DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.
ACKNOWLEDGEMENTS

The authors acknowledge and thank Jacques Franco from CalRecycle for his time spent discussing and updating his tracking list on solid waste conversion projects in California.

We also thank and appreciate Steve Kaffka for his advice and review of this report.

Thanks also to Judy Hanna her quick work with final formatting efforts.
ABSTRACT

California disposed 29.3 million tons of municipal solid waste (MSW) in landfills in 2012 and diverted an estimated 54 million tons. Total and per-capita and total waste disposal have decreased by about 30% since 2006. Biomass or biogenic materials account for approximately 59% of the landfill disposal stream. The landfill disposal stream is a large resource that potentially could support 16,000 GWh/y of electricity (10,400 GWh/y from biogenic materials). A number of California jurisdictions are exploring alternatives to landfilling for reasons that include; limited local landfill space, increasing disposal costs, difficulty and expense of siting new landfills, and increased diversion goals and other policies.

Conversion technologies (CT) with energy recovery and other byproducts is one landfill alternative (others include reducing waste generation at the source, increasing reuse, recycling, and composting efforts). Conversion can proceed along three main pathways—thermochemical, biochemical, and physiochemical, which can produce a variety of products that include heat, electricity, solid, liquid, and gaseous fuels, chemicals.

There are some 800 solid fuel combustion systems consuming MSW worldwide (three are in California). Approximately 100 gasification facilities that consume some kind of waste material are operating worldwide, most of which is high energy industrial or source-separated plastic wastes. Most MSW gasifiers operate as close-coupled combustion (“two-step oxidation”, but some advanced facilities are in development including projects in North America and California.

Anaerobic Digestion of the organic fraction of MSW has been extensively developed in Europe (installed capacity is more than 6 million tons per year) but there are a number of projects operating in California with more being developed.

AD in California is perceived to be relatively benign by the legislature and some stakeholders and enjoys some policy advantages. Thermochemical conversion of solid waste suffers from poor public image and is somewhat handicapped by state policy (is considered the same as landfilling). Countries in Northern Europe have achieved very low landfill rates by implementing policies that favor waste reduction and recycling as well as energy recovery (both from thermal conversion and AD).

It is a policy goal in California that 75% waste diversion be achieved by 2020. Appropriate policy instruments based on best practices, that reflect current science and incorporate life-cycle modeling of waste management options (recycling, energy, landfill, etc.) that reflect actual impacts and emissions for recycling commodities from California that enter the global market should be considered.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS ............................................................................................................. i

ABSTRACT .................................................................................................................................... ii

LIST OF FIGURES ....................................................................................................................... iv

LIST OF TABLES ......................................................................................................................... iv

Introduction ..................................................................................................................................... 1

Resource Potential .......................................................................................................................... 1

Disposal Stream .......................................................................................................................... 1

Energy Potential in the Disposal Stream .................................................................................... 2

Alternatives to Landfill Disposal ............................................................................................... 4

Conversion Pathways .................................................................................................................. 5

Thermochemical Conversion ...................................................................................................... 5

Biochemical Conversion ............................................................................................................. 6

Physicochemical Conversion ...................................................................................................... 7

Status of Conversion Technologies ........................................................................................... 7

Combustion Systems ................................................................................................................... 7

Gasification Systems ................................................................................................................... 7

Plasma Systems .......................................................................................................................... 12

Fuels production from MSW ....................................................................................................... 17

Biochemical Conversion Systems (Anaerobic Digestion) ........................................................ 19

   AD Systems in California ......................................................................................................... 19

   AD in Europe ............................................................................................................................ 23

Issues, barriers, potential solutions ........................................................................................ 24

LCA Synopsis ........................................................................................................................... 24

Recycling and Energy Recovery in the EU ............................................................................... 25

State Waste Policy ..................................................................................................................... 27

Conclusions and Recommendations ......................................................................................... 28

Appendix A: California Anaerobic Digestion projects (A partial list, August 2013) .......... 30
LIST OF FIGURES

Figure 1. Per-capita and total solid waste disposal in California (1989-2012).............................................. 1
Figure 2. California landfilled waste stream by material type. ................................................................. 2
Figure 3. Principal Biomass Conversion Pathways..................................................................................... 5
Figure 4. Ebara TwinRec schematic ......................................................................................................... 9
Figure 5. Enegos system schematic ........................................................................................................... 10
Figure 6. Schematic of the Kymijärvi II facility ......................................................................................... 11
Figure 7, Thermoselect schematic .......................................................................................................... 11
Figure 8. Westinghouse Plasma (AlterNRG) Reactor ............................................................................. 13
Figure 9. Schematic of Tees Valley IGCC facility .................................................................................... 13
Figure 10. Delivery and installation of plasma gasifier vessel, Tees Valley ............................................. 14
Figure 11. Schematic and photo of the InEnTec PEM system ............................................................... 15
Figure 12. Schematic of Plasco gasifier system ......................................................................................... 16
Figure 13. Ineos Bio process schematic ................................................................................................... 18
Figure 14. Enerkem process schematic ................................................................................................... 19
Figure 15. CWP facility at American River Packaging ........................................................................... 20
Figure 16. ZWE Smartferm facility in Marina........................................................................................... 21
Figure 17. ZWE San Jose Facility under construction ......................................................................... 21
Figure 18. Kroger’s Compton Digester ..................................................................................................... 22
Figure 19. Solid waste anaerobic digester capacity in Europe ................................................................... 23
Figure 20. MSW treatment strategies in the EU. ......................................................................................... 26
Figure 21. MSW treatment strategy trend, EU Group 1. ................................................................. 27

LIST OF TABLES

Table 1. Landfill stream composition and energy potential ........................................................................ 3
**Introduction**

California diverts approximately 65% of its municipal solid waste (MSW) from landfill.\(^1\) Diverted material is recycled or otherwise repurposed (e.g., compost, etc.). The amount of California MSW disposed in landfills was 29.3 million tons in 2012.\(^2\)

Total and per-capita and waste disposal have decreased by about 30% since 2006 (Figure 1).\(^3\)

![Figure 1. Per-capita and total solid waste disposal in California (1989-2012)](image)

**Resource Potential**

**Disposal Stream**

Biomass or biogenic materials account for approximately 59% of the landfill disposal stream (Figure 2) [Note: this is based on a 2008 characterization study]. Plastics, textiles and carpet make up 15% of the disposal stream, inert and non-wood construction waste contribute 14.6% and glass and metals account for another 6% (Figure 2).

---


\(^3\) Note: The 2006 local disposal peak closely follows a local housing construction peak in 2004 and 2005. Like disposal, housing starts dropped drastically in the lead up to the Great Recession (CA Dept. of Finance, California Construction Data: http://www.dof.ca.gov/html/fs_data/latestsecondata/FS_Construction.htm )
Energy Potential in the Disposal Stream

The potential energy from the California MSW landfill disposal stream is large. Primary energy of the disposed stream is about 0.28 Quads per year which is equivalent to the energy in 50 million barrels of crude oil. If converted to electricity, the disposal stream would support more than 1800 MW of generating capacity or about 16,000 GWh of electric energy (1190 MW and 10,400 GWh renewable energy from the biogenic components) [Table 1].

