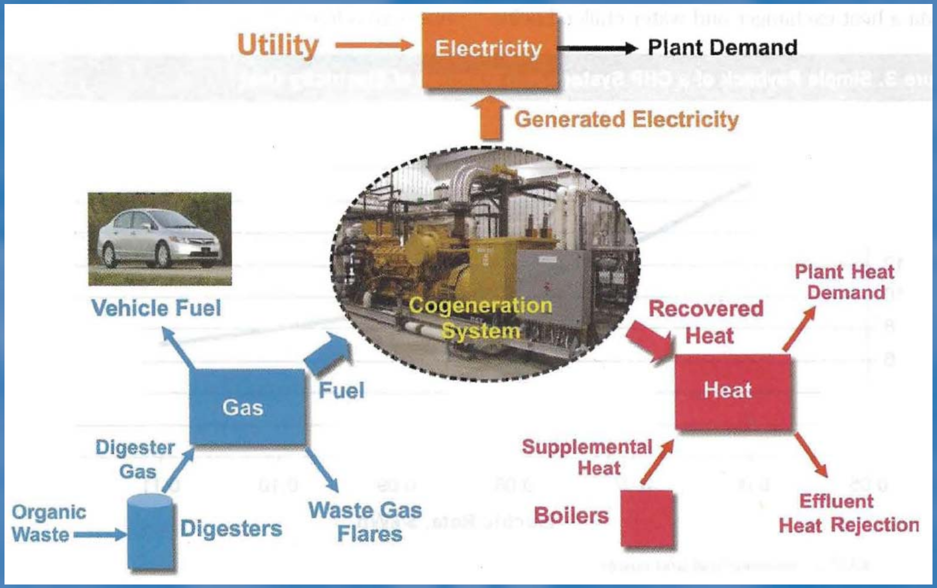
State of the Science on Cogeneration of Heat and Power from Anaerobic Digestion of Municipal Biosolids



Metropolitan Water Reclamation District of Greater Chicago
July 31, 2009

J. (Jim) E. Smith, Jr., D.Sc., BCEEM
USEPA's Pathogen Equivalency Committee
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What Will be Discussed?

- **Energy Issues & Wastewater Treatment**
- **Digester Feed**
  - **Sources**
  - **Preparation**
- **Digester Operation**
  - **Gas Production**
- **Combined Heat and Power**
  - **Gas Cleanup**
  - **Power Production**
  - **Heat Recovery**
- **Case Studies**
- **New WEF/WERF/EPA Solids Manual**

Significance and Drivers

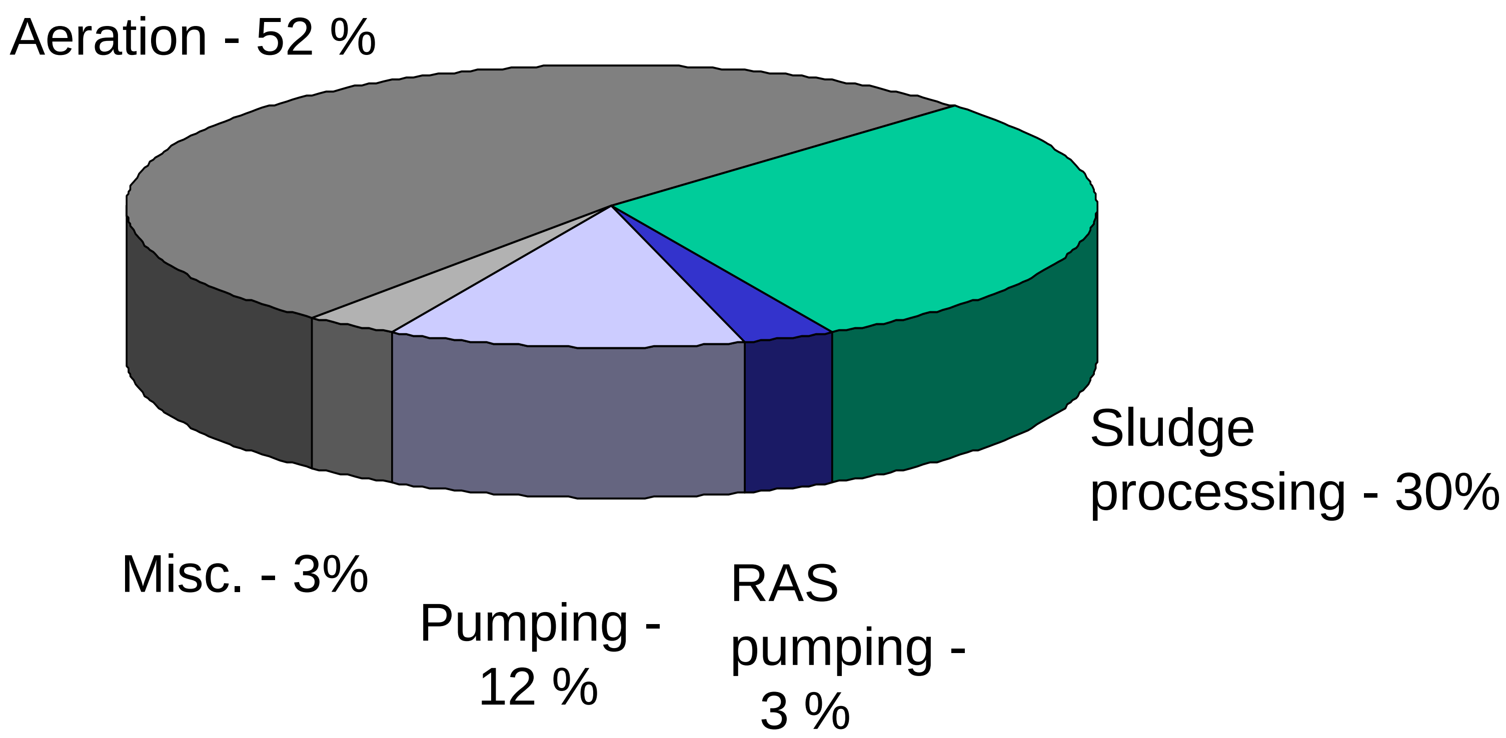
- **Electric use for centralized W&WW treatment accounts for 3.0%[*] of US electricity use**
  - **$4 billion annually, 25-30% of total plant O&M Cost[**]**

- **Direct US GHG Emissions (2006)[***] - Municipal WW treatment-**
  - **0.4 % of total GHG emissions**
  - **3.0% of total anthropogenic Methane (CH_4) and 2.2% of total Nitrous Oxide (N_2O) emissions**
  - **CH_4 : 16 Tg CO_2 eq., N_2O: 8.1 Tg CO_2 eq.**

- **Estimated US GHG Emissions (2006) from electricity generation for centralized W&WW treatment: 69.8 Tg CO_2 eq. [****] (1.2% of total US GHG emissions)**

* Electric Power Research Institute (EPRI)
** Energy Star Program
*** *Inventory of Greenhouse Gas Emissions and Sinks: 1990 – 2006*, EPA, 2008
**** EPRI estimate & *Inventory of Greenhouse Gas Emissions and Sinks: 1990 – 2006*, EPA, 2008

Energy Used in Wastewater Treatment



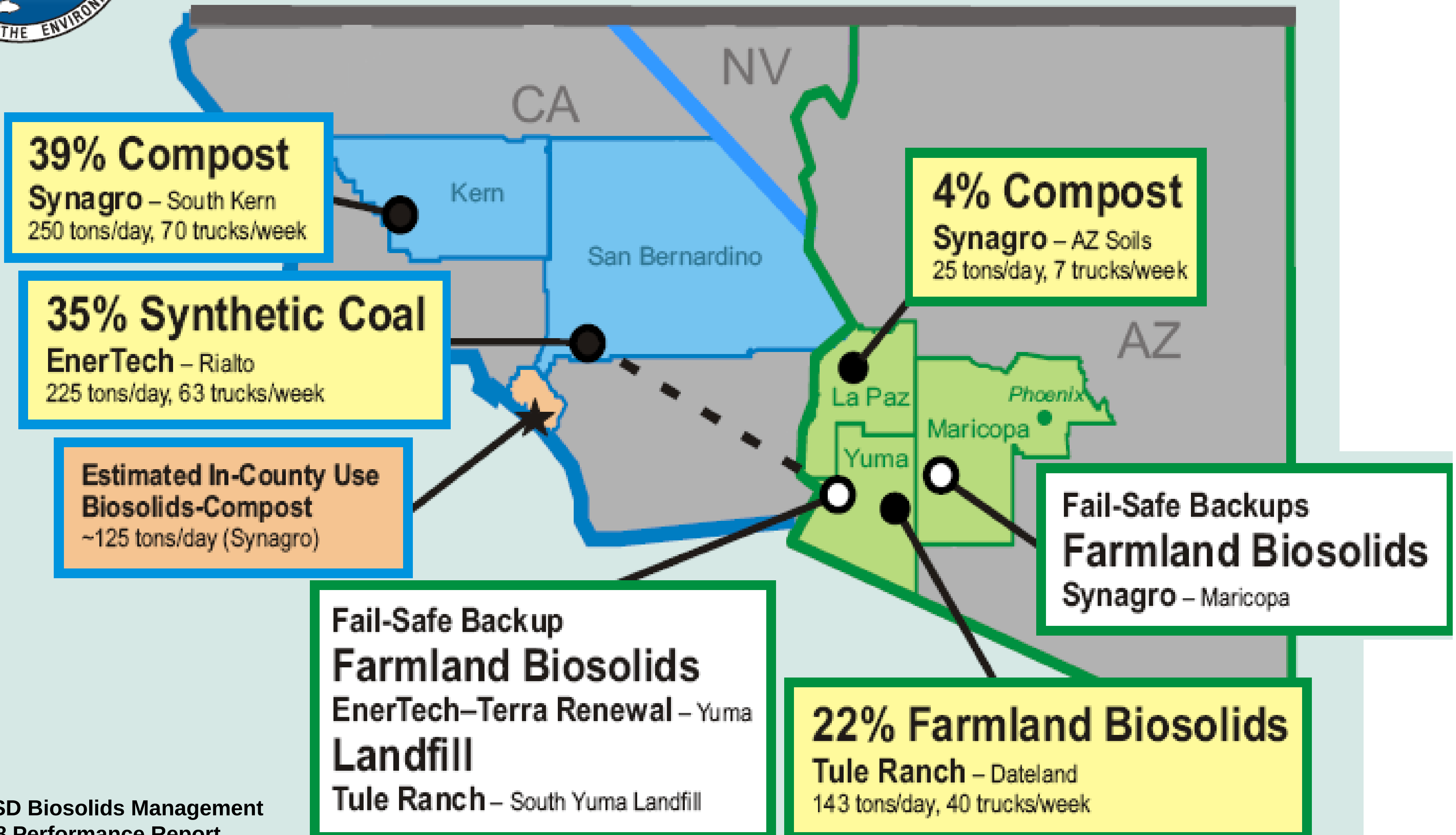
Figures shown are typical for activated sludge plants, which use approximately 1200 kWh/MG treated.

