How Philadelphia Water moved from flaring their methane to a co-generation plant with 5.6 MW power generation

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Outline

- Introduction and objectives
- Northeast Water Pollution Control Plant
- Digester optimization work
- Co-digestion studies
- Details of co-generation plant
- Concluding remarks

Introduction and objectives

Philadelphia is 5th largest city in USA with approximately 1.5 million people living in the city

Philadelphia Water (PW) is municipal department responsible for water supply and sanitary operations

Sanitary operations include operating three wastewater treatment plants, all performing secondary treatment of wastewater by some form of activated sludge process

Introduction and objectives (Cont.)

These three plants treat a combined 471 MGD wastewater

1. Southwest Water Pollution Control Plant (SW-WPCP)
   - About 200 MGD plant (500 MGD wet whether)
   - Uses pure oxygen activated sludge

2. Northeast Water Pollution Control Plant (NE-WPCP)
   - About 200 MGD plant (500 MGD wet whether)
   - Second largest

3. Southeast Water Pollution Control Plant
   - Smallest
   - No anaerobic digestion (thickened sludge is transferred to SW-WPCP for digestion and processing)

Introduction and objectives (Cont.)

Prior to co-generation operation, PW conducted pilot and bench-scale studies in order to optimize performance of anaerobic sludge digestion process at their NEWPCP

Villanova University's Environmental Microbiology and Biotechnology Laboratory (Civil and Environmental Engineering Department) was chosen through a competitive application process to carry out digester optimization work

These studies focused on ways to improve volatile solids destruction and thereby improve methane production and evaluate feasibility of co-digestion of different substrates

Northeast Water Pollution Control Plant

NEWPCP is second largest of three PW wastewater treatment plant with average discharge flow of 200 MGD (including stormwater from combined sewer system areas)

Conventional activated sludge process including preliminary treatment (screening, grit removal, and primary settling) and secondary treatment (aeration, secondary clarification, and chlorination) is used

Sludge management includes dissolved air flotation thickening of waste activated sludge, anaerobic digestion for stabilization

NEWPCP (Cont.)

NEWPCP has eight “pancake type” anaerobic digesters each with 2 MG capacity

Mesophilic digesters has design SRT/HRT of 18 days and each is cleaned once about every four to five years

Digesters at NEWPCP are mixed by sludge circulation (sludge drawn off from the bottom of digester is mixed with feed sludge after going through a tube heat exchanger and then discharged back to digester five feet below normal liquid level)

NEWPCP (Cont.)

Digested solids are transported to a privately operated facility for , and high speed centrifuge dewatering, drying, pelletisation and subsequent use as fertilizer and fuel

Until 2013, about half of methane generated was used for heating and remaining was flared

Since then all methane generated is used to power a co-generation plant for heat and electricity production

Digester optimization work

1. Tracer study

Due to "pancake type" configuration and lack of mechanical mixing, NEWPC digesters might be susceptible to grit accumulation and subsequent loss of effective volume, *i.e*. reduced HRT/SRT

A tracer study was conducted on a recently cleaned (low grit accumulation) and a soon-to-be-cleaned (possibly high grit accumulation) digester to determine effective volume available for digestion

Lithium chloride (LiCl) was used as conserved tracer due to being a common choice and ease of analysis

Optimization work (Cont.): Digester cleaning

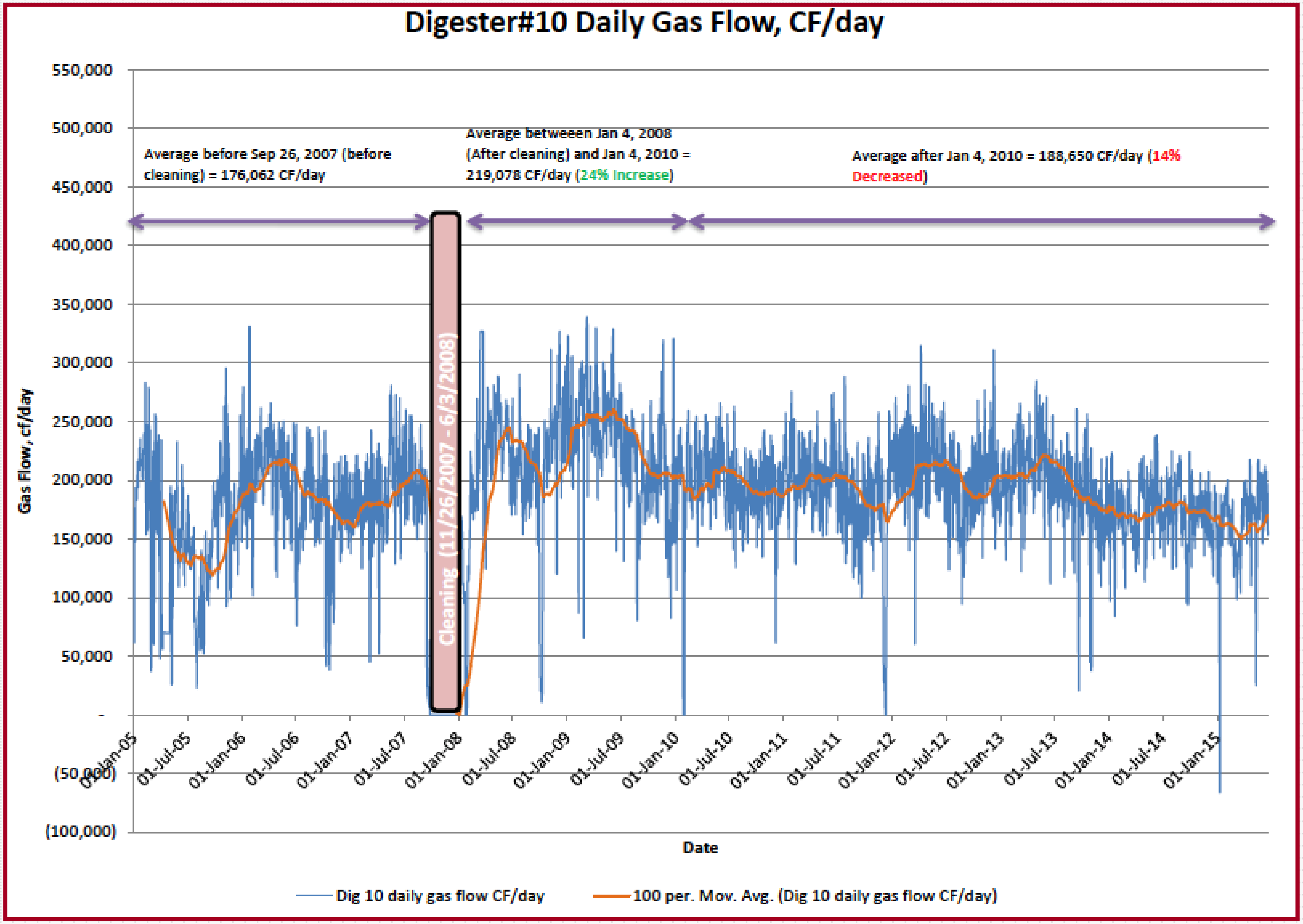
Tracer study results suggested loss of effective volume due to grit accumulation

