INTEGRATED THERMO-BIOREFINERY

Michael Theroux
Theroux Environmental, California, USA

Keywords: allothermal, autothermal, biomass, biofuel, biorefinery, conversion, devolatilization, distributed energy, gasification, incineration, plasma, pyrolysis, recovery, secondary recycling, thermal continuum, validation, waste.

Contents

Summary

This paper explores the utility of including a thermal processing platform for multi-technologic conversion of feedstock into electrical and thermal energy, fuels, and co-products. Conversion of a waste liability into a commodity asset can bring about the largest gain; thermo-biorefinery resource recovery is placed in context of regional waste management. Characteristics of feedstock are examined for thermal biorefinery

processing; biomass is contrasted to waste for heating value, intermediary products, contaminant profile, and variability.

Conversion, which combined both dissociation and recombination of feedstock requires application and control of energy; the energetic balance of a thermal platform for biorefining is considered. Optimal process design varies by the desired product(s), and there is no single “best” combination of multi-technologic complement and operational method suitable for all applications. The benefits of a flexible, integrated design are discussed. When thermal energy generation is closely integrated with the process load to be served, synergies extend beyond savings on equipment and controls: one system’s waste becomes the next system’s feedstock in a multi-process Integrated Thermo-BioRefinery (ITBR).

Thermal technology energetics help place in context the key technical approaches of the thermal complement to an ITBR. Parameters of the thermal continuum must be compared to characteristics of available feedstock, and to manufacture of products gauged to best meet market demand.

Two forms of thermal processing, destructive and non-destructive, are compared. The former is most appropriate when volume reduction and heat production are the primary requirements; the later allows interception, characterization and modification of the intermediary products. The ability for non-destructive thermal processing within an ITBR to effect conversion of feedstock into fuels and chemicals deserves special consideration. For this reason, a “bright line” is drawn between incineration and conversion.

A sustainable ITBR should combine socio-economic and industrial integration to encompass a thorough understanding of the complexity of available feedstock with access to the best available processing and control technologies and methods, to achieve the system-flexible optimal recovery and intermediary product re-manufacturing needed to meet the market’s ever-changing demand for to-specification commodities.

1. Introduction

The entrenched habits of a “throw-away society” continue to take an unconscionable toll on our environment, our economy and our quality of life. Yet our demand for manufactured goods, and the generation of waste as a bi-product, isn’t likely to stop or even stabilize. Production of goods from virgin stock must give way wherever possible to remanufacturing from recovered goods and resources; this conserves both our finite raw material supply and the energy required. If this is to be our new commodities paradigm, how then can we optimize the process? It is difficult to “unbake the cake”: chemical changes that put something together are not simply reversed, such that we can recover the base materials.

Integrated resource management may be defined as goods reclamation and recycling, remanufacturing for re-use, and recovery through advanced technologic bio-refining. Waste management must be reborn as resource management and recovery, with the object of near-zero disposal. The entire materials flow must be redesigned to segregate all useful elements to be sent back for re-use; residuals not reclaimed must then be subjected to appropriate processing that can cleanly take apart, at the molecular level, almost anything that would otherwise be destined for ultimate disposal.

At the center, there needs to be a flexible, closely-integrated and controlled suite of tools capable of introducing the energy necessary to break the molecular bonds of the feedstock presented. We can combine at need the kinetic energy of shears and grinders, the microbial energy of decomposition and fermentation, and the thermal energy of controlled heating with either combustion or conversion. This paper focuses on the last critical component of decomposition and recovery: the controlled application of thermal energy.

Resource recovery requires management of a process flow, with a front-end infrastructure for feedstock acquisition, a multi-technology mid-section dedicated to decomposition, conversion and impact minimization, and an extensive “back-end” producing diverse products for re-introduction to the marketplace. To clearly view this “middle” tool complement in context and especially to understand the utility of thermal energy application in integrated processing, one must start at the front end of the process stream, with the feedstock. Once the source of a material is recognized and that material characterized, careful selection and integration of available processing systems can provide a pathway for return to beneficial use.

