# ACCELERATING RESOURCE RECOVERY

## Biosolids Innovations and Opportunities

NATIONAL biosolids PARTNERSHIP

Water Environment Federation®
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# Accelerating Resource Recovery:

# BIOSOLIDS

## INNOVATIONS and OPPORTUNITIES

2017

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# List of Acronyms

## Acronyms

| | |
|---|---|
| AWTP | Advanced Wastewater Treatment Plant |
| BNQ | Bureau de normalisation du Québec |
| BPR | Biological P removal |
| Btu/lb | British thermal units per pound |
| CHP | Combined Heat and Power |
| CNG | Compressed Natural Gas |
| DOE | Department of Energy |
| FBI | Fluidized Bed Incinerator |
| FOG | Fats, oils, and grease |
| GGE | Gallon gasoline equivalent |
| GTW | Grease Trap Waste |
| GHG | Greenhouse gas |
| IC engines | Internal Combustion engines |
| kWh | Kilowatt per hour |
| LNG | Liquid Natural Gas |
| MGD | Million gallons per day |
| MHI | Multiple Hearth Incinerator |
| MW | Mega Watts |
| N | Nitrogen |
| O&M | Operation and Maintenance |
| P | Phosphorus |
| PPCP | Pharmaceuticals and personal care products |
| PPP | Pollution Prevention Program |
| REC | Renewable Energy Credits |
| Scfm | Standard cubic feet per minute |
| SCW | Supercritical water |
| SCWO | Supercritical Water Oxidation |
| SGIP | Self-Generation Incentive Program |
| TS | Total solids |
| U.S. | United States |
| VS | Volatile Solids |
| VSr | Volatile Solids reduction |
| WAS | Waste Activated Sludge |
| WRRF | Water Resource Recovery Facility |
| WPCF | Water Pollution Control Facility |

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# Section 1

# Introduction

Unprecedented opportunities exist for biosolids as recognition of the importance of resource recovery reflects widespread interest in sustainability, energy, climate change, resource depletion, materials cycling, and zero waste goals. The journey toward meaningful change continues to be explored in this report, which is an update to the 2013 publication, entitled *Enabling the Future: Advancing Resource Recovery from Biosolids*. Specifically, this document examines the prospects that exist and are emerging for the organics, energy, and nutrients in biosolids. Lessons learned and documented experiences have also been captured in this publication as part of an effort to provide practical guidance for utilities embarking on the road to resource recovery.

A first step on that journey is defining regulatory and policy requirements that might promote or hinder resource recovery. While regulations at the federal level do not appear to actively support resource recovery from biosolids, some states are developing regulations and policies that remove barriers to resource recovery. These activities are driven, in part, by "zero waste initiatives" in many cities, which seek to maximize the diversion of recyclables away from landfills. Key examples include regulations and policies in Massachusetts intended to facilitate co-digestion and recent efforts to encourage composting in California. This regulatory evolution will need to continue to support resource recovery, and may soon need to address a portfolio of new products such as biosolids-derived bio-plastics.

In the absence of regulatory drivers, policies and market needs help shape resource recovery opportunities. The new view of a traditional beneficial use – land application – provides an example of our changing focus. Once viewed primarily as an approach to add nutrients and organics for soil improvement only, we now understand that biosolids can play a critical role with respect to climate change through a variety of mechanisms. First, the organic matter provided by biosolids can replenish soil organic carbon lost through climate change-induced wind and water erosion. Additionally, biosolids can reduce agricultural carbon footprints through both fertilizer production offsets and biosolids use to meet plant nutrient requirements. A better understanding of the role that biosolids can play in carbon footprint reduction will serve as a catalyst for their recognition as a valued resource.

Biosolids also play a key role in carbon footprint reduction through the conversion of the energy in solids to a useable form (heat or fuel) via biological or thermal processes. Energy recovery options range from mature, well-established systems such as anaerobic digestion and incineration to emerging technologies, such as Supercritical Water Oxidation and hydrothermal gasification. Solids treatment provides the greatest potential for energy recovery and production, as the chemical energy embedded in biosolids is greater than the energy needed for treatment. Wastewater utilities have an opportunity to recover the embedded energy to reduce costs and increase sustainability.

In addition to organic and energy resources, nutrients in biosolids are also a focus for resource recovery, going beyond recycling of nutrients through land application to nutrient extraction and recovery. Extractive nutrient recovery provides a mechanism to effectively remove nutrients from liquid streams while creating a marketable product. At present, commercial technologies for extractive nutrient recovery primarily produce chemical nutrient products that are used in agricultural applications (because 85% of all nutrient products are associated with agriculture). Since food demand is expected to rise with an increasing global population, it is expected that demand for chemical nutrient products will also increase. This represents an opportunity for the wastewater treatment market to develop niche products that can be used in this field.

In exploring technologies to recover any of the resources discussed here, it is important to note that the evolutionary path for emerging technologies is not an easy one. New technologies must overcome tremendous obstacles to travel from "emerging" to "established" status. Incentives provided to utilities by state and federal programs to test and implement innovative technologies would facilitate the development and application of these technologies by reducing the economic risk. To that end, a joint WEF/WE&RF initiative, the Leaders Innovation Forum for Technology (LIFT) program, was developed to help move innovation into practice in the water quality industry. The LIFT Technology Evaluation Program (TEP) Working Group provides facility owners a forum for technology prioritization and evaluation. To date, there are six technology areas related to biosolids: phosphorus recovery, digestion enhancements, energy from wastewater, biosolids to energy, odor control, and biological nutrient removal. Enabling the future will require enhancing the capacity, skills, and knowledge in the public and private sectors involved in biosolids management. As the focus on resource recovery from biosolids intensifies, the importance of the distributed network of support for biosolids professionals becomes even greater. Communication of research findings—both historic and new—is a specific pressing need, as it appears that existing research has been underutilized as a tool to communicate the safety of biosolids to the public. The increased complexity of biosolids management and the need for increased communications with more diverse audiences requires that these support mechanisms continue to grow and evolve to meet future needs.

Engaging in effective communication continues to be a key tenet to successfully developing systematic, proactive response and education strategies in which public outreach ensures appropriate developmental materials and biosolids curriculums are in place, as well as ensuring that working relationships with key environmental and public health organizations are cultivated. The biosolids sector should also continue to leverage and build upon the existing communication structure, which includes WEF, NBP, WE&RF, regional associations, and utilities, and to emulate successful outreach programs (such as the documentary "Liquid Assets," which was co-funded by WEF).

The theme of biosolids as a renewable resource is perhaps the key to repositioning both the role and value of biosolids. This document highlights ongoing activities in this area, existing and emerging opportunities, potential challenges, and activities required to fully leverage biosolids potential. Today, our concept of "beneficial use" for biosolids is being redefined – both philosophically and literally – reflecting an expanded vision of the resource recovery potential of municipal wastewater solids. This new perspective is reflected in the following Water Environment Federation (WEF) 2011 policy statement:

*"The Water Environment Federation supports a comprehensive approach to wastewater treatment and solids management that ensures the recycling and recovery of valuable resources including water, nutrients, organic matter, and energy."*

Biosolids are a community resource too valuable to waste in the context of not only renewable energy needs, but also in terms of urban sustainability interests and soil depletion.

WEF continues to establish conditions that promote accelerated development and implementation of innovative technologies and approaches, and is collaborating with water sector partners in a call to action to accelerate resource recovery (WEF Strategic Plan, 2015).

# Section 2

# Building a Framework for Resource Recovery: Regulations and Policy

Sound regulatory framework and supporting policies are essential to leverage resource recovery potential. The impact of a strong regulatory foundation, especially, cannot be underestimated, as evidenced by the impact of 40 CFR 503 regulation (and its underpinning policies) on biosolids beneficial use in the United States. While a variety of factors contributed to the shift away from disposal, the 503 rule created incentives for beneficial use and reflected the EPA position that biosolids are an important resource (EPA, 1984). Conversely, regulations can constrain resource recovery as well: "legitimacy criteria" for renewable fuels is a current example.

This section explores regulatory and policy issues that have the potential to impact the trajectory of biosolids resource recovery in the U.S. and, based upon those issues, identifies foundational changes needed to advance the role of biosolids as a renewable resource.

## Regulatory Overview

On both federal and state levels, regulatory trends provide a mix of rules that may limit or promote resource recovery from biosolids, as described below.

### Federal Regulations and Policy

Two recent changes at the federal level – one in regulation and the other in policy – appear to limit the full recovery potential in biosolids in some cases: the EPA clarification of the sewage sludge definition and the adoption of a new United States Department of Agriculture (USDA) nutrient management standard.

#### EPA Sludge Definition and Legitimacy Criteria

In March 2011, the EPA clarified the definition of sewage sludge to expressly define sludge as a non-hazardous solid waste when used in a combustion unit. This clarification is of concern for processes that would combust wastewater solids to recover their energy and EPA "legitimacy criteria" for consideration as a renewable fuel are at the heart of industry concerns. To meet these criteria, sludge must:

- Have meaningful heating value and be used as a fuel in a combustion unit that recovers energy,
- Be managed as a valuable commodity, and
- Contain contaminants at levels comparable to or lower than those in traditional fuels, which the combustion unit is designed to burn.

Per the EPA, sewage sludge does not meet these criteria and is defined as a solid waste. Wastewater professionals contend that some sludges do, in fact, meet these criteria (especially sludges that have been dried) and that the use of sludge and biosolids as a renewable fuel should be encouraged as part of the nation's effort to promote green energy.

While EPA has not made a blanket determination that wastewater solids are renewable fuels when burned, the Agency promulgated a categorical non-waste determination rulemaking process that could potentially be used to seek a nationwide exclusion for wastewater solids burned for energy recovery (EPA, 2013).

Additionally, some utilities have sought – and received – EPA approval of their solids as renewable fuels via a separate "non-waste petition process" (a process available for other solid wastes as well). This process allows generators or managers to demonstrate to EPA that their solids meet the legitimacy criteria, providing a pathway for individual solids to be classified as a renewable fuel. In some instances, where the generator and combustor are the same entity, the legitimacy criteria and non-waste determination process can be "self-implemented" and do not require EPA approval (Hornback, 2012).

The potential role of solids as a fuel lies not only in the hands of EPA but potentially in the hands of state regulators as well. States can set more stringent requirements than the EPA, and the potential impacts of any state-specific requirements, as well as the potential basis of such requirements – remain in question. Moreover, some states adopt policies that shape solids management strategies (as rulemaking can be a long and arduous process) and informal policies (that discourage incineration, for example) could also limit the role of wastewater solids as a renewable fuel.

## USDA Nutrient Management Standard Revision

An update by USDA to its nutrient management standard exemplifies both the potential constraints and complexities facing biosolids managers that wish to include land application in their resource recovery tool box. In January 2012, the USDA Natural Resources Conservation Service (NRCS) revised its Code 590 Nutrient Management Standard (available at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046433.pdf). This federal standard, essentially a template that states had until January 2013 to modify for their unique conditions, defines approaches to manage nutrient sources such as manures and biosolids that are applied to the land. The revision reflects USDA's effort to bring more uniformity to state standards, most especially in the development and application of the primary tool used to assess risks from the over-application of phosphorus (P): the Phosphorus Index (PI). For the first time, the standard explicitly includes biosolids in the materials that it covers.

Although Code 590 was originally intended for use by farmers participating in NRCS assistance programs, it has been incorporated into regulations governing manure management and in some states, into biosolids land application regulations and/or permits as well. Thus, the standard has taken on the weight of law for biosolids applications in some states, especially those in the mid-Atlantic region; in these states, biosolids application rates generally reflect phosphorus management requirements.

In general, the move toward P-based management poses a significant challenge to biosolids land application programs, as it can result in reduced application rates and, consequently, an increase in the land area required for such programs. The issue is exacerbated by the fact that most PIs do not account for the differing P availability from nutrient sources; this is especially critical, as research has shown that many biosolids products have lower P availability than fertilizers and manures. The following figure illustrates the differing P availability for these materials, as measured by Water Extractable Phosphorus (WEP).

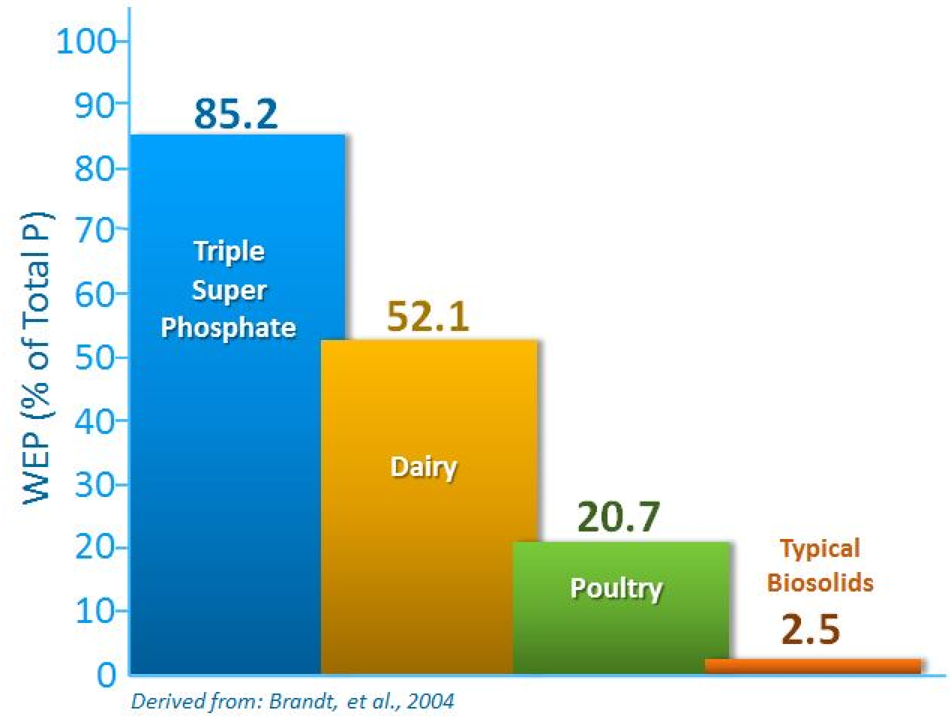



Figure 1: Relative P Availability of Biosolids and Other Nutrient Sources

Phosphorus availability in biosolids should be – and in some cases, already has been – reflected in PIs through "P source coefficients." The P source coefficient (PSC) "quantifies the environmental availability of a P source relative to inorganic P fertilizer," which has a PSC = 1 (Elliot, 2012). Incorporating a product-specific PSC can both improve the predictive capability of a PI and keep P management requirements from being overly restrictive. As such, the adoption of source coefficients into Code 590 PIs is a critical element in sustainable nutrient management planning for biosolids. A dozen states now incorporate source coefficients in their PIs, and several of those states include a biosolids PSC of some kind. Additionally, Pennsylvania and Maryland allow for water extractable P testing to determine product-specific PSCs. The following table shows approaches to PSCs used in P Indices. It is important to note that the difference in states' approaches to nutrient management extends well beyond their approach to PIs. Some states practicing P management rely on soil P threshold values to manage P in land-applied biosolids. Still others have no P-based requirements at this time and retain nitrogen-based application rates for nutrient management. This varied approach

<table>
<tr><th>P Source</th><th>Florida</th><th>Pennsylvania Virginia</th><th>Most States</th></tr>
<tr><td>Mineral Fertilizer</td><td>1.0</td><td>1.0</td><td rowspan="5">1.0</td></tr>
<tr><td>BPR Biosolids</td><td>0.8</td><td>0.8</td></tr>
<tr><td>Alkaline or Conventionally Stabilized</td><td>0.4</td><td rowspan="3">0.4</td></tr>
<tr><td>Composted Biosolids</td><td>0.3</td></tr>
<tr><td>Advanced Alkaline & Heat Dried</td><td>0.2</td></tr>
</table>

Source: Elliot, 2012

Table 1: Select Phosphorus Source Coefficients Used in P Indices

reflects, to some extent, the differences in P demand vs P supply across the U.S., and should be considered when assessing potential impacts of P-based management in various locales.

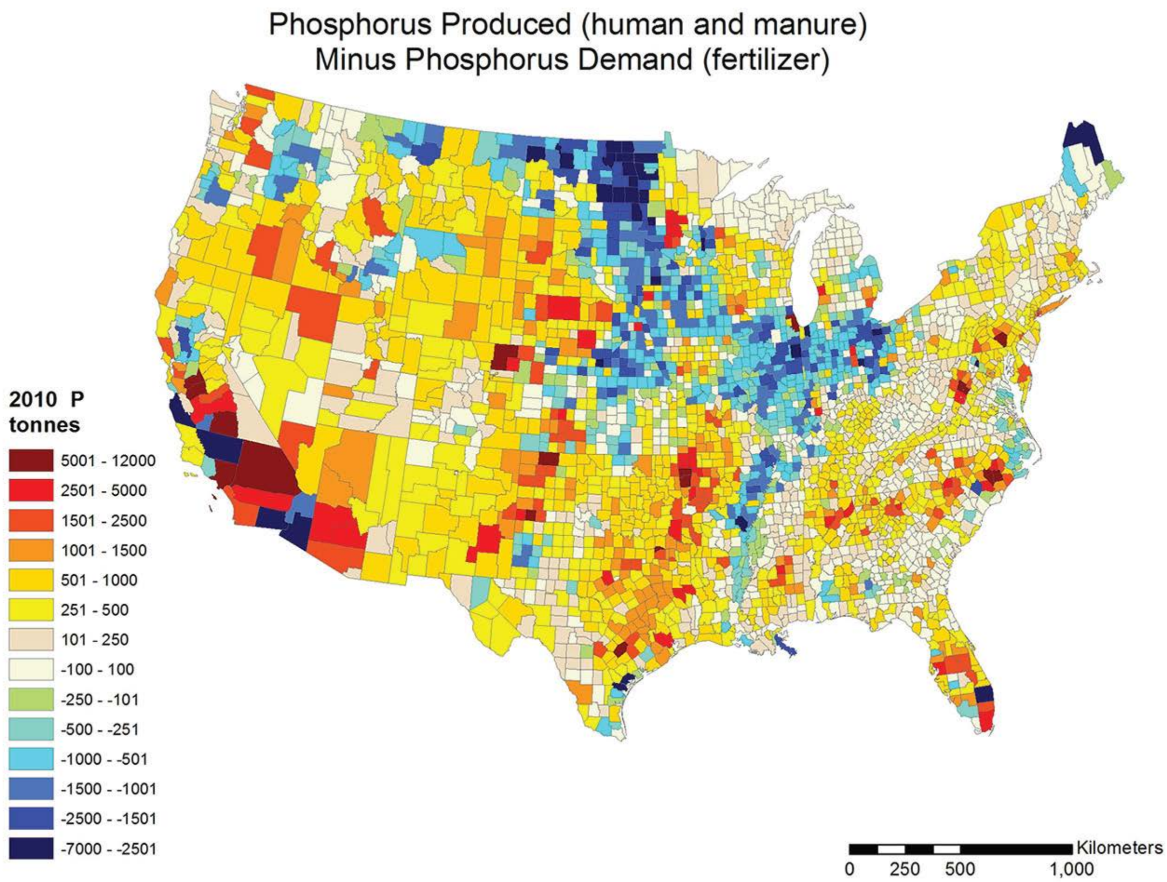



Figure 2: Phosphorus Supply versus Demand (Jarvie et al., 2015)

## FDA Food Safety Rule

The safety of biosolids for the growth of covered produce was reinforced by the U.S. Food and Drug Administration's (FDA) recent Food Safety Modernization Act Produce Safety Rule, published on November 27, 2015 (FDA, 2015). This rule, also known as the "Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption", establishes science-based minimum standards for safe food production and specifically addresses biosolids use. Section 112.53 of the rule states that growers "may not use human waste for growing covered produce, except sewage sludge biosolids used in accordance with the requirements of 40 CFR part 503, subpart D, or equivalent regulatory requirements." In its response to concerns regarding the safety of biosolids for growing covered produce, FDA concluded in the final rule that "adherence to 40 CFR part 503 remains an appropriate approach to the use of biosolids for the growing of covered produce. We continue to believe that these requirements are appropriately protective of public health."

## Renewable Fuel Standard

EPA developed the Renewable Fuel Standard (RFS) program in response to the 2005 Energy Policy Act as a mechanism to ensure that transportation fuels contain a minimum volume of renewable fuel. In 2007 the program was significantly expanded in response to the Independence and Security Act (EISA) (EPA, 2007). By 2022, the RFS requires the use of 36 billion gallons of renewable fuels, including 21 billion gallons of advanced biofuels (derived from biomass and cellulosic materials).

Eligibility requirements for the RFS have evolved over the years but, until July 18, 2014, fuels derived from digester biogas at municipal WRRFs were classified as "advanced fuels"; the July 2014 "RFS Pathways II and Technical Amendments to the RFS Standards" changed the classification of these fuels to "cellulosic fuels", a key distinction that can impact the economics of recovering digester gas.

Specifically, EPA announced that the following "fuel pathways" meet the life-cycle GHG reduction requirements for cellulosic biofuels established under the RFS program:

- Compressed natural gas produced from biogas from landfills, municipal WRRF digesters, agricultural digesters, and separated municipal solid waste (MSW) digesters.
- Liquefied natural gas produced from biogas from landfills, municipal WRRF digesters, agricultural digesters, and separated MSW digesters.
- Electricity used to power electric vehicles produced from biogas from landfills, municipal WRRF digesters, agricultural digesters, and separated MSW digesters.
- EPA notes that the inclusion of these fuels in the RFS program will help achieve program goals and, in many cases, provide credits (known as Renewable Identification Numbers, or RINs) to biofuel producers. Each gallon of renewable fuel in the RFS program equates to one RIN, which can be bought and sold as a commodity. For additional information, see WEF fact sheets: Renewable Identification Numbers: A Guideline for Water Resource Recovery Facilities (2016), and Biogas to Renewable Natural Gas (RNG): A Guideline for Water Resource Recovery Facilities (2016).

Cellulosic fuel increases Renewable Identification Number (RIN) value (compared to advanced fuels). For example, in 2015, advanced biofuels (or D-5 RINs) traded for $0.70 to $0.90/gallon ethanol equivalent (GEE); cellulosic fuels (D-3 RINS) can provide a premium (added to the D-5 RIN) of $0.40 to $0.80/GEE (Willis, et al., 2015). Also see, "Renewable Identification Numbers: A Guideline for Water Resource Recovery Facilities," (WEF, 2016)

Willis et al. (2015) also note that the potential value of biogas-derived vehicle fuels – and the potential return on investments – is further enhanced when the relative energy content of these fuels (compared to ethanol) is considered.

## Regulatory Status of Biosolids-derived Products

The focus on renewable-sourced products, coupled with an industry-specific need to diversify biosolids outlets has led to innovative solids-derived products (i.e., biodegradable plastics) and products from sidestream processes such as struvite recovery, both of which were never envisioned when the 503 rule was promulgated (Section 6 provides additional detail on "non-traditional" products). While these products fall well within the paradigm of beneficial use, some diverge significantly from "traditional" biosolids in both form and function; therefore, the applicability of the 503 rule is in question and the regulatory status of these products is far from certain.

Because of the relatively early development status for some of these products, the regulatory framework for their use has not been defined, but vendors of such products are seeking feedback from regulators to guide them as they seek to enter the marketplace. As the portfolio of new solids-derived products expands, defining an approach to regulations that reflects the diversity of these products will become increasingly important.

## State Regulation and Policy

Trends at the state level both constrain and promote resource recovery. Increasing stringency for land applied biosolids continues as a trend, with a focus on odors and phosphorus. Other state level regulatory actions and policies are specifically attempting to remove regulatory barriers to resource recovery; however, these activities are driven, in part, by "zero waste initiatives" in a number of states (and cities), which seek to maximize the diversion of recyclables away from landfills. Each of these state-level trends is discussed below.

### Odor-driven Land Application Regulations

Odor continues to drive state regulations for land application. As noted in WEF's Charting the Future (WEF, 2011), lime stabilized materials appear to be the focus of more stringent requirements in Florida and might be considered part of a larger regulatory trend that treats Class A materials generated under Alternatives 2, 3, and 4 as inferior to Class A products generated under Alternatives 1, 5, and 6 (Ohio and Washington, for example, have eliminated Alternatives 3 and 4 as means to demonstrate Class A compliance). Rule changes enacted in 2014 in Texas provide an example.

| 40 CFR 503 pathogen reduction alternatives:<br><br>In addition to meeting the requirements in one of the six alternatives listed below, the requirements in Table 5-2 [of the Guide to the Part 503 Rule] must be met for all six Class A alternatives. | |
|---|---|
| Alternative 1 | **Thermally treated biosolids** – Biosolids must be subjected to one of four time-temperature regimes. |
| Alternative 2 | **Biosolids treated in a high pH-High temperature process** – Biosolids must meet specific pH, temperature, and air-drying requirements. |
| Alternative 3 | **Biosolids treated in other processes** – Demonstrate that the process can reduce enteric viruses and viable helminth ova. Maintain operating conditions used in the demonstration after pathogen reduction demonstration is completed. |
| Alternative 4 | **Biosolids treated in unknown process** – Biosolids must be tested for pathogens – *Salmonella* sp. or fecal coliform bacteria, enteric viruses, and viable helminth ova – at the time the biosolids are used or disposed, or, in certain situations, prepared for use or disposal. |
| Alternative 5 | **Biosolids treated in a PFRP** – Biosolids must be treated in one of the Processes to Further Reduce Pathogens (PFRP). |
| Alternative 6 | **Biosolids treated in a process equivalent to a PFRP** – Biosolids must be treated in a process equivalent to one of the PFRPs, as determined by the permitting authority. |

Table 2: Guide to the Part 503 Rule, U.S. EPA, p. 110, Web., https://www3.epa.gov/npdes/pubs/503pe_5.pdf

Odor complaints received for two products in Texas, both of which had lime added but used Alternative 4 to demonstrate Class A status, led regulator concerns about the odor of products qualifying for Class A under Alternatives 2, 3, and 4. Based upon these concerns, the state added a third tier for pathogen reduction: Class AB biosolids. When surface applied, these materials are subject to a host of requirements that are more stringent than Class A products, including: signage at application sites, buffer zones, staging of biosolids away from odor receptors, and best management practices (BMPs) to address tracking of biosolids offsite. Class AB products do not require permits for use (permits are required for Class B applications), and, like Class A biosolids, are managed under the state's notification tier. With the new regulations, all biosolids (with the exception of value-added materials such as composts and heat-dried products) are also subject to additional "core requirements" that can include the development of an Odor Control Plan if deemed necessary by the Texas regulators.

## Phosphorus Regulations

The move to phosphorus-based management as discussed above focused on agricultural applications, but increasingly stringent requirements for P applications to turf and lawns are appearing as well. The status of P fertilizer regulations was addressed in the WEF fact sheet "Phosphorus In Biosolids: How To Protect Water Quality While Advancing Biosolids Use" (WEF, 2014). Specific text on this subject is excerpted below.

At least 15 states have laws and/or regulations related to turfgrass fertilizers, including 11 states that have completely banned the use or sale of P for lawn maintenance. While most of these are in the mid-Atlantic, Northeast, and upper mid-West (bordering the Great Lakes), Florida is also a leader in this area (Columbus Dispatch, 2013). Many of these laws/regulations have been adopted in the past few years and are still in the process of being implemented. In general, these state restrictions on turf fertilizers include:

- focus on P, but, in many cases, nitrogen as well;
- definitions of specific materials (e.g., fertilizers, composts) to which the restrictions apply;
- prohibitions on particular uses and/or permissions for particular uses;
- site and management restrictions (e.g., setbacks from surface waters, no application to impervious surfaces or frozen or saturated soils); and
- requirements regarding labeling and display of P-containing fertilizer products at the point of sale.

While the underlying theme of these turfgrass fertilizer regulations is generally consistent, the specific details vary a good deal among states. Some states completely prohibit use of fertilizer or P-containing fertilizer (WEF, 2014) (defined either as having no measurable P or having less than 0.67% P) on turfgrass. Some states have specific restrictions for applications during winter months. As a result, Scotts removed P from most of its Turf Builder lawn fertilizers and because Scotts is a leader in the fertilizer marketplace, other companies that have not already done so will likely follow suit (Columbus Dispatch, 2013).

## Co-digestion Regulations

The co-management of wastewater residuals and source-separated organics (SSOs) is increasing. A 2014 survey indicated that 9 states had mandates to divert these materials from landfills and 39 states have disposal bans (Platt and Goldstein, 2014), with the number of states (and cities) with diversion mandates expected to grow.

The trend toward digesting Fats, Oils, and Grease (FOG) and SSOs, such as food scraps at water resource recovery facilities has created a regulatory conundrum: should WRRF digesters processing these materials be treated as solid waste or wastewater processing facilities? The conflict stems from the traditional handling of FOG and food waste treatment under solid waste regulations (specifically the Resource Conservation and Recovery Act Subtitle D, which covers non-hazardous solid wastes, and 40 CFR Part 258, which covers landfills versus biosolids digestion, which is typically regulated by Clean Water Act requirements. In some states, the processing of food waste and other organics in a WRRF digester may result in the designation of the digester as a solid waste processing facility.

The question of how to permit such facilities is complicated by the fact that neither solid waste nor water-quality regulations were intended – or are well equipped – to accommodate mixed biomass recovery in digesters.

Because solid waste and wastewater permitting are generally state-level activities, solutions to this conundrum are appearing at a state level as well. States can also be more agile and flexible than the federal government, and are better positioned to enact changes to support local conditions and demands.

Although many states are believed to be grappling with this issue, several have already identified paths to facilitate resource recovery in digesters. As described in the examples below, the approaches vary, but all reflect a recognition of the opportunities to meet both solid waste reduction and biogas optimization goals through mixed biomass digestion.

### Ohio: Multi-Agency Permitting Framework

The digestion of wastewater solids at Ohio WRRFs is regulated by the Ohio Environmental Protection Agency's Division of Surface Water through the National Pollutant Discharge Elimination System (NPDES) program, while foodwaste processing is regulated through the Division of Solid Waste and Infectious Waste Management. Faced with requests to process foodwaste in WRRF digestion facilities, the state has assigned primacy to the Surface Water Division for permitting involving biosolids, but provides for feedback from other relevant divisions during the permitting process. This general permitting framework (primacy for one agency, in collaboration with others) is also applied for digesters at Concentrated Animal Feeding Operations, with the Department of Agriculture leading the permitting effort; facilities digesting other materials (i.e. that do not include biosolids or manures) are usually permitted through the Solid Waste Division (BioCycle, 2009).

### Massachusetts: Policy-driven Rule Modifications

The Massachusetts Department of Environmental Protection (DEP) has focused a great deal of attention on SSOs and, as part of the Massachusetts Organics Action Plan, the agency banned certain large scale (e.g. institutional) SSO from landfills on October 1, 2014. While waste diversion is a primary goal, a cornerstone of its policy is supporting renewable energy in the state through its Clean Energy Results Program (CERP). Launched in November 2011, the CERP program is a collaboration between the Massachusetts DEP (MassDEP) and the Massachusetts Department of Energy Resources (DOER) and "under CERP, MassDEP will continue to harness its expertise to bolster energy efficiency and renewable energy and will expand activities to: Encourage dramatic expansion of recycling/conversion of organics to renewable energy (via anaerobic digestion) with the goal of diverting 450,000 tons per year of organic material from landfills and incinerators by 2020 and increasing energy production from aerobic and anaerobic digestion to 50 megawatts (from under 10mw today)." (Massachusetts Department of Environmental Protection Program Plan/Performance Partnership Agreement Work Plan: Federal Fiscal Year 2014, p. 3, FINAL Oct., 2013, WEB, http://www.mass.gov/eea/docs/dep/about/priorities/14ppa.pdf) The processing of SSOs in digesters is a primary tool to accomplish these objectives.

Additionally, the state began funding efforts in 2012 to meet its long-term goals. With that funding, a number of MA utilities have assessed either constructing digestion facilities in their towns or co-digesting food wastes at their wastewater treatment facilities. At least one utility, the Greater Lawrence Sanitary District, has received grants (a total of $5,900,000) from the state to support the installation of a new digester, food waste receiving facilities, and a CHP (Mosher and Weare, 2015). Once complete, the facility is expected to meet up to 40% of the state's diversion goals and will produce more than 27 million MWhrs of electricity per year (Mass DEP, 2016) with 2-1.5 MW engines.

### California: Rule Modifications to Eliminate Regulatory Overlap

CalRecycle, the primary solid waste regulatory agency in California, adopted regulations in January 2016, which exclude water resource recovery facilities (WRRFs) that process select organics from its solid waste transfer/processing and in-vessel digestion regulations. The regulatory revisions were the culmination of a 6- year process with close coordination with the State Water Resource Control Board (SWRCB) and other stakeholders. Specifically, the revisions exempt a Publicly Owned Treatment Works (POTW) Treatment Plant that receives vehicle-transported solid waste that is an anaerobically digestible material for the purpose of anaerobic co-digestion with POTW wastewater. For the rule, "anaerobically digested material" is defined to include inedible kitchen grease and specific vegetative food material, though the regulations outline a process by which CalRecycle may approve other organic feedstocks on a case-by-case basis, via a multi-agency process that includes consultation with the SWRCB and the California Department of Food and Agriculture.

Figure 3: Biosolids Sustainable Management Focal

The regulatory exemption requires that WRRFs be in compliance with a standard permit condition developed by the SWRCB, which requires notification to the Regional Water Boards and the development of a standard operating procedure (SOP). A key factor in these new rules is CalRecycle's recognition that the SOP and Regional Water Quality Control Board oversight adequately address the receipt, handling, anaerobic digestion, and residual solids management of specific types of organic material for co-digestion. Additional details on the regulations can be found at: http://www.calrecycle.ca.gov/laws/rulemaking/Archive/2015/Compost/default.htm

# Policy and Planning

With respect to policy and planning, the overarching driver for resource recovery is the broader focus on sustainability, viewed through the perspective of triple bottom line (TBL) analyses that reflect environmental, economic, and social concerns. This focal shift is reflected in the increasing use of TBL analyses for solids planning, but is also driving research, voluntary programs, and a renewed interest in the environmental benefits of biosolids. As shown in the figure 3 and described below, many of these focal points – which are actually tools to forward resource recovery – address multiple elements in the sustainability trifecta.

