Bioproducts

A Framework for Market Analysis

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Abstract

This paper provides an industrial context and a market framework for analyzing investments in the emerging industry that has been built on turning organic residuals into bioproducts. The paper's integrated whole-systems context includes the following four organic residual generators:

- wastewater treatment facilities – generating biosolids
- municipal solid waste collection, recycling, and disposal – generating green waste, food scraps, and compostable consumer discards
- agricultural companies – generating harvest residue, livestock manure, and food processing waste
- forestry (silvaculture) operations – generating woody material

The whole-systems perspective treats organic carbon compounds as being continuously recycled through new "organic value cycles" in a circular, rather than linear, economy. These value cycles start with renewable carbon, proceed through a series of processing steps, and ultimately generate one or more bioproducts. The new value cycles are emerging as a result of regulations that are making it either too costly, or illegal, to simply dispose of organic residuals in landfills or to burn them.

A portfolio of bioproducts contained within four broad end-use market categories form the titled centerpiece of this paper:

- <u>Soil Amendments</u> –mulch, compost, fertilizer, and biochar
- <u>Animal Feed</u> – for cattle, poultry, hogs, and fish
- <u>Energy</u> - fuel for use in transportation and heating, along with electricity
- <u>Chemicals and Materials</u> – a broad set of organic chemicals produced from renewable resources

A "market centric" approach is developed in this paper from each of the four facets of the emerging organics value cycle: feedstocks, technology, bioproducts, and capital. This market-based approach is an explicit framework for investors, technologists, and enterprise developers to analyze and make market-based, risk-managed investments to build and profit from this industry.

We conclude with a discussion of the integrated market assessments and analyses that must be undertaken in order to build profitable and environmentally sustainable bioproduct production facilities in local communities. All of these analyses will need research and information to be acquired from locally or privately funded market assessments. We end with a preliminary outline of bioproduct market development guidelines.

This paper is intended to be a cornerstone in the foundation upon which the bioproducts industry can develop with lower investment risk to local community, private enterprise, capital, resource, and social investors.

Introduction

A bioproducts industry, based on renewable carbon, is beginning to emerge alongside of a mature petrochemical industry that has been based on fossil fuels. The sources of renewable plant-based carbon compounds are produced in a matter of years or decades. This is in contrast to oil, coal, and natural gas, which are produced from organic matter over millions of years.[1]

One key renewable carbon source is organic waste. In this paper, we will use the term, "organic residuals", rather than organic waste. The authors are aware that the word "waste" is written into many legal statutes at the national, state, and local levels. However, as will be discussed, the trend is to transition away from the word "waste" to a more resource value-focused term.

There are six categories of organic residuals: biosolids from sewage sludge, food scraps, woody material, green material from yard and urban landscape trimmings, agricultural residue, and manure.

We call a mechanism or scheme to convert renewable plant-based carbon feedstocks to various bioproducts a "bioproduct technology" (sometimes abbreviated "technology"). A bioproduct technology for organic residuals thus proceeds in the following fashion:

feedstock(s) (organic residuals) → **process train** → **bioproduct(s)**

The term "process train" may be composed of multiple sub-processes that must take place in order to convert a given feedstock or set of feedstocks into one or more bioproducts. A bioproduct can also be a feedstock for another process.

We often refer to a single dominant process when describing a bioproduct technology. As we will see later on in our discussion, the three facets of a bioproduct technology (feedstock, process, and bioproduct) form a critical triumvirate for market analysis and decision-making. One can start with any one of these three facets and then determine combinations of the other two which will be both consistent and profitable.

An instance of a bioproduct technology is generally termed a "bioproduct facility", or simply a "facility", in this paper. A bioproduct facility *instantiates* one type of bioproduct technology.

Purpose

The purpose of this paper is to provide an industry framework for municipal wastewater treatment plants, municipal solid waste sanitation systems, agricultural facilities, and silviculture operations that need to process organic residuals into economically and environmentally beneficial bioproducts. The place of this framework in the decision-making process is to help potential facility owners and investors understand the technical, market, and enterprise landscape and make an informed decision about what bioproduct technology *category* they would like to investigate for processing organic residuals. Once that decision is made, the next step would be to take a deeper dive, through a consulting engagement

[1] For more on the carbon cycle, see http://en.wikipedia.org/wiki/Carboncycle

with appropriate engineers, facility developers, or industry experts and unpack more details about a particular category of interest.

However, we have another purpose in conceiving this paper. Not only do we endeavor to serve the organic residuals industry, but we intend to provide a conceptual framework for continuing to build the industry. We hope that industry visionaries, leaders, and investors can use our paper to develop their own local renewable carbon economy and to extend it to other communities as part of developing many individual, but highly integrated and sustainable local economies. We believe this is important, since we are in the early stages of developing a viable, renewable carbon industry that drives all facets of our economy. We feel that renewable carbon management is important for all communities and that this framework is but a first step. Because communities make up states, nations, and the planet, what each of us do in our local community has an influence on global health.

The renewable carbon industry is central to our entire economy, starting with general cultivation of food, fiber and timber. This has been true for previous centuries before and through the industrial revolution. However, these first bioproducts industries became eclipsed by machines and energy which not only took precedence over the living environment but changed and continue to change our climate, thus becoming "a defining environmental challenge of our time."[2]

As you will see in our framework, we identify multiple specific feedstocks, processes, and bioproducts. One significant discovery is that the currently lowest-valued bioproducts (in terms of dollars per ton) - the soil amendment bioproduct portfolio - may be the most essential for reversing global warming;[3] it will be the actual expansion of the bioproducts industry, and the further monetizing of our water and carbon resources which will be the ultimate arbiter of this preliminary observation.

This paper presents a bioproducts industry framework *map*. It will be in the further articulation and appropriate use of this map, with additional quantitative and qualitative tools, equipment, and counsel that will make this map useful to your organization. We anticipate collaborating with our readers on the further articulation and use of this framework to help build sustainable local communities through growing, local, vibrant bioproduct economies.

Context

Market and industry intelligence, for any industry, needs to have a framework or context for the quantitative and qualitative information that is contained in the research data and the record (or) chronicle of the industry and its developmental pathway. This paper provides a framework of much of the existing literature on the bioproducts industry for the audience of organic residual generators. This context allows members of this audience to think comprehensively about bioproduct technology opportunities. In particular, this paper considers the following key factors:

- **Organic Residual Generators** – We focus on four broad categories of organic residual generators:
    - Wastewater treatment plants, aka sewage agencies and facilities. The organic residuals arrive at the facility via sewer pipes.

[2] From "Background Paper, Joint Oversight Hearing of the Senate Environmental Quality Committee and the Select Committee on Climate Change and AB 32 Implementation. Bob Wieckowski, Chair, Fran Pavely, Chair, Wednesday, February 3, 2016.
[3] See www.thesoilstory.com, especially the 4 minute video on regenerating soil carbon.

- Municipal solid waste (MSW) and recycling systems, aka solid waste collection, sorting, and recycling. The organic residuals arrive at the facility via trucks.
- Agricultural facilities, aka the food and fiber industry. The organic residuals are typically managed onsite but are increasingly being trucked to offsite facilities.
- Silviculture operations, aka forest byproduct collection and processing facilities. The forest products industry and the national forest agencies both must manage woody material.

- **Comprehensive Approach** – This paper considers all categories of organic residual generators (above), the feedstocks that they generate, the processes, and the bioproduct spectrum of soil amendments, animal feed, energy, chemicals, and materials. We also consider capital markets and how they play a key role in the development of a bioproduct facility. Each local facility developer or owner will have to assess their unique situation, and we endeavor to provide a perspective that is inclusive of currently available bioproduct facility opportunities.
- **Quantitative Foundation** – The context presented by this paper is designed to provide a foundation for further quantitative research. In order to analyze any market, technology, or investment, the prospective owner of a bioproduct facility must be able to quantify feedstocks, processes, and bioproducts relevant to any business opportunity.
- **Multiple Resource Perspectives** – We understand that feedstocks are tightly linked to other critical resources, especially water and energy. This linkage can be described by the term "integrated utilities."[4] All feedstocks require water to be produced. For example, 95% of California's fresh water is used to grow vegetation in the environments of natural lands (50%), working lands (i.e. agriculture, 40%), and landscapes (5%). Only 5% of the water is used for non-growing purposes. Organic residuals are themselves a potential source of bioenergy, as we will discuss further in this paper.
- **Economic Levels** – We are constantly operating in three interdependent economic levels:
  - microeconomic - local level of economics, whether a for-profit company, a not-for-profit government agency, or non-government organization. These are the economics of business plans and local government budgets. Many bioproduct facilities operate at the local level.
  - mesoeconomic – regional level of economics. Bioproduct facilities may also operate at the regional level. Regional and local markets for feedstocks, process technologies, and bioproduct sales are key to developing and financing any bioproduct facility.
  - macroeconomic - national and international level of economics. We are living in a robust and highly interactive global economy. This is especially true for capital and energy. So while bioproducts are very much local, and the lower value bioproducts are very much based on local markets almost exclusively, other bioproducts, especially fertilizers, energy, and chemicals are capable of participating in national or international commodity markets.

[4] See "INTEGRATED UTILITIES: A Model for Creating Economies of Scope in Water, Organics and Bioenergy Value Cycles", by Dan Noble, Noble Resources Group, 2012. Download from www.linkedin.com/pub/dan-noble/1/a26/a69

We have endeavored to provide this context for the benefit of industry participants with a vision to research, strategize, invest, market, and grow a sustainable bioproducts industry. This comprehensive context can be viewed as the "brand" of this paper and the work of our company; our set of interlinked value activities.[5]

In addition, the focus of this paper will be primarily on the developing bioproducts industry in California. This is because California has put into place multiple regulations and economic assistance programs to specifically drive the development of organic residuals management. In addition, regulations are state specific and we have chosen California as our example, it being the largest agricultural state in U.S., and the eighth largest economy in the world.

An Industry Framework

As recycling of renewable resources surpass 50%, as it has in California, Austria, Germany and other EU countries, the concept of a renewable, or circular, economy is beginning to become a reality.[6] Simply put:

- Our current linear economy - extract, manufacture, consume, and dispose. Examples include both renewable (water, timber, agricultural products) and nonrenewable (minerals, oil, natural gas) resources. This is a depletion approach to resource management.
- The emergent circular economy - extract, manufacture, reduce, use, reuse, and/or recycle. Examples include renewable and recyclable resources (water, timber, agricultural products, aluminum cans). This is a reutilization approach to resource management.

The necessity of developing a global circular economy is now being popularized and funded through the work of the Ellen McArthur Foundation.[7] The reason this emerging method of analyzing markets is important is that a renewable carbon and nitrogen economy will create new dimensions that are not possible with a linear economy. This fundamental shift affects all aspects of bioproduct facility development, from technology decisions through local market development processes, to cost/benefit and investment analyses. While the impact of these developments is beyond the scope of this paper, the NRG team continues to analyze the evolving foundations of the circular economy in order to best support the readers of this paper.

The transition from a linear to circular economy is occurring by way of the following steps:

- **Increasing burden on linear and non-renewable industries** (emerging in the early 1970's): We are exhausting resources, while also increasing all forms of pollution (spent resources deposited in the environment) that cause degradation of air, water, land, and life.
- **Formation of an "environmental industry"** (emerging in late 1970's): Ever since the formation of the Environmental Protection Agency (EPA) there has been a push to improve and protect the environment.[8]

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[5] For a comprehensive discussion of "interlinked value activities" and how it can become an enterprise's sustainable strategy, competitive advantage and brand, see "What is Strategy?" by Michael Porter, 1996.

[6] Early references to the need for a circular economy can be found in the "Fundamentals of Ecology" text of Eugene Odum, University of Georgia, 1953.

[7] Ellen MacArthur Foundation, www.ellenmacarthurfoundation.org/circular-economy/

[8] To track the development and growth of the environmental industry, see "Environmental Business Journal", www.ebionline.org.

- **Formation of renewable and recycling industries** (emerging in late 1980's): Recognizing the limits to growth, efforts at recycling and renewing are increasing year-by-year.
- **Formation of the circular renewable economy** (emerging in the early 2000's): Recycling laws and programs, combined with sustainable resource policies, are driving the transition from a linear, non-renewable industrial economy to an integrated, circular renewable economy.
- **Formation of the bioproducts industry** (emerging in the early 2010's): one circular renewable resource is carbon, which is continuously recycled in the biosphere through the interdependent transformations of water, carbon, nitrogen, and phosphorous, all powered by sunlight.

It is critically important that local policymakers and investors understand the important choices they are faced with when building renewable manufacturing facilities and using bioproduct technologies vs. building non-renewable depletion facilities like fossil fuel refineries, coal-fired power plants, fossil natural gas powered vehicles, fossil fuel fertilizer production, etc.

Collaboration

Individual thought leaders, within both government and industry, work together in order to ensure that systems, markets, and economies of renewable carbon, water, and energy are at once integrated, dynamic, and evolving. This type of collaboration is not only required in the engineering and construction of large projects and programs (e.g. skyscrapers, aircraft carriers, spacecraft, and space programs), it is even more critical when developing a new, sustainable approach to the management of bioproduct resources.

This paper endeavors to not only describe the formation of the emerging bioproducts industry, but also to provide strategies and pathways for integration into whole systems perspectives, strategies, and tactical collaboration. However, even as we endeavor to do this, we also understand that cross-functional and organization collaboration, or collaborative leadership, is itself an emerging discipline.[9]

The Role of Healthy Soil

An underlying theme in this paper is our focus on bioproducts for healthy soil. This is based on our belief that healthy soil can provide an essential component in a global strategy to deal with the challenges of climate change and of our present limits to generate ample food supplies for our growing population. As we shall see, a number of bioproducts support healthy soil: mulch, digestate, compost, fertilizer, and biochar.

Though there has been much interest in biofuels and renewable chemicals, at present, the petrochemical fuel industry is extremely dominant in the political sphere and it will be some time before this changes. The low cost of oil and gas make it difficult for renewable forms of these products to be successful. It has been historically the case that renewable technologies for producing chemicals have taken an extremely long time to bring to market, very often up to 10 years or more. This is a high barrier to entry, especially against a well-established existing petrochemical alternative.

In contrast, the "lower value" bioproducts which support healthy soil face no petrochemical competition nor have they been difficult to bring to market.

[9] See more on "collaborative leadership" at https://en.wikipedia.org/wiki/Collaborative_leadership.

In the interest of presenting a full framework, we will list and consider the “higher value” bioproducts such as animal feed, fuel, heat, electricity, chemicals, and materials. However, it is our intention to ultimately focus on the healthy soil group in our business going forward.

Regulations

Regulations, for the past 40+ years, play an extremely critical role in the renewable resource industries of water, organics, and energy. This is true for a number of interdependent reasons:

- Resource extraction regulations for oil, timber, agricultural land use, etc., have evolved and developed through the Department of the Interior since 1849 and are increasingly applied to various land owners and lease holders of private and public lands.
- The US EPA (starting in the early 1970's under the Nixon Administration) has managed laws and regulations (outlined below) that were applied to industries and municipalities in order to control waste and pollution of air, water, and land.
- State and local laws and regulations have been added to supersede or supplement the Federal environmental protection regulations. These local laws and regulations include land use, zoning, traffic, and other dimensions of community life.

Taken together, these legal and regulatory forces at the federal, state, and local levels continue to drive the transition from a linear to a circular economy. Some manufacturing industries such as plastics have been proactive in recycling and reuse of their products due to regulations as well as competitive economics.

We can think of regulations as a kind of a train rail switching process that over the course of the past 40+ years has put the entire manufacturing sector of the economy onto a new track of using renewable resources to drive the economy. This is especially true in the energy sector, where renewable resources (manure, plant oils) are being substituted for nonrenewable resources (oil and natural gas). This is true in the materials sector, as well, where renewable resources (bioplastics) are being substituted for nonrenewable resources or fossil carbon sourced plastics.

The following aspects will further drive the circular economy to out-compete the old linear economy in the near future:

- **Profitability**: As disposal costs increase and as "resource depletion allowances"[10] are retired from the tax code (a current subsidy for the linear, non-renewable industries) and as virgin resource prices continue to rise, the circular economy will be increasingly driven by profitability rather than by regulations.
- **Innovation**: One key strategy for avoiding the cost of regulations is eliminate pollution and thereby avoid paying ever higher "pollution control" costs. The concept of "net zero" energy and "zero waste" are approaches to new facility construction and operations that are current driving innovation in those resource utilization sectors.[11]
- **Sustainability**: Creating sustainable commodity resource markets is central to the circular economy paradigm.

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[10] For resource and oil depletion allowances in the IRS Tax code, see: https://www.irs.gov/publications/p535/ch09.html. For a short discussion of these allowances, see: https://en.wikipedia.org/wiki/Oil_depletion_allowance

[11] For discussions of "net zero" energy see: https://www.wbdg.org/resources/netzeroenergybuildings.php and https://en.wikipedia.org/wiki/Zero-energy_building. For discussions of "zero waste" municipal sanitation approaches see: http://www.zerowaste.org/ and https://en.wikipedia.org/wiki/Zero_waste

How regulations actually drive the circular economy has not been understood as a straightforward path. Because the linear economic industries have developed over the past two to three centuries, the transition toward a circular economy will not be straightforward or instantaneous.

Federal Regulations and Resource Agencies

Since regulations are driving the environmental industry, and now the bioproducts industry, an outline of the major federal regulations can provide a foundation for understanding the state and local regulations which also drive the bioproducts industry, especially in California. A detailed description of state and local regulations is beyond the scope of this paper. It is nevertheless incumbent upon each bioproduct facility investor and customer to be clearly aware of the developing regulations up and down the legal spectrum, from federal to state to local.