2. Priorities of Waste Management and Resource Recovery

Mixed municipal and industrial wastes and bi-products constitute an overwhelming social liability, yet are also a complex and ever-shifting resource for recovery, dependent as much on governance policies and market demands as on process capability and material availability. Waste management can therefore be described as a hierarchy of choice [see also– *Environmental Biotechnology*].

The United States Environmental Protection Agency (USEPA) established a “National Waste Management Hierarchy” in 1989, providing guidance to first promote waste prevention and reduction, then prepare for reuse where discards can be cleaned and immediately put back into the marketplace, next recycle (including composting) involving physical recovery and remanufacturing of discarded materials, and lastly, disposal by burial in landfills or destructive incineration.

Source segregation for beneficial use of the remnants of manufacturing removes usable goods before being released as “waste”, and when put to beneficial use effectively prevents their disposal. Primary recycling separating usable goods from mixed waste streams, as accomplished at a material recovery facility (MRF), is now standard practice in many regions, globally. Advanced mass-burn incinerators are now far cleaner than open burning or “burn barrels”. The modern designs of sanitary landfills provide superior means of disposal over open dumping.

For all of our care however, slightly less than one third of waste generated in the United States (US) in 2006 found its way back into the marketplace, while the tonnage discarded and disposed continues to increase. Increased attention to the detail of resource management and recovery has made certain facts quite clear: (1) the extreme volume, and variability, of waste now extends beyond what we can effectively control through source reduction, reuse, recycling, and our best methods of disposal; (2) there is often as much or more value hidden in what we throw away, than in what we keep; and (3) if we find clean and economical ways to convert those materials, instead of dedicating our time and resources on disposal, we would observe a positive impact throughout our resource-dependent society.

"Once a waste, always a waste" may be an aphorism of the past. Solid Waste can be defined to mean any "putrescible or non-putrescible solid, semi-solid and liquid…" material discarded by its owner when no longer considered useful. Materials legally become "waste" upon release by that owner to the environment, and where institutionalized waste management regimes are in place, the chain of custody transfers ownership to the collection and hauling entity, on to the MRF, and finally to incineration or landfill.

Global perspectives on the waste management hierarchy are changing. The European Union (EU) passed a directive in October 2008 to insert recovery as the appropriate step between recycling and disposal. Finding # 19 of the Directive provides a clear goal: *"The definitions of recovery and disposal need to be modified in order to ensure a clear distinction between the two concepts, based on a genuine difference in environmental impact through the substitution of natural resources in the economy and recognizing the potential benefits to the environment and human health of using waste as a resource."*

The Directive in Article 3 #15, "Definitions" provides the following, in part: *""recovery" means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy."* [spelling per official text]

This critical addition now directs the EU to recognize and incorporate the recovery of waste-sourced resources for purposes of energy and fuels generation in the waste management hierarchy. The benefits include replacement of other materials (such as petroleum-based products) currently being used for energy and fuel, reduced environmental impacts (especially greenhouse gas emissions) to be garnered through conversion, and diversion of waste from disposal.

3. Secondary Recycling via Thermal Recovery

Beyond the recognizable paper, glass, metal and plastic fragments that can be sorted and removed, it is beneficial to convert the post-recycling residuals into clean base materials for return to the market cycle by what might be termed secondary recycling. When such residuals become feedstock, conversion will require process complexity. Pre-conversion processing can accomplish size reduction, moisture control and separation based upon friability, absorption, flotation, magnetism and molecular density; post-conversion processing can further clean and refine intermediary products to environmental and market specifications.

Synergies available through systems integration allow us to optimize multiple technologic approaches, drawing upon our best physical, biological and thermochemical methods. This potential for synergistic processing is changing the basis of resource management. With this change, a new socio-economic vision can be pursued where every bit of value is extracted from those precious resources that have for so long been simply discarded.