## Case Study: The USCC Seal of Testing Assurance (STA) Program Role in Texas Compost Market Development

STA testing is the foundation requirement for all composts used by the Texas Department of Transportation (TxDOT). Soon after the STA program was developed, TxDOT, working with the Texas Commission on Environmental Quality (TCEQ) incorporated STA testing requirements into new specifications for a variety of compost products used in their projects. To ensure that they had access to the large TxDOT market, nearly all Texas compost producers joined the STA program, participating in required testing. The stringent quality requirements in the specifications were critical to TxDOT and to contractors bidding on TxDOT projects, as they provided them with the assurance that the composts they purchased would be suitable for their needs. Today, TxDOT is believed to be the largest user of compost in the nation, purchasing about 300,000 cubic yards annually for its construction projects.

## Partnerships

The paradigm shift to resource recovery is being thwarted by the harsh economic reality that capital funding budgets are being stretched to the breaking point and that economics continue to influence (if not dominate) decision making and, in some cases, prevent the investment in biosolids management choices that offer the greatest long-term environmental benefit. One trend that has developed in response to these dual pressures is the growth of partnerships that benefit all participants.

Partnership opportunities can take several forms, including private enterprise funding, collaboration with Energy Service Companies (ESCOs), and the development of synergistic relationships between wastewater utilities and other municipal departments, industry, and manufacturers of new technologies.

## Product Marketability Criteria

Diversity is a key tenet of sustainable solids management, and toward that end, utilities are seeking multiple outlets for their renewable-sourced products, including biosolids, biogas, and specialty fertilizers. For biogas, access to markets such as vehicle fuel is a function of gas cleaning and compression, while specialty fertilizers (such as the phosphorus fertilizer resulting from Ostara's Pearl process) generally are marketed by process vendors. Requirements for entering retail biosolids markets (typically with a composted or heat-dried biosolid) are more complicated as utilities need to satisfy customers that range from homeowners to farmers. Toward that end, biosolids products must meet not only regulatory criteria, but also "marketability criteria" – i.e., those characteristics that are critical to targeted customers.

Biosolids marketability criteria include two basic parameters: consistency (of both supply and quality) and product characteristics. Desired characteristics generally vary by product and are highlighted in the table below. Additional information on specific criteria can be found in *Design of Municipal Wastewater Treatment Plants* (WEF, 2010).

| Compost | Heat-dried Product |
|---|---|
| **pH** | **Particle Size** |
| **Soluble salts/Salt Index** | **Nutrient content** |
| **Nutrient content** | **Durability (hardness)** |
| **Water-holding capacity** | **Dust** |
| **Bulk density** | **Odor** |
| **Moisture content** | **Bulk density** |
| **Organic matter content** | **Soluble salts** |
| **Particle size** | **Heating value** |
| **Maturity (phytotoxicity)** | |
| **Stability** | |
| **Odor** | |

Table 3: Product Quality Criteria (Source: Derived from WEF, 2010)

Few of the parameters noted are regulatory in nature, although stability and odor criteria in some respects are intended to be addressed by the 503 rule's Vector Attraction Reduction (VAR) requirements.

VAR requirements are not market-based but the United States Composting Council (USCC) has developed a robust approach to measure and uniformly compare products with respect to marketability for compost. The USCC effort, which culminated in its Seal of Testing Approval (STA) program and the testing method manual that supports the program, Test Methods for the Examination of Composting and Composts (USCC, 2002). The USCC effort, many years in the making, was initiated on the simple principles that: (1) material testing is needed to verify product market (and safety) claims and (2) that product data should be truly comparable for all customers in order to be meaningful. The resulting program is an example of criteria – and, critically, associated testing – developed to support product markets that might serve as a model for other biosolids products.

The Water Environment & Reuse Foundation (WE&RF) is also addressing the disconnect between regulatory and market criteria through their recently initiated High Quality Biosolids from Wastewater (Project Number NTRY7R15). The primary goal of this project is to significantly expand biosolids use nationwide by helping define the standards and specifications needed for WRRFs to cost-effectively produce and more successfully market high quality, safe, and stable biosolids in areas across the country, with identified benefits for both the generator (the WRRF) and the end user (recognizing that this can vary for specific markets and regions of the country). Initiated in 2015, this sweeping project includes the following key elements:

- The development of the criteria needed to define a biosolids product as high quality.

- Demonstrate the benefits and possible challenges of using high quality biosolids (HQB) in urban applications using real world application.
- Assemble a marketing template for utilities to use that are producing HQB and need assistance promoting their products.
- Use non-traditional communication channels (website, invite-only LinkedIn page, Facebook page) to build and engage a community of HQB producers, users, and supporters.

## Research (Odor and Safety)

Public acceptance is critical to maximizing the recovery of nutrients, organics, and other resources through land application. Two key impediments to public acceptance are odors and the perceived safety of biosolids. WE&RF recently brought research addressing these issues together into a single comprehensive project known as the Regrowth, Odors and Sudden Increase (ROSI) Project. The project is comprised of two separate but interrelated research trains:

- Sudden Increase/Regrowth – The terms "sudden increase" and "regrowth" refer to increases in fecal coliform counts observed in some types of dewatered and anaerobically digested biosolids. Sudden increase (SI) is defined as an increase observed in freshly dewatered cake while regrowth is defined as an increase observed in stored biosolids. Researchers found that the higher shear that contributes to cake odors is also a factor in both SI and regrowth in digested cake (WE&RF, 2012). Digestion processes had differing impacts on SI, however, with the phenomenon observed more frequently with thermophilically digested (and centrifuged) biosolids (WE&RF, 2012). In subsequent research on SI, the team determined that "the required time-temperature from the EPA curve may be adequate for pathogen destruction (which is its intent), but not adequate for the indicators such as FC and E. coli." (WE&RF, 2015), because of issues enumerating non-cultural bacteria. Accordingly, they recommend that "enumeration methods for the indicator bacteria need to be evaluated for their accuracy, followed by investigation of an appropriate EPA time-temperature curve or E. coli destruction requirements to conservatively meet pathogen and indicator destruction goals."

- Biosolids Odors – Building on a decade of research on biosolids odors, the research team is investigating short-term and long-term odor characteristics and approaches to reduce those odors. The researchers found that odors do, in fact, change with time, reflecting the release of different compounds (WE&RF, 2012). Volatile organic sulfur compounds are largely responsible for odors after dewatering, but indole, skatole, p-cresol, and butyric acid contribute to odors that might be emitted over long-term storage. These compounds are decomposition products of organics (mainly protein) suggesting that processes that remove readily bioavailable proteins (and other precursors) may help reduce odors in biosolids. The results showed that the level of odorants measured after longer-term storage was correlated to shorter-term total volatile organic compound concentrations.

  The research further found that shear during dewatering and conveyance contributes to short-term odors and that higher shear operations (centrifuge dewatering, screw conveyance) and polymer can have an impact as well. Lastly, the researchers determined that while digestion in general decreases odors, the improvement may not meet odor reduction objectives.

In the most recent phase of the ROSI project, the research team investigated approaches to reduce biosolids odors, focusing on the addition of amendments added to centrifuge cake (WE&RF, 2015).

The team found that the incubation of anaerobically digested biosolids with protein-degrading enzymes in laboratory studies both reduced odorant emissions after dewatering and improved gas production. The team concluded that targeted microbial inhibitors might also reduce odors and mitigate regrowth. Another approach to reduce biosolids odors investigated by WE&RF in 2011 was the use of nanoparticles (the dual-focus study also assessed the impact of nanoparticles on dewaterability). The researchers investigated 10 different nanoparticles for the study, generating the materials from chemicals used in water and wastewater treatment or other benign materials. The study found that the three of the 10 products studied lowered or delayed odorant release from biosolids, but noted that additional research is needed to better understand how these materials work and what specific characteristics might best provide economical and effective odor (and dewatering) improvements (WE&RF, 2011).

Because of the importance of odor and perceived safety concerns to the sustainability of land application as a biosolids recycling approach, WE&RF has invested and continues to invest in additional research in these issues. Appendix A lists additional research in these areas. As noted in the appendix, the research extends into emerging issues such as the fate of trace organics and nanoparticles in land-applied biosolids.

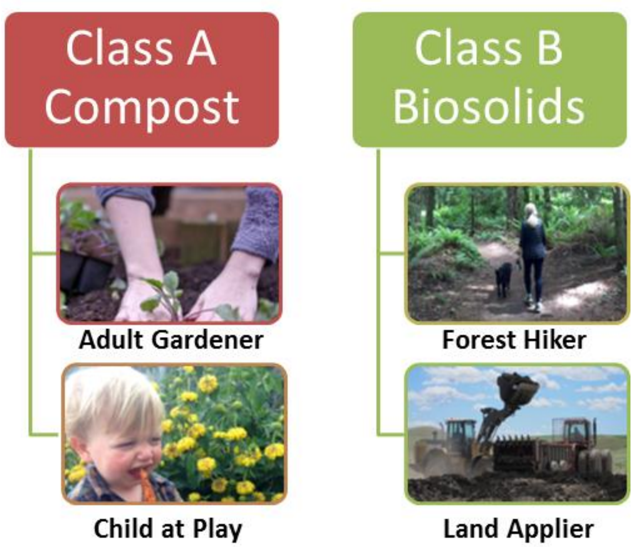



Figure 4: NBMA/King County Risk Assessment Scenarios (WERF, 2012)

In addition to WE&RF-led research, several utilities and organizations are leading efforts to better understand the fate and transport of emerging contaminants – and, critically, to effectively communicate this information to the public. For example, King County and the Northwest Biosolids Association recently spearheaded a focused risk assessment for emerging contaminants to address public concerns (NW Biosolids, 2017). The research assessed 12 compounds, and was completed by Kennedy Jenks in collaboration with the University of Washington. As shown, two products were assessed, with two most exposed individuals targeted for each product.

The assessment revealed that risks were extremely low, as expected, but the what was more unusual about the project was the way that the information was presented for the public, as well as the collaboration cited as a key to project implementation. The brochure prepared by King County to present project results can be found at http://www.kingcounty.gov/~/media/services/environment/wastewater/resource-recovery/docs/biosolids/Loop_Risk_Brochure.ashx?la=en

## Carbon Footprint

Some have noted that climate change may be a key driver of biosolids management strategies in the future. While neither the federal government nor most states require greenhouse gas (GHG) reductions at this time, there is nonetheless an increased focus on both quantifying and reducing carbon footprints from biosolids operations, and a corresponding emphasis on renewable fuels. This interest may reflect a sense that regulations are pending, as well as a growing awareness of our role in a sustainable urban ecology. The term "carbon footprint" is often used to discuss GHG impacts, as their emission rates are typically quantified in terms of carbon dioxide ($CO_2$) equivalents. This measure reflects the varying global warming potential of different greenhouse gases.

| GHG (tons) | $CO_2$ Equivalents (tons) |
|---|---|
| **Carbon Dioxide** | 1 |
| **Methane** | 23 |
| **Nitrous Oxide** | 296 |

Table 4: $CO_2$ Equivalents of Green House Gases

Solids treatment and disposal/use operations are potential emitters of GHGs, but biosolids management programs also offer opportunities to reduce net greenhouse gas emissions through the use of biosolids as a resource. Biosolids themselves do not impact a carbon footprint, as they are "new" carbon, created from photosynthesis and biogenic in origin. *(Biogenic $CO_2$ originates from the decomposition of organic matter that was created by recent photosynthesis; the emission of biogenic $CO_2$ does not create a net increase in $CO_2$ since the carbon is recently derived from atmospheric $CO_2$.).*

Biosolids processing and management activities can reduce or increase a facility's carbon footprint, as shown in the figure below. Chemicals, fuel, and electricity used in processing can increase GHG impacts if they require the combustion of fossil fuel. Another source of GHG impacts from biosolids

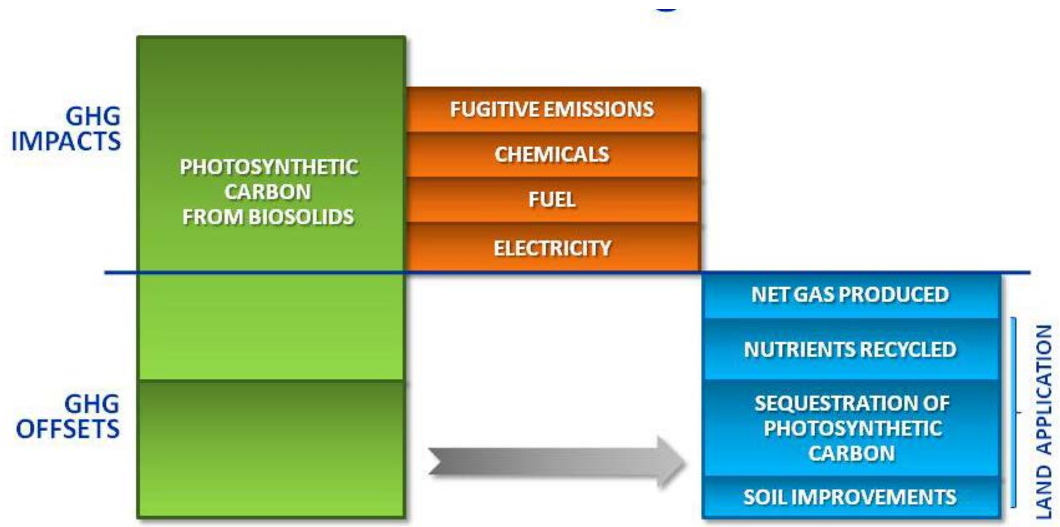



Figure 5: Biosolids Carbon Accounting

operations is the conversion of $CO_2$ or nitrogen into more potent GHGs. This might occur via the conversion of biogenic carbon to methane in digesters (if the methane escapes), or via the release of nitrous oxide from the application of biosolids to soils or biosolids combustion. Biosolids management can provide significant opportunities for GHG reductions through the generation and use of biogas, replacing mineral fertilizer, and sequestering carbon in the soil (carbon sequestration and fertilizer replacement are discussed further in Section 3).

Utilities are increasingly scrutinizing their operations to assess ways to reduce their carbon footprints but a consistent approach for estimating GHG emissions has proven to be elusive. Several organizations around the world have developed protocols for GHG estimates and although many follow the general approach adopted in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), the protocols vary in many ways. In North America, it appears that efforts may be focusing on a protocol published by The Climate Registry (TCR) General Reporting Protocol (2008), which attempts to integrate several existing state protocols.

Based upon the TCR protocol, the CCME has developed an emissions model specifically for biosolids management programs, the Biosolids Emissions Assessment Model, or BEAM (SYLVIS, 2009). To our knowledge, this is the first government agency-sponsored model for biosolids GHG estimates that has been developed. CCME (2009) notes that the BEAM can be used to define existing GHG emissions, assess GHG reduction opportunities, and document GHG reductions for emerging carbon markets (with independent verification).

The desire to take advantage of emerging carbon markets has presented a quandary for some utilities as the value of carbon credits is currently low. Some utilities may choose to postpone proposed GHG reduction measures until those markets mature, fearing that implementing them earlier would change their baseline footprint and make them ineligible for such credits. The general push for sustainability and resource recovery has minimized the focus on credits at this time, but an improved credit value could incentivize utilities to pursue resource recovery programs.

## Voluntary Programs

As indicated by the discussions above, meeting existing regulatory requirements is not always sufficient to ensure public acceptance. Toward that end, several programs have been developed that focus on optimized biosolids quality, management practices, and/or public outreach, with the goal of alleviating public concerns. These programs advance the goal of resource recovery through improved public acceptance. Examples of programs that fall into this category are the National Biosolids Partnership (NBP) Environmental Management System (EMS) and voluntary programs to divert pharmaceuticals and personal care products (PPCPs) from wastewater and biosolids.

### National Biosolids Partnership BMP (EMS)

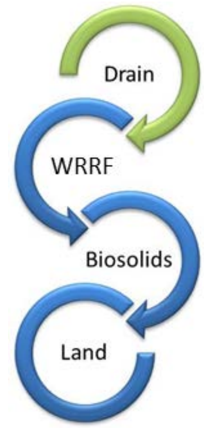
The NBP BMP (EMS) is a voluntary program that uses a flexible framework to help public and private sector organizations improve the quality of their biosolids management programs. The BMP framework is designed to accommodate all types of biosolids management practices and is based on elements that encompass all levels of a program, including policy making, management planning, program implementation, measurement and corrective action, and management review.

Organizations that achieve BMP certification are committed to the use of best management practices and conform to the NBP's Code of Good Practice. Over 30 organizations, representing more than 12% of the biosolids generated in the U.S. have achieved certification, and many others have received recognition. One of the key features of the BMP program is the use of third-party audits to improve the credibility of the biosolids program with the public. The audits also help participants identify areas of strength as well as areas of weakness that can be improved upon.

Though initially offered as a certification program only, the BMP now offers a tiered system that includes recognized programs (bronze through gold) as well as the traditional platinum-certified programs. This change was made to recognize those organizations that have committed to and trained for NBP goals, but have not had the ability to meet financial commitments for the program.

It should be noted that while the NBP program was developed primarily to focus on environmental and social issues, the program can also offer financial benefits to participants in terms of improved and more efficient operations. Additional information on the program can be found at: http://www.wef.org/biosolids.

## Product Stewardship




Concerns regarding microconstituents (originating from pharmaceuticals and personal care products, PCPPs) persist among the public, although research to determine the effects of biosolids-borne microconstituents is still under way meaning research-based regulations are likely years away. In the interim, product stewardship and pollution prevention programs (PPPs) offer an approach to minimize microconstituents entering the waste stream, preventing these materials from entering wastewater collection systems, and maximizing both biosolids quality and resource recovery potential.

### Pharmaceuticals

To date, two product stewardship approaches have been adopted to divert pharmaceuticals from wastewater collection systems: one approach focuses on returning unused medicines for disposal, and another goes a step further, requiring manufacturers to be responsible for the fate of their products.

Perhaps the most well-known “take back program,” “National Prescription Drug Take Back Day,” is led by the Drug Enforcement Agency (DEA). This program, initiated in 2010, has been steadily growing and as of September 2015, has eliminated more than 5.5 million pounds of pharmaceuticals from circulation (OS&H, 2016) with the assistance of state and local partners, including utilities. A number of utilities across the nation also have kiosks for pharmaceutical drop offs, supplementing the DEA-led program and providing more consistent access for safe pharmaceutical disposal.

The DEA program was expanded in 2014 to allow unused prescriptions to be returned to pharmacies; while participation in this program was limited in its first year, Walgreens plans to install 500 product return kiosks in its stores in 2016.

A newer trend in the U.S. (following similar trends in Canada and Europe) is the implementation of “Extended Producer Responsibility” (EPR) programs. These programs generally require that pharmaceutical manufacturers develop, manage, and fund take-back programs and properly dispose of the collected products.

The first U.S. program was established via ordinance in Alameda County, CA in 2012, but implementation was delayed by litigation as pharmaceutical firms challenged the ordinance. The ordinance was upheld in court, but the challenge was ultimately directed to the Supreme Court, who refused to hear the case in May 2015; this action set the precedent allowing local governments to develop these programs.

Today a number of agencies have implemented EPRs in addition to Alameda, including San Francisco, San Mateo, Santa Clara and Marin County, CA, and King County, WA. Each of these programs include over-the-counter medicines, in addition to prescriptions, enhancing the potential for diversions from wastewater and biosolids.

### Personal Care Products

To date, efforts (both voluntary and regulatory) to reduce the quantities of personal care products in wastestreams and the environment have focused on the ubiquitous triclosan and other antimicrobials found in antibacterial soaps.

Effective on January 1, 2017, the state of Minnesota banned triclosan in personal care products, stating "no person shall offer for retail sale in Minnesota any cleaning product that that contains triclosan and is used by consumers for sanitizing or hand and body cleansing."

The Federal Drug Administration also weighed in on antibacterial soaps, proposing new rules in 2013 that "all consumer antiseptic wash active ingredients have data that demonstrate a clinical benefit from the use of these consumer antiseptic wash products compared to nonantibacterial soap and water" (FDA, 2013). The proposed rule is expected to be finalized in late 2016, but based on FDA research, there is an expectation that proving the efficacy of these products will be difficult.

Prior to the final FDA ruling, triclosan is already disappearing from several major manufacturing lines, though whether these recent changes have impacted wastewater and biosolids quality are not yet known.

## Regulation and Policy Needs

As evidenced above, a wide range of actions are required on regulatory and policy levels to advance resource recovery in biosolids.

Critical activities include:

- *Continued efforts to promote and facilitate multi-agency coordination,* which will be critical to addressing overlapping regulations and responsibilities as the lines between solid waste management and wastewater treatment blur. Additionally, coordination will be required to emphasize the concept of "maximum environmental benefit" in regulatory development to minimize regulations that shift pollutant issues from one medium to another (i.e., air to water), rather than effectively and holistically managing pollutants.
- *Collaboration between experienced biosolids practitioners and regulators* as new products emerge from wastewater and biosolids processing (such as fertilizer derived from struvite) and questions arise as to how (or if) those products should be regulated.
- Continued expansion of voluntary programs that support biosolids quality such as the NBP EMS and PPPs.
- Continued research is required to address both existing and emerging concerns regarding biosolids safety.

Specific research areas requiring attention include:

- *Odor*—Continued research into processes to reduce biosolids odor, a primary public concern and a driver of resistance to biosolids use, is warranted. This information would supplement the significant work done by WE&RF over the last decade or so on the mechanisms of odor generation.
- *Stability*—Stability is closely related to odor and is therefore a continued focus (especially through WE&RF's High Quality Biosolids Project).

- *Emerging Pollutants*— Interest in the future will continue to center on the fate and significance of emerging contaminants, including personal care products, pharmaceuticals, emerging pathogens, and nanoparticles.
- *Surrogate Indicators*—Research is also needed to support the development of new surrogate indicators (for pathogens), as research in this area, described in *Charting the Future of Biosolids* (WEF, 2011) reveals potentially improved approaches to demonstrate effective pathogen reduction.

Though this research is critical, it is equally important to ensure the research findings are effectively disseminated to practitioners and the public. Specific education and outreach needs and potential solutions are addressed later in this report.

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# Section 3

# Organics Recycling: A New Perspective

The recycling of organics through application to the land has been practiced for millennia, with farmers long recognizing the benefits of the organic matter and nutrients in manures, night soil – and more recently, biosolids – to soil and crop systems. While these benefits are still a focal point, our perspective has expanded to include benefits associated with carbon footprint and climate change, as biosolids provide opportunities for GHG reductions through carbon sequestration and fertilizer production offsets. They can also play a role in sustainable soil management by building better soils and importantly, by restoring ecosystem functioning and services to degraded lands. This section explores these relationships.

## Soils and Climate Change

The relationship between biosolids applied to the land and climate change is best viewed in the broader context of sustainable soil management, considering not only how our soils have changed with intensive cultivation, but also predicted soil impacts due to climate change. One soil parameter impacted by both agricultural practices and climate change is soil organic carbon (SOC). SOC comprises about 50% of soil organic matter (SOM), which also includes materials from plants, animals or microorganisms (living or dead) (Overstreet and DeJong-Hughes, 2009).

Agriculture takes a heavy toll on SOM, and thus studies indicate that the heavily farmed Midwestern U.S. soils have lost 30-50% of their SOC level since they have been cultivated (Lal, 2002). Intensive agricultural practices can lead to a "soil degradation spiral" increasing cultivation can ultimately lead to poor soils and declining crop yields, and therefore ever increasing cultivation needs, which further degrade soils.

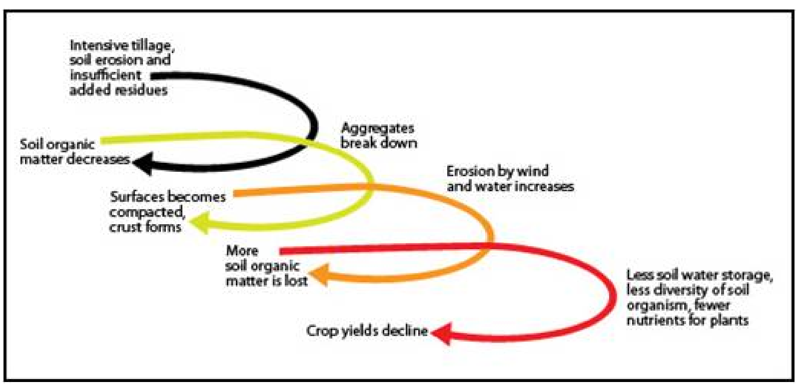


Figure 6: Soil Degradation Spiral (Adapted from Magdoff and Van Es, 2009)

As shown, climate change can exacerbate soil degradation via three mechanisms: higher temperatures can increase microbial decomposition of SOM, drought can lead to wind erosion and loss of SOM, while flooding can scour the soil surface and reduce SOM (van den Born-et al., 2000). Of these degradation processes, erosion – by wind or water – has the most severe impact on soil SOC content (Lal, 2004).

The impact of erosion on soils cannot be underestimated. Erosion can remove the most fertile part of soil, reducing productivity up to 50% and in the U.S. alone, the annual cost of erosion loss is estimated to be $44 billion per year (Eswaran, Lal and Reich, et al. 2001).

Climate change impacts on soil are not limited to loss of fertility: soil compaction is also a critical issue. Compacted soils can increase energy costs for tillage by 50% (Raper et al., 2000) and can reduce yields by 10% to 20% (Iowa State University, 2009).

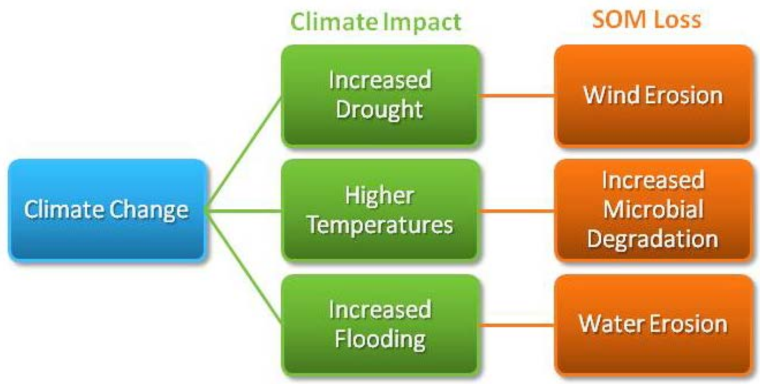


Figure 7: Climate Change Impacts on Soil Organic Matter (SOM)

Biosolids can play a critical role with respect to climate change and its impacts on soil by providing the SOC and organic matter to build soils.

The addition of biosolids can also sequester carbon in the soil. Lal (2002) estimates that about 60 to 70% of the SOC lost from U.S. mid-western soils could be re-sequestered through the adoption of recommended soil and crop management practices, such as the conversion from plow till to no till, the "liberal use of biosolids," and other practices.

In addition to SOC loss, the increased reliance on fertilizers to maintain soils productivity has a strong carbon footprint impact, as fertilizer production, distribution, and use contributes 2.5% to global GHG emissions (IFA, 2009). As shown in the figure below**,** biosolids contain macronutrients (nitrogen, phosphorus, potassium) – albeit in lower concentrations than mineral fertilizers – and their use can offset fertilizer requirements (biosolids also contain micronutrients, such as iron and zinc).

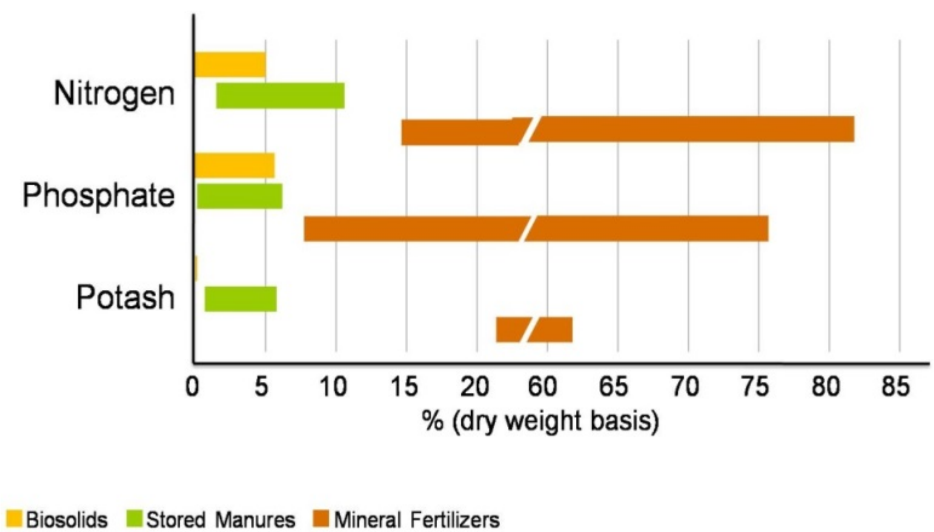


Figure 8: Biosolids, Manure, and Fertilizer Macronutrient Content

The potential role of biosolids in carbon footprint reduction – via fertilizer replacement and carbon sequestration – is described below.

# Biosolids and Carbon Accounting

As noted in Section 2, protocols to estimate GHG emissions from biosolids processes are still evolving, but the development of the Biosolids Emissions Assessment Model (BEAM) provides a strong foundation for such assessments. Developed at the request of the Canadian Council of Ministers for the Environment, BEAM can be used to define existing GHG emissions, assess GHG reduction opportunities, and document GHG reductions for emerging carbon markets (SYLVIS, 2009). Key processes addressed in the model are shown in the following figure, which also indicates GHG impacts and offsets associated with solids processing.

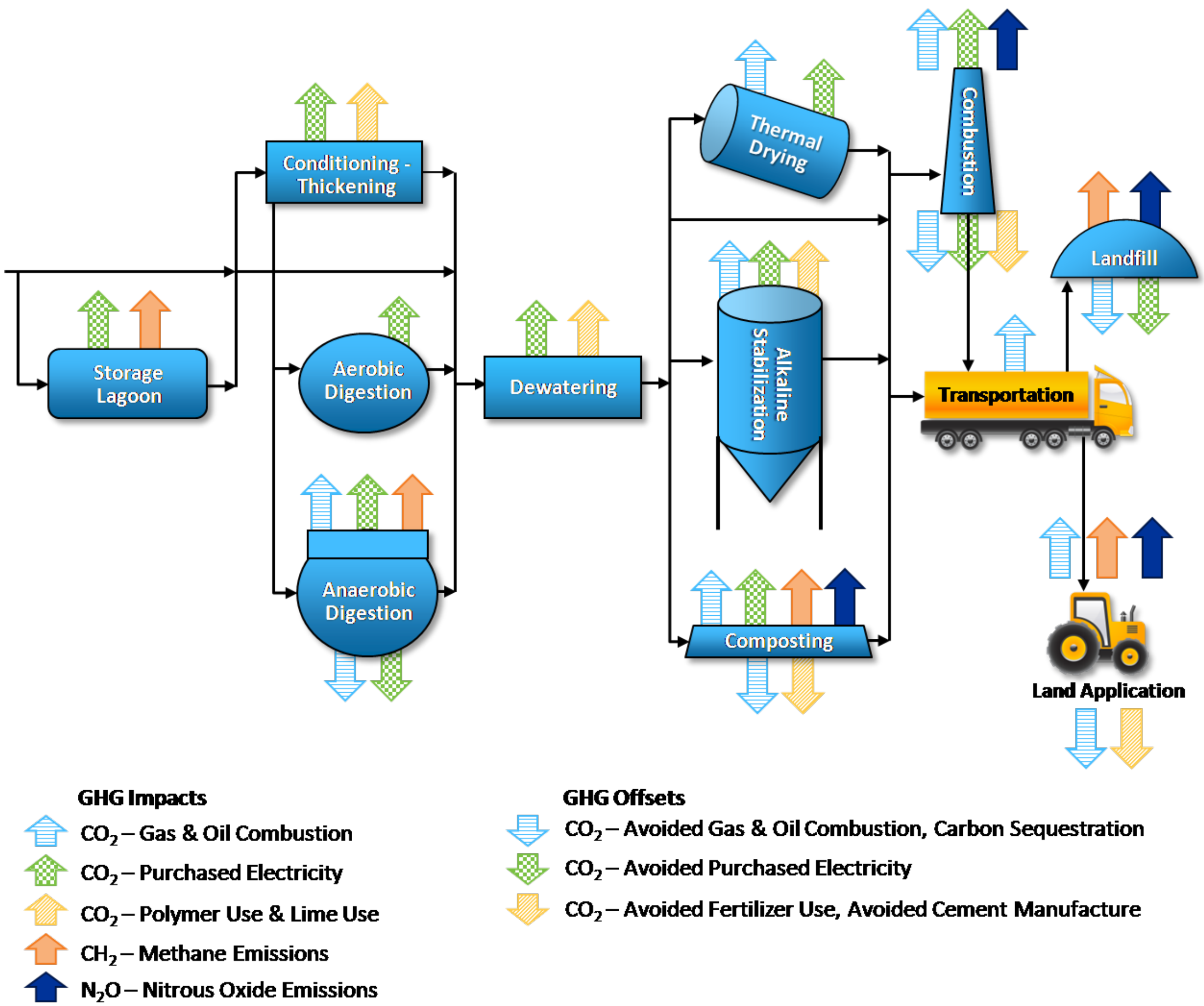


Figure 9: Biosolids GHG Impacts and Offsets (Brown, et al., 2010)

For the purposes of this report, key areas of focus include fertilizer replacement and carbon sequestration, both described below.

