

Waste Conversion for Resource Recovery

An Examination of Terminology, Infrastructure, Regulation and Standards

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Toward the New Hierarchy

It seems so pointless to throw our National Resources into a hole and pay to keep them there, just to once again pay to put virgin resources back into the one-way flow of our supply chain. Yet anyone who has been witness to indiscriminant “trashing” of our environment understands that today’s best management practices are a grand improvement over past calamities.

We can’t (yet) stop throwing away at least a fraction of what we acquire. After consumer choice effects Reduction of packaging (for example) and even after used items have indeed been Reused, utility eventually expires and the remainder will be discarded by the owner. This release of a discarded item identifies it in law as a “waste”, and passes ownership back to whatever means society at large has designated for waste management.

We *can* maintain the socially and environmentally sound practice of extracting materials that can be Recycled from the mixed municipal solid waste (MSW) stream. This process of segregating waste and returning materials to the supply chain is not without cost, but the alternative of *no* recycling is far worse, especially socially. We *must* break this self-destructive “throw-away” habit, and Recycling helps retrain society in addition to the obvious reduction in disposal.

Once Recycling has been accomplished, however, there remains a *post-recycling residual*. This residual is highly heterogeneous, following as it does the nature of MSW, and must be assumed to occasionally contain every possible form of contaminant that originally was a constituent of the initial discard.

If the only goal is to reduce the volume and toxicity of that residual waste, sanitary disposal can be managed through state-of-the art landfilling, or by *incineration*, where wastes are “rendered to ash”. But incineration is still a form of disposal, and Disposal does not *recover* the resource, only places it permanently “out of the way”. What a waste.

We have means now to carefully “un-bake the cake” of that complex residual waste accumulation with a variety of methods we might recognize collectively as *reverse manufacturing*. These processes disassemble waste components at the molecular level, and prepare the foundation resources to be remanufactured into New Goods. When this ability is properly used as a last-resort instead of disposal in an ordered Waste Management Hierarchy, molecular reclamation can be called **Recovery**.

The European Union recently modified their Waste Management Hierarchy. They have now officially added a fifth step of preference in their overall schema for waste-management-by-choice: **Reduce, Reuse, Recycle ... Recover ... Dispose**. Logic prevails; hopefully, our own national common sense will follow suit.

The lines are drawn, but the fine gradations between these Waste Management Hierarchy steps tend to represent a continuum, instead of offering clear and discrete categories of action.

What is “Recovery”, and how may this step be accomplished cleanly and economically? What must we do to firmly establish this paradigm not just in institutionalized law, but also more broadly as a universal part of our social and industrial infrastructure?

Conversion for Optimal Recovery

Conversion of discarded waste materials at the molecular level for recovery of intrinsic resources requires two parts: (1) the technology *by design* must allow access to intermediary products, such that those chars, liquids and/or gases can be sampled, characterized, and modified as needed to result in ultra-clean final products; and (2) this process of interception, characterization and modification must be accomplished *by operational mode*, such that the information feed-back loop that intermediary sampling facilitates is actually acted upon.

A decade ago, requirements for real-time sensing and computer analysis of the intricate changes occurring within the explosive reactions of a thermal treatment unit were far too expensive, requiring massive data handling capabilities not available outside universities and military facilities. Today, small and inexpensive computers can assimilate those same data, the algorithms can be applied, and the resulting analyses become feed-back for programmable logic controls (PLCs) directing the moment-by-moment operation of the equipment.

Energy is the underlying requirement, when molecular bonds are to be separated. The surrounding molecules must be sufficiently energized to overcome the strength of each bond to be disassembled, and the input amount varies depending on that inherent bonding tenacity. That energy can be introduced in a number of ways, some better suited to managing specific waste residuals than others. Some resources hold more molecular-level value than others in the marketplace. The market will naturally promote *cost-effective recovery*. Those that believe an economy should be solely market-based might argue that this guideline should be sufficient. Yet cheaper is not necessarily better.