Average biogas production data confirmed tracer study findings with increased biogas production after cleaning

More frequent cleaning or more rigorous mixing recommended to help increase effective volume and thus volatile solids destruction

Since then, PW invested in improving headwork (screening, grit removal) to reduce grit accumulation in digesters

Optimization work (Cont.): Digester cleaning



2. Effects of operating parameters

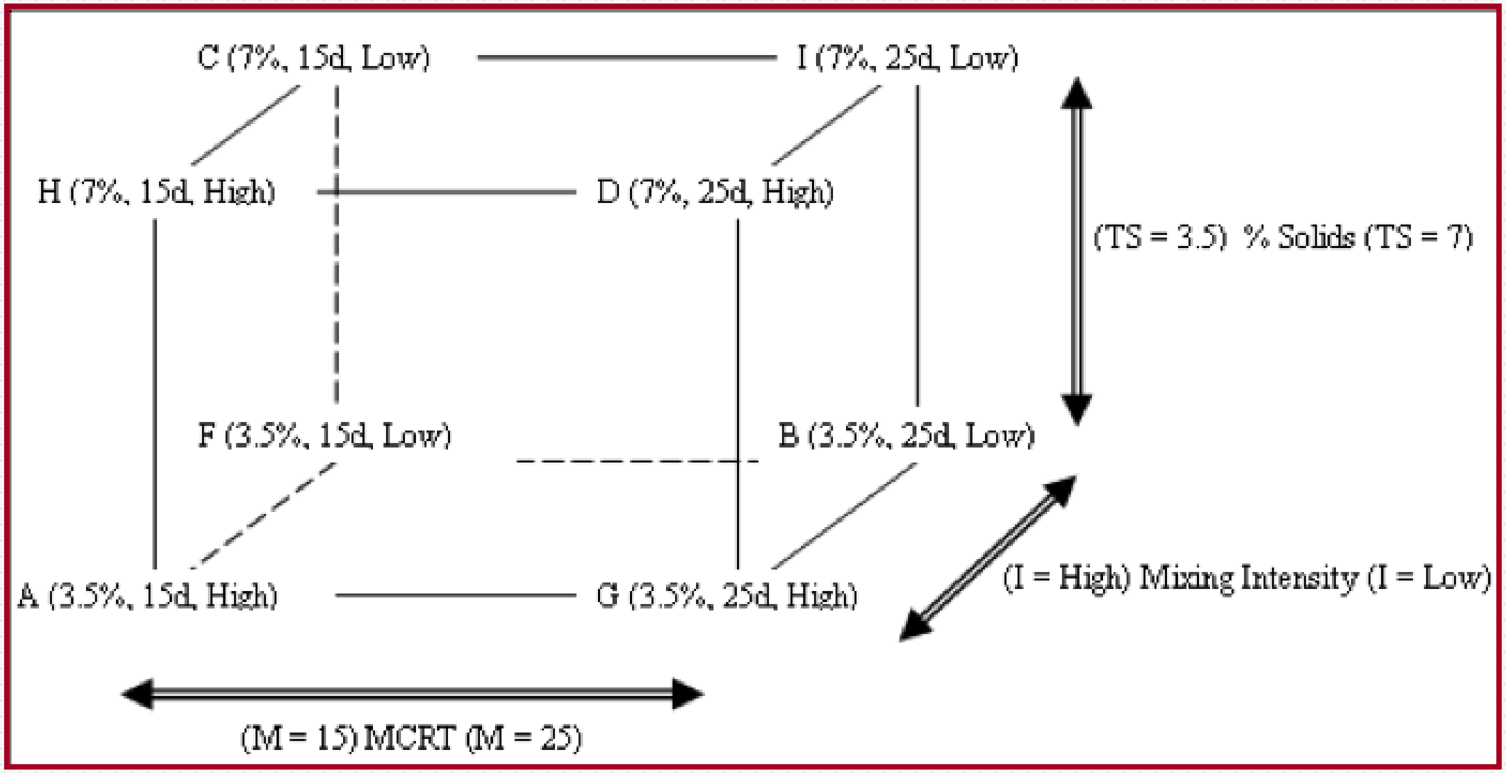
A factorial design approach was used to study effects of three main operating parameters on digestion efficiency: Mixing; Mean cell residence time (MCRT or SRT); and Feed solids (TS) contents