Energy Conservation Measures

Solids Handling

- **Improved digester heating and mixing**
- **New dewatering equipment**
- **Improved methods of drying (including using anaerobic digester gas)**
- **Increased recycle (land application and recycled products)**

OCSD Biosolids Management – February 2009 Update
Product Locations and Contractors



OCSD Biosolids Management
2008 Performance Report

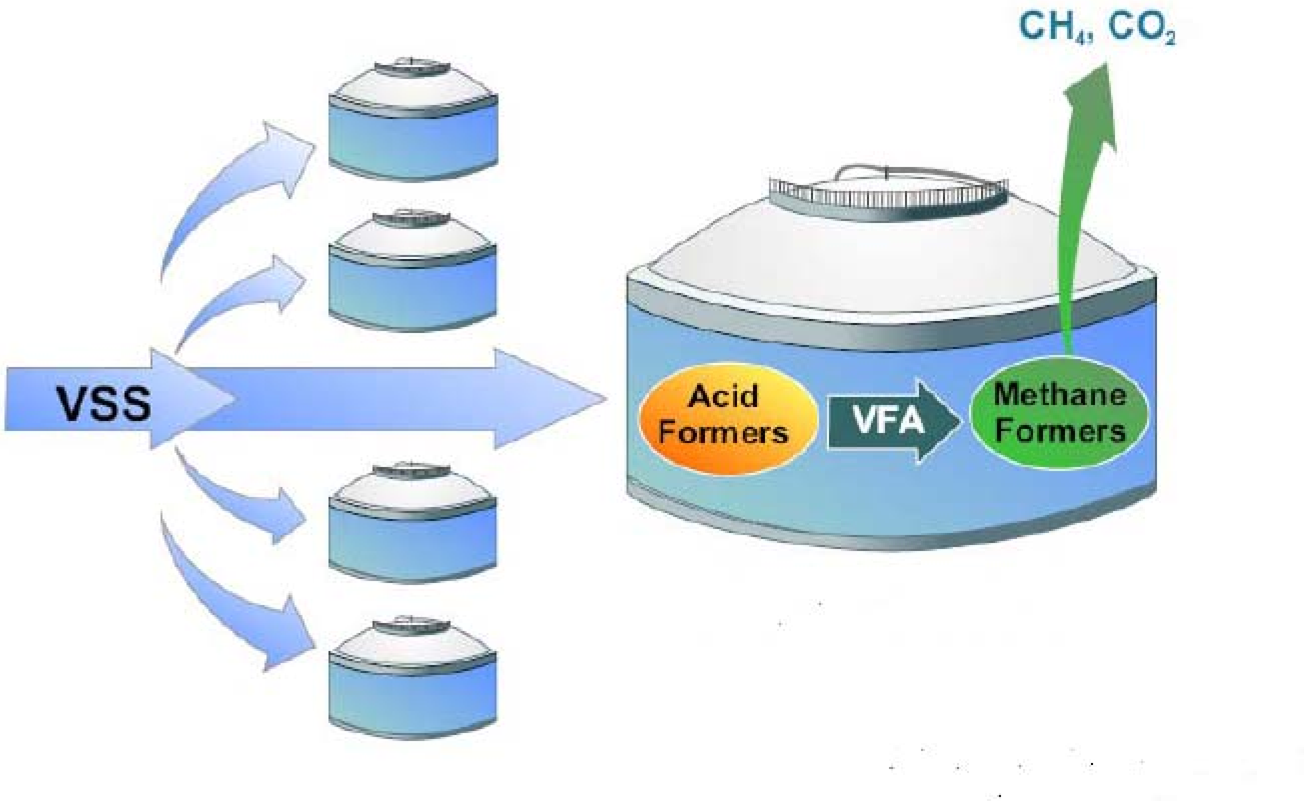
Summary of OCSD Biosolids Disposal Options

Recycling Sites	Distance	Distribution	Load	Haul
	(miles)	(%)	(tons/day)	(trucks/wk)
Dateland	335	22%	143	40
Arizona Soils	270	4%	25	7
South Kern Organics	160	39%	250	70
EnerTech	55	35%	225	63
Total			643	100

Net Carbon Footprint for All Sites

Recycling Sites	Total Emissions	TOC	TOC	Net CFP
	kgCO2Eq/yr	% of dry solids	kgCO2Eq/yr	kgCO2Eq/yr
Dateland	9.18E+06	20%	7.02E+06	2.16E+06
Arizona Soils	1.29E+06	20%	1.23E+06	6.66E+04
South Kern Organics	7.67E+06	20%	1.23E+07	-4.61E+06
Enertech	2.37E+06	20%	1.10E+07	-8.67E+06
Total	2.05E+07	20%	3.16E+07	-1.10E+07

Anaerobic Digestion



Courtesy of R Dale Richwine, MWH

Products of Anaerobic Digestion

- **Yields gases and residues**
- **Gases used to make heat, electricity or fuel**
- **Produce Methanol (being done in Utah in large scale from pig manure fermentation).**
- **Residues used to make fertilizer**

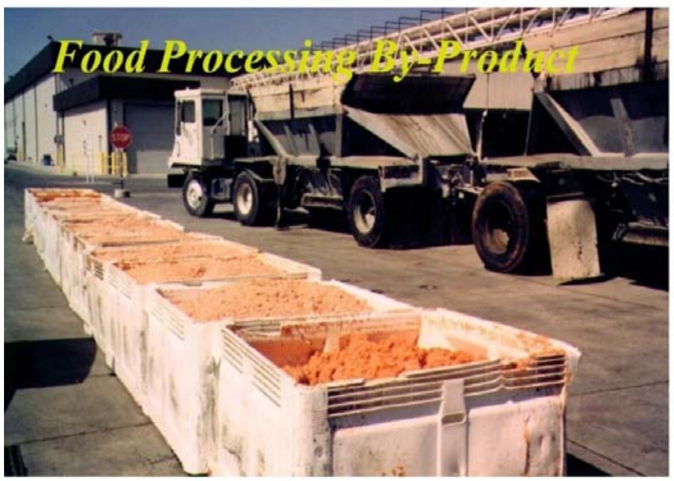
Courtesy of Mike Moore, OCSD

Why Anaerobic Digestion and Wastes are an Opportunity in California?

- 36 Million TPY disposed
- Potential to reduce GHGs
- Reduces reliance on landfills
- Alternatives to natural gas
- Helps achieve 33% threshold of renewable energy by 2020
- Low Carbon Fuel Standard (10% reduction in carbon intensity by 2020)
- 15% of waste stream is food waste - high value feedstock for digesters

Courtesy of Michael Moore, OCSD

Types of Anaerobic Digester feedstock



Courtesy of Michael Moore, OCSD

RECOVERING & USING ENERGY FROM WWTP RESIDUALS

Engineering Rules of Thumb for Considering CHP at a WWTF

- A typical WWTF processes 100 gallons per day of wastewater for every person served.
- Approximately 1.0 cubic foot (ft^3) of digester gas can be produced by an anaerobic digester per person per day. This volume of gas can provide approximately 2.2 watts of power generation.
- The heating value of the biogas produced by anaerobic digesters is approximately 600 British thermal units per cubic foot (Btu/ft^3).
- For each 4.5 million gallons per day processed by a WWTF with anaerobic digestion, the generated biogas can produce approximately 100 kilowatts (kW) of electricity and 12.5 million Btu (MMBtu) of thermal energy.

- To sell back to the grid as green power.
- To operate pumps and blowers used throughout the treatment process.
- To maintain optimal digester temperatures, dry the biosolids, and provide space heating for the WWTF.

US Wastewater Treatment Facilities (WWTFs) with Anaerobic Digestion & Off Gas Utilization

- **# WWTFs in USA is 16,583**
- **# WWTFs in USA treating a wastewater flow > 5 MGD is 1,066 or ~ 6 % of total number**
  - **# of these with anaerobic digesters is 544**
  - **# of facilities with anaerobic digesters that utilize biogas is 106**

Source: 2004 Clean Watersheds Needs Survey

Current Situation / Potential

POTW anaerobic digester gas utilization for combined heat and/or power (CHP)

If all 544 facilities install CHP:

- **340 MW of clean electricity generation,**
- **2.3 million metric tons of CO_2, offset annually,**
- **Equivalent to cutting emissions from 430,000 cars**

Significant opportunities for savings in energy costs

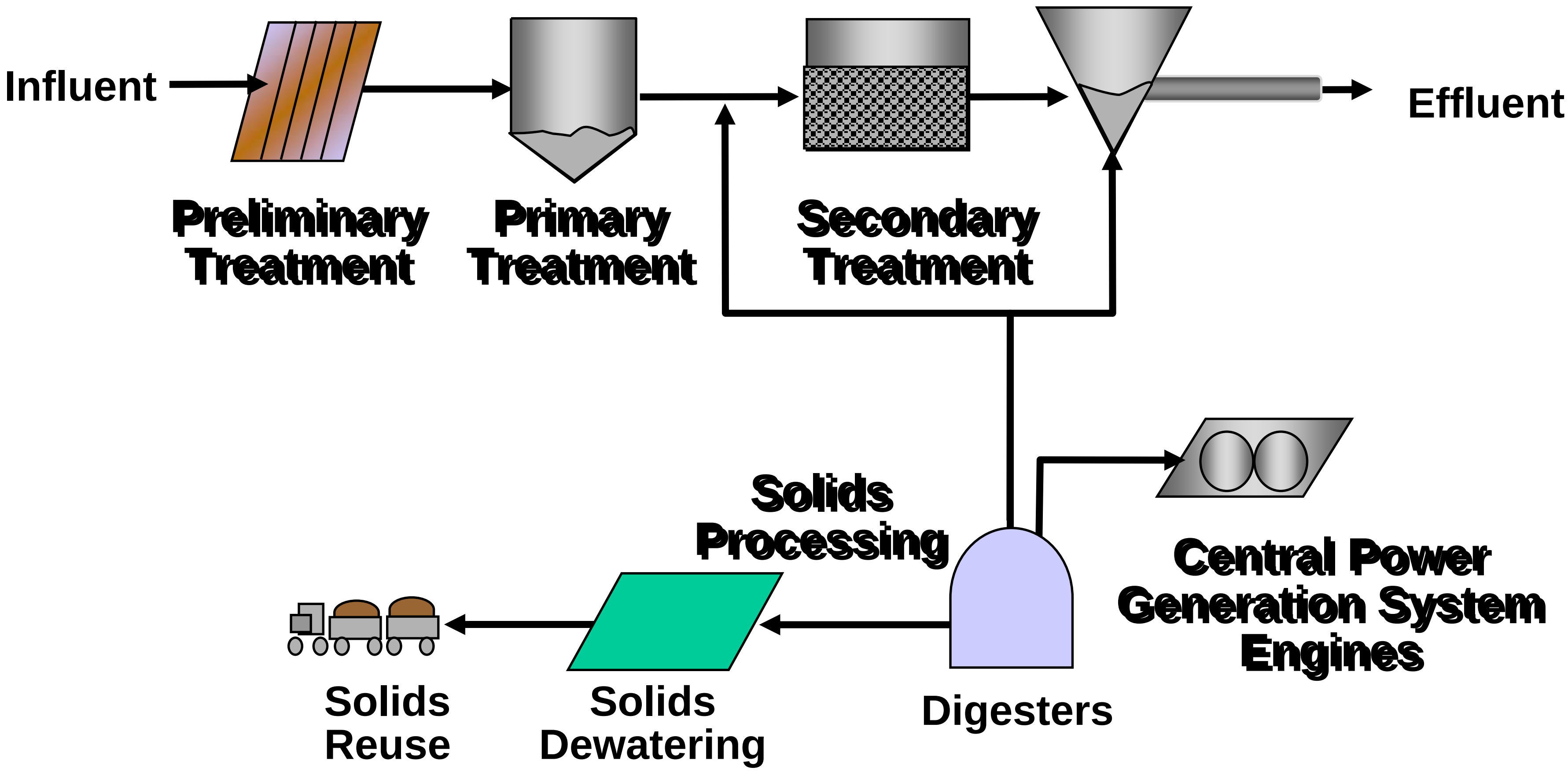
* Opportunities and Benefits of Combined Heat and Power at Wastewater Treatment Facilities, Combined Heat and Power Partnership, EPA 2006

Co-generation at Wastewater Treatment Plants in California

- ~ 50 % POTWs > 1 MGD have anaerobic digesters
- ~ 95 % of sewage treated, however, has its solids treated by anaerobic digesters
- Randomly interviewed 32 facilities
  - 21 have installed cogeneration (66 %)
  - 5 use methane for heat only
  - 6 flare methane (20 %)

USEPA-Region 9, 2008

Wastewater Plant Diagram



Anaerobic Digestion

Simplified Process Summary

Hydrolysis	Acid Formation	Methane Formation
Insoluble Organics → Soluble Organics	Soluble Organics → Organic Acids	Organic Acids → Methane CO_2
Biological (Extra-cellular Enzymes) or Physical (Heat & Pressure)	Acid Producers	Methane Producers

Steve Arant, "Recent Advances in Biosolids Stabilization Case Histories," WEF/AWWA/CWEA Joint Residuals and Biosolids Management Conference and Exhibition, February 19-22, 2003, Baltimore, Maryland USA

Requirements for Anaerobic Digestion

Feedstock

- biodegradability
- moisture content and particle size
- C/N ratio
- presence of inhibitory or toxic compounds

Process Conditions

- temperature
- retention time
- organic loading rates
- chemical environment (pH, volatile fatty acids, ammonia, etc.)