Our goal then is to cleanly convert the broadest array possible of available crops, by-products and wastes, whether biomass or otherwise, into a diverse and flexible suite of safe, economical and beneficial products. In addition to providing "building block" foundation chemicals, commodities include thermal and electrical energy, non-petroleum fuels and fuel additives, and diverse "bio-products" such as bioplastics, nutraceuticals, fertilizers, and high-quality animal foods. Where incineration simply combusts the feedstock as a fuel and produces heat and CO2, thermal conversion technologies convert the feedstock to an intermediate product, syngas, which can then be utilized directly or further processed/recombined into a wide range of products and by-products. [see also– *Special Processes for Products, Fuel and Energy*].

4. Feedstock Considerations

The thermal processing complement of an ITBR utilizes retention time, temperature regime, and oxygenation to affect control over the decomposition and conversion of feedstock to energy and products; each control mechanism is responsive to the molecular composition of the feedstock. Biorefining causes input raw materials to be reformed to new products; with the feedstock comes whatever contaminants that material contains, and these also are impacted (for better or worse) by molecular disassembly and reconfiguration. Further, system energetics provides an ample window of reformation, wherein previously innocuous chemical constituents can be recombined into less-than-beneficial products. Feedstock characterization, technology application and contaminant control must proceed together [see also – *Biomass Feedstocks*].

The proper technology complement and operational mode needed for optimal resource recovery and contaminant control is thus largely determined by the characteristics of a feedstock, and this needs to be both initially understood and constantly monitored during processing. Feedstock characteristics dictate the acceptability for a specific process flow, and largely determine paths of conversion to products. The degree of homogeneity with respect to density, contaminant levels, moisture, carbon-nitrogen balance, and heating value all must be taken into consideration to choose the right process flow, and the extent of pre-processing necessary.

In almost every civilized region, a great wealth of base material resource is constantly being wasted; institutionalized waste recycling remains only 50 percent effective at best, and many forms of waste never enter an organized regime of waste management. Waste and bi-product sourced feedstock acquisition therefore bridges all paradigms; reclaiming materials from vegetation management and forestry practices will require a different skill set than will utilization of urban, institutional post-consumer food wastes. Each interactive suite of feedstock sources exhibits inherent cycles of availability, volumes, contaminant spiking, cost/benefit valuation, governmental oversight and social importance. A simplified diagram in Figure 1 helps visualize the typical ITBR - feedstock source integration.

ITBR “Power Parks” can co-locate and integrate Bioenergy and Biofuels Conversion Technologies to absorb a regional supply chain of Urban, Agricultural and Forest feedstock sources into a bioenergy / biofuels processing campus.

Any one region will present multiple categories of feedstock, and each generation category is distinct. Urban wastes are controlled by a different set of regulations than forestry residues; agricultural stover generated during grain harvesting requires different logistics than does collection and handling of organics from coastal fishery processing plants. Complexity within and between categories requires constant active reassessment and flexible management, yet it is this diversity that can ensure sustainable feedstock sourcing (see also– *Socio-economic strategies for sustainability).* This inherent variability, this non-homogeneity, also determines the processing design of an ITBR. Technical details are demanding, but a common-sense approach offered by the USEPA can provide valuable guidance: if the waste is wet, keep it wet in processing, but if it is already dry, keep it dry.

