Digester Gas Utilization at SWRP
Where Should the Biogas Go?

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MWRD Monthly Seminar Series
Oct 28th, 2011
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Presentation Outline

- Background/Purpose
- Digester Gas Production at SWRP
- Energy Consumption at SWRP
- Selection of Gas Utilization Alternatives
- Energy Flow Modeling
- Evaluation of Results and System Selection
Situation:

- Anaerobic digesters produce biogas
- Future conditions will nearly double the biogas production
- Biogas = Energy = $
- There are many different options available for utilizing biogas
Energy Value of Digester Gas

- 1 cubic foot of Digester Gas = 600 Btu
- 1 cubic foot of Natural Gas = 1,000 Btu
  - Last 10 years, natural gas ~ $4 to $12/mmBtu
- District currently uses digester gas for heating but requirements are much lower in the summer
- Amount of digester gas flared at SWRP in summer of 2009:
  - 707,000 cubic feet per day (707 Mcf/day)
  - 424 mmBtu/day
  - @ $6/mmBtu approximate value = $500K per year (summer)
- Digester gas production estimated to increase at SWRP
Digester Gas Utilization – Purpose of Project

- Examine the ways SWRP currently utilizes energy
- Project the amount of digester gas energy that will be available in the future
- Select the most beneficial strategy for utilizing digester gas at SWRP moving forward
Specific Concerns for SWRP

- Expected increase in gas production
- Existing plant heating system is steam
- Plant boilers nearing replacement
- MBM facility can use biogas
Current Digester Gas Production

**From 2007 – 2009 Plant Data**

- Avg Production: 3,400 Mcf/day
- Avg VSR: 31% (low, typical = 40-50%)
- Avg Gas Yield: 21.5 cf/lb VSR (high, typical = 12-18)

**Items affecting future SWRP Gas Production**

- Replacement of WS Imhoff tanks with Primary Settling Tanks
- Upgrades to sludge thickening facilities
- Increase in flows and loads projected by Master Plan (SWRP and NSWRP)
Projected Digester Performance

**VSR**
- VSR assumed to be low due to destruction of readily degradable VS in Imhoff Tanks
- Future VSR with solids handling improvements should resemble typical range of 40-50%

**Gas Yield**
- A standard typical value of 16 cf/lb VSR was used
Digester Gas Production Modeling

**Model Inputs**
- Influent Flow and Influent TSS to Plant – from Master Plan GPS-X
  - 2040 Annual Average: 750 mgd, 480 dtpd TSS
- Influent %VS – from Master Plan GPS-X
  - Influent %VS = 75% (all conditions)

**Model Outputs**
- VS to digesters
- Digester Gas Produced
Digester Gas Production Modeling Variables

Input Flow Conditions
- 2011 Annual Average, 2020 Annual Average, 2040 Annual Average
- 2040 Max Month, 2040 Max Month Winter

Primary Clarifier SS Removal
- 50% Removal (standard), 60% Removal (enhanced)

VSR
- 40% (low efficiency), 45% (mid efficiency), 50% (high efficiency)
- 55% (digester improvements), 60% (multiple digester improvements)
Selected Future Gas Production Value

Selected Future Evaluation Point

- Plant Influent: 2040 Annual Average
- Primary Clarifier SS Capture: 50%
- VSR: 45% (Middle Efficiency)
- Digester Gas Production = 6,722 Mcf/day
  - Double current production of 3,400 Mcf/day
- Energy Production = 168 mmBtu/hr
Projected SWRP Digester Gas Production

Digester Gas Production [Mcf/day]

Energy Consumption at SWRP

- Building heating system comprised of extensive steam piping network operated at 90 psig
- Steam is used for building cooling in the summer via absorption chillers
- For digester heating, steam is converted to hot water at each individual digester bank
- Heating demands have significant seasonal variation
- Plant electrical consumption is ~ 31 MW without much seasonal variation
Heating Energy Consumption