US EPA

The US EPA, along with the state agencies (e.g. CalEPA in California), drives the development of the bioproducts industry in the following ways:

- **Emerging Global Warming Initiatives and Laws --** (mostly at the state level, e.g. AB 32 in California)**:** Arguably, the biggest driver of the emerging bioproducts industry is the concern over CO_2 buildups in the atmosphere from burning fossil fuels (the foundation of the current linear economy). However, laws regulating the burning of fossil fuels have not developed in a robust fashion at the Federal level. Rather, a divided Congress has given mixed messages over the past two decades on global warming initiatives. On the other hand, in California, starting in 2005, AB 32 has been driving the bioproducts industry; one example being through a recently formed Bioenergy Association of California.[12] Many states, including California, are also instituting "renewable fuel portfolio standards" for both stationary and mobile sources of energy generation. The newer biofuels have a lower impact on long term CO_2 production, since plants grown in the biosphere, from which biofuels are derived, reabsorb CO_2 from the atmosphere and turn it back into carbon compounds via photosynthesis. This carbon cycle is much shorter than the corresponding one for fossil-derived fuels.
- **Air** – Clean Air Act of 1970/1977, and Amendments of 1990: Closely related to CO_2 buildup, but preceding its regulatory attention by over 50 years, are the air pollutants (e.g. particulates, sulfur, and ozone-forming chemicals like volatile organic compounds). Air pollution laws push for increasingly cleaner burning fuels. It turns out that biofuels are also lower in some of these pollutants (e.g. low- to no sulfur and less particulates).
- **Wastewater** – Clean Water Act: Point discharges of waterborne pollutants to surface water and groundwater are regulated throughout the country. Wastewater treatment plants and industrial facilities are both considered point discharges.
- **Drinking water** – Safe Drinking Water Act: While this is an indirect driver of the bioproducts industry, it is a central piece of the water industry, especially relative to recycling water for potable reuse.
- **Stormwater** – Stormwater management under the Clean Water Act: Rain falling on buildings, streets, and yards has been a heavy pollutant of surface water for many years. For the past two decades, stormwater has been increasingly managed, and now this nonpoint source pollution is

[12] See www.bioenergyca.org

being merged with source water management. In California, for example, this effort is being run through a new program, initiated by the Department of Water Resources, called Integrated Regional Water Management Planning. The organic residuals industry is getting involved, since higher organic content soils are shown to conserve water (on average 30%) for water landing on soils used to grow plants..

- **Solid waste** – Resource Conservation and Recovery Act – Subtitle D
  - Municipal Solid Waste: Residential and commercial waste is picked up and hauled to either a landfill or a materials recovery facility (MRF). Organic residual waste constitutes about 1/3 of landfilled waste. This residual waste comprises an important feedstock for the bioproducts industry.
  - Industrial Food Waste: The industrial waste from food processing facilities is another significant feedstock for bioproducts development.
- **Hazardous waste** – Resource Conservation and Recovery Act – Subtitle C. Hazardous waste is not considered an organic residual and will not be covered in this paper.

Resource Agencies: DOE, BoR, USDA

Several federal and state agencies oversee the production and use of public resources. These include the Department of Energy (DOE), Bureau of Reclamation (BoR), and US Department of Agriculture (USDA). All of these agencies have a role in the development of the bioproducts industry.

- Energy (DOE) – The DOE has been promoting energy efficiency and renewable energy (EERE) through their Office of EERE. Bioenergy has been a particular focus.
- Water (BoR) – Many of the BoR water projects are related to either energy or agriculture. Water is a key resource for all bioproduct feedstocks but it can also be a product.
- Agricultural Waste (USDA) – All agriculture outputs could be bioproduct feedstocks, but harvest residues, food scraps, and manure are the main agricultural feedstocks for bioproduct production. Programs through the USDA can either support or suppress local market development.

State Laws and Regulations

The main regulations that actually drive the environmental industry, and in turn the bioproducts industry, are promulgated at the state and local level. We have already given some references to California's involvement in such regulations.

A detailed synopsis of state and local regulations is well beyond the scope of this paper. However, building a bioproduct facility requires a detailed understanding of the ongoing changes, limitations, and integration of all of the regulatory drivers at the local level. It is typical for each bioproduct facility developer to have either a staff member, team, or set of outside consultants each of whom are experienced in the applicable state and local regulations in order to guide the permitting, construction, and commissioning of the facility.

Industry Strategy

Non-renewable resource industries have notoriously fought environmental regulations, since they perceive these as limits to business development. This same behavior also threatens the renewable resource industry. When regulators don't understand the technology, operations or markets for the industry that they are regulating, they are vulnerable to attacks by antagonistic parties. To mitigate this problem, the bioproducts industry is taking the following approach: 1) use regulations as a driver for innovation and 2) collaborate with lawmakers and regulators to help drive regulations in a favorable direction.

Regulations, a Driver of Innovation

The first approach is to use regulation to help make the industry more efficient in achieving its goals. This can be done by inventing new ways to use inputs and outputs more effectively. One example of this strategy is described in the paper "Greenwaste Compost Site Emissions Reductions from Solar-powered Aeration and Biofilter Layer".[13] This example demonstrates a situation where, through air pollution regulations, VOC (volatile organic carbon) emissions from compost piles[14] could be reduced by using a new technology that reduces VOC by 98% over conventional mechanisms and at lower overall capital and operating costs of production.

Regulatory Collaboration

The second approach is to collaborate in the formation of new laws and regulations. This has been done with practically every environmental regulation. Typically, there have been environmental advocates that endorse a given statute and the resulting regulations. Across the table sits the affected industry who will live under the regulations, rules, and guidelines. These two groups are finding they often are now sitting on the same side of the table. These industries can be considered "environmental entrepreneurs".[15]

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[13] See http://www.valleyair.org/Grant_Programs/TAP/documents/C-15636-ACP/C-15636_ACP_FinalReport.pdf
[14] For VOC regulations on compost in California see http://www.arb.ca.gov/cc/compost/compost.htm
[15] Cf: Environmental Entrepreneurs https://www.e2.org/jsp/generic.jsp

Industrial Domains for Renewable Bioproducts

Bioproduct technologies that are designed to convert organic residual feedstocks into renewable products tend to fall within four major industrial domains:

- wastewater treatment facilities
- municipal solid waste collection, recycling, and disposal
- agricultural companies
- silvaculture operations

Wastewater treatment facilities are predominately public utilities (i.e. sewage agencies). Solid waste collection, recycling, and disposal operations are a mixture of public agencies (solid waste departments of cities and counties) and private companies (hauling and recycling companies that typically have franchise contracts with municipalities). Agriculture is almost entirely a private business in the United States. Silvaculture operations, that grow and harvest timber, are a mix of government and private entities for timber land ownership (mostly government resources) and timber cutting, lumber and paper milling, and forest replanting (mostly private company operations).

These four enterprise types generate and manage the vast majority of organic residual feedstocks for current and future bioproduct facilities. We will discuss each of them in turn.

Prior to entering into the discussion of each of these organics residual generating sectors, it is important to point out that there is a highly developed infrastructure within each of these industries. The extent, age, type and depreciation of these infrastructure assets in each local market provide the actual foundation for all the market analyses discussed in this paper. These existing local infrastructures must be analyzed in terms of quantity, quality, and lifecycle capital. Maintenance costs of local infrastructures influence the base costs in each of the feedstocks, processes, and bioproduct markets that arise from each of their organic residual streams. Examples of these infrastructures include:

- wastewater – collection pipes and systems, wastewater treatment plants, receiving water
- municipal solid waste – collection trucks and systems, material recovery facilities, local or international markets for commodities
- agricultural companies – farm land acreage and value; crop type diversity and value; food, fiber, feed, fuel, horticulture market size and distance to market
- silvaculture operations – forest size, health, mills, forest product markets

The installed infrastructure for each of these organic residual sectors will set the foundation of the playing field upon which the emerging bioproducts industry will be built.

Wastewater Industry

Wastewater is produced in all municipal environments and is composed of all the water and constituents that go down the drain and toilet: bath and shower water, washer and sink water, and toilet water. It is toilet water that contains the bulk of the carbon in wastewater in the form of toilet paper and fecal matter. However, home with food scrap disposers also provide additional solids that go to the wastewater treatment plant with the sewerage. Each home, business, and industry is connected to sewer lines which are, in turn, connected to sewer mains. These then go to trunk lines and eventually end up at wastewater treatment plants (WWTP), also known as publically owned treatment works (POTW).

Wastewater Industry Overview

The wastewater, as it enters the WWTP, contains a mixture of all the sewage that is discharged upstream. A small plant (for a city of around 100,000 residents) will treat in the low millions of gallons of wastewater per day (MGD). A large city or district (e.g. New York City, the city of Los Angeles, or the LA County Sanitation District) treats between 400 and 500 MGD of wastewater. Large cities or districts produce and process for reuse or disposal approximately 500 million wet tons of biosolids per year.

There are just under 15,000 WWTPs, servicing 226 million people, in the U.S. alone. Since wastewater is produced in every city, the WWTPs are managed locally, either by the city sanitation department or by special agencies made up of multiple cities in a service area. The industry has its own education, research, and advocacy organization: the National Association of Clean Water Agencies (NACWA), whose website is www.nacwa.org. NACWA also has a professional organization that helps to coordinate policy, education, and certification of WWTP professionals: Water Environment Federation (WEF) (see www.wef.org).

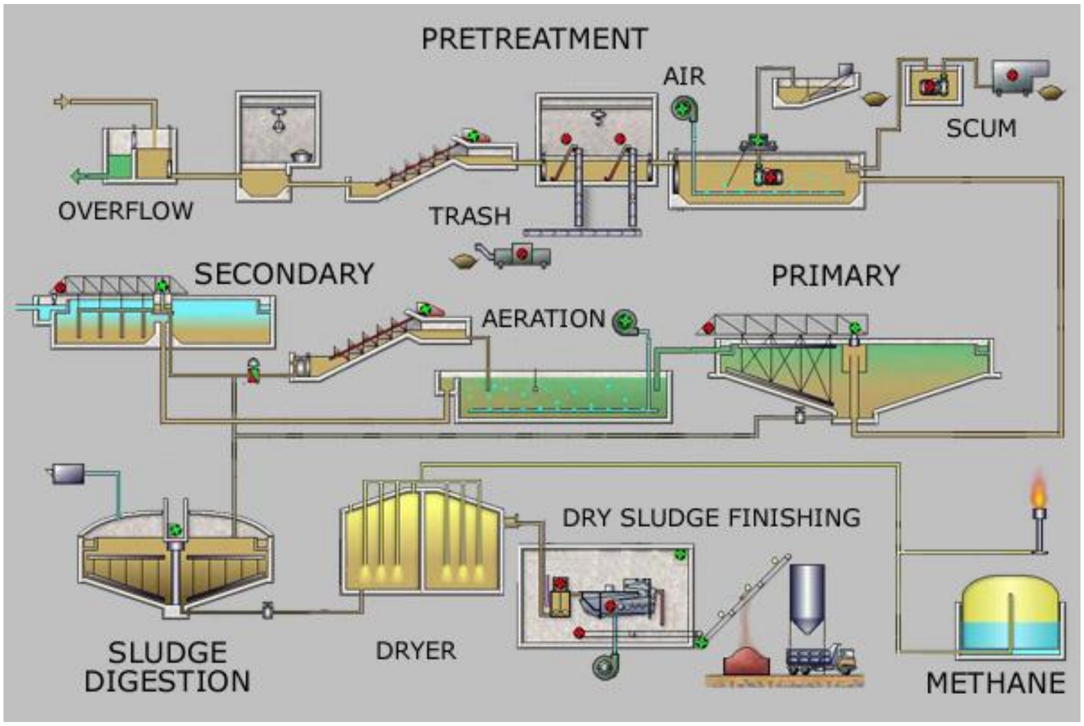
Each WWTP has its own management team, and each member is trained via a series of professional stages established through WEF. For Certification Courses, see www.wef.org/StudyGuides. For a discussion of typical treatment training process see "CSS04-14 -wastewater".

The majority of equipment and technology used in the WWTPs is produced by private companies. These firms have their own industry association, the Water and Wastewater Equipment Manufacturers Association (WWEMA) (see www.wwema.org), that has been in existence for a century; so, this is a mature industry.

The typical WWTP produces three products, or off-takes: water, nutrients, and energy:

- **Water**: Water is the main resource that is discharged from WWTP.
- **Nutrients**: The solids fraction of wastewater, sewage sludge, passes through the following treatment train –
    - Primary settling tanks -- The solids that are heavier than water (more dense) settle out. The settled fraction contains a high proportion of grit. The water on top contains a high amount of soluble nitrogen.
    - Aeration – The water from the primary tanks is then aerated. The dissolved nitrogen is metabolized by endogenous microorganisms which multiply and thereby increase the mass of the biosolids. This high solid mass is now the feedstock for anaerobic digestion.
    - Anaerobic digestion – The anaerobic digestion process reduces the carbon biomass by converting it to methane, which is either captured and flared, scrubbed and used as vehicle fuel, or used to run gas engines (reciprocating or gas turbines) to defray some of the power load for the WWTP. The other output of anaerobic digestion is called digestate, which can then be used directly as a soil amendment or further processed through composting.
    - **Energy**: Energy is produced by a WWTP only if the biosolids are treated by anaerobic digestion.

The Flow of a WWTP



Aerial View of a Wastewater Treatment Plant

Trends

The wastewater industry, and the corresponding biosolids generation, is entering its third phase of development. Sewage collection and disposal is as old as cities (e.g. the water system in Rome flowed through the public baths and toilets and the wastewater was conveyed in pipes and aqueducts into the local river or ocean). In industrial cities without sewage collection and disposal, smells and disease are rampant. The first stage of progress is simply to add sewage lines to improve sanitation, i.e. remove the sewage from homes and businesses.

Over the years, and especially with low available natural water in arid climates like the Pacific Southwest of the U.S., the strength of untreated sewage was destroying the aquatic environment by having too much biochemical oxygen demand (BOD) in those water bodies. BOD is the amount of dissolved oxygen required by aerobic organisms to break down organic material in a given water sample. High levels of BOD lead to an explosive growth of microorganisms that eventually deplete oxygen levels in the water. This results in eutrophication of lakes and ponds that receive the untreated sewage. The Clean Water Act, which included not only BOD but the hazardous chemicals that were also put down the sewers, was enacted to deal with this problem. The result was increased treatment, mainly oxygenating the sewage water, which further stimulated the growth of microorganisms. The resulting “activated sludge” contains both biosolids and clean water. This is the second phase of wastewater industry development.

The third phase of the wastewater treatment industry is occurring now. Rather than simply discharging non-potable clean water and producing biosolids (used as a partially treated or fully composted soil amendment), the industry over the past few decades has been engaging in the anaerobic digestion of the sewage sludge. This has two benefits: 1) it reduces the biomass of the biosolids and 2) it produces renewable natural gas (RNG) in the form of methane. The methane is then used to lower the energy costs of the WWTP. In this third phase of the industry, WWTP are starting to refer to themselves as “Resource Recovery Facilities”. The three main resources are water, energy, and nutrients from anaerobic digestion digestate.

Environmental Issues

The evolution of the wastewater industry has been driven by a combination of increasing population and increasing regulations. All of the resulting water, energy and nutrient products from wastewater treatment are affected:

- **Water** – National Pollution Discharge Elimination Systems (NPDES) control water discharge via the Clean Water Act at the Federal Level. Some states, such as California, supplement these regulations with their own set.
- **Energy** – Fuel, heat, and electricity produced at a wastewater treatment plant comprise three of the nine bioproducts outlined in this paper. The proportion of biosolids that are converted to these bioproducts will be based on the investment and markets determined during the WWTP bioproduct facility development process.
- **Nutrients** – Nutrients have transitioned through three phases at WWTPs :
    1. Prior to 1970s, they were simply dumped in rivers and oceans
    2. From the 1970s onward, biosolids were predominantly “land applied” and used as a low cost source of nitrogen fertilizer by farmers, for example: wheat crops in Eastern Washington, sod farms throughout California, or pasture lands in Colorado. [see “Biosolids Use and Disposal” chart on “CSS04-14 -wastewater”]

3. As the industry enters the third phase, the carbon and nitrogen compounds will be fully converted and recovered through anaerobic digestion and composting

Bioproduct Facility Needs

The need for a bioproduct facility at a given WWTP location is based on a set of interdependent factors. These include:

- WWTP Size – The volume that needs to be treated (millions of gallons/day (MGD)) will provide the scale of the capital investment required.
- Heterogeneity of BOD and Flow – The variability of dissolved oxygen and the flow throughout the year will determine the peak flow and the treatment technology requirements of the plant.
- Local Bioproduct Markets – The scale of markets for the main bioproducts (compost, fertilizer, fuel, heat, and electricity) will determine which bioproducts should be optimized.
- Capital Availability – The amount of capital that the WWTP owner has available will determine what technical solution is feasible.

Municipal Solid Waste and Recycling

The term "MSW" is used both for an industry segment and a solid waste material. MSW as a solid waste material, also called trash or garbage, is generated by everyone living in an industrial market economy. Solid waste is categorized in most municipalities into three distinct fractions:

- Recyclable non-biotic materials – plastic, glass, and metals
- Organic residuals – woody material, green material, and food scraps
- Landfill – mixed waste that is not recyclable, typically baby diapers, pet litter, and composite materials like coated juice containers, ceramics, or contaminated film plastics

MSW and Recycling Industry Overview

The MSW and recycling industry is composed of two main players:

- Agencies – municipal governments (cities, counties, and townships), sanitation or solid waste departments or divisions, special purpose districts, joint power authorities, or other public/municipal non-profit corporations. These government agencies serve the public by implementing solid waste collection and disposal programs. As recycling laws are enacted, either at the state or local level, these agencies represent the public in the development and implementation of the waste collection and the return of material for recycling and remanufacturing.
- Contractors – in many jurisdictions, private contractors compete for exclusive franchise contracts to pick up and recycle or dispose of waste. They are responsible for assuring that refuse containers exist, they own and operate the collection trucks, and they engage in the consolidation of existing waste hauling companies.

Trash collection has been a feature of urban life for over the past century. So the industry is mature. However, consolidation in the private sector has occurred extensively over the past 30 years so that the two largest companies in the U.S. are now Waste Management (www.wm.com) and Republic Services (www.republicservices.com).

Trends

The major trends in solid waste management are fairly intuitive, since all of us are "waste generators" from our homes and businesses, and, as waste generators, participate in the waste collection and disposal system on a daily and weekly basis. The major trends, especially in California, can be analyzed into the following four elements of recycling, zero waste, upstream management, and funding challenges:

- **Recycling** – Recycling has been developing in most municipalities for the past three or more decades. The groundbreaking California legislation that initiated statewide recycling, beginning with each municipality in the state, was AB 939.[16] More recently AB 341 has been implementing "Mandatory Commercial Recycling" throughout this leading state, and contains a 75% recycling goal by 2020.[17]
- **Zero waste** – As municipalities and states surpass 50% recycling goals and move forward towards 75% to the ultimate 100% recycling, or "zero waste", many corporate and municipal entities have adopted and are already starting to achieve "zero waste goals." Zero waste is a set of strategies where all waste is to be eliminated both upstream (i.e. prior to generation) and downstream. Upstream is referred to as "waste minimization", and downstream is where all discards or residuals are plugged back into the resource stream. This has the intended result of converting "take-make-waste" value chains from the linear economy in past centuries of industrial economic development, into a "reduce, reuse, recycle" value cycle based on local, emerging, and integrated resource circular economics.[18] The zero waste trend started at the beginning of the new millennium and is represented in the following two diagrams.