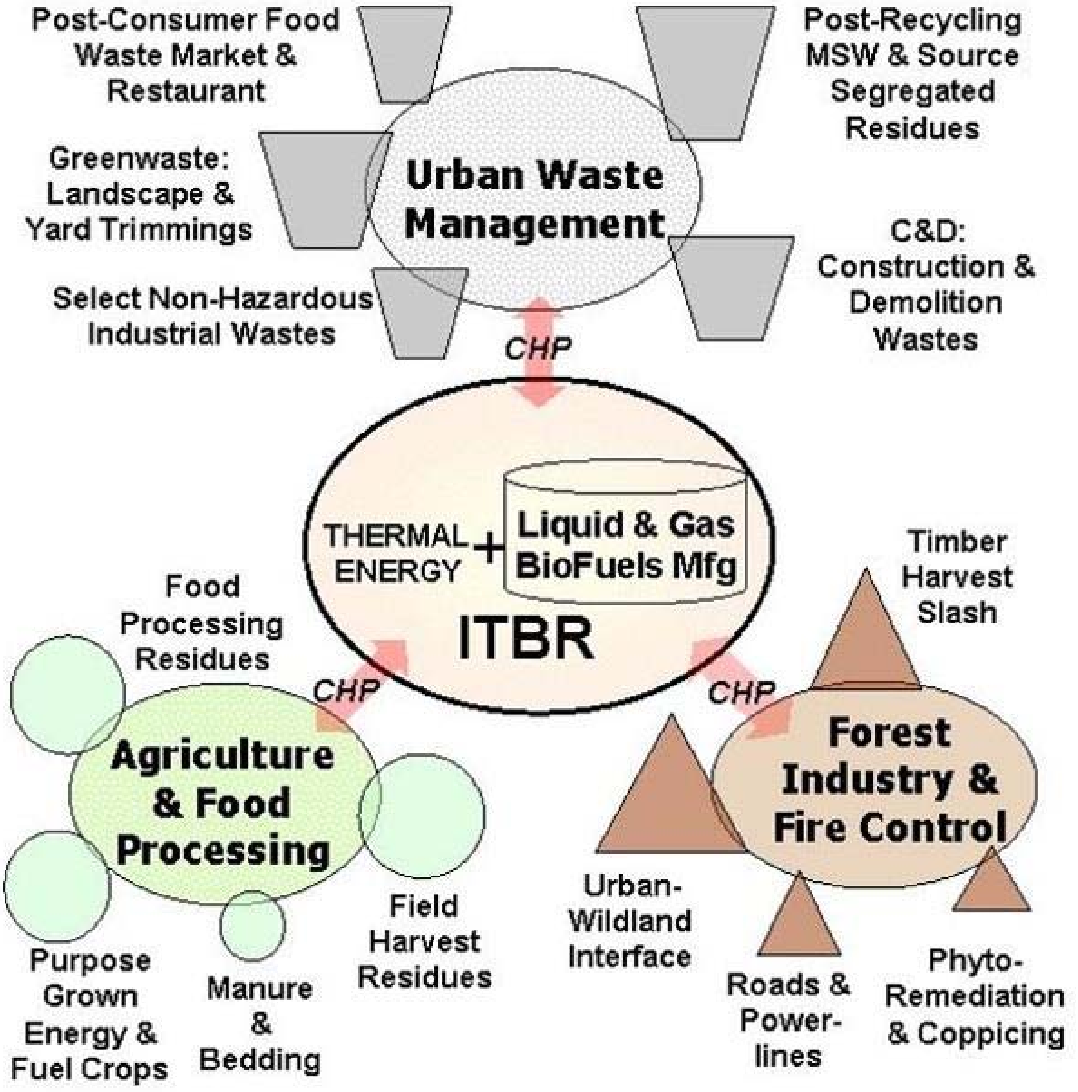

Figure 1. ITBR Supply Chain

Heating value is a metric of the recoverable latent energy stored in a feedstock. The dense and relatively impervious carbon molecules of cellulose and hemicellulose do not easily give up their inherent energy. Measured in the standard of British thermal units (Btu) common to heat-producing fuels assessment, field-dry woody biomass can provide 4500 to perhaps 8500 Btu per pound of feedstock, about two-thirds of that contained in coal. Consumption of a fuel for energy generation per unit time is referred to as heat rate, measured (for electricity) as heat use to electric energy generated per hour, or Btu per kilowatt hour (Btu/KWh). Field moisture levels are usually 40 percent to 60 percent, requiring drying, and that drying action requires energy; thus, freshly collected moist woody biomass may effectively produce as little as one-fourth the energy as present in the same weight of coal, given the energy needed to drive off the water. Once thoroughly dried, however, biomass heating values range from a low of 6000 to over 9000 Btu per bone-dry pound of feedstock.

The molecular composition of woody biomass is quite homogenous when compared to municipal or industrial waste-derived fuels; the ratios of carbon, hydrogen and oxygen vary little from one biomass material to the next. This greatly simplifies maintenance of optimal heat, air and retention timing. Nitrogen varies considerably in biomass feedstock: some organics contain “fertilizer-grade” amounts, others contain little at all. Yet one of the primary benefits of feedstock homogeneity is that whatever the contaminant profile of a particular source of discarded biomass, it will remain relatively consistent.

