germany and Switzerland during WWII. However, cheaper fossil fuels, better post-war economies, and lack of appropriate technology rendered commercial wood-to-ethanol facilities uneconomical in most developed countries into the 1980s although the USSR had full scale hydrolysis facilities in the 1970s and 1980s. Dunning and Lathrop [3]. Kent [4]. Technical hurdles to commercial deployment of concentrated acid hydrolysis prior to 1980 were appropriate materials to resist corrosion, recovery and reuse of acid, and efficient recovery and concentration of sugars.

Masada addressed these issues beginning in the early 1990s by working with the Tennessee Valley Authority ("TVA") and its research partner, Mississippi State University, as well as the U.S. Department of Energy and the National Renewable Energy Laboratory. TVA researchers headed a governmental initiative in the 1970s and 1980s to develop economical alternative fuels using commercially available processes in response to increased concern about reliance on imported petroleum. TVA examined acid hydrolysis among other technologies and concluded that the generally low cost of competing fossil fuels made the economics marginal for utilization of agricultural and wood wastes as feedstock. However, they also projected that MSW-to-ethanol using acid hydrolysis had "more profitability because the waste has a negative cost", meaning the fees paid to dispose of waste. Broder and Barrier [5]. Using private investment Masada built upon TVA's research to solve technical and economic problems that hindered commercial deployment of this acid hydrolysis.

Besides technical hurdles, Masada also closely examined economic and financial hurdles to successfully deploy a waste-to-ethanol process. Three major external elements helped make Masada's process economically viable today. First, disposal costs have risen dramatically over the last 20 years in many markets. Second, reliable equipment to separate sugars from acid and to recycle acid are widely used and proven. Third, demand for fuel ethanol at a relatively consistent retail price in the USA has grown steadily. Production was approximately a record 1.77 billion gallons in 2001 [6] and annual production is projected to triple over the next few years [7]. Ethanol production grew nearly four fold between 1993 and 2000 in the European Union, reaching 64.5 million gallons excluding imports. Takash [8].

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Description of the CES OxyNol™ Process

The MRF: MSW receiving and preparation to feedstock

MSW including source separated materials are delivered to the mixed waste MRF during a daily 10 to 12 hour operating period. MSW is discharged on the tipping floor for inspection. Masada emphasizes MSW inspection and processing to remove as much non-cellulose material as possible, even if some material is not marketable. This approach avoids introduction of unwanted materials and reduces operation and capital costs downstream of the MRF. Unacceptable (e.g., hazardous waste) and un-processible wastes (e.g., leathers; synthetics) are segregated. Unacceptable wastes are removed from the facility by trained personnel. Un-processible waste are sent to traditional disposal sites. White goods (appliances such as refrigerators) are also separated on the tipping floor for recovery and recycling off-site.

The remainder of the MSW is placed on infeed conveyors where it is manually pre-sorted prior to entering a trommel screen. The trommel splits the MSW into three process streams: fines, middlings, and overs. Each of the three process lines contain manual, mechanical or electro-mechanic sorting devices to further divide each stream and to divert recyclable materials. A "de-stoner" is utilized to capture organic from fines for use as feedstock. The middlings and overs go to manual and mechanical sorting lines where glass, metals and plastics are removed and recovered and marketed as recyclables.

The MSW remaining after removing recyclables is fed to the shredder where it is reduced to a uniform size and conveyed to the dryer. The dryer dries this "feedstock" to facilitate hydrolysis and to eliminate odors. Feedstock storage areas are sized to allow 24 hour, 7 day per week operation of the downstream acid hydrolysis and ethanol production processes.

Sewage sludge processing

The sludge receiving facility accepts sludge in liquid and dewatered "cake" forms. Mixed liquor ("graywater") from co-located sewage treatment plant can be pumped directly to the Facility. Sludge blended in tanks is pumped to the heated sludge acidification tank where it is mixed with acid and acidic filtrate. The heat and acidification kills pathogens, reduces sludge solids, mobilizes heavy metals in the sludge and generates carbon dioxide. The "acidified biosolids" are dewatered and centrate from the dewatering trains may be used for hydrolyzate washing. Dewatered acidified biosolids are used to augment gasifier fuel.