Current
- From 2007 – 2009 plant data
- Heating Demand: 40 [mmBtu/hr] (summer)
  120 [mmBtu/hr] (winter)
  87 [mmBtu/hr] (average)

Adjustments for 2040 Heating Energy Consumption
- Additional flow to digesters
- Addition of new facilities

Future Heating Demand
- Summer: 30 (Digesters) + 20 (Buildings) = 50 [mmBtu/hr]
- Winter: 48 (Digesters) + 87 (Buildings) = 135 [mmBtu/hr]
- Average: 39 (Digesters) + 60 (Buildings) = 99 [mmBtu/hr]
Long List of Utilization Alternatives

**Internal Utilizations**
- Utilize Gas in Plant Heating Boilers
- Gas to MBM
- Cogeneration – Reciprocating Engines
- Cogeneration – Combustion Turbines
- Cogeneration – Steam Turbines
- Cogeneration – Microturbines
- Cogeneration – Fuel Cells
- Cogeneration – Stirling Engines
- Direct Drive Engines

**External Utilizations**
- Sell Raw Gas to 3rd Party
- Upgrade to Natural Gas and sell to pipeline
- Upgrade to Natural Gas and make Compressed Natural Gas (CNG)

**External Utilizations Not in Scope**

**Short List**
- Utilize Gas in Plant Heating Boilers
- Gas to MBM
- Cogeneration – Reciprocating Engines
- Cogeneration – Combustion Turbines
- Cogeneration – Steam Turbines
Sizing of Systems

**Cogeneration Sizing:** Requires iterative loop to size capital equipment *(maximum capacity)*

- **Average Gas Production** used to determine operating costs and economic performance
Gas to MBM

- Digester gas piped to MBM for use in process heating
- Pipeline in place, burners can use digester gas
- Assumed that H$_2$S removal is not required

Components

- No new components needed

Benefits

- Replaces Natural Gas that would be purchased for MBM
Cogeneration - Engines

- Digester gas combusted in piston Engine
- Mechanical energy used to generate electricity
- Heat Recovered from exhaust and cooling water
- H₂S removal required. SiO removal recommended

Components
- Engine Generators
- Hot water loop to heat digesters
- Electrical Infrastructure
- New Building
- Gas Cleaning System

Benefits
- Electricity generated reduces plant electric bill
- Digesters can be heated with recovered hot water
Cogeneration – Combustion (Gas) Turbines

- Digester gas compressed (250 psi) and combusted with compressed air. Expansion of combustion gas turns a generator
- Mechanical energy used to generate electricity
- Heat recovered from combustion exhaust as steam
- H₂S removal required. SiO removal recommended

Components
- Gas Turbine Generators
- Gas Compressors
- Electrical Infrastructure
- Heat Recovery Steam Generators (HRSG)
- New Building
- Gas Cleaning System

Benefits
- Electricity generated reduces plant electric bill
- Recovered steam can be used for plant heating
Cogeneration - Steam Turbine

- Digester gas burned in boilers to make high pressure steam (750 psi)
- Steam is expanded through a turbine to generate electricity
- Heat recovered from exhaust steam
- No Gas Cleaning recommended

Components
- Steam Turbine Generator
- Surface Condenser
- Electrical Infrastructure

Benefits
- Electricity generated reduces plant electric bill
- Recovered steam can be used for plant heating
### Summary – Economics and Performance

<table>
<thead>
<tr>
<th>Short List Option</th>
<th>Capital Cost</th>
<th>O&amp;M Cost (Annual)</th>
<th>Electrical Efficiency</th>
<th>Heat Recovery Efficiency</th>
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<tr>
<td>Reciprocating Engines (with siloxane cleaning)</td>
<td>$48.4 million</td>
<td>$2.8 million</td>
<td>42%</td>
<td>43%</td>
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<td>Gas Turbines (with siloxane cleaning)</td>
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<td>28/33%*</td>
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<td>Steam Turbines (no gas cleaning)</td>
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<td>$250,000</td>
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<td>Send Digester Gas to MBM</td>
<td>$0</td>
<td>$0</td>
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*Due to the compressibility of air, electrical efficiency differs from summer to winter.*
Energy Flow Scenarios:

Digester Gas

Natural Gas

Plant
Heating
Boilers

Biosolids
Drying
Facility

Plant
Electric
Demand

Cogeneration

Plant
Heat
Demand

Build a Model!
Energy Flow Model

- Outputs = Annualized Cost, GHG Reduction, Unused Energy
Model Components – Gas Production

- Turn Northside sludge ON/OFF
- Account for Imhoff Tank replacement
- Adjust to 2011, 2020 or 2040 gas production
Model Components – Gas Cleaning

- Turn H$_2$S and Siloxane cleaning ON/OFF
- Capital and O&M cost for cleaning scaled to amount of digester gas received
- Cleaning affects downstream maintenance costs
- Cleaning affects downstream equipment performance
- MBM turned ON/OFF at varying solids loads
- Cogen systems turned ON/OFF and can receive varying digester gas amounts
- Capital and variable O&M cost for cogen are calculated and scaled to amount of digester gas received
- Cogen performance parameters determine electrical production and heat recovery
- Heat recovered as either steam or hot water
Model Components – Plant Energy Demands

- Model requires that plant heat demands are satisfied
- Summer and Winter heat demand conditions
- Accounts for boiler efficiency
- Type of heating (i.e. steam or hot water) is considered when satisfying heat demands
Model Components – Natural Gas Input

- Natural gas from utility can be input as additional energy
- Natural gas to either plant heating and/or MBM
- Variable amounts of natural gas can be provided to balance plant heating demands
- Natural gas prices can be varied (as well as electricity prices)
- MBM contract pricing is considered
Projecting Future Energy Prices

- Utility Prices were estimated for 20 year period beginning in 2016
  - Electricity: Currently $0.05/kWh
  - Estimated rise for 2016+: $0.08/kWh
- Natural Gas: Currently Estimated at $6/mmBtu
  - Estimated rise for same 20 year period: $8/mmBtu

Note: Thousand Cubic Foot = Million Btu [mmBtu]
Energy Flow Model - Baseline

- **2016 conditions selected as baseline**
  - 2016 plant influent (from master plan)
  - Half of WS Imhoff Tanks Replaced with PCs
  - All Thickening Improvements Complete
  - Cost of Operating MBM Facility included
  - No Cogeneration Option – Excess Gas Flared
  - Utility Prices: $0.08/kWh (Electric) and $8/mmBtu (Gas)

- **2016 Baseline Values (Annual)**
  - Annualized Cost: **-$1,752,000** ➔ must spend money for MBM
  - GHG Reduction: **-23,214 MT eCO2** ➔ must send natural gas to MBM
  - Unused Energy: **355,419 mmBtu** ➔ must flare lots of excess gas
Energy Flow Model - Scenarios

Scenario Group 1 (No Cogen)
- DG Priority = 1.
  1. Plant Heating Boilers
  2. MBM Facility

Scenario Group 2 (No Cogen)
- DG Priority = 1.
  1. MBM Facility
  2. Plant Heating Boilers

Scenario Group 3
- DG Priority = 1.
  1. Plant Heating Boilers
  2. MBM Facility
  3. Cogeneration

Scenario Group 4
- DG Priority = 1.
  1. Plant Heating Boilers
  2. Cogeneration
  3. MBM Facility = NG

Scenario Group 5
- DG Priority = 1.
  1. MBM Facility
  2. Cogeneration
  3. Plant Heating Boilers

Scenario Group 6
- DG Priority = 1.
  1. Cogeneration
  2. Plant Heating Boilers
  3. MBM Facility = NG
Energy Flow Model - Results

- **Group 1+2**: No Cogen
  - DG to 1) Plant, 2) MBM, 3) Cogen

- **Group 3**: DG to 1) Plant, 2) MBM, 3) Cogen

- **Group 4**: DG to 1) MBM, 2) Cogen, 3) Plant

- **Group 5**: DG to 1) Cogen, 2) Plant, 3) MBM

- **Group 6**: DG to 1) MBM, 2) Cogen, 3) Plant

Annualized Cost ($), GHG reduction (MT eCO2), Unused Energy (mmBtu)
Energy Flow Model - Results