Each variable was tested within typical design and operating ranges:

- Mixing: Low (130 ft*lb_f/ft^3*d twice a day for 5 min.) to high (130 for 5 minutes hourly totaling 1580 ft*lb_f/ft^3*d)
- MCRT: 15 to 25 days
- Feed TS: 3.5 to 7%

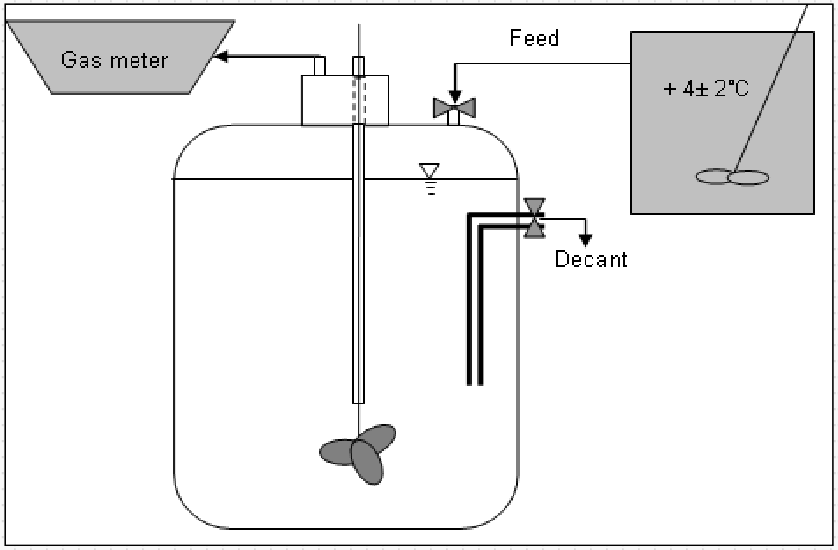
Optimization work: Operating parameters (Cont.)

Factorial design approach was chosen since it requires fewer experiments and gives a quantitative estimate on how these parameters interact



Optimization work: Operating parameters (Cont.)

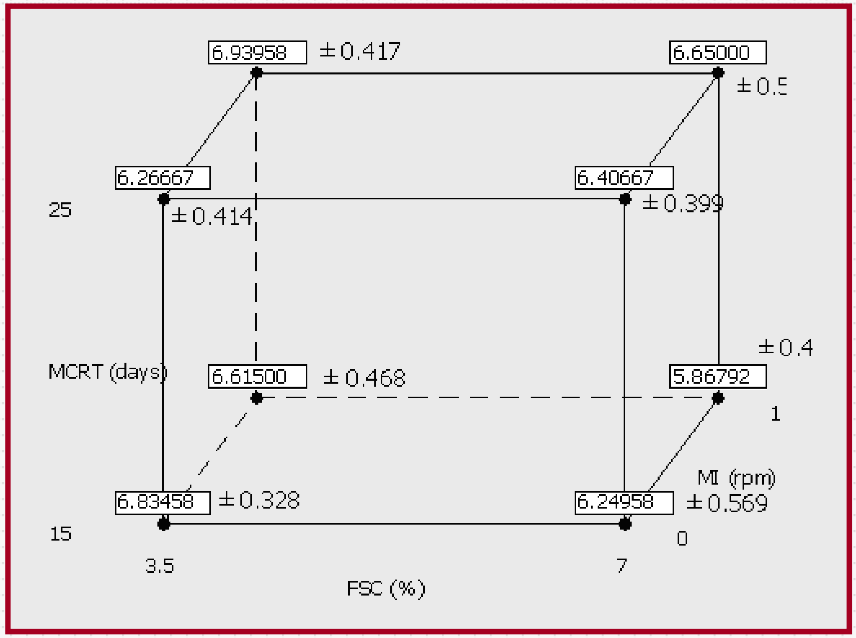
Eight 5-gallong digesters were operated to carry out "factorial design" experiments, four in each phase, due to logistical considerations