Linear Economy[19]

[16] For AB 939 see: http://www.calrecycle.ca.gov/laws/legislation/calhist/1985to1989.htm
[17] For AB 341 see: http://www.calrecycle.ca.gov/recycle/commercial/
[18] For more on the Zero Waste Movement, see the US Zero Waste Business Council's activities, at: www.uszwbc.org or the Zero Waste International Alliance, www.zwia.org
[19] The linear and circular economy diagrams are from www.Ecocycle.org.

Emerging Circular Economy

- **Upstream management** – The emergence of the zero waste movement is further driving the development of a completely closed loop circular economy which fulfills the original promise of the recycling "3 R's" of reduce, reuse and recycle. This includes the reduction of the volume and tonnage of waste generation in the first place via a combination of design and production practices, e.g. reduced mass in the products, design for recycling, reduced packaging, reusable shopping bags, etc. It also includes the further development of the reuse economy through the resale and donation of used items. Of course, it's technically only "upstream" relative to the linear economic resource model. In the emerging circular economic model, all aspects of renewable resource management come into play in the emergence of "value cycles" from the former "value chains." This is illustrated in the following diagram.
- **Funding challenges** – The solid waste industry has been funded primarily on a combination of waste collection and landfill tipping fees. For example, CalRecycle, California's waste and recycling oversight and regulating agency, has been funded in large part based on a tipping fee surcharge of $1.40 per ton of trash buried in landfills throughout the state. As recycling has increased, this state agency is experiencing flat or decreasing income. While the waste haulers and recyclers are still charging for their services based on collection fees, the landfills are suffering from continually declining revenues. Since these facilities must be managed in perpetuity, they are running the risk of becoming insolvent. This means that landfill owners

must find new sources of income to manage these stranded assets that are now becoming local community liabilities.[20]

Environmental Issues

The uncontrolled decomposition of organic waste in landfills produces both methane and CO2. Though atmospheric CO2 has the largest mass impact on climate change, its lifetime is about 100 years. Methane, on the other hand, has 84 times the impact of CO2 during the first two decades, yet it is relatively short-lived. According to the report entitled, "Short-Lived Primary Pollutant Reduction Strategy", issued by the California Air Resources Board (ARB), immediate cuts in short-lived air pollutants are absolutely necessary to keep average global surface temperature warming below 2 °C by the middle of this century. It is this 2 °C target which is also essential if we are to avoid very significant, if not catastrophic, climate change impacts to cities and local communities.

The Intergovernmental Panel on Climate Change estimates that in order to limit temperature increase to 2°C, the planet cannot emit more than 1000 Gt of CO2. This entire budget will be used up by 2040 in WEO's central scenario.[21] It is clear that urgent action is needed to prevent a potential global warming catastrophe.

Then again, there are a number of experts who are now saying that a 2°C target is too high and that we must be more aggressive about stopping the increase in average surface temperature. At the recent COP21 climate talks in Paris, there was a growing consensus that 1.5°C is the appropriate target rather than 2°C.[22]

More concerning, two Union of Concerned Scientists argue that the world is already on track for warming beyond 2°C. James Hansen, retired NASA climate scientist, has suggested that a 1°C target is actually necessary if we are to avoid climate catastrophe.[23] According to data from the UK Met Office and the Climate Research Unit, the global average temperature has already slightly surpassed 1°C above preindustrial levels (Tech Times, November 14, 2015).

The World Economic Forum in 2010 identified bioproduct technologies as one potential solution to the problem of climate change and the great demand for soil amendments, animal feed, energy, fuels, chemicals, and materials.[24]

Bioproduct Facility Needs

United States

In 2013, Americans generated about 254 million tons of trash and recycled or composted almost 87 million tons of this material, equivalent to a 34.3 percent recycling rate. This means that, on average,

[20] For more on this topic see CalRecycle's initiation of a process of developing a new funding strategy to sustainably meet its 75% Recycling Goal, outlined in AB 341. http://www.calrecycle.ca.gov/75Percent/FocusAreas/#MaterialsManagement
[21] See International Energy Agency, "World Energy Outlook 2014", http://www.worldenergyoutlook.org/weo2014/
[22] See http://www.theguardian.com/environment/2015/dec/07/paris-climate-talks-biggest-polluters-back-tougher-warming-target
[23] See http://news.nationalgeographic.com/news/energy/2014/02/1402277-global-warming-2-degree-target/
[24] See http://www3.weforum.org/docs/WEF_FutureIndustrialBiorefineries_Report_2010.pdf

Americans recycled or composted 1.51 pounds out of an individual waste generation rate of 4.40 pounds per person per day.[25]

The EPA is thinking beyond waste to sustainable materials management (SMM). In the 2015 report, the EPA explores the connection between personal consumer expenditures and the generation of waste. The transition is well under way, with the U.S. economy continuing to provide goods and services for household consumption more efficiently with respect to the MSW generated from consuming those goods and services. [26]

California

As the diversion of organic residuals away from landfills progresses,[27] a robust renewable carbon industry is emerging. The many new regulations requiring the recycling of organic residuals are the direct result of the negative impact of failing to recirculate carbon between its many sources and sinks. To implement the emerging organic recycling regulations requires a concerted management effort and investment, so as not to create excesses of CO_2, methane, other noxious gases, and water pollution.

In California alone, approximately 30-40 million tons of municipal solid waste are currently disposed of in landfills (depending on the economic rate of bioproduct purchase and disposal), even though it is estimated that 50% of all solid disposables are being recycled. Recently, California passed legislation (AB 341) that made commercial recycling programs mandatory for all 361 solid waste management jurisdictions throughout the state and set a 75% recycling goal by 2020.[28] Of the 20 million tons of waste that need to be recycled to meet this ambitious goal, about 1/3 (32% or 6.4 million tons) are organic residuals. This material is potentially available to be manufactured into a spectrum of bioproducts.

However, California has two systems for viewing how waste generation, disposal, and recycling are calculated; based on two separate recycling laws, one older, AB 939, and one newer, AB 341.[28] California generated about 87 million tons of solid waste in 2013. Of this, approximately 30.2 million tons were disposed of in landfills within California or exported out-of-state. With a population of about 38 million residents, California had a per capita diversion rate of 4.4 pounds per resident per day. This put California well below the statewide target of 6.3 pounds per person per day needed to meet the 50 percent diversion mandate.

In California, what counts as recycling has been redefined in AB 341, which states that only three broad classes of waste management fall under the 75 percent statewide recycling goal: source reduction, composting and recycling.[29] This information is required by law to be collected and reported by the local solid waste jurisdictions. AB 341 provides a new goal of 75% recycling by 2020. AB 341, along with follow-on regulations (especially AB 1826), will aggressively push the recycling of organic residuals, driving the development of bioproduct facilities in California for years to come.

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[25] http://www3.epa.gov/epawaste/nonhaz/municipal/

[26] See, http://www3.epa.gov/epawaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

[27] See, especially for California, a leading recycling state, the history of solid waste recycling laws show a steady progression away from disposal toward recycling, http://www.calrecycle.ca.gov/Laws/Legislation/CalHist/. Environmental advocates refer to the movement as one of moving toward "zero waste." See also the US Zero Waste Business Council, www.uszwbc.org, for more information about this movement.

[28] See "Calif 75% Recycling Goal - Plan May 2012", at http://www.calrecycle.ca.gov/75Percent/

[29] See "State of Recycling in California, March 2015" by CalRecycle, http://www.calrecycle.ca.gov/Publications/Documents/1522/20151522.pdf

It is important to note that these regulations emphasize compost as the principal outcome of organic residual processing. This is consistent with our intuition that soil amendments may in fact be the bioproducts with the highest net value in aggregate. (See the section on Products below).

To recap, California has three main sets of laws related to recycling:

- AB 939 - California Integrated Waste Management Act (IWMA) of 1989 (http://www.calrecycle.ca.gov/laws/legislation/calhist/1985to1989.htm) .
- AB 341 - Mandatory Commercial Recycling (http://www.calrecycle.ca.gov/recycle/commercial/)
- AB 1826 – Mandatory Commercial Organics Recycling (http://www.calrecycle.ca.gov/recycle/commercial/organics/FAQ.htm)

Technically, after trash is collected, the green material is taken to a compost or other bioproduct facility. The remainder is taken to a materials recovery facility to be further sorted into commodity type (plastic, glass, and metals). After the sorting step, the rest goes to a landfill.

Material Recovery Facility (MRF)

Sorted and Bailed Recyclable Commodities

Bioproduct Technology Needs in California

According to a recent report published in California, there are a total of 400 active organics materials management facilities in California.

Table 1: Active Organics Materials Management Facilities in California[30]

Facility Type	Active Facilities	Total Capacity (Tons/Year)	Current Throughput (Tons/Year)	Available Capacity (Tons/Year)
Anaerobic Digestion	13	467,000	187,000	281,000
Biomass Conversion*	32	5,300,000	5,300,000	56,000
Composting	169	8,000,000	6,200,000	1,800,000
Composting –Research Operation	14	93,000	92,000	1,000
Chip and Grind	156	11,200,000	7,300,000	4,000,000
Other Organics Management	23	790,000	740,000	50,000
Totals:	**407**	**25,850,000**	**19,819,000**	**6,188,000**

* "Biomass Conversion" is the process of producing energy by burning woody materials.

[30] Page 22: "State of Recycling in California, March 2015" by CalRecycle, http://www.calrecycle.ca.gov/Publications/Documents/1522/20151522.pdf

However, according to the analysis in the “State of Recycling in California, March 2015”, in order for the state to meet its 75% recycling goal by 2020, it will need to build on the order of 50-100 new bioproduct facilities (depending on throughput). The type of facility that needs to be built is currently being left to the local community waste management systems. It is this capacity expansion that will primarily drive the development of new composting facilities in California. It is noteworthy from Table 1 that chip and grind has the largest available capacity of bioproduct technology in California, followed by composting as a close second. It is also particularly interesting that composting dominates anaerobic digestion and biomass conversion (the process of converting biomass to energy) as the process technology of choice.

Agriculture

Agriculture and related industries contributed $789 billion to the U.S. gross domestic product (GDP) in 2013, a 4.7 percent share. The output of America's farms contributed $166.9 billion of this sum—about 1 percent of GDP.[31] By comparison, American’s healthcare expenditures in the United States are currently about 18 percent of GDP.

As shown in the “Biomass Estimates” section of this paper (see Table 2), agriculture is responsible for 81% of the organic residual biomass, while 19% is from urban activities. Therefore, even though farms represent a declining percent of the US GDP, they nevertheless provide the largest source of residual organics by a factor of over 4 times the urban biomass generation.

The large percentage of organic residual biomass produced by agriculture would suggest that process technologies such as anaerobic digestion and composting are most likely the predominant ones for this industry sector.

Agriculture Overview

The agricultural industry has evolved greatly over the past century from a population of 29 million working small family farms, representing 38% of the labor force in the United States, to 2.1 million farm workers in 2012, representing only 3% of the labor force. The amount of land in farms in the United States declined from 922 million acres to 915 million acres.[32]

The three agricultural organic residual streams, or feedstocks, come from food processing waste and scraps, agricultural residue and livestock manure. Plant-based agricultural residue is often used as an animal feed additive. For example, corn silage is a common cattle feed supplement. Manure has historically been used as an organic fertilizer. But more recently its energy value has been extracted and converted to methane (natural gas) through anaerobic digestion. The remaining biomass (digestate) from anaerobic digestion contains the nitrogen compounds, which make for an even more concentrated fertilizer. These agricultural organic residuals are discussed in further detail in the feedstock section of this paper.

[31] http://www.ers.usda.gov/data-products/chart-gallery/detail.aspx?chartId=40037
[32] http://www.agcensus.usda.gov/Publications/2012/Preliminary_Report/Highlights.pdf

Corn **Soy Bean**

The agricultural industry has the following general structure:

- Input Producers – fertilizer, seed, pesticide, and herbicide producers
- Growers – or "farmers"
- Processors – clean, manufacture, package, or can the finished food or fiber products for market
- Marketers/Branders – sell the processed and packaged food products to the grocery stores, and develop, advertise, and merchandise their brand to consumers (e.g. Dole, Del Monte, General Mills, etc.)

Trends

While consolidation has been the dominant trend in agriculture for the past century, there has been a persistent movement in the opposite direction, albeit, not as dramatic. This movement is not generating investment returns so much as adding new value to communities and environments. This alternative movement can be outlined by several interrelated transformations:

- Organic Certification – The organic movement started growing in the 1950's, pioneered by Rhodale Press, and many others. The National Organics Program (NOP) has developed in the past 20 years as part of the USDA. Organic produce markets continue to grow due to concerns about the effect of pesticides and herbicides on the environment and farm worker and consumer health.[33]
- Local Food – In the past 20 years, the emergence of the local organic food movement has been pioneered by small farmers, chefs, and food writers, like Alice Waters, Michael Pollen, and thousands of small "slow food" farmers across the U.S.[34,35,36] Through their efforts to market and popularize local and organic food, shown to be more flavorful, nutritious, and healthful, local farmers' markets are now becoming popular. A number of local and national grocery stores (e.g. Whole Foods, Inc.) are supporting the local food movement.[37]

[33] http://www.ams.usda.gov/about-ams/programs-offices/national-organic-program
[34] http://www.slowfoodusa.org/
[35] http://www.biography.com/people/alice-waters-21359967
[36] http://michaelpollan.com/
[37] http://www.wholefoodsmarket.com/

Local Farmers in Farmers Market Space

- Urban Farming Movements – In addition to the local food movement, there is also a fledgling urban farm movement that is bringing food cultivation into cities in vacant lots, roof tops, and even indoors. Urban farming is as much a social movement as it is an agricultural movement.[38]

- Polyculture – part of smaller farm development is an innovative return to growing multiple cultivars and livestock in smaller, but diverse and integrated cultivation and feeding regimes. This is in contrast to corporate agriculture, which is mainly monoculture.

Two Examples of Urban Farms, (including various examples of polyculture)

- Sustainable – Healthy Soil Initiative – Coming full circle and driven by global warming mitigation concerns, there is an emerging "healthy soil initiative" that is local (e.g. the Governor's Healthy Soil Initiative in California) as well as global in any location that has desertification and food production issues (especially in the developing world). [39] It turns out that high organic content soil has two main benefits: 1) it infiltrates and holds more water, thereby conserving water, and 2) it sequesters carbon temporarily for annual crops, and more long term for perennial crops. In

[38] http://www.urbanfarming.org/

[39] See http://under2mou.org/ and https://www.cdfa.ca.gov/EnvironmentalStewardship/HealthySoils.html

fact, it has been demonstrated by Berkeley soil scientists, in collaboration with ranchers in nearby Marin County, that the addition of 1" of compost to rangeland pastures initiates a state change in the growth pattern of the perennial grasses, leading to a shift from soil carbon loss to multi-year soil carbon sequestration.[40] Again, It Is worthwhile noting the key role that compost plays in the agricultural sector.

The effect is that these interrelated farming trends change the narrative around food production, diet, and food enjoyment. This means that there is an ever-heightening awareness that everyone is part of a larger food web. The web is tied to critical resource stewardship of water, carbon, nitrogen and energy, thereby laying the groundwork for local business policies.

Environmental Issues

The agricultural industry has been largely overlooked by regulatory agencies. The regulatory establishment paid more attention to the technical nutrient industries like mining, manufacturing, oil refining, etc. However, that is changing. The agricultural industry has had serious impacts on air, water, and land for many decades, and the regulators of these media, as well as the pesticide, fertilizer, organic, and food safety concerns, are putting increased environmental regulations on farmers. This can be seen in the microcosm of California agriculture by listing a few examples that are affecting our food, fiber, feed, and animal production. A few of the current trends include:

- Air (diesel and dust): dust from farming operations as well as diesel emissions are being increasingly regulated, especially in sensitive airsheds like the San Joaquin Valley in California, one of the largest and most diverse farming regions in the US.
- Water (fertilizer and soil loss): fertilizer (both carbon and nitrogen loss) has contributed to water pollution in most rivers and lakes in the world, as well as the "dead zone" in the Gulf of Mexico at the outflow of the Mississippi River. Fertilizer loss goes along with soil loss, which contributes to nitrogen and phosphorous pollution.
- Solids (manure): Manure needs to be carefully managed due to its extensive production. Manure contributes heavily to surface and groundwater pollution.
- Pesticide and herbicide: These compounds have been implicated in many health and environmental problems.
- Food safety: Contamination of crops by weeds and wild animals is an issue.

A new movement in the US under the offices of the USDA and the National Resource Conservation Service is the development of a "healthy soil" initiative.[41] This was spurred forward in 2015, which was designated as "The International Year of Soils" by the Food and Agricultural Organization of the United Nations (FAO).[42] It is the intent of the healthy soil initiative to address all the agricultural environmental issues identified above including carbon sequestration. Remember that it is the explicit intent of this paper to emphasize the vital need of healthy soil to our environment as well as to point out the bioproduct portfolio which best contributes to healthy soil.

[40] http://www.marincarbonproject.org/
[41] https://www.cdfa.ca.gov/EnvironmentalStewardship/HealthySoils.html
[42] http://www.fao.org/soils-2015/en/

Bioproduct Facility Needs

Farmers continue to endeavor to remain viable, without succumbing to the many pressures that make farming a marginal business. These pressures include:

- Rising land prices – which make it increasingly difficult to pay farm mortgages
- Regulatory pressures – which control farm runoff, water pollution, and air pollution from farming in concentrated areas
- Price squeeze – between input costs and price pressures from processors

Given the price and regulatory pressures, a farmer must become creative in order stay viable as an enterprise. For this reason, extracting additional value, while at the same time manufacturing worthwhile agricultural products for local markets, can both mitigate potential pollution while at the same time provide extra income. Currently, farmers are capable of producing multiple products from their organic residuals.

Farmers, whether corporate monoculture, organic polyculture, or urban will all be managing their soil, water, and organic residuals much more intensively than at any time in history. Hence, the bioproduct technology industry will continue to grow right along with the crops and livestock.