Some methods for energizing and breaking molecular bonds are more costly than others. Technical designs and modes of operation that can effectively recovery resources from homogenous waste types may not be sufficiently robust for highly heterogeneous feedstock. Technical specifications become important, defining “envelopes” of design and operation according to the input, and the intended end-product. Permitting processes guide proper usage, and implement restrictions on use of the wrong tool for the job at hand. These checks on the market forces need to be constructed only where optimization for cleanliness and percentage recovery trumps the underlying economics.

As the molecular diversity of the feedstock increases, the nature of bonds requiring deconstruction also varies. Some of the most toxic residuals are also the most difficult to devolve; to maximize environmental cleanliness, the conversion process must be optimized to effectively reduce these most reticent fractions to their non-toxic constituents. Environmental concern must drive Conversion Technology design and operation toward both maximum recovery of resources AND maximum reduction of toxicity; these responses to appropriate environmental concern become *performance standards*.

Many of the technologies available for conversion of waste into recoverable resources have been around for half a century or more. Our industrial ability to design, operate, monitor and modify the process “on the fly” is only now able to meet our modern and ever-tightening standards of environmental cleanliness. Design and operational control advances allow conversion operations to be scaled to fit within our communities. Conversion of wastes *at the*

source (rather than regionally) can dramatically reduce shipped volume and weight, thus minimizing both cost and impact of transport. Community-scaled, ultra-clean conversion of post-recycling municipal solid waste residual for cost-effective recovery of our natural resources: *this* is new. And because it is new, much remains to be developed to define, and to ensure, proper integration within this shifting paradigm that now informs our Waste Management Hierarchy.

The Integrated Conversion Platform

What are the tools of this new Recovery trade? What do these systems look like; where can they be located? How “clean” is *clean*?

First: there is no “silver bullet”, no single system or method of operation that can handle every molecular recovery challenge. Our waste stream is simply too complex. Our best hope is to carefully select “best of class”, in a number of classes, each tuned to manage a breadth of materials as feedstock. We may then combine a suite of these selected modules into one integrated process flow, capable of optimally receiving, processing and recovering the greatest degree of resources available for conversion, in any particular region. The optimal *conversion platform*, therefore, would be an integration of subsystems, custom designed to effectively process the region’s materials requiring conversion and recovery.

One basic waste conversion guideline for conversion process selection has been offered by the Environmental Protection Agency, as part of their AgStar program: if the waste is wet, keep it wet; if dry, keep it dry.

Of course, “waste” comes in all degrees of moisture as well as molecular diversity, and conversion processes have developed over time to meet these widely disparate characteristics. Three basic categories of Conversion Platform, or integrated mechanisms: *thermal*, *microbial* and *chemical / kinetic*. Each category contains technical complements proficient at conversion across the range of the moisture and molecular profile.

Thermal Conversion. Technologies based upon Pyrolysis, Gasification and Plasma effect carbon molecule breakdown to create a molecularly rich selection of solid, liquid and/or gas, depending on the feedstock, the system and its various modes of operation.

Optimal Operation - Our goal is to create enough thermal energy in the retort chamber to break molecular bonds, while retaining as much of the value as possible. There are three controls we can adjust over our *mode of operation*, given any specific technology: (1) *feedstock*, the still-bound molecular resources we which to take apart and reconfigure; (2) *retention*, the time the feedstock remains in the chamber; and (3) the amount of oxygen (or similar bond-filling elemental) allowed to interact with that feedstock during its time in the retort. Three “legs” of control provide flexibility and resilience.

Again, the degree of heterogeneity of molecular structure enters the equation: the system’s sensing, data analysis and PLC feedback control needs to constantly provide for conversion of the greatest challenge presented - the highest contaminant spike, the most explosive heat value. Wood chips vary little molecularly as a feedstock; MSW residuals vary dramatically.

Molecular dissociation and instability is the condition that allows us to direct molecular recombination to *reform* to desired foundation chemicals and fuels. It is also the condition that if not properly controlled, can create some of the most extreme toxins. Accessing hot char, oil and/or producer gas for purposes of characterization, separation, and reforming is a difficult,

often dangerous exercise. Once the molecular “cake” of waste is unbaked, much of the *real* work of Recovery has just started.