Typical Operational and Design Criteria for Thermophilic Anaerobic Digestion as compared to Mesophilic Digestion

Criterion	Mesophilic	Thermophilic
Typical SRT	15 to 20 days	8 to 12 days
Minimum Design SRT	12 days	4.5 to 6 days
Operating Temperature	35 to 39 degrees C (95 to 102 degrees F)	50 to 58 degrees C (122 to 136 degrees F)
Feedstock Concentration	3 to 6 percent total solids	4.5 to 6.5 percent total solids
Digesting Sludge Concentration	1.5 to 4 percent total solids	2.5 to 4.5 percent total solids
VS Loading	0.1 to 0.15 lb VS/cubic foot/day	0.2 to 0.4 lb VS/cubic foot/day
Volatile Fatty Acid Concentrations (total as acetic acid)	<200 mg/l	400 to 1200 mg/L
pH	6.8 to 7.2	7.0 to 7.7

Typical Properties of Primary and Waste Activated Sludges

Total dry solids (%)	5-9	0.8-1.2
Volatile fraction (%)	60-80	59-88
Ether Extract	7-35	5-12
Protein (% of TS)	20-30	32-41
Nitrogen 170 (N, % of TS)	1.5-4	2.4-5.0
Phosphorous (P_2O_5, % of TS)	0.8-2.8	2.8-11
pH	5-8	6.5-8.0
Alkalinity (mg/L as $CaCO_3$)	500-1500	580-1100
Organic Acids (mg/L as HAc)	200-2000	1100-1700
Energy Content (kJ/kg TS)	23000-29000	19000-23000

BTU Value of Different Types of Wastewater Treatment Residuals

Wastewater Treatment Sludge Material	Heating Value (Btu per pound of dry solids)
Fine Screenings	9,000
Grit	4,000
Grease and Scum	16,700
Dewatered Raw Biosolids	10,300
Chemical Precipitated Biosolids	7,500
Dewatered Digested Biosolids	5,300

Source:
NBP 2005, p 15-10

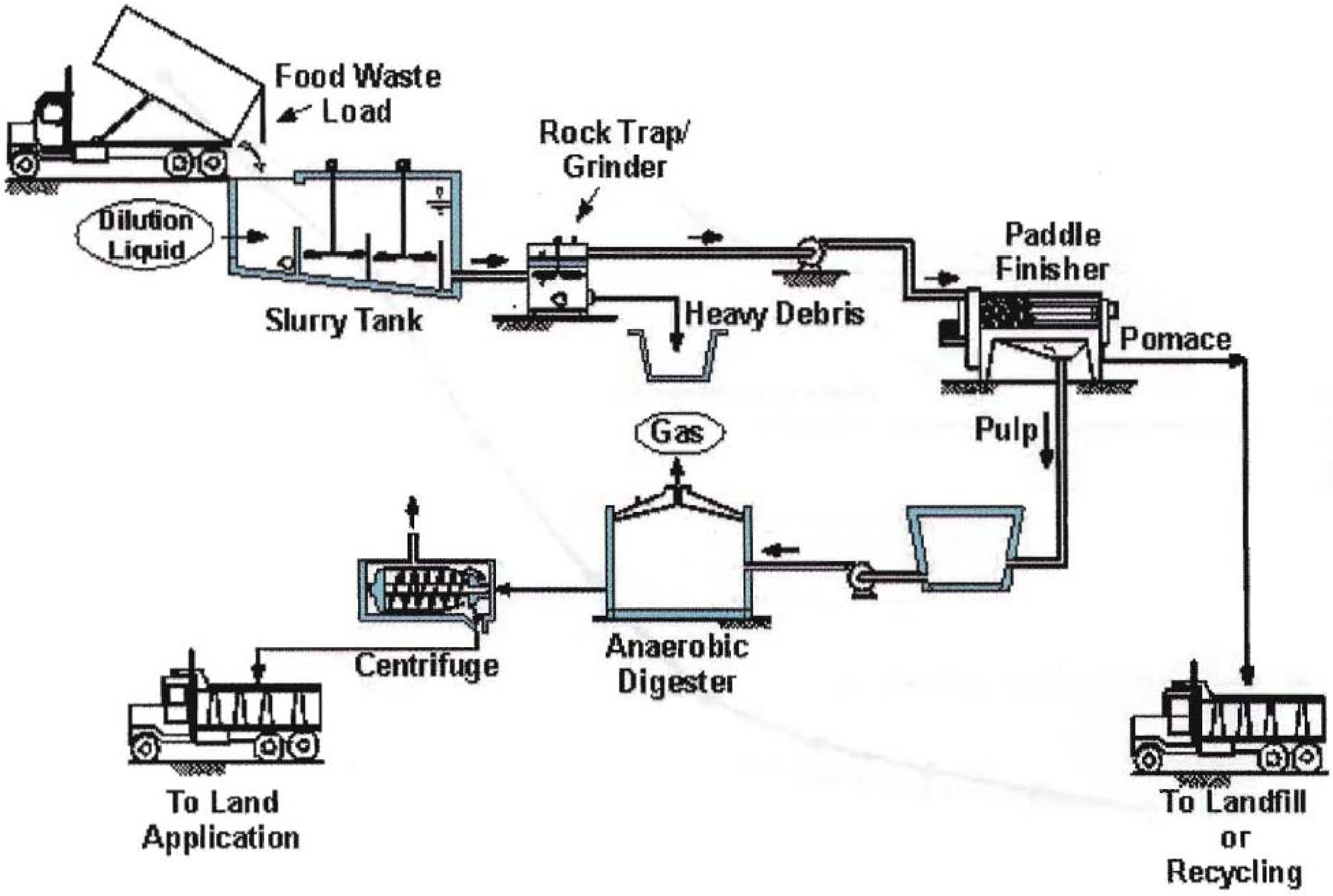
Comparing Gas Production Capabilities of Different Sources

Food waste has THREE TIMES the methane potential as biosolids!

- Cattle manure= 25m³ gas/ton
- Biosolids= 120 m³ gas/ton
- Food waste= 376 m³ gas/ton

From USEPA-Region 9 & EBMUD

Schematic of EBMUD Food –Waste Recycling Process



Example of Innovative Approach – EBMUD, CA

Food Waste vs. Wastewater Solids Comparison

Parameter	Food Waste Pulp	Wastewater Solids
Volatile Solids in Feed (%)	85-90	70-80
Volatile Solids Loading (lbs/ft3-day)	0.60 +	0.20 max
COD Loading (lbs/ft3-day)	1.25 +	0.06-0.30
Total Solid Fed (%)	10+	4
Volatile Solids Reduction (%)	80	56
Hydraulic Detention Time (days)	10	15
Methane Gas Produced ($meter^3$/ton) Gas Produced (liters/liter of feed)	367 58	120 17
Biosolids Produced (lbs/lbs fed)	0.28	0.55

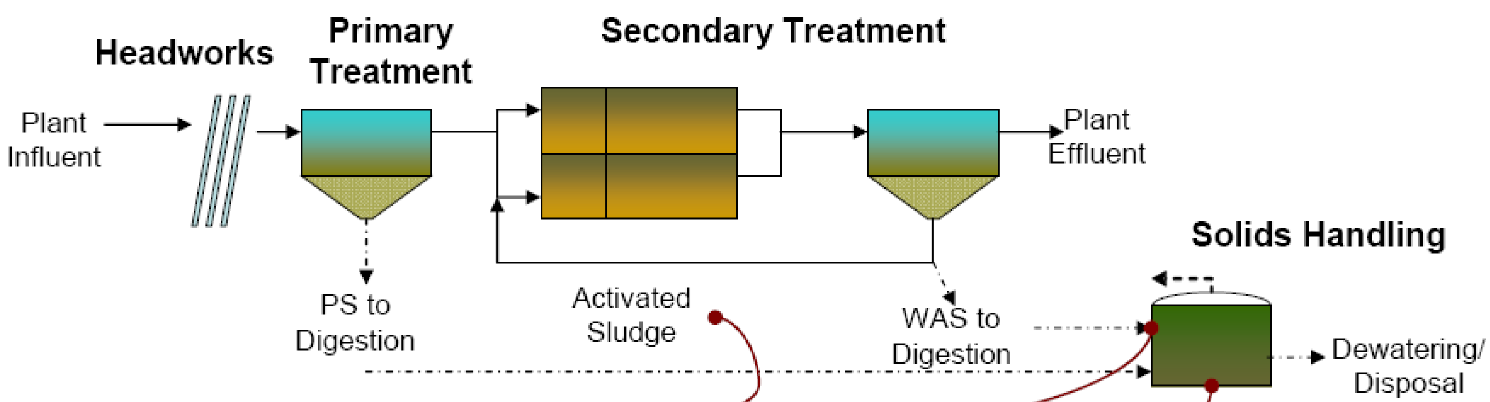
Diverting food waste from landfills prevents uncontrolled emissions of methane. Only 2.5% of food waste is recycled nationwide, and the principal technology is composting which produces volatile organic compounds and consumes energy. In California, approximately 137 wastewater treatment plants have anaerobic digesters, with an estimated excess capacity of 15-30% . Anaerobic Digestion of Food Waste funded by EPA-R9-WST-06-004.

Examples of Organizations Using Grease for Fuel/Energy

Agency/Organization	Summary Description of Process or System Utilized
City of Riverside, California Wastewater Treatment Plant (WWTP)	Accepting trucked brown grease for co-digestion with wastewater sludge. Gas used in cogeneration engines.
City of Lincoln, Nebraska - Theresa St. WWTP	Accepting trucked grease and related wastes for co-digestion with wastewater sludge. Gas used in cogeneration engines.
East Bay Municipal Utility District, Oakland California, Main WWTP	Accepting trucked grease and related wastes for co-digestion with wastewater sludge. Gas used in cogeneration engines. Also, a pilot plant for biodiesel production from grease has operated at the EBMUD plant site.
Covanta Energy, Carver, Massachusetts	Trucked grease/FOG materials used as fuel for solid waste to energy plant in Massachusetts.
City of Oxnard, California WWTP	Accepts trucked brown grease for co-digestion with wastewater sludge. Gas used in cogeneration engines.
City of Millbrae, California WWTP	Started accepting trucked grease in 2007 for co-digestion with wastewater sludge. Privatized system by Chevron Energy Solutions includes cogeneration engine using digester gas.