Manure Anaerobic Digester

Truck Mounted Gasification System

Silviculture

Silviculture is the practice of controlling the establishment, growth, composition, health, and quality of forests to meet diverse needs and values.[43] The forest products industry then converts silvicultured forests into usable products, and in the process generates a significant quantity of organics residuals. Therefore, while "silviculture" is about growing and maintaining forests for multiple benefits (forest products, wildlife, watershed management, etc.), there are still millions of tons of forest byproducts, or woody material. This high lignocellulosic material can be used either for energy or remanufactured into many other bioproducts.

[43] See https://en.wikipedia.org/wiki/Silviculture

Silviculture Overview

The forest products industry has its roots in the civilization itself. This paper highlights that in California, forested lands account for 33 million acres, or one third of California's 101 million acres.[44] The original method of forestry still practiced in many parts of the globe today, has been more similar to mining than silviculture. Silviculture has implemented management methods that are more akin to using the regenerative capabilities of forests. The intent is to use "sustained yield" practices that work with the natural forest processes rather than simply clearcutting and repurposing the land. (For more, see the silviculture reference).

Milling lumber was an ordinary part of most farms and towns during California's early history. When California became a state, "mill towns" sprung up near many of the forests in the state. As part of these operations, massive quantities of forest byproducts have been produced. These include:

- Forest slash – these are the woody materials that are left behind after a logging operation, mainly branches, small trees that can't be milled, and other broken woody materials
- Milling waste – bark, un-milled lumber scrap, and sawdust

As seen in the Feedstocks section of this paper, woody material represents a large volume of cellulosic materials (~20 million tons per year nationwide, with about 2 million in California). This value will be increasing as will be seen in our discussion of trends.

Trends

As of this writing, lumber prices are returning to the long time high of ~$400 per mbf (1000 board feet) of a decade ago. This will influence the profitability of timber companies, as well as the rate at which timber is harvested. As one would expect, the trees that are harvested for lumber track the rate of the building industry. Alternatively, lumber that is converted to pulp for paper manufacturing has been relatively flat for the past two years at $875 per metric ton.[45] These commodity prices set a relative price for cellulose used in these two dominant markets.

The forest byproducts are usually sold for much less than forestry commodity product prices. Typically, woody materials are left in the forest, since it is not economic to bring them out unless energy production from these materials is cost-effective. For example, one energy company in California operates seven facilities that produce 191 megawatts of "renewable electricity."[46] While prices for woody material biomass fluctuate along with other forest product cellulose products, the prices for woody material feedstocks are in the $20/bone dry ton range.[47] Yet, as discussed in this reference, the main cost of this material to the energy producer is in the transportation of the material from the forest to the biomass energy facility.

[44] http://ucanr.edu/sites/forestry/California_forests/
[45] http://www.indexmundi.com/commodities/
[46] http://www.covanta.com/facilities/other-renewable-energy.aspx
[47] From: Biomass power plant feedstock procurement: Modeling transportation cost zones and the potential for competition

Forest residues are fed into a grinder at a centralized site and then loaded into a container for transport to the power plant. In Humboldt County, power plants use approximately 472,500 bone dry tons of biomass per year to generate electricity *(from the aforementioned reference)*

In the past, much of the forest byproducts did not have sufficient economic value to grind and remove from the woodlands, hence the "slash and burn" techniques that were used throughout Europe for centuries, and still in many parts of the world.[48] However, these practices were never extensive in California, due to the ongoing fire danger in many of the state's forest lands. From about 1990 to 1993, California's biomass power generation was at its highest (more than 800 MW of installed capacity). In 1996, the energy production from biomass dwindled to about 590 MW. The expiration of price support to the biomass industry from the government is the main reason for the reduction in biomass power generation in California. Currently, there are about 30 direct-combustion biomass facilities in operation with a capacity of 640 MW. This is less than half of the facilities in operation (66) during the industries' peak.[49]

Most recently however, extreme drought conditions have led to a massive die off of trees in California, and this will greatly affect the entire cellulosic biomass markets for years to come. It has been referred to as a "crisis" by not only the forest industry, but also by the bioenergy, compost, and mulch industries.

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48 https://en.wikipedia.org/wiki/Slash-and-burn
49 http://www.energy.ca.gov/biomass/biomass.html

A large patch of dead trees is seen in the Sierra Nevada from a helicopter tour in December 2015. The ponderosa and sugar pine trees are dying off in large numbers around Bass Lake and throughout the Sierra Nevada due to a bark beetle infestation brought on by four years of extreme drought in California.[50]

The California Department of Forestry and Fire Protection (CalFire) is reporting that, according to their research and estimates, there are "29 million dead or dying trees in the Sierra last year [alone]."[51] This result is a combination of not only the drought, but also fire suppression management practices that has left millions of the dead trees standing, and available to further fuel California's many wild fires.[52]

Environmental Issues

There are multiple environmental issues in forest land management. These apply to all forested lands, publicly or privately owned. However, consistent with the focus of this paper, we will cover four of the salient issues affecting California markets:

- Monoculture vs. forest diversity – A long term trend within silviculture practice, driven by a needed response to climate change, is to manage *both* forest cellulose production *and* forest biodiversity.[53] This requires implementing new methods of logging and replanting management, to be consistent with multiple uses of the forest biome. The forest biome includes grazing lands, as well as wildlife (aquatic, avian and terrestrial) and snowpack/water. Especially during extreme drought conditions, these practices will emphasize water resource (forest watershed) management techniques that optimize the multiple use or whole system management practices that continue to evolve and develop on BLM, US Forest, and private forest lands. See USDA Strategic Goal 2, which states, "Ensure Our National Forests and Private Working Lands Are

[50] From http://www.fresnobee.com/news/local/article58894963.html
[51] http://www.fresnobee.com/news/state/california/article59100343.html
[52] http://news.nationalgeographic.com/news/2015/01/150119-california-forests-shrinking-climate-drought-science/
[53] http://www.profor.info/Documents/pdf/Spears%20-%20Final%20Document.pdf

Conserved, Restored, and Made More Resilient to Climate Change, While Enhancing Our Water Resources."[54]

- Wildfire issues and black carbon (SLCP) – Recent studies in California looking at the particulate matter (PM) in the atmosphere and its effect on global warming,[55] have shown that black carbon (BC: i.e. soot that is put into the atmosphere from combustion of carbon compounds) has been lowered significantly on diesel engines (by over 90% since 1960). However, the recent fires throughout California have been producing large quantities of BC, to the point that BC from fires are now included in one of the "5 pillars" of Greenhouse Gas Reduction Strategy in California[56] as one of the important short-lived climate pollutant (SLCP) within California's SLCP Reduction Strategy.[57] The current goal is to manage fires by culling the forests of their dead wood and by using the cellulose to produce bioenergy.[58]
- Biomass energy decreasing – The biomass fuel to energy (the burning of woody material to produce energy) has been trending downward in recent years (as stated above in this section). This is presenting both an economic and an environmental challenge. These biomass to energy plants that are closing are not able to reopen, since they are not currently economically competitive with energy prices produced using fossil fuel-based energy sources. This also presents an economic challenge to both farmers and mulch and compost producers who provide this material, formerly at a good price, to the local biomass energy company. This, in turn, presents an environmental problem, since the unburned woody material is typically either burned in open burning piles, or sent to landfills. The open burning, certainly contributes to black carbon, the same as wildfires. If sent to landfills, the woody material contributes to increased methane, a powerful greenhouse gas. In some cases, the excess woody material is chipped and ground, then "land applied" without being composted, and subsequently applied as green mulch to open fields. While it increases the carbon of the soil, any anaerobic decomposition of it in the stockpiles or fields will contribute to methane pollution, as with the landfill. However, most of it will be oxidized slowly, and return to the atmosphere as CO_2.
- Watershed integrity and management – Clear cut logging and fires both disrupt the biological and ecological integrity of the forest watershed. In the case of logging operations, this can be mitigated by using the green material (branches, leaves or needles, aka slash) left behind to protect the exposed soil. Typically, seedling trees are planted in the slash between the branches and small logs left behind. In the case of fire ravaged lands, compost has been shown to be an effective method to restore the lands more quickly than simply leaving them to erode, naturally reseed, and/or return to forest succession.[59]

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54 http://www.usda.gov/documents/usda-fy14-agency-financial-report.pdf
55 http://www.arb.ca.gov/research/rsc/3-8-13/item8dfr08-323.pdf
56 http://www.arb.ca.gov/cc/pillars/pillars.htm
57 http://www.arb.ca.gov/cc/shortlived/shortlived.htm
58 See "Resolution E-4770. Commission Motion Authorizing Procurement from Forest Fuelstock Bioenergy Facilities supplied from High Hazard Zones for wildfires and falling trees pursuant to the Governor's Emergency Proclamation" http://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Transparency/Commission_Meetings/Presentations/2016/Revised%20PowerPoint%20for%20the%203-17-16%20Commission%20Meeting%20[Read-Only].pdf
59 https://www.researchgate.net/publication/228779447_Restoring_fire_ravaged_land_in_California_with_biosolids

Bioproduct Facility Needs

As this paper states, the bioproducts industry is the centerpiece of developing a renewable carbon industry. The silviculture industry is a centerpiece of renewable carbon management. Each tree represents either tons of cellulose for potential paper pulp or board feet of lumber. The tons of remaining woody forest byproducts are potentially available as a feedstock for the bioproducts industry. Depending on the local market proximity to facilities that use woody material as a feedstock, several bioproducts could be produced:

- Mulch – Manufactured using chip and grind technology, the primary bioproduct produced from woody organic residuals is woody mulch. This product is used either directly to protect soil from erosion or to conserve water for agriculture or landscape.
- Compost – Woody mulch is used as a bulking agent for compost production. Typically, woodchips, a high carbon, low nitrogen feedstock is best combined with a higher nitrogen containing material, such as food scraps, manure or biosolids.
- Biochar – This material is manufactured from any high lignocellulosic matter. Chipped and ground woody material is the main feedstock for producing biochar via low or no oxygen combustion (called thermochemical conversion)
- Building materials – Wood chips have been used as a building material for decades as particle board and chip board. Newer materials, developed at the Forest Products Laboratory at the University of Wisconsin,[60] use no chemical adhesives, and produce recycled products that are much stronger and lighter than current woody material products; these are fully recyclable into new materials.
- Energy – As discussed above, combustion through heat boilers and power steam turbines to produce power is a decades-old technology which will likely continue into the future until disrupted by more innovative and efficient technologies for producing usable energy from woody material.

[60] See http://www.fpl.fs.fed.us/ for the work on developing new products and processes from forest byproducts

Feedstocks

All of the organic residual feedstocks, sometimes referred to as "bioresources", have a long history and have been produced for as long as humans have engaged in agriculture. The reasons these feedstocks are becoming so important now is due to the parallel rise in population and the decreasing ability of natural sinks to absorb the feedstocks and convert them back into ecosystem nutrients.

Organic residual feedstocks for bioproduct technologies can be used to:

1. begin replacing the fossil fuels
2. return the organic compounds (mainly carbohydrates, oils, and amino acids) back into the organic value cycle

The six categories of organic residual feedstock are derived from four bioresource industries or functions of modern economy outlined above:

- Wastewater – biosolids (containing carbon and nitrogen from toilet contents and food scraps)
- MSW – woody material, green material, food scraps
- Agriculture – manure, food scraps, woody material, green material, agricultural residue
- Silviculture – woody material

MSW can be either source separated, typically into recyclables, green material, woody material, food scraps, and nonorganic waste. While some bioproduct technologies can use mixed feedstocks of all these wastes, it is typically not preferred. So for the purposes of this paper, we do not refer to MSW in total as a feedstock, but rather refer to the specific feedstock that is being converted into bioproducts once it is sorted out of the MSW stream of materials.

We discuss each feedstock in detail in this section. The generation, recycling and/or disposal of these materials is itself a "market" in the sense that feedstock generators either have to pay to dispose of these materials, called "tipping fee," or, in some cases can make some money selling them. This market, be it positive or negative, depends on a number of related factors, e.g. energy or water content, homogeneity or heterogeneity, e.g. woody material as a lower tipping fee, than biosolids and food scraps, depending, also on local bioproduct market conditions.

Biosolids

Approximately 7.1 million dry metric tons of biosolids are generated each year at approximately 16,500 municipal wastewater treatment facilities in the United States. California generated 723,000 dry metric tons of biosolids in 2013. Qualified biosolids can be beneficially used after a "stabilization" stage which kills pathogens and decomposes "vector attractive substances" (e.g. sugars, starches, fats, and oils) that can attract vermin. The benefit to farmers and rangeland managers is that stabilized biosolids provide an inexpensive (sometimes free) source of nitrogen and carbon fertilizer. Most of the stabilized biosolids are applied to agricultural sites, with minor amounts applied to forestry and reclamation sites (e.g. Superfund and Brownfield lands) and urban areas (e.g. park land).[61] About 54% of biosolids are beneficially used. The rest is currently being deposited in landfills.

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[61] US Wastewater - Center for Sustainable Systems, University of Michigan, Fact Sheet, Oct. 2014

Biosolids being spread on a field ("beneficially used")

Biosolids are currently used in three different ways: as an energy source, as a soil amendment, and as a biofertilizer:

- Energy – Anaerobic digestion reduces pathogens and produces energy in the form of methane
- Soil Amendments – Class B (stabilized, but not pathogen reduced) and Class A (stabilized and pathogen reduced) compost
- Biofertilizer – For example, see Milorganite (City of Milwaukee), and TAGRO (city of Tacoma) [62]

Food scraps

Food scraps are found in three of the feedstock generators: wastewater, municipal solid waste (MSW) and agriculture.

Up until now, MSW-generated food scraps have been a part of the waste stream, mixed with food wrappers and other discards. New programs, e.g. AB 1826 in California, are now *requiring* local municipalities to institute food scrap recycling programs. It is then up to the local communities to develop composting or other bioproduct facilities to handle this material.

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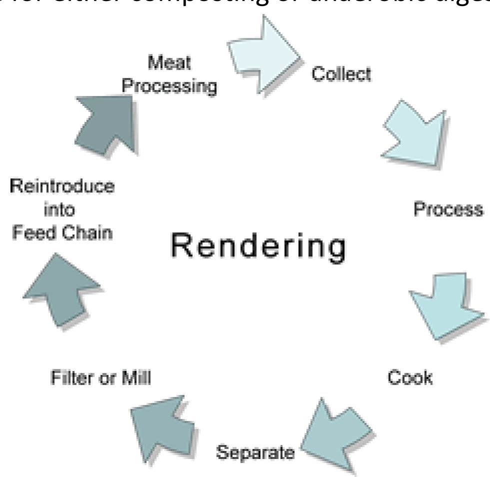
[62] www.milorganite.com, https://www.cityoftacoma.org/government/city_departments/environmentalservices/tagro/tagro_home_users

Food scraps contain much more protein (nitrogen compounds) and energy (from fats, oils, and grease) than any of the other organic residual feedstocks. Because food scraps contain a high amount of water (~80% by weight), they are very amenable to biological decomposition, either aerobically or anaerobically. Even if food scraps are co-mingled with green or woody material, it is still most cost effective to use such a mixture as a feedstock for anaerobic digestion.

Large quantities of food scraps are generated by retail and industrial food production:

- **Retail**
  - Restaurants – food scraps from restaurants come in three forms:
    - Vegetables and fruits – trimmings, spoiled, or blemished fruits and greens
    - Meat – trimmings, bones, and skin from beef, chicken, pork, and lamb
    - Fats, oils, and grease – generated daily from both deep fat fryers (yellow grease) and from grease traps (brown grease) in the plumbing system
  - Grocery Stores –culls from the produce section along with meat trimmings
- **Industrial**
  - Slaughterhouses – manage large quantities of animal waste. They are regulated not only under federal food safety laws (USDA Inspected) but also as a “point source discharger” into air, water, and soil. All slaughterhouses work closely with rendering plants and make as productive use of all the animal byproducts as possible. There is not a lot of residue that is available for either composting or anaerobic digestion.



  - Concentrated Animal Feeding Operations (CAFO)[63] – The manure and animal carcasses from these operations is an ongoing concern to environmental regulators and both types of residuals are prime prospects for bioproduct facility development.
  - Canning Operations –Vegetable and meat canning operations produce tons of food scrap waste daily. One can find various bioproducts routinely refined from the organic wastes generated by these operations. These materials are still often disposed of in a wastewater treatment plant or landfill.

[63] https://en.wikipedia.org/wiki/Concentrated_Animal_Feeding_Operation

Example of food scraps from a tomato processing plant

Life cycle tomato by-products

- <u>Breweries and Vintners</u> – Breweries and vintners can generate tons of organic waste daily. Both operations have been handling and managing their waste for as long as they have been in business and ever since the air, water, and solid waste regulations came into effect in the 1970's. Brewery and vintner waste has been economical as an animal feed additive. However, until recently, it has not been economical to transform such wastes into higher value byproducts.

Examples of Brewery Waste

Woody material

Woody organic residual material is found in urban landscape trimmings (more recently being referred to as "urban forests[64]"), fruit and nut tree crop trimmings, as well as forest product residuals.

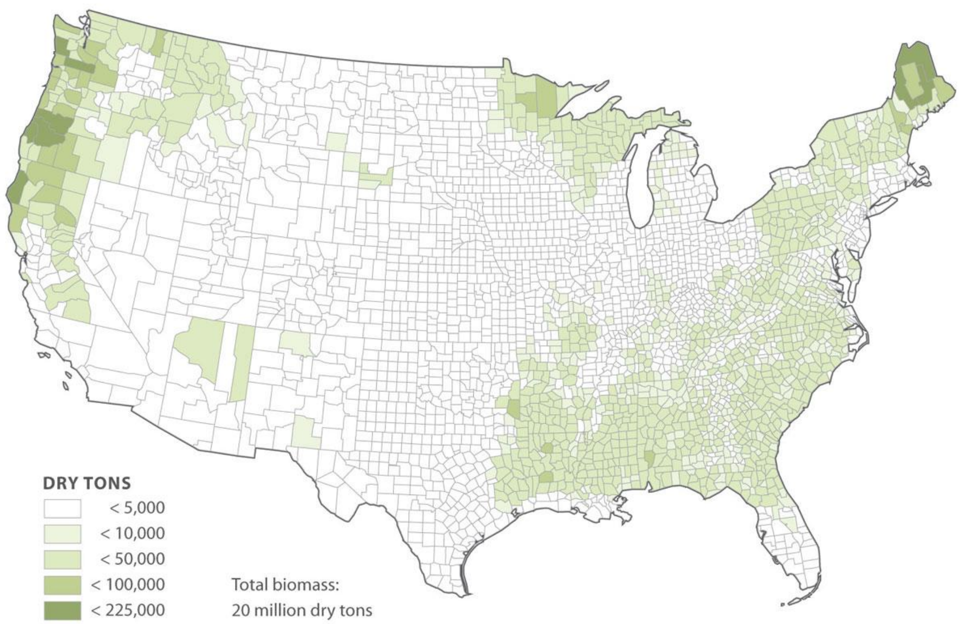
Traditionally these materials have been used over the years for many purposes, for example:

- Fire wood
- Wood chip mulch
- Biomass fuel for energy production (either pellets or mass burn)
- Building materials (e.g. mill waste used in chip board, particle board, etc.)
- Paper, cardboard, Masonite, etc.