Regulatory Dysfunction - The California Public Resources Code currently includes a prescriptive standard that stipulates mode of operation where there is to be no added (or *excess*) oxygen, other than as needed for temperature control. Change in temperature is in affect a *symptom*, not a controlling cause; it is one of the physical conditions we can monitor as an indicator of the results of the three-part conversion reaction control. An operator can raise or lower temperature by altering any one or more of the input factors of feedstock, retention time and/or oxygenation. Constraints applied to only one control simply shift the operational emphasis to the other two.

The law does not stipulate that *minimum* temperatures be maintained, nor is there a direct correlation with maximum contaminant control. The language only provides that an *excess* of oxygen not be used, beyond whatever thermal set-point is established. If higher temperature regimes are to be achieved and maintained, greater through-put rates and/or introduction of less reticent feedstock must become the compensating control factor(s), rather than introduction of more oxygen. Beyond being terribly confusing, this “two-legged stool” approach restricts process optimization, especially when conversion must respond in an instant to the vagaries of constantly-varying feedstock such as our target, post-recycling MSW residual.

Microbial Conversion. Molecular breakdown is a *natural*, for bacteria, fungus and a few other very small, simple-celled organisms. Some work best wet, some effectively convert high-solids slurries, others can “digest” dry feedstock. There are high-temperature microbes, and there are those that function in extreme cold. Some microbes do their best work in near or complete absence of oxygen (anaerobic processing; fermentation); other demand a constant high level of oxygen to function (aerobic processing; composting). Still others (yeast strains, for example), can operate with varying levels, and often the products of their molecular breakdown can be adjusted by varying the oxygen percentage as one of the available control factors. All the myriad microbial processes offer keys to Recovery, when properly harnessed in a controlled process flow: whatever they eat, they break down and recombine into simpler molecular structures. Ours is the task of selection and husbandry.

Optimal Operation – Any population of microbes will act according to their genetic make-up, in concert with (1) *feedstock*, the resource to be reconfigured; (2) *retention*, the time the feedstock remains in the chamber; and (3) the amount of oxygen (or similar bond-filling elemental) interacting with that microbial population as it consumes and converts the feedstock during its time in the retort. Again, we have the three “legs” of control that provide operational flexibility and resilience.

Again, we can vary one, two or all of these controls to optimize for a specific desired outcome, and change this “on the fly” with the critical aid of real-time sensing, computerized analysis and system operations feedback.

Regulatory Dysfunction – For *microbial* conversion, the regulatory language is less specific and perhaps more forgiving, if thoroughly inaccurate to the point of absurdity. Conflicting permitting standards prescriptively restrict an operator’s ability to select an optimal feedstock blend specific to the requirements of the technology and the desired products of the conversion. Those that would convert animal manure microbially to recovery fuel gases and liquids cannot add necessary nutrients found in available post-consumer food waste, even when management of this municipal waste fraction is problematic at best, for the existing waste management regime.

Perhaps a more basic error, if less objectionable, is the technically inaccurate depiction of *all* microbially-driven conversion as “composting”. Our federal law provides definitions for and conditions appropriate to a group of related processes referred to as *composting*; these are primarily designed to protect the public health by reducing the pathogenicity of the feedstock. The far more complex issue of molecular decomposition and resource recovery involved in Conversion is ill-suited to being lumped in with composting, per se. There are more exceptions than fitting examples; new terms and standards are needed.

Chemical / Kinetic Conversion. Molecular bond energy certainly can be broken using various combinations of chemicals, positive and negative pressures, and motion. Our bodies rely on these principles as much or more than upon enteric microbiota ... the “bugs” in our guts ... and every transfer of energy from our food through our blood to our nervous system is conferred by breaking down a complex molecular structure specifically to harness the energy released.

Optimal Operation - This energetic decomposition and conversion in our bodies usually occurs via *enzymes*. Our understanding of what enzymes are, how they function, and how they can be controlled has transferred in part to the field of resource recovery: the science of *enzymatic hydrolysis* is one of the most promising for controlled conversion of recalcitrant large-chain woody fiber molecules into biofuels.