Schafer, P et al, 2008

Waste Minimization / Conditioning Technologies



- Cannibal®
- Ozonation
- Chemical Uncoupling
- Extended Aeration

- Thermal Hydrolysis
- Homogenization/ Extreme Pressure Release
- Focused Pulse Electricity
- Sonication

- Acid/Enzymatic Hydrolysis
- Phased Digestion
- Thermophilic Digestion
- ATAD-2nd Gen.

Courtesy of Tom Kutcher of CH2M Hill

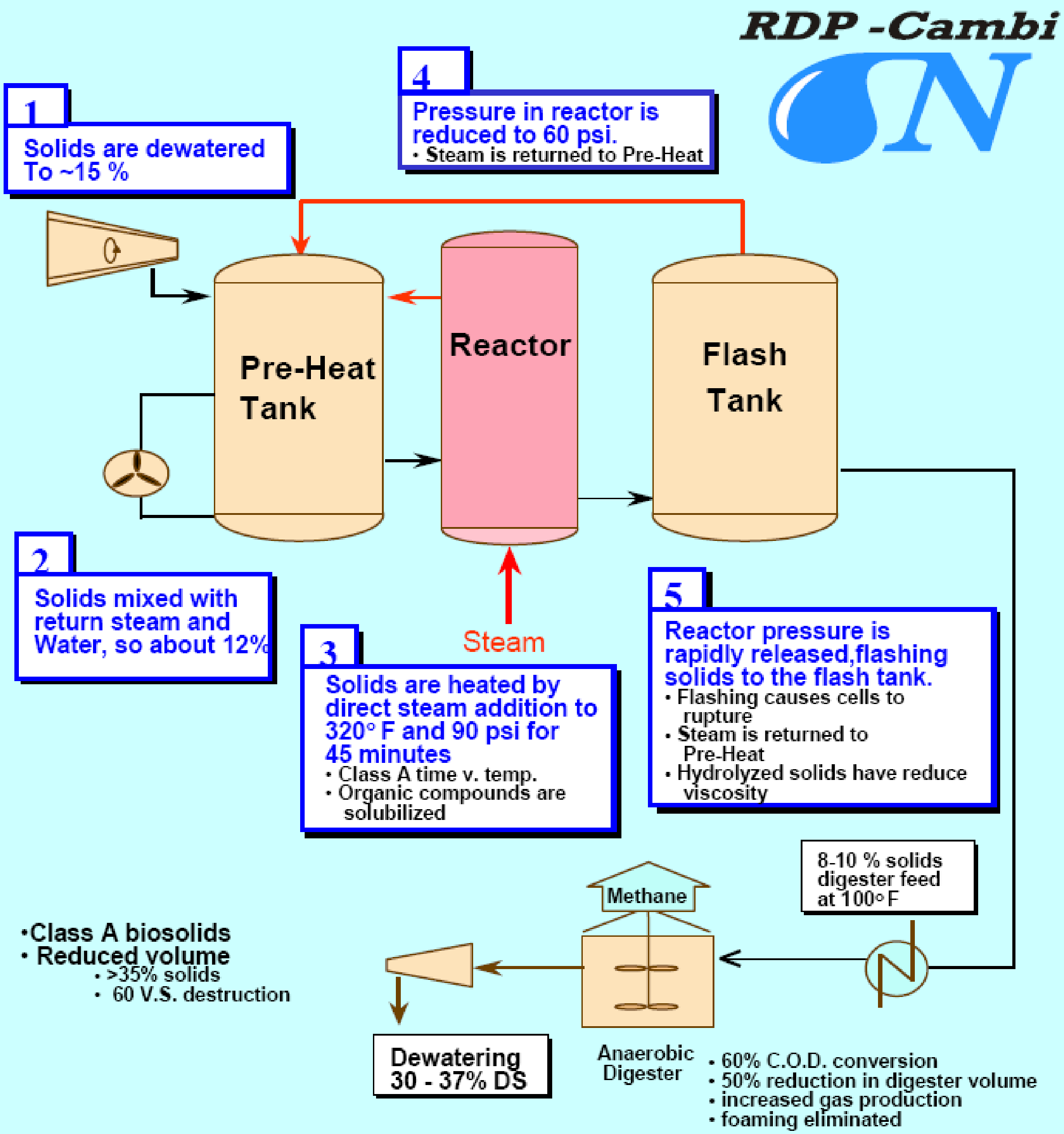
Why Condition Sludge for Anaerobic Digestion?

- Solubilize sludge solids and lyse cells, thereby increasing the rate of degradation
- Render the non-degradable organic fraction degradable, thereby increasing the extent of degradation
- Ultimately result in the generation of less residuals to further manage

Thermal Hydrolysis

- High pressure-high temperature process: thermal hydrolysis of dewatered sludge under pressure using live steam.
- Hydrolyzed and pasteurized sludge digested at greater VSL (smaller vessels).

- Three systems:
  - Cambi® Thermal Hydrolysis Process (THP)
  - BioThelys® Process



Slide courtesy of Dru Whtilock, CH2MHill & WERF

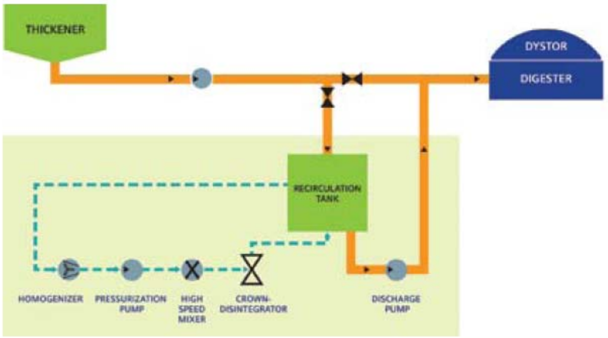
CAMBI's Performance Claims

Parameter	Mesophilic AD	CAMBI + Meso AD
Digester Feed (%TS)	4-6	12-15
VSLR (kg VS/m^3/d)	1.5	3.5
VS Destruction (%)	40-55	55-65
Pathogen content	Class B	Class A
Dewatered Cake TS (%)	20-25	30-35

Sludge Disintegration Processes

- Macerate sludge to homogenize
- Increase pressure (12 Bar) with PC pump
- high pressure mixer, flow into disintegration nozzle.
- As the flow exits the nozzle, cavitation occurs rupturing cell structure
- Sludge can be passed through system three times before discharge to the digesters.

Crown Disintegrator
Wiesbaden WWTP - 60m3/hr

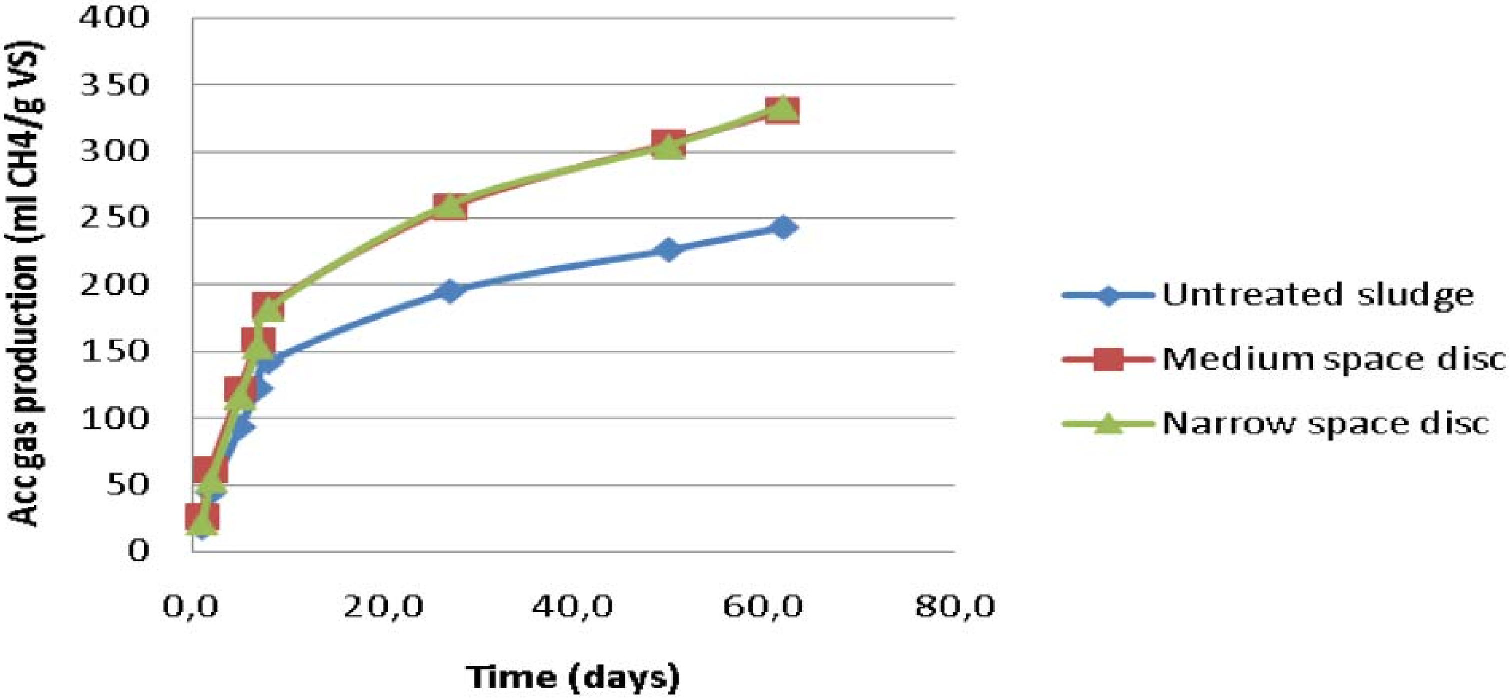


Performance Data by Crown

Site Name	VSr %			Biogas production cf/lb VS des		
	Before	After	% inc	Before	After	% inc
Wiesbaden Biebrich	32%	38%	20.0%	25.1	24.7	-1.7%
Taunusstein	32%	44%	38.9%	22.6	20.8	-7.8%
Ingelheim	36%	49%	34.1%	17.0	17.7	4.4%
Ginsheim	45%	54%	19.9%	14.7	14.3	-3.1%
Münchwilen	32%	43%	32.0%	20.2	19.1	-5.3%
Rosedale WWTP	51%	62%	21.6%	18.2	17.9	-1.8%
Average	**38.1%**	**48.3%**	**27.7%**	**19.6**	**19.1**	**-2.6%**