## Fertilizer Replacement

Biosolids can reduce agricultural carbon footprints through fertilizer production offsets to meet plant nutrient requirements. The reported GHG offset values for fertilizer replacement vary in literature, but based upon the data presented in the following table, the BEAM model assumes values of 4 and 2 kg $CO_2e$/kg for N and P, respectively (Brown, et al., 2010). The default values are expected to be conservative, as they do not distinguish between plant available and total nutrient content and do not account for the micronutrients (and macronutrients such as potassium) that are present in biosolids (Brown, et al., 2010).

Reported Values for Energy Required to Produce, Transport and Apply Synthetic Fertilizers

| Author | Title | Journal | Nitrogen | Phosphorus | Comments |
|---|---|---|---|---|---|
| Brown, S. and P. Leonard. 2004. | Biosolids and global warming: Evaluating the management impacts | BioCycle, August. | | 3 g $CO_2$ per g P | Used Sitting 1979 to calculate energy required for P production, and IPCC factor used for N for multiplier to take into account transport and production inefficiencies |
| Murray, A., A. Horvath, and K.L. Nelson. 2008. | Hybrid life-cycle environmental and cost inventory of sewage sludge treatment and end-use scenarios: a case study from China | Enivon. Sci. Tech. Published online 3/20/08 | 3.6 g $CO_2$ per g N | 4.86 g $CO_2$ per g P | |
| Kim, S. and B.E. Dale. 2008. | Effects of nitrogen fertilizer application on greenhouse gas emissions and economics of corn production | Environ. Sci. Tech 42:6028-6033 | 3.1-4.7 g of $CO_2$ per g N | | Total emissions from all other fertilizer use (P, K, S, lime, pesticides and herbicides) similar to N fertilizer emission |
| Intergovernmental Panel on Climate Change (IPCC). 2006. | Guidelines for National Greenhouse Gas Inventories | Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html | 1.3 g of $CO_2$ per g N | | Manufacture only |
| Recycled Organics Unit. 2006. | Life cycle inventory and life-cycle assessment for windrow composting systems | Univ. of New South Wales, Sydney, Australia. Available at http://www.recycledorganics.com/publications/reports/lca/lca.htm | 3.96 g of $CO_2$ per g N | 1.76 g of CO2 per g P | Potassium, factor of 1.36 given |
| Schlesinger, W. H. 1999. | Carbon sequestration soils: some cautions amidst optimism | Agriculture, Ecosystems and Environ. 82: 121-127 | 4.5 g $CO_2$ per g N | | 1.436 moles of CO2-C per mole of N |

Table 5: Reported Values for Energy Required to Produce, Transport, and Apply Synthetic Fertilizers (Brown, et al., 2010)

# Carbon Sequestration

Atmospheric $CO_2$ has increased by more than 30% since 1750, with losses of SOC contributing significantly to the increase of the estimated 240-300 billion tons of $CO_2$ emitted since the industrial revolution, and an estimated 66-80 billion tons have been contributed by the SOC pool (Lal, 2004).

In his comprehensive report on soil carbon sequestration and climate change, Lal (2004) cited replenishing the soil's carbon supply as a strategy to offset (but not eliminate) increases in atmospheric $CO_2$, and estimated the cumulative potential of soil C sequestration to be 30-60 billion tons over 25-50 years. Because other factors – specifically fossil fuel use – contribute so heavily to $CO_2$ emissions, he also notes that carbon sequestration has a limited (albeit critical) potential to impact climate change because it also improves soil quality, soil "C sequestration is something that we cannot afford to ignore."

Recognizing the role that biosolids can play in sequestering carbon, research on this topic has intensified over the last decade or so, and while information remains sparse, data were identified and included in the BEAM model (see below).

The table illustrates a critical consideration when quantifying carbon sequestration from biosolids amendments: the amount of carbon sequestered will vary according to land use and management practices, with surface applications apparently yielding lower C storage than single one-time applications (such as might be seen for vegetation establishment on roadway embankments or reclamation).

| Land use | Summary | Change in Soil C Storage (Mg $CO_2$ per dry Mg biosolids) |
|---|---|---|
| Dryland wheat, conventional tillage | Cumulative loading rate of 18-40 Mg $ha^{-1}$ . Site 14 years old | 1.25-1.6 |
| Surface application to fescue | Annual application from 1993-2000, sampled in 2008, cumulative loading rates 67-201 Mg $ha^{-1}$ | 0.15 to 0.3 |
| Roadside, incorporated | Single 147 Mg $ha^{-1}$ application 2 years prior to sampling | 1.74 |

Table 6: Carbon Sequestration in Biosolids Amended Soils (Kurtz, 2010)

C storage is also impacted by climate and soil type (Lal, et al., 2007). The following figure illustrates the impact of differing climates and soils on sequestration.

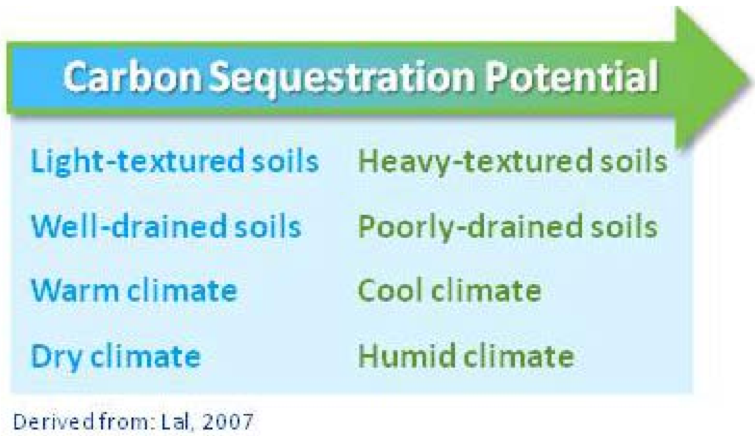


Figure 10: Impact of Differing Climates and Soils on Sequestration

Generally, depleted soils (those with low SOM) and disturbed lands offer promise for C sequestration, and the use of biosolids on reclaimed lands has therefore been a focus. Studies of three U.S. and two Canadian mines demonstrated that biosolids addition enhanced carbon storage in reclaimed mine soils, finding that every Mg of biosolids applied resulted in 0.03 to 0.31 Mg of carbon stored in soil (Trlica, 2010). In a longer-term study covering decades of biosolids applications for land reclamation in Fulton County, Ill., Tian et al. (2009) found that the mean net C sequestration in amended fields was 1.73 Mg C/ha$^{-1}$ yr$^{-1}$, compared to values ranging from -0.7 to 0.17 Mg C/ha$^{-1}$ yr$^{-1}$ in fertilizer control fields.

Research also indicates that the type of biosolids applied can influence carbon sequestration, with more stable products more resistant to decomposition (WSDE, 2015). For example, Powlson et al. (2011) found that the application of digested biosolids provided a greater increase in the mean annual rate of SOC compared to undigested biosolids (180 kg C ha$^{-1}$ t$^{-1}$ dry solids compared to 130 kg C ha$^{-1}$ t$^{-1}$ dry solids of the mean annual rate of SOC increase).

Despite the promising role of biosolids for sequestering carbon, additional research is needed to better support carbon footprint accounting tools such as the BEAM model and to reflect the broad diversity of biosolids management practices currently employed. Additionally, GHG impacts from land application must be considered when considering the overall carbon footprint of this practice. These include transportation impacts (which can be minimal in many cases) and nitrous oxide emissions.

It is also critical to remember that even if carbon accounting tools show that land application does not offer the greatest carbon footprint reductions (or lowest cost), the value of biosolids for improving soil SOC, SOM, and soil tilth should not be ignored.

# Ecosystem Service and Function Restoration

Carbon sequestration is but one of the benefits of biosolids use that fall within the category of ecosystem service restoration (nutrient cycling is another).

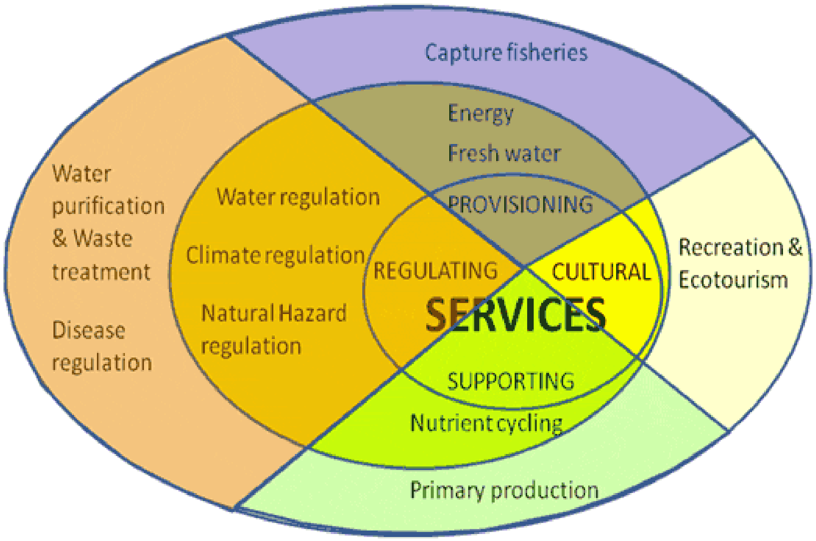


Figure 11: Ecosystem Services (Mitchell, M.G.E., 2016)

Ecosystem services are the benefits provided by functioning ecosystems, and are typically allocated into four categories: supporting, regulating, provisioning, and cultural. Services within these categories are shown on the figure to the left.

With ecosystem services as a framework, the metrics of restoration success are expanding beyond vegetative cover percentages, metal bioavailability, soil fertility and carbon sequestration to include key ecological measures such as microbial function, soil biota population counts and diversity, and bioassays (for mammals and plants).

As noted by Brown and Chaney (2016), the full valuation of this holistic ecological approach is still developing. Nonetheless, several studies have demonstrated the benefits of biosolids for ecosystem restoration of disturbed and contaminated sites, as highlighted below.

**Summary of studies on restoration of environmental sites using biosolids**

| Author/Title/Journal | Synopsis |
|---|---|
| Basta, N.T., D.M., Busalacchi, L.S. Hundal., K. Kumar, R.P. Dick, R.P. Lanno, J. Calson, A.E. Cox, and T.C. Granato<br><br>Restoring ecosystem function in degraded urban soil using biosolids, biosolids blend, and compost<br><br>J. Environ. Qual. 2016 45:74-83 | At a brownfield site in Calumet, IL, amendments rototilled into the top 12.5 cm of soil included: biosolids at 202 Mg $ha^{-1}$; biosolids at 404 Mg $ha^{-1}$; vegetative compost at 137 Mg $ha^{-1}$; and a blend consisting of biosolids applied at 202 Mg $ha^{-1}$, drinking water treatment residual, and biochar. Rainfall runoff from experimental plots was collected for 3 years. One year after soil amendments were incorporated, a native seed mix containing grasses, legumes, and forbs was planted.<br>Soil amendments improved soil quality and nutrient pools, established a dense and high-quality vegetative cover, and improved earthworm reproductive measures. Amendments increased soil enzymatic activities that support soil function. Biosolid treatments increased the Shannon–Weaver Diversity Index for grasses. For the forbs group, control plots had the lowest diversity index and the biosolids blend had the highest diversity index. Biosolids and compost increased the number of earthworm juveniles. In general, biosolids outperformed compost. Biosolids increased N and P in rainfall runoff more than compost before vegetation was established. Several microconstituents were detected in runoff water but at concentrations below the probable no-effect level. Future restoration design should ensure that runoff control measures are used to control sediment loss from the restored sites at least until vegetation is established. |
| Pepper, I.L., H.G. Zerzghi, S.A. Bengson, B.C. Iker, M.J. Banerjee, and J.P. Brooks<br><br>Bacterial populations within copper mine tailings: long-term effects of amendment with Class A biosolids<br><br>J. Appl. Microbiol. 2012 113:569-577 | Mine tailing sites were established at ASARCO Mission Mine close to Sahuarita Ariz. Site 1 (December 1998) was amended with 248 tons $ha^{-1}$ of Class A biosolids. Sites 2 (December 2000) and 3 (April 2006) were amended with 371 and 270 tons $ha^{-1}$, respectively. Site D, a neighboring native desert soil, acted as a control for the evaluation of soil microbial characteristics. Surface amendment of Class A biosolids showed a 4 log10 increase in heterotrophic plate counts (HPCs) compared to unamended tailings, with the increase being maintained for 10-year period. Microbial activities such as nitrification, sulphur oxidation, and dehydrogenase activity were also sustained throughout the study period. 16S rRNA clone libraries obtained from community DNA suggest that mine tailings amended with biosolids achieve diversity and bacterial populations similar to native soil bacterial phyla, 10 years post-application. The study concluded that the addition of Class A biosolids to copper mine tailings in the desert southwest increased soil microbial numbers, activity, and diversity relative to unamended mine tailings. |
| Kurunthachalam, K., S. Corsolini, J. Falandysz, G. Fillmann, K. S. Kumar, B.G. Loganathan, M.A. Mohd, J. Olivero, N. Van Wouwe, J.J. Yang, and K. M. Aldous<br><br>A comparison of the efficacy and ecosystem impact of residual-based and topsoil-based amendments for restoring historic mine tailings in the Tri-State mining district<br><br>Sci. Total Environ. 2014 485-486: 624-632 | A research and demonstration site on Pb and Zn mine was established in 1999. Municipal biosolids and lime and composts were mixed into the wastes at different loading rates. The site was monitored intensively after establishment and again in 2012. A site restored with topsoil was also included in the 2012 sampling. Initial results including plant, earthworm, and small mammal assays indicate that the bioaccessibility of metals had been significantly reduced as a result of amendment addition. The recent sampling showed that at higher loading rates, the residual mixtures have maintained a vegetative cover and are similar to the topsoil treatment based on nutrient availability and cycling and soil physical properties including bulk density and water holding capacity. The ecosystem implications of restoration with residuals versus mined topsoil were evaluated. Harvesting topsoil from nearby farms would require 1875 years to replace based on natural rates of soil formation. In contrast, diverting biosolids from combustion facilities (60% of biosolids generated in Missouri are incinerated) would result in greenhouse gas savings of close to 400 Mg $CO_2$ per ha. |

Table 7: Summary of Studies on Restoration of Environmental Sites Using Biosolids

## Enabling Organics Recycling

Fully leveraging the resource potential of biosolids applied to the land requires three key areas of focus (beyond those identified in Section 2):

- Further demonstration of the benefits of biosolids as amendments, with a focus on their role in restoring depleted and disturbed soils ecosystems.
- Further research and documentation of the carbon footprint impacts of land application and reclamation activities.
- Broad-based and effective communications regarding all the above.

### Demonstrating Biosolids Benefits

Continued work to document the benefits of biosolids use in land application and reclamation should both continue and expand in scope. As noted earlier, the value of biosolids in the restoration of ecosystem services, in particular, is not yet well documented – but it is critical in our effort to quantify the value of biosolids beyond traditional measures of soil fertility.

### Carbon Footprint Documentation

The BEAM model discussed above provides a solid foundation for quantifying the carbon footprint of biosolids operations, but additional data is needed to expand and strengthen the model. Specifically, additional data on carbon sequestration, reflecting the depth and breadth of biosolids practices across the continent, is needed. Additionally, further information regarding nitrous oxide emissions from land application and combustion are needed to strengthen the model.

### Broad Based and Effective Communications Regarding Biosolids Benefits

Recycling of biosolids to the land is clearly not new, yet the demonstrated benefits that biosolids provide to our soils do not seem to be well understood by the public. Moreover, these benefits are often overshadowed by persistent uncertainties about the safety of biosolids. While additional research to demonstrate benefits to the soil could be helpful, effective dissemination of the multiple success stories and research regarding biosolids benefits is essential. The need to communicate what we know about biosolids to foster resource recovery is critical enough to be the topic of a separate discussion and is the focus of Section 7 of this report.

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# Section 4

# Energy Recovery

Because the energy contained in wastewater and biosolids exceeds the energy needed for treatment by a factor of five, energy neutrality is not just a pipe dream. It is a challenging yet reachable goal when WRRFs are designed and operated for this objective through a combination of energy efficiency best practices and energy production technologies. As stated in WEF's position statement, water resource recovery facilities have the potential to be energy neutral or even net energy producers through holistic energy management approaches, incorporation of conservation practices, and generating renewable energy through treatment of their byproducts, such as biosolids. Solids treatment provides the greatest potential for energy recovery and production, with the chemical energy embedded in biosolids greater than the energy needed for treatment. This chapter focuses on energy recovery and presents an extensive menu of technologies available to optimize, extract, and use energy from biosolids, benefits and limitations, and research and implementation initiatives that are needed to realize biosolids' energy potential.

## Drivers

Wastewater treatment is a huge cost center for utilities, often exacerbated by aging infrastructure and outdated technology. Energy is the second or third most expensive item in a wastewater utility's operations and management budget. Any effort to reduce purchased energy requirements benefits the utility by not only lowering operational costs, but also by decreasing its carbon footprint and increasing the sustainability of the operations. The impacts go beyond the utility as when a utility decreases its net energy use, the local and national communities also benefit from increased energy security and fewer greenhouse gas emissions.

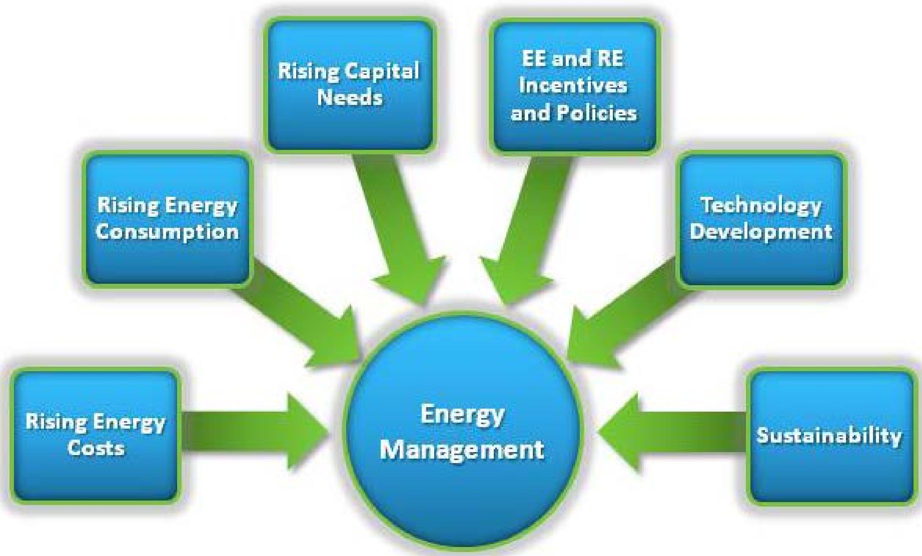

Figure 12: Factors driving utilities to reduce net energy consumption (Fillmore et al., 2011)

Although wastewater possesses theoretically more energy than needed to operate a treatment facility, the number of net zero energy WRRFs is still low worldwide. The water sector is actively investigating barriers and solutions associated with reducing energy use and maximizing energy production, with the goal of operating solely on the energy from the water and wastes they treat.

## Insights Encourage WRRF Energy Neutrality

Recent research conducted in collaboration with WE&RF and the New York State Energy Research and Development Authority (NYSERDA) offers numerous insights to aid WRRFs in moving toward net-zero energy use through best practices, energy conservation, demand reduction, and enhanced production. The researchers modeled 25 common process configurations and identified the pathway followed by representative WRRFs to achieve energy neutrality (Tarallo and Kohl, 2015). Sankey energy diagrams of these process configurations were developed so similar facility types can be identified and evaluated with respect to energy usage and production. Findings related to solids management included:

- Improvements to primary treatment and solids capture had the most significant total positive impact of all the best practices involved.
- Anaerobic digestion with combined heat and power (CHP) was the most lucrative energy approach, reducing energy requirements by up to 35%.
- Co-digestion of fats, oils, and grease/food waste in anaerobic digesters increased biogas production and energy production potential.
- Additional energy recovery potential existed with dewatered biosolids due to their retained chemical energy (approximately 30% post-digestion and 50 % for lime stabilization).

A triple-bottom line (social, environmental, and financial) sustainability score of six different biosolids management options was also developed. The results showed that anaerobic digestion with co-digestion, as well as CHP, with land application of biosolids had the best overall sustainability score.

# Energy in Wastewater and Biosolids

As noted earlier, the energy contained in wastewater and biosolids has been estimated to exceed the energy needed for treatment by a factor of five. Based on this premise, WE&RF has developed an initiative to achieve net-zero energy in wastewater treatment plants.

The energy in wastewater exists in three forms: thermal energy, hydraulic energy, and chemical or calorific energy. The following table illustrates the energy content of wastewater. **Thermal energy** is controlled by the temperature of the wastewater entering the plant. Heat can be recovered from the raw influent using heat exchangers and the resulting low-grade heat energy can be used to satisfy some of the building and process heating needs of the plant. **Hydraulic energy** is the energy of the moving water. Low head turbines on gravity flow can be used to convert kinetic energy into electricity (WE&RF Fact Sheet, 2012).

**Energy in wastewater (Tchobanoglous and Leverenz, 2009)**

| Constituent | Value | Unit |
|---|---|---|
| Average heat in wastewater | 41,900 | $MJ/10°C \cdot 10^3 m^3$ |
| Chemical oxygen demand (COD) in wastewater | 250 – 800 (430) | mg/L |

| | | |
|---|---|---|
| Chemical energy in wastewater, COD basis | 12 – 15 | MJ/kg COD |
| Chemical energy in primary solids, dry | 15 – 15.9 | MJ/kg TSS |
| Chemical energy in secondary biosolids, dry | 12.4 – 13.5 | MJ/kg TSS |

Table 8: Energy in Wastewater (Tchobanoglous and Leverenz, 2009)

The embedded **chemical energy** in wastewater is on average five times the energy needed for treatment, with the values ranging from 0.4 to 6.3. In many cases, recovering the chemical energy in solids alone is sufficient to achieve energy neutrality.

## Energy in Biosolids

There are many opportunities to convert the chemical energy in solids to a useable form (heat or fuel) through biological or thermal processes. Biosolids typically contain approximately 6,500 to 9,500 British thermal units per pound (Btu/lb) on a dry weight basis (2.3 kWh/lb), which is similar to the energy content of low-grade coal. The following table shows a comparison of the energy in biosolids to the energy in other fuels. For comparison, the average daily residential energy use in the U.S. is 31 kWh per home, which would require the energy equivalent of 13.4 lbs of dry biosolids (Stone et al., 2010).

| Fuel | Energy (Btu) |
|---|---|
| 1 pound of dry biosolids | 8,000 |
| 1 kiloWatt hour of electricity | 3,412 |
| 1 cubic foot of natural gas | 1,028 |
| 1 cubic foot of biogas | 600 – 700 |

Table 9: Biosolids energy in perspective (Stone et al., 2010)

# Energy Optimization and Recovery Technologies

Energy recovery options range from mature, well-established systems, such as anaerobic digestion and incineration, to emerging technologies, such as Supercritical Water Oxidation (SCWO) and hydrothermal gasification. These options fall into two main categories: bioconversion and thermal conversion. This section provides a description of optimization and recovery technologies, including advantages and disadvantages, and the current status of each technology (from research and development phase to established and adaptive use).

## Bioconversion: Anaerobic Digestion

The bioconversion of biosolids energy is typically accomplished using anaerobic digestion. In high-rate anaerobic digestion (AD), the readily biodegradable portion of the volatile solids in sludge is converted into biogas by microorganisms in the absence of oxygen. The biogas is composed primarily of methane (60 to 65%) and carbon dioxide (30 to 40%), with small concentrations of nitrogen, hydrogen sulfide, and other constituents. The methane portion of the biogas is a valuable fuel and, with conditioning, can be used in place of natural gas for many energy needs.

Biogas, rich in methane, is a powerful greenhouse gas and should be controlled. Most WRRFs that produce biogas either flare or beneficially use the gas to produce energy. Recognizing the energy value of the biogas, WRRFs have long used biogas in boilers to maintain mesophilic temperatures during the digestion process. Today, there are a variety of technologies to recover energy from the biogas generated by AD systems, as well as multiple uses for that gas.

# Maximizing Biogas Production

Biogas production through anaerobic digestion is limited to conversion of the readily biodegradable portion of the solids. To overcome this limitation, and thus maximize biogas production, co-digestion and pretreatment processes have become rapidly growing practices in recent years.

Co-digestion consists of adding readily biodegradable feedstocks directly into the digester to co-digest them with the biosolids. Fats, oils, and grease (FOG), for example, are readily biodegradable by anaerobic bacteria. Other high-strength wastes can also be co-digested to increase biogas production.

Pretreatment processes, on the other hand, increase biodegradable materials by breaking open the bacterial cells in the waste activated solids (WAS), releasing the cell contents, making them available to the anaerobic bacteria for conversion to biogas. Some of the pretreatment systems also reduce the viscosity of the feed solids, allowing the loading of digestion processes at solids concentrations significantly higher than can be performed with conventional digestion practices.

Co-digestion of high-strength wastes and digester pretreatment technologies are discussed in the following sections.

## Co-digestion

Co-digestion of high-strength wastes in anaerobic digesters has been a rapidly growing practice to meet WRRF goals of maximizing biogas production for energy recovery. Transitioning toward energy neutral or positive operation at WRRFs requires an integrated approach whereby energy recovery is maximized while energy consumption is reduced. Co-digestion of high-strength organic wastes (HSWs) that contain readily degradable, high-energy density organics with wastewater solids represents an opportunity for WRRFs to increase biogas production using existing digester capacity. The additional digester gas can be captured and utilized for a variety of purposes including combined heat and power, generation of CNG/LNG for pipeline or vehicle fuel, or other beneficial uses.

Approximately 17% of U.S. WRRFs with anaerobic digestion take in outside wastes and feed them directly into the digesters (WEF, 2013). FOG is the most common high-strength organic waste co-digested with biosolids. HSWs from food processing, breweries, cheese production, animal farming, biodiesel production, and de-icing operations (glycols) can also be co-digested to increase biogas production in anaerobic digesters with spare capacity. A compendium of data regarding HSWs (post-consumer, institutional, commercial, or industrial sources) that have been successfully treated through co-digestion is being developed as part of a WE&RF/NYSERDA research program (ENER9R13). This research expands upon previous WE&RF research (OWSO5R07) and includes a comprehensive survey of WRRFs with varying levels of experience with co-digestion to best understand the different elements that are considered during the various stages of project implementation. A main goal of this survey was to identify the primary operational impacts that result from the receipt, pretreatment, digestion, residual handling, and dewatering sidestream management of the various high strength materials. This survey is discussed in more detail in Section 8.

Co-digestion can add revenue streams and reduce costs through tipping fees, as well as additional gas production. Because of these benefits, most of the pilot-testing and research of co-digestion have focused on the effects on digester performance, especially biogas production. HSW addition can potentially alter digester rheology, cation balances, and other characteristics; therefore, altering digester performance and downstream processes either positively or negatively (Higgins, et al., 2016). The relationship between fundamental properties of HSW and their effects need to be researched for various anaerobic digestion configurations and dewatering processes to determine trends, interactions, and correlations.

Recent energy efficiency and production modeling results revealed several financial and local barriers to maximizing energy generation at WRRFs. The market availability of feedstocks for anaerobic co-digestion was more of a limiting factor for energy recovery potential than digester capacity or operational constraints (Tarallo and Kohl, 2015). The market demand and fee structure for high strength wastes are critical elements for a successful co-digestion program.

Since co-digestion increases biogas production, it can improve the economies of scale for on-site power generation, especially at small facilities. At the Village of Essex Junction WRRF in Vermont, co-digestion improves biogas production, allowing this small 2 mgd plant to run a successful CHP system. Fueling two 30-kW microturbines with biogas, the plant has reduced its electricity costs by 30% and is receiving renewable energy credits (RECs) for the electricity it generates (Willis, et al., 2012). The Derry Township Municipal Authority, PA has a separate receiving and treatment system for its imported wastes, and has been co-digesting since 1991. The import of additional wastes and cell lysis are being evaluated to increase biogas and energy production.

## Digestion Pretreatment

Digestion pretreatment processes improve the digestibility by making internal cellular matter of biological solids more available for digestion. This increases the volatile solids reduction (VSr) achieved in anaerobic digestion and consequently increases the biogas production.

Over the last decade there have been a number of pretreatment technologies that have been introduced and marketed in North America. Many of these systems have not been successful for various technical and commercial reasons. However, European experience with some of these pretreatment systems has been positive, and the technologies are beginning to gain a foothold in the North American market.

Some of the pretreatment technologies that have been introduced to the market in recent years have included thermal hydrolysis (THP), sonication, mechanical disintegration, and electrical pulse treatment. Of these, the technology that is gaining a foothold in the U.S. is THP, with two facilities operating in early 2016 and numerous new facilities in the planning and design phase. In addition, one mechanical disintegration technology, Evoqua's Crown™ Disintegration technology, has a relatively large number of European installations and has been recently installed at a facility in the U.S. Following is a summary of the various THP processes and the Evoqua Crown™ technology.

## Thermal Hydrolysis (THP)

THP is an advanced wastewater solids treatment process that boasts both financial and environmental advantages. There are several suppliers of THP systems, each with their own unique method of thermally hydrolyzing the solids. Some (Cambi and Veolia THP systems) inject steam at high temperature and pressure into sludge to rupture cells and improve the conversion of organic matter to biogas in the digestion process. Other suppliers (CNP and Lystek) use chemical addition along with heat to achieve hydrolysis.

THP is a proven and reliable technology with full-scale installations that date back to 1995. There are more than 25 installations of the Cambi® THP system operating in Europe with numerous additional facilities under development. There are more than 10 installations of the Veolia processes (marketed under the Biothelys® and Exelys™ names) in operation or under construction in Europe, with the oldest installation in operation since 2004.

Thermal hydrolysis has only recently been implemented in North America, with the initiation of Cambi system operations at the District of Columbia Water and Sewer Authority (DC Water) Blue Plains Advanced Wastewater Treatment Plant (AWTP) in late 2014, and a CNP PONDUS system beginning operation in early 2016 in Kenosha, WI. Lystek has six installations operating in Canada and one facility under construction in Fairfield, Calif. in early 2016.

There are numerous North American utilities in the design development stage for THP systems as of mid-2016, including Trinity River Authority of Texas (Dallas, TX), Hampton Roads Sanitation District (Virginia Beach, Va.), Raleigh, N.C., Oakland County Water Resources Commission (Waterford, Mich.), San Francisco Public Utilities Commission, and others. As the number of facilities that use THP grows, those considering the technology will have more opportunities to see it in operation firsthand and understand both its challenges and benefits.

### The Benefit of Biogas Systems

DC Water processes 370 mgd and used to move 60+ truck trips a day of biosolids before building their new biogas system. Now, they have half as many truck trips and are **saving an estimated $10 million/year in electricity costs and $15 million/year in other costs.** The facility generates 13 MW of power, produces all emergency power on site, if there's a major failure and the material the trucks are hauling away is a high-quality fertilizer that's supporting the local silvaculture farms.

One of the benefits of THP is its reduction on solids viscosity, making THP solids easier to mix and pump at higher solids concentrations, which leads to increased digester loading rates. The higher solids loading rate corresponds to higher organic loading rates than conventional digestion. This can be appealing to facilities that need to process more solids in existing systems or need to minimize the size and number of new digesters.

Performance enhancements with THP can include improved VSr and biogas production, improved dewatering, reduced cake odor, and, depending on the wastestream hydrolyzed, the generation of a Class A biosolids. For example, with the improved biodegradability in the digestion process, VSr of approximately 60% can be achieved, and biogas production can increase by 20 to 30%. Additionally, THP conditioning significantly improves the dewaterability of the biosolids after digestion, producing a drier cake. DC Water is achieving 30% or greater total solids concentration from their belt filter presses following approximately one year of operation with THP conditioning. The drier cake and the improved volatile solids destruction result in a substantial reduction in the volume of biosolids, providing significant annual hauling and land application cost savings. Lastly, demonstration testing has shown that THP conditioned and digested biosolids are less odorous than digested biosolids from non-THP systems.

There are many nuances between the methods suppliers use to accomplish hydrolysis. For example, some systems are well-suited to processing the combined sludges (primary and secondary) as well as imported organic wastes, while others are designed to hydrolyze only the secondary sludges. Some systems can handle either scenario and one supplier has even implemented systems that hydrolyze between digestion steps. The configuration selected can affect the ability of the overall process to comply with the more stringent requirements associated with Class A pathogen reduction. The complexity of the THP system configuration also varies depending on the supplier. Generally, these systems are highly automated and some systems use multiple tanks under high pressure with steam injection while others use chemical feed and heat.

### Evoqua Crown™ Disintegration System

The Crown™ disintegration system is a mechanical cell lysing system consisting of a high-speed mixer, a homogenizer, two progressive cavity pumps, a recirculation tank, and a disintegration nozzle. Pressurized solids are forced through a

#### City of Gresham, OR—Producing 10% more energy than the facility needs, innovative financing

Using biogas produced from the co-digestion of municipal sewage and commercial and food industry fats, oil and grease (FOG), the City of Gresham Wastewater Treatment Plant (WWTP) recently became the first energy net zero WWTP in the Pacific Northwest, and one of a handful in the U.S. Partnering with Energy Trust of Oregon and Oregon Department of Energy, the Cogen and FOG Receiving Station Expansion Project became operational in 2014. Since February 2015, the plant has produced about 10% more energy than it consumes onsite, becoming better than energy net-zero. Renewable energy generation and energy efficiency measures have eliminated $500,000 in annual electrical costs at the WWTP and generated $250,000 in annual FOG tipping fee revenues. The project won the American Biogas Council's Project of the Year Award in 2015. More Info: http://www.americanbiogascouncil.org/projectProfiles/greshamOR_to_print.pdf and https://youtu.be/n_zTBSxyTeQ?list=FLn3Or8oJw01b846RVoW7pYg disintegration nozzle, resulting in a sudden pressure drop that causes cavitation. The shear forces resulting from the implosion of the micro-bubbles cause the cell walls to rupture.