Acidity of a substrate tends to control solubility: basic pH keeps molecules stable and insoluble, while acidic conditions rip the molecular structures apart and make them more like to dissolve into other fluids. *Acid Hydrolysis* (with greatly varying strengths of the acidic condition) is an “old standard”, a naturally occurring process that breaks down and puts into solution both organic and inorganic materials. When used for *conversion*, acid hydrolysis can “grind” and homogenize the larger molecules into smaller, more easily managed fragments.

Curious changes take place, in extremes of size, temperature and pressure: Super-Critical Water Oxidation” (or SCWO) is a field that has been shown effective for decomposition of feedstock containing highly toxic contaminants and/or explosive tendencies; the military finds SCWO quite useful for decommissioning munitions and drugs. The concept of using SCWO for *recovery* is only recently following its use for disposal. Similarly obtuse and astounding are the changes that take place at the sub-molecular scale: aspects of *nano-technology* impart control over molecular structure surface tension, facilitating access to and decomposition of those structures in new and dramatic ways.

Regulatory Dysfunction – If these processes are no less necessary for integrated conversion of waste and recovery of resources than are thermal and microbial methods, they are also new to the regulations erected. The steps necessary to reverse and “decommission” what our elite manufacturing processes have so carefully built will naturally include all of the methods used to build those molecular constructs. Manufacturing is innately understood to live or die by the *performance* of the products created. Yet these methods entering our industrial tool-box to take those materials apart, separate them, and ready them for re-manufacturing are somehow held to a different and most often, *prescriptive*, standard.

Conclusions

Science *must* lead this field of Conversion for Recovery, both in the necessary research and development, and in the design and operation of integrated platforms of Conversion Technologies. The guidelines developed as an environmental safety net need to be based upon tested and proven *performance*, certainly not upon arbitrarily assigned prescriptive standards.

The construct for environmental control during full operation that is implemented through permitting and licensing must also facilitate a constant process of data gathering and analysis, upon which this Science can remain current with the products of the exploration.

If Conversion for Recovery requires that both design and operational parameters be met, it is this second step that is usually skipped, or only minimally employed. This is perhaps most clearly seen in the thermal conversion complement. It is both costly and dangerous to do *anything* with hot, explosive liquids and gases. Yet there is a difference we can establish between raw "producer" gas and carefully designed "syngas", just as there is a difference between raw biofuel and to-specification "biodiesel".

If technologic design allows, but operations do not stand ready to act on occasionally spiking conditions, then all that is left is to "clean up the mess" after the fact, and this is no different than can be done with a world class incinerator. *Any* system can be operated in a range from clean, to dirty. It is the *human* factor that we keep ignoring, and in general, it costs more to run clean than it does to operate dirty.

If a Conversion Technology can be operated without intrusively taking samples, by doing nothing more than taking sensor readings and *being ready* to act as necessary, then both points are covered, and the system is a conversion technology being operated for conversion, not destruction or disposal. This is usually the case where electricity and / heat are the desired products of the conversion. No molecular recovery occurs, when conversion only results in capture of the energy released by the breaking molecular bonds. The electric and thermal energy thus harvested may be *renewable*, but this does not constitute Conversion for Molecular Recovery.

But when Molecular Recovery is the target, the difficult and dangerous industrial step of sampling, segregating and sequestering fractions of the intermediary process products must almost always be considered a necessity.

To reach this most sustainable goal of Conversion for Molecular Resource Recovery, all factors have to come into play:

- *The Technology must by design allow access to and modification of intermediary products;*
- *The operational mode employed collects real-time sensed data of the process. The computerized system performs the necessary analyses, and instantaneously and constantly acts to correct the operations of the process.*
- *Both the Conversion Technology and the Operational Mode are selected to optimize for Recovery of the molecular resources present in the feedstock, including as needed separation and characterization of the constantly changing intermediary products.*

In this way, our fledgling industrial efforts can integrate whatever Conversion Technology modules might be required to address the diversity of feedstock presented, and to perform optimal resource recovery, at the molecular level.

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