Performance Data by Crown

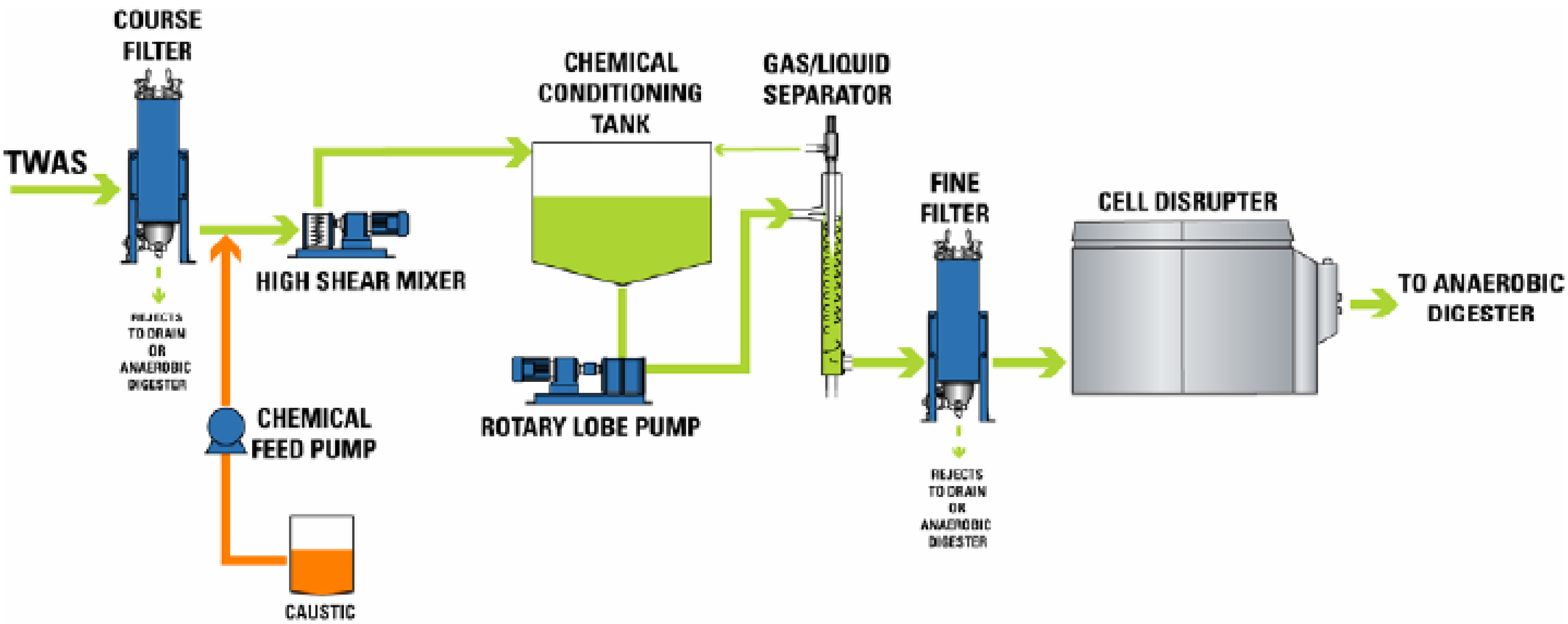
Site Name	DS after dewatering %		
	Before	After	% increase
Wiesbaden Biebrich	31	36	16.1%
Taunusstein	31	36	16.1%
Ingelheim	28	34	21.4%
Ginsheim	20	23.4	17.0%
Münchwilen	22	26.4	20.0%
Rosedale WWTP	18.5	22.2	20.0%
Average	**25.1**	**29.7**	**18.4%**



Specific methane production of biological excess sludge (DS content 5.7%, VS content 3.7%) treated with the Krima disperser narrow spaced disc and medium spaced disc respectively

Anna Maria Sundin, DISINTEGRATION OF SLUDGE - A WAY OF OPTIMIZING ANAEROBIC DIGESTION, Procs 13th European Biosolids & Organic Resources Conference & Workshop, www.european-biosolids.com

Micro-Sludge Process Flow Diagram

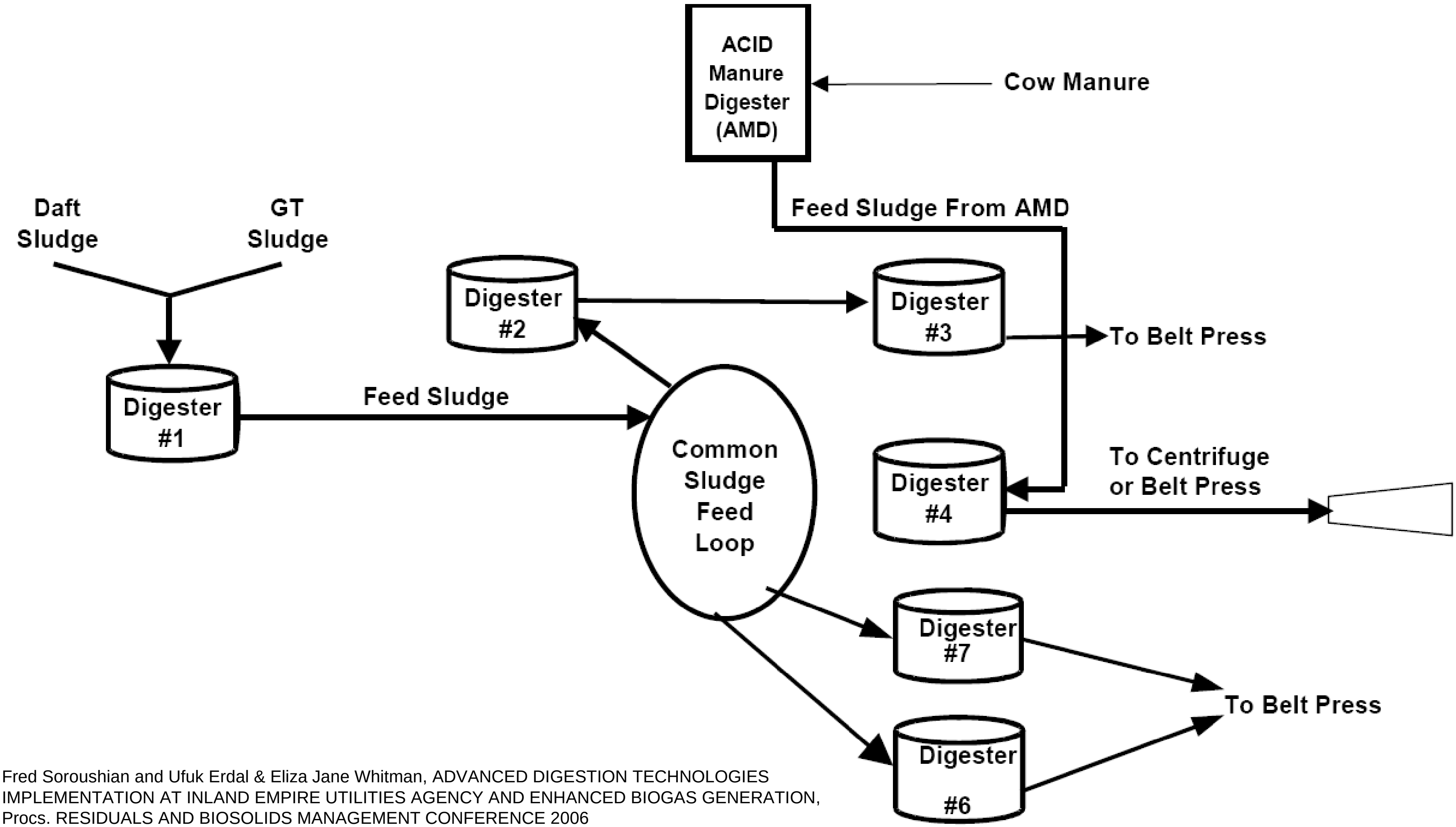


Rob Stephenson et al, "FULL SCALE AND LABORATORY SCALE RESULTS FROM THE TRIAL OF MICROSLUDGE AT THE JOINT WATER POLLUTION CONTROL PLANT AT LOS ANGELES COUNTY, " WEF/AWWA Joint Residuals and Biosolids Management Conference 2007

Summary of Sludge Pre-Treatment Options at JWPCP

Pre-treatment Option	Result	Current Status at JWPCP
Ultrasound	No material change in VSr or gas production	Tested
Thermal hydrolysis	Concerns over high odour potential, pressure vessels	Not tested
Acid Phase Digestion	No improvement in VSr or gas production at lab scale	Tested
MicroSludge + Acid Phase Digestion	20% improvement in VSr or gas production at lab scale	Tested
MicroSludge + Co-digestion of WAS + PS	16% increase in VSr or gas production at lab and commercial scales	Tested
MicroSludge + WAS Only Digestion	16% improvement in VSr or gas production at lab scale	Tested
Build More Digesters for 30 Day HRT	Increase in VSr and gas production at lab scale by 16%	Under consideration to increase HRT

Inland Empire, CA Digester Research



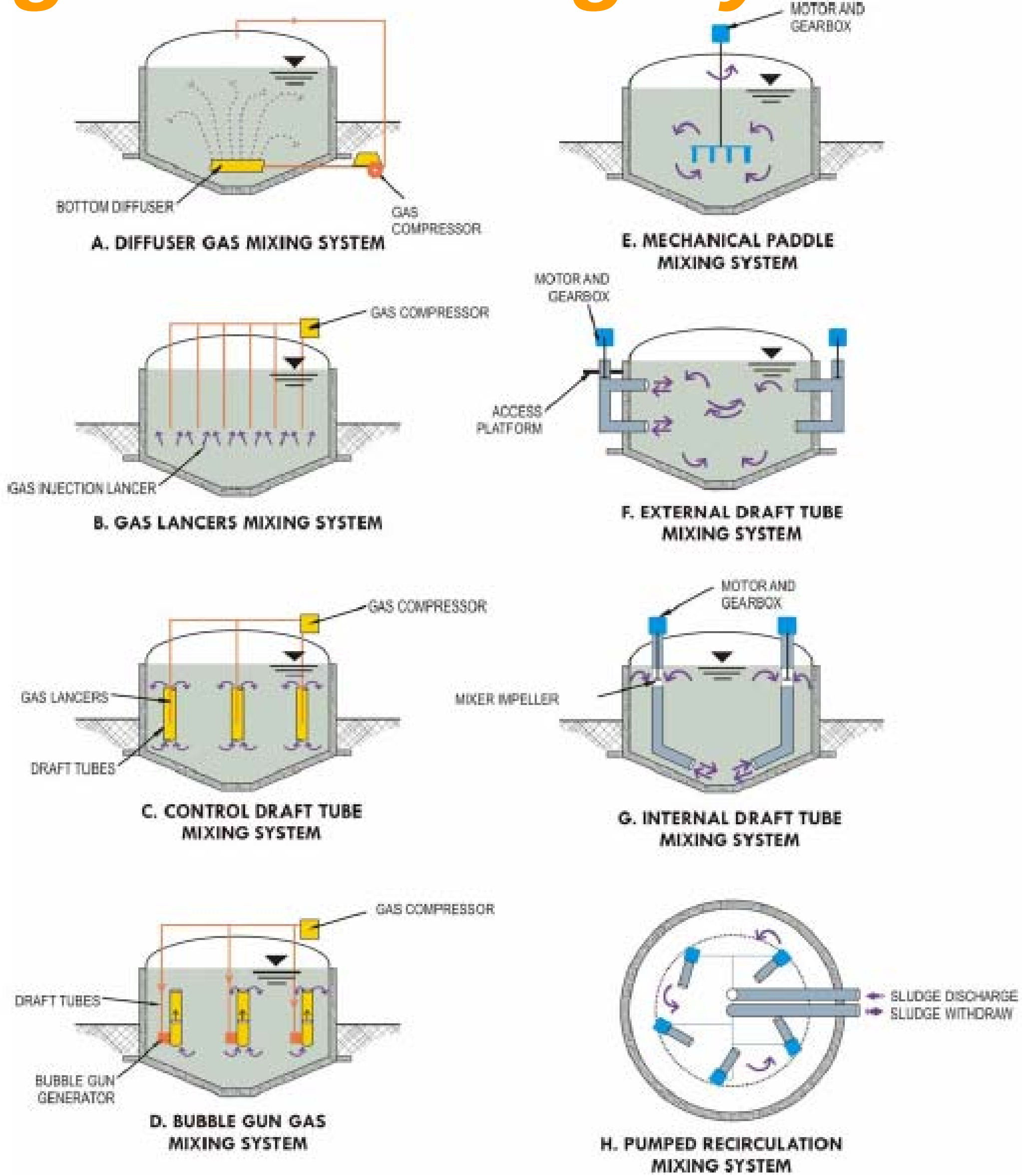
Fred Soroushian and Ufuk Erdal & Eliza Jane Whitman, ADVANCED DIGESTION TECHNOLOGIES IMPLEMENTATION AT INLAND EMPIRE UTILITIES AGENCY AND ENHANCED BIOGAS GENERATION, Procs. RESIDUALS AND BIOSOLIDS MANAGEMENT CONFERENCE 2006