Acid hydrolysis

The dried feedstock is placed on floor conveyors feeding one or more modular processing trains. Acid hydrolysis of the cellulose in the feedstock starts in the sulfuric acid mixers. Concentrated sulfuric acid (H_2SO_4) is used as a catalyst to

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react the feedstock in acid batch mixers. Black gel is formed and diluted with heated centrate from the sewage sludge processing or lignin de-watering train. Over 80 percent of the sulfuric acid used as a catalyst is recycled using acid evaporators. Demonstration scale testing optimized yields of sugar to commercially viable levels from cellulose extracted from incoming solid waste given the practical constraints of reaction time and variability in feedstock (e.g., paper coatings, inorganic contaminants, etc.).

After dilution, the diluted gel is cooked in heated vessels to complete the break down of cellulose to sugar. Cooking is accomplished with a reasonable residence time at 1atm and temperatures below 100°C to produce a hydrolyzate slurry. The slurry is dewatered and filtered. Solids are a renewable biomass fuel named"lignin residue" which is primarily unreacted cellulose and hemicellulose. Remnant solids made of un-reacted materials (e.g., finely divided glass, paper, plant fiber, and plastic) generally comprise less than 20 percent of the lignin residue (by weight). Lignin residue is repeatedly washed and filtered to minimize sugar losses and sulfur carryover prior to being used to produce facility steam in a fluidized bed gasifier. Liquid from the dewatered hydrolyzate slurry is an acid/sugar mixture.

Acid/Sugar separation, acid recycling and heavy metal control

The acid/sugar liquid is introduced into chromatographic columns to separate the sugar (glucose, mannose, and xylose) from the now diluted sulfuric acid. After separation, the acid is recycled and concentrated in a multiple effect evaporator. New acid is incrementally added to make up for loses.

The sugar stream from the acid/sugar separator is pumped to a reaction tank for pH adjustment with hydrated lime. Hydrated lime conditioning of the sugar stream creates a non-hazardous gypsum precipitate and heavy metals mobilized upstream are captured in this precipitate. This process step controls release of much of the following metals: iron, chromium, copper, lead, nickel, cadmium, cobalt, mercury, manganese, zinc, chromium and aluminum. The nonhazardous gypsum precipitate is thickened and sold or used as an alternate cover for landfills. The neutralized sugar solution is filtered, concentrated and sent to the fermentation and distillation area of the facility.

Fermentation and distillation

Alcohol production from concentrated sugar derived from cellulose in MSW uses traditional fermentation, distillation and dehydration. The fermentation process is a continuous, cascade system using standard brewer's yeast. Demonstration testing indicates that yields of sugar to ethanol should approach theoretical values at commercial scale. Carbon dioxide from the fermenters is captured, cleaned and compressed for sale as an industrial gas. After fermentation, the dilute ethanol is distilled, dehydrated and condensed before it is pumped to the ethanol storage.

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Related processes, residual waste and emissions

Environmental performance

The CES OxyNol™ process is designed to minimize solid, liquid, and air emissions to achieve superior environmental performance. Facility capacity, incoming waste characteristics, and co-location opportunities, combined with environmental regulations, drive environmental performance of each facility. Current OxyNol™ facility design and environmental models indicate emission levels are far less than traditional disposal methods due to enhanced processing and conversion of waste and application of sophisticated gasifier/boiler systems and environmental controls.

Gasifier and package Boiler

The lignin residue and acidified biosolids from the filtration steps are gasified in a circular bubbling fluidized bed system to generate steam for the OxyNol™ facility. A stand-by natural gas fired package boiler may be included for start-up and shut down. Air emission controls include a selective non-catalytic reduction, a spray dry absorber and bag house, in addition to separate scrubbers for the sludge receiving and the acid hydrolysis areas.

Air emissions and odor control

A primary design emphasis is control and minimization of odors and noxious emissions. In general, all contaminated streams of gas, air, or vapors from the process areas (depending on the type of contamination) are controlled either singly or through a combination of combustion, scrubbing, neutralizing, or operational controls.

Operational controls on the tipping floor are the first line of defense to prohibit noxious odors from MSW. These primary controls include:

- Rapid material throughput and processing
- Doors closed when not in use
- Doors located away from receptors
- Good housekeeping measures
- No storage during normal operations

Rapid processing of MSW into dried feedstock after sorting in the Masada MRF assures odor control since the odor causing degradation of MSW essentially stops when the moisture content of feedstock is sufficiently reduced. Also, contingency measures mandate switching operations to full transfer station mode in the event of MRF shutdowns.