[64] https://en.wikipedia.org/wiki/Urban_forest

Examples of traditional woody material feedstocks

Increasingly, as bioproduct technology develops, more woody material will be used as a feedstock. However, whether bioproduct technology will ever disrupt the current markets for woody material remains to be seen. It will be incumbent on the bioproduct facility developer to assess these local traditional product markets as part of their development due diligence.



Potential Biomass Resources from Forests

Tree tops and limbs make up a small but important component of our biomass supply.

© Union of Concerned Scientists 2012; www.ucsusa.org/biomassresources

Green material

Green material is generated primarily from yard trimmings, collected in local municipal solid waste systems.

Yard trimmings

Yard trimmings are composed of a gradation, starting with plant material that has a high lignocellulose content (i.e. woody material) and ending with leafy green material that is higher in sugars, starches, and proteinaceous compounds (i.e. green material proper). This spectrum in the composition of yard trimmings makes the material challenging to transform. The green material lends itself more readily to biological treatment owing to the high moisture and nitrogen content, while the woody material lends itself to thermochemical treatment owing to the low moisture and high lignocellulose content. In principal, two facilities, a thermochemical and a biological, could be used on a mixture of green and woody material. But to date, most developers have chosen to segregate the materials; processing them by using one or the other types of technology, not both.

Agricultural Residue

Agricultural residues have been eyed for many years as a very viable source of feedstock for bioproduct technologies. Agricultural residues come in a spectrum delineated by two extremes. On the one hand, there is a massive amount of high cellulosic material like corn and wheat stalks.

Bailed Corn Stover

Bundled Wheat Sheaves

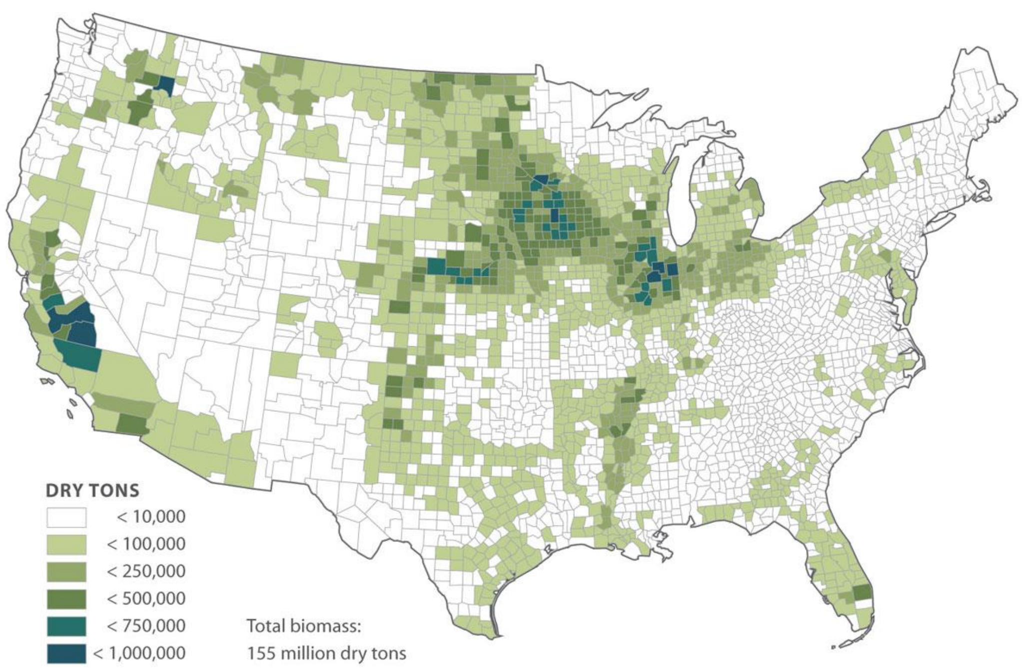
On the other hand, there are more vegetative residuals like lettuce, tomatoes, tomato stalks, melon vines, etc.

Tomato Harvest Residue (open field)

Cantaloupe harvest residue (small plot)

The more vegetative crops are more akin to food scraps owing to the moisture and higher nitrogen content of the residuals. Most of the agricultural residuals are of the lignocellulose variety (corn stover, wheat stalks, and soybean residuals) because these are massive and subsidized crops.

As shown in the diagram of the US, these lignocellulosic materials are concentrated in specific counties in California and in upper Midwestern states.



Potential Biomass Resources from Agricultural Residues

This category is comprised of both primary and secondary residues from corn and small grains, as well as cotton, orchard prunings, and other parts of the plant not needed for food or other uses.

Some of the advantages and drawbacks of leaving agricultural residues in the field are listed in the following table[65]:

Advantages and drawbacks of agricultural residues

Advantages	Drawbacks
Increase infiltration and storage of rainfall	Decrease surface soil temperatures
Reduce sealing of surface soil	Increase some crop diseases
Reduce runoff	Retain more surface soil water, which can restrict access to field
Reduce water erosion	Reduce herbicide effectiveness
Reduce soil water evaporation	Create challenges for seeding and crop establishment
Provide habitat and food sources for earthworms	
Increase snow trapping and subsequent water storage from melted snow	

Since this material is high in lignocellulose, and low in nitrogen, it is more amenable to thermochemical process technologies, rather than biological ones.

Manure

Manure is the largest class of organic residual feedstock in the US. Its source is meat production at concentrated animal feeding operations, and includes mainly dairy, beef, hog, and poultry production.

Dairy manure

Chicken manure

65 http://www.californiaagriculture.ucanr.edu/

Biomass Estimates

A quantitative estimate of the annual amount of each of the organic residual feedstock categories, derived from the above references and data from CalRecycle in California, is summarized in the following table:

Table 2 – Biomass Generation Estimates; US and California

dry tons per year (million)

Feedstock	US		California	
	dtpy	**% total**	**dtpy**	**% total**
Biosolids	7.1	1%	0.72	1%
Food Scraps	37	5%	5	6%
Woody Material	20	3%	2	2%
Green Material	34	5%	8	10%
Agricultural Residue	155	21%	15	19%
Manure	500	66%	50	62%
Total:	**753**	**100%**	**81**	**100%**

The data tells us that animal manure is the largest source of carbon by a factor of 2 over biosolids, food scraps, woody material, green material, and agricultural residue combined. It is also curious to note that livestock manure is 70 times the biomass of human biosolids.

It is worth noting that in the bioproducts industry, feedstocks are on a spectrum of negative value. As stated in the beginning of this chapter, facilities are getting paid a "tipping fee" to accept these feedstock materials. However, in the non-renewable fossil fuel and chemical industry, about 60 % of the total cost is for raw material resources. Potential use of feedstocks noted in Table 2 should offer attractive economics for bioproducts based on renewable carbon if the technologies, infrastructure and markets are developed.

Processes

Keeping in mind the framework of a bioproduct technology:

feedstock(s) (organic residuals) → **process train** → **bioproduct(s)**

in this section we focus on the primary process in the process train found in organic residual transformation. In general, bioproduct processes can be categorized as physical, chemical, biological and various combinations. Examples of these include, in increasing complexity:

- Physical – chip and/or grinding of woody material
- Chemical – oxygenation, combustion, pH adjustments, pyrolytic conversion
- Biological – compost, microbial fermentation, anaerobic digestion, whole organism digestion

It should be pointed out that each process category generally includes the other less complex technologies, i.e. chemical must include one or more physical processes, and biological includes one or more physical *and* chemical processes.

The five key transformative processes discussed in this paper are chip and grind, composting, anaerobic digestion, thermochemical conversion, and microbial fermentation.

A sixth transformative process, whole organism digestion, is typically worm or insect larval growth, while feeding on food scraps. For example, the soldier fly larva holds great promise as a mechanism for transforming food scraps into high quality animal feed. Since it is relatively new as a bioproduct technology, we do not treat it further in this edition of the paper, though we will be following its development, especially to serve the need for food scrap recycling in California. At the same time, vermicomposting (i.e. composting using worms) is a common technology used to digest food scraps and animal manure to produce a high value compost. We do not treat vermicomposting in this paper.

Chip and Grind

Green material and woody material are very often the starting feedstocks for a bioproduct technology transformation. In the municipal environment, green material is derived predominantly from landscape clippings and therefore is high in lignocellulose (essentially woody material). For this reason, if woody material is part of a feedstock, it typically must be chipped and ground into smaller particle sizes before being processed into a product. In some locations, such as southern California, the volume of chipped and ground material vastly exceeds the amount of other products being produced, especially compost.

Chip and grind is a technologically simple process and involves either a chipping machine (e.g. a Vermeer chipper that you see on the back of landscape maintenance trucks), or a tub grinder.

(e.g. a Morbark, Vermeer, or other brand tub grinder used at most processing areas for generating precursors to large compost operations).

Chip and Grind is relatively "low tech" compared to the other bioproduct technologies. However, it is important to note that for woody material it is best to make the particles as small as possible (less than ¼" for refining) for two reasons:

- Provide the maximum amount of surface area for further biological or physical-chemical transformation of the lignocellulosic compounds

- Provide ease of handling in the solid phase (for mulch or composting) or as a suspended solid in water (for biological processing)

Large particle size Chip and Grind material (1-4" in average length) is often sold as a landscape mulching material without being composted. This material is often used to both conserve water (by reducing evaporation from the ground), as well as reduce the amount of weeds produced (depending on the depth of the material spread and the original vegetation at the site). Medium size particles (¼" to 2") are generally best for compost production. These are small enough for bacteria and fungi surface area degradation but large enough to let air flow through the pile (be it passively or actively aerated).

Composting

Compost is a stable, humus-like product resulting from aerobic whole organismal decomposition of organic matter. Four feedstock types (biosolids, food scraps, green material, and manure) can be composted. Composting reduces the total volume of the feedstock by 30 to 50%. That biomass is lost predominantly as oxidized carbon (CO_2).

The importance of composting for a sustainable carbon cycle should not be underestimated. Often, digestate from other biological processes, especially anaerobic digestion, is composted in order to make it biologically more stable and ready to be used as a soil amendment.

There are a number of different compost technologies, and compost production is enjoying a resurgence of growth in those parts of the U.S. and the world where returning organic carbon to replenish soils is considered a priority (especially North America, Europe, Australia and Africa). Compost technologies can be divided into passive vs. active aeration systems:

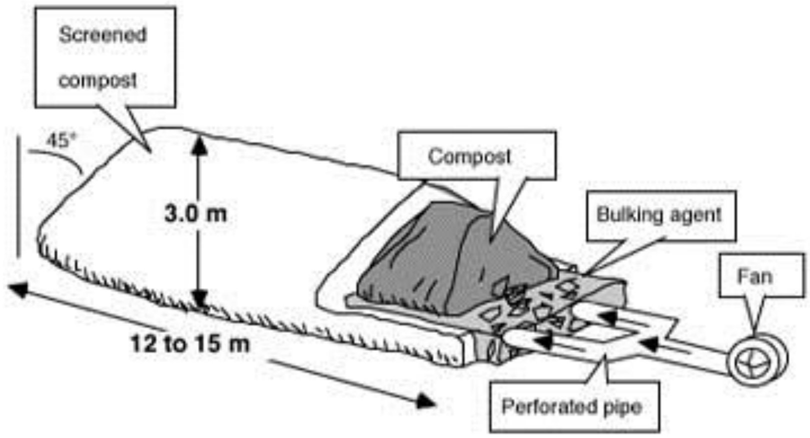
Passive aeration:

- static pile – As the name implies, a pile of organic material is simply staked up and the natural thermophilic processes cause the pile to draw air from the bottom sides of the pile, and then produce exhaust through the top.
- turned windrow – This method takes the piles and extends them into rows where they are turned or mixed and "fluffed up" using a "windrow turner" [66]

[66] See https://en.wikipedia.org/wiki/Windrow_composting

Active aeration – Forced air, aeration, either positive or negative.[67]

- positive aeration– blowing air through the pile, from bottom up through the pile and out the top.[68]



- negative aeration– drawing air out of the pile, instead of pushing it through the pile (structured the same as the above diagram, however, with air flow arrows going in the opposite direction

Chemically, compost is complex. It is the result of both catalytic and synthetic processes in the decaying material. Compost products vary depending on the nature of the original feedstocks and the conditions under which the decomposition occurs. Carbon is the most abundant element in compost, generally about one half of the total mass. Nitrogen is also present, but in much smaller quantities, generally 1 to 2%.[69]

Anaerobic digestion

In anaerobic digestion, microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, which is a mixture of CO_2 and methane. Biogas can be combusted to generate electricity and heat, or processed further to generate renewable natural gas (pure methane). The other output of anaerobic digestion is called "digestate", which is a material rich in carbon and nitrogen (from protein in the feedstock). It is a valuable soil amendment somewhat similar to compost.

Anaerobic digestion can be used to process biosolids, food scraps (including fats, oils, and grease), green material, and manure. It is a four stage process chain consisting of the following steps:

1. Digestion begins with bacterial hydrolysis which breaks down organic polymers, such as carbohydrates and proteins to simple sugars, amino acids and fatty acids.
2. In the next stage, acidogenic bacteria convert the simple monomers produced in stage one to volatile fatty acids, ammonia, carbon dioxide and hydrogen sulfide.
3. In the third stage, the molecules created through acidogenesis are further digested by acetogens to produce acetic acid, carbon dioxide, and hydrogen.

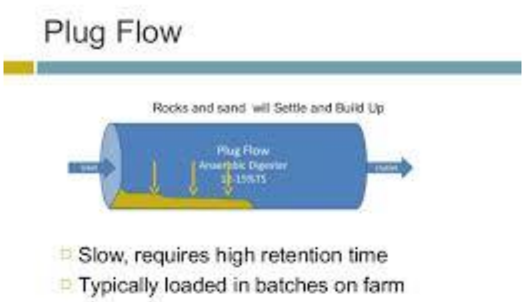
[67] See https://en.wikipedia.org/wiki/Aerated_static_pile_composting
[68] http://ohioline.osu.edu/b792/b792_5.html
[69] For a more detailed discussion of compost product see: https://en.wikipedia.org/wiki/Compost

4. Lastly, methanogenic bacteria convert these products to methane, water, and carbon dioxide. The remaining indigestible material that the microbes cannot use and any bacterial remains constitute the digestate, a nutrient rich soil amendment.

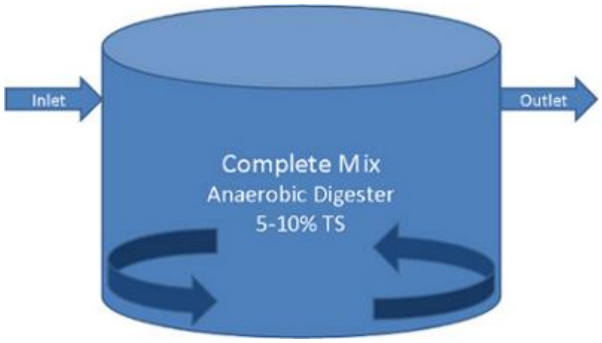
Anaerobic digestion systems fall into several categories:

1. Covered lagoon: A lagoon is sealed with a flexible cover, and methane is recovered and piped to a combustion device. Often covered lagoon systems use a single space for both digestion and storage.

2. Plug flow digester: This system consists of a long, narrow concrete tank with either a rigid or flexible cover. The tank is usually built partially or fully below ground level to limit the requirement for supplemental heat. Plug flow digesters are used at dairies that collect manure by scraping.



3. Complete mix digester: This system is composed of an enclosed, heated tank, with a mechanical, hydraulic, or gas mixing mechanism. Complete mix digesters work best when the feedstock is diluted with water.



4. Dry digestion: in this system, an upright, silo digester is made of concrete and steel with a rigid cover. Dry digesters work at 20 to 40% total solids.

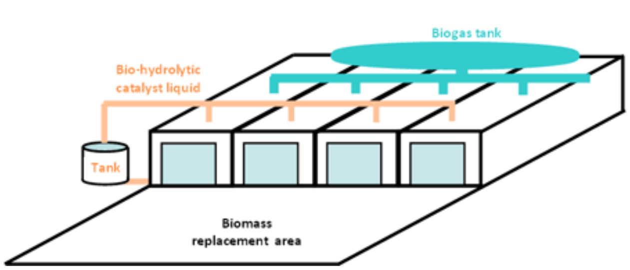


Table 3
Recommended Solids Content for Various Types of AD Facilities

Recommended Solids Content

Technology	Recommended Waste Solids Content
Covered Lagoon	< 3%
Plug Flow	11 - 17%
Complete Mix	5 - 10%
Upflow Sludge Blanket	3 - 7%
Fixed Film	<3%
Dry Digestion	> 40%

Temperatures for anaerobic digestion are in the range of 20-45°C (supporting mesophilic organisms) or 49-70°C (supporting thermophilic organisms). Mesophilic systems are considered more stable, but thermophilic systems produce methane containing biogas most rapidly.

Anaerobic digestion can be undertaken either as a batch or continuous process. In a batch system, biomass is added at the start of the process and then sealed for the duration. Batch processing normally needs an inoculation of already processed material in order to kick start the anaerobic digestion.

In the continuous method, organic matter is added throughout the process, either constantly or in stages. The end products are removed continually or at intervals, generating a fairly constant production of biogas.

Digesters may be constructed as multistage: either two or even three stage systems are possible. In multistage digestion systems, different vessels are optimized to support the bacterial communities in the digester at a particular phase. For example, acidogenic bacteria produce organic acids and grow more quickly than methanogenic bacteria. Methanogenic bacteria require stable pH and temperature for optimal growth.