---

5 See Table 1 -note d) for assumptions used to estimate electricity potential
Table 1. Landfill stream composition and energy potential (2012 disposal amounts and 2008 waste stream composition data)  

<table>
<thead>
<tr>
<th>Landfilled</th>
<th>% of Total</th>
<th>Ash</th>
<th>Ash (million ton y⁻¹)</th>
<th>HHV (\text{MJ/kg, ar})</th>
<th>HHV %wb</th>
<th>Moisture %wb</th>
<th>Landfilled (million ton dry)</th>
<th>HHV (MJ/kg, dry)</th>
<th>Primary Energy by Component (EJ)c</th>
<th>Primary Energy by Component (%)</th>
<th>Electricity Potentiald (MWe) (GWh y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper/Cardboard</td>
<td>5.1</td>
<td>17.3</td>
<td>5.3</td>
<td>0.3</td>
<td>16</td>
<td>2.77</td>
<td>10</td>
<td>4.6</td>
<td>17.8</td>
<td>0.074</td>
<td>26</td>
</tr>
<tr>
<td>Food</td>
<td>4.5</td>
<td>15.5</td>
<td>5.0</td>
<td>0.2</td>
<td>4.2</td>
<td>0.65</td>
<td>70</td>
<td>1.4</td>
<td>14.0</td>
<td>0.017</td>
<td>6</td>
</tr>
<tr>
<td>C&amp;D Lumber</td>
<td>4.2</td>
<td>14.5</td>
<td>5.0</td>
<td>0.2</td>
<td>17</td>
<td>2.47</td>
<td>12</td>
<td>3.7</td>
<td>19.3</td>
<td>0.066</td>
<td>23</td>
</tr>
<tr>
<td>Prunings, trimmings, branches, stumps</td>
<td>1.0</td>
<td>3.3</td>
<td>3.6</td>
<td>0.03</td>
<td>11.4</td>
<td>0.38</td>
<td>40</td>
<td>0.6</td>
<td>19.0</td>
<td>0.010</td>
<td>4</td>
</tr>
<tr>
<td>Other Organics</td>
<td>1.3</td>
<td>4.3</td>
<td>10.0</td>
<td>0.1</td>
<td>8.5</td>
<td>0.37</td>
<td>4</td>
<td>1.2</td>
<td>8.9</td>
<td>0.010</td>
<td>3</td>
</tr>
<tr>
<td>Leaves and Grass</td>
<td>1.1</td>
<td>3.8</td>
<td>4.0</td>
<td>0.0</td>
<td>6</td>
<td>0.23</td>
<td>60</td>
<td>0.4</td>
<td>15.0</td>
<td>0.006</td>
<td>2</td>
</tr>
<tr>
<td><strong>Biomass Components of MSW Total</strong></td>
<td><strong>17.2</strong></td>
<td><strong>58.8</strong></td>
<td><strong>0.9</strong></td>
<td><strong>6.9</strong></td>
<td><strong>11.9</strong></td>
<td><strong>0.18</strong></td>
<td><strong>64</strong></td>
<td><strong>1190</strong></td>
<td><strong>10,427</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All non-Film Plastic</td>
<td>1.8</td>
<td>6.2</td>
<td>2.0</td>
<td>0.04</td>
<td>22</td>
<td>1.37</td>
<td>0.2</td>
<td>1.8</td>
<td>22.0</td>
<td>0.036</td>
<td>13</td>
</tr>
<tr>
<td>Film Plastic</td>
<td>1.0</td>
<td>3.4</td>
<td>3.0</td>
<td>0.03</td>
<td>45</td>
<td>1.53</td>
<td>0.2</td>
<td>1.0</td>
<td>45.1</td>
<td>0.041</td>
<td>14</td>
</tr>
<tr>
<td>Textiles</td>
<td>1.6</td>
<td>5.4</td>
<td>7.0</td>
<td>0.11</td>
<td>17.4</td>
<td>0.94</td>
<td>10</td>
<td>1.4</td>
<td>19.3</td>
<td>0.025</td>
<td>9</td>
</tr>
<tr>
<td><strong>Non-Renewable Carbon Compounds Total</strong></td>
<td><strong>4.4</strong></td>
<td><strong>15.0</strong></td>
<td><strong>0.18</strong></td>
<td><strong>3.84</strong></td>
<td><strong>4.2</strong></td>
<td><strong>0.10</strong></td>
<td><strong>36</strong></td>
<td><strong>646</strong></td>
<td><strong>5,663</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other C&amp;D</td>
<td>4.3</td>
<td>14.6</td>
<td>100</td>
<td>4.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal</td>
<td>1.3</td>
<td>4.6</td>
<td>100</td>
<td>1.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Mixed and Mineralized</td>
<td>1.6</td>
<td>5.6</td>
<td>100</td>
<td>1.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>0.4</td>
<td>1.4</td>
<td>100</td>
<td>0.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mineral Total</strong></td>
<td><strong>7.7</strong></td>
<td><strong>26.2</strong></td>
<td><strong>7.7</strong></td>
<td><strong>0.0</strong></td>
<td><strong>7.7</strong></td>
<td><strong>0.0</strong></td>
<td><strong>0</strong></td>
<td><strong>0</strong></td>
<td><strong>0</strong></td>
<td><strong>0</strong></td>
<td><strong>0</strong></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>29.3</strong></td>
<td><strong>100</strong></td>
<td><strong>8.8</strong></td>
<td><strong>10.70</strong></td>
<td><strong>19</strong></td>
<td><strong>23.8</strong></td>
<td><strong>13.2</strong></td>
<td><strong>0.284</strong></td>
<td><strong>100</strong></td>
<td><strong>1837</strong></td>
<td><strong>16,089</strong></td>
</tr>
</tbody>
</table>

c) \(EJ = 10^{18} \text{J} (\text{exajoule})\) = \(10^{18} \text{J} (\text{exajoule})\) and is approximately equal to 1 Quad (1 \(Q = 1.055 \text{EJ}\))  
d) Electricity generation calculations assume thermal conversion means for low moisture stream (paper/cardboard, other organics, C&D Lumber, all plastics and textiles) and biological means (anaerobic digestion) for the high moisture components (food and green waste). Energy efficiency of conversion of matter to electricity by thermal means is assumed to be 20%. Biomethane potentials of 0.29 and 0.14 g CH4/g VS for food and leaves/grass mixture respectively are assumed for biogas production which is converted at 30% thermal efficiency in reciprocating engines. Capacity factor of 1 is used.  
e) Note: updated to show 2012 disposal. Does not include green ADC and ADC  

---  
Alternatives to Landfill Disposal

California communities and waste jurisdictions are exploring alternatives to landfill disposal of municipal solid waste (MSW). A list of those jurisdictions would include:

- City of Los Angeles,
- County of Los Angeles
- Santa Barbara City/County
- Solvang
- Buelton
- Goleta
- San Bernardino City / County
- San Jose
- San Francisco
- Glendale,
- Salinas Valley
- West Placer,
- Humboldt County
- San Rafael
- Yolo County

There are a number of reasons for this including limited landfill space, increasing disposal costs in some regions in California, difficulty and expense of siting new landfills, and increased diversion goals. Policies, such as AB 32 climate change legislation, also influence landfill disposal decision making.