Pretreatment through the Crown™ system appears to improve solids destruction and biogas production during anaerobic digestion, as well as reduce foaming potential by disrupting filamentous bacteria. There are 21 Crown™ disintegration system installations, mostly in Germany and one in New Zealand. The first installation in the U.S., which began operation in May, 2016, is located in the City of Visalia, Calif.

## Using Biogas Systems at WRRFs to Convert Organics to Energy and Soil Products

Of the roughly 16,000 WRRFs, the American Biogas Council (ABC) considers about 5,000 of them able to economically support the construction of a biogas system to convert the organics filtered out of the wastewater into energy and soil products. The common, but unofficial, rule of thumb is that if a facility processes more than 1 million gallons per day, there is probably enough organics in the wastewater that, when converted to energy, can provide enough of the facility's energy needs to make the construction of a biogas system economical. This section gives an overview of the WRRFs using biogas systems, how they are using their biogas systems, the potential for other WRRFs to use biogas systems and some vignettes for a quick, but deeper look at a few facilities in the U.S.

### What is a biogas system?

Biogas systems use anaerobic digestion to recycle organic waste, turning it into biogas, for energy (the gas), and valuable soil products, using a natural, biological process. After processing, biogas is a renewable substitute for natural gas, and the digested materials—the liquid and solids—can be turned into a wide variety of useful soil products, similar or identical to peat moss, pellets and finished compost. Biogas systems can also recover nutrients.

### U.S. Biogas Market

Today, the U.S. has over 2,100 sites producing biogas in all 50 states: 247 anaerobic digesters on farms, 1,269 WRRFs using an anaerobic digester, 54 stand-alone systems that digest food waste, and 645 landfill gas projects. For comparison, Europe has over 10,000 operating digesters and some communities are essentially fossil fuel free because of them.

The potential for growth of the U.S. biogas industry is huge. A recent industry assessment conducted with the USDA, EPA and DOE as part of the Federal Biogas Opportunities Roadmap[1] estimates nearly 11,000 sites are ripe for development: 8,241 dairy and swine farms and 2,440 WRRFs, which could support a digester (including 380 who are making biogas but not using it) and 440 untapped landfill gas projects. If fully realized, these new biogas systems could produce enough energy to power 3.5 million American homes and reduce emissions equivalent to removing up to 11 million passenger vehicles from the road. It would also result in an estimated $33 billion in construction spending, creating approximately 275,000 short-term construction jobs and 18,000 permanent jobs to operate the biogas systems and manage ongoing business activities.

[1] http://www.americanbiogascouncil.org/biogas_resources.asp#reports

In addition to this federal assessment, the American Biogas Council counts an additional 1,448 biogas systems that could be developed at WRRFs and 931 food waste only systems that could be built. If these additional facilities were constructed, they would generate an additional $7 billion in construction spending along with 60,000 construction jobs and almost 5,000 permanent jobs. If the biogas was used to generate electricity, they could power more than 4 million homes and the emission reduction would be like removing 4.4 million cars from American roads.

## Use of Biogas Systems at Water Resource Recovery Facilities

Currently the U.S. has 1,269 WRRFs with biogas systems. They range in size from over 300 million gallons per day (mgd) to as small as 0.32 mgd, bucking the rule of thumb that a WRRF must process at least 1 mgd to be able to economically support a biogas system. In fact, of the 1,269 WRRFs with operational biogas systems, about 8% - 100 facilities - process less than 1 mgd. This suggests that another couple hundred biogas systems might be developed in addition to the 3,888 already recognized.

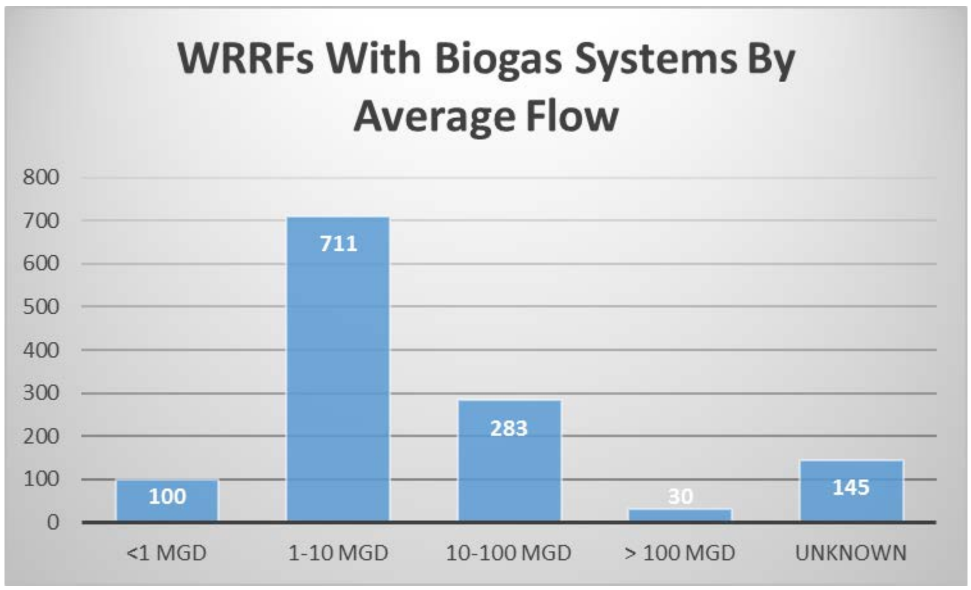


Figure 13: WRRFs with Biogas Systems by Average Flow

While only one quarter of the market for biogas systems at WRRFs has been realized, the type of biogas system almost always used is quite clear—the mesophilic anaerobic digester system. Mesophilic digesters operate in a lower temperature range--between about 20 °C and about 40 °C—compared to thermophilic digesters which operate at a higher temperature range—above 50 °C. This reflects the trend worldwide with digesters. Thermophilic digesters, mostly due to the higher temperatures, can digest their material as much as 6-10 times faster than a mesophilic digester and often don't need as much agitation or mixing. However, the heating requirements are an energy hog, and if space exists for a larger digester that can process the organics more slowly, a mesophilic digester will more often make the most economical sense.

In terms of the total number of biogas systems operational today, the majority, 56%, can be found at smaller WRRFs that process 1-10 mgd. Perhaps that reflects the larger number of facilities overall at that size. Of the 5,157 WRRFs that process 1 mgd or more, 34% of those facilities are rated in the 1-10 mgd range.

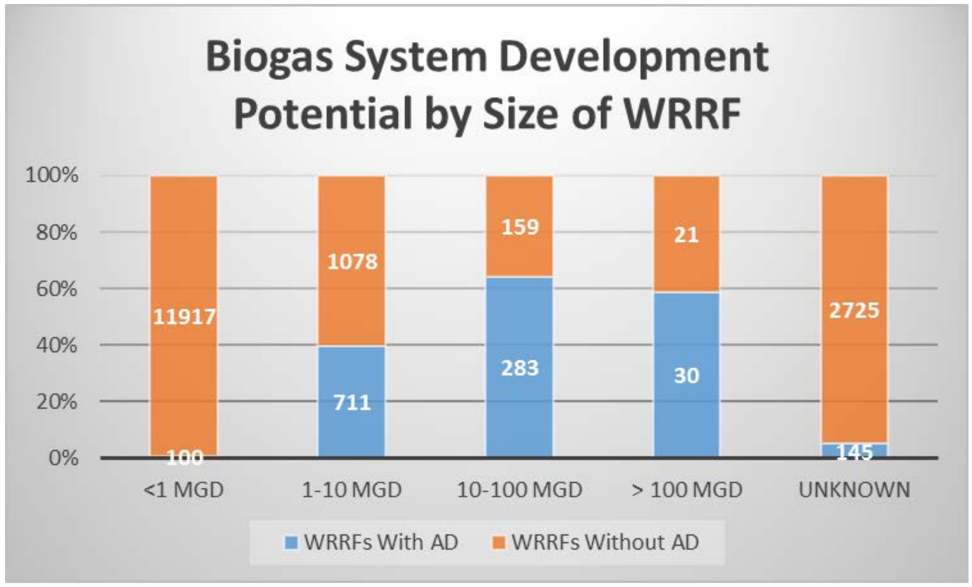

Figure 14. WRRFs ≥ 1mgd with Biogas Systems and Types

It's at the larger facilities, however, that biogas systems have the most penetration—about 60% of all WRRFs greater than 10 mgd already have a biogas system. This is most likely due to the large volume of organics each facility must handle. The larger the volume of material, the larger the cost for the WRRF to handle the material and the larger the revenue potential if the organics can be both handled on site and generate valuable energy with a biogas system. For the WRRF, the biogas system can reduce or eliminate material handling costs and also save money for the WRRF through the generation of energy.

Opportunities for new biogas systems abound at any size, especially since only one-quarter of all WRRFs larger than 1 mgd use a biogas system. For WRRFs evaluating whether a biogas system makes sense, dozens of companies in the U.S. biogas industry are ready to assist. And WRRFs of similar size that already have an operational biogas system are an excellent resource as well.

## Biogas Utilization

For years, many in the wastewater and biogas industries have suspected that large volumes of gas are being flared—wasted—since historically, the primary motivation for installing a biogas system has been to reduce the volume of biosolids the WRRF has to handle. The data from this most recent collection supports those suspicions; however, it's clear that we still don't know how much gas is being flared—even the most efficient facilities will flare occasionally when having issues with the equipment that uses the biogas (eg., an engine).

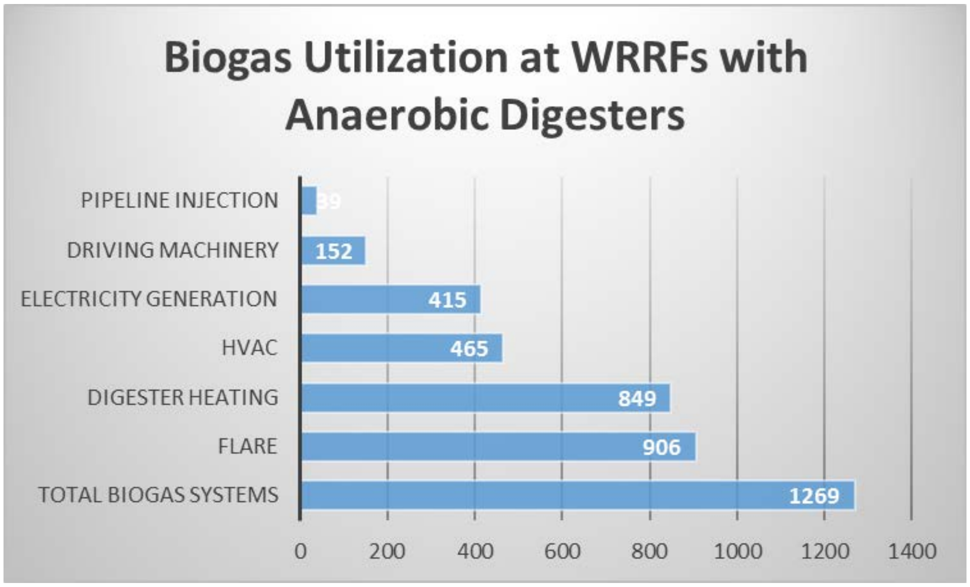

Figure 15. Biogas Utilization at WRRFs with Anaerobic Digesters

The most common uses for biogas, other than flaring, include heating or cooling needs, and electricity generation—the most common energy needs at a WRRF. While a few facilities are upgrading their biogas to natural gas pipeline quality and injecting it into the gas grid, only 39 facilities were doing this in 2016. The trend to upgrade biogas to renewable natural gas standards is increasing, primarily driven by Renewable Fuel Standards, air quality limits on IC engines in key areas like southern California, and increasing biogas yields from adding substrates like food waste.

One of the largest opportunities for biogas utilization today seems to be at facilities that are flaring their biogas. Equipment, like a gas engine, microturbine, or fuel cell, that will use biogas to generate electricity and heat, could be added at an estimated 1,000 facilities across the U.S.

## Beneficial Use of Digestate

Environmentally, the beneficial reuse of digestate is critical to making a sound argument on the performance of a WRRF. In 2016, 59% of WRRFs with a biogas system are beneficially using their digested material. We're unsure what the majority of the WRRFs are doing with their digestate; however, based on anecdotal evidence, we expect most facilities are giving it away. At most, 22%, or 282 facilities, may sell their digestate. The American Biogas Council believes that digestate is significantly undervalued and is working with the wastewater, agriculture, and food waste industries to create a standard testing and certification program for digestate with the hopes that validation of quality will help more facilities to sell their digestate, both increasing beneficial reuse and revenue.

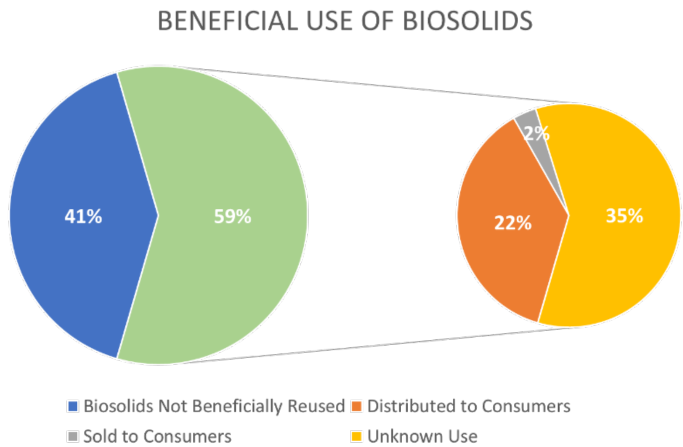


Figure 16. Beneficial Use of Digestate

## Adding Food Waste to Wastewater Biogas Systems

In an anaerobic digester, biogas yields increase by 10-35 times when food waste (especially fats, oils and grease or carbohydrates, like bread) is digested, when compared to manure or wastewater sludge. However, since the primary focus of a WRRF is usually cleaning wastewater and not energy generation, adding food waste to wastewater systems is just beginning to catch on as a biogas enhancing mechanism. As of 2016, only 14% or 172 of the 1,269 operational biogas systems at WRRFs report adding additional organic material to their digesters. If a WRRF is considering adding food waste, there are more than a few reasons to do so:

- Additional revenue (or cost savings) generated from increased biogas production, and therefore the electricity or fuel cost offset by the biogas.
- Additional revenue generated from tipping fees for accepting the food waste from a school, hospital or food processor.
- Municipal recycling rates increase. There are only two ways to recycle organics: composting and biogas systems.

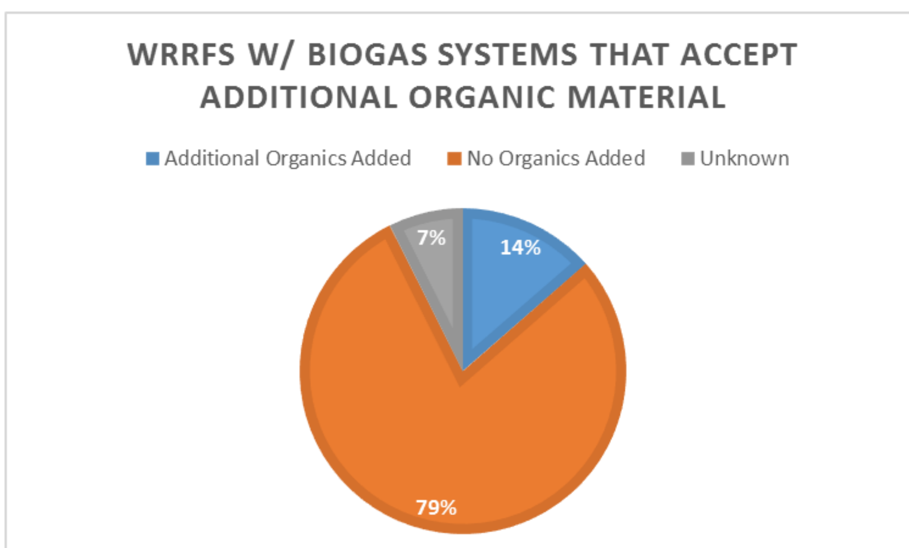


Figure 17. WRRFs w/ Biogas Systems That Accept Additional Organic Material

According to the American Biogas Council, some manure digesters have reported doubling of their biogas generation with just a 10% intake of food waste substrates. However, food waste, depending on the generator, can also include contamination and the impact of that contamination should be considered. Additional equipment may be needed for pre-processing, but it can be well worth the extra effort.

## Biogas Use

The biogas generated by AD systems is an extremely versatile fuel and can replace natural gas for heating and power generation needs. According to the WEF Biogas Survey, as of 2012, 85% of the WRRFs with AD beneficially used their biogas. Beneficial use as heat for process needs or conversion to electricity or fuel was found to be more common in larger plants, with smaller plants burning biogas in flares. Biogas has long been used to fuel boilers for process heat, such as for anaerobic digestion. As shown in the figure below, about half of WRRFs use their biogas for digester heating, either directly through combustion in a boiler, or through recovery of waste heat from another process, such as CHP systems. The figure also shows other biogas uses employed at WRRFs.

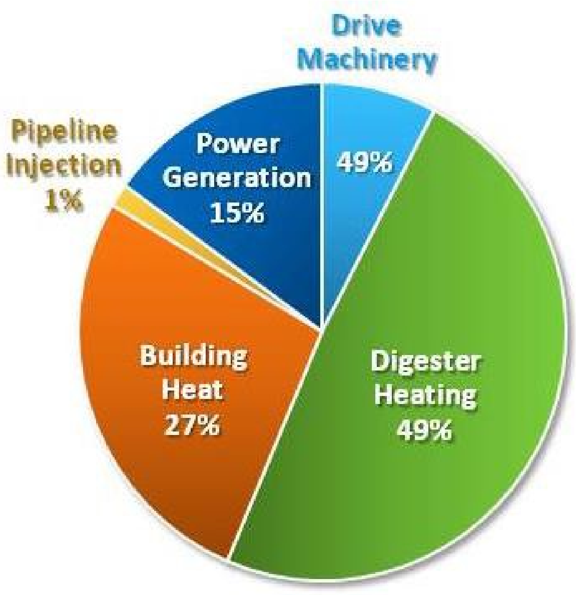


Figure 18: How Common Each Use of Biogas is at U.S. WRRFs Operating Anaerobic Digestion (Beecher and Qi, 2013)

### Village of Ridgewood, NJ—Innovative Financing, WRRF Runs on 100% Renewable Energy

The Village of Ridgewood, N.J.'s Department of Public Works wanted to improve the affordability, resiliency, and sustainability of their wastewater treatment operations. Natural Systems Utilities and Middlesex Water Company started a project to enhance existing anaerobic digesters at a municipal WRRF to produce an amount of renewable energy that is equivalent to up to 100% of the power demand of the plant. The project used innovative but repeatable financing through a public private partnership between the Village of Ridgewood and Ridgewood Green RME (RGRME) that provided the merchant

- waste receiving facilities, biogas conditioning and combined heat and power,
- equipment at no capital cost to the Village of Ridgewood, and
- RGRME recovers the investment by selling power to the Village of Ridgewood through a power purchase agreement.

And the municipality enjoys reduced electric costs, reduced sludge hauling costs, and a share of tipping fee revenues. The project won the American Biogas Council's Project of the Year Award in 2014. More info: http://www.americanbiogascouncil.org/projectProfiles/ridgewoodNJ.pdf and http://www.middlesexwater.com/upload/about-us/in-your-community-update/IYC_2014_Web.pdf

The following sections describe in more detail the various uses of biogas as a renewable fuel.

## Heat/Boiler

Heat recovery is by far the most common use of biogas, with a majority of facilities using biogas in boilers or recovering heat from CHP to heat digesters and/or buildings. The primary use of biogas at most facilities is digester heating. Biogas production is usually more than adequate for digester heating needs for all but the coldest months in colder climates and surplus biogas is often available during most months. Surplus gas can be used for building heat or other needs such as thermal drying or CHP. Surplus biogas can also be used in absorption chillers to cool buildings during the summer.

## Combined Heat and Power (CHP)

With increasing fuel costs and sustainability concerns, many plants are trying to maximize the use of biogas in place of purchased energy. Increasingly, plants are using biogas in CHP systems to generate electricity from the biogas. Waste heat from the prime mover (turbine or engine) is used in the treatment processes or for building heat. The WEF Biogas Survey confirmed that 270 out of 1,238, corresponding to 22%, of plants with anaerobic digestion use their biogas to generate power. This number is almost three times that reported by the U. S. EPA Combined Heat & Power Partnership (U. S. EPA – CHPP, 2011); that estimate was 104. Power generation from biogas is particularly attractive in areas with high electricity rates.

**Comparison of CHP Technologies**

| | Internal Combustion Engines | Combustion Gas Turbines | Micro Turbines | Fuel Cells | Stirling Engines |
|---|---|---|---|---|---|
| Development Status | Established | Established | Established | Emerging | Established |
| Size (kW) | 110 – 3,700 | 1,200 – 4,700 | 30 – 250 | 200 – 1,200 | ~15 – 43 |
| Electrical Efficiency (%) | 30 – 42 | 26 – 37 | 26 – 30 | 36 – 45 | ~27 |
| Thermal Efficiency (%) | 35 – 49 | 30 – 52 | 30 – 37 | 30 – 40 | ~48 |
| Equipment Cost ($/kW) | 465 – 1,600 | 1,100 – 2,000 | 800 – 1,650 | 3,800 – 5,280 | 4,000 – 10,000 |
| Maintenance Cost ($/kWh) | 0.01 – 0.025 | 0.008 – 0.014 | 0.012 – 0.025 | 0.004 – 0.019 | N/A |
| Biogas Cleaning Requirements | Medium | Low | High | High | Low |
| Emissions | Medium | Low | Low | Low | Medium |

*Source: Wiser et al., 2012 for IC engine, gas turbine, microturbine, and fuel cell data; Arespachaga et al., for Stirling engine data.*

Table 10: Comparison of CHP Technologies

The suitability of on-site CHP technologies varyies with respect to size, fuel requirements, local air emissions requirements, efficiency, cost, and overall compatibility with the existing treatment processes. Biogas requires cleaning systems upstream of the combustion equipment for the removal of moisture, $H_2S$, and siloxanes depending on the type of combustion equipment selected. Some established technologies, such as microturbines, are available in smaller capacities suitable for a range of WRRF sizes. The WEF survey found that 88% of the 292 WRRFs using biogas for CHP use either internal combustion (IC) engines or microturbines. Other CHP technologies, such as combustion gas turbines, are only economically feasible at the largest plants and are used by only 7% of WRRFs. Some locations with strict air quality regulations have turned to fuel cells (5% of WRRFs) with their clean emissions; however, current fuel cell economics often require financial incentives to make this technology attractive.

In addition to current CHP technologies, innovative technologies may become competitive in the future by reducing the need for biogas cleaning prior to use, therefore reducing overall complexity and equipment cost. Established and innovative CHP technologies are described in the following sections.

## Internal Combustion Engines

Internal combustion (IC) engines are the most widely used CHP technology. They are often the most economical CHP technology for WRRFs and have combined electrical and heat recovery efficiencies higher than any other currently available CHP technology. Heat can be recovered from the engine jacket water and from the exhaust gas. The available size range for IC engines matches biogas production rates of most WRRFs and the technology is reliable and available from a number of reputable manufacturers. IC engines typically have high power efficiencies relative to other power generation technologies. They are less sensitive to biogas contaminants than most other CHP technologies, reducing the gas cleaning requirements; however, cleaning is recommended to remove moisture, hydrogen sulfide, and siloxanes. One disadvantage of IC engines is their relatively high emissions as compared to other CHP technologies, such as microturbines and fuel cells. IC engine emissions can cause permitting difficulties in areas with strict air quality limits and may require additional emissions control, such as selective catalytic reduction to meet emission requirements.

Most IC engines installed since 2005 are lean-burn engines, with higher fuel efficiency and lower emissions than rich-burn engines, which were more commonly used before the 1970s. IC engine technology continues to improve and in 2001, national research laboratories, in collaboration with three large engine manufacturers, received contracts from the DOE to make further improvements to lean-burn engines. This resulted in a new generation of engines with even lower emissions and higher fuel-efficiency (Wiser et al., 2012).

## Combustion Gas Turbines

Combustion gas turbines are often a good fit for the largest WRRFs. Like IC engines, combustion gas turbines are a reliable, well-proven technology available from several manufacturers. Large WRRFs in the U.S. use biogas-fueled combustion gas turbines for CHP with heat being recovered from the exhaust gas. Combustion gas turbines are relatively simple, containing few moving parts and consequently requiring little maintenance. While infrequent, the maintenance of combustion gas turbines requires specialized service (Wiser et al., 2012).

## Microturbines

As the name suggests, a microturbine is a much smaller version of a combustion gas turbine. Microturbine capacities range from 30 kW to 250 kW and are often a good fit for smaller WRRFs with anaerobic digestion. Microturbines are relatively new, being introduced about 15 years ago. Despite their somewhat recent development, microturbines have become the second most widely used CHP technology at WRRFs due to their small capacity and clean emissions. However, microturbine electrical efficiency is considerably lower than that of IC engines. They are available as modular packaged units that include the combustor, turbine, generator, and cooling and heat recovery equipment. Multiple units can be installed in parallel for higher capacity.

The 370-mgd DC Water Blue Plains Advanced Wastewater Treatment Plant (AWTP) installed combustion gas turbines that will produce 10 MW net energy, providing energy for nearly half of the plant's total power demand.

Microturbines require relatively clean fuel, increasing the performance requirements and cost of biogas treatment, but their exhaust emissions are among the lowest of all CHP technologies. Microturbines are currently available from two manufacturers (Wiser et al., 2012).

The Sheboygan Regional WRRF in Wisconsin has been successfully operating microturbines since 2006. The 10.5 mgd plant started with a generation capacity of 300 kW in 2006. In 2010, the plant added an additional 200 kW in order to use the increased biogas production resulting from their co-digestion program. The Sheboygan CHP installation is an example of positive collaboration with the electric utility. With the goal of adding biogas to their renewable energy portfolio, the local, privately owned power utility funded 80% of the capital cost of the microturbines (Willis, et al., 2012).

*"With energy costs increasing each year, we were actively looking at different ways to reduce our total energy cost. Since we were wasting excess biogas, it became evident that we could use it as fuel for microturbines and reduce our energy costs."*

*– Dale Doerr, Wastewater Superintendent, City of Sheboygan*

Figure 19: Microturbine Installation at the Sheboygan Regional WWTP

## Fuel Cells

Fuel cells are unique in that they do not combust biogas to produce power and heat. Instead, fuel cells convert chemical energy to electricity using electrochemical reactions. Their benefits include high electric efficiency and extremely clean exhaust emissions. However, fuel cells are one of the most expensive CHP technologies in terms of both capital and operation and maintenance (O&M) costs. In addition, they are extremely sensitive to impurities in the biogas, requiring the highest level of biogas cleaning of all CHP technologies. For these reasons, fuel cell installations are typically limited to locations with strict air quality regulations and fuel cell-specific grants or incentives. For example, several installations in California have benefited from the Self-Generation Incentive Program (SGIP), which subsidizes the capital cost of fuel cells by $4,500/kW. Fuel cells suitable for use with biogas are currently available from only one manufacturer (Wiser et al., 2011).

## Stirling Engines

While Stirling engine technology is established, their application to biogas is innovative, especially in North America where there are few applications. There has been increased interest in this CHP technology in recent years due to its reduced biogas cleaning requirements. A Stirling engine is an *external* combustion process. Biogas is combusted outside of the prime mover. The heat generated by the combustion process expands a working gas (generally helium), which moves a piston inside a cylinder. Because combustion occurs externally to the cylinder and moving parts, very little biogas cleaning is required (Arespachaga et al., 2012).

A 35 kW Stirling Engine has been running on biogas at the Niederfrohna WRRF in Germany since 2010. Despite the biogas being rich in siloxanes, only sulfur and moisture removal are required (Stirling, 2012). In the U.S., a 43 kW Stirling Biopower demonstration facility has been operating since 1995 in Corvallis, Ore. (Arespachage et al., 2012).

Figure 20: Stirling Engine Installation at the Niederfrohna WRRF in Germany

*The Combined Heat & Power Partnership has estimated that additional capacity for biogas generation at U.S. WRRFs could generate up to 400 additional megawatts (MW) of electricity (although their estimate was based on an underestimate of current electricity production at such facilities). CHPP equations indicate that 400 MW could provide the electricity for 300,000 homes. (Speaking practically, however, electricity generated at WRRFs is usually used most cost-efficiently to offset WRRF electricity use, saving other grid electricity for powering homes.) By any measure, the potential for future growth of CHP at WRRFs is significant.*

## Biogas Upgrading

Currently, only 1% of the biogas beneficially used is upgraded to natural gas quality for injection into the natural gas transmission system. Biogas is also upgraded to CNG for use as fuel for CNG vehicles.

### Pipeline Injection

Pipeline quality biogas has extremely low concentrations of contaminants and must be compressed to match the natural gas transmission line pressure. Biogas contaminants that must be removed include foam, sediment, water, siloxanes, hydrogen sulfide, and carbon dioxide. Technologies used for removal are listed in the following table. Following cleaning, biogas must be compressed for pipeline injection.

**Biogas Treatment Technologies**

| Contaminant | Removal Technology |
|---|---|
| Moisture | Water chiller |
| Siloxanes | Activated carbon vessels |
| Hydrogen sulfide | Vessel with iron sponge or proprietary media |
| Particulates | Particulate filters |
| Carbon dioxide | Pressure Swing Absorption, Cryogenic, Membrane |

Table 11: Biogas Treatment Technologies

Biogas cleaning to pipeline quality has high capital and O&M costs. If financial incentives are available, pipeline injection can become attractive as it can have lower operating costs, higher revenues, lower compression onsite, emission reductions as a result of offsetting transportation fuel, limited required storage, and no onsite vehicle traffic (WEF, 2016). As of 2016, there were at least six WRRFs either already cleaning biogas to pipeline quality in the U.S., or in the development stage: San Antonio, TX; Newark, OH; Renton, WA, Phoenix, AZ, Raleigh, NC and Des Moines, IA.

#### Phoenix, AZ—Net $1.2M Annually from Biogas

In mid-2016, the city of Phoenix signed a deal with Ameresco to build a new system at the Phoenix WRRF to take the gas, treat it, compress it and pipe into a commercial gas pipeline nearby to sell on the market. By Spring 2018, the new system to use the biogas produced on site should be operational and begin sending upgraded, pipeline quality biogas, or Renewable Natural Gas (RNG), into the Kinder Morgan pipeline. The city expects to make an estimated $1.2 million in annual revenue from selling the gas, which will be shared among the cities that jointly own the treatment plant – Glendale, Mesa, Tempe, Scottsdale, and Phoenix.

### CNG or LNG Vehicle Fuel

Biogas can be upgraded to displace CNG or liquid natural gas (LNG) in vehicles capable of using these fuels. In Europe, upgrading biogas to fuel vehicular fleets is an established practice whereas in the U.S., there are only a few installations. Purity requirements for vehicular fuel are lower than those for pipeline injection. The biggest barriers to CNG or LNG conversion are the lack of a widespread infrastructure for gas filling stations and the cost of vehicle conversion for CNG or LNG use.

Small-scale packaged CNG conversion systems and filling station equipment are available from a single manufacturer and include sulfur removal in a vessel with proprietary media, siloxanes removal in an activated carbon vessel and membrane carbon dioxide removal. There are currently three biogas CNG installations in the US: the Dane County, WI landfill, St. Landry Parish, LA WRRF and the Janesville, WI WRRF. Other facilities are currently in design stage, including Lincoln, NE and Grand Junction, CO. The system in the photo has a 50 standard cubic feet per minute (scfm) capacity and can produce up to 275 gasoline gallon equivalents (GGE) per day (BioCNG, 2012).


Figure 21: BioCNG installation at Janesville, WI WWTP (BioCNG, 2012)

### Use of Biogas in Industrial Processes

There are several examples of efficient use of biogas by industries sited in proximity to WRRFs. In these situations, biogas that is untreated or minimally treated is provided to an industrial facility that utilizes the gas in its processes. For example, the Des Moines Metropolitan Wastewater Reclamation Authority sells 40% of the biogas it produces from co-digestion of wastewater solids, FOG, and other high strength organic residuals to a neighboring industrial facility (Greer, 2011).

## Thermal Conversion

In contrast to biological conversion (anaerobic digestion), thermal conversion of wastewater solids can make use of the chemical energy embedded in the solids, regardless of degradation potential. While the theoretical energy available through thermal conversion is higher, a significant amount of the energy is used to drive off moisture in the incinerator feed, which is typically in the form of dewatered cake. Consequently, net energy recovery from incineration can be lower than experienced from anaerobic digestion. Biosolids generally need to be dewatered to 26 to 35% total solids (TS) to result in autogenous incineration, that is, incineration without the need of auxiliary fuel. Gasification is another thermal conversion technology that has gained interest in recent years for solids treatment. Before

### City of Grand Junction and Mesa County, CO—Biogas to Vehicle Fuel

Persigo WRRF is owned jointly by the City of Grand Junction and Mesa County, CO. The WRRF will produce up to 500 gallons of GGE per day from approximately 100 scfm of digester gas, which is then piped in a dedicated pipeline about 6 miles to the existing CNG fueling station. The pipeline was completed entirely on City easements and it successfully permitted to cross railroad spurs, streams, an interstate highway, and wetlands. The fuel will be used as fuel for a fleet of buses owned by Grand Valley Transit and fueled at the City of Grand Junction facility, as well as City refuse trucks, street sweepers, and general utility pickups. More info: http://www.americanbiogascouncil.org/projectProfiles/grandjunctionCO_final.pdf feeding biosolids to a gasifier, it is usually necessary to dry them to 80 to 90% TS. The need for drying, be it in the incinerator or in a dryer prior to a gasifier, reduces the potential net energy output of the system.