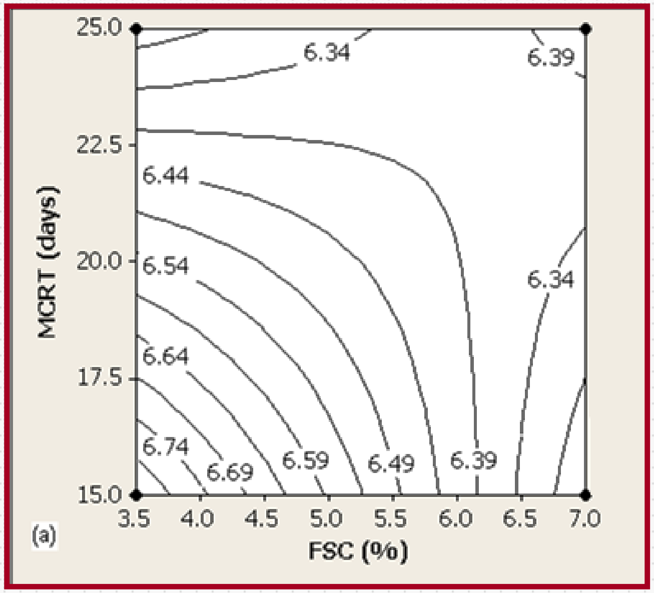


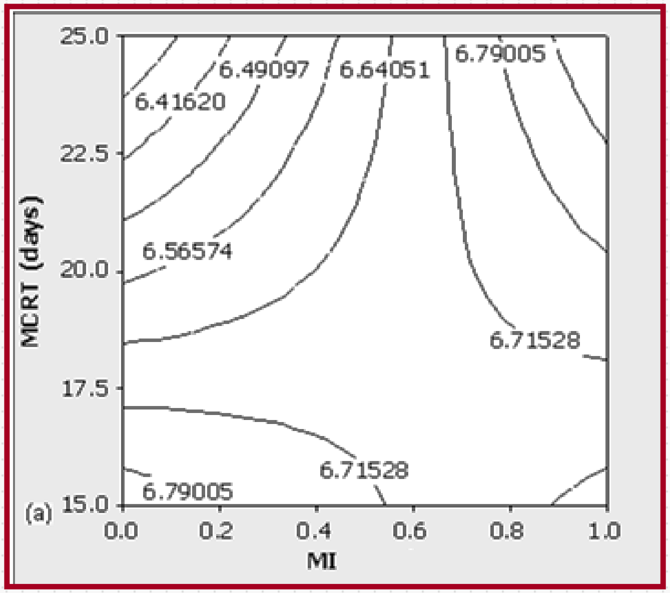
	Digester	Factors (Operating conditions)		
		TS (%)	MCRT (days)	Mixing
Period I	A	**3.5**	**15**	**High**
	B	3.5	25	Low
	C	7	15	Low
	D	7	25	High
Period II	E*	**3.5**	**15**	**High**
	F	3.5	15	Low
	G	3.5	25	High
	H	7	15	High
	I	7	25	Low

Optimization work: Operating parameters (Cont.)

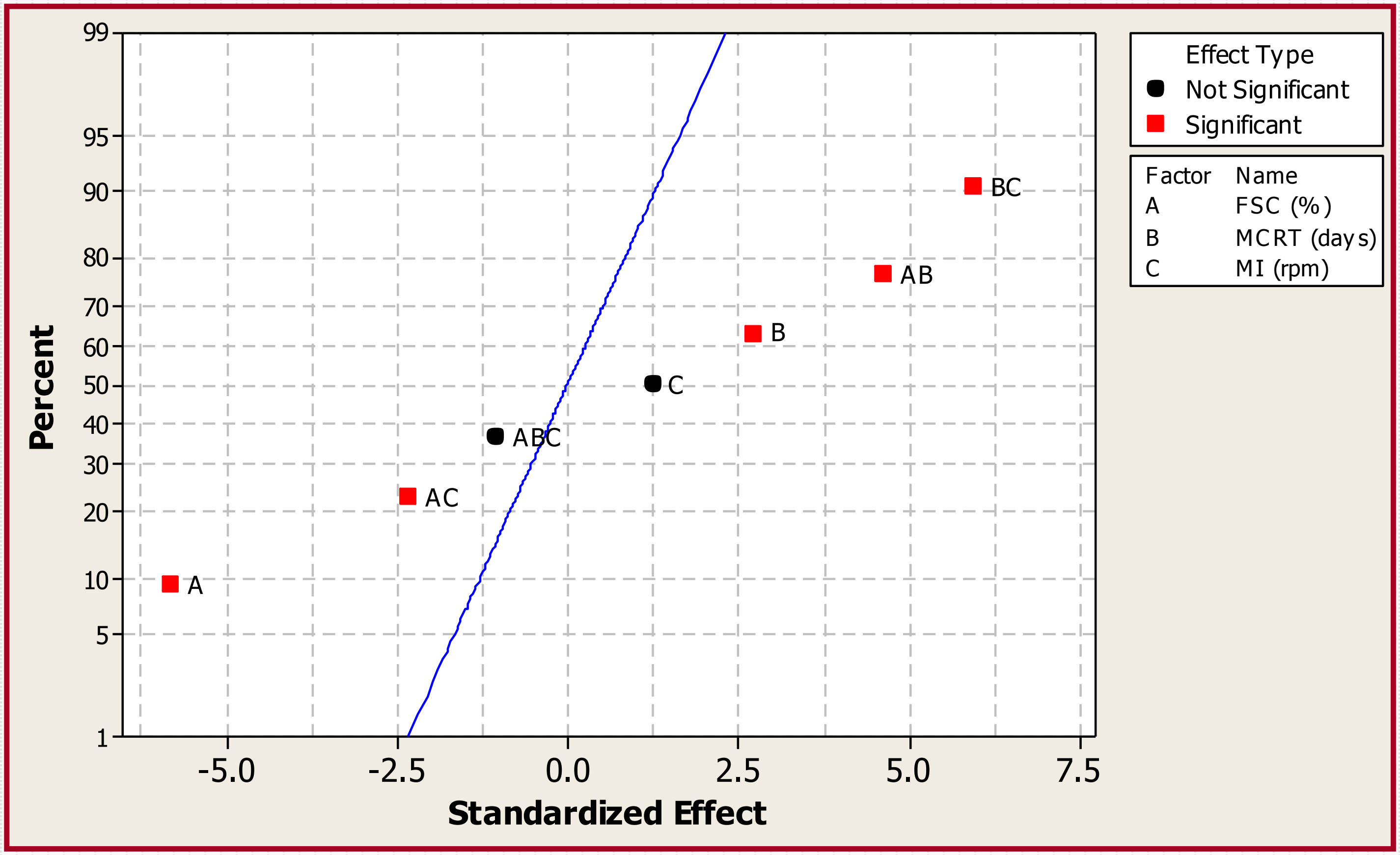
Specific CH_4 production (ft^3 CH_4/lb VS fed) was used as a measure of digestion performance to quantify effects of operating parameters on CH_4 generation







Optimization work: Operating parameters (Cont.)