Landfill alternatives include reducing waste generation at the source, increasing reuse, recycling, and composting efforts or increasing conversion to energy or other products. The use of conversion technologies [CTs], offers the opportunity to produce energy (some of it renewable) while reducing landfill disposal.
Conversion Pathways

Conversion of organic (or carbon-containing) material can proceed along three main pathways—thermochemical, biochemical, and physiochemical, which can produce a variety of products that include heat, electricity, solid, liquid, and gaseous fuels, chemicals and more (Figure 3).

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Conversion</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>Thermochemical Conversion</td>
<td>Energy</td>
</tr>
<tr>
<td>Collection</td>
<td>– Combustion</td>
<td>– Heat</td>
</tr>
<tr>
<td>Processing</td>
<td>– Gasification</td>
<td>– Electricity</td>
</tr>
<tr>
<td>Storage</td>
<td>– Pyrolysis</td>
<td>– Fuels</td>
</tr>
<tr>
<td>Transportation</td>
<td>Bioconversion</td>
<td>– Solids</td>
</tr>
<tr>
<td></td>
<td>– Anaerobic/Fermentation</td>
<td>– Liquids</td>
</tr>
<tr>
<td></td>
<td>– Aerobic Processing</td>
<td>– Gases</td>
</tr>
<tr>
<td></td>
<td>– Biophotolysis</td>
<td>– Products</td>
</tr>
<tr>
<td></td>
<td>Physicochemical</td>
<td>– Chemicals</td>
</tr>
<tr>
<td></td>
<td>– Heat/Pressure/Catalysts</td>
<td>– Materials</td>
</tr>
<tr>
<td></td>
<td>– Hydrotreating/Cracking/Refining</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 3. Principal Biomass Conversion Pathways*

**Thermochemical Conversion**

Thermochemical (thermal) conversion processes include combustion, gasification and pyrolysis. Thermal conversion is characterized by higher temperature and conversion rates and can generally convert all the carbon-containing components in the feedstock (e.g., lignin and lignocellulose or woody materials). It is best suited for lower moisture feedstocks.

**Combustion** (also called incineration) is the complete oxidation of the feedstock without generating intermediate fuel gases, liquids, or solids for use. Combustion processes can provide useful heat at high temperature for heating or steam production. Electricity can be produced usually from a steam turbine power system (steam Rankine cycle).

**Gasification** is the conversion of a solid or liquid carbonaceous feedstock into a gaseous fuel. This is often done by direct heating (autothermal) through partial oxidation of the feedstock to provide the necessary heat to drive the gasification reactions. Gasification can also occur by indirect heating (allothermal) with steam used for the gasification agent. The product fuel gas has a wide range of potential uses or final products. It can
be burned directly in a furnace or boiler to produce heat and/or steam (like the direct combustion pathway), or with sufficient cleaning and upgrading, the gas can be used as a fuel for stationary engines, gas turbines or even fuel cells for work or power production. With the appropriate level of gas processing and reforming, a “synthesis” gas or “syn-gas”, composed of carbon monoxide and hydrogen can be produced which can then be used as a feedstock for liquid or gaseous vehicle fuels or chemical production.

**Pyrolysis** is the thermal decomposition of a feedstock by heating in the absence of oxygen (or air). Energy must be supplied to the process from an outside source (or by burning some of the feedstock or product and transferring the heat into the pyrolyzer). Pyrolysis yields a fuel gas, a liquid (pyrolysis liquids or bio-oil) and a solid char and ash product or residue. The relative amounts of these three products depend on reactor temperature and rate of feedstock heating and feedstock composition and morphology. Further processing or upgrading of pyrolysis products is usually required before use as fuel or energy products. Catalytic pyrolysis technologies use appropriate catalyst material in the pyrolysis reactor to improve product quality and/or increase relative amounts of a particular product type.

**Plasma arc and radio frequency** (or microwave) heating refer to specific devices used for reactor heating. These systems can operate as gasifiers or pyrolyzers depending on the amount of oxygen fed to the reactor.

**Biochemical Conversion**

Biochemical conversion (bioconversion) processes include anaerobic digestion, aerobic conversion, fermentation and others. Bioconversion proceeds at lower temperatures and lower reaction rates. Higher moisture feedstocks are preferred. Bioconversion does not readily convert or degrade the lignocellulosic or woody materials in the feedstock.

**Anaerobic digestion** is a fermentation technique that is sometimes employed in waste water treatment facilities for sludge degradation and stabilization but also the principal process occurring in landfills. Engineered anaerobic digester systems can be used to treat or stabilize waste waters and solid residues from food processing, confined animal feeding operations, etc. as well as some components of the municipal solid waste stream (food wastes, high moisture green waste, etc.). Anaerobic digestion operates without free oxygen and results in a fuel gas called biogas containing mostly methane and carbon dioxide.

**Aerobic conversion** includes most commercial composting and activated sludge wastewater treatment processes. Aerobic conversion uses air or oxygen to support the metabolism of the aerobic microorganisms degrading the substrate. Aerobic processes
operate higher reaction rates than anaerobic processes and produce more cell mass, but generally do not produce useful fuel gases.

**Fermentation**, also operates without oxygen, is generally used industrially to produce fuel liquids such as ethanol and other chemicals as well as consumable alcohol products. Although fermentation and anaerobic digestion are commonly classified separately, both are fermentation methods designed to produce different product streams. Cellulosic feedstocks need pretreatment (acid, enzymatic, or hydrothermal hydrolysis) for sugar molecules to be available for fermentation.

**Physicochemical Conversion**
Physicochemical conversion involves the synthesis of products using physical and chemical processing at near-ambient temperatures and pressures. It is primarily associated with the transformation of fresh or used vegetable oils, animal fats, greases, tallow, and other suitable feedstocks into useful liquid fuels and chemicals such as biodiesel, frequently by transesterification, a reaction of an organic glyceride with alcohol in the presence of catalyst.

**Status of Conversion Technologies**

**Combustion Systems**
It’s estimated that there are more than 800 thermal MSW-to-energy facilities operating in the world for a combined capacity of about 195 million tons per year. The vast majority of these use solid-fuel grate-fired combustion technology. There are three of this type of facility operating in California.

**Gasification Systems**
A report by UC Riverside lists more than 100 gasifier facilities worldwide built since 1979 that had operated using solid waste feedstocks that included MSW or industrial wastes. Facility scale ranged from 500 to 200,000 tons per year. It is not known if all are still operating.

It is reported that more than 100 solid waste gasifiers are operating in Japan.