Given the high moisture content of wastewater solids, there has been much interest in developing innovative technologies for thermal conversion suitable to a liquid medium, such as SCWP or hydrothermal catalytic gasification. These technologies are in their early stages of development, but are promising in that they are developed for treatment of solids with solids concentrations ranging from 1 to 10% and allow the recovery of heat, nutrients, and marketable gases (SCWP) or syngas and nutrients (hydrothermal catalytic gasification).

The following sections describe thermal conversion technologies suitable to dewatered or dry solids: thermal oxidation (incineration), gasification, and pyrolysis, as well as the more innovative thermal conversion technologies suitable for a liquid medium. The equipment required for the three technologies is relatively similar. The difference among the technologies is the amount of oxygen available for the combustion reaction, which controls the oxidation of the fuel (solids). The incineration process uses excess oxygen, resulting in oxidation of all carbonaceous matter and generating ash. Gasification is performed in a sub-stoichiometric condition, with oxygen limited to 25% of the oxidation requirement. Pyrolysis is performed in a zero-oxygen environment.

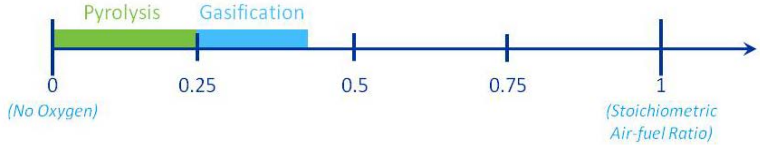


Figure 22: Thermal Conversion Oxygen Requirements

## Thermal Oxidation

Thermal oxidation (incineration) is the most established biosolids thermal conversion technology, having been used since the 1930s, and has been practiced in the wastewater sector mainly as a volume reduction/sterilization method of biosolids management. Looking towards the future, municipal utilities are actively looking at energy recovery and production. Thermal oxidation involves the complete oxidation of all organic material by applying heat in the presence of excess oxygen. The volatile fraction of the feed material is converted to hot flue gases, while the nonvolatile or inert fraction becomes ash. Thermal energy is often recovered from the high temperature flue gas and may be used to generate electricity using a steam turbine. The flue gas contains contaminants that must be removed prior to emission to meet regulatory limits; consequently, air pollution control devices are integral parts of incineration facilities.

Incineration is used throughout the world and approximately 17 to 25% of solids produced in the U.S. are incinerated. Biosolids generally need to be dewatered to 26 to 35% TS to support autogenous incineration. The dominant incineration technologies are multiple hearth incinerators (MHI) and fluidized-bed incinerators (FBI). MHIs are being phased out in many areas in favor of more efficient FBIs.

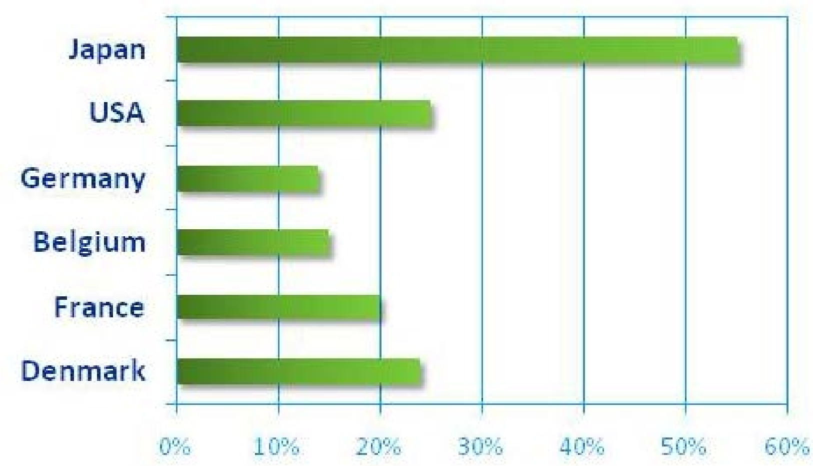

Figure 23: Prevalence of Biosolids Incineration

Although thermal oxidation has been practiced for almost a century, it is only in the last decade that energy recovery from incineration has become a well-established practice in the U.S. Forward-thinking utilities with incineration energy recovery systems include the Metropolitan Council of Environmental Services (MCES), the Northeast Ohio Regional Sewer District (NEORSD), the Metropolitan District of Connecticut (MDC, Hartford), and Albany, NY. MCES has operated three FBIs with energy recovery for a number of years; Hartford's incineration facility started up in 2013; the NEORSD incineration facility is about to be commissioned; and the Green Bay facility is in construction with a completion date anticipated in 2018.

The following figure shows a typical schematic of an energy recovery system. A portion of the heat available in the exhaust gases is first recovered in a primary heat exchanger to preheat the fluidizing air fed to the incinerator. Another portion of the heat is then recovered in a waste heat boiler, producing super-heated steam. The steam is then used to run a steam turbine, generating electricity. The electricity generated can be significant, with some installations generating about 50% of the total plant electricity usage.

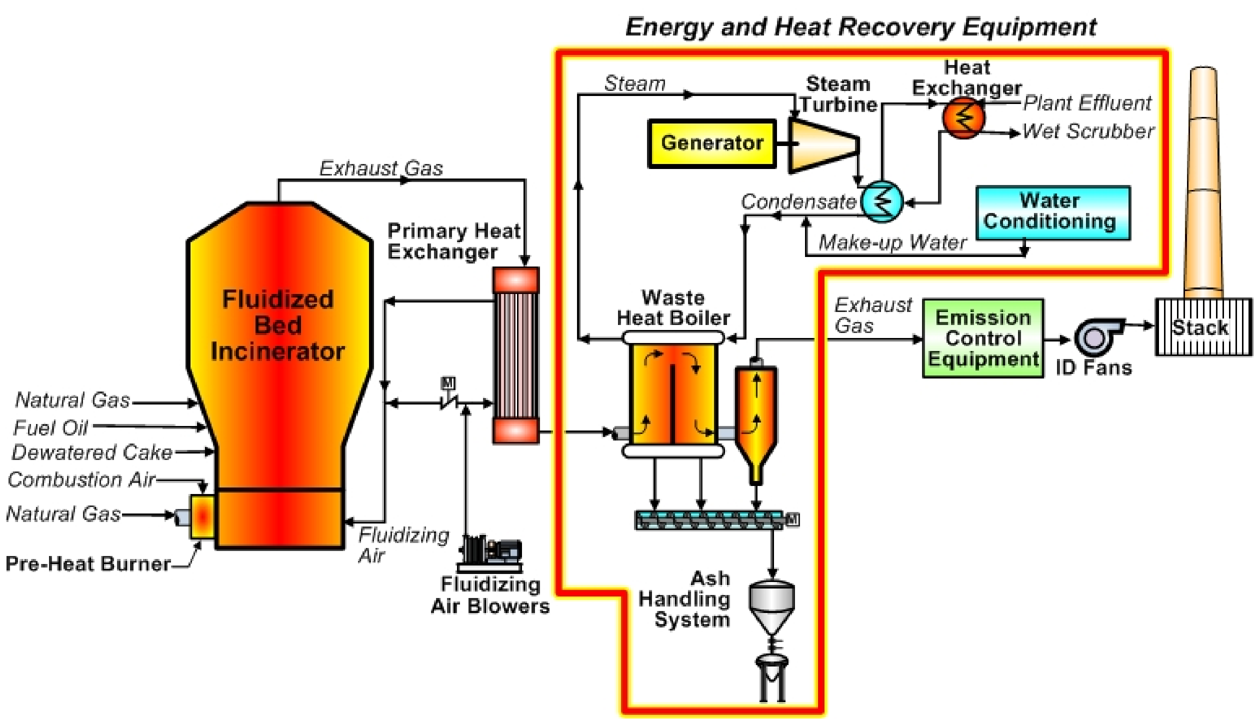

Figure 24: Energy recovery system schematic

The Hartford Water Pollution Control Facility (WPCF) in Connecticut is an example of one of the progressive utilities that are currently implementing power production from incinerator waste heat. The Hartford WPCF, an 80 mgd plant, processes dewatered solids in three MHIs, each rated at 2.5 dry tons per hour. Limited by air permit, the plant can only run two of the three incinerators at any one time. Exhaust gases from the incinerators are induced through the waste heat boilers to produce steam. The steam generated in the waste heat boilers is used to produce nearly 2 MW of electricity with a steam turbine-generator, which is equivalent to approximately 40% of the current plant demand.

Advancement in incinerator design has made thermal oxidation of wastewater solids more efficient. Because most biosolids contain water and are not autogenous (e.g., do not have enough energy to be combusted on their own), the biggest impediment to energy recovery is the need to remove water and preheat air and solids prior to combustion. Like the trends in anaerobic digestion, where co-digestion with FOG or HSWs is used to increase biogas production, co-combustion with alternative feedstocks with fuel value properties also offer the ability to increase energy recovery potential from thermal oxidation. A state of the science review of energy recovery associated with the thermal oxidation of wastewater solids is underway with WE&RF(ENER13T14) and anticipated to be published in April 2017, with the objectives to:

- Compare the value of energy recovered from wastewater solids by thermal oxidation with that from coal, based on a triple-bottom-line (TBL) approach, evaluating economic, environmental, and social criteria;
- Estimate the quantity of renewable energy available from thermal oxidation of wastewater solids and residuals from domestic wastewater and associated feedstocks, such as FOG, scum, and imported biomass; and
- Evaluate the potential for energy and heat recovery from the thermal oxidation of wastewater solids based on existing and emerging energy recovery technologies. Investigated technologies include, waste heat boiler, steam turbine generators, Organic Rankine Cycle (ORC) systems, fluidized bed boilers, gas to thermal oil heat exchangers, and in-bed energy recovery coils.

Case studies have been prepared on energy recovery methods being utilized by the Metropolitan WRRF (St. Paul, MN), Köhlbrandhöft WRRF (Hamburg, Germany) and the North WRRF (Menands, NY) (Welp and Dominak, 2016). In operation for over 10 years, the St. Paul, MN facility had the most operating experience in North America with power generation and generates 20% of the plant's electricity demand. The North Plant, NY is the only municipal facility in the U.S. to use an ORC system for energy recovery.

Although permitting a new thermal combustion facility can be difficult, utilities that have existing incinerators or are upgrading to newer technology should consider the benefits of energy recovery.

## Off-site Co-combustion

Instead of incinerating biosolids at the treatment plant, biosolids can be used to supplement or replace coal in cement kilns and coal fired power plants. Biosolids must typically be dried to 90% TS or greater to make co-firing attractive to those industries.

Co-firing of dried biosolids is currently performed by the cement industry in a number of locations in Europe and in two locations in North America. Lehigh Cement owns a 2 million metric ton per year cement production facility in Maryland, which burns approximately 14,000 metric tons of dried biosolids annually, with plans to increase capacity to 36,000 metric tons per year. This represents approximately 3 to 5% of its average daily fuel use and is reported to have no adverse impacts to product quality (Maestri, 2009).

## Gasification

Gasification is the thermal conversion of carbonaceous biomass into syngas, a gaseous fuel composed mainly of hydrogen and carbon monoxide, and impurities including carbon dioxide, water, methane, nitrogen gas, and tars. The conversion is accomplished by heating the biomass to temperatures of 500 to 1600°C under pressures ranging from 1 to 60 bar in the presence of a controlled supply of oxygen (Yassin, et al., 2005). Directly heated gasifiers are heated by combusting a portion of the feedstock. Alternatively, gasifiers can be indirectly heated with electric heating elements.

While the gasification of biomass is a commercial technology with many installations worldwide, there are limited commercial scale biosolids gasifiers, making it innovative with respect to biosolids. Gasification emissions do not fall under the USEPA municipal biosolids incinerator emissions requirements (SSI MACT), therefore reducing emission control requirements and permitting issues. The following table describes the existing commercial, demonstration, and testing biosolids gasification facilities.

The moisture in biosolids can make it difficult to gasify without the addition of energy or blending with other materials, like wood waste. Before feeding biosolids to a gasifier, it is usually necessary to dry them to 50 to 90% TS, depending on the technology. Mechanical dewatering is preferred over heat drying, due to the high-energy use of thermal drying. However, mechanical processes can only dewater to about 20 to 30% TS. The need for thermal drying reduces the potential net energy output of the system resulting in insufficient energy for onsite electricity generation due to the additional energy necessary to drive off excess water. However, a major benefit of gasification over incineration is lower natural gas requirement (about 83% lower) (Tarallo and Kohl, 2015).

Further restrictions on incinerator emissions may make gasification an attractive alternative in the future. Increased experience in the municipal biosolids market is necessary to develop further operational data and determine the economic viability of the technology/system.

| Vendor | Installation | Through-put | Description |
|---|---|---|---|
| KOPF | Commercial facility in Balingen, Germany operating since 2004 | 375 dry lb/hr | Solar-dried digested solids (75 to 85% solids) are fed to fluidized-bed gasifier. Gas is used in IC engines. Of the 0.5 kWh of electricity produced per kg of solids treated, 0.1 kWh is used to run the gasifier, and 0.4 kWh is used to displace electricity use of the WRRF. |
| Nexterra/ Stamford, CT WPCA | Testing facility in Kamloops, Canada | 1354 dry lb/hr | Thermally dried biosolids (93% TS) fed to fixed-bed updraft gasifier. Tested solids from Stamford, CT WPCA in 2009. |
| Maxwest | Commercial facility in Sanford, FL operated 2009-2014 | 1800 dry lb/hr | Dewatered solids were received from several plants at an average dryness of 16% TS. Solids were thermally dried and fed to a fluidized bed gasifier. Syngas was combusted in a thermal oxidizer, from which heat was recovered to supply the dryer. |
| M2Renewables/ Pyromex | Demonstration facility in Emmerich, Germany operating since 2009 | 83 dry lb/hr | Solids are dewatered mechanically to 55%, then thermally to 80%. Ultra-high temperature gasifier operates in the absence of oxygen. The source of oxygen and hydrogen for the syngas comes from the moisture in the feed. Gasifier is indirectly heated, producing high-quality syngas (63% hydrogen, 30% carbon monoxide) |
| Tokyo Bureau of Sewerage | Commercial facility in Kiyose, Japan, operating since 2010 | 8000 dry lb/hr | Thermally dried biosolids (80% TS) fed to a fluidized-bed gasifier. Heat from the syngas is recovered to dry the feedstock. Syngas is converted to motor power via an aeration blower or to electricity via an IC engine. |
| PHG Energy | Full-scale facility in Covington, TN, since 2013 (July 2015 PHG Energy assumed operation and fiscal responsibility for the system and operate for research and development) | 12 ton/day | Uses downdraft gasifier to process wood waste and wastewater residuals. Wood is chipped, mixed with residuals, then dried before gasification. Syngas is combusted in a thermal oxidizer with heat recovered to drive an organic rankine cycle generator. |

| | | | |
|---|---|---|---|
| PHG Energy | Full-scale facility under construction in Lebanon, TN, scheduled to begin operation in 2016<br><br>Plans for future facility in Pigeon Forge, TN planned to begin construction in 2016 | 64-ton/day | Will use downdraft gasifier to process wood wastes, shredded tires, and wastewater residuals. Syngas will be combusted in a thermal oxidizer with heat recovered to drive an organic rankine cycle generator. |

*Sources: Greenhouse Gas Technology Center, 2012, and PHG, 2016*

Table 12: Summary of Biosolids Gasification Facilities

## Pyrolysis

Pyrolysis is the thermal conversion of carbonaceous biomass in the absence of oxygen. Three products are generated through pyrolysis: a liquid fuel or bio-oil, a solid char, and combustible gas (Zhang et al., 2010). Pyrolysis processes are typically carried out at atmospheric pressure and temperatures ranging from 300 to 600°C (Venderbosch and Prins, 2010) and typically occurs at lower temperatures than either gasification or incineration. The temperature and reaction time affect product generation. Slow pyrolysis, which occurs at low temperatures and low heating rates, maximizes char production; fast pyrolysis, involving moderate temperatures, fast heating rates, and short residence times, maximizes bio-oil production (Yurtsever et al., 2009).

Three fast pyrolysis facilities have tested the production of bio-oil from biosolids, with two installations in California and one in Australia. However, all three have ceased operations. Additional development is necessary to address technology limitations and costs that currently limit commercial implementation. A demonstration-scale facility was planned for the San Francisco Bay Area Biosolids to Energy Coalition but was not implemented due to financial reasons. One slow pyrolysis process has been operating successfully in Japan since 2007 (Oda, 2007), and Kore Infrastructure is developing a commercial facility that should be capable of processing 150 dry tons per day at 27% TS in San Bernardino County, CA, which is scheduled to start accepting solids in late 2016.

## Thermal Conversion in Supercritical Water

The concept of applying thermal conversion to liquids is attractive, since it eliminates the need for moisture removal and therefore reduces process energy requirements. Supercritical water (SCW) is a state in which water behaves as both a gas and a liquid and occurs at high temperatures (greater than 374°C) and pressure (greater than 221 bar). The gas-like properties of the SCW promote mass transfer, while the liquid-like properties promote solvation (dissolution). These properties, combined with high temperatures that increase reaction rates, result in a medium in which chemical reactions occur extremely rapidly.

*Similar to incineration, supercritical water oxidation (SCWO) is the complete oxidation of organic matter. The key difference is that SCWO occurs in supercritical water.*

### Supercritical Water Oxidation

Supercritical water oxidation is the complete oxidation of organic matter and achieves high destruction efficiencies of organics (greater than 99.99%) in short reaction times (less than 1 minute). However, the properties that make

SCW a good reaction medium can also be a disadvantage, increasing the potential for corrosion in the reactor.

The SCWO process has been used since the 1980s for military hazardous waste destruction. In the SCWO process, carbon is converted to carbon dioxide, hydrogen to water, and nitrogen to nitrogen gas or nitrous oxide. Inert, non-reactive materials remain as particulate matter. The effluent from the SCW oxidizer is fed to a cyclone that separates the particulate solids from the liquid. Heat can be recovered from the high-temperature, high-pressure liquid effluent for process needs or in a steam turbine to generate electricity. Carbon dioxide and nitrogen gas can be recovered as by-products for commercial sale (O'Regan, et al., 2008; Gidner et al., 2001).

One technology that is similar to a SCW process, hydrothermal processing, is being developed by Genifuel. The technology, which is in the research and development stage, uses pressurized hot water at 350°C and 207 bar pressure, which is below the supercritical point, to process dewatered solids to create bio-crude oil and methane gas, along with an inert solids precipitate. Bench scale testing was conducted with solids provided by Metro Vancouver, and the results showed greater than a 99% COD reduction in the effluent and a greater than 94% solids reduction. The bio-crude quality was approximately 80% of the heating value of petroleum crude and needs to be upgraded. (WE&RF, 2016).

Figure 25: Supercritical Water Oxidation Facility in Cork, Ireland

The use of SCWO technology for biosolids applications is still in developmental stages. There are currently two operating biosolids SCWO facilities in the world, in Orlando, FL and in Ireland. The 1 dtpd facility in Ireland has been operating successfully since 2008. A second, larger (10 dtpd) facility has been installed in Ireland (O'Regan, 2012). Limited cost and operating information are available for either facility; consequently, success and suitability for treating wastewater solids are not well known.

# Delivery Methods to Implement Energy Savings Projects

Performance contracting with an energy services company (ESCO) can be an alternative approach for WRRFs to implement energy efficiency and generation projects. An ESCO is a commercial business that delivers operational efficiency improvements in a progressive design-build environment. The facility owner benefits from the savings and pays a fee to the ESCO in return. ESCOs provide a guarantee of energy savings, which are specified in a performance contract and also provide a financial guarantee to project lenders that the savings generated will cover the debt service for any new requirement equipment. A typical engineering savings performance contract (ESPC) involves four phases as shown below: investment grade audit, proposed ESPC agreement, project execution, and measurement and verification.

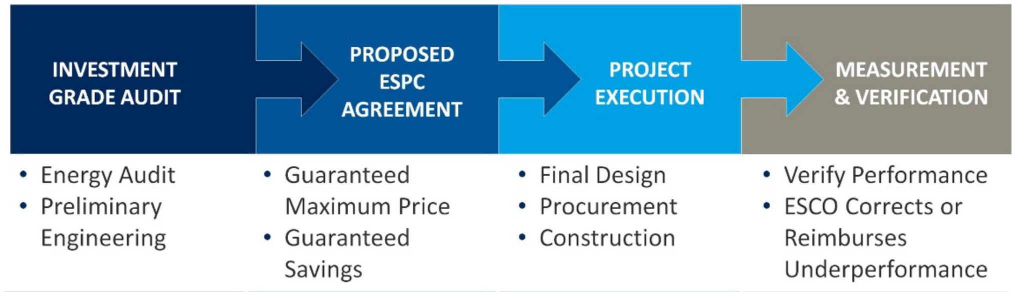


Figure 26: Energy Savings Performance Contract Steps

The ESCO approach was taken for the Upper Occoquan Service Authority (UOSA), VA with the primary goal of financial efficiency, which resulted in energy projects that maximized payback and minimized capital costs. The energy projects included a cogeneration facility (848 kW IC engine) and blower replacement with high-efficiency gearless turbo blowers. Another utility, Frederick-Winchester Service Authority (FWSA), VA, is also using an ESCO approach for energy savings upgrades including lighting efficiency, blower replacement, and a green energy project comprised of anaerobic digestion, HSW receiving and co-digestion, and cogeneration facilities.

Performance contracting provides alternative delivery options to utilities to implement energy projects. Increasing experience in the water sector has led to the development of best practices for utilities and ESCOs to follow. Active participation between all parties during each phase of the contracting process is a necessity, especially during the investment-grade audit and verification steps.

## Enabling Energy Recovery

Driven by rising energy costs and sustainability concerns, utilities are recovering previously wasted resources – flared biogas and waste heat – to increase their energy self-sufficiency. A variety of proven energy recovery technologies is available for on-site energy production, and innovative technologies are poised to expand the options. While the shift in the biosolids industry from waste disposal to resource recovery is already happening (albeit slowly), utilities face economic and regulatory barriers to implementing sustainable energy recovery systems. An economic and regulatory environment that facilitates and promotes energy recovery is needed to hasten this shift towards an economically and environmentally sustainable biosolids industry.

## Barriers

Many of the barriers to energy recovery from biosolids are shared with the renewable energy industry at large. Primarily legislative and economic, these barriers are based on the enormous difficulties that come from having to **compete with the established fossil fuel industry**. Legislative support through consistent, reliable financial incentives could turn this around, giving renewable energies the opportunity to have a competitive starting point in the energy race. For biosolids in particular, the barriers can be higher. As noted earlier, federal and state legislation does not clearly **recognize biosolids as a renewable energy source**. This makes it difficult or impossible for biosolids-to-energy projects to benefit from existing state and federal renewable energy incentives.

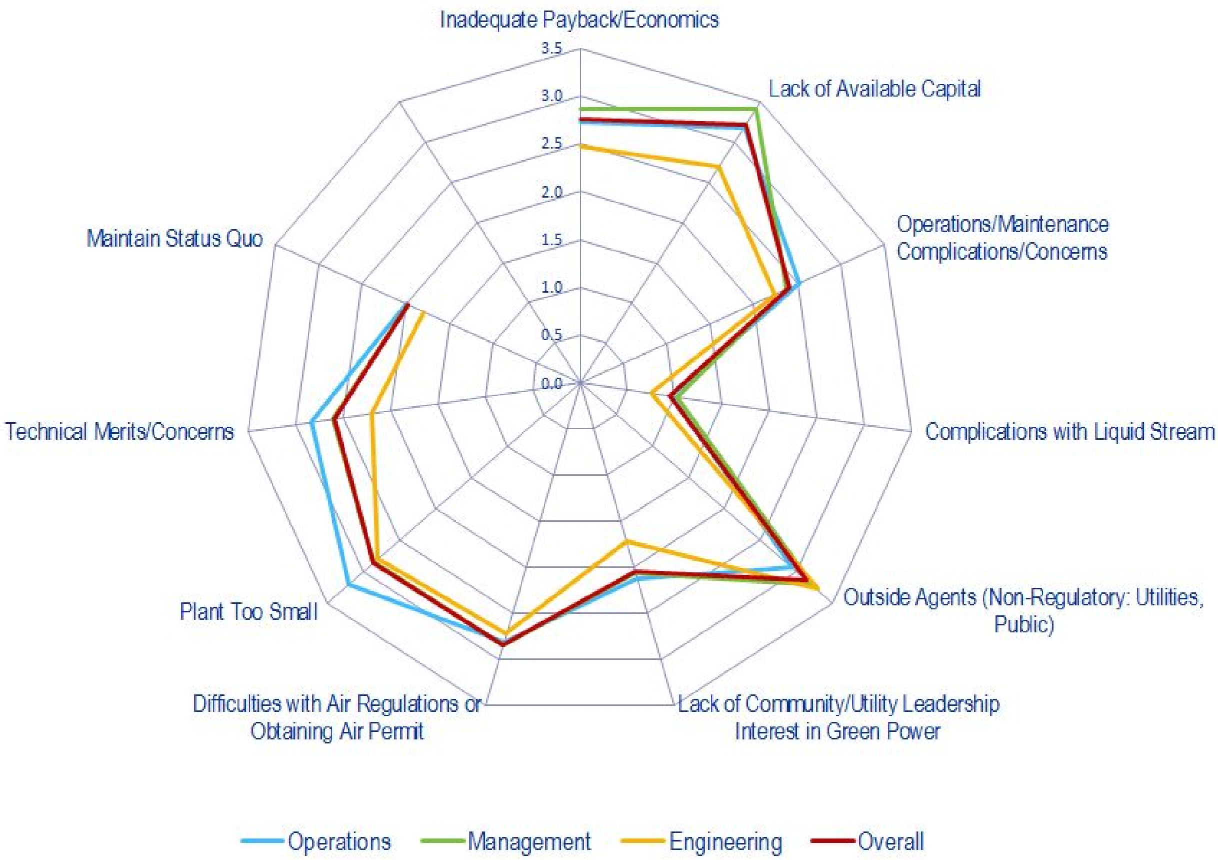


Figure 27: Key barriers to biogas use, as perceived by WWTP operators, managers, and engineers (Willis, et al., 2012)

A survey of over 200 wastewater treatment utilities conducted in 2011 by WE&RF and NYSERDA sheds light on the barriers to biogas use (Willis, et al., 2012). While the survey focuses on biogas use, most of these barriers are common to those faced by other energy recovery technologies. The survey found that the most important barrier to biogas use was economic, related to higher priority demands on limited capital resources or to perceptions that the economics do not justify the investment. Of the 10 barrier categories introduced, all but "complication with the liquid stream" were deemed significant. However, the economic barriers were dominant; given sufficient funding, the other barriers can be overcome. Strategies to overcome the barriers were developed during focus group meetings, and are shown in and highlighted at the end of this section**.**

## Initiatives and Research Needed

Government initiatives to incentivize energy recovery, continued research to further improve established technologies and develop new ones, and education and outreach efforts are necessary steps to maximize the renewable energy potential of biosolids. Recommended actions are listed below.

## Government Initiatives

Government initiatives promoting new renewable energy technologies have the greatest potential to help wastewater utilities overcome the economic barriers to energy recovery. Three key initiatives are:

- Incentivize renewable energy generation by providing grants or RECs for biosolids-to-energy recovery projects,
- Put a price on carbon that accounts for the negative environmental and social effects of greenhouse gas emissions, as demonstrated by California and the European Union Cap-and-Trade programs, and
- Support the WEF renewable energy statement to move biogas and biosolids to the DOE list of renewable energy.

## Development of Analytical Tools

Energy recovery systems can be complicated. Tools to facilitate analysis of the mass and energy balances, greenhouse gas emissions, and life-cycle environmental and economic impacts can help prove and quantify their economic and environmental value.

- Encourage WRRFs to use an **economic analysis tool** that uses other financial evaluation methods in addition to simple payback.
- Update the University of Alberta **Flare Emissions Calculator** to include nitrogen oxides and carbon monoxide to document the relative performance of biogas flares compared to CHP technologies.
- Develop a comprehensive **Life-Cycle Analysis** tool for biosolids treatment processes, including all biological and thermal energy recovery technologies.

## Outreach and Communications

An educated population is invaluable for acceptance and support of new technologies. Education efforts should focus first on the key decision makers: regulators and utility managers. Develop active communications between stakeholders – wastewater utilities, power companies, regulators, and the general public – to ensure that the best solutions for all stakeholders are achieved. Recommended activities in this category include:

- Developing a **training course** to assist in the understanding of the benefits of energy recovery from biosolids, including a course specifically for decision-makers, and
- Expanding outreach and **information exchange** between the wastewater industry and power companies and natural gas utilities.

## Primary Research

Primary research at academic and other institutions includes bench-scale and pilot studies to further understand and develop innovative technologies – and potentially discover new ones. Recommended activities include to:

- Continue to quantify and define the **energy generation potential** from anaerobic digestion and thermal processes throughout the U.S.;
- Promote research to develop **more efficient mechanical dewatering** technologies, so that the energy losses associated with drying solids prior to or during thermal oxidation processes can be minimized;
- Promote research into technologies that **increase the ratio of primary to secondary solids** by either minimizing production of waste activated solids, or improving primary clarification. Primary solids are more readily biodegradable in anaerobic digestion;
- Promote research to identify **less-costly methods to achieve anaerobic digestion** and biogas production, so it can become more widely applicable, particularly to small WRRFs;
- Promote research on **innovative gasification and pyrolysis technologies**. Transfer lessons learned from biomass full-scale installations into the biosolids industry; and
- **Follow performance and O&M cost data** for demonstration and full-scale installations of innovative technologies: digester pretreatment installations, advanced digestion, gasification, and supercritical water oxidation.

## Development and Maintenance of Databases

In addition, secondary research is needed to gather information and consolidate it into publicly available databases. Once developed, the databases require continued maintenance efforts to keep them up to date. The following database is needed:

- **High-strength waste database**, such as that developed by U.S. EPA Region 9, listing potential sources of high-strength waste (FOG, food waste, etc.) that could be used to boost biogas production, and support the expansion of the Region 9 database.

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# Section 5

# Changing Perspectives: From Nutrient Removal to Nutrient Recovery

Nitrogen (N) and phosphorus (P) are life essential nutrients that are extensively used for agricultural purposes. At present, the synthetic N and P fertilizers that are used for food production are produced through energy-intensive processes that use non-renewable resources (e.g., natural gas and phosphate rock).

*"Recovery of nutrients from wastewater can play an important role in integrated nutrient management strategies that maximizes reuse"*

These nutrients once incorporated into crops are ingested by animals and humans who in turn excrete nutrients into wastestreams. It has been estimated that up to 8% of nitrogen and 14% of phosphorus used in agriculture enter municipal WRRFs (Penuelas et al., 2012). To avoid the accumulation of these nutrients in the environment, we typically employ technologies to remove these nutrients from the wastestreams entering the WWRF. In this combined scenario, we supply energy and other non-renewable resources to constantly replenish nutrient supply for agricultural uses and then further supply energy and non-renewable resources to remove these nutrients from wastewater before discharge to the environment. This approach to nutrient use is unsustainable and must change to reflect the non-renewable nature of the resources used for fertilizer synthesis.

*"The 'fit-for-purpose' concept recognizes that all water is good water and there is only one water cycle."*

As the nutrients in these wastestreams represent a renewable resource, recovery of nutrients into a useable form from wastestreams has emerged as a key component of sustainable approaches to managing global and regional nutrient use. Indeed, research has indicated that recovery of resources (e.g., water, energy, nutrients) from wastewaters has the potential to reduce energy consumption and improve treatment efficiency for municipal WRRFs (Shu et al., 2006; Mulder, 2003).

This shift to embrace nutrient recovery embraces the "fit-for-purpose" concept (Novotny, et al., 2010), whereby all resources in water are harvested to meet current and future demands of our growing urban society. It also fits within the larger concept of integrated nutrient management approaches that emphasize reuse and can allow utilities to truly become resource recovery plants.

Nutrients can be recovered in biosolids, liquid streams, or as chemical nutrient products. In this chapter, we focus on reviewing the state of science regarding nutrient recovery technologies that produce chemical nutrient products devoid of significant organic matter content. We have denoted this approach as extractive nutrient recovery, to differentiate from accumulative nutrient recovery in which biosolids are used as the primary vehicle for nutrient recovery and reuse.

# Challenges in Implementing Extractive Nutrient Recovery

Nutrient removal from wastewater represents a major demand on resources and expenses for WRRFs. For instance, electricity costs for aeration can account for between 30 and 80% of total electricity expenditure at WRRFs performing biological nitrogen removal (Willis et al., 2012). These needs are expected to increase as more stringent effluent nutrient limits are promulgated in the future. It should be noted, however, that some plants are implementing zones in aeration basins to save energy, and this also allows BNR, so performing BNR can save energy over traditional aerated practices.

As a result, development of alternative nutrient treatment strategies that allow for effective nutrient removal in a cost-effective manner is needed. Extractive nutrient recovery could represent an alternative strategy for managing nutrients during wastewater treatment. In this option, energy and resources are used to accumulate and produce a nutrient product that has value in a secondary market. Resale of this product can also potentially help plants offset operating costs. It should be acknowledged that nutrient recovery and reuse is not a new concept. It has been applied in different forms in the past e.g., land application of biosolids and reuse of secondary effluent for irrigation; however, extraction of a chemical nutrient product with low organic matter content has not been widely applied within the wastewater treatment industry. The key barriers against adoption of this type of extractive nutrient recovery are summarized in the following figure. Lack of knowledge regarding the options available for performing nutrient recovery as well as the cost of installation and operation can limit more widespread adoption of the extractive nutrient recovery approach. Consequently, there is a need to improve the transfer of knowledge to help utilities make rational and informed decisions about implementation of extractive nutrient recovery.