Study Results

Parameter	Units	Single Phase Meso Jan. 99 – Sep. 99	Single Phase Thermo Oct. 98 – Dec. 98	Two Phase Meso-Meso Acid-Gas Mar. 00 – Jun. 00	Two Phase Meso-Thermo Acid-Gas May 03 – Dec. 03	Three Phase Meso-Thermo Acid-Gas Jan. 03 – May 03
Acid Phase Loading Rate	lbVS/cf-d	N/A	N/A	0.84	0.79	0.92
Loading Rate	lbVS/cf-d	0.09	0.06	0.20	0.26	0.29
Acid Phase HRT	d	N/A	N/A	3.0	2.7	2.4
Total HRT	d	31.8	51	26.9	19.3	21.5
Acid Phase VSR	%	N/A	N/A	17.2	15.9	18.2
Overall VSR	%	54.5	51	55.7	53.7	58.5
Specific Gas Yield	cf/lb VS reduced	15.6	14.9	15.3	18.2	14.2
Digested Biosolids NH_3-N	mg/L	1,600	1,610	1,530	1,410	1,600
Digested Biosolids Alkalinity	mg/L	5,730	5,620	5,430	5,050	5,700
BFP Feed TS	%	2.94	N/A	2.61	2.38	2.55
BFP Solids In	dry ton/d	24	N/A	23.4	27.3	26.8
BFP Solids Capture	%	88	N/A	99	94	94
BFP Cake TS	%	17.5	N/A	18.2	19.1	19.0
Polymer Usage	lb/d	909	N/A	876	895	806
	lb/ton solids	16.8	N/A	15	13	12
BFP Loading Rate	lb/sf	1.95	N/A	2.18	2.18	2.1

NR : Not Reported; N/A : Not Applicable

Digester Mixing Systems



After D. Parry for WEF/WERF/EPA
Solids Manual, March 2009

Discussion of Different Mixing Technologies

Mixing System Description	Advantages	Disadvantages
External Pump Circulation Involves installation of large pumps and piping to provide physical turn-over rate of >16/day	• Simple, reliable, measurable pumping technology • Easily maintained, nothing inside digester to maintain other than piping • Low foaming potential	• Most applicable to smaller (<50 ft diameter) digesters • Moderate energy efficiency • Potential for dead spots (moderate mixing effectiveness) • Large pumps and piping require more space than gas system
Dynamic Mixing A variation of external pump circulation. Mixing energy is provided by specially designed and placed nozzles.	• Simple, reliable, pump mixing • May be adapted to larger (>50 ft) diameter digesters • Easily maintained, nothing inside digester to maintain other than piping • Low foaming potential • Rapid re-suspension of settled solids after shutdown • Smaller pumps and piping • Lower energy consumption than conventional pump circulation • Suitable for varying tank levels. • Natural vortex surface motion draws floating solids down to reduce matting.	• Mixing must be evaluated by tracer testing • Limited installations in the US. • External nozzle adjustment (Jet Mix™ system)

Kenneth D. Fonda, SHAKEN OR STIRRED: DIGESTER MIXING DESIGN AND OPERATION SUCCESS STORIES, WEF/AWWA Joint Residuals and Biosolids Management Conference 2007

Discussion of Different Mixing Technologies

Mixing System Description	Advantages	Disadvantages
Mechanical Draft Tube Mixing High volume, low head pump mixing system with submerged impeller in a draft tube draws liquid in from the bottom or top and promotes a rolling action. Primarily for fixed cover digesters, but may be adapted for certain types of floating cover digesters.	• High mixing effectiveness • High energy efficiency • Single manufacturer responsibility • Accessible equipment • Low foaming potential • Flexible operation (forward or reverse) • May qualify for energy conservation rebates from electric utility company to offset construction costs	• Some models have experienced shaft seal and main bearing failures • Crane removal required • Careful vertical alignment required • Internal draft tube mixing with floating cover requires internal tube to have telescopic operation • Unable to see problems with mixing
Unconfined Gas Mixing Mixing energy is provided by the velocity gradient obtained from gas bubbles as they rise within the digester. Digester gas is recirculated and discharged through individual gas lances or fixed floor mounted spargers .	• Lances can be pulled for maintenance • Lances can have individual purge systems • Flexibility to modify mixing pattern	• Potential for ragging • Mixing efficiency effected by depth of submergence • Unable to see problems • Potential for surface debris accumulation • Potential for foaming • Handling flammable gases

Discussion of Different Mixing Technologies

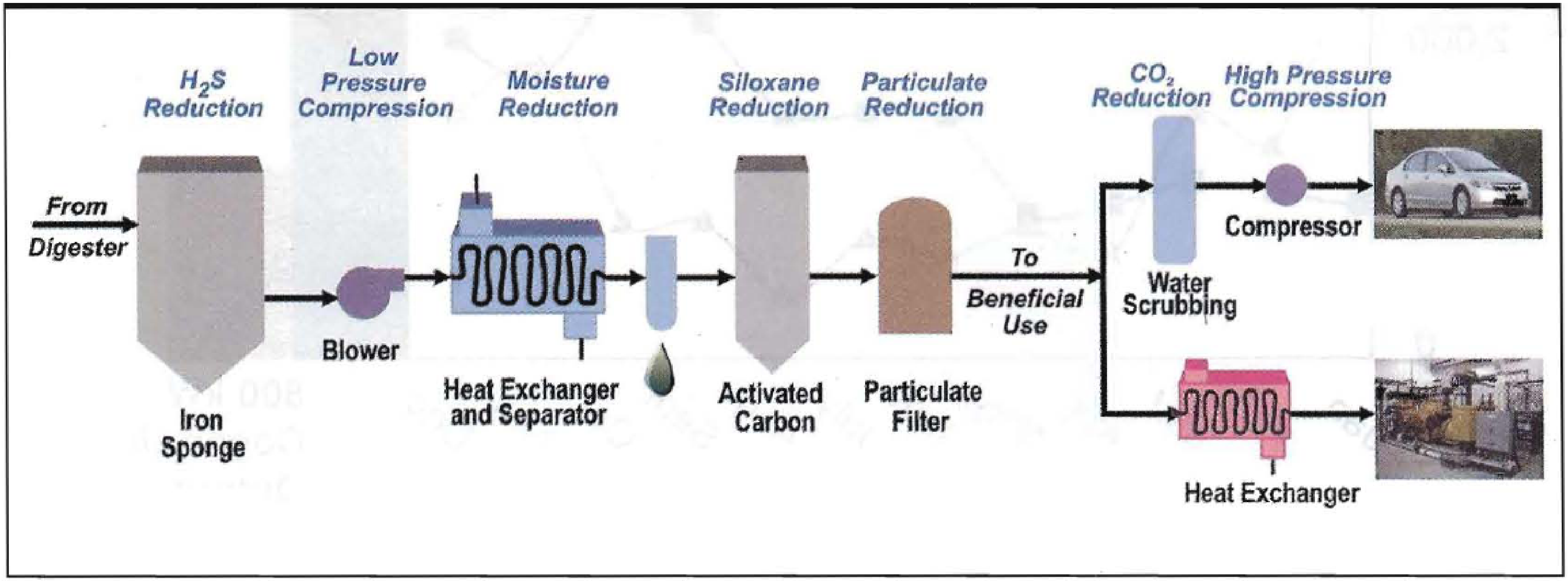
Mixing System Description	Advantages	Disadvantages
Bubble Gun Gas Mixing Is a variation of the confined gas mixing system that utilizes large bubbles the same size as the tube. The bubbles are released into the tube force the liquid column above the bubble to the surface in a piston action and drawing liquid in from the bottom of the tube.	• High mixing effectiveness • High energy efficiency • High local velocity gradients and good bottom scour • Unit responsibility for bubble gun systems • Compressor redundancy can be provided • Flexibility to vary mixing pattern and intensity • Performance guarantee available, tracer data supporting backup • Internal tubes may be heated to be used as a primary or supplemental digester heating system.	• All working parts, except compressor are inside digester (includes sludge heat exchangers) • Subject to ragging, plugging, and corrosion • Unable to see or troubleshoot effectively • Requires digester dewatering for major maintenance
Confined Gas Mixing Mixing energy is provided by the velocity gradient created by gas bubbles as they rise within a tube in the digester. As the gas bubbles accelerate towards the surface and expand under lower pressure, fluid is pumped from the bottom at the same rate it leaves the top. Digester gas is recirculated and discharged through individual gas lances or spargers mounted below the confined tube.	• Confined gas systems provide greater local velocity gradients, better bottom scouring, and higher mixing effectiveness compared to unconfined • Lances can be pulled for maintenance • Lances and spargers both can have reliable individual purge systems • Spargers may be made from stainless steel for longer lasting equipment • Unit responsibility for lance or sparger systems • Compressor redundancy can be provided • Exceptional flexibility to vary mixing pattern and intensity	• Potential for foaming • Handling of flammable gases • Unable to see problems • Potential for ragging • Works best when all discharge at same level

Typical Concentration Ranges for Anaerobic Digester Gas

CONSTITUENT	PERCENTAGE
Methane	40 – 65
Carbon Dioxide	30 – 55
Nitrogen	1 – 5
Oxygen	0.1 – 1
Ammonia	0.1 – 1
Hydrogen	<0.2
Hydrogen Sulfide	<0.2
Siloxanes	<0.01

Source:
Characterization of the Installed Costs of Prime Movers using Gaseous Opportunity Fuels. Prepared for: Energy Efficiency and Renewable Energy US Department of Energy Washington DC, and Oak Ridge National Laboratory Oak Ridge, TN. Prepared by: Resource Dynamics Corp., McLean, VA, www.rdcnet.com, September 2007.

Biogas Treatment for Beneficial Use



Problems with Siloxane

The sand-like material is SiO_2 produced through oxidation (burning) of the volatized siloxanes contained in the digester gas. Figure shows siloxane deposition on boiler tubes.

Damage from H_2S & Siloxane

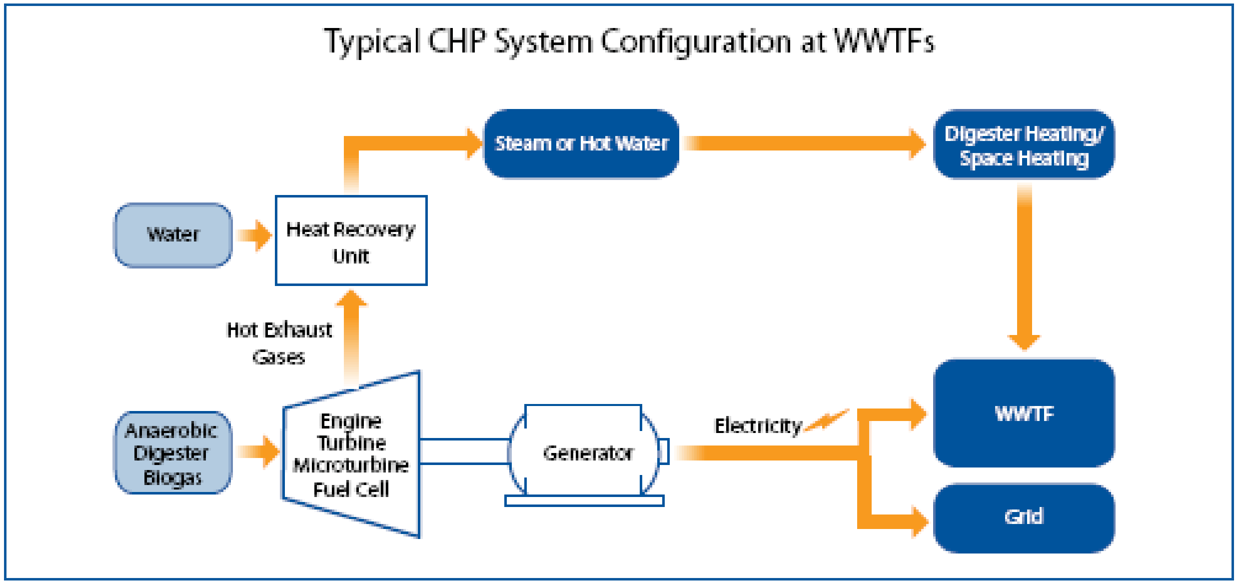
Engine Generator is shown.