---

Though gasification offers the potential to produce a wider range of products (or produce energy more efficiently) than solid-fuel combustion, most MSW gasification facilities direct-fire the product gas in boilers or furnaces for energy recovery (sometimes called “two-step oxidation” or close-coupled combustion). Overall energy efficiencies for these systems are usually slightly lower than large scale solid fuel combustion with energy recovery.11

The nonhomogeneity of MSW is challenging for gasifiers to produce a uniform and high quality gas needed for chemical and fuels production. Gas cleaning and processing systems needed to prepare the gas for use in high efficiency energy conversion (i.e., gas-turbine-combined-cycles or fuel cells) or fuels and chemical production are complex and expensive. In fact, even for uniform and “clean” biomass feedstocks, gasifier systems for fuels, chemicals or high-efficiency energy conversion are not yet commercial.

There are several MSW gasification projects being planned or built in the United Kingdom, including an “advanced system” which will employ high efficiency gas-turbine-combined-cycle energy system (along with the necessary and extensive gas cleaning equipment). Economics are more favorable in the UK for waste gasification projects due, in part, to relatively high tip fees (more than $100 per ton) and the availability of Renewable Obligation Credits (ROCs). Electricity from waste gasification that employs close-coupled combustion with a steam cycle (so called standard gasification) is eligible for 0.5 ROC/MWh of delivered electricity. Advanced gasification systems (defined in the UK as gasifiers that utilize engines or gas turbines and/or combined cycles to produce power) are eligible for 2 ROCs/MWh.12 ROCs in the UK are worth about £42 which is equivalent to ~$0.12/kWh for 2 ROCs/MWh.13

Pilot and pre-commercial demonstration projects targeting high value liquid fuels production from MSW gasification (and sometimes industrial wastes) are being pursued currently worldwide. A variety of conversion techniques and product types (e.g., alcohol or “drop-in” hydrocarbon fuels) are being developed. Projects being developed by Sierra Energy, Ineos Bio, and Energem are briefly discussed below.

Examples of gasifier-close-coupled-combustion systems fueled by solid waste are the Ebara “TwinRec” and the Energos systems (Figures 4 and 5).

**Ebara TwinRec**

The Ebara TwinRec system consists of an air-blown fluidized bed gasifier which is close-coupled to a combustion chamber. Product gas leaves the gasifier and enters the combustion chamber along with secondary air where it is burned. Temperatures are high enough in the

---


combustor (up to 1350 °C) to melt or slag the ash that carries over with the product gas.¹⁴ Hot flue gas can be sent to a heat recovery boiler. There are approximately 15 TwinRec facilities operating in Japan and at least one in Europe.¹⁵

Figure 4. Ebara TwinRec schematic.

**Energos**

The Energos system is essentially a grate-fired combustor operated as a gasifier in ‘partial oxidation’ mode. The product gas transfers to an oxidation chamber where secondary air is added to complete the combustion. The hot flue gases continue on to a heat recovery boiler.

The Energos system was developed in Norway to provide relatively small communities with an economic alternative to much larger conventional mass burn combustion facilities. The capacity of Energos facilities ranges from 30 to 118 tons per day. They consume similar types of MSW feedstocks as the large combustion systems and produce the same types of air pollutants (which means that appropriate flue gas emissions controls are needed to meet permit levels). There are eight operating Energos facilities in Europe.¹⁶

Figure 5. Energos system schematic.

Direct-fire application with intermediate gas conditioning.

Kymijärvi II
The Kymijärvi II facility at Lahti, Finland is an example of solid waste gasification where the raw product gas is conditioned prior to being burned in a boiler for steam production. This facility began operation in 2012 and consists of two Metso circulating fluidized bed gasifiers. The facility produces 50 MW electricity (from a steam turbine-generator) and 90 MW thermal energy for district heating purposes.

The facility capacity is 250,000 metric tonnes per year of solid recovered fuel (SRF) spec’d to meet the CEN/TC 343 SRF standard. The SRF is described as a shredded, source-separated solid waste mixture of wood, and non-recyclable paper, cardboard and (non PVC) plastic.\textsuperscript{17}

The gas conditioning step consists of cooling from about 900 °C to 400 °C to condense alkali chlorides, lead and zinc compounds while leaving tar compounds in vapor phase. This is followed by hot gas filtering to remove solid and condensed particulate matter.

This gas conditioning reduces the potential for boiler tube corrosion which allows for higher steam pressure and temperature (120 bar and 540°C compared to 65 bar and 480°C typically). Better steam parameters give improved steam cycle energy efficiency.

\textsuperscript{17} Lahti Energia. Accessed August 2013: http://www.lahtigasification.com/power-plant/terminology
Thermoselect
Thermoselect is an oxygen-blown gasifier system developed in Europe in the 1990’s with approximately six facilities now operating in Japan.\(^{18}\) The product gas is variously used in boilers or, with sufficient gas cleaning, in stationary engines for heat and power. Temperatures are high enough to melt the ash which is cooled and recovered in vitrified form. Figure 7, taken from the Thermoselect website, shows potential gas cleaning and conditioning apparatus that could be employed to produce high quality syngas suitable for chemical or fuels production. It’s not clear if the existing facilities have this level of gas cleanup installed since they are producing heat or steam or running stationary reciprocating engines for heat and power.

---

Plasma Systems

Plasma or plasma arc is a heating method that can be used in pyrolysis, gasification or combustion systems depending on the amount of air, oxygen, steam or hydrogen fed to the reactor. Plasma is a high temperature ionized gas created by flowing gas through an electric arc. The technology was used as a heat source in the metals industry (electric arc furnaces) and lighting (carbon arc lamp) beginning in the late 19th century. In recent decades, the technology has been adapted to treat hazardous radioactive waste through vitrification, making the material less susceptible to leaching to ground water when buried. The main advantage of plasma in waste treatment is the intense heat and very high temperatures it can generate.

Plasma based gasification systems are being developed and marketed by multiple technology and project developers. Based on an internet search, we believe there remains one plasma gasification facility in commercial operation that consumes MSW (and sewage sludge). This is a 24 ton per day Westinghouse Plasma facility in Mihama Japan. A larger facility (220 tons per day MSW and auto shredder residue) in Utashinai Japan has closed sometime after 2010 due to lack of feedstock.19

There are numerous plasma-based melters and gasifiers operating in the world consuming hazardous wastes.

Westinghouse Plasma (AlterNRG)
The system developed by Westinghouse Plasma Corp. (now owned by AlterNRG) is probably the best known or most marketed plasma gasifier technology. The reactor design employees plasma torches near the lower end of the reactor which provide heat for reaction and to melt the inorganic (or ash) residue. Air, oxygen, and/or steam are injected to support gasification or combustion (Figure 8).

Tees Valley Renewable Energy Facility

A large waste-to-energy facility that will use the Westinghouse Plasma technology is being built in Tees Valley, England. The project developer is Air Products. The facility will be sized to consume up to 1100 tons per day of non-recyclable MSW and produce about 50 MW electricity.

The integrated-gasifier-combined-cycle (IGCC) facility will use a single large Westinghouse Plasma oxygen-blown plasma gasifier. The product gas will be cooled and cleaned to remove particulate matter, HCl and other acid gases, ammonia, sulfur, and mercury. The gas will fuel two combustion gas turbine-generators with exhaust heat recovered in a heat recovery steam generator. The steam will run a steam turbine-generator for additional electricity (Figure 9).