Residence time in the digester varies between 1 and 90 days.

Anaerobic digestion offers the potential for low-cost energy for cooking and lighting. Methane and, indirectly, heat and electricity produced in anaerobic digestion facilities can replace energy derived from fossil fuels because the carbon in biodegradable material is part of a short carbon cycle (i.e. is quickly returned to the soil via plant photosynthesis), as opposed to a long carbon cycle for fossil fuels.

Multistage Anaerobic Digester[70]

Thermochemical conversion

Thermochemical conversion is a very important bioproduct technology. There are two major types of thermochemical conversion: gasification and pyrolysis.

Gasification takes place at high temperature (150-300°C) in the presence of limited amounts of oxygen. Besides oxygen, steam may also be present. Gasification is capable of converting 70-80% of the feedstock carbon into syngas, a mixture of carbon monoxide and hydrogen, along with biochar, a valuable soil amendment with excellent carbon sequestration properties.

Syngas alone can be used as a fuel to produce heat and electricity. After impurities are removed, it can be converted further into transportation fuels and chemicals. For example, using chemical catalysis at high temperature and pressure, it can be converted to methanol, an important primary chemical for further organic synthesis. It is also possible to produce ethanol, propanol, and butanol directly from syngas.

Gasification is very often followed by Fischer-Tropsch synthesis, a collection of chemical reactions which generate a mixture of variable length hydrocarbons chains, such as paraffinic wax, naphtha, diesel, and jet fuel. The advantage of gasification is that it is able to handle a wide variety of feedstocks, and perhaps most importantly, woody material.

The difference between gasification and pyrolysis is that gasification is performed in the presence of an oxygen reduced environment, while pyrolysis is performed in the total absence of oxygen. The pyrolysis process takes place at around 500°C to produce biochar, syngas, and pyrolysis oil. Syngas can be

[70] From www.clearcovesystems.com/anaerobic-digestion-101/

converted to a variety of products, as described above for gasification. Pyrolysis oil is normally upgraded to drop-in fuels through hydrodeoxygenation, hydrotreatment or fluid catalytic cracking.

Pyrolysis is a particularly valuable technology due to its wide acceptance of feedstock types, including: biosolids, food scraps, woody material, green material, agricultural residue, manure, rubber tires, and even plastics.

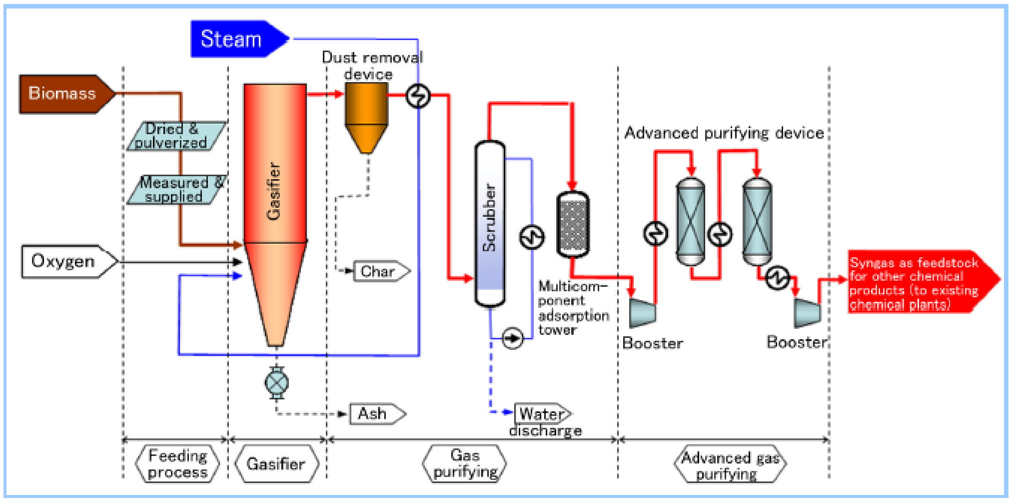


Figure 4 Diagram of the biomass gasification and syngas purifying system.

https://ahilan007.wordpress.com/2012/07/20/can-bio-gasification-transform-our-world/biomass-gasification-diagram/

Microbial fermentation

Microbial fermentation is a widely used bioproduct technology. Microbial fermentation is usually not the first step in the process chain, since microorganisms in general have difficulty metabolizing lignocellulose. In combination with chemical or enzymatic catalysis as a precursor step, microbes are able to ferment cereal grains, sugarcane, agricultural residue, and even woody material.

Products generated by microbial fermentation include ethanol, glycerin, animal feed, butanol, acetone, diesel, butanol, acetaldehyde, ethyl acetate, acetic acid, and succinic acid. In addition, several pre-commercial companies have harnessed genetically engineered microbes to produce fatty acids, fatty alcohols, triacylglycerides, PHA biopolymers, dodecanedoic acid, sebacic acid, adipic acid, isobutene, and isooctane.

Genetically engineered microbes are capable of producing high-value chemicals. Genetic engineering allows scientists to tailor microorganisms to produce desired outputs from fermentation pathways. This shows great promise for the future.

Bioproducts

A brief discussion of each of the 11 bioproduct categories, within the context of the four main markets is provided in this section. The purpose is to provide an overview of each product category and to lay the foundation for further, more detailed market category research, discussed in the final "Markets" section of this paper.

The four broad end-use market categories that the various bioproducts are sold into, are:

- Soil Amendments – These products provide benefits that include water conservation, lower pesticide and herbicide use, and improved soil tilth. They are mulch, compost, fertilizer and biochar.
- Animal Feed – Animal and fish feed provide the carbohydrates and protein necessary for growth and overall health.
- Energy - This category includes fuel for use in transportation, heating and electricity for onsite use or, in the case of electricity, to feed into the electric utility grid.
- Chemicals and Materials – This category includes the broad set of organic chemicals produced from renewable resources. These chemicals provide the raw materials for consumer products (materials) such as furniture, building materials, plastic bottles, etc.

In addition, each of these bioproduct categories, within the context of the four broad markets, represents its own industry subsector. And there are national and, in California, state industry associations that represent each sector. These associations are a good jumping off point to gain a deeper understanding of the framework of each product sector, and a key URL is listed at the end of each section.

Mulch

The term "mulch" refers to any soil covering. For example, one can use chipped landscape material, rocks, plastic, or compost as mulches. Typically though, material that is referred to as mulch is chipped or ground up landscape clippings. This material is used to protect the soil from wind and rain erosion, used to beautify a landscape, and to slow evaporation from the soil.

Mulch is the lowest value product generated from green material feedstocks. The price can be anywhere from negative, i.e. "pay to dump," to a positive value of upwards of $10-$20 a cubic yard, depending on local supply, demand, and quality. Higher quality means uniformity without any non-organic contaminants (e.g. plastic, glass, paper).

Various types of natural and painted wood chip mulch

See www.mulchandsoilcouncil.org for more information about this industry sector.

Digestate

Digestate is the solid and aqueous material that remains after either aerobic or anaerobic digestion of biological material in the aqueous phase of digesters. The first digestate produced in mass quantities was a combined aerobic and anaerobic solid material produced from wastewater treatment facilities. This special material has been given its own name of "biosolids".[71] While biosolid digestate is typically used as a separate product, it is also used as a feedstock for manufacture of other products, including fertilizer pellets, compost and, very recently, biochar.

In both Europe and the U.S., "digestate" is the solid material remaining after the anaerobic digestion (AD) of higher nitrogen containing feedstocks, mainly manure and food scraps. This digestate is getting increased attention in California, owing to the new mandatory commercial recycling laws that went into effect in 2015.[72] As those materials are being collected and recycled, grocery stores and restaurants are needing to find new accommodations instead of landfills, for this material. This, as discussed above, is a major driver for bioproduct technology development in California. However, the digestate can't be easily land applied without being further processed, because of its high potential for exceeding nitrogen, phosphorous and potassium concentrations, as well as the potential for exceeding total dissolved solids from any of the rain or irrigation run-off. Though this can be controlled, with proper application management, it is still a very active area of research and product development.

Digestate is composed of a solid and much larger aqueous portion, in both volume and mass. Both of these AD residuals, or off-takes, must be managed so as not to degrade but rather to enhance the environment. The liquid digestate must be treated prior to discharge, since it contains high total dissolved and suspended solids (TDS and TSS). In addition, it has a high biochemical oxygen demand (BOD), owing to the carbon and nitrogen compounds it contains. These two aspects of liquid digestate are the largest pollutants from agricultural operations throughout the world and are increasingly being

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[71] For more on biosolids in California, see http://www.calrecycle.ca.gov/organics/biosolids/
[72] See http://www.calrecycle.ca.gov/recycle/commercial/organics/

managed more stringently in agricultural operations by the local water quality control boards.[73] Regulatory agencies on the solid waste side do control the solid digestate beneficial use, or environmentally safe disposal, as well.[74]

The solid fraction of the AD digestate, like biosolids, can be used as a feedstock for compost production, or land applied as a high carbon and nitrogen soil amendment. In California, this is currently under detailed scrutiny by the water quality and solid resource agencies. That is, it is still a work in progress. The Healthy Soil Initiative, discussed above, includes the appropriate use of all digestate types as a potentially valuable agronomic input, as long as they don't degrade air, water or soil environment.[75]

AD Solid Digestate[76]

The association devoted to the beneficial use of digestate as a valuable co-product of AD is the American Biogas Council, www.americanbiogascouncil.org.

Compost

Compost is generated when organic matter is consumed and decomposed by microorganisms under favorable environmental conditions. Key factors for the compost process include maintaining a good nutrient balance, the correct moisture content and temperature, and an adequate level of aeration. Composting is a managed process for accelerating the creation of compost while improving its characteristics.

Nutrient balance: The most important nutrient balance when generating compost is the ratio of carbon to nitrogen (C:N) in the decomposing mixture. Bacteria, actinomycetes, and fungi use available carbon for energy needed to grow and reproduce. Nitrogen is required to build protein and genetic material.

[73] For California, see http://www.calrecycle.ca.gov/swfacilities/compostables/AnaerobicDig/DPEIR.pdf
[74] For regulating AD facilities, including digestate, see http://www.calrecycle.ca.gov/swfacilities/compostables/AnaerobicDig/DPEIR.pdf
[75] Personal communication with the Environmental Farm Act – Science Advisory Panel, (https://www.cdfa.ca.gov/EnvironmentalStewardship/EFA-SAP.html), which is overseeing the implementation of the Governor's Healthy Soil Initiative.
[76] From http://questor.qub.ac.uk/AppliedTechnologyUnit/ATUServices/BiogasServices/

Initially, the C:N ratio in the pile might be around 30 to 1. As the microbes consume carbon, they convert it to carbon dioxide gas (respiration), which is returned to the atmosphere. This causes the C:N ratio to fall as the compost process progresses. By the time the compost is ready to use, its C:N ratio will have decreased considerably, typically to between 10 and 20 to 1.

Phosphorus and other nutrients are also required by composting microbes but are usually available in adequate amounts in compost material with the correct C:N ratio.

Moisture: The moisture content of compost should ideally be about 60% after mixing. Microbes need water to live and grow, but too much water will block the supply of oxygen from the air. A general rule of thumb is that a handful of compost should feel moist and hold together without dripping (referred to as the "squeeze test." Depending on the components of the mixture, the initial moisture content can range from 55-70%. However, as the moisture content increases above 70%, oxygen movement is inhibited, leading to low oxygen (anaerobic conditions). Under these conditions, microbes become less efficient, the compost pile loses heat energy, and chemical pathways are altered, leading to the production of odors. Under dry conditions, the microbes lose their natural habitat, and the rate of decomposition decreases rapidly. While composting actually generates moisture, a significant amount is usually removed by air flowing through the compost pile. Therefore, moisture often must be added during composting to support active microbial respiration.

Temperature: The temperature increase that occurs during the composting process results from the breakdown of organic material by bacteria, actinomycetes, fungi, and protozoa. Compost piles can reach 150 °F in less than 2 days. Applying heat to compost from an external source is therefore not necessary. The increased temperature raises the biochemical decomposition rate by a factor of 25 over the rate at mesophilic temperatures (68-113 °F). This greatly accelerates the formation of humus (organic soil material) from the raw organic feedstock, allowing composted organic material to be returned to the soil faster than simply letting the matter degrade at mesophilic temperatures.

Aeration: A fresh supply of air is vital for composting. A number of controllable factors are involved in regulating aeration. For example, if compost particle sizes are too fine, air will not be able to enter and diffuse within the pile, a condition leading to odors and to the development of phytotoxic contaminants. Some compost techniques, called *turned windrow systems*, physically turn the compost to promote aeration. Turning the pile restores the pore spaces in the material so that cooler fresh air can enter the sides of the pile to replace the hot carbon dioxide and water vapor escaping from the top. In another common approach, called a *static pile system*, air is physically forced into, or drawn out of, the pile (alternatively referred to as positive vs. negative aeration). Static pile systems do not need to be turned and can be aerated for much less energy than is required to turn them.

Traditional Watering and Aeration Technology
Turned Windrow Watering

New Watering and Aeration Technology
Static pile watering

Aerating a window with a diesel powered Scarab turner (450 HP engine)

Aerating a static pile with a solar powered blower (1.5 HP engine)

Large particle (from a chip and grind process) components that are high in lignocellulose and often referred to by composters as "bulking agents" are typically chipped or ground up wood, straw, rice hulls, saw dust, or similar materials. These are added to the compost mixture to increase porosity and improve aeration. Because smaller particles provide greater surface area to microbes than larger ones, they decompose more rapidly than bulking agents. When ready, composts are typically screened to separate large and small particles. The coarser fractions, or "overs", are often sold as surface mulches, or as a wood energy feedstock, depending on the contaminant level; while the "fines" are marketed for use as soil amendments.

When compost feedstock preparation is correct, the active phase will start immediately and thermophilic conditions will be reached as microbes consume readily available carbon and nitrogen containing compounds. After several days or weeks (based on the quantity and size of the feedstock), the temperature will drop and the mesophiles will take over, consuming lignin and other hard to decompose organic materials over longer time periods. Materials are typically re-piled for this curing phase. Compost is considered finished, stable, and mature when:

- Its core temperature stabilizes and the material does not reheat or generate excess carbon dioxide when stirred or rewetted
- It is dark brown or black with no recognizable feedstocks or inert materials
- It has an earthy smell

Finished Compost

See www.compostingcouncil.org (national) or www.healthysoil.org and californiacompostcoalition.org (California) for more information about this bioproduct category.

Fertilizer

Modern fertilizers typically contain nitrogen (N), phosphorous (P), and potassium (K). These compounds are labeled in standard fertilizer as a percent by weight in the mix. Chemical fertilizers look like white or colored pellets, e.g.

However, fertilizers made from organic feedstocks (often digestate from anaerobic digestion or manure) have a much darker color, owing to the presence of organic carbon in the mix. Some examples of fertilizers made from biological sources and often blended to make a complete and robust fertilizer:

Fertilizer made from organic residual feedstock is increasingly being referred to as “biofertilizer.” Fertilizers, whether chemical or made from biological feedstock, must be registered with the appropriate fertilizer regulatory agency.

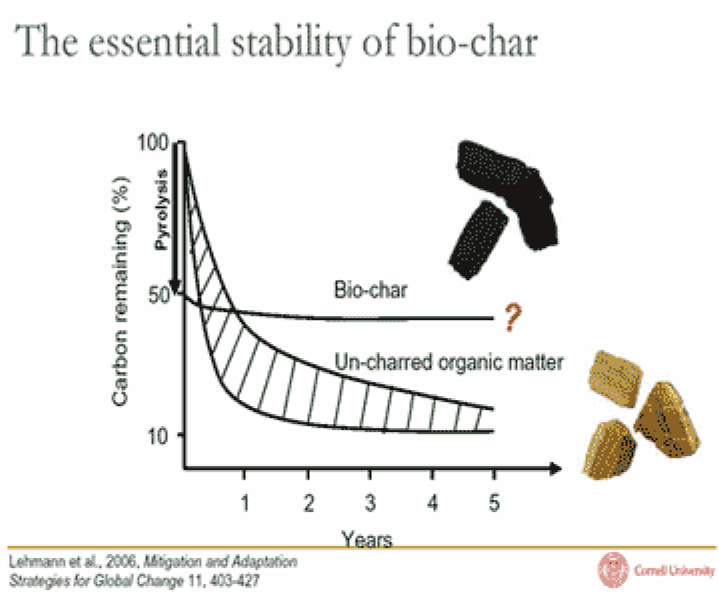
Biofertilizer manufacturing system

Manure, decomposed food scraps, and biosolids are all often manufactured into biofertilizers. Fertilizers are also now being combined with biochar, either during the biochar manufacturing process (where the nitrogen molecules become imbedded, or attached during the biochar production process) or combined after each component is made separately. Since fertilizers are continuously needed for agriculture, this represents a very important market for the biorefining of all relevant residual organics, especially high nitrogen containing (i.e. protein rich) organic residuals.

See www.organicfertilizerassociation.org for more information about this bioproduct category.

Biochar

Biochar is a solid, carbon rich material produced by thermochemical conversion of biomass in an oxygen limited environment, either by gasification (some oxygen) or pyrolysis (no oxygen). It is very much like charcoal.



Organically rich soils have developed over time through the decay of plant and animal matter. This soil-building activity is a positive feedback loop: the richer the soil, the more productive is the land, which in turn generates more organic material for the soil.

On the other hand, agriculture can deplete soil carbon by reducing the amount of natural organic inputs and by using chemically-based fertilizers. The latter, combined with tillage, accelerate microbial respiration, which burns up soil carbon faster than it can be replaced.

It is possible to substitute for some of this missing soil carbon through the use of biochar. Nature produces biochar from naturally occurring fires. Biochar is a mixture of both organic and mineral carbon, and the relative proportions depend on its condition of formation.

Because biochar is produced under conditions of very limited or no oxygen, it will contain very little hydrogen and oxygen. The lignin, hemicellulose, and cellulose of the original biomass will have been converted to various inorganic carbon forms, termed allotropes (see the accompanying figure below).

Biochar is basically a collection of graphite crystals in hexagonally shaped carbon rings, with some hydrogen and oxygen attached, along with ash (minerals) that was present in the original feedstock. These carbon rings are very stable and resistant to degradation by microbes.

If biochar is created at higher temperature, it becomes more mineral like and even less biodegradable. However, condensed vapors in the biochar pores and on the surface are biodegradable, and thus even this form of biochar can be considered to contain organic carbon.