GHG Reduction Vs. Cost Savings

- **Steam Turbines**
  - 6C
  - 4C
  - 4F
  - 6F

- **Engines**
  - 4A
  - 6A

**Axes:**
- Y-axis: Annualized Cost
  - $2,000,000
  - $1,500,000
  - $1,000,000
  - $500,000
  - $0
  - $(500,000)
  - $(1,000,000)
  - $(1,500,000)
  - $(2,000,000)
- X-axis: GHG Reduction (MT eCO2)
  - 40,000
  - 20,000
  - 0
  - -20,000
  - -40,000

**Legend:**
- Baseline 2016
## Selected Scenarios for Further Evaluation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cogeneration System</th>
<th>Digester Gas 1st Priority</th>
<th>Digester Gas 2nd Priority</th>
<th>Digester Gas 3rd Priority</th>
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<tbody>
<tr>
<td>4A</td>
<td>Engines</td>
<td>Plant Heating</td>
<td>Cogeneration</td>
<td>MBM (Fueled by NG)</td>
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<tr>
<td>4C</td>
<td>Steam Turbine</td>
<td>Cogeneration</td>
<td>Plant Heating</td>
<td>MBM (Fueled by NG)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(Plant heated entirely by recovered cogeneration heat)</td>
<td></td>
</tr>
<tr>
<td>6A</td>
<td>Engines</td>
<td>Cogeneration</td>
<td>Plant Heating</td>
<td>MBM (Fueled by NG)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(Supplemental NG needed)</td>
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Engine Operation Alternatives

- **Balance DG**
  Digester gas first routed to heating boilers then balance to engines.

- **Max with NG**
  Digester gas first routed to heating boilers then balance to engines.

Supply engines with natural gas when engine capacity is available
(typically in winter)
Steam Turbine Operation Alternatives

- **ST – A** = Use extraction steam for building and digester heat
- **ST – B** = Use extraction steam for building heat, condenser water heats digesters via recirculation line
- **ST – C** = Use extraction steam for building heat, condenser water pre-heats influent sludge to digesters
Updated Model Parameters

- New Performance for Steam Turbines
- Updated Cost for Heat Recovery Infrastructure
- Updated Cost for Electrical Distribution Infrastructure
- Addition of Digester Gas Storage Costs
Advanced Energy Flow Model Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Annualized Scenario Cost [$]</th>
<th>GHG Reduction [MT eCO2]</th>
<th>Unused Energy [mmBtu]</th>
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<tbody>
<tr>
<td>Baseline</td>
<td>$-1,752,000</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Engine - Balance</td>
<td>$166,105</td>
<td>$538,639</td>
<td>$1,093,784</td>
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<tr>
<td>Engine - Natural Gas</td>
<td>$1,093,784</td>
<td>$1,408,316</td>
<td>$1,130,646</td>
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<td>Steam Turbine A</td>
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<td>$1,130,646</td>
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<td>Steam Turbine B</td>
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<td>Steam Turbine C</td>
<td>$1,130,646</td>
<td>$1,130,646</td>
<td>-</td>
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</tbody>
</table>

GHG Reduction [MT eCO2] / Unused Energy [mmBtu]
Sensitivity Analysis – Electricity Price

Natural Gas Constant at Baseline Price ($8/mmBtu)

Annualized Cost

Scenario

Baseline 2015 4A 4C 6A 4A 4C 6A 4A 4C 6A 4A 4C 6A 4A 4C 6A

Electricity Low ($0.07/kWh) $836,134 $894,236 $995,086 $995,086 $995,086 $995,086 $995,086 $995,086 $995,086 $995,086 $995,086 $995,086 $995,086 $995,086 $995,086 $995,086