Figure 8. Westinghouse Plasma (AlterNRG) Reactor

Figure 9. Schematic of Tees Valley IGCC facility (steam turbine cycle not shown)
The “largest plasma gasifier reactor vessel in the world” was delivered to the Tees Valley site May 2013 with commissioning and start-up planned to occur in 2014. 20 The facility capital cost is $500 million ($10,000/kW). In addition to power sales, project revenue will include Renewable Obligation Credits, and tipping fee for the feedstock material (tipping fees in England are ~ $125/ton). 21 Air Products is developing or planning two similar projects in the UK (same scale and technology).

![Image of plasma gasifier vessel](image)

**Figure 10. Delivery and installation of plasma gasifier vessel, Tees Valley**
(source: Howard (2013))

---


21 Ibid.
InEnTec Plasma System
InEnTec, Richland, WA has developed the “Plasma Enhanced Melter” (PEM) system that uses a fixed bed oxygen and steam blown gasifier to convert most of the carbon containing feedstock to gas. The char and ash residue is transferred to the plasma process vessel where plasma arcs operate to provide heat to rapidly gasify the remaining carbon and melt the inorganic (ash) fraction. The gas from the gasifier and the plasma vessel flow to a thermal residence chamber (TRC) to allow final gas products to reach equilibrium (Figure 11).22

!!Figure 11. Schematic and photo of the InEnTec PEM system!!

The InEnTec PEM is operating at a Dow Corning facility processing industrial byproduct and producing hydrochloric acid and syngas. There is also a demonstration facility at the Columbia Ridge Landfill, Arlington, OR that consumes about 25 tons per day of high plastics content MSW.

Plasco
Plasco (Ontario, Canada) has developed a gasifier system for MSW that utilizes a grate fired reactor operated as a gasifier (see “Converter” in Figure 12). The system also employs plasma torches in two locations; (1) the “solid residual melter,” which gasifies the char and melts the inert material left over from the main gasifier, and, (2) the duct between the gasifier and cyclone where the raw product gas is subjected to high temperatures which crack hydrocarbons and tars to improve gas quality. Proposed projects would use the product gas to fuel stationary reciprocating engine generators for power and heat.

Plasco operates an 85 tpd demonstration facility in Ottawa, Canada and a 5 tpd research facility in Spain. Plasco is currently designing and permitting a 150,000 ton per year facility in Ottawa. The facility will use three gasifier modules and a number of engine-generators and a steam turbine system to generate approximately 20 MW gross with about 15 MW net available to the grid. A tipping fee of more than $80 per ton has been negotiated for material consumed in the facility.

Plasco participated in a number of California requests for information (RFIs) and requests for proposals (RFPs) including both the City and County of Los Angeles and the Salinas Valley Solid Waste Authority (SVSWA).

Plasco was ranked among the top two responses in the SVSWA evaluation. In preparation for potential permitting and project financing, Plasco obtained a legal opinion in 2010 on their technology from CalRecycle that helped earn pre-certification for RPS eligibility for the project from the Energy Commission. Approximately 18 months later, CalRecycle rescinded the 2010

---

legal opinion.\textsuperscript{24} Plasco appealed to the Governor and lobbied the legislature for relief. Plasco ceased development in California when the appeal effort failed.\textsuperscript{25}

\textbf{Fuels production from MSW}

Liquid and gaseous fuels can be produced from thermochemical and biochemical conversion processes. Fuels typically have higher value than electricity and there are many companies attempting to commercialize processes that convert biomass and MSW into fuels. Companies with pilot or demonstration projects in California include Sierra Energy, West Biofuels and KORE Infrastructure LLC, among others.

\textbf{Sierra Energy}

Sierra Energy is a small company with a development unit at McClellan Business Park, Sacramento. The main component of their process is an updraft oxygen-blown gasifier based on a blast furnace design used in the steel industry.

They are working with Velocys, a Fischer Tropsch technology provider to produce “drop in” hydrocarbon fuels (diesel and gasoline) from thermal conversion of biomass, MSW, petcoke, tires and other waste materials. A small process development unit has operated on various feedstocks for short duration test runs.

Sierra Energy has several grants from the Energy Commission and the Federal Government including a project funded by the Department of Defense to demonstrate electricity production from waste materials generated on base at US Army Fort Hunter Liggett in Monterey County.\textsuperscript{26}

\textbf{Ineos Bio}

Ineos Bio reported July 2013 that operation has begun at its woody/green waste-to-ethanol facility in Vero Beach Florida.\textsuperscript{27} The facility is designed to produce 8 million gpy of ethanol and 6 MW of electricity. The process uses a combination of thermal conversion (gasification) and biochemical conversion (fermentation) to produce ethanol (Figure 13).

Ineos Bio licensed the process from Bioengineering Resources, Inc. (BRI) in 2008. The BRI process, developed by a team led by Dr. James L. Gaddy at the University of Arkansas, utilizes

\textsuperscript{24} The 2010 legal opinion and the 2012 Rescission Letter are available here: \url{http://www.terutalk.com/pdf/plasco-salinas/20101123CalRecycle.pdf} \url{http://www.terutalk.com/pdf/plasco-salinas/20120523Mortenson.pdf}


a culture of acetogenic bacteria (*Clostridium ljungdahlii*) that produces ethanol from CO and H2 (syngas).²⁸

![Figure 13. Ineos Bio process schematic.](image)

**Enerkem**

Enerkem is building a facility at the Edmonton Solid Waste Management Center (Canada) to convert post-MRF solid waste to methanol and ethanol fuels. This is the first commercial facility built by Enerkem. The system will use a bubbling fluid bed oxygen-blown gasifier with extensive gas cleaning and conditioning followed by catalytic reactors to produce methanol and ethanol (Figure 14). The product capacity is 36 million liters per year (about 10 million gallons alcohol per year, or 7 million gallons gasoline equivalent/year) from conversion of 110,000 tons (dry basis) of refuse derived feedstock (RDF). The facility capital cost is reported to be $80 million with commissioning planned for late 2013.²⁹ The capital cost equates to ~$11.40/ gallon-gasoline-equivalent of annual capacity which is within the $7.60-$15.10/gge annual capacity range discussed by Anex et al. (2010) for a 37 million gge facility.³⁰

Biochemical Conversion Systems (Anaerobic Digestion)

AD Systems in California
There are a number of anaerobic digestion facilities in California that are operational or planned that consume (or will consume) food waste, green waste, or fats, oil and grease (FOG). At least six facilities are believed to be operating with another twenty-five projects that some stage ranging from pilot demonstration, feasibility study, permitting, construction or commissioning (See Appendix I). The known operating AD projects include co-digestion at East Bay MUD, green & food waste digestion in Marina, and projects in Sacramento, Los Angeles and Chino.31

East Bay Municipal Utility District
East Bay Municipal Utility District (EBMUD) is a publically owned waste water treatment facility in Oakland which has excess biosolids digester capacity. In order to utilize some of the idle digester capacity and increase biogas production for onsite energy purposes, EBMUD began investigating co-digestion of food waste and eventually developed infrastructure for receiving, pre-processing, and digesting pre- and post-consumer food waste and waste fats, oils

and grease (FOG). The facility processes about 20 tons per day of food waste. It is claimed that EBMUD is the first sewage treatment plant in the United States to co-digest food scraps.32

**Clean World Partners**

Clean World Partners (CWP) has licensed the APS, high-solids, two-stage digester system developed at UC Davis and is developing projects in the Sacramento Area. The projects are partially funded by Energy Commission and Federal grants.