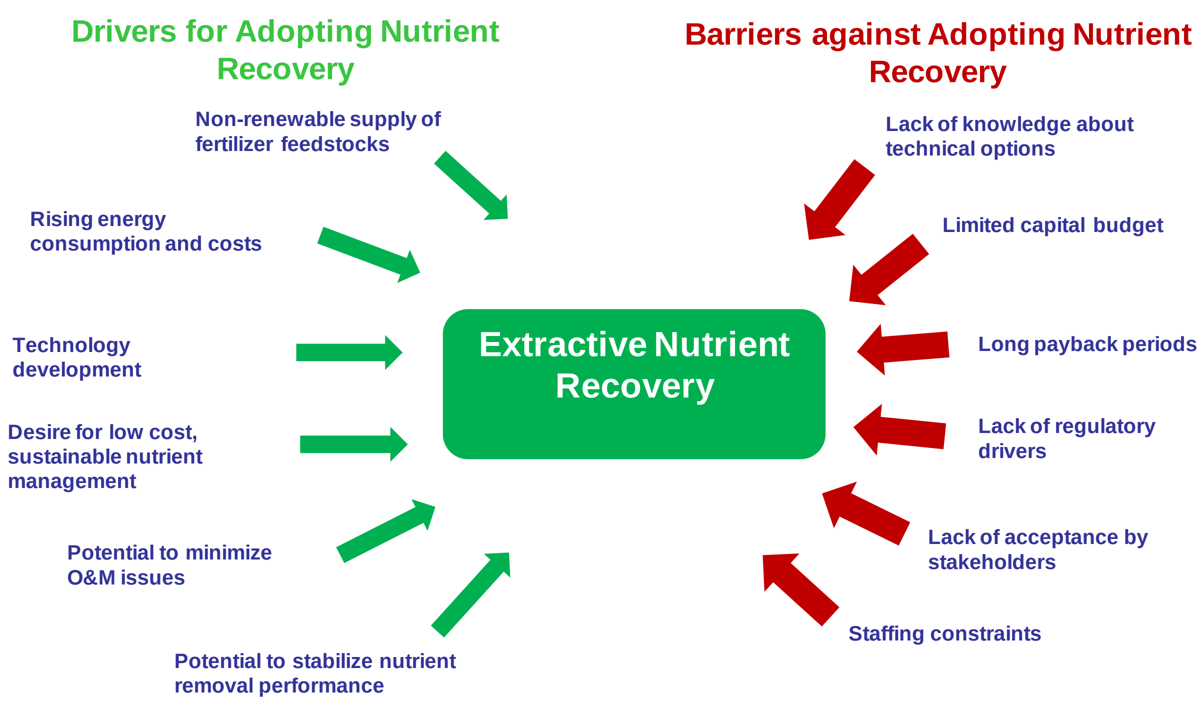


Figure 28: Drivers and Barriers against Adoption of Extractive Nutrient Recovery at Municipal WWTPs (From Latimer et al., 2015a)

# Nutrients in Wastewater

The nutrient concentration in the influent to municipal WRRFs typically ranges from 10 to 50 mg N/L for N and from 1 to 10 mg P/L for P. As the nutrients progress through wastewater treatment, they can be removed in a gaseous form (N), accumulate in the solids (both N and P) or be discharged in the liquid effluent (both N and P). Since extractive nutrient recovery is most effective when nutrient concentrations are above 1000 mg N/L and 100 mg P/L, and when flows are relatively low, one primary opportunity to implement extractive nutrient recovery lies in the solids processing treatment train of a WRRF. This aligns with the existing strategy used to recycle nutrients through the production of biosolids. Indeed, extractive nutrient recovery can complement existing efforts in which biosolids are used as the primary means for nutrient recovery. However, in order to facilitate the adoption of extractive nutrient recovery as a separate process for managing nutrients in WRRFs, there is a need to develop multiple strategies that allow us to work with different concentrations and forms of nutrients at different points throughout the plant.

*"There is no single technology that is perfectly suited for complete nutrient recovery from all scenarios."*

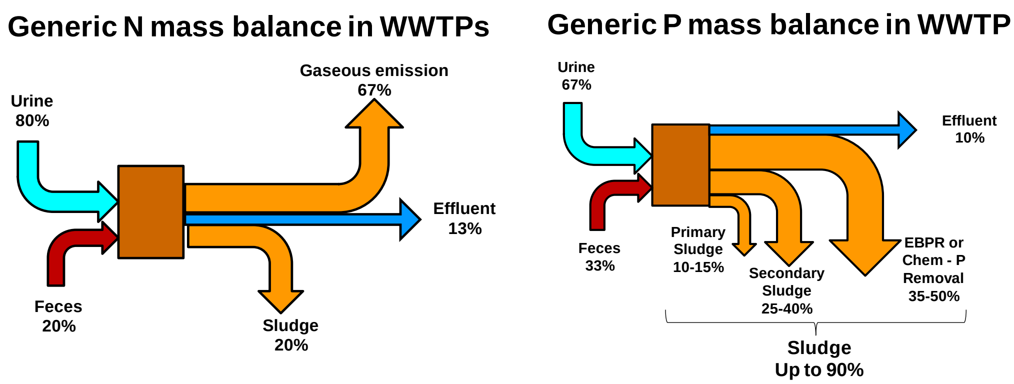


Figure 29: Nutrient Balances in WRRFs (Adapted from Cornel et al., 2009, Phillips et al., 2011 and Jonsson et al., 2006)

# Enabling Extractive Nutrient Recovery from Wastewater

The use of extractive nutrient recovery to help manage the nutrient content of domestic wastewater can be facilitated if it is performed within a three step framework (Latimer, 2015a):

1. Accumulation of nutrients to high concentrations,
2. Release of nutrients to a small liquid flow with low organic matter and solids content,
3. Extraction and recovery of nutrients as a chemical nutrient product.

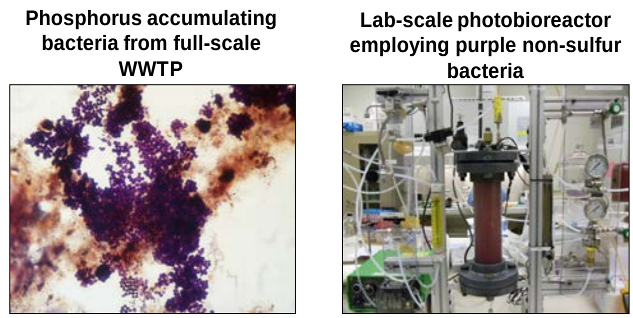


Figure 30: Nutrient Accumulating Organisms (Latimer et al., 2012a, Battelle memorial Institute, 2012)


Figure 31: Three-Step Framework for Enabling Extractive Nutrient Recovery from Dilute Wastewater (Latimer et al., 2015a)

In this approach, biological, physical, thermal, and chemical methods can be used to manipulate the concentration and form of nutrients present in domestic wastewater into a chemical nutrient product that has a secondary market value. One of the advantages to using this approach is that multiple options for each stage of treatment can be developed and optimized separately, thereby allowing utilities to select the most appropriate solution for their needs. It is also possible that some utilities may not need capital investment for all three processes since existing infrastructure can be reused.

A thorough review of state-of-the-art options available for the accumulation, release, and extraction framework is provided as part of the WE&RF Resource Recovery Challenge (Latimer, et al., 2015a). In this work, we focus on providing a brief description of these options as well as the scale of applicability.

## Nutrient Accumulation Options Suitable for Full-Scale Application

Nutrient accumulation technologies focus on concentrating the low nutrient content of municipal wastewater. This can be accomplished using biological (N and P), physical (N and P) and chemical (mainly P) techniques. Biological accumulation techniques center around microbial accumulation in which specially adapted microorganisms (e.g., microalgae, polyphosphate-accumulating bacteria (PAOs), purple non-sulfur bacteria (PNSB), cyanobacteria) are able to uptake (N and P) and store nutrients (P). Plants such as duckweed can also be used as part of passive nutrient treatment/accumulation strategies.

Research has shown that biological systems can remove between 70 to 90 % of N and P from wastestreams and are effective for treating a wide range of nutrient concentrations including the dilute content of nutrients typically associated with municipal WRRFs. Biological processes have already been extensively applied for wastewater treatment, with more than 84% of WRRFs in the USA employing some form of biological process (CWNS, 2004). Since these processes are expected to be further employed as effluent nutrient regulations become more stringent, this represents an opportunity for the extractive nutrient recovery field, as it becomes possible to stage implementation of the extractive nutrient recovery over multiple years, with the first step initially being use of biological nutrient accumulation processes. Key requirements for using biological accumulation processes are an effective solid-liquid separation process like clarification or membranes to allow recovery of the nutrient-rich biomass, as well as an appropriate release technology for subsequent processing.

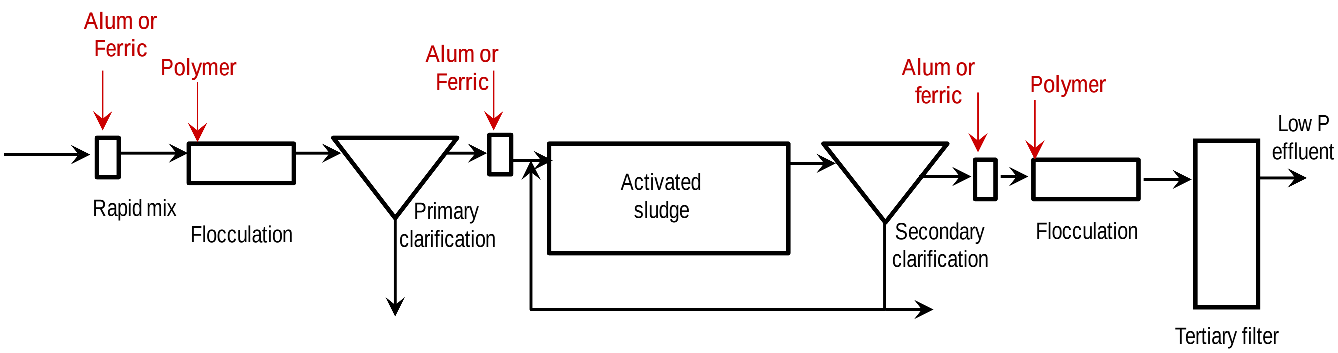


Figure 32: Multi-Point Injection Approach for Chemical Accumulation/Removal of Phosphorus from Wastewater (From Latimer et al., 2015a)

Chemical accumulation using metal salt addition is another option that can be used to help accumulate nutrients (mostly P). In this process, the metal salt reacts with soluble P to form an insoluble phosphate complex, which is a solid and can then be physically separated from the wastestream. Aluminum and iron solutions are often used for this purpose and can achieve greater than 85% P removal from the dilute stream, with the chemical solids being separated during clarification or filtration. Among the key challenges with using chemical accumulation techniques is that the chemically accumulated P is less useful because of the high metal salt content of the final product which restricts its use in agricultural applications. Chemical accumulation is widely applied at domestic WRRFs. Therefore, it may be possible to accomplish extractive nutrient recovery at existing WRRFs by implementing suitable release and extraction processes to process the solids generated.

Another strategy that can be used to accumulate nutrients from the mainstream flow is adsorption and/or ion exchange. These processes can be used to remove N and P from dilute wastestreams, with removal efficiencies ranging between 50-90% removal. In this approach, a sorbent or ion exchange material is packed into a column. As the wastewater flows through the column, N or P (depending on the material) is either sorbed or chemically attracted to specific sites on the material.

This approach has been used at pilot and full-scale tertiary filtration applications to help remove phosphorus. One of the biggest challenges with using adsorption and/or ion exchange for nutrient accumulation is the regeneration step which requires use of costly chemical brines and the need for replacement of spent adsorption media. Therefore, it may not currently be economically feasible to implement adsorption and/or ion exchange at larger plants.

Embryonic research at the lab-scale is investigating the use of bio-regeneration as a method to help reduce costs associated with regeneration and replacement of sorbent material. It is expected that these processes will continue to become more important as WRRFs are increasingly asked to achieve effluent TP limits below 0.1 mg/L. In this scenario where adsorption and/or ion exchange is used in a tertiary filtration step, it may be possible to harvest the nutrient from this material for beneficial reuse.

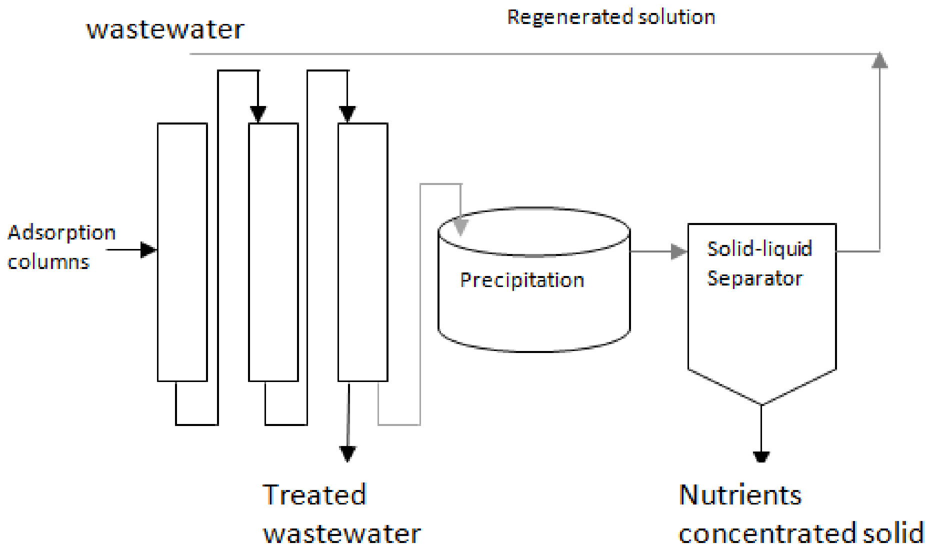


Figure 33: Conceptual Process Flow Diagram for Adsorption and/or Ion-Exchange for Nutrient Accumulation (From Latimer et al., 2015a)

| Development Status | | Operating Conditions | | Level of Pre-treatment required | Input | Commercial process | Nutrient(s) Accumulated |
|---|---|---|---|---|---|---|---|
| | | Temp. (°C) | pH | | | | |
| Embryonic | Purple non-sulfur bacteria | 27-34 | 6-8 | Low | Alginate, light Source | - | P |
| | MAlgae | 15 - 30 | 7.5 – 8.5 | Low | light source | Lemna Technologies | N and P |
| | Cyanobacteria | 5 - 40 | 6.5 - 8 | Low | Carbon source, light | - | N and P |
| Innovative | Adsorption/Ion exchange | 10-40 | <8.0 | Solid-liquid separation | Adsorbent | P-ROC, RECYPHOS, PHOSIEDI, RIM NUT, BIOCON | N, P and K |
| Established | EBPR | 5 - 40 | 6.5 - 8 | Low | Extreme Carbon, pH adjustment | - | P only |
| | Chemical (precipitation) | 25 - 40 | 6 - 11 | Low | Metal salts (Al or Fe), pH adjustment | - | N and P |

Table 13: Summary of Technologies Suitable for Nutrient Accumulation at Full-Scale WRRFs (From Latimer et al., 2015a)

*embryonic – technologies that are in the developmental stage (bench/pilot scale)*
*innovative – developed technologies with limited full-scale application*
*established – commercially viable technologies with a proven history of success*

## Nutrient Release Options Suitable for Full-Scale Application

Once accumulated, the nutrients within the biomass or chemical sludge/slurry must be either released and then extracted to a chemical nutrient product or directly extracted to obtain a chemical nutrient product. Release technologies allow us to recover the nutrients into a low-flow, high-nutrient content stream with minimal solids content, which can be used for extraction processes. Release technologies typically employ some combination of biological, thermal, chemical or physical processes.

Biological release is the most commonly used process that has been implemented at WRRFs. In this process, the biomass is broken down and the organic carbon, nitrogen and phosphorus are converted to carbon dioxide and methane or ammonia and soluble phosphorus, respectively. Biological release can occur under anaerobic conditions (e.g., anaerobic digestion) or under aerobic conditions (e.g., aerobic digestion), and the extent of nutrient release is dependent on the conditions employed during digestion. After biological release, the effluent streams can contain greater than 100 mg P/L and 1000 mg N/L, as well as particulate matter that must be removed. One of the biggest advantages of using an anaerobic biological release process is the opportunity to not only recover nutrients, but also biogas. Indeed, anaerobic digestion has been extensively applied as a cost-effective option for reducing the solids content of primary and waste activated sludges. Recent work performed as part of the WEF-funded national survey of anaerobic digestion and biogas use indicates that close to 25% of all WRRFs greater than 1 mgd currently employ anaerobic digestion (WEF Biogas Data Collection Project). Also, as the industry increasingly aims to achieve energy neutrality, it is expected that anaerobic digestion processes will be increasingly implemented. In a WRRF that already employs biological and/or chemical accumulation followed by biological release using anaerobic digestion, implementation of extractive nutrient recovery would simply require the installation of the extraction step. This latter upgrade has been done at several full-scale facilities in the U.S. and Europe.

Another option for biological release is enhanced P release processes. In this approach, phosphorus that has been biologically accumulated by PAOs is selectively released from these microorganisms (in WAS). One variation of this process is called WASStrip™ and has been patented by Clean Water Services. Enhanced P release processes can be used in combination with anaerobic digestion to

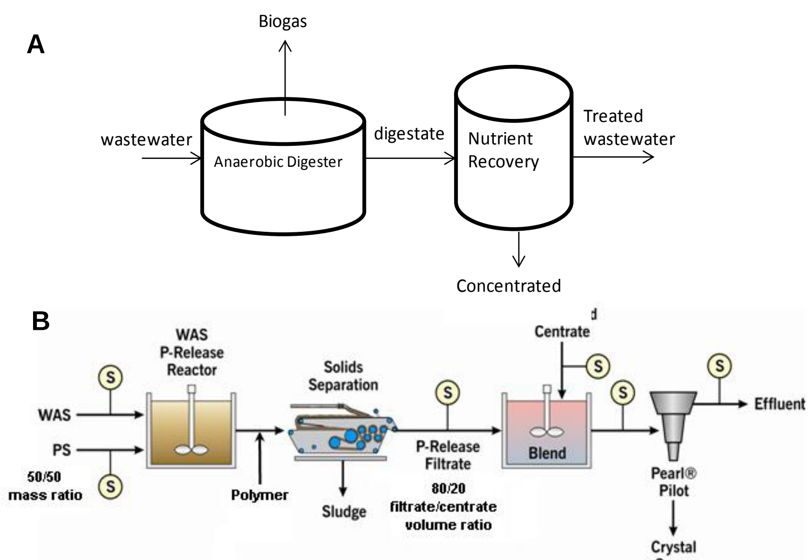


Figure 34: Conceptual Process Flow Diagram for A) Anaerobic digestion, B) Enhanced Waste Activated Sludge Enhanced P Release (From Latimer et al., 2015a; Latimer et al., 2012)

help minimize the O&M requirements associated with nuisance struvite/vivianite formation that is related with the operation of biological accumulation processes.

Another commonly used practice for releasing nutrients bound in biomass and chemical sludge is thermochemical processes coupled with chemical release. Thermochemical options can include wet oxidation, incineration, gasification or pyrolysis. In these processes, high temperature is used to destroy organic material and produce a solid product containing P, which can then be chemically released. It is important to note that N is typically lost through gaseous emissions during these processes. As a result, thermochemical processes are most suitable for extractive nutrient recovery of P. Great advances in thermochemical processes have been achieved over the past 5-10 years and they have emerged as innovative alternatives to using anaerobic digestion for managing solids at municipal WRRFs. Chemical release of nutrients from the char, ash, biosolids (digested, dewatered activated sludge) or undigested sludge can then be accomplished using concentrated acids or bases at temperatures between 100 to 200$^{0}$C. The liquid stream is then subjected to extraction technologies to recover the nutrients.

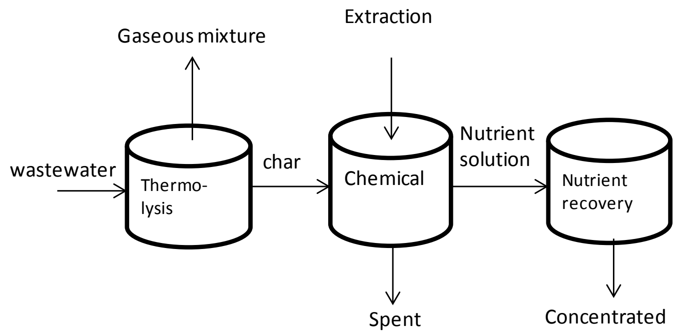


Figure 35: Conceptual Process Flow Diagram for Thermochemical and Chemical Release Processes (Latimer et al., 2012a, Latimer et al., 2012b)

Coupling these processes to the extractive nutrient recovery framework could allow facilities who have limited expansion capacity or are limited in disposal options for biosolids to still become resource recovery treatment plants. One of the biggest challenges associated with this release option is the presence of heavy metals in the generated liquid stream. Post-treatment will be required to limit the heavy metal content of the chemical product. These additional treatment steps can make this option economically challenging to implement at the current market value of the chemical nutrient products that are typically recovered from these processes.

Table 14: Summary of Technologies Suitable for Nutrient Release at Full-Scale WRRFs (Adapted from Latimer et al., 2015a)

| Development Status | | Operating conditions | | Level of Pre-treatment required | Input | Commercial process | Nutrient (s) Released |
|---|---|---|---|---|---|---|---|
| | | Temp. (°C) | pH | | | | |
| Embryonic | Bioleaching | 20-40 | 1-3 | Low | Sulfur, iron source, pH adjustment | BIOCON | N and P |
| Innovative | Chemical release | 25-200 | 2 - 3 | - | Leaching solution, pH adjustment | SEABORNE, STUTTGARTER VERFAHREN, LOPROX/PHOXAN, CAMBI, KREPCO, BIOCON, SEPHOS, AQUARECI, SESAL-PHOS, PASCH | N, P and K |
| | Chemical (liquid) extraction | | 1 - 3 | | $Na_2CO_3$, NaOH, aliphatic, non volatile solvents with extractants | AD-LLX | N and P |
| | Thermochemical release | 150 – 1100 | all | Medium (heating required) | Heat | MEPHREC, ASHDEC, THERMPHOS | P and K |
| | Anaerobic digestion | 35 – 60 | 6.5 – 7.5 | Medium (heating required) | - | - | N,P and K |
| Established | Anaerobic digestion | 35 – 60 | 6.5 – 7.5 | Medium (heating required) | - | - | N,P and K |

| Name of Technology | Pearl® Nutrient Recovery Process | Multiform Harvest Struvite Technology | NuReSys | Phospaq | Crystalactor® | AirPrex |
|---|---|---|---|---|---|---|
| **Technology Provider** | Ostara | Multiform Havest | NuReSys bvba | Paques | DHV | CNP |
| **Type of reactor** | Upflow fluidized bed | Upflow fluidized bed | CSTR | CSTR with diffused air | Upflow fluidized bed | Upflow fluidized bed |
| **Name of product recovered** | Struvite (marketed as Crystal Green ®) | Struvite | Struvite (marketed as BioStru®) | Struvite | Struvite, Calcium-phosphate, Magnesium-phosphate | Struvite |
| **% Efficiency of recovery/ treatment (range)** | 80-90% P 10-50% N | 80-90% P | 45% P | 80% P | 85-95% P for struvite > 90% P for calcium phosphate | 90% total P |
| **# of full-scale installations** | 16 | 2 | 7 | 2 | 30 | 8 |

Table 15: Description of Commercial Struvite Crystallization Processes

## Nutrient Extraction Options Suitable for Full-Scale Application

The next step of the extractive nutrient recovery process is the extraction and recovery of chemical nutrient products from concentrated liquid streams. These extraction processes can be inserted downstream of accumulation or release technologies. Most extraction technologies are applied to the sidestream flows after dewatering. Removing the solids prior to chemical extraction has the advantage of producing a cleaner precipitate. One exception to this is the AirPrex process, which is applied to the digested sludge flow before dewatering. The advantage of extracting the P prior to dewatering is that it may improve sludge dewaterability. Whether applied to the sidestream or the digested sludge flow, all extraction technologies involve a change in the temperature or pH of the liquid stream to a suitable condition for the process. One example of a commonly applied extraction technology is chemical crystallization where the soluble nutrient is precipitated and recovered as crystalline products. Products that can be generated by this process includes struvite (magnesium ammonium phosphate) and calcium phosphate (hydroxyapetite, P only). In the case of struvite formation, the pH and concentration of magnesium, phosphate, and ammonium is controlled to allow the precipitation of the chemical nutrient product, which is then separated from the liquid stream via gravity or mechanical separation. Further drying and processing of the product is also commonly performed.

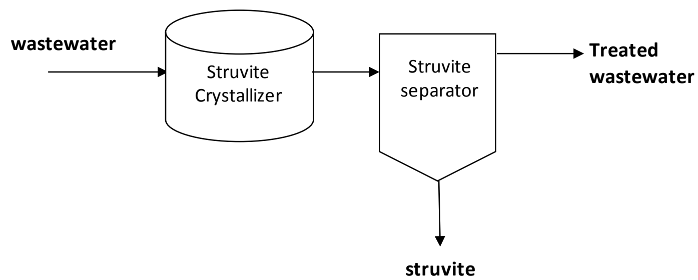


Figure 36: Conceptual Process Flow Diagram for Chemical Crystallization (Latimer et al., 2015a, Latimer et al., 2015b)

There are multiple variations of this chemical crystallization process that have been commercialized. In each of these systems, soluble P removal efficiencies up to 90% and ammonia removal efficiencies up to 30% can be expected if struvite is the product of choice. Addition of magnesium chloride or hydroxide as well as caustic (NaOH) is typically needed for the process to proceed. Precipitation of calcium phosphate is also possible with the addition of calcium instead of magnesium. There are over 50 full-scale installations of these processes throughout the world. For municipal WRRFs, these processes are commonly installed downstream of biological accumulation (e.g., EBPR) and biological release technologies (anaerobic digestion).

In order to recover N only products, liquid-gas stripping of ammonia can be used. In order to extract the ammonia from the nutrient rich liquid stream, it is necessary to raise the pH above 9.3 and increase the temperature above 80$^{0}$C. Air can then be bubbled through the mixture, forcing the soluble N into the gas phase. This gas phase ammonia is then recovered by bubbling the nutrient rich gas into sulfuric or nitric acid, producing ammonium sulfate or ammonium nitrate, respectively. In this process, ammonia removal efficiencies up to 98% is possible; however, the relatively high cost of this method makes this option challenging for implementation in wastestreams with N content less than 2,000 mg/L. As thermal hydrolysis processes like CAMBI™ and Exelys™ are increasingly implemented at municipal WRRFs, liquid-gas extraction of ammonia will become more technically feasible; however, the ultimate implementation of this process will be dependent on the cost of the products that will be recovered. While this process is established in industrial applications, it has not been extensively applied for recovery of N from municipal WRRFs.

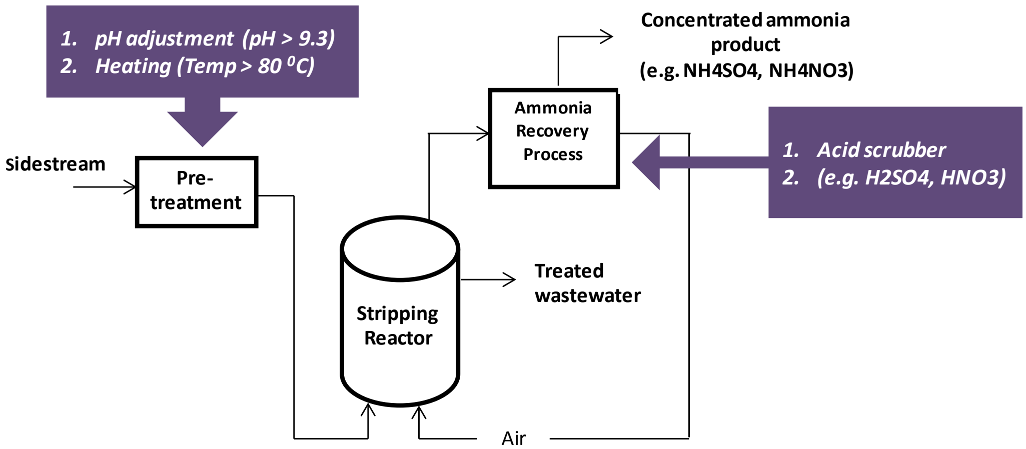


Figure 37: Conceptual Process Flow Diagram for Liquid-Gas Stripping (Latimer et al., 2015a)

Electrodialysis represents an embryonic extraction technology that allows for the recovery of all ions from nutrient streams at nutrient concentrations below 2,000 mg/L. It represents a highly promising technology to the extractive nutrient recovery field. In this process, an electrical current is used to separate anion and cations across an ion exchange membrane. At present, this technology has been implemented at the lab-scale; however, its suitability for implementation at low concentrations of nutrients matches well with the domestic WRRF industry needs. Ongoing research has shown that successful application of this technology in full-scale facilities may be hampered by the high energy consumption, chemicals required for the regeneration of the membranes, membrane fouling, and heavy metal contamination. Additional research into this technology is warranted.

| | | OPERATING CONDITIONS | | LEVEL OF PRE-TREATMENT REQUIRED | INPUT | COMMERCIAL PROCESS | NUTRIENT(S) EXTRACTED |
|---|---|---|---|---|---|---|---|
| | | Temp. (°C) | pH | | | | |
| Embryonic | Gas-permeable membranes | 10-80 | >9.5 | High (pH and temperature adjustment) | Heat, pH adjustment | - | N |
| | Electrodialysis | 10 - 40 | < 8.0 | Solid-liquid separation | Electricity | GE Water | N and P |
| Innovative | Liquid-gas stripping | >80°C | > 9.5 | pH and temperature adjustment | Caustic | ThermoEnergy Castion™ | N only |
| Established | Struvite crystallization | 25 - 40 | 8 – 9 | Solid-liquid separation | Caustic, magnesium or calcium pH adjustment | DHV CRYSTALACTOR, CSIR, KURITA, PHONIX, OSTARA, BERLINER VERFAHEN, FIX-PHOS, Multiform Harvest, NuReSys, PhosPhaq, Airprex | N and P |

*embryonic – technologies that are in the developmental stage (bench/pilot scale)*
*innovative – developed technologies with limited full-scale application*
*established - commercially viable technologies with a proven history of success*

Table 16: Summary of Technologies Suitable for Nutrient Extraction at Full-Scale WRRFs (From Latimer et al., 2015a)

# Considerations for Chemical Nutrient Products

At present, commercial technologies for extractive nutrient recovery primarily produce chemical nutrient products that are used in agricultural applications. This is because 85% of all nutrient products are associated with agronomy. Since food demand is expected to rise with an increasing global population, it is expected that demand for chemical nutrient products will also increase. This represents an opportunity for the wastewater treatment market to develop niche products that can be used in this field.

At present, biosolids are commonly the primary product used to recycle nutrients from wastewater. One of the biggest challenges with biosolids is the expense associated with transporting a product with a high moisture content (~80% - 90%). Since the current value of nutrients in biosolids (~US$8 per tonne) is a fraction of the transport costs (US$30 per tonne to transport 50 km in the U.S. or Australia with higher costs in Europe), nutrient recovery via biosolids can be an expensive undertaking. Even in scenarios where thermal processes are used to reduce the moisture content, the energy required (~800 kWh of energy (as gas) required to evaporate one tonne of water) is significant.

Consequently, recovery of nutrients into chemical nutrient products like struvite is the primary focus of several commercial extractive nutrient recovery technologies. In addition to struvite, other products like calcium phosphate (hydroxyapetite), iron phosphate (vivianite), phosphoric acid, ammonium sulfate, and ammonium nitrate can also be recovered depending on the nature of the wastewater as well as the secondary market being targeted. An additional advantage of recovering chemical nutrient products is the fact that some of these products have use in alternative industries.

## P Recovery at the Stickney Water Reclamation Plant

In May 2016, the world's largest nutrient recovery facility was launched at the Stickney Water Reclamation Plant (WRP), operated by the Metropolitan Water Reclamation District (MWRD) of Greater Chicago. The Stickney WRP is the one of the largest treatment plants in the world with a capacity to treat up to 1,400 mgd and serving a population of 4.5 million people equivalents. The Ostara process was selected for the Stickney WRP. The decision to add P removal was driven by tightening P discharge limits and sustainability goals. Furthermore, the project made financial sense. The savings from adding P removal, including a reduction of return loads to the main plant and revenue from sales of struvite, outweigh the costs. The P recovery facility has a capacity of 9,000 tons per year of struvite production.

| COMMON NAME | CHEMICAL NAME | PRODUCT FORM | USES |
|---|---|---|---|
| Struvite | Magnesium ammonium phosphate | Solid | Agricultural and ornamental crop fertilizer |
| Hydroxyapatite | Calcium phosphate | Solid | Agricultural and ornamental crop fertilizer.<br>Sorbent for heavy metal contained in flue gas. |
| Vivianite | Iron Phosphate | Solid | Ornamental crop fertilizer.<br>Inexpensive blue pigment for arts and crafts. |
| Phosphoric acid | Phosphoric acid | Liquid | Agricultural and ornamental crop fertilizer.<br>Removal of rust, de-scaling of boilers and heat exchange tubes. |
| Ammonium nitrate | Ammonium nitrate | Liquid | Agricultural and ornamental crop fertilizer.<br>Oxidizing agent in explosives. |
| Ammonium sulfate | Ammonium sulfate | Liquid or Solid | Agricultural and ornamental crop fertilizer.<br>Used in flame retardant materials. |

Table 17: Summary of Chemical Nutrient Products Resulting from Extractive Nutrient Recovery Processes (From Latimer et al., 2015a)

In order for chemical nutrient products to be used for agricultural purposes, they must meet some minimum requirements. For instance, all products must have consistent nutrient content and possess minimal odors. Solid products must have uniform size, comprise no less than 95% total solids, have less than 1% dust content, and have a minimum bulk density of at least 45 pounds per cubic foot. Due to the limited mass production rate of the wastewater treatment sector, it will be challenging to compete with existing supply chains. Instead, recovered products from WRRFs should be marketed within niche markets to maximize resale. An example of this is the case of the Ostara CrystalGreen™ product, which is used as a soil amendment product.