Specific Methane (ft^3/lb VS fed.day) =

9.35896–0.47786*FSL–0.12929*MCRT–1.7975*MI+0.02071*(FSL*MCRT)

+0.068333*(FSL*MI)+0.11600*(MCRT*MI)-0.00764*(FSL*MCRT*MI)

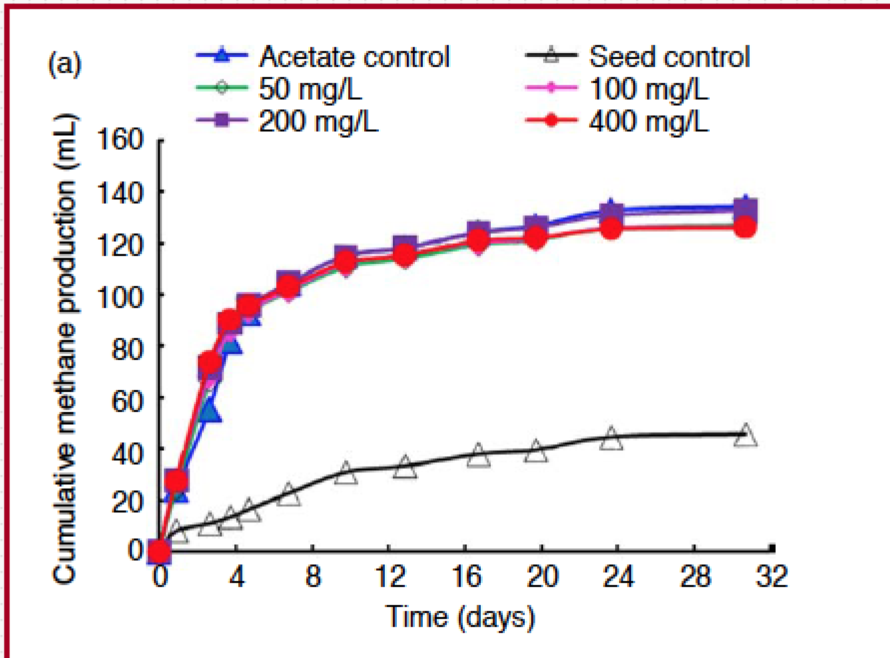
Optimization work (Cont.)

3. Nutrient supplement study

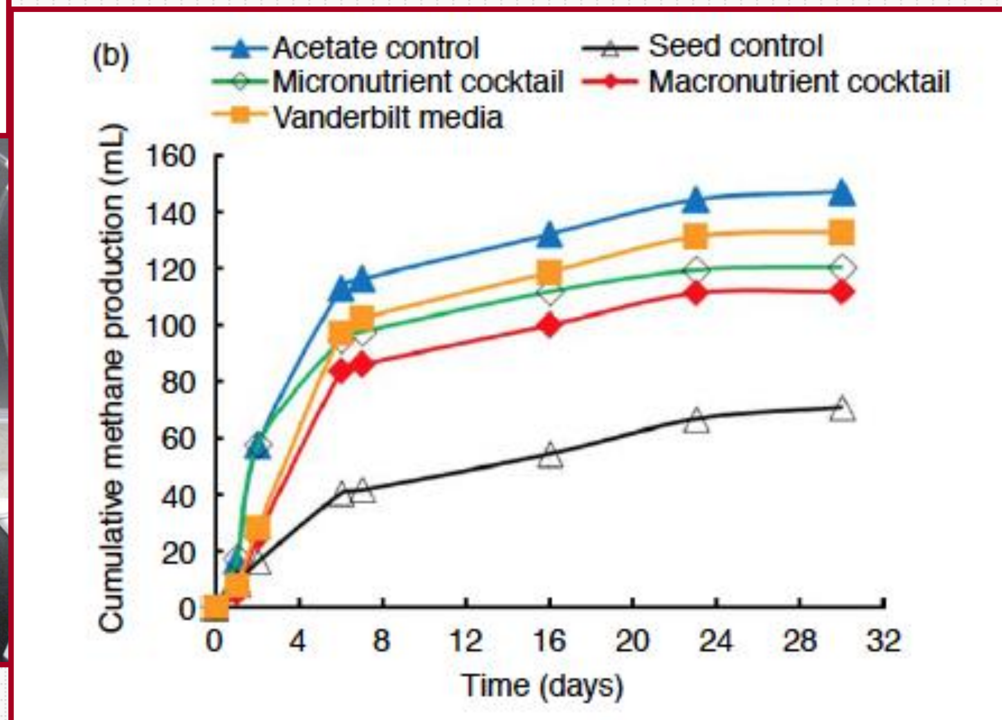
Previous studies showed that full-scale anaerobic digesters could benefit from trace metal and nutrient supplementation, particularly beneficial effects of Fe, Ni, Co addition has been emphasized

A bench scale biochemical methane potential (BMP) study was conducted to determine if digesters at NEWPCP would benefit from supplement of : 1)Various concentrations of Fe, Ni, Co; 2) A macro nutrient cocktail; 3) A trace metal cocktail; 4) A combination of macro nutrient and trace metal cocktails (Vanderbilt Media)

Optimization work: Nutrient supplementation (Cont.)