In general, woody biomass by-products of forest and agricultural operations are not legally deemed “waste” unless they become contaminated with more than 10 percent non-biomass refuse, such as plastics, metals, and chemicals ancillary to those practices, or have become mixed with common municipal solid waste (MSW). Problems do exist in contaminant control, and caution is warranted. Nails, staples and paint add nickel, vanadium and lead. Certain plants concentrate toxins from the soil: nut crops can up-take heavy metals from orchard soils or imported composts, and sequester the toxins in branch tips; trimmings used as fuel can concentrate hazardous levels in the ash.

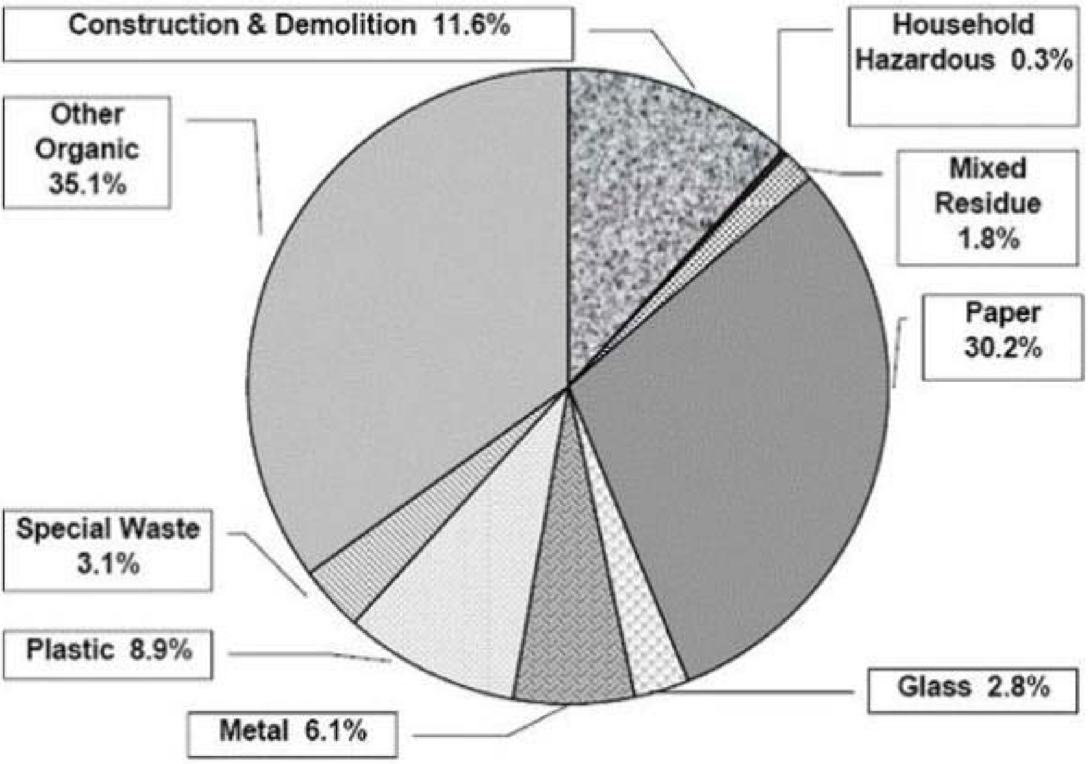

Figure 2. Municipal Solid Waste Characterization

Extraneous materials can dramatically contribute to contaminants carrying through conversion processes; pesticide bags and plastic irrigation tubing discarded into orchard-trimmings used as feedstock can create dangerous, highly toxic compounds during thermal processing. Toxins can be anticipated and successfully managed with pre-processing screening. Removing contaminants prior to thermal processing is generally simpler and more cost-effective than controlling complex emissions.