Treating Digester Gas with Activated Carbon

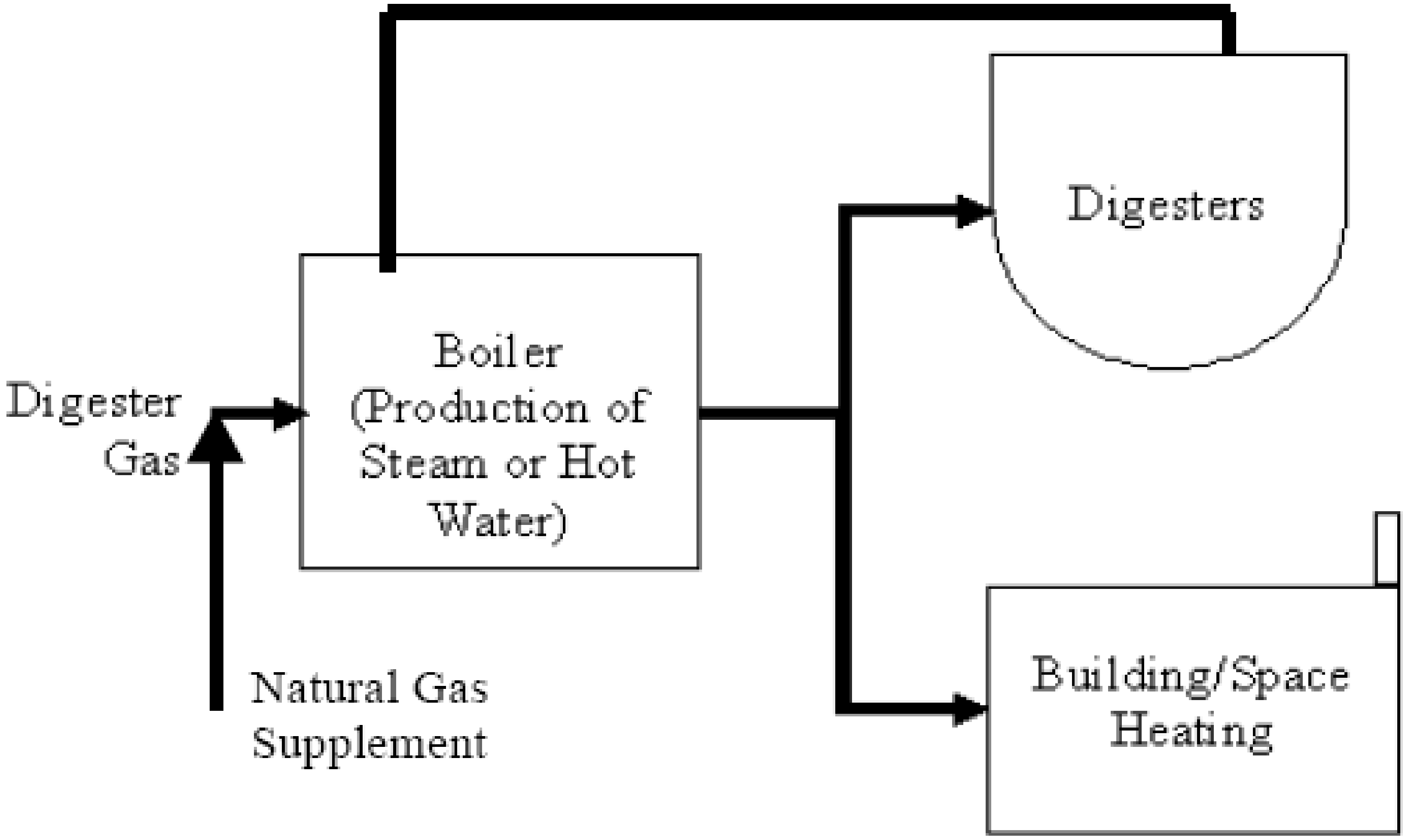
Plant	Gas flow	Installation	Technology details and efficiencies
Alvardo WWTP, Union City, CA (Slezak *et al.*, 2002)	17000 m3/day (600,300 scf/d)	One unit, 820kg media. Use gas compression, condenser/moisture removal, reheating, and particle filter	Protect Gas Engines
Annacis Island, Vancouver, BC (Slezak *et al.*, 2002)	45000m3/day (1,589,000 scf/d)	One unit with 500kg media. Treats 800m3 gas/kg media). Use gas compression, condenser/moisture removal, reheating, and particle filter	Protect Gas Engines Treatment involves outlet concentration of 5mg/m3 (survey data)
Bergen County Utility, Little Ferry, NJ (Tower, 2003b)	8150-32600 m3/day (287,800 - 1,151,000 scf/d)	Implemented full scale: 2 vessels operating series (plus 1 on standby), 3600lb media each (PMG). 3 different types of media in layers	Gas engine and OCR catalyst protection. Inlet 2-4ppm, reduced to non-detectable limits, H2S was also consistently <1ppm in pilot tests (Liang et al, 2002)

Combined Heat and Power

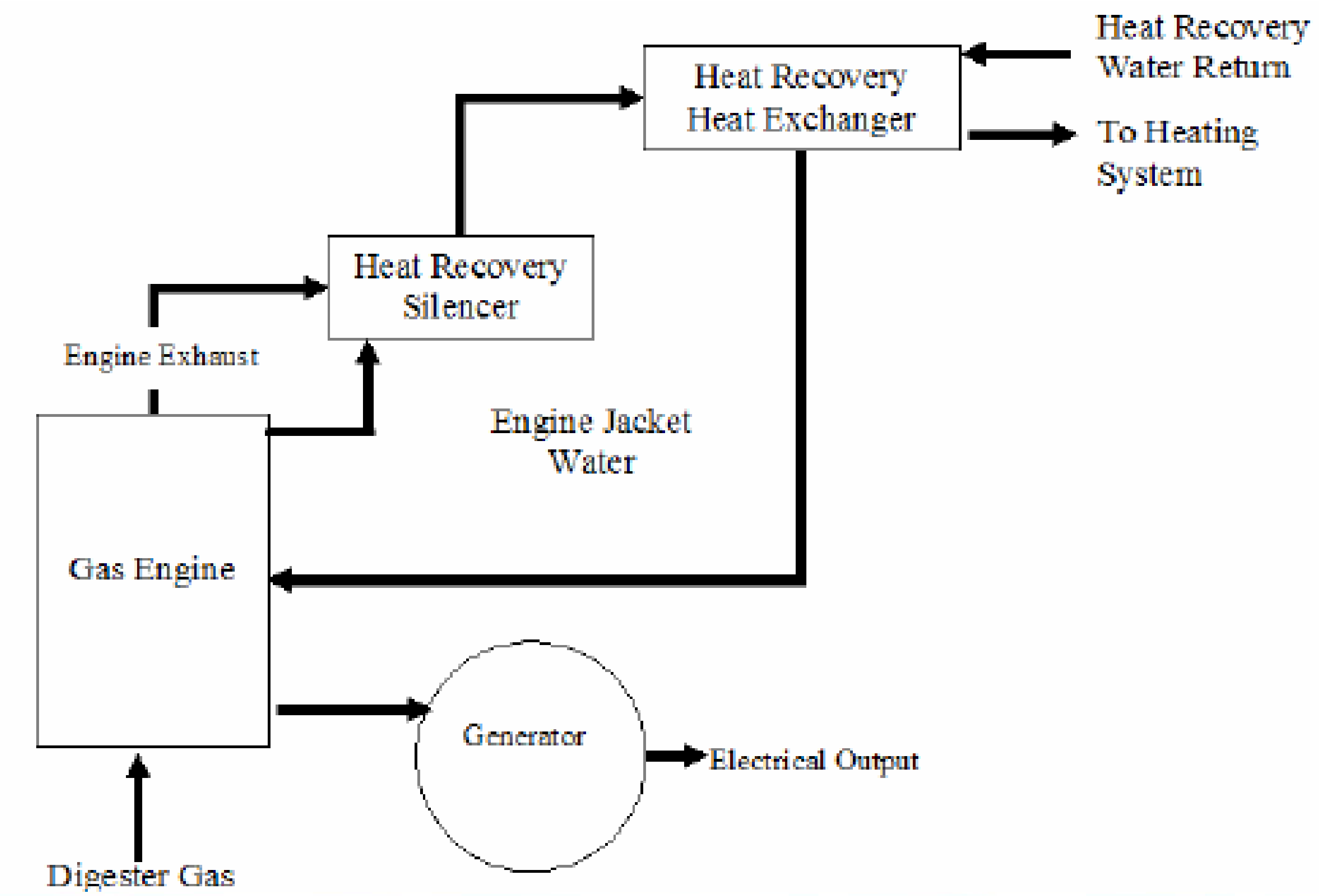
- **Definition: Utilizing equipment to simultaneously generate electricity and heat using anaerobic digester biogas**



Energy Recovery from Digester Gas using Boilers



Energy Recovery from Digester Gas using Engine Generators



Energy Recovery from Digester Gas from a Microturbine Unit

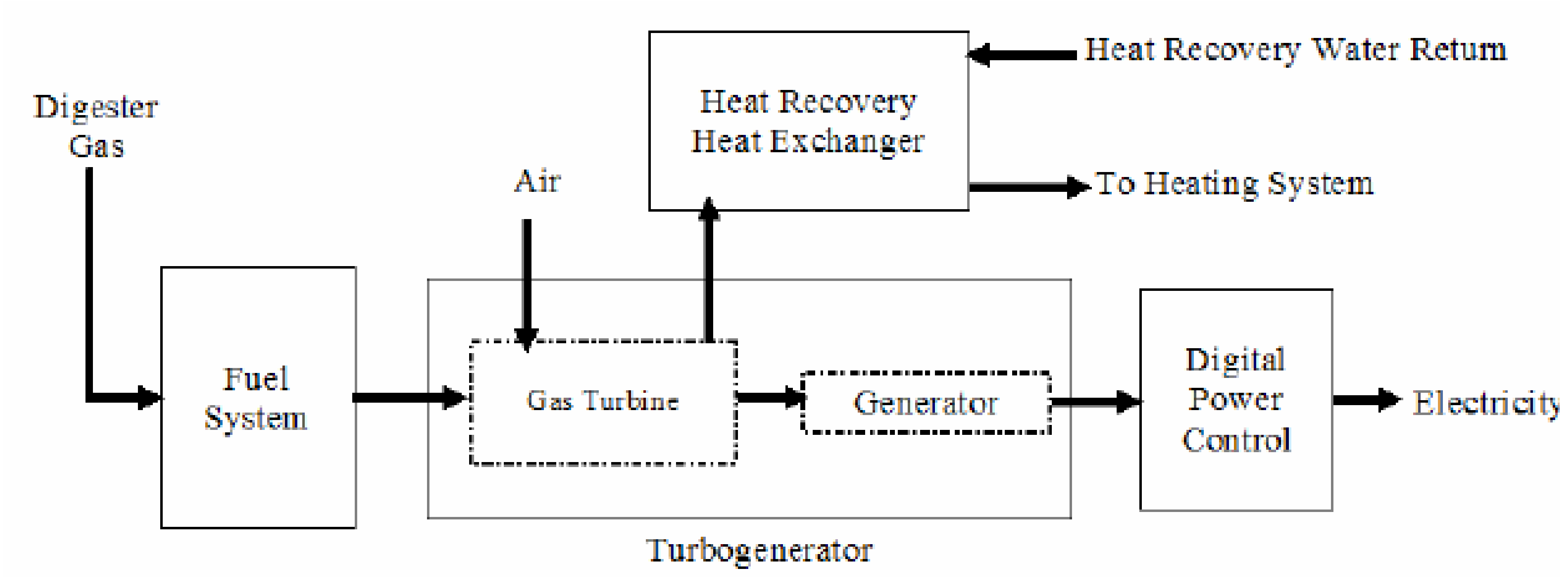


Table 1. Comparison of Capacity and Efficiency for CHP Technologies		
CHP Technology	**Capacity**	**Electrical Efficiency**
Internal-combustion engine	100 to 4000 kW	30% to 42%
Gas turbine	1000 to 4600 kW	25% to 38%
Microturbine	70 to 250 kW	24% to 26%
Stirling engine	55 kW	29%
Fuel cells	200 to 300 kW	38% to 42%