Results suggested that there was no benefit of nutrient supplementation (there was slight inhibition in some cases)



Water Science and Technology (2010) 62(12):2905-2911

Co-digestion studies

1. Co-digestion of aircraft deicing fluid (ADF)

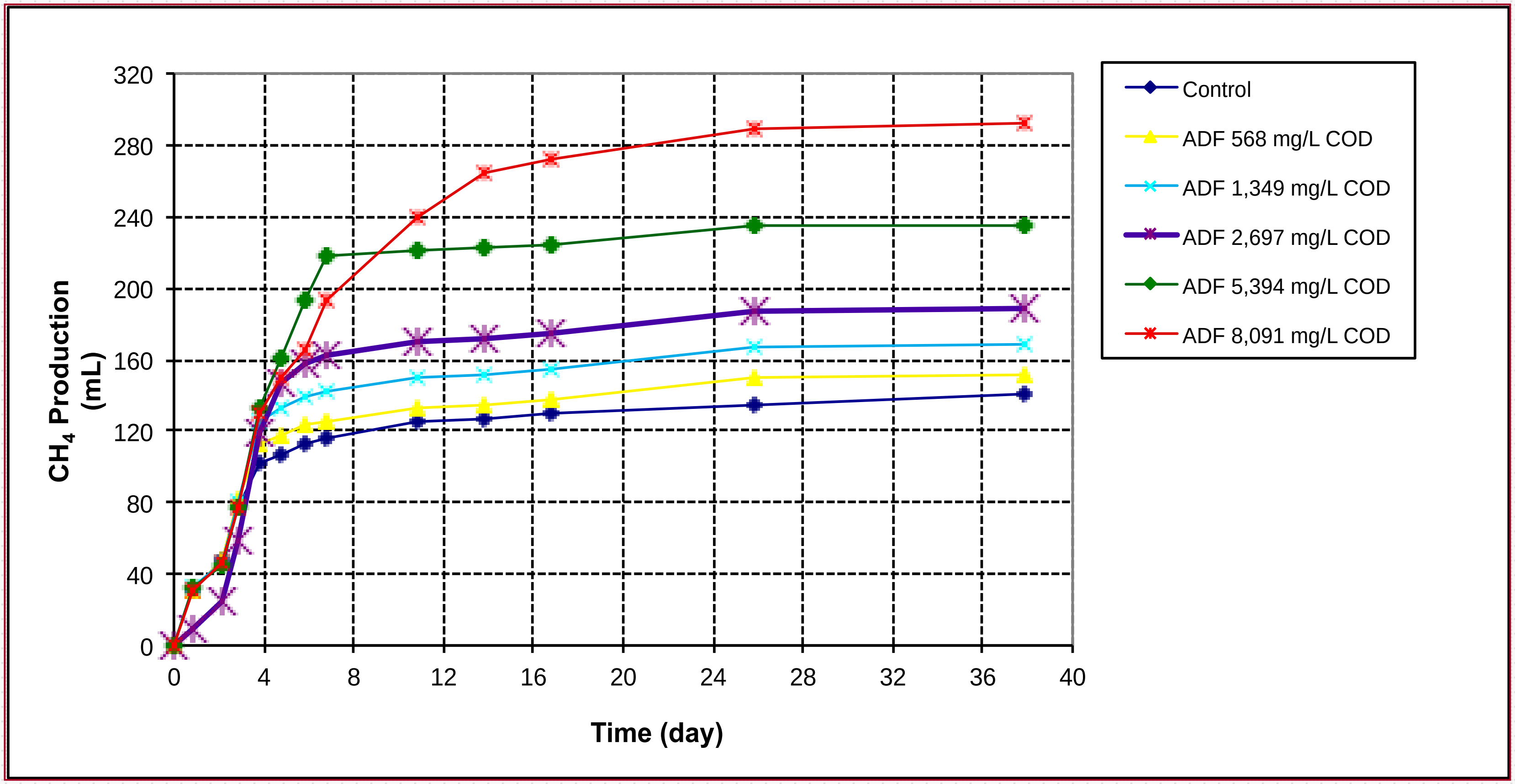
As a potential co-digestion feed-stock, captured ADF from Philadelphia International Airport (PHL) deicing operation was studied for its BMP and degradation kinetics

PHL uses propylene glycol-based Type I (88% propylene glycol and 11% water) and Type IV (52.2% propylene glycol and 46.8% water) aircraft deicing fluids (ADF)

Various diluted concentrations of both ADF types were tested

Co-digestion studies: ADF (Cont.)

Results indicated both ADF types have high CH_4 potential and they are easily co-digested in bench-scale anaerobic digesters that simulated the full-scale digesters at NEWPCP



PW's ADF co-digestion: A model program (Cont.)