In addition to having specific physical characteristics, chemical nutrient products must also have minimal pathogen content and low concentrations of trace organic contaminants (TOrC). To date, research has shown that chemical nutrient products resulting from extractive nutrient recovery processes have negligible pathogen or TOrC content. This is an additional benefit that these products have over biosolids.

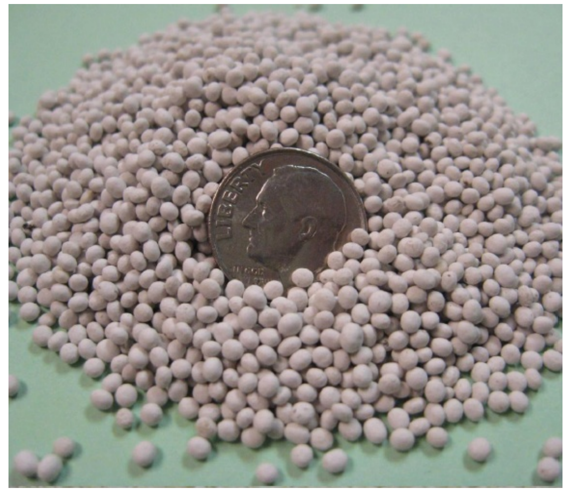

Figure 38: Example of Struvite Product

Perhaps the most critical aspect of extractive nutrient recovery processes is the resale price of the chemical nutrient product. Work performed as part of the WE&RF Nutrient Recovery Challenge (Latimer et al., 2015a) shows that products comprising of P only or N and P tend to have a higher resale value than products comprising N only. This may be directly related to the high demand for easily minable phosphate rock which can drive up the cost of P fertilizers. As natural prices vary due to its adoption as a mainstream transportation fuel, it is expected that N product resale values will also increase. If the price of N products increases, this can make extractive nutrient recovery of N products more economically feasible. At present, current market prices favor recovery of chemical P products. While technologies like struvite crystallization in which both N and P are recovered provide the added treatment benefit of removing N from the wastewater, the primary value of the product will continue to lie in the P content.

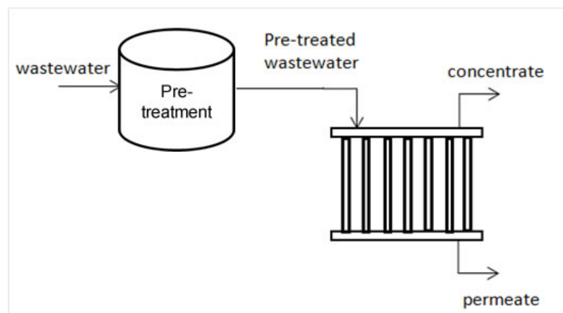


Figure 39: Conceptual process flow diagram for electrodialysis (Latimer et al., 2015a)

Based on historical data, Latimer et al. (2015a) estimated a market price for N solutions ranging from ~US$1,200 to 2,500/metric tonne of N, while the corresponding market price for phosphorus was estimated to range from US$5,500 to 7,500/metric tonne of P. This cost does not reflect transportation and distribution fees, nor the impact of competing products, all of which could impact product revenues.

| | AMMONIUM SULFATE SOLUTION | AMMONIUM NITRATE SOLID | AMMONIUM SULFATE SOLID | TRIPLE SUPER-PHOSPHATE | DI-AMMONIUM PHOSPHATE |
|---|---|---|---|---|---|
| **Recovered product analogue from WRRFs** | Ammonium sulfate solution | Ammonium nitrate solid | Ammonium sulfate solid | Hydroxyapetite | none |
| **%TP-%TN-%K-%S-%Ca content** | 0-30/34-0-0-0 | 0-34-0-0-0 | 0-21-0-24-0 | 46/46-0-0-0-15 | 46-18-0-0-0 |
| **Chemical formula** | - | $NH_4NO_3$ | $(NH_4)_2SO_4$ | $Ca_3(PO_4)_2$ | $(NH_4)_2HPO_4$ |
| **Price / lb. of nutrient product in 2011** | 58.5¢ | 71.5¢ | $1.00 | 70¢ | 76¢ |

Table 18: Average Price for Recovered Product Analogues (From Latimer et al., 2015a)

# Challenges and Solutions for Implementing N and P Recovery at WRRFs

Although there appears to be a general consensus that nutrient recovery can benefit the industry, there remain technical, social, and economic challenges towards an industry-wide adoption of this approach (Guest et al. 2009). Many of these barriers largely revolve around a lack of technical and economic knowledge. For instance, although there are multiple options that can be considered for recovery, *a systematic evaluation of treatment efficiencies, costs, energy balances, and recovered product yields is currently absent*. Thus, when faced with the option of recovering resources, utilities must generate this data from scratch.

> *"Perhaps the most critical aspect of extractive nutrient recovery processes is the resale price of the chemical nutrient product."*

To address this need, WE&RF funded research that provides peer reviewed resources (reports, a technology database, and a tool) that can aid in the technical selection processes. The technology database (Resource Recovery Matrix – Nutrients) includes references to technology providers and existing sites with nutrient facilities. The tool (Tool for Evaluation of Resource Recovery, or TERRY-Phosphorus) was designed for utilities seeking preliminary evaluations on whether or not extractive nutrient recovery processes will benefit their facility. In addition to the database and tool, the WE&RF Resource Recovery Challenge Project (NTRY1R12) provides supporting documentation on the state of the science and market assessment report, as well as cases studies from 20 facilities. Data collected through the case studies were used to identify scenarios that allow for more widespread adoption of extractive nutrient recovery and helped build TERRY-Phosphorus.

Efforts will be made to parallel the progress made as per the WE&RF Energy Challenge in the development of case studies for all participating utilities.

To date, collective experience has shown that successful implementation of extractive nutrient recovery systems is highly dependent on the amount of nutrient that must be removed or recovered and that payback periods are shorter for more concentrated wastestreams. Accordingly, direct extraction of nutrients from mainstream flows is not technically or economically feasible. Instead, it will be more appropriate to use the three-step framework whereby nutrients are first accumulated, released, and then extracted. It is important to note that not all WRRFs will require all three components. Indeed, the existing data from WRRFs that have successfully implemented extractive nutrient recovery shows that there are three scenarios where adopting extractive nutrient recovery at WRRFs can be economically and technically viable solutions. In the first scenario, energy and chemical costs savings resulting from sidestream extractive nutrient recovery versus conventional mainstream nutrient removal treatment can allow the plant to implement extractive nutrient recovery. In the second scenario, extractive nutrient recovery can be used to help minimize nuisance struvite/vivianite formation. This can reduce operational and maintenance costs at WRRFs, making nutrient recovery an asset to plant operation. The third scenario is one in which extractive nutrient recovery processes are used to manage the nutrient content of the biosolids production process. By changing the nutrient content of the biosolids, WRRFs can add flexibility to their existing nutrient recovery efforts and allow them to maximize the use of acreage used for land application.

Each of these scenarios is based on providing utilities with a cost-effective solution for managing or removing nutrients from liquid or solids streams. As a result, it should be no surprise that the adoption of nutrient recovery is closely hinged to the economic viability of extraction options. As the economics of extractive nutrient recovery is plant and region specific based on markets for recovered products, detailed evaluations that encompass triple-bottom-line assessments of nutrient recovery options are needed. These assessments must consider the social, technical, and economic aspects of nutrient recovery as part of an integrated nutrient management plan for utilities. This will continue to be challenging in the foreseeable future since extensive data on nutrient recovery is only available for a few commercial processes (e.g., struvite crystallization). Extreme care should be taken as we attempt to extrapolate results from established systems to innovative and embryonic technologies.

## Research Needs for N and P Recovery Technologies

It should be acknowledged that there is no single technology that is perfectly suited for complete nutrient recovery from all scenarios. Therefore, it is critical that we develop robust data to define the optimum operation space for each option. At present, the dearth of information regarding nutrient accumulation, release, and extraction precludes detailed comparisons to conventional options for removing nutrients from wastewater. If we were to implement nutrient recovery as part of an integrated nutrient management plan for WRRFs, development of the performance benchmarks and cost data are necessary.

There is a need to facilitate further research into technologies defined as embryonic (technologies that are in the developmental stage with bench/pilot scale data) and innovative (technologies with limited full-scale application). Future research should focus on compiling full-scale data for innovative technologies (e.g., adsorption/ion exchange accumulation and chemical release technologies), with a special emphasis of deriving costs associated with treatment of N and P. Efforts should also be made to pilot test embryonic options (e.g., electrodialysis) with a view to determining the operating space that may be appropriate for implementing these technologies. Once this is identified, full-scale data collection should aim to derive costs associated with recovery of N and P.

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# Section 6

# Other Resource Recovery Opportunities: Expanding Horizons

The biosolids industry is not alone in some of the challenges it faces – industries across a wide spectrum are grappling with economic constraints and the need for sustainable solutions. This need, coupled with technology transfers into the wastewater solids arena from other areas has spurred the emergence of new approaches that use biosolids as a feedstock to create a variety of non-traditional products, such as biodegradable plastics, fertilizers, and alternative fuels. This section features examples of emerging technologies that may offer the potential for future large-scale applications.

In exploring these technologies, it is important to note that the evolutionary path for emerging technologies is not an easy one: new technologies must overcome tremendous obstacles to travel from "emerging" to "established" status. As shown in the figure below, technologies can be challenged at all stages of development, facing technical performance issues throughout their development and economic viability challenges as they move toward full-scale operation.

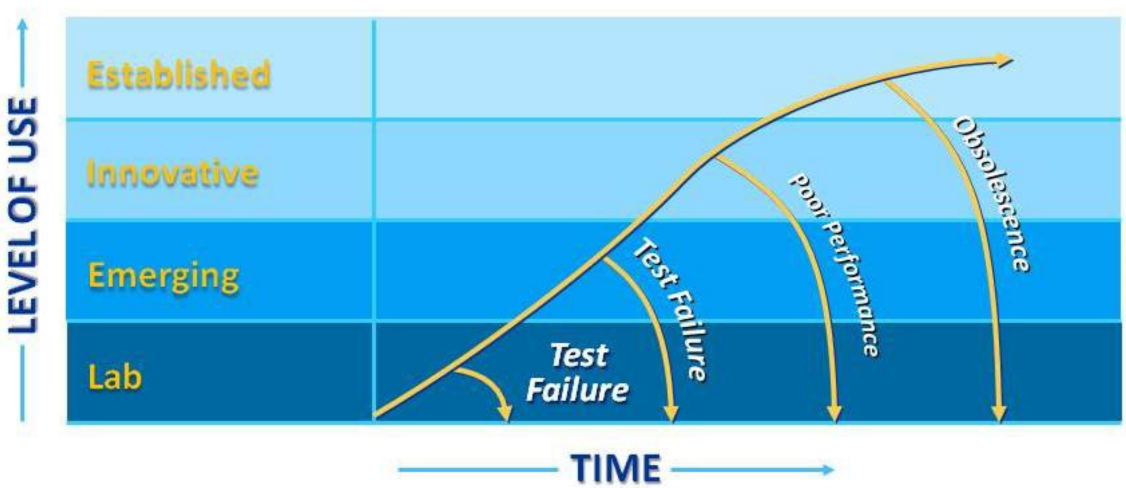


Figure 40: Technology Evolution

The nature of wastewater solids appears to be a specific challenge for processes operating at high pressures and or temperatures. Several promising technologies have been proven to work with homogenous materials as the raw feedstock, but have not been able to overcome the problems associated with the variable characteristics of biosolids. For example, the 2012 closure of the thermal conditioning plant operated by EnerTech Environmental, Inc., in Rialto, California culminated years of research and development in the formation of a bio-fuel from biosolids. The complexity of the process and other factors, including sidestream treatment and cost ultimately resulted in EnerTech being forced to cease operations. Minergy's Glass Pack technology is another example of a technology that tested out with promising results, working well with pulp wood processing wastes, but full-scale implementation with biosolids in Waukegan, Ill. has encountered too many obstacles for it to be considered successful. That being said, the drive for new and synergistic technologies appears to remain strong, with new processes (including those featured below) working their way through the evolutionary process.

# Overview of Technologies

## Enhanced Fertilizer Production

Probably one of the most proven "non-traditional" technologies emerging in the marketplace is the manufacturing of a chemical fertilizer with biosolids as a component. Two fertilizer manufacturing companies have built upon the Unity Process used by Cypress Chemical in the late 1990's early 2000's period. Cypress Chemical developed a process for manufacturing ammonium sulfate fertilizer using biosolids as a component as illustrated in the figure below.

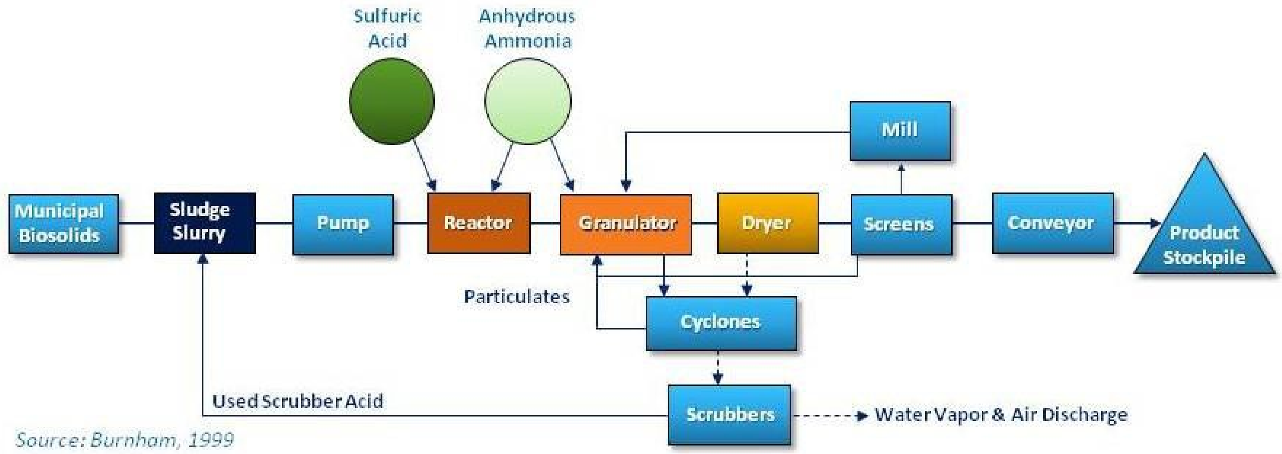


Figure 41: Cypress Chemical Process for Manufacturing Ammonium Sulfate Fertilizer Using Biosolids as a Component

Over 100,000 tons of biosolids from New York City wastewater plants were processed at a rehabilitated fertilizer plant in Helena, Ark. during this period. The economics of transporting the biosolids such long distances led to the closure of the plant and the breakup of Cypress Chemical, but Anuvia (formerly VitAG), a new company with enhancements to the Cypress Chemical process opened a facility in Zellwood, Fla., in February 2016. The resulting product is a high-grade commercial fertilizer that will be marketed through fertilizer distributors and brokers. The company has adapted traditional chemical fertilizer technologies to use biosolids and introduce an organic fraction to the fertilizers, although it is also pursuing digested food waste, algae, and other nutrient-rich feedstocks in addition to biosolids. The facilities will vary in capacity but will typically have capacities exceeding 100 wet tons per day of dewatered, digested biosolids. Between February and May of 2016, the Zellwood facility produced and sold over 3,000 tons of fertilizer.

## Biodegradable Plastics

One of the most non-traditional technologies under development is the production of a biodegradable plastic using biosolids. Micromidas LLC is developing a biological process that will use the carbon and other nutrients in biosolids to generate small particles of biodegradable plastic, similar to the process that uses glucose or fructose to make biodegradable plastics. The resulting plastic will have a lifespan of months, instead of the centuries needed now to breakdown petroleum based plastics.

Micromidas was founded in 2008 and has been focused on identifying the proper bacteria and environment for their growth. They are in the process of developing a trailer-mounted pilot unit that can be taken to wastewater treatment facilities to be tested on a larger scale. (Meyers, 2011).

Another method of creating biopolymers is under development by Mango Materials, a California-based company that was founded in 2010. The Mango process uses waste biogas or landfill gas as a feedstock for PHB biopolymers that are economically competitive with oil-based plastics. PHB stands for poly-hydroxybutryate which is a biopolymer that has properties similar to polypropylene. PHB can be made into a variety of products, including electronic casings, children's toys, shampoo bottles, and packaging. Since many WRRFs operate in areas with low energy prices, recovering biogas for energy can be economically challenging. In these situations, using the biogas for an alternate purpose could allow for beneficial reuse of the gas without the costs associated with CHP equipment. Additionally, the bioplastics produced by Mango Materials are able to be digested again to produce more biogas at the end of their useful life.

The figure below illustrates the Mango Materials concept.

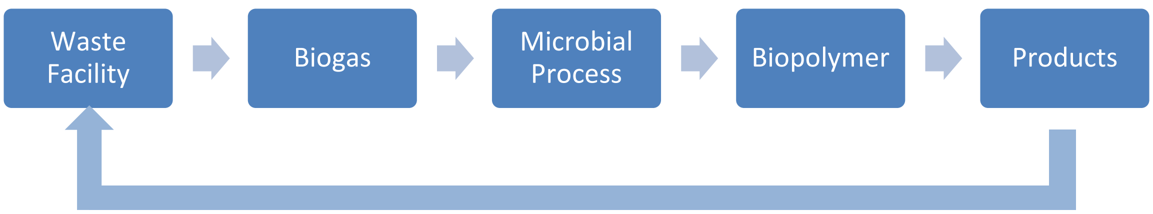


Figure 42: Mango Materials concept for biopolymer production using biogas.

## Methanol Replacement

In contrast to the previous technologies that use biosolids to make alternative products, OpenCEL is developing an alternative use to their sludge conditioning process that will allow wastewater plant operators to replace purchased chemicals and reduce operational costs. OpenCEL uses focused pulse technology to lyse waste activated sludge and make it more amenable to biological degradation. In recent studies, OpenCEL determined that the conditioned sludge can enhance the

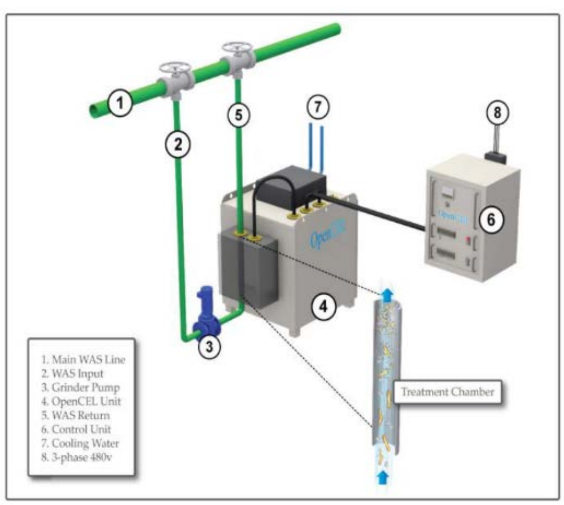


Figure 43: Simple equipment layout diagram provided by OpenCEL

denitrification aspect of biological nutrient removal processes. The primary benefit of adding focused pulse treated sludge will be at plants that need to add methanol or another source of carbon to sustain the BNR process. The treated sludge can replace a portion of the outside carbon source. During full-scale testing at the Mesa Northwest Water Reclamation Plant, OpenCEL was able to demonstrate a 40% reduction in the methanol needed to support BNR. The figure below illustrates the major components required for an OpenCEL system.

## Low Temperature Thermal Hydrolysis

Lystek, a Canadian company founded in 2000, has developed a low temperature thermal hydrolysis process that includes high-speed shearing, alkali addition, and low temperature steam. The resulting product is a stable liquid that meets Class A fertilizer requirements. In addition to fertilizer, the product has a high concentration of soluble COD and can be added back to the digester to augment biogas production or added to tertiary treatment processes to replace outside carbon sources. The product thus crosses into several of the categories above, depending on its end use. The firm has six operating facilities in Ontario and Saskatchewan and is opening its first U.S. facility in the first quarter of 2016 in Fairfield, CA.

## Conversion of Biosolids to Biodiesel

Dr. Kartik Chandran of Columbia University conducts research into advanced wastewater and fecal sludge management techniques. One promising approach now in development in his lab is the concept of stopping the anaerobic digestion process after only a few days, before the methanogens can convert the carbon to biogas. If the process is stopped after the sludge has been converted to volatile fatty acids (VFAs), the VFAs can then be converted to biodiesel. Not only would this allow for a smaller, cheaper reactor than a conventional biogas-generating anaerobic digester, the end product (biodiesel) has a higher economic value than biogas and can be used in a wider array of equipment. For his work researching ways to convert wastewater and fecal sludge into a more valuable resource, Dr. Chandran was awarded the MacArthur Foundation Fellows Award in 2015. Although biosolids to biodiesel production is not yet in commercial development, it is included here as an example of the kind of creative solution that could radically change the future of biosolids management.

# Enabling Further Development

As previously noted, these technologies have many obstacles to overcome before they will be considered mainstream technologies. The overarching obstacle is proving the technology will work consistently on a large scale. To reach that point, developers typically invest in years of bench and pilot-scale studies to identify the proper materials and processing methodologies. They then usually have to find a utility willing to allow them to test on a full-scale basis at no cost to the utility. All this requires significant financial resources, time, and patience on the part of the developer. Owners and their engineers are often resistant to experiment with new technologies because of the involvement of public funds and the risk associated with the unproven technology.

To aid in the advancement of developing and validating new water resource recovery technologies, WE&RF and WEF have organized the related LIFT (Leaders Innovation Forum for Technology) program. The program has four parts:

1. Technology Focus Areas identified by WE&RF members during technology surveys. Relevant focus areas include biosolids to energy, digestion enhancements, and energy from wastewater.
2. Technology Scans identify and evaluate innovative technologies to inform water facility owners, funders, advisors, and end users in order to promote early adoption of the

technologies. They offer technology providers an optimal platform to introduce their emerging, pre-commercial, and newly commercialized technologies.

3. The National Water Resource Recovery Test Bed Facility Network and Directory connects researchers, new technology providers, and other innovators in the water resource recovery industry with test facilities appropriate for their needs. It is hoped that this network will assist in the developing and piloting of technology at various scales to help manage risk and accelerate the adoption of innovation. The test bed network and directory was developed in coordination with EPA, NSF, DOE, and USDA. The goal of the network is to help innovators locate potential facilities for testing new technologies at various scales to help manage risk and accelerate adoption of innovation.
4. LIFT Link is an online platform which allows users to discover new water technologies and research needs; connect with others with similar needs, technology interests, and desired expertise; and collaborate on ideas, proposals, projects, demonstrations, and implementation.

Even after being proven on a full-scale basis, some technologies will be best suited as niche technologies serving a select few wastewater resource recovery facilities. One of the best examples of this is the use of biosolids in the manufacturing of bricks. During the late 1980s and early 1990s, several brick manufacturers used biosolids in the manufacturing of bricks. Small quantities of biosolids would be added to the clay prior to firing to add organic matter that would combust during the firing process, producing the desired brick density. In other applications, ash from incineration of sludges was used in the brick manufacturing process to add color from the minerals in the ash. Despite the proven success of the process, it did not take off on a large scale because of the limited number of brick manufacturers and the difficulty the manufacturers experienced in dealing with the solids. The batch process for making bricks and small percentage of solids used in each base created logistics problems, and in some states special permits were required for firing alternative wastes. Worker perceptions of biosolids also proved to be an issue for some manufacturers. Therefore, even if a technology is technically and economically feasible, other factors could prevent it from becoming an established technology or practice.

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# Section 7

# Enabling the Future: Investing in People, Quality, and Communications

The National Biosolids Partnership effort in "Charting the Future of Biosolids Management" (NBP, 2011), "Enabling the Future: Advancing Resource Recovery from Biosolids" (WEF, 2013), and this report have defined and documented important turning points in biosolids management in North America.

Over the past several years, there has been a shift in how wastewater solids are perceived within the wastewater and biosolids management profession. This perception is driven by forces internal and external to the field, including widespread interest in sustainability, energy, climate change, resource depletion, materials cycling, and zero waste goals. WEF and other professional organizations have recognized the new paradigm in position statements (WEF, 2011).

As biosolids management professionals look to the future they are asking what will be needed to make the "the vision" a reality? In 2017, the U. S. EPA Part 503 biosolids rule is 24 years old. Risk management, regulation, and best management practices have advanced and biosolids are products widely bought and sold in the marketplace. There are still skeptics, and biosolids recycling continues to need defending. But now, we are looking ahead, seeing the potential of maximizing resource recovery.

What will it take to get there?

This chapter identifies five steps to follow to reach maximum resource recovery.

## Steps to Maximum Resource Recovery

If accelerating the future of biosolids management means maximizing the use of this resource, then reaching that goal will require continuous, consistent effort toward these five specific initiatives described below.

### Increase Professional Capacity and Skills

Over the next decade, the wastewater and biosolids management profession will continue to lose the largest cohort of retiring engineers and operators in U.S. history. This wave of professionals came to work during the 1980s, a period of large federal construction grants. They designed, managed, and operated thousands of new or upgraded secondary treatment systems and learned how best to manage the solids. As retirements occur, experience and institutional knowledge are being lost. As WEF and other organizations have recognized, this loss can only be mitigated through the increased recruitment, training and support of young professionals.

But the need for education and training is even greater than merely replacing what is quickly being lost. The field also needs greater expertise, especially in areas not traditionally associated with wastewater treatment, such as computer technologies (SCADA and other systems), energy management, new technologies (e.g., for combined heat & power), agronomy, climate change mitigation and adaptation, financial management, and public outreach and communications. Providing this training costs money.

Furthermore, the expectation for increased professionalism and higher skill levels in the field will result in higher paid staff operating the water resource recovery facilities. Crawford (WE&RF, 2010) reported this fact in reviewing the success of the ~10 mgd Strass, Austria WRRF, which produces more energy than it consumes.

The key factors noted were:

- A "highly educated, well-paid workforce,"
- A "high level of automation,"
- A "use of advanced process analysis tools," and
- A "tolerance of process risk" and "quantifying gains."

Investment in people is as imperative as the investment in advanced infrastructure in the effort to maximize resource recovery. Energy savings and improved efficiencies in recovering resources will contribute to payback. However, fulfilling this return on investment is complicated, requiring more highly educated people.

Training in university engineering departments must continue to be diversified, providing budding professionals with courses beyond engineering, such as communications and sustainability. WEF and its member associations (MAs), regional biosolids groups, and state operator associations offering training need to keep pace with the demands of the profession.

Finally, information, training, and day-to-day support for biosolids management professionals and related programs are currently provided by a variety of organizations and agencies around the continent. For example:

- *National wastewater organizations* – WEF, NACWA, and the Canadian Water & Wastewater Association provide information and support biosolids programs. WEF and NACWA have staff dedicated to supporting biosolids management.
- *Regional biosolids associations* – Located in California, the Northwest, the Northeast, the Mid-Atlantic states, and Virginia, these associations are designed and operated to provide support specifically to biosolids management programs and professionals, through paid staff.
- *Regulatory guidance programs* – Some state and provincial regulatory programs provide considerable assistance to biosolids managers through regular training programs, operator certifications, newsletters, and informal consultations. However, many state programs may be susceptible to budget cuts that could reduce or eliminate assistance.
- *Biosolids committees of WEF member associations* – These committees are driven by volunteers, and, therefore, provide varying and limited levels of support to biosolids professionals.

These organizations form a distributed network for biosolids professionals that have considerable strength and resiliency, which supports and facilitates the exchange of accurate information. Today, as the focus on resource recovery from biosolids intensifies, the importance of the distributed network of support for biosolids professionals is even greater. The increased complexity of biosolids management, and the need for increased communications with more diverse audiences, requires continued growth of supporting mechanisms as they evolve to meet future needs.

Enabling the future of biosolids management success requires enhancing the capacity, skills, and knowledge of workers in the public utility and private sectors.

## Advance Policies and Rules Supporting Resource Recovery

Current laws and regulations related to biosolids management were developed within the paradigm of waste management, and while this approach is important, adjustments to these laws are necessary if maximum resource recovery from these materials is to be achieved. For example, wastewater agencies are running into obstacles with state policies that preclude co-digestion of biosolids with other organics or with energy utilities that are unable or unwilling to accept treated biogas (biomethane) or biosolids-generated electricity (Willis et al., 2012). In addition, energy derived from biosolids and other organic residuals is not recognized in some states' renewable energy credit (REC) programs or other incentive programs. Legislation or regulatory changes are needed to correct these policies.

The paradigm shift from sewage plants to water resource recovery facilities must be integrated into policy, legislation, regulations, and politics if maximum use of this resource is to be achieved. This will require expanded outreach to organizations outside of the biosolids profession. Biosolids interests should – and can – join coalitions focused on renewable energy, nutrient management, and green infrastructure; however, it will take concerted effort to explain to some of these organizations and people, who are focused on other issues, how biosolids can be a part of their work and offer solutions:

- WRRFs can provide communities with integrated management of challenging low-solids organic "wastes" from diverse sources, wastes that can be significant sources of pollution if not managed properly.
- Biogas generated from these facilities is a reliable, 24-hour renewable energy source.
- Nutrients in biosolids can reduce reliance on fertilizers mined and transported from a distance.
- Biosolids products are suited for building soils for improved stormwater retention and treatment.
- Maximizing use of the resources in biosolids reduces greenhouse gas emissions in several ways, including reduced use of fossil fuels and sequestration of carbon (C) in soils.

These are messages that should resonate with other environmental professionals and advocacy groups.

## Continue to Improve Biosolids Quality and Programs

Maximizing resource recovery from biosolids cannot be achieved if specific issues of public concern are not adequately addressed.

For land-applied biosolids, the following concerns should continue to be addressed, as needed, through research, regulations, and best management practices:

- Trace elements (e.g., heavy metals).
- Chemicals (including emerging contaminants, pharmaceuticals and personal care products (PPCPs), flame retardants, perfluorinated compounds (PFCs), etc.).
- Pathogens (including "emerging pathogens" such as norovirus).
- Nutrients (e.g., N and P).
- Odors and other nuisances.

The most significant concerns related to these topics (in terms of risk to public health and the environment) have been addressed, but refinements are needed as science develops further understanding. Biosolids land appliers need to continue to update their knowledge and practices to keep up with the science and public expectations for quality. For example, the current isolated state of relatively high soil levels of PFCs associated with biosolids application in Decatur, Ala., is a situation to learn from (Lindstrom et al., 2011). Precautionary actions to avoid similar issues in the future have been taken (phasing out of some PFCs) and should continue to be taken (e.g., stricter pretreatment and monitoring at facilities that potentially receive waste streams from industries manufacturing or using such chemicals).

With regards to thermal processing, biosolids managers must pay attention to such public concerns as:

- Air emissions (e.g., heavy metals, NOx, nitrous oxide ($N_2O$), dioxins/furans, CO, HCl, $SO_2$, particulate matter),
- Net energy consumption, and
- Odors and other nuisances.

In the coming years, best management practices for incineration will require greater net energy efficiency through increased combustion efficiencies, heat recovery and utilization, and ash utilization.

The public – and regulators – demand quality and expect continual improvement. The biosolids management profession must continue to meet these expectations.

Since the late 1990s, there has been a formal program that advances best management practices: the National Biosolids Partnership Environmental Management System (EMS, also known as the "Biosolids Management Program" or BMP). The NBP BMP independent audit process recognizes the extensive quality practices and continual improvement demanded of the program. And, of course, there is ever-improving guidance on current best practices in documents such as the EPA *Guide to Field Storage of Biosolids and Other Organic By-Products Use in Agriculture and for Soil Resource Management* (EPA, 2000), the NBP *National Manual of Good Practice for Biosolids* (NBP, 2003), and *Solids Process Design and Management* (WEF, 2012). BMPs ensure:

- Biosolids products of appropriate quality for the intended use,
- Managed to standards beyond those required by minimum regulations,
- Avoiding creation of nuisances, and
- With attention to building trust and relationships with neighbors, other stakeholders, and the general public.

Continuing to demonstrably minimize risk as much as is reasonably possible and advance best practices that build public confidence will increase opportunities for resource recovery. Thus, maximizing and demonstrating quality is a prerequisite for successful resource recovery and the communications and outreach that accompany it.

## Expand Dialogue Outside of the Biosolids Profession

To fully leverage resource recovery potential, the biosolids profession must improve communications and outreach with environmental groups, agricultural groups, and the general public regarding beneficial uses of biosolids and the importance of its use.

In the past decade, biosolids professionals have been encouraged to increase public involvement, communications, and outreach to interested parties, addressing topics such as the risks and benefits of biosolids use on soils and the acceptability of solids combustion facilities in neighborhoods. Understanding and use of risk communications has increased, and there are several resources specific to biosolids management now available (see resources listed below). WEF has recently released the *Biosolids Messaging* Book (WEF, 2016) which provides a comprehensive resource to educate the public, stakeholders, media, and other parties about biosolids in a factual, science-based way that is easily understandable by the lay person. Additionally, recent communication materials such as those produced by King County and the Northwest Biosolids Management Association provide excellent examples of approaches that can be used to effectively communicate such issues to the public. Going forward, new outreach and education efforts should also focus on biosolids for renewable energy, recycling of nutrients, land and ecosystem restoration, and solutions to the management of trace pollutants.