The fused carbon rings in the biochar are the basis of chemical bonds which allow electrons to move around the rings. Depending on the creation temperature, a given batch of biochar can be an insulator, a semiconductor, or a conductor of electricity. Electrically active carbon rings in the biochar also support oxidation-reduction reactions that are important in helping microbial metabolism.

Since biochar is porous and electrically charged, it is capable of both absorption and adsorption. Larger pores absorb water, air, and soluble minerals. Adsorption is the adherence of atoms, ions, or molecules to a surface. In this way, biochar can act like an electric sponge.

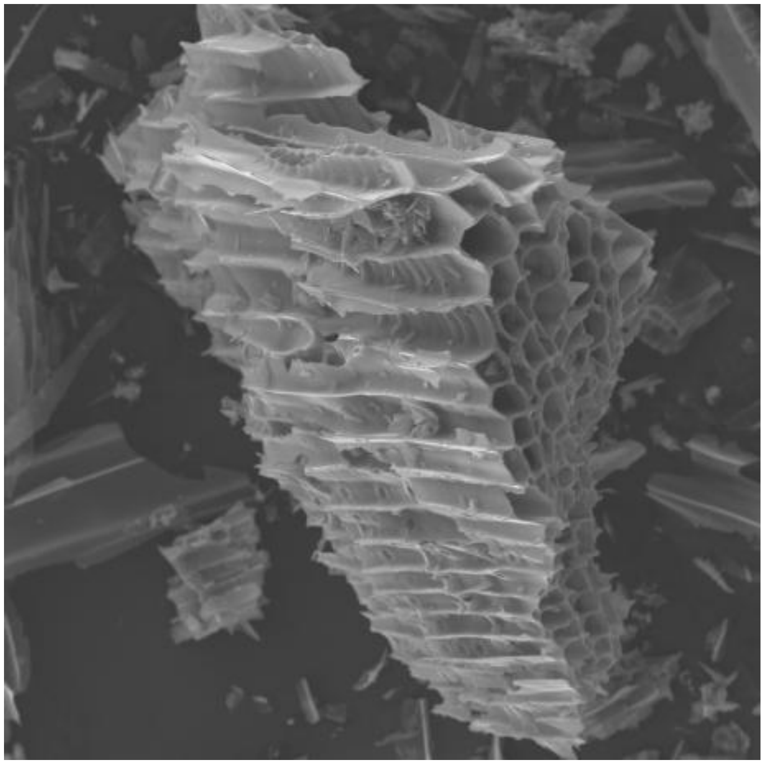
The porosity of biochar depends on the feedstock material and the temperature of the thermochemical conversion. In general, higher temperatures produce greater porosity. For woody material, porosity generally peaks about 750°C.

It is important that one wait a period of time after generating biochar before adding it to soil. This is because from the moment the biochar is removed from the pyrolysis or gasification unit, its surfaces begin to oxidize and form new compounds. These new compounds are able to bond with nutrients and minerals. Raw biochar placed in the soils before it can charge itself with nutrients can actually reduce crop yields. This problem can also be resolved by adding an organically rich material, such as anaerobic digestate or compost.

Now the biochar enters its final phase, where its matrix is stable for hundreds to thousands of years. Biochar has many benefits when it is added to soil along with compost. First, biochar keeps compost moist and aerated, and that promotes increased biological activity. Both water and air are held in the pores of biochar. Biochar also accepts electrons from decomposing organic compounds, thereby buffering electric charges that could otherwise impair microbial activity.

Biochar also increases nitrogen retention, reducing emissions of ammonia. It also improves compost maturity and humic content.

Electron Micrograph of Cellulose-based Biochar



(from "How biochar works in soil," Kelpie Wilson, the Biochar Journal)

See www.biochar-international.org for more information about this bioproduct category.

Animal feed

Animal feed has been produced from organic residuals ever since the beginning of domesticated livestock (e.g. "hog slop"). In fact, "garbage" in the urban environment, for the first half of the 20th century, was often collected in garbage pails from homes and taken to nearby hog farms. But as urban development continued to encroach on local farmlands, and as single stream waste management disposal gained popularity for managing urban discards increased (starting in the 1950's), this practice died out.

However, the development of new organics recycling laws, e.g. AB 1826 (mandatory recycling of commercial food scrap programs in California), are causing a resurgence of multiple alternatives for generating animal feed. In addition, in grain-based ethanol production, distiller's grains (the organic residual from that process) continue to be used as an important source of animal feed. Another alternative that is gaining favor is the use of food scrap dehydrators, which turn unstable putrescible food scraps into a dry stable material.

More recently, insect larvae are being used to convert food scraps into high quality animal feed. For example soldier fly larva are being used on food scraps, to produce an energy rich animal feed or fish (aquaculture) and other terrestrial livestock food aditives.

Food Scrap DyerDried Food scraps that can be used either as animal feed additive or soil additive

Animal feed markets are not available in every locale. Therefore, these products may not always be part of a product portfolio.

See www.cgfa.org or www.afia.org for more information about this bioproduct category.

Fuel

Fuel is a very common bioproduct. The first fuel bioproduct was ethanol, beginning in the 1970s. As of August 2015, there were 213 ethanol generating bioproduct facilities, with a total capacity to produce 15.5 billion gallons of ethanol. There is a limit to how much ethanol can be profitably produced, however, since regulations limit the percentage of ethanol in gasoline to 10%. Though it is possible to produce automobile engines which run on higher percentages of ethanol, such engines are not generally produced in the United States.

In the beginning, ethanol was produced from corn and sugar cane. Although this was technically rather straightforward (through microbial fermentation), it raised the specter of a fuel versus food conflict. Therefore, much research has gone into the possibility of producing ethanol from lignocellulosic biomass. This can now be done, either through thermochemical conversion (gasification), through steam pretreatment, or through enzymatic breakdown.

While ethanol is most often used as a fuel, it is also a valuable feedstock for further chemical synthesis. For example, ethyl halides, ethyl esters, diethyl ether, acetic acid, and ethyl amines can all be generated from ethanol.

The second source of liquid fuel comes from gasification and Fischer-Tropsch synthesis. Depending on process tuning, Fischer-Tropsch synthesis can generate the entire petrochemical fuel stack: paraffinic wax, diesel, kerosene, jet fuel, and gasoline.

Pyrolysis, on the other hand, generates an oil, called pyrolysis oil which, upon hydrodeoxygenation, hydrotreatment, or fluid catalytic cracking can generate drop-in heating oil, diesel and jet fuel.

A third source of liquid fuel comes from fats, oils and grease. These feedstocks are transformed by a process called transesterification into what is known as biodiesel. Biodiesel has many good properties, e.g. low sulfur, renewable, etc., though it is not identical with petrochemical diesel, and it cannot be treated as a drop-in fuel. There are blending limits associated with biodiesel.

Lastly, gas or liquid fuel can be generated from the biogas produced by anaerobic digestion. Biogas is a combination of CO2 and methane. Biogas can be used directly for cooking, heating, or electricity. Alternatively, the biogas can be "scrubbed" to remove CO2 and generate pure methane, which can be used as fuel in the gaseous form (renewable natural gas or RNG) or in the liquid form as compressed natural gas (CNG).

See www.bioenergyca.org or www.americanbiogascouncil.org for more information about this bioproduct category.

Heat

Heat is an important bioproduct that is indirectly generated through combustion of fuel produced during the transformation of feedstock into ultimate product. For example, heat can be generated by burning such intermediates as syngas or biogas.

In many facilities, the production of heat is combined with the generation of power, typically in the form of electricity. The term “combined heat and power” is often found in the literature and is particularly prevalent as a combined bioproduct of anaerobic digestion.

See http://aceee.org/topics/combined-heat-and-power-chp or www.energy.gov for more information about this bioproduct category.

Electricity

Electricity is a common bioproduct, very often generated along with heat and fuel. Anaerobic digestion and gasification are the two processes most commonly used to produce electricity. Electricity is generated by gas-driven turbines that run off either methane or syngas.

The advantage of electricity is that it may be used locally and also fed back into the electrical grid. The disadvantage of electricity is that it cannot be easily stored. Rather, it must be used as soon as it is produced. Since our culture uses vast amounts of electricity, this is not a problem. When accessing the various bioproducts available from anaerobic digestion and gasification, electricity is a very attractive offering. Besides being a valuable commodity, it directly offsets electricity produced by coal or natural gas consuming power plants, thereby reducing CO2 emissions.

See www.bioenergyca.org or www.americanbiogascouncil.org for more information about this bioproduct category.

Chemicals and Materials

Chemicals are very valuable bioproduct class and span a large range of compounds. Chemicals are often directly produced by a microbial fermentation-based process. This is due to the power of genetic engineering and synthetic biology to alter metabolic pathways.

The chemicals produced by bioproduct technologies are very often used as precursor compounds for the production of materials.

Feedstock chemicals include some of the following examples. Fatty acids, fatty alcohols and triacylglycerol hides can be used in consumer products such as soaps, shampoos, skin cream, and detergents. PHA biopolymers are direct precursor for biodegradable plastics. Levulinic acid can be used for plasticizers, surfactants, and various polymers. Dodecanedoic acid is used in the production of high-performance nylon, molding resins, and adhesives. Adipic acid is a key component of nylon, as well as thermoplastic polyurethanes. Sebacic acid is also used in the production of nylon. Xylene, benzene, and toluene are precursors for polycarbonates, polyurethanes, nylons, and other polymers which are in turn used to produce beverage bottles, clothing, carpeting, and automotive components.

In addition to chemicals, solid biomaterials (fine wood chips and paper pulp) have been made into products for many decades. For example, chip board became popular when open burning of wood wastes was stopped in many wood miles beginning with clean air act in the 1970's. Also, cardboard has been a staple of boxes in the distribution of goods to the present time. These materials are increasingly going to made from ag and municipal wastes in the immediate future.


See www.bio.org for more information about these two bioproduct categories.

Markets

"Markets are born when two subjective senses of value meet in an objective price."[77] We can broadly segment the bioproduct technology industry's markets into four main categories:

- **Feedstocks** – One market for feedstocks is comprised of tipping fees. Tipping fees are the price that a facility receives when a waste generator "tips" the organic residual load at the facility for processing. Another market for feedstocks comes from landfill fees. This market will eventually dry up when there is a complete ban on organic residual disposal in landfills.
- **Process technology** – The process technology market is comprised of permitting, capital costs, and operating costs for acquiring, constructing, and maintaining various process technologies and biorefining equipment.
- **Products** – Product markets may be local, regional, or global and depend on the relative competition for the 11 classes of bioproducts (see bioproducts section above).
- **Capital** – The so-called "capital markets" are the source for the necessary monetary, natural, social, and informational assets required to build, commission, and operate a bioproduct facility.

It is essential that these four broad market categories be analyzed and applied to each individual enterprise using an integrated and collaborative approach. Articulating and integrating these four essential markets is the focus of this final section of our paper.

Feedstocks

Each organic residual feedstock has a set of separate and unique local market options. These market options represent an income stream for the individual bioproduct facility. However, feedstocks must be analyzed for their amounts (the materials flow), the purity or contamination of the feedstock (i.e. its quality) and the tipping value at a particular facility site. Each of these three aspects of the feedstock market must be analyzed for every feedstock individually and for all the feedstocks in aggregate. Next, potential product markets which can be generated from these feedstocks need to be evaluated in order to make a sound technology acquisition decision.

Quantity

The presence of organic residuals in the "waste stream" is the driver for building a bioproduct facility in at given site. Therefore, a waste characterization study of the waste streams available in the local market is a key first step. If wastewater treatment plants, municipal solid waste jurisdictions and agricultural generators don't already know about quantities and their trends, they will need to investigate:

- What are the types and amounts of materials that could be processed?
- What is the variability of flow of each feedstock throughout the year?

Quality

The question of "contamination" is at the heart of feedstock quality. A feedstock "contaminant" is defined as any non-biologically produced material (element or compound) that could disrupt a given

[77] This is a paraphrased quote from John Chamberlain, "Roots of Capitalism", 1977.

biological or physical/chemical bioproduct process. Contaminants can be classified into three broad groups:

- **Physical** – mainly non-biologically produced or non-biodegradable material, e.g. plastics, rubber, or metals.
- **Chemical and Nuclear** – any chemical or nuclear compound that would impede or inhibit a particular bioproduct process
- **Biological** – any biological contaminant (organism of any phyla or species) that could disrupt a bioproduct process

Value

The value of a particular feedstock needs to be viewed in the context of a particular process train. The question for the feedstock receiver is: does it enhance or degrade my process? Will it produce more or less of my desired bioproduct? Will it add extra processes (and associated costs) to my bioproduct process train to accommodate that particular feedstock?

The value, or price per ton, to tip a given organic residual at a particular bioproduct facility creates an important market. The average fee will likely need to be compared to the landfill tipping fee if there are organic landfill bans in place in a given locale. If the landfill tipping fee is lower than the bioproduct facility tipping fee, there will be a tendency for organic waste producers to choose the landfill over the bioproduct facility.

Processes

Process technologies must also be assessed in detail.[78] This stage may require an engineering firm that is able to both provide the engineering assessment of the technologies, and also to make sure that they are geared to the available feedstocks and bioproduct assessments outlined below. It is likely that this will be an iterative process of analyzing all three markets in an integrated, incremental approach.

Within the process technology assessment, there are three fundamental phases of analysis: availability, longevity, and value. This three-part assessment is the basic discipline of "value engineering."[79]

Availability

Availability must be analyzed by the proximity and delivery (shipping) of a given system. If the shipping costs are too large, then on-site or local fabrication must be considered.

Once the bioproduct facility is built and commissioned, it will have to be maintained to produce quality product, meeting both its specifications and the regulatory limits imposed on the facility. Either the maintenance staff will have to be trained and kept in shifts on site, or the facility must be managed non-locally over the Internet, with the appropriate on-call expertise to be available for both routine and emergency maintenance.

[78] Note that Noble Resources Group maintains a "technology database" that has a large number of bioproduct production process technologies, that can be used as a starting point in the processes market assessment phase.
[79] For more on value engineering, see: https://en.wikipedia.org/wiki/Value_engineering

Longevity

A core concept within value engineering is cost engineering.[80] One important element of this is the capital depreciation schedule for each of the pieces of equipment and for the bioproduct facility as a whole. In other words, the question is how long will the processes last with routine maintenance, given the scale of the particular plant.

Value

Value analysis is by its nature iterative, integrative, and dynamic, in that it evolves and/or develops over time as feedstocks, technologies, local product and capital markets change. This points to a flexible approach to bioproduct facility development. This essentially entails bringing into alignment the four main financial dimensions for any bioproduct technology: feedstocks, processes, products, and capital. We term these the four broad market categories.

Bioproducts

A bioproduct generated from various process technology systems could be considered a finished, commodity, specialty, or branded product.[81] The next task is to locate and build markets within the four broad market categories (feedstocks, processes, products, and capital), and the 11 specific bioproduct categories that we outlined in the Bioproducts section.

To recap the four broad end-use bioproduct categories:

- Soil Amendments – These bioproducts provide benefits that include water conservation, lower pesticide and herbicide use, and improved soil tilth. They are mulch, digestate, compost, fertilizer, and biochar.
- Animal Feed – Animal and fish feed provide the carbohydrates and protein necessary for growth and overall health.
- Energy - This category includes fuel for use in transportation or heating and electricity for onsite use or to feed into the electric utility grid.
- Chemicals and Materials – This category includes the broad set of organic chemicals produced from renewable resources. These chemicals provide the raw materials for consumer products such as furniture, building materials, plastic bottles, etc.

Product Portfolio Management

In the bioproduct marketplace, most owners of bioproduct facilities are focused either on expanding the *scale* of producing a single bioproduct (e.g. compost) or on optimizing the appropriate balance of multiple bioproducts (i.e. increasing production *scope*). This means that production optimization calculations require both a strategic and tactical assessment of the portfolio of bioproducts that can be generated from a given complement of feedstocks and technologies. A portfolio of potential bioproducts must be analyzed in the same way as any portfolio of investments. The analysis algorithms will need to include, at a minimum, all of the four bioproduct types outlined above (soil amendments,

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[80] For more on cost engineering, see: https://en.wikipedia.org/wiki/Cost_engineering

[81] For a more detailed discussion of the value and process of branding commodities, see "The 22 Immutable Laws of Branding," By Ries and Ries, 2002.

animal feed, energy, chemicals and materials). These algorithms have not been fully articulated and published in any accessible form. But as with any other informational business, it is a make or buy decision on the part of the owner/investor as to how to obtain the appropriate portfolio algorithms needed to analyze their developmental investment.[82]

Scope and Scale Spectrum

We can define the market in terms of the diversity of bioproducts produced (portfolio scope) or in terms of the quantity, or scale, of a specific bioproduct relative to the other off-takes of a given process. Most producers, especially in the energy markets, are so used to competing on commodity scale that it is assumed that scale will be the uppermost concern in bioproduct markets as well. However, with organic residuals, where the feedstocks are both distributed and diverse, there is a need to "tune" a given system to accommodate the diversity of feedstocks as well as the diversity of local markets. Therefore, a bioproduct portfolio approach based on scope is often more competitive in local markets.[83]

Depending on the bioproduct category, we can also define the market as either onsite/local, regional (within a 10-250 mile radius of the facility), or national/international. For example, high bulk, low-value bioproducts (like mulch and compost) will have local markets. The cost of shipping these lower value, higher mass (low price/ton) bioproducts makes it unattractive to consider markets beyond 100 miles from the production facility. By contrast, a low bulk, high-value bioproduct (like a chemical) is very suited to regional or national distribution.

Integrated Value Analysis

The range of a potential bioproduct portfolio suggests that one take an integrated value analysis of potential markets. Performing an integrated value analysis prior to designing or investing in a given bioproduct technology is important. This paper provides the basic framework for performing this integrated bioproduct market value analysis. How this is performed, who performs it, and the degree of time and money that is invested in the analysis will likely determine the success or failure of the proposed bioproduct facility.

Capital

It is common for investors to think in terms of the "capital markets." Capital is typically thought of as monetary, and therefore, located in banks, the stock market, government bonds, and private equity holdings. However, capital assets also include property natural resources, human resources, and information.

When considering capital formation for a specific bioproduct facility, there are both traditional as well as emerging considerations for obtaining capital of the above-mentioned types. We will provide a brief overview of these aspects of capital markets that a bioproduct facility developer, owner, or manager can expect to utilize to design, build, and operate that facility.