CWP operates a facility in Natomas at American River Packaging (ARP) where 5-7 tons per day of food waste and cardboard scraps are digested (Figure 15). Microturbines are used to produce electricity that is used by ARP.

Another CWP facility is being commissioned at the Sacramento Area Transfer Station (SATS). The SATS facility is designed to convert 25 tons per day of food waste. The facility includes equipment to upgrade the biogas into renewable natural gas (biomethane) for vehicle fuel (identical to compressed natural gas). The biomethane is used in Atlas Disposal’s waste trucks.

CWP and UC Davis are planning a digester installation at the closed UCD landfill. Feedstock would come from various campus residue sources (approximately 10,000 tons per year of food and green waste and possibly animal manures). The gas would be used for electric power to contribute to the “Net Zero” energy goal of the West Village community on the west side of campus.

---

**Zero Waste Energy**

Zero Waste Energy (ZWE) is involved in at least six AD projects in California; one is operating and the others are either under construction or in permitting and planning stages. ZWE has licensed the “Kompoferm” and “Smartferm” high solids (or dry) digestion systems developed by Eggersmann Group in Germany. These systems use “garage type” or container style reactor vessels which are have an air tight door on one end. The relatively dry feedstock (~40% solids) is batch loaded with a front end loader. After loading and closing the door, a biologically active percolate (liquid) is circulated through the substrate during anaerobic decomposition. After the appropriate reaction time (on the order of 10-21 days), the percolate flow is stopped and the digestate is removed and sent to compost for final stabilization.

ZWE built and operates a Smartferm facility for the Monterey Regional Waste Management District in Marina, CA. The Marina facility is designed for 5,000 tons per year of green and food waste (Figure 16). The biogas is used for energy production from a containerized combined heat and power system supplied by 2G-Cenergy. The energy system includes 100 kWe reciprocating engine-generator (MAN Engines) with heat recovery.

The ZWE facility at San Jose is under construction with the first phase expected to be operational by the end of 2013 (Figure 17). The facility is planned for three phases each with capacity of about 80,000 tons per year of pre- and post-consumer food waste, MRF residuals and green waste. This facility will use the Kompoferm technology which is generally larger than Smartferm installations and includes the “dry” digestion components as well as an in-vessel composting system. Each 80,000 tpy phase is expected to produce about 1.6 MW of power plus up to 1.8 MWth of heat. The facility is being built on a closed landfill.

Other ZWE Smartferm facilities being built, permitted or planned in California include a 10,000 tpy facility in South San Francisco that will produce biomethane for CNG fuel, and two facilities in Ventura County; a 5000 tpy facility with 100 kW electric power production and a 150,000 tpy facility for biomethane CNG production and a 20,000 tpy facility in the city of Napa.

---

34 Ibid.
**Kroger’s, Compton CA**

Kroger resource recovery project uses non-sellable food items returned from Ralph’s and Food4Less to the Kroger’s Compton distribution facility. The anaerobic digester system was designed and is operated by Feed Resource Recovery Inc. (Figure 18). The facility is expected to process 50,000 tpy of material that otherwise would have been hauled some 100 miles to a compost facility. The gas is used for heat and power, partially offsetting the distribution center’s purchased energy.

**Other California AD Projects**

Other California AD Projects in varying stages of development include:

A refurbishment and restart of a closed digester facility, owned by the Inland Empire Utility Agency (IEUA) in Chino, Environ Strategies Consultants has leased the facility and is in the process of restarting. The facility will used source separated food waste from the area. Biogas will be used for power production which will be sold to IEUA.37

The Central Marin F2E (food to energy) project is in permitting and preliminary construction. It is a public-private partnership between the Marin Sanitary Service ([MSS] a private solid waste collection and recycling/recovery company) and the Central Marin Sanitation Agency ([CMSA] a publically owned waste water treatment facility). The project involves sourcing and separating food waste at the MSS which is then hauled to the CMSA where the material will be processed into a slurry and added to existing activated sludge digesters. The extra biogas produced by the co-digestion will increase energy production which is used onsite and will be exported if there is excess.38

A brief list of other known AD projects in California, provided by Jacques Franco (CalRecycle) is included in Appendix I.

---

AD in Europe
AD of the organic fraction of municipal solid waste (MSW) is used in different regions worldwide to:\(^{39}\)

- Reduce the amount of material being landfilled
- Stabilize organic material before disposal in order to reduce future environmental impacts from air and water emissions
- Recover energy

Anaerobic digestion of MSW technology has advanced in Europe over the past 30 years due in large part to progressive waste management policies intended to reduce long-term health and environmental impacts of landfill disposal.\(^ {40}\) This, and relative scarcity of land (compared to the US) has led to high waste tipping fees for landfill disposal. Total installed capacity of AD systems that process MSW in Europe is now more than six million tons per year (Figure 19).\(^ {41}\)

Figure 19. Solid waste anaerobic digester capacity in Europe (de Baere & McDonald, 2012)

---


\(^ {40}\) Ibid.

Issues, barriers, potential solutions

Thermal conversion of MSW components is handicapped by state policy and seems to have a poor public image that can, perhaps, be traced to early generations of waste combustion systems which were significant sources of hazardous air pollutants. On the other hand, biological conversion (anaerobic digestion and aerobic composting) is perceived to be much more benign.

As such, current state policy makes no distinction between thermal conversion of solid waste for energy recovery and landfill disposal. Both are considered disposal (not diversion) and the electricity produced by thermal conversion is not RPS eligible. The state’s “waste management hierarchy”prioritizes management practice:

(1) source reduction,  
(2) recycling and composting, and  
(3) environmentally safe transformation and environmentally safe land disposal.42

“Transformation” (solid fuel combustion with energy recovery) occupies the same rung on the California waste hierarchy as landfilling.

There is a pathway for RPS eligibility for power from gasification of MSW but the statutory definition of gasification is vague and generally considered not technically achievable. No projects in California meet the interpretation of the statutory definition (see discussion of Plasco above). Biological conversion with energy recovery is allowed RPS and diversion credit.

The waste hierarchy observed by the European Union and the USEPA include a separate rung for energy recovery (below recycling/composting and above landfilling).43

(1) source reduction,  
(2) recycling and composting,  
(3) energy recovery  
(4) environmentally safe land disposal.