Secondary controls during MSW preparation include an odor misting system utilized as needed to neutralize odors from the tipping floor and other areas where unprocessed MSW or undried feedstock is held. The system consists of an odor

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neutralizing chemical storage tank, a high-pressure pump, and strategically located fogging nozzles to distribute an odor-neutralizing chemical. Additionally MRF designs may include an exhaust system which will replace building air and pass the discharged air through a particle and odor filtration system. Emissions from the shredder and dryer are controlled by dedicated scrubbers to meet applicable air regulations, and to address fugitive emissions of particulate matter and (possibly) offensive odors.

Sewage sludge areas

The sewage sludge system scrubber receives gasses collected from the sewage sludge receiving area, the sludge storage tank, the sludge centrifuge and the hot filtrate tank. These gasses are scrubbed with NaOH liquor. The gases discharged from the scrubber may be additionally treated with an odor misting system.

The unloading area sludge storage tank is ventilated to the sludge system scrubber for odor control. The entire sludge receiving and processing area is curbed to contain spills. Any spills that might occur are contained in a dedicated sump, where they are fed back into the process.

Hydrolysis and dewatering areas

The acid mixers, gel blend tank, and cooking tank vents are scrubbed in the H_2SO_4 scrubber. The gasses from the H_2SO_4 scrubber are used as combustion air in the gasifier to remove VOC's. The vents from the presses, press filtrate tanks, lignin wash tank and associated conveyors are treated in the process building scrubber.

Liquid effluent

Facility waste water has a high BOD primarily composed of unfermented five carbon sugars. Depending on siting constraints and co-location opportunities, two options are available for pretreatment of facility liquid effluent. Traditional anaerobic-aerobic batch treatment can reduce high BOD wastewater to levels normally accepted in municipal treatment facilities. Alternatively, an evaporative system can achieve essentially zero discharge of process effluent and also create usable condensate that further reduces water demands from off site sources. Residual solids from both systems are routed back into the sludge processing system. Methane from anaerobic digesters is used to offset external natural gas purchases.

Residual solids disposal

The primary source of residual solids from a Masada OxyNol™ facility consists of unacceptable and unprocessible wastes separated on the tipping floor and during MSW processing in the MRF. Incremental amounts of generally non-marketable

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materials such as bag plastic, PVC or glass removed to improve the quality of post-MRF feedstock may augment this waste stream. Masada evaluates local market demand for add-on processing units to allow on-site processing of bulky waste or wood, but even absent these additional processing units, residual solid waste requiring traditional disposal does not typically exceed 15 percent (by weight) of incoming MSW. When combined with incoming sludge processing capacity, total solid waste disposal required is less than 10 percent (by weight) of the total incoming waste stream (depending on incoming waste composition and local markets).

Facility siting options

CES OxyNol™ facilities are designed to meet the volume and siting requirements of the specific metropolitan area served. Due to multiple processing trains a plant can be optimized to address quantities of MSW and sewage sludge in a local or regional area (nominally in a radius 50 to 100 miles [80 to 160 km] depending on population density). Appropriate site locations can be selected to minimize costs of transferring and transporting wastes which are the highest single cost component of most waste disposal programs serving the public from curb to disposal. A Masada OxyNol™ plant is suitable for sites in industrial areas, in areas that handle solid waste, on "brownfield"sites, and other similar locations.

Co-locating the CES OxyNol™ process with a sewage treatment plant has numerous benefits including cost-effective sludge processing at the OxyNol™ plant and use of graywater and treated effluent from the sewer treatment plant. Co-locating lignin residue incrementally added to coal fired boilers has been shown to reduce air emissions and enhance combustion. High pressure steam producers such as electrical generating plants that use coal offer prime co-locating opportunities since low pressure "trash" steam can be utilized for process steam in the OxyNol™ facility while renewable lignin can be used by the steam producer.

Summary

The Masada OxyNol™ process addresses pressing environmental and fiscal needs for many local governmental authorities by achieving 90 percent beneficial re-use and recycling of solid waste, sewage sludge, and other wastes. Based on the nearly century old acid hydrolysis process, Masada's proprietary CES OxNol process is an environmentally responsible alternative to incineration and landfilling. The process is commercially viable today because of current waste markets demand higher disposal fees, current ethanol markets are favorable, and development work accomplished in association with TVA, NREL and USDOE is predicated on reliable existing equipment for critical unit operations. Deployment opportunities depend on financing arrangements desired by the host authority and on related market and site conditions. By giving local authorities control of waste disposal escalating

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disposal costs can be stabilized and new economic development opportunities can be created.

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