FY	Tipping Fees Received	ADF Load (gal)	Theoretical Methane Production (scf)	Theoretical Methane Production (MMBTU)	Average Annual Cost per MMBTU Methane ($)	Theoretical Methane Production Avoided Cost[1]	Total ADF Benefit
2009	$104,733	1,939,500	9,817,273	9,925		$0	$104,733
2010	$188,298	3,487,000	5,843,428	5,908		$0	$188,298
2011	$157,248	2,912,000	9,665,176	9,771		$0	$157,248
2012	$73,548	1,362,000	2,662,976	2,692	$8.50	$22,884	$96,432
2013	$195,993	3,629,500	6,116,576	6,184	$7.50	$46,379	$242,372
2014	$345,131	6,391,300	17,737,397	17,933	$6.50	$116,561	$461,692
2015	$385,754	7,143,600	18,241,444	18,442	$5.90	$108,808	$494,563
Average per Year	$207,244	3,837,843	10,012,039	10,122		$42,090	$249,334
Total	**$1,450,705**	**$26,864,900**	**$70,084,270**	**$70,855**		**$294,632**	**$1,745,338**

[1] FYs 2009-2011: Phase 1 of BRC, no beneficial use for additional biogas generated. Theoretical value does not confirm that the gas was actually used by BRC facility; additional biogas may have been flared.

Co-digestion studies (Cont.)

2. Co-digestion of biosolids from a refinery

Waste activated sludge from two different treatment plants of the same refinery process were investigated for their potential toxicity and BMP as potential co-digestion feed-stock

Results suggested that although not inhibitory for co-digestion, biosolids from that particularly refinery had limited CH_4 potential

Co-digestion studies (Cont.)

3. Co-digestion of FOG (scum)

Possible inhibitory effect and BMP potential of clarifier skimmings (fats, oil, and grease, *aka* scum) was investigated when they are co-digested

This particular work was carried out using five-gallon bench-scale digesters

Parameter	Scum sample From primary settlers	From skimmings concentration tank
Total solids (TS), mg/L	287,000 (13,900)	627,000 (1,710)
Volatile solids (VS), % of TS	97 (1.22)	98 (1.69)
Chemical oxygen demand (COD), g/g scum	1.18 (0.084)	1.40 (0.065)

[a]Values in parenthesis represent standard deviations of triplicate samples.

Water Science and Technology. 2013. 67(1):174--179

Co-digestion studies: Scum co-digestion (Cont.)

Results indicated scum is a viable co-digestion candidate with high potential (about 0.3 MW additional power equivalent)

However, due to presence of excessive debris in scum collection tanks, materials handling in feeding scum to digester may pose issues and improving headworks screening process might be necessary

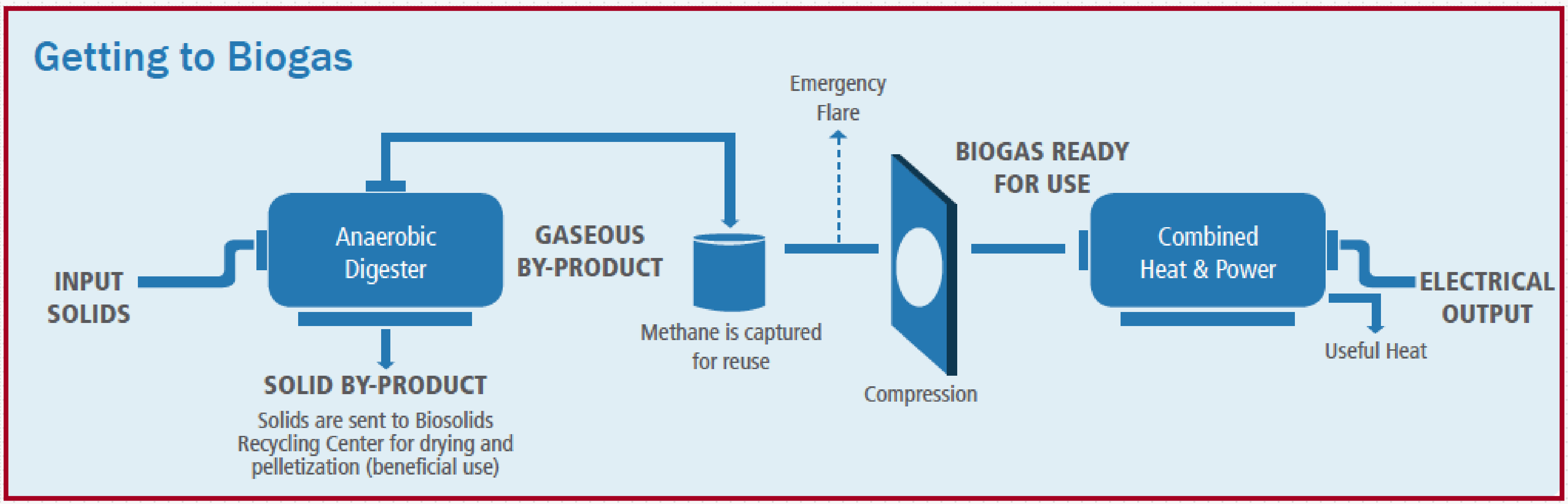
COD loading rate (g COD/(L·d))		CH_4 yield (L CH_4/d)		Specific CH_4 yield (L CH_4/kg COD)	
Scum and feed	Scum only[a]	Scum and feed	Scum only	Scum and feed	Scum only
5.6	1.5	17.4 (1.8)	7.7 (1.4)	238.4 (24.8)	105.1 (18.8)
6.7	2.6	22.6 (3.4)	12.6 (2.8)	257.7 (39.2)	143.5 (32.1)
7.6	3.5	25.9 (3.1)	16.2 (2.9)	262.2 (31.6)	163.9 (29.8)
11.0	7.0	44.1 (5.1)	35.9 (4.4)	308.4 (35.9)	251.3 (30.5)

[a] CH_4 production from 'scum only' was calculated by taking the difference in CH_4 generation from R1 and R2.
[b] Values in parenthesis represent standard deviations of triplicate samples.