An essential part of understanding progressive biosolids management programs of today and of the future is that *biosolids products are tools valued in the marketplace.*

Accordingly, biosolids managers are increasingly focused on creating products of real value – with low contaminant levels. The ongoing regulatory structure and the focus on product quality are driving scrutiny of what is in biosolids, what is in wastewater, and ultimately, what is in use in society. As more biosolids are recycled and put to use, more emphasis is placed on cleaning up the “waste” stream, to create a true “resource” stream.

By moving in the direction of quality, solids management is aligned with progressive environmental efforts. Biosolids recycling becomes something that community, agricultural, conservation, and environmental groups embrace. Biosolids managers communicate with such groups, share vision and goals, and work together. There are examples of this cooperation (shown below) dating back 15 years and more and there will be more into the future.

As the quality of biosolids products and programs continues to improve, and their value in environmental projects and for environmental good is further demonstrated, biosolids managers must go beyond risk communication. Outreach programs with environmentalists and the public are needed to develop an appreciation of recycling of the “waste” about which most would prefer to forget.

## Secure Funding for Resource Recovery Initiatives and Infrastructure

The aforementioned recommendations reflect a dramatic need for increased funding for resource recovery from wastewater and solids. Improved technical efficiencies and resource recovery (e.g., energy production) will provide some pay back, but not enough to fund the needed work on policies, laws, and regulations. There will be funding required for additional education, higher paid staff, improved outreach, and more infrastructure.

As WEF, its MAs, and related organizations working on water-related topics recognize, there needs to be renewed public focus on this field. Wastewater and solids management are some of the most basic functions in which a society must focus. Biosolids professionals are increasing efforts to bring attention to our work and society needs to be made aware of how cost-efficiently these wastes/resources are managed, given the stakes in terms of public health and the environment.

The challenge for the biosolids management profession (and the wastewater field in general) is to convince decision-makers and the public of the need to dramatically increase funding. Aging infrastructure dictates that funding must be addressed now.

As necessity drives invention, biosolids professionals are figuring out innovative ways to do more with

## Resources for Biosolids-Specific Outreach & Public Involvement


Decision Partners (2011) *Conducting Effective Outreach and Dialogue on Biosolids Land Application.* Water Environment Research Foundation, Alexandria, VA.

Eggers, S.; S. Thorne; G. Butte; Sousa, K. (2011) *A Strategic Risk Communications Process for Outreach and Dialogue on Biosolids Land Application*; Water Environment Research Foundation: Alexandria, VA.

Federation of Canadian Municipalities and National Research Council (2005) *Communication and Public Consultation for Biosolids Management*, http://fcm.ca/Documents/reports/Infraguide/Communication_and_Public_Consultation_for_Biosolids_Management_EN.pdf (accessed Jan. 9, 2013).

Water Environment Federation (WEF), Water Environment Research Foundation (WERF), and U.S. Environmental Protection Agency (EPA) (2012). *Solids Process Design and Management.* Water Environment Research Foundation: Alexandria, VA. (see Chapter 3: Public Outreach and Involvement)

Water Environment Federation (WEF) (2016) *Biosolids Messaging Book*; Water Environment Federation: Alexandria, VA.

Water Environment Federation (WEF) http://www.biosolidsresources.org


## Other Outreach and Public Involvement Resources


Deeb, R.; Means, E. (2009) *Communication Principles and Practices, Public Perception and Message Effectiveness*; Water Environment Research Foundation: Alexandria, VA.

Hartley, T. 2001. *Public Perception & Participation in Water Reuse*; Water Environment Research Foundation, National Water Research Institute (NWRI), American Water Works Association Research Foundation (AWWARF), WateReuse Foundation.

International Association for Public Participation (2000) *IAP2 Public Participation Toolbox*. Available at http://www.iap2.org (accessed Jan. 9, 2013).

Water Environment Federation (2002) *Survival Guide: Public Communications for Water Professionals;* Sheri Wantland, Ed.; Water Environment Federation: Alexandria, VA.


fewer public dollars. For example, there is considerable discussion and increased use of:

- Public-private partnerships;
- Out-sourcing and privatizing;
- Design-build-operate (DBO) and other even more complex configurations of projects;
- More complex financing arrangements, such as having the capital costs of energy projects being borne through operational budgets; and

- Use of more accurate and helpful financial analysis and decision-making tools, such as those discussed in the follow-up to WE&RF's project Barriers to Biogas Use for Renewable Energy (WE&RF, 2012).

Of course, different approaches add complexity and require even more skills and education – requiring additional investment.

## Critical Success Factors

To manifest the developing paradigm of maximizing biosolids resource recovery, biosolids management professionals will need to pay attention to the following critical success factors:

- The skills and knowledge of biosolids management professionals;
- The age distribution of biosolids management professionals;
- The strength and capacity of biosolids-focused organizations;
- The status (number, tone, and complexity) of federal and state policies, laws, and regulations pertaining to biosolids;
- The quality of biosolids products (trace elements, trace chemicals, pathogens, nutrient balance, odors);
- The quality of biosolids management, including the constant of continual improvement;
- The level of federal and state policy support for biosolids resource recovery;
- The level of agricultural, conservation, and environmental group support;
- The level of public support (trust);
- The levels of public and private funding for biosolids management infrastructure, training, and operations; and
- The trend in biosolids resource recovery and the rate of biosolids recycling.

# References

Additional references are included in the highlighted section above regarding outreach and public involvement resources.

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Lindstrom, A. B.; Strynar, Mark J.; Delinsky, A. D.; Nakayama, S. F,; McMillan, L; Libelo, E. L.; Neill, M.; Thomas, L. 2011. Application of WRRF biosolids and resulting perfluorinated compound contamination of surface and well water in Decatur, Alabama, USA. *Env. Sci. Technol.*, **45** (19), 8015-8021.

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National Biosolids Partnership (2011) "Charting the Future of Biosolids Management", prepared by CDM, May 2011.

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U. S. EPA, Office of Solid Waste & Emergency Response (1999) Biosolids Generation, Use, and Disposal in the United States. EPA530-R-99-009.

U. S. EPA, Office of Water, Office of Wastewater Management (2000) Guide to Field Storage of Biosolids. EPA/832-B-00-007.

Water Environment Federation, position statement, biosolids, adopted by the Board of Directors December 2, 2011.

Water Environment & Reuse Foundation (WE&RF) (2010) Best Practices for Sustainable Wastewater Treatment: Initial Case Study Incorporating European Experience and Evaluation Tool Concept. WE&RF, Alexandria, VA, and International Water Association.

Water Environment & Reuse Foundation (WE&RF) (2012) Reframing the Economics of Combined Heat and Power Projects: Creating a Better Business Case Through Holistic Benefit and Cost Analysis (a publication building on Willis et al., 2012).

Willis, J.; Stone, L.; Durden, K.; Beecher, N.; Hemenway, C.; Greenwood, R. (2012) Barriers to Biogas Use for Renewable Energy. WE&RF, Alexandria, VA, and NY State Energy Research and Development Authority (NYSERDA).

# Section 8

# The Pulse of the Industry: Biosolids and Related Data

This report focuses on the new paradigm of resource recovery from biosolids (and, by inference, other residuals). In order to understand the full potential for resource recovery, data are needed. To date, the biosolids profession has had minimal data available. For example, even basic data on the generation of wastewater solids in the U.S. is inadequate for helping biosolids managers and policy makers understand the potential amounts and qualities of energy and nutrient resources. 2017 marked a milestone in data gathering efforts with the U.S. Environmental Protection Agency (EPA) providing a means to electronically submit annual biosolids reports. This is a step forward in obtaining an improved snapshot of the industry.

Some data surveys have been performed and are highlighted below, but as made clear in the text, there is a continuous need for updating the data.

## Biosolids Generation, Use, and Disposal in the United States

In the late 1990s, EPA and WEF developed estimates of wastewater solids generated nationwide based on data on flows treated at wastewater treatment facilities and standard per-person sludge generation estimates. The data was presented in the report *Biosolids Generation, Use and Disposal in the United States* (EPA, 1999).

At the time, some states were keeping more accurate data based on actual reports of solids generated and managed at each water resource recovery facility (WRRF), and EPA were receiving paper copies of required annual reports from facilities generating biosolids, but this information was not easily accessible. Therefore, EPA's Office of Solid Waste (1999) used flow data to generate the most comprehensive estimates of that time: 6.9 million tons of biosolids generated, of which 60% were beneficially used (land application, composting, and landfill cover). The report estimated that, by 2010, 70% of wastewater solids would be recycled to land. This prediction was not borne out; the likely percentage was probably closer to 55%.

## A National Biosolids Regulation, Quality, End Use, and Disposal Survey

In the mid-2000s, the U.S. EPA Office of Water funded *A National Biosolids Regulation, Quality, End Use, & Disposal Survey* (NEBRA, 2007), which used 2004 data from the Clean Watersheds Need Survey (CWNS) (the 2012 CWNS is the 16th survey produced since 1972, see, https://www.epa.gov/cwns/clean-watersheds-needs-survey-cwns-2012-report-and-data) and from state regulatory agencies to improve estimates of the mass of wastewater solids generated and managed in each state and for the country as a whole. The data for many states was based on annual reports to state agencies of actual solids production. But, for some states, no such tracking existed, and solids production continued to have to be estimated. In total, approximately 7,180,000 dry U.S. tons of wastewater solids were used or disposed in the U.S. in 2004.

Almost 10 years later, the 2007 report is becoming outdated, although the overall picture it paints is not dramatically different from what we estimate is happening today. A compilation of current (2011) biosolids generation and management in the New England states shows significant, but mostly not dramatic, changes in the rates of biosolids beneficial use in five of the six states. The one exception is Vermont, where biosolids beneficial use dropped from 70% in 2004 to 29% in 2011, with landfill disposal increasing to 69%. However, because VT is a small state, this dramatic change has negligible impact on national data.

## Other North American Biosolids Practice Surveys

Data for Canada are just as limited. A report from 2000 was quoted as estimating "approximately 388,700 dry [metric] tonnes of biosolids are produced every year. About 43% of these biosolids are applied to land, 47% are incinerated and 4% are sent to landfill, with the remainder used in land reclamation and other uses." (Apedaile, 2001)

Additional descriptions of biosolids management in North America and around the world are reported in the second "Global Atlas," produced in 2008 (Leblanc et al, Eds., 2008).

If resource recovery from biosolids is to advance, basic data collection is imperative. In addition, goals should be encouraged at the national level and in every state, similar to municipal solid waste (MSW) recycling goals, and tracking of progress toward these goals will be needed. This requires an ongoing requirement for current data. At a minimum, biosolids generation, use, and disposal data should be updated every few years.

## Routine Wastewater and Solids Surveys

U.S. EPA conducts the Clean Watershed Needs Survey (CWNS) every 4 years; the most recent report to Congress was in 2016 for data collected in 2012 (see, https://www.epa.gov/sites/production/files/2015-12/documents/cwns_2012_report_to_congress-508-opt.pdf). Wastewater treatment facilities are generally required to report data for this survey, but not all do, and some of the data is out-of-date. In addition, the CWNS is focused on identifying the funding needs for wastewater infrastructure, therefore it contains scant data on solids treatment, use, and disposal.

In the meantime, annual sewage sludge/biosolids reports required under Part 503 are now being gathered in electronic form. U.S. EPA has recently replaced filing written paper reports and implemented electronic reporting of Discharge Monitoring Reports (DMRs), Notices of Intent to discharge in compliance with a general permit and other specified program reports. Phase 1 of implementation began on December 21, 2016 (requiring electronic reporting of the above reports) with Phase 2 starting on December 21, 2020, which will require additional forms to be electronically submitted. More information can be found at the EPA NPDES eReporting website: https://www.epa.gov/compliance/npdes-ereporting.

### Current Online EPA Water, Wastewater & Biosolids Data for the U. S.

- Facility Registry System (FRS): http://www.epa.gov/enviro/html/fii/
- EPA Clean Watershed Needs Survey: http://water.epa.gov/scitech/datait/databases/cwns/index.cfm
- Enforcement & Compliance History (ECHO): http://www.epa-echo.gov/echo/
- Discharge Monitoring Report (DMR): http://cfpub.epa.gov/dmr/index.cfm

## Barriers to Biogas Survey

As noted, this 2012 survey of over 200 wastewater treatment utilities, conducted in 2011 by WE&RF and NYSERDA, focused on the barriers to biogas use (Willis et al., 2012). While biogas was the singular focus, most of these barriers are common to those faced by other energy recovery technologies. The survey found that the most important barrier to biogas use was economic, related to higher priority demands on limited capital resources or to perceptions that the economics do not justify the investment. A key component of the survey was the identification of strategies, developed during focus group meetings, to overcome identified barriers.

## Biogas Use Survey

As renewable energy sources and related technologies are evaluated, wastewater, biosolids, and biogas show promise as future energy sources that could reshape energy trends in the U.S. and beyond. To fully realize the benefits of these programs and of renewable energy on the whole, renewable energy technologies must be further developed and applied widely to provide clean, reliable, affordable energy on a much larger scale. To that end, the wastewater profession has been striving to promote greater use of biogas produced at municipal WRRFs as a renewable and sustainable energy source. Biogas project developers, engineering consultants, and others require accurate data on biogas production to conceptualize, design, and develop renewable energy and resource recovery projects. In June 2011, WEF identified an information gap and sought to fill that gap by assessing the current and potential utilization of biogas from WRRFs for energy production, by identifying opportunities to support expanded biogas utilization through WEF's core capabilities in areas such as technology evaluation/transfer and education and training. A diverse project team, comprised of nonprofit organizations, communications outlets, consulting engineers, and vendors was established to assist with this project. With the help of the Project Steering Committee and Advisory Team convened by WEF, the team defined what data would be collected in the initial data collection effort that culminated in the release of the 2013 report, entitled Biogas Production and Use at Water Resource Recovery Facilities in the United States. The report highlights existing anaerobic digestion systems at U.S. WRRFs, as well as current uses of, and potential future opportunities for, using biogas produced by these facilities. The Phase 1 report was considered a beginning to a longer ongoing data compilation process that would involve the collection of additional, more detailed data.

The portfolio of data is continuously being augmented. The data from Phase 1 and Phase 2 activities is currently available at biogasdata.org or resourcerecoverydata.org. In an effort to focus on gaps identified in the dataset after the completion of Phase 1, a focus on innovative approaches to the data collection was employed to ensure effectiveness and efficiency in moving forward. Robust processes and requirements management were applied to enable the continuation of the collaborative commitment to advancing knowledge regarding biogas from biosolids. Phase 2 data collection efforts concentrated on gathering data in “regional sprints” aimed at focusing on populating data gaps identified during the Phase 1 data analysis, review, and reflections. The sprint teams were assigned states in specific regions of the country (based on U.S. EPA regional designations). The regions 4 and 6 data have provided a fascinating snapshot of emerging trends that can be obtained from current and developing data collection efforts, and are highlighted in the 2014 Phase 2 report, entitled Biogas Utilization: A Regional Snapshot in Understanding Factors that Affect Water Resource Recovery Facilities.

WEF Volunteers from a broad range of perspectives and areas of expertise assisted in the collection of this data. The Phase 1 and Phase 2 efforts to collect and compile data on biogas production and use at water resource recovery facilities in the United States relied on the efforts of many people and organizations, many of whom made significant voluntary in-kind contributions of their time.

Data collected through the survey and data collection activities of resourcerecoverydata.org, which build on EPA data, show that wastewater solids from more than 1,200 U.S. WRRFs undergo anaerobic digestion and produce biogas. Almost all of this wastewater biogas production occurs at facilities that treat from 1 to hundreds of millions of gallons per day (mgd) of wastewater. (See, Section 4 on Energy Recovery for additional results of recent data collection.) There is clearly potential for considerably more biogas production from wastewater. These data collection activities supersede recent surveys performed by U.S. EPA’s Combined Heat & Power Partnership (CHPP) in 2007 and 2011. These surveys compiled initial data on the potential for biogas production at WRRFs in the U.S., but many working in the field of biosolids management expressed concerns with the data used.

## Co-digestion Survey Expands Data on HSW and Operational Impacts

As part of a co-digestion research program funded by WE&RF and NYSERDA, Hazen and Sawyer, Kennedy/Jenks Consultants, and Carollo Engineers have collaborated to develop a common survey to obtain information for three separate research projects related to co-digestion of high-strength wastes. These projects all are being performed as part of WE&RF’s “Energy” knowledge area. The common theme of the three projects is evaluating operational impacts of processing feedstocks such as postconsumer food waste, FOG and food processing residuals on WRRFs. Utilities in all stages of implementation of co-digestion programs were requested to take the survey and there were questions specific to planning, design, and operations for any project stage. A main goal of the survey was to identify the primary operational impacts that result from the receipt, pretreatment, digestion, residual handling and dewatering sidestream management of the various high strength materials (Van Horne, et al., 2016). The survey was conducted in two parts in which facilities with active co-digestion program and facilities considering co-digestion responded to questions regarding high-strength waste (HSW) source, receiving/pretreatment, digestion, and dewatering operations, biosolids management impacts, and odor control. Only WRRFs with active co-digestion programs participated in the second phase of the survey.


Figure 44: Survey Responses

To summarize the results of the survey, a series of case studies and guidance documents are being developed to provide utilities with strategies that can be used to overcome operational side effects associated with co-digestion of HSWs. A total of 10 case studies from the U.S. and Australia have been selected to provide more detailed investigations into the operational impacts of co-digestion and how these have been handled for various source materials. These case studies will also provide insight into the most effective actions taken by the various utilities to address the potential operational impacts from co-digestion. The case study locations were selected to demonstrate a variety of co-digestion feedstocks, a range of observed operational impacts and a variety of process conditions to provide information on a range of elements that will further the understanding of the true costs and benefits of co-digestion.

Representatives from nearly 50 facilities worldwide responded to Phase I and about 15 facilities (with active co-digestion programs) responded to Phase II of the survey. The survey results to date indicate:

- FOG and food waste are the most common types of co-digested HSW.
- Most facilities utilize mesophilic digestion treatment, and digester gas is most often used for heat and electricity generation.
- Most facilities monitor HSW loading on a volumetric basis.
- Reported VSr values were between 38% and 85%.
- Facilities that co-digest overwhelmingly see increases in biogas production from 15% to 200%.
- Only 21% of respondents have a backup plan if imported HSW becomes unavailable; 79% do not.
- The major operational burdens due to co-digestion center around receiving and digestion equipment. HSW characteristics, such as pH, solids content, and viscosity, vary widely making the material difficult to handle.
- Impacts to downstream processes and biosolids quality were minimal as the HSW is mixed with plant solids and digested.

# Enabling Resource Recovery: Data Support Needed

The recent biogas-focused surveys will be invaluable tools to support resource recovery in biosolids, but more is needed, and the wastewater and biosolids management professions should consider taking steps to ensure we have the data we need. Specific needs identified are described below.

| Barrier | Solutions |
|---|---|
| Inadequate Payback/Economics and/or Lack of Available Capital | ▪ Use better financial comparison metrics, such as net present value and operational savings, instead of relying solely on payback period.<br>▪ Increase biogas production by co-digestion, improved anaerobic digestion operations, and digestion pretreatment processes.<br>▪ Negotiate better contracts with power utilities and natural gas companies.<br>▪ Use triple-bottom-line evaluations that consider the value of environmental and social benefits in addition to economic factors. Consider benefits of renewable energy production and greenhouse gas emission reductions.<br>▪ Consider renewable energy credits (RECs) in financial analysis.<br>▪ Consider partnering with third-party that can fund the initial capital and ongoing O&M costs in a build-own-operate or similar model.<br>▪ Investigate alternative sources of funding, such as grants, low-interest loans, and state-supported financing.<br>▪ Track energy use and benchmark energy use against other WRRFs. Use energy as a performance metric and incentive for renewable energy development. |
| Complications with Outside Agents | ▪ Leverage existing relationships with regulators, power companies and natural gas utilities to discuss energy recovery projects.<br>▪ Educate regulators and the public on the benefits of energy recovery from biosolids.<br>▪ Promote and encourage the classification of biogas and biosolids as a renewable energy resource. |
| Plant Too Small | ▪ Increase biogas production by co-digestion or WAS pretreatment.<br>▪ Consolidate solids handling at a larger centralized facility. |
| O&M Complications and Concerns/ Technical Merits | ▪ Provide better training for operators on energy recovery technologies.<br>▪ Consider third-party maintenance service contracts.<br>▪ Visit successful sites to improve familiarity/acceptance. |
| Difficulties with Air Regulations or Obtaining Air Permit | ▪ Educate air permitting authorities on the benefits of CHP.<br>▪ Select technologies with low emissions. |
| Maintain Status Quo and Lack of Community/Utility Leadership Interest in Green Power | ▪ Involve potential blockers and engage internal stakeholders in the decision-making process.<br>▪ Involve a strong supporter or advocate (a champion) for energy recovery.<br>▪ Highlight risk of status quo to decision makers.<br>▪ Provide holistic education on energy recovery technologies. |

Table 19: Strategies to Overcome Barriers to Energy Recovery (adapted from Willis, et al., 2012)

## Maintaining and Expanding Current Databases

A critical next step is further discussions on how biogas data will be kept current and how it might be expanded to include additional biosolids management data for all WRRFs, including, perhaps, data from Canada. WEF has continued to support the biogas data collection efforts in collaboration with the American Biogas Council, and continuous collection efforts can be enhanced as additional features and data are collected to meet the needs of the industry. As the paradigm of resource recovery from biosolids takes hold, there will be additional metrics for which data will be needed on a regular basis, in order to keep the profession focused on resource recovery and to track its progress.

## Define Sustainability Metrics

Finally, it is important for the profession to consider how biosolids management can be an indicator of the level of sustainability of a particular community, state, region, or nation. Biosolids quality and how they are managed tells a lot about the impacts civilization is having on the environment.

Potential candidates for metrics that could be used as indicators for the sustainability of biosolids management could include the following (most of the following to be expressed as a ratio in relation to the total dry solids managed per year):

- The national biosolids recycling rate (calculated in the same ways as MSW recycling rates);
- The amount of energy generated (thermal, electrical, and kinetic combined into a common unit);
- Labor force statistics;
- The number of recognized quality management programs for biosolids (NBP EMS/BMP certifications, ISO 14001 certifications, etc.);
- The net income or expense of solids management (biosolids, biogas, electricity, and heat product revenues *minus* treatment and management costs); and
- The concentrations of sentinel, representative trace contaminants of concern (e.g. Hg, Pb, dioxins, PCBs, estrogen, PBDEs, PFCs, in representative biosolids, which represent the level of use and circulation of these contaminants in society and the environment.

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# Section 9

# Conclusion

Biosolids resource recovery affords an excellent opportunity to promote many of the topics at the forefront of the water industry. Providing solutions to sustainability and environmental issues offers an opportunity to promote innovation and improve the economic potential for utilities. Biosolids resource recovery can impact climate change, address nutrient issues in soils, generate energy, and more. Therefore, it is important to focus on driving education, policy, research, and quality of biosolids products to ensure this valuable resource is ideally being used.

Biosolids provide a variety of environmental benefits while simultaneously increasing their value and standing in the public eye. Not only are they an excellent chemical fertilizer alternative, but their use can improve soil health, water holding capacity, and help restore reclamation areas. Anaerobic digestion of biosolids produces biogas, potentially replacing the need for fossil fuels and thus helping to mitigate climate change. Continued research on other ways biosolids resource recovery can provide environmentally friendly benefits will help the public acknowledge them as a valuable and critical resource.

One of the most attractive characteristics of biosolids is their potential as net energy producers. As the energy needed for treatment is less than the energy biosolids can provide, positive net energy is a great strength in a world where energy concerns are a rising priority. Technologies for energy production vary from established (anaerobic digestion and incineration) to new and experimental (hydrothermal gasification and Supercritical Water Oxidation). WRRFs throughout the world are experimenting with variations of these technologies and others as they aim to be as energy efficient as possible. As the world moves towards more sustainable and environmentally friendly waste solutions, energy recovery from biosolids will increase in necessity, but it is not without improvement (of existing technologies, investment in innovation, and policy assistance) that it will compete with the fossil fuel industry.

Resource recovery can play an important role in improving economies by generating jobs and lowering utility costs on a local level. Biogas produced on-site can be used for heating facilities or generating electricity, lowering operational costs, generating savings, which can then be passed on to customers. Implementing a biosolids resource recovery program requires engineering, science, and additional facility maintenance jobs provided from the local economy. Furthermore, as land and space are becoming more valuable, removing biosolids from the waste stream helps free up space while generating an economic incentive.

The biosolids industry is greatly lacking or in need of updated data to fully realize the potential of resource recovery. Current data collection methods rely on state reporting, which can be lacking on non-specific estimates. Accurate and up-to-date data helps biosolids managers and policy makers understand the landscape of biosolids. Improvements in data collection are being made, such as the EPA switching from paper to electronic annual sewage sludge/biosolids reporting, but more consistent data will have a great impact on the industry.

The biosolids industry has begun to look for new sources of innovation as advancing biosolids resource recovery technologies can improve the recovery of valuable products, reduce nitrogen and phosphorus levels, and generate energy. As the market for biosolids products expands, researchers are aiming to increase efficiency, lower costs, and improve the quality of recovered products to keep biosolids resource recovery competitive in the marketplace. Improved technology and efficiency is good for the overall biosolids market and will lead to easier widespread adoption.

Biosolids provide potential to safely recover nutrients, reduce organic matter, and generate energy while lowering consumer costs, providing environmental benefits and promoting sustainability. As more opportunities for biosolids are identified, there is a need for innovation and effective education in the industry to ensure biosolids are well positioned. Biosolids resource recovery will be most effective by focusing on solving the current challenges and embracing the potential opportunities in the future.

# Appendix A - WE&RF Research 2014-Present

| Publication Year | Project Number and Project Title | Principal Investigator(s) | Contracting Organization(s) | Research Objectives |
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| 2014 | U1R10, Fate of Engineered Nanomaterials in Wastewater Biosolids, Land Application and Incineration | Paul Westerhoff, Ph.D. | Arizona State University | Develop tools to quantify and understand how engineered nanomaterials accumulate in biosolids, undergo biosolids treatment, and are disposed of and potentially accumulate in the environment. Include both model ENMs and ENMs in consumer products to improve our knowledge into their material life cycles, final disposition in the environment, and exposures to ENM by biota in rivers and soils. |
| 2014 | INFR1SG10, Wastewater Treatment Anaerobic Digester Foaming Prevention and Control Methods | Krishna Pagilla, Ph.D. | Illinois Institute of Technology | Investigate causes and identify effective prevention and / or control measures for anaerobic digester foaming. Implementation of longer SRT processes such as biological nutrient removal (BNR) and MBR (membrane bioreactor) processes may have increased the incidence of digester foaming. Digester foaming has caused significant reduction in performance, capacity, and/or operational difficulties in the liquid and solids processing trains. Anaerobic digestion is also the primary energy production method from organic matter in wastewater, and it is the key to the overall energy sustainability of WRRFs. |
| 2014 | OWSO10C10, Evaluation of Biogas Treatment for the Removal of Siloxanes | Nicolas de Arespacochaga | Suez Environnement | Researchers will assess commonly employed sampling and analytical methods for determining siloxane content in biogas, identify the impact of the analytical method on measured siloxane content and evaluate method sensitivity for measurement of low concentrations. They will develop practical guidelines for sampling and analysis of siloxanes in biogas and validate a protocol for sampling and analysis of siloxanes in biogas. |
| 2014 | OWSO5R07, Assessment of Operational and Performance Parameters for Co-Digestion | David Parry, Ph.D. P.E. | CDM | A practical procedure developed to assess the potential impacts of a particular organic waste as a co-digestion feedstock in anaerobic digestion. The project provides access to empirical data necessary to support digester design and |

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| | | | | operational stability parameters. Will result in an economic model to assess the viability of co-digestion. |
| 2015 | SRSK4T08, Wastewater Treatment Plant Design Operation and Modification to Improve Management of Biosolids Odors and Sudden Increases in Indicator Organisms | Matthew J. Higgins, Ph.D., P.E.<br><br>Sudhir Murthy, Ph.D., P.E. | Bucknell University<br><br>DC Water | Provide wastewater treatment personnel and their consultants with practical design and operational procedures that holistically address biosolids odors and sudden increases in indicator organisms. |
| 2016 | LIFT6T14, Genifuel Hydrothermal Processing Bench Scale Technology Evaluation | Philip Marrone, Ph.D. | Leidos | This test program will determine: 1) whether the Genifuel HTL-CHG process has the potential to work for a wastewater sludge feed from a technical perspective; and 2) whether the Genifuel process could be economically viable to implement at a WRRF (both with and without the presence of anaerobic digesters). This will be accomplished through several, limited proof-of-concept tests to be conducted at lab-scale on equipment located at Pacific Northwest National Laboratory (PNNL). |
| 2016 | NTRY1R12, Towards a Renewable Future: Assessing Resource Recovery as a Viable Treatment Alternative | Ron Latimer, P.E. | Hazen & Sawyer | While there is general consensus that resource recovery can benefit the wastewater industry, some technical, social, and economic challenges currently exist towards achieving broader industry-wide adoption. This project reviews the technical and economic benefits as well as challenges associated with extractive nutrient recovery to help water resource recovery facilities (WRRFs) considering nutrient recovery to produce additional value added products from wastewater. Project deliverables include a state of the science review of extractive nutrient recovery (both nitrogen and phosphorus technologies), an interactive matrix which serves as a reference guide for users to quickly learn about the basics of nutrient recovery technologies, case studies of 20 WRRFs, and TERRY (Tool for Evaluating Resource RecoverY) which allows users to perform a high level evaluation of implementing extractive nutrient recovery at their facility |
| 2017 | NTRY5R14, Producing Value-Added Bioplastic from Methane Gas Generated by Water Resource Recovery Facilities | Molly Morse, Ph.D. | Mango Materials | The objective of this project is to advance the practical implementation of bioplastics generation from methane gas at water resource recovery facilities. Using microbial processes, plastics can be produced from waste biogas (methane). For example, use of the biogas from a 10 MGD WRRF could |

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| | | | | produce around 2 million pounds of bioplastic per year. The bioplastic production process has numerous environmental benefits including use of greenhouse gas as feedstock, lower energy requirements compared to traditional feedstock, and production of a biobased, biocompatible, completely degradable product. The production of bioplastics at WRRFs would not only increase the amount of environmentally friendly, non-toxic polymer on the market, but would also provide a revenue stream for WRRFs creating great cost savings associated with the use of biogas for energy production. The project team will perform a feasibility analysis based on their findings. |
| Ongoing | NTRY11T15, High-Tech Analysis of Low-Tech Methods of Sustainable Class A Biosolids Production | Jennifer G. Becker, Ph.D. | Michigan Technological University | The goal of this project is to develop a rational and universal approach for the design of low cost, low tech Class A biosolids treatment processes, basically to address Alternative 6 of the Part 503 rule – "Processes to Further Reduce Pathogens". |
| Ongoing | NTRY7R15, High Quality Biosolids from Wastewater | Trudy Johnston | Material Matters, Inc. | The primary goal for this project is to significantly expand biosolids use nation-wide by helping define the standards and specifications needed for WRRFs to cost-effectively produce and more successfully market high quality, safe, and stable biosolids in areas across the country (and world), with identified benefits for both the generator (WRRFs) and the end user. |
| Ongoing | TOBI2R15, Developing Exposure and Toxicity Data for Priority Trace Organics in Biosolids | Drew McAvoy, Ph.D | McAvoy Consulting/University of Cincinnati | As follow-on to TOBI1T11-Gathering Unpublished Data for Compounds Detected in Biosolids, this research will specifically focus on developing the needed fate, exposure and toxicity data to derive human health benchmarks and ecotoxicity endpoints for PBDEs, Azithromycin, and Ciprofloxacin as these are identified among those considered as higher priority TNSSS chemicals in biosolids. |
| Ongoing | ENER13T14, Energy Recovery from Thermal Oxidation of Wastewater Solids: State of the Science Review | Jim Welp, P.E. | Black & Veatch | This research will examine the energy potential from the thermal oxidation of biosolids and other residuals by documenting the effectiveness of energy or heat recovery from up-to-date thermal oxidation units with combined heat and power (CHP). Researchers will determine the potential for renewable energy recovery from thermal oxidation of wastewater residuals at WRRFs practicing incineration nationwide and compare the triple bottom line (TBL) value of energy recovered from biosolids by thermal oxidation to the same units of energy obtained from coal. |

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| Ongoing | ENER12R13,<br>Co-Digestion of Organic Waste – Addressing Operational Side Effects | Ganesh Rajagopalan, Ph.D.<br><br>Matt Higgins, Ph.D | Kennedy/Jenks Consultants<br><br>Bucknell University | Team will determine if co-digestion side-effects can be predicted by analyzing a combination of fundamental parameters. Once these fundamental relationships are established, the team will develop systems modeling to predict the side-effects of co-waste addition such that the practice can be managed. The research focus is based on developing these relationships. |
| Ongoing | ENER9C13,<br>Co-Digestion of Organic Waste – Addressing Operational Side Effects | Rudy Kilian, P.E. | Carollo Engineers | The first phase focuses on analysis of available operations and maintenance data and identification of operations and maintenance issues at participating treatment facilities. The second phase focuses on sampling at select treatment facilities and bench-scale testing to identify variability in as-received supplemental organic waste characteristics. The second phase will use typical anaerobic treatability testing to provide additional data to better estimate the impacts of supplemental organic waste(s) on dewatered sludge production and final effluent nitrogen concentration. |
| Ongoing | ENER8R13,<br>Developing Solutions to Operational Side-effects Associated by Co-digestion of High Strength Organic Wastes | Matthew Van Horne, P.E. | Hazen and Sawyer | Part of a 3 study collaboration on operational side-effects of co-digestion, this team will evaluate survey responses from a set of utility partners practicing co-digestion to collect data on various aspects of the practice and the utility experience. In addition, the team will prepare several case studies and create an economic tool to aid co-digestion decision-making. |