Compared to woody biomass, MSW presents constantly changing molecular diversity and contaminant profile. Although the non-anthropogenic “biomass” fraction of MSW ranges roughly from 60 percent to 80 percent, as shown in Figure 2 below, it is the heterogeneity of molecular composition, and the constantly varying contaminant profile, that makes conversion of MSW the technical and socio-economic challenge that it is. Combining “Paper” and “Other Waste” categories in this standard MSW characterization, combustible biomass comprises over 65 percent. When inert materials are removed, MSW can contain upwards of 80 percent potential feedstock for thermal conversion.

-
-
-

Bibliography

California Energy Commission. July 2006. Technology Roadmap: Energy Efficiency in California’s Food Processing Industry. CEC-500-2006-073. [Application of thermal energy for process efficiency]

Cascadia Consulting Group et.al, for California Integrated Waste Management Board.1999. Statewide Waste Characterization Study: Results and Final Report. [Municipal solid waste characterization].

European Union 2008. EU Register, Directive 2008/…/EC of the European Parliament and of the Council. Brussels, 2 October 2008. http://register.consilium.europa.eu/pdf/en/08/st03/st03646.en08.pdf. [for use of the Parliament and of the Council, regarding “waste”: inserts category of “recovery”]

Jenkins, Brian M., LL Baxter, TR Miles Jr., TR Miles, 1998. Combustion Properties of Biomass, Fuel Processing Technology 54 1998 17–46. [Biomass contaminant profile, detailed breakdown]

Juniper Consultancy Services Ltd., Second Edition, September 2001. Pyrolysis & Gasification of Waste – A Worldwide Technology & Business Review. Volume 2: Technologies & Processes; ppg 39-42. ISBN for 2-vol set: 0-9534305-6-1. [Conversion vs Incineration]

National Academy of Science (NAS). 2004. Dioxin Reassessment, Review Draft. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=87843 [Dioxin & Furan Toxins]

National Renewable Energy Laboratory. July 2002. The Biomass Economy. NREL/JA-810-31967. www.eere.energy.gov/afdc/pdfs/6748.pdf. [ITBR concepts of the US National Renewable Energy Laboratory (NREL), www.nrel.gov/biomass/biorefinery.html]

Sims, Ralph E. 2002. The Brilliance of Bioenergy in Business and Practice. James & James Ltd publishers. London, UK. Ppg 143-167, esp. pg. 145.

US EPA. 1989. Solid Waste Hierarchy Fact Sheet: www.epa.gov/msw/facts.htm. [Direction for United States characterization of waste management]

US EPA. 2001. A Citizen’s Guide to Vitrification, EPA 542-F-01-017. 2001. www.epa.gov/superfund/community/pdfs/suppmaterials/treatmenttech/vitrification.pdf [Plasma vitrification] van Loo, Sjaak. 2008. The Handbook of Biomass Combustion & Co-Firing. IES Task 32 Leader, International Energy Agency (IEA). Ed.: Chapter 9: Environmental Aspects of Biomass Combustion, pp. 329-378. [Contaminant Identification and Control]

Biographical Sketch

Michael Theroux, Vice President, JDMT, INC. dba THEROUX ENVIRONMENTAL, is a California Registered Environmental Health Specialist with more than 30 years of diverse environmental assessment, waste management and resource recovery experience. Mr. Theroux provides leadership in inter-agency, multi-disciplinary project management, permitting and regulatory compliance. Mr. Theroux provides technical and regulatory path assistance for urban, agricultural and forest-sourced waste-derived feedstock characterization, conversion technology permissibility and systems efficiency, and Distributed Energy / Combined Heat and Power (DE/CHP) market analyses. Clients include industrial facility owners, systems developers, municipalities, non-profit and educational institutions, task forces and special councils, and state and federal agencies. Most recently, Mr. Theroux has focused on the complex issues surrounding conversion of waste derived feedstock to renewable energy and green fuels. This work has encompassed contaminant tracking and management for toxic emissions control, biofuel certification and valuation, and direct interaction with developers of a range of technical pre-commercial and commercial approaches including both thermal and non-thermal organics conversion. Mr. Theroux is assisting the California State Legislature and state and county agencies in exploring the synergies and barriers between conversion of waste to energy and biofuels, and reduction of greenhouse gas emissions.