Electricity Baseline Electricity ($0.08/kWh) $1,518,767 $1,747,895 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399 $2,017,399

Electricity High ($0.09/kWh) $1,752,000 $2,201,399 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683 $2,408,683

Electricity High ($0.10/kWh) $4,186,800
Year 2016 - 2035
Capital cost and annual O&M costs subtracted
Triple Bottom Line Analysis

- **Economics**
  - Cost Savings
  - Sensitivity to Energy Prices

- **Environmental**
  - GHG Reduction
  - Air Pollution

- **Social**
  - Operability
  - Maintainability
  - Implementability
Large WWTP Reference Installations

Orange County Sanitation District
Plants 1+2 (220 MGD)
Orange County, CA
3 engine units rated at 2.5 MW

Deer Island WWTP (360 MGD)
Boston, MA
18 MW capacity Steam Turbine
Other Reference Installations

Metropolitan WWTP,  
St. Paul, MN  
4 MW Steam Turbine

Site Visits

- South Shore WRP, Milwaukee, WI  
  - 5 engine units of 1 to 1.5 MW

- Abbott Power Plant, Champaign, IL (U of I)  
  - Several 12 MW steam turbines operating off natural gas
Calls and Field Visits - Engines

- Operations can be automated but still require significant operator attention
- Siloxane cleaning dropped maintenance costs
- Preventative maintenance is labor intensive and could be done in house or contracted out
- “Top Ends” and Major Overhauls every 3-5 years
  - Contracted out
  - Takes ~1 month
- Availability can be good but is highly dependent on proper maintenance by owner
Calls and Field Visits – Steam Turbine

- Operation is automated and requires less operator attention
- Responds well to changing loads
- Preventative maintenance is done in house and consists of minor procedures and monitoring
- Major Rotor Overhauls every 5-7 years
  - Contracted out
  - Takes ~1 month
- Availability is very high and major O&M issues are rare
- SWRP boiler feed water system needs upgrading
Recommended Utilization System

Steam Turbine Alternate A –
Uses extraction steam for building and digester heating

**SWRP Specific Advantages**

- Takes advantage of required boiler replacement
- Utilizes the existing skills of plant personnel
- Maintains consistency in plant heating scheme and heating infrastructure
Conclusions/Discussion

- A Combined Heat and Power option provides the greatest economic advantage of all options, so long as the CHP is priority loaded with biogas.
- Reciprocating Engines have highest electrical efficiency, and therefore offer greatest GHG reduction but requires greater gas cleaning, capital outlay, and maintenance.
- Engines are more sensitive (volatile) to changes in electrical prices than steam turbines.
- Therefore, economic returns for Steam Turbines are greater than Engines for this plant.
- Slight changes in electricity rates have a significant affect on the economic payback of all co-generation alternatives.
Questions
Sizing of Cogeneration Systems

**Cogeneration Sizing**: Requires iterative loop to size capital equipment (maximum capacity)

- *Average Gas Production* used to determine operating costs and economic performance
Energy Flow Modeling

- Different Operational Scenarios Possible
## Triple Bottom Line Scoring

<table>
<thead>
<tr>
<th>Category</th>
<th>Weight</th>
<th>Sub Category</th>
<th>Max Score</th>
<th>ENG-NG</th>
<th>ST-A</th>
<th>ST-B</th>
<th>ST-C</th>
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<td><strong>Total Environmental</strong></td>
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<td><strong>TOTAL OVERALL SCORE</strong></td>
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<td><strong>1000</strong></td>
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<td><strong>867</strong></td>
<td><strong>833</strong></td>
<td><strong>800</strong></td>
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Model Components

- Capital Cost Annualized over 20 years, 6% interest (estimates annual bond payments for capital)
- O&M Cost (both variable and fixed)
- Cost of purchasing natural gas for supplemental/MBM heating
- Cost Savings from electrical production
- Reduction in emissions due to net electrical production (reduces electricity purchased from coal based power plant)
- Emissions from purchased natural gas
- Flared digester gas
- Recovered waste heat that cannot be utilized