LCA Synopsis

A synopsis of the literature on environmental impacts of waste management practices, including recycling, waste-to-energy, landfilling, composting etc. would conclude that beyond waste reduction;44 45 46 47 48 49 50

42 California Public Resource Code, Division 30, Part 1,§40051  
• The more recycling, the better; provided the material is clean enough to be suitable for recycling (i.e., source-separated or at least not comingled with food waste) and collection and transport of the material is efficient
• The less landfilling of the biogenic fraction (biomass), the better (biodegradable components in the landfill decompose producing a leachate that needs to be managed for decades to protect ground water, and methane which is only partially recovered in the best landfill gas collection systems)
• Zero landfill (or zero waste) without employing energy recovery for mixed and soiled material is not likely with practical waste management systems

These broad conclusions from waste management LCA literature generally support the US EPA / EU waste hierarchy but are somewhat inconsistent with the California hierarchy.

**Recycling and Energy Recovery in the EU**

High rates of recycling coexist with relatively high levels of waste-to-energy in some countries in the EU. In fact, those countries with the lowest landfill disposal rates have the highest recycling rates (composting/biotreatment and conventional recycling) [See Figure 20, where Group 1 countries are: Switzerland, Germany, Austria, Netherlands, Sweden, Denmark, Belgium, Norway, Luxembourg, and France].

---

The Group 1 countries have achieved conventional recycling and energy recovery rates greater than 25% each, while landfill rates vary from almost zero (Switzerland) to about 33% (France). The low landfill rates were achieved by implementing a range of policies since the late 1980’s that include landfill bans for biodegradable and/or combustible material, landfill taxes, source separated collection schemes for various waste types and other. Figure 21 shows the combined disposal, recycling, energy and compost trends for the Group 1 EU countries. Landfilling, on average, has declined from more than 40% of waste in 1995 to about 10% by 2009.

---

State Waste Policy

There is approximately 1.2 billion tons of waste-in-place in California landfills with an estimated remaining capacity of 1.5 – 3 billion tons statewide.\(^5^2\) There are some local regions with limited landfill capacity including City and County of Los Angeles.

State policy for solid waste management requires that 50 percent of generated waste be diverted from landfill (AB 939, Sher, Statutes of 1989) by 2000. The 50% diversion was generally achieved by 2005 with many jurisdictions moving beyond that target. The current estimated statewide diversion rate is approximately 65%.\(^5^3\)

AB 1126 (Gordon) Engineered Municipal Solid Waste (EMSW) conversion: defines a processed waste derived fuel for use in energy recovery and that replaces/displaces fossil fuel feedstocks. It sets a minimum moisture and energy content and limits the facility to 500 tpd. The bill declares that EMSW conversion is not “transformation”, is not “recycling” but that it is defined as “disposal”. The bill apparently meant to provide a permitting pathway to facilities such as cement kilns (and possibly coal fired power plants) to use MSW derived fuel as a means of offsetting fossil fuels presumably in order to reduce greenhouse gas emissions of the facility. No disposal or RPS credits would accrue.

http://www.calrecycle.ca.gov/actions/Documents%5c2013%5cLandfilling%20of%20Waste%20FINAL.pdf

More recently, the legislature declared a policy goal for 75% waste diversion by 2020 (AB 341, Chesbro, Statutes of 2011). If the goal is realized, then some local landfill lifetimes would be extended before reaching capacity.

Time will tell whether the AB 341 75% diversion goal is achieved. If it appears not to be on track as 2020 approaches, enabling policy measures could be taken.

Pending California legislation related to MSW that may affect landfill disposal includes AB 1126 (Gordon) and SB 804 (Lara) [see sidebars]. AB 1126 defines an engineered MSW feedstock for energy purposes. Though this would repurpose material that would have been landfilled, it would not be eligible for diversion credit. If passed, SB 804 may be more effective for reducing landfill disposal. It creates a pathway for allowing biomass that had been in the mixed waste stream to be used in bioenergy facilities and accrue diversion credit.

**Conclusions and Recommendations**

The landfill disposal stream (disposed MSW) represents a significant energy resource. Solid fuel combustion and Anaerobic Digestion are used extensively worldwide as a non-landfill method of waste treatment and for energy production. Gasification of MSW is still considered emerging though there are examples of operating facilities in Europe and Japan. Most of these facilities operate in close-combustion mode (or two-step oxidation) but there are perhaps a handful of facilities that upgrade the gas and use it in reciprocating engine-generators. Advanced MSW gasification facilities (for heat and power and/or fuels production) are being built or planned in Europe and North America. These are either commercial scale demonstration projects or the first commercial facility (for technology/energy product type).

There are no commercial operating solid waste gasification facilities in North America (the Ineos Bio facility being commissioned in Florida has not yet used MSW on a regular basis). There are numerous pilot and demonstration facilities that have tested MSW or are planning to. There are a handful AD systems in California now operating on food or green waste.

Waste management policy in California prioritizes source reduction and recycling/reuse as does the US EPA and the European Union. However, unlike the US EPA and the EU, energy recovery from post-MRF residuals is considered the same as landfill disposal.
California legislature and CalRecycle have published goals to minimize landfill disposal including increasing diversion of the biogenic fraction of the waste stream.

Northern European countries have achieved high levels of both recycling and energy recovery which has resulted in very low amounts of landfill disposal, due primarily to policy instruments and relative scarcity of space for landfills.

It remains to be seen if California waste policy and goals will achieve low levels of landfill disposal and reduced greenhouse emissions from the waste sector. A closer alignment of waste management policy to the AB32 climate change legislation could be a pathway to reduced landfill disposal. Appropriate policy instruments based on best practices, that reflect current science and incorporate life-cycle modeling of waste management options (recycling, energy, landfill, etc.) that reflect actual impacts and emissions for recycling commodities from California that enter the global market should be considered.
## Appendix A: California Anaerobic Digestion projects (A partial list, August 2013)