CHP = combined heat and power.

Table 2. Comparison of Emissions of CHP Technologies		
CHP Technology	**NOx Emissions (g/kWh)**	**CO Emissions (g/kWh)**
Rich-burn engines	~ 9	~ 9
Lean-burn engines	0.8 to 1.3	3.4 to 7.4
Gas turbine	0.14	0.14
Fuel cell	~ 0	~ 0

CHP = combined heat and power.
NOx = nitrogen oxides.
CO = carbon monoxide.

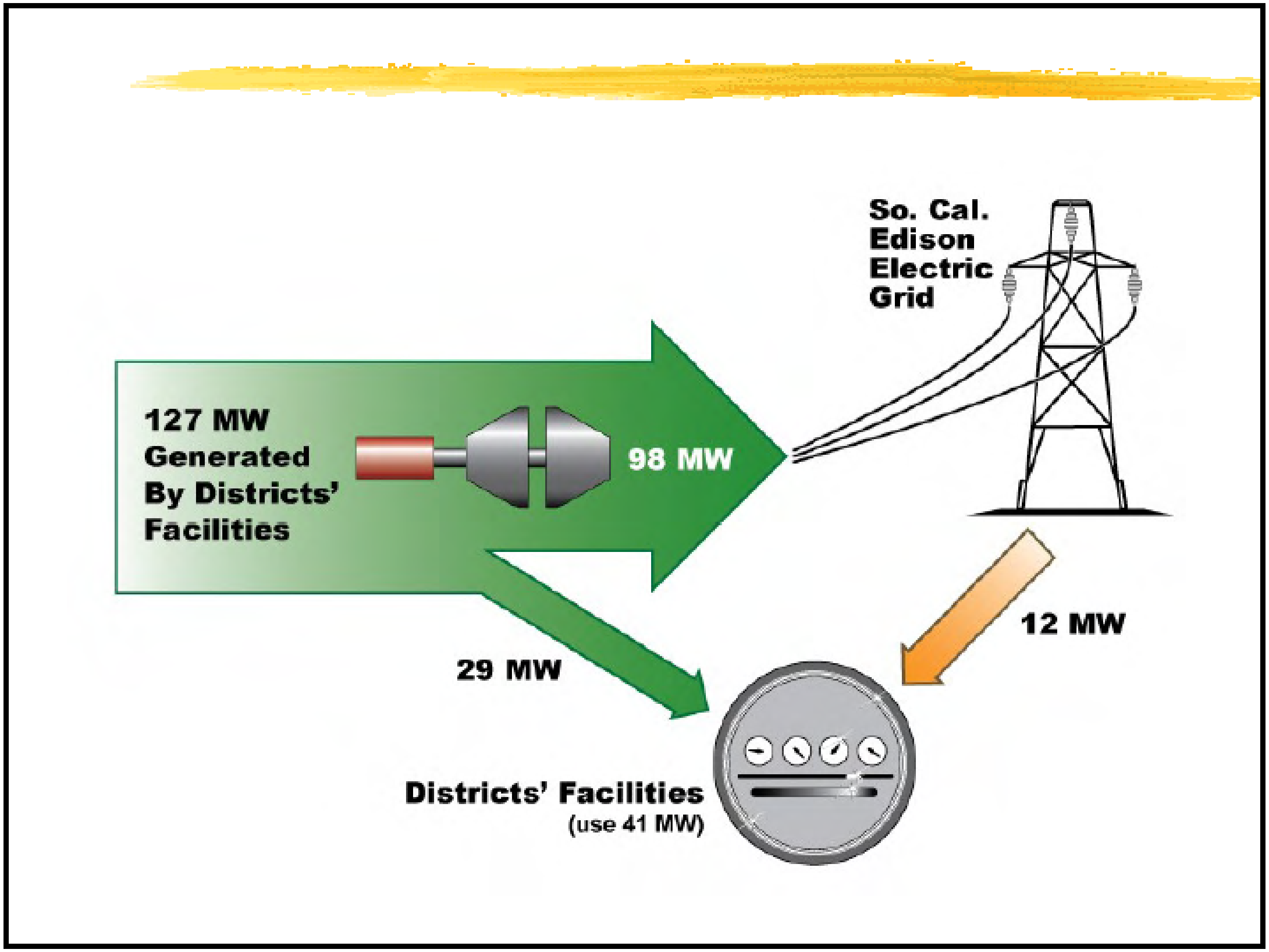
ELECTRIC & THERMAL ENERGY POTENTIAL WITH CHP FOR TYPICALLY SIZED DIGESTER: MESOPHILIC

	No CHP system	Microturbine CHP	Fuel Cell CHP	Internal Combustion Engine CHP
Total POTW Flow (MGD)	9.1	9.1	9.1	9.1
Heat Requirement for Sludge (Btu/day)	5,148,750	5,148,750	5,148,750	5,148,750
Wall Heat Transfer (Btu/day)	541,727	541,727	541,727	541,727
Floor Heat Transfer (Btu/day)	507,869	507,869	507,869	507,869
Roof Heat Transfer (Btu/day)	326,231	326,231	326,231	326,231
Total Digester Heat Load (Btu/day)	6,524,577	6,524,577	6,524,577	6,524,577
Heat Required for Digester Heat Load* (Btu/day)	**8,155,721**			
Heat Potential of Gas (Btu/day)	54,370,800	54,370,800	54,370,800	54,370,800
% of Gas Used for Digester Heat Load (Btu/day)	15.0%			
Amount of Gas Flared (Btu/day)**	**46,215,079**			
Electric Efficiency		0.28	0.43	0.30
Power to Heat Ratio		0.61	1.95	0.64
Electric Production (Btu/day)		**15,223,824**	**23,379,444**	**16,311,240**
Electric Production (kW)		**186**	**286**	**199**
Heat Recovery (Btu/day)		**24,957,089**	**11,989,458**	**25,486,313**
Additional Heat Available* (Btu/day)**		**18,432,512**	**5,464,882**	**18,961,736**

ESTIMATED CAPITAL COSTS FOR THREE CHP SYSTEMS AT WASTEWATER TREATMENT FACILITIES

Capital Cost	CHP System Type					
	126 kW (net) Microturbine		300 kW Fuel Cell		1,060 kW Internal Combustion Engine	
	Cost ($)	Cost per kW ($/kW)	Cost ($)	Cost per kW ($/kW)	Cost ($)	Cost per kW ($/kW)
Gen-Set	$143,000	$1,135	$1,200,000	$4,000	$685,000	$646
Fuel Treatment and Compression	$202,000	$1,603	$194,000	$647	$369,000	$348
Switchgear & Controls	$19,500	$155	$97,600	$325	$125,000	$118
Heat Recovery	$26,000	$206	$23,200	$77	$100,000	$94
Total Equipment Costs	**$390,500**	**$3,099**	**$1,514,800**	**$5,049**	**$1,279,000**	**$1,207**
Consulting and Design	$23,400	$186	$125,000	$417	$150,000	$142
Installation	$114,400	$908	$457,000	$1,523	$604,500	$570
Permits & Inspection	$9,750	$77	$25,000	$83	$25,000	$24
Contingency 5%	$26,903	$214	$106,090	$354	$102,925	$97
Total Project Costs	**$564,953**	**$4,484**	**$2,227,890**	**$7,426**	**$2,161,425**	**$2,039**

Case Study



From "The Power of Digester Gas: A Technology Review from Micro to Megawatts," Mark McDannel, Los Angeles County Sanitation Districts, WEFTEC, October 16, 2007

Case Study - LACSD

FACILITY	POWER PRODUCTION TECHNOLOGY/ (FUEL)	NET POWER PRODUCED
Joint WPCP	CC Gas Turbine(Digester Gas)	22 MW
Valencia WRP	IC Engine (Digester Gas)	400 kW
Puente Hills LF	Steam Boiler/Turbine (LFG)	46 MW
Palos Verdes LF	Steam Boiler/Turbine (LFG)	4 MW
Spadra LF	Steam Boiler/Turbine (LFG)	8 MW
Puente Hills LF	Gas Turbine (standby) (LFG)	0 MW
Calabasas Landfill	Capstone Microturbines (LFG)	250 kW
Lancaster WRP	Ingersoll-Rand Microturbine (DG)	225 kW
Palmdale WRP	Molten Carbonate Fuel Cell (DG)	225 kW
Puente Hills LF (2005)	IC Engine (LFG)	6 MW
	TOTAL BIOGAS GENERATION	87 MW

Power Generation Cost Summary Comparison for Different Approaches

	Installed Cost ($/kW)	Operating Cost ($/kWh)	Power Production Cost* ($/kWh)
Gas Turbines	$2,000	$0.010	$0.04
IC Engines	$1,700	$0.015	$0.04
Microturbines	$3,000	$0.016	$0.06
Fuel Cell	$8,500	$0.035	$0.16

*10 year write down @5%

CHP Case Studies

- **Albert Lee, MN**
  - **Flow 2.82 MGD**
  - **Fuel Type – Digester gas**
  - **Prime Mover – (4) 30 kW Capstone microturbines**
  - **Energy savings – 800,000 kWh/yr (30%)**
  - **Installed Cost - $250k**
  - **Annual energy savings - $40-$60k**
  - **Simple payback - 4-6 years**
  - **Year installed 2003**

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UPDATE
SOLIDS PROCESSING DESIGN AND MANAGEMENT MANUAL

Manual Objectives

- **Easy to update on CDs / online**
- **Best management, technical practices emphasis**
- **Operator and Designer perspectives**
- **Neutral on bioenergy sources (thermal and biological)**
- **Case studies, lessons learned, example designs**
- **Dated and location-specified cost estimates**
- **Cross-referenced**

More than half way there!

Online Version Available – WEFTEC October 2010

3rd Peer Final Review –

2nd Peer Draft Review –

1st Peer Draft Review – May 2009

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27. **Treatment and Utilization of Green Gas**

Jim Schettler, Brown and Caldwell

Questions?