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[82] For more on portfolio analysis, see https://en.wikipedia.org/wiki/Modern_portfolio_theory. For more information and/or assistance on performing portfolio analysis on a particular local bioproduct portfolio, contact the authors of this paper.
[83] For more on economies of scope and scale, see https://en.wikipedia.org/wiki/Economies_of_scope, and https://en.wikipedia.org/wiki/Economies_of_scale

Types of Capital

It has become common in sustainability discussions since the World Business Council on Sustainable Development,[84] to speak of a "triple bottom line" of monetary, natural, and social capital. These three types of capital, combined with informational capital, play a role in every bioproduct facility siting, commissioning, and operation. These four forms of capital will now be briefly described:

- **Monetary** - Investment and philanthropic capital is typically what is sought when building industrial bioproduct facilities. This form of capital is the basis of most enterprises, and the goal is typically to make cash-on-cash returns on investments.
- **Natural** - Minerals, timber, air, and soil are all forms of natural capital assets. The importance of factoring the use, depletion, and regeneration of natural capital has become an additional discipline.[85] Because, natural capital is typically part of the commonwealth, it is generally managed by governments or non-profits. It is antithetical for any one individual or corporation to excessively profit from the common natural capital. This is especially true for ecosystem services such as oxygen production, carbon sequestration, or water [86]
- **Social** – Knowledge, intelligence, skill, and labor are all forms of collective human assets that are essential for any enterprise. All company and government projects depend on a requisite amount and quality of skilled workers and thinkers to make the project happen.
- **Informational** – Data, algorithms, patents, and branding play a crucial role in any commercial project, however large or small. As society makes the transition from 'industrial' to 'informational' capitalism, the role of information as a capital asset is ever more important.[87] This also includes computational crowd sourcing.[88]

Sources of Capital

Monetary capital can be generated from multiple sources. Any one, or all, can be used to fund a bioproduct technology project:

- **Public Equity** – stocks, bonds, mutual funds, etc.
- **Private Equity** – individual investors and corporate investment banks
- **Grants** - public or private donations of money
- **Debt** – loaned money, repaid with interest
- **Taxes** – federal, state, local revenue levied on individuals

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[84] See www.wbcsd.org, "Vision 2050: The new agenda for business"
[85] See www.natcap.org and www.naturalcapitalproject.org
[86] For more see: www.unep.org/maweb/documents/document.300.aspx.pdf
[87] See www.philecon.capcog.com/informational-capitalism
[88] "Computational, heuristic crowd sourcing" is a term the authors coined to describe searchable Internet cloud stored information that is currently being developed and used to provide crowd-sourced information and intelligence. It can be manipulated to provide a kind of "artificial intelligence" database for use by particular user communities of practice. As the bioproducts industry participants move forward with gathering more organics residuals (discarded carbon and nitrogen based materials and compounds) and with converting them into bioproducts, this type of database, will need to be developed by and for this industry to support environmental, financial, and social risk-reduced and managed industry growth. See the "Bioproduct Market Development Guidelines" section of this paper for a beginning outline of how this database can be developed to support the emerging bioproducts industry.

- **Service and resource fees** – state and local levies for services (e.g. street cleaning, sanitation, etc.) or resources (e.g. water or energy).

Return on Capital Assets

Given the diversity of capital types and sources, as well as the continued evolution and development of these forms of value over time, there is an ongoing trend of increasing options and techniques for creating value in local, regional, national, and international economies.

Traditional Capital Markets:

Traditional carbon-based commodity capital markets (with a greater than 100 year history):

- Energy – Oil and gas companies (Chevron, Exon, BP, Shell, etc.), electric utilities (Duke, PGandE, Sempra, SoCal Edison, etc.), coal companies (Peabody Energy Corp, Arch Coal Inc., Cloud Peak Energy)
- Food, fiber – ADM, Cargill, Weyerhaeuser, Boise Cascade, etc.
- Waste collection – Waste Management, Republic Services
- Tipping Fees – Landfills near every municipality

Emerging Capital Markets:

Emerging renewable solar and carbon-based commodity capital markets include:[89]

- Renewable energy – solar, wind, and bioenergy
- Local food and fiber – harvested vs. cultivated, corporate vs. locally owned, open field vs. urban
- Recycling and Remanufacturing – collecting and shipping from the waste generating economies to manufacturing economies (e.g. recycled plastic and cardboard shipped from California to China for remanufacturing). There is a new movement to build local remanufacturing facilities from locally generated feedstocks.
- Carbon credits and Cap and Trade Proceeds – various climate or carbon credit exchanges have been developed and will be increasingly important as a viable form of capital formation (e.g. California has its own captive cap and trade system and, annually, is raising billions of dollars of revenue to reinvest in low carbon processes and products).[90]
- Net zero energy, water, and waste – the development of residential, commercial, municipal, and industrial facilities that are net zero relative to energy, water consumption, and waste production. These are called "net zero facilities."[91]

How all of these types, sources, and returns on capital affect each individual bioproduct facility project, is, of course, dependent on the local market conditions. The success of each bioproduct facility project will depend on an integrated market assessment and analysis.

Integrated Market Assessments and Analyses

Bioproduct facilities are different from fossil carbon refineries and factories in the following ways:

[89] Note that renewable carbon (plant based) is of course "manufactured" by plants from free *solar energy*, i.e. photosynthesis.
[90] For more on California's Climate Investments, see www.arb.ca.gov/cc/capandtrade/auctionproceeds/auctionproceeds.htm
[91] For more on net zero, especially relative to energy, see www.usgbc.org/education/sessions/making-net-zero-net-positive-solving-efficiency-cost-paradox-9849136

- **Drivers**: The bioproduct industry is not driven by a demand for products (except for the emerging demand for organic soil amendments of all types). Rather, it is driven by the desire to discontinue using the land, water, and air as a sink for the waste byproducts of the traditional "take, make, waste" linear economy.
- **Circularity**: As discussed in the MSW Trends, the "waste to recycling" laws have the effect of driving the formation of a circular economy. The development of a circular economy deeply changes the fundamentals of economic development, compared to the declining wasting, resource limited, linear economy. This vision and trend is briefly outlined in the following ways, as the renewable carbon industry (bioproducts industry) continues to emerge:
    - <u>Resource feedstock acquisition</u> – Fundamental to developing sustainable bioproduct value cycles means having an evolving efficiency in the capture and re-manufacture of renewable feedstocks that is hyper-efficient compared to the non-renewable resource economy. Since renewable resources (sunlight, water, and bio-based carbon) are all distributed locally, and are relatively "free" for the taking, they do not fit the old economic paradigm and model of "scarcity."[92]
    - <u>Process technology innovation and investment</u> – Since renewable resources are essentially "free", (for example, rainwater and sunlight falling on a building and landscape), they can be captured and put under renewable resource onsite management (i.e. site-based purification, refining, and reuse technologies and programs, as outlined in this paper). Given this scenario, the economics will migrate from resource "extraction and refining" toward "information and technology applications" of ever-more efficient onsite, or local, renewable capture, use, and perpetual re-use.[93] The fundamental economic innovation can be "onsite information technology based," rather than "resource extraction and sale" based.
    - <u>A new marketing narrative</u> – Given the free resource, information-based, distributed site potential inherent in the emerging circular economy, this changes the water, energy, and biomaterials market narrative profoundly. We can already see the emergence of green energy, local foods, and water utility vs. irrigation district marketing and public relations communications. The narrative is changing from one of "purchase, consume, and dispose," to one of "product and resource stewardship" in the home, business, and community. This involves transitioning away from the behaviors of over-purchasing, to one of intelligent use of everyday commodity resources (water, energy, and food). Ultimately, this represents a transition from being an unconscious "consumer," to becoming an intelligent system "collaborator" in the use and reuse of these essential renewable resources for life and living.
- **Interdependent Resources**: bioresources (cultivated and residuals) are highly integrated with:
    - Water resources - All bioresources require water to grow, i.e. $CO_2 + H_2O$ + sunlight + chlorophyll = carbohydrates through the process of photosynthesis

[92] For a thorough discussion of the "the myth of scarcity" and the application of the economics of sufficiency and abundance see "Part Two – Scarcity and Sufficiency: The Search for Prosperity" in "The Soul of Money", by Lynne Twist, 2003 and "Abundance: The Future Is Better Than You Think", by Diamandis and Kotler, 2012.
[93] See https://en.wikipedia.org/wiki/Killer_application

- Soil - All water to create bioresources is applied to soil first (save in a very small amount needed by hydroponic operations). Therefore, the soil health is a major contributor to water management and plant health, vigor, and productivity
- Energy – Organic residuals contain energy. To grow crops requires a significant amount of energy to both pump and wheel the water as well as to keep the soil aerated, be it through plowing or through other less soil invasive techniques (e.g. no-till, cut-till, cover crops, compost application, etc.).

The bioproducts industry is still required to develop alongside a fossil carbon economy which is the current foundation and lifeblood of the modern industrial economy. However, this could change as the bioproduct technologies continue to develop.

Assessing market fundamentals

Therefore, the job of bioproducts market assessment is first to analyze the local markets for the relevant bioproduct types within the context of the existing local feedstock types and economics, followed by the need to assess the volatility and sustainability of those markets.

However, the bioproduct markets must, of necessity, be viewed within the integrated context of feedstocks, process technologies, products and capital. These four "markets", as outlined in this paper, are inextricably interwoven in the development of the circular bioproducts industry. They must be analyzed and treated together, or the entire integration of these values will overlook the potential economies of scope and scale that can and will be achieved in the process of renewable carbon and nitrogen value cycle development.

Existing and potential markets-local to international

It is often said by marketing and sales professionals, that "all markets are local." This is especially true of the majority of bioproducts markets. The assessing of markets is required first at the local level. Once this is accomplished, regional, and finally, national and international markets can be analyzed for the potential applicable to higher value (price per ton) chemical, material, and energy bioproducts

Unfortunately, nascent bioproduct facility developers generally do not have active market information functions, even though it is important that such data be collected. Data collection is the primary step in determining market viability of a potential bioproduct facility and its capacity to generate products with appropriate economies of scope and scale. The process for this bioproduct market intelligence is outlined in the "Bioproducts Market Development Guidelines" section.

Market volatility and longevity

Once potential markets have been assessed for all three interrelated areas of the organics value cycle (feedstocks, processes, and bioproducts), the final step in bioproduct facility development planning is to determine the volatility and longevity of each given market (on-site, local, and regional/national). Noble Resources Group is developing a process for such an assessment.

Capital Market Integration

- The integration of the four markets of feedstocks, processes, bioproducts, and capital is foundational to the development of the bioproducts industry. This integration will require the assessment and local development of data, information, and the resulting intelligence and wisdom. Some of the information is already being collected, both by local communities and government agencies. Government agencies are required to collect and develop this information in all the three integrated resources of water, energy and organic residuals.[94] The types of data and information that need to be collected and integrated include, but are not limited to:

  - feedstock market data, information and analyses
  - type, location, amounts over time of organics residuals generated
  - organic residual tipping fees at landfills and existing or prospective processing facilities
  - transportation costs for various organic residuals, by location and geography
- Process technology market data, information and analyses
  - Technical data in terms of physical/chemical/biological transformations and throughput data
  - capital and operating costs
- Bioproduct and non-renewable carbon product market data, information and analyses
  - commodity prices for all carbon and nitrogen based compounds and materials
  - finished product types and prices
  - individual and aggregate market value of the bioproduct portfolio categories
  - commodity and branded product portfolios and dynamics
- Capital market data, information and analyses
  - forms and types of capital available at the local level
  - circular economic analysis of the organics value cycle in a community and region
  - economics of scope (optimizing multiple ROI's) vs. scale (maximizing a single ROI) analyses
  - capital integration analysis and algorithms

Using the above data information and analyses, it is possible to perform an integrated scenario assessment of the bioproducts that can be generated through capital and operating cost competitive and proven conversion technologies. For example, capital expense should be in the range of $ 1/lb of product produced, amortized over 15 years, i.e. about 6 cents per pound. Thus, if the cost of carbon from bio-based carbon and nitrogen feedstocks are significantly lower than fossil carbon, even at $30-$40/barrel, then bioproducts would be priced attractively. Of course, many feedstocks are currently being paid to be tipped, so unlike traditional resources markets, the bioproduct facility *can get paid to accept the organic residuals, rather than having to pay for the resource*. Therefore, feedstocks are another source of income, not a cost. Using the above information, the integrated feedstock, process, bioproduct, and capital market portfolio analysis can be used to *develop a cost and revenue competitive business model for a bioproduct manufacturing facility*. This is accomplished through a *market integration optimization process*, of the various types of capital used in, and formed by, the bioproduct facility. This is in contrast to the *economies of scale and profit maximization approach*, which is used in

[94] For example see the Solid Waste Information System (SWIS), http://www.calrecycle.ca.gov/swfacilities/directory/Search.aspx and the Facility Information Toolbox (FacIT), http://www.calrecycle.ca.gov/FacIT/, systems developed maintained and managed by CalREcycle; as well as all the water and energy databases managed by the California Water Board and California Energy Commission, respectively.

the traditional value chain market analysis in the linear market economy. The steps of this entire process are outlined in the next section.

Bioproduct Market Development Guidelines

In practice, the above integration of the four interrelated and interwoven bioproduct industry markets of feedstocks, technology, products, and capital can be articulated into the four phases of:

I. Initial Market Assessment Database
II. Bioproduct Facility Database
III. Enterprise Planning
IV. Bioproducts Facility Construction and Operation

The steps within each of these phases, can be turned into a new online system by the local facility developer, in association with other bioproduct developers in a given region or locality. The reason it *must be regional,* is because, as outlined in this paper, the majority of bioproduct markets (especially soil amendment markets) are local and to some extent regional (depending on transportation costs). Each of these phases can be broken into steps within open-system phases (I and II) and the more proprietary phases (III and IV), as follows:

I. Initial Market Assessment Database

1. ***Feedstock Assessment***
    - a. Feedstock Generation Sources (biosolids, food scraps, woody and/or green material, agricultural residue and manure)
        - i. Residential
        - ii. Commercial
        - iii. Industrial
    - b. Catalogue of Options
        - i. Organic Product Offerings
        - ii. Onsite, Local, Regional, National/International
2. ***Technology Assessment***
    - a. Product Appropriate
    - b. Scope to Scale Specific
    - c. Value and Investment Desired
3. ***Bioproduct Market Assessment***
    - a. Product Specific
    - b. Brand Value Options
    - c. Channel Availability
4. ***Capital Assessment***
    - a. Capital Elements Available
        - i. monetary (capital sources and revenue streams)
        - ii. natural (feedstocks and local positive and/or negative impacts on the facility)
        - iii. social (labor and environmental justice)
        - iv. informational (monitoring, dashboards/control, transparency, market/education)
    - b. Capital Elements to Source

II. Bioproduct Facility Database

1. Market Assessment System – structure in the cloud, and populate with above data
2. Provide access to clients –database access based on appropriate business model
3. Provide access to all others through a subscription – value based database access

III. Enterprise Planning

1. Enterprise Scenarios (relevant case studies)

   a. Public (wastewater) – Small, Medium, and Large
   b. Public (municipal solid waste) - Small, Medium, and Large
   c. Private (waste hauler/recycler) - Small, Medium, and Large
   d. Private (agriculture – manure, agricultural residue) – Small, Medium, and Large
   e. Public/Private (silvaculture – woody waste) – Small, Medium, and Large

2. Enterprise Plan Development

   a. Manufacturing and Operations
   b. Marketing and Sales
   c. Finance and Accounting

IV. Invest and Build Bioproducts Facility

1. Form the Capital

   a. Monetary - Venture, Debt, Bond, User Fees
   b. Natural – feedstock agreements, and permits (at all levels: zoning/building, water, air, solids, others)
   c. Social - labor (all skill levels)
   d. Informational – facility control, and product marketing

2. Design and Engineer the facility

   a. Science and Engineering plans
   b. Construction contractor
   c. Operational Resource Development – hiring, training

3. Market Development

   a. Detailed market assessment system set up
   b. Business proposition
   c. Merchandising and PR

4. Commission Facility(s)

   a. Trial Runs
   b. Hiring
   c. Press Releases, Sales
   d. Launch and Begin Operations

5. Operate the Facility

   a. Facility Operations
   b. Marketing and Sales of Bioproducts
   c. Accounting and Financial Management

Conclusion and Next Steps

This paper has been designed to provide a unique overview of the emerging bioproduct technology industry in the US, with a focus on California. It offers an integrated perspective of this industry, focusing on the organic residual value cycle of feedstocks, processes, bioproducts, and capital formation. In addition, it also acknowledges the interdependence of the bioresources with the companion and obligate resources of water and energy that both reinforce as well as comprise many of the bioproducts.

What this paper outlines:

- Industry drivers – regulations, policy, and investment strategies of municipalities and private companies
- Bioproduct facility developers – wastewater treatment plants, municipal solid waste programs (collection, processing, and recycling), agricultural operations (concentrated animal feeding operations, various food and fiber production, as well as natural, forest, and working land management), and silviculture operations
- Integrated markets – feedstocks, process technologies, bioproducts, and capital are treated in an integrated fashion in the context of the emerging integrated circular economic framework

Taken together, the elements of the emerging bioproduct technology industry outlined above provide a framework for a robust industry and market analysis useful for public or private investment. The investors may be feedstock generators, technology providers, bioproduct facility implementers, bioproduct marketers, or capital providers. It is also possible for a partnered combination of two or more of these investor categories to be involved simultaneously. What emerges from this analysis is a set of steps for bioproduct facility implementation. These steps are evolving as the industry emerges and learns from its own innovation, development and facility construction experiences.

Bioproduct facility implementation steps:

- Analyze feedstocks available in local markets – A bioproduct facility cannot be built if there is no long term stable source of grown or residual organics. The dynamic of the feedstock resources is the primary market driver of bioproduct facility development.
- Analyze potential bioproducts – Based on the quantity and quality of the feedstocks available over time, along with the capital and operating costs of processes available, a preliminary list of potential products can be created.
- Analyze local, regional, and national markets – This requires a market assessment both at the outset of the bioproduct facility development process, and on an ongoing basis as bioproduct markets fluctuate.
- Scenario development – Various scenarios need to be documented that outline multiple feedstock, process, and bioproduct combinations relative to the market values and cost of each. Then an analysis and ranking of the various scenarios must be completed.

Further concrete discussion of each of these steps will be forthcoming in subsequent papers.