<table>
<thead>
<tr>
<th>Project</th>
<th>County</th>
<th>City</th>
<th>Feedstocks</th>
<th>AD type</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBMUD FW Co-Digestion</td>
<td>Alameda</td>
<td>Oakland</td>
<td>Biosolids, FOG &amp; FW (Post)</td>
<td>Wet, Thermophillic</td>
<td>Operational</td>
</tr>
<tr>
<td>Inland Empire-Environ AD prjt</td>
<td>San Bernardino</td>
<td>Chino</td>
<td>FW (Pre)</td>
<td>Wet, Mesophillic</td>
<td>Operational</td>
</tr>
<tr>
<td>Monterey-ZWE AD Project</td>
<td>Monterey</td>
<td>Marina</td>
<td>GW and FW (Post)</td>
<td>Dry, Thermophillic</td>
<td>Operational</td>
</tr>
<tr>
<td>Sac Regional San AD project</td>
<td>Sacramento</td>
<td>Sacramento</td>
<td>FOG &amp; FW (Pre)</td>
<td>Wet, Mesophillic</td>
<td>Operational</td>
</tr>
<tr>
<td>Clean World Partners, ARP</td>
<td>Sacramento</td>
<td>Sacramento</td>
<td>GW and FW (Pre and Post)</td>
<td>High Solids AD (UCD)</td>
<td>Operational</td>
</tr>
<tr>
<td>Ralph's Compton AD prjt</td>
<td>Los Angeles</td>
<td>Compton</td>
<td>FW (Post)</td>
<td>Wet</td>
<td>Operational</td>
</tr>
<tr>
<td>Clean World Partners, SATS</td>
<td>Sacramento</td>
<td>Sacramento</td>
<td>GW and FW (Pre and Post)</td>
<td>High Solids AD (UCD)</td>
<td>Commissioning</td>
</tr>
<tr>
<td>Central Marin FZE Project</td>
<td>Marin</td>
<td>San Rafael</td>
<td>GW and FW (Post)</td>
<td>Wet, Mesophillic</td>
<td>Commissioning</td>
</tr>
<tr>
<td>San Jose Zero Waste AD Project</td>
<td>Santa Clara</td>
<td>San Jose</td>
<td>GW, FW &amp; Post MRF Resid.</td>
<td>Dry, Thermophillic</td>
<td>In construction</td>
</tr>
<tr>
<td>Blue Line Zero Waste AD Project</td>
<td>San Mateo</td>
<td>South S. Fran</td>
<td>GW and FW (Post)</td>
<td>Dry, Thermophillic</td>
<td>In construction</td>
</tr>
<tr>
<td>LA Sanitation FW pilot</td>
<td>Los Angeles</td>
<td>Carson</td>
<td>FW (Post) &amp; Biosolids</td>
<td>Wet</td>
<td>Pre-construction</td>
</tr>
<tr>
<td>Colony Energy Partners</td>
<td>Tulare</td>
<td>Tulare</td>
<td>GW and FW (Pre and Post)</td>
<td>TBD</td>
<td>Pre-construction</td>
</tr>
<tr>
<td>Perris CR&amp;R AD project</td>
<td>Riverside</td>
<td>Perris</td>
<td>FW and Post MRF Residuals</td>
<td>Dry Plug-flow</td>
<td>Pre-construction</td>
</tr>
<tr>
<td>UC Davis AD - West Village</td>
<td>Yolo</td>
<td>Davis</td>
<td>GW, FW (Post) &amp; Manure</td>
<td>High Solids AD (UCD)</td>
<td>Pre-construction</td>
</tr>
<tr>
<td>Agromin Zero Waste AD Project</td>
<td>Ventura</td>
<td>Oxnard</td>
<td>GW and FW (Post)</td>
<td>Dry, Thermophillic</td>
<td>Pre-construction</td>
</tr>
<tr>
<td>Tajiguas LF MRF &amp; AD project</td>
<td>S. Barbara</td>
<td>Unincorp</td>
<td>GW, FW (Post)</td>
<td>TBD</td>
<td>Permitting</td>
</tr>
<tr>
<td>City of Napa MRF AD Project</td>
<td>Napa</td>
<td>Amer Canyon</td>
<td>GW and FW (Post)</td>
<td>Dry, Thermophillic</td>
<td>Permitting</td>
</tr>
<tr>
<td>Humboldt AD project</td>
<td>Humboldt</td>
<td>Eureka</td>
<td>GW, FW (Pre &amp; Post) &amp; other</td>
<td>TBD</td>
<td>Permitting</td>
</tr>
<tr>
<td>El Sobrante LF Bioreactor</td>
<td>Riverside</td>
<td>Corona</td>
<td>MSW, GW &amp; FW (Post)</td>
<td>LF Bioreactor</td>
<td>Permitting</td>
</tr>
<tr>
<td>Napa WWTP AD Project</td>
<td>Napa</td>
<td>Amer Canyon</td>
<td>GW and FW (Post) &amp; Ag</td>
<td>Wet</td>
<td>Permitting</td>
</tr>
<tr>
<td>Tulare Harvest Power</td>
<td>Tulare</td>
<td>Unincorp</td>
<td>GW, FW &amp; Ag (Pre &amp; Post)</td>
<td>Dry</td>
<td>Permitting</td>
</tr>
<tr>
<td>Pebble Beach LF project</td>
<td>Los Angeles</td>
<td>Avalon</td>
<td>MSW, GW &amp; FW (Post)</td>
<td>NA</td>
<td>Feasibility</td>
</tr>
<tr>
<td>Palo Alto Compost AD Project</td>
<td>Santa Clara</td>
<td>Palo Alto</td>
<td>GW and FW (Post)</td>
<td>TBD</td>
<td>Feasibility</td>
</tr>
<tr>
<td>Glenn Co. AD project</td>
<td>Glenn Co.</td>
<td>Glenn Co.</td>
<td>MSW</td>
<td>TBD</td>
<td>Feasibility</td>
</tr>
<tr>
<td>Mendota Beet AD Project</td>
<td>Fresno</td>
<td>Mendota</td>
<td>Ag waste and FW (Pre)</td>
<td>NA</td>
<td>Feasibility</td>
</tr>
<tr>
<td>San Leandro MRF and AD Project</td>
<td>Alameda</td>
<td>San Leandro</td>
<td>GW and FW (Post)</td>
<td>DODA to Slurry</td>
<td>Feasibility</td>
</tr>
<tr>
<td>Orange Co Sanitation</td>
<td>Orange</td>
<td>Fountain Valley</td>
<td>Biosolids, FOG &amp; FW (Post)</td>
<td>Wet</td>
<td>Feasibility</td>
</tr>
<tr>
<td>Crazy Horse LF AD pilot</td>
<td>Monterey</td>
<td>Unincorp</td>
<td>GW, FW (Post)</td>
<td>LF Bioreactor</td>
<td>Pilot (Construction)</td>
</tr>
<tr>
<td>Orange Co, Ts FW Pre process</td>
<td>Orange</td>
<td>Orange</td>
<td>FW (Post)</td>
<td>DODA to Slurry</td>
<td>Pilot (Operational)</td>
</tr>
<tr>
<td>Victor Valley FW AD pilot</td>
<td>S. Bernardino</td>
<td>Hesperia</td>
<td>Biosolids, FOG &amp; FW (Post)</td>
<td>TBD</td>
<td>Pilot (complete)</td>
</tr>
<tr>
<td>Yolo Bioreactor Demo</td>
<td>Yolo</td>
<td>Unincorporated</td>
<td>GW and FW (Post)</td>
<td>LF Bioreactor</td>
<td>Pilot (complete)</td>
</tr>
<tr>
<td>SLO WWTP Anaergia demo</td>
<td>San Luis</td>
<td>San Luis</td>
<td>Biosolids, FOG &amp; FW (Post)</td>
<td>Wet</td>
<td>Pilot</td>
</tr>
<tr>
<td>Lancaster LF Bioreactor &quot;RAC&quot;</td>
<td>Los Angeles</td>
<td>Lancaster</td>
<td>MSW</td>
<td>LF Bioreactor</td>
<td>Pilot</td>
</tr>
</tbody>
</table>

**Legend:** FW Food waste, GW Green waste, FOG Fats Oils & Grease - Post/Pre: Post or Pre Consumer feedstock

Source: Jacques Franco, CalRecycle.