Co-generation plant

On December 13, 2013, PW began to operate its Biogas Co-generation plant at NEWPCP

5.6 MW capacity plant runs on CH_4 generated from anaerobic digesters in NEWCP and it is capable of producing 43 million kW-h energy annually, enough to meet all process heat needs and eighty-five percent of the electrical requirements of NEWPCP

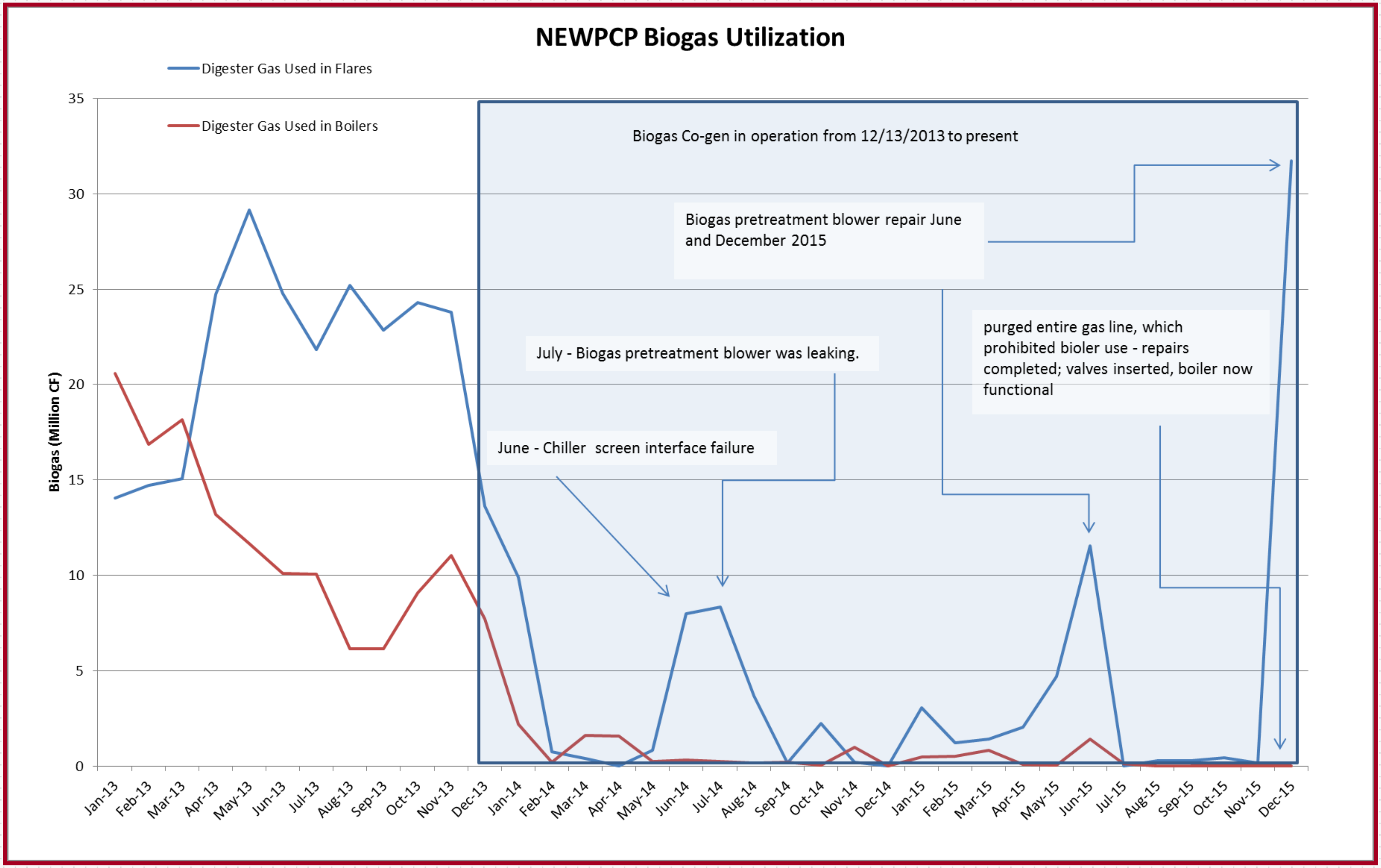


Co-generation plant (Cont.): Financing

Financing was a Public Private Partnership (PPP)

- Access to Investment Tax Credit (30%)
  - Ameresco (Developer)
  - Bank of America (Owner)
  - PW (Leases facility)
- Project Cost
  - Total cost $47.5M
  - ITC goal $14M downgraded to $12M
  - AEPS Act 129 State Law $3.5M

Co-generation plant (Cont.)



Concluding remarks

- Anaerobic digester optimization and additional feed stocks for co-digestion could make co-generation plants economically feasible especially for large wastewater treatment plants
- CH_4 to energy projects are especially attractive in countries where cost of energy is relatively high
- University-industry collaboration is key in conducting bench-scale optimization and co-digestion studies within a limited budget
- NEWPCP work could serve as a model for other large-scale facilities around the world
- Beneficial use is an organization building block