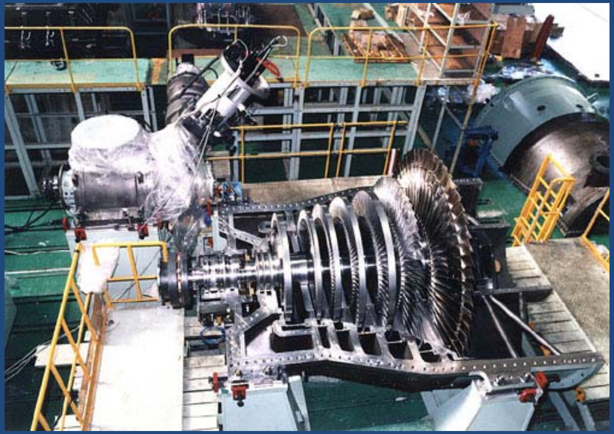
Digester Gas Utilization at SWRP

Where Should the Biogas Go?

Steve McGowan, P.E., BCEE
Malcolm Pirnie – The Water Division of Arcadis



MWRD Monthly Seminar Series
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Protecting Our Water Environment
Metropolitan Water Reclamation District of Greater Chicago

MALCOLM PIRNIE
ARCADIS

Project Contributors

- Tom Kunetz, MWRD
- Ed Brosius, MWRD
- Paul O'Brien, MWRD
- Jarek Fink-Finowicki, MWRD
- Eric Auerbach, Malcolm Pirnie/Arcadis
- Tom Lachcik, Malcolm Pirnie/Arcadis
- Eric Wang, Malcolm Pirnie/Arcadis
- Krishna Pagilla, MPR
- Arun Mande, MPR
- Cathy Busking, Busking Engineering

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

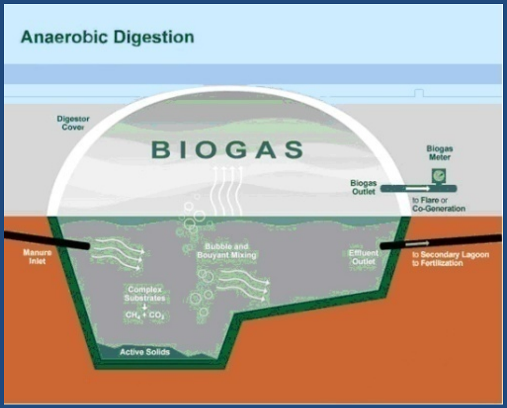
Digester Gas Utilization – Purpose of Project

- 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



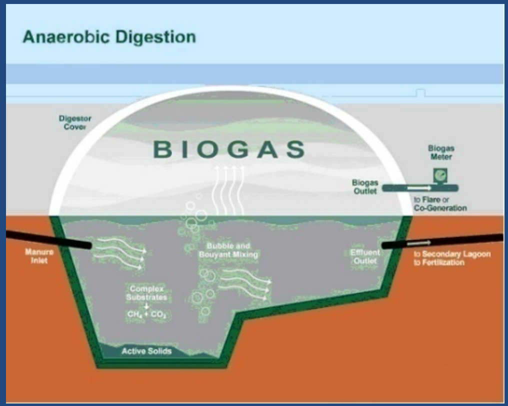
<u>From 2007 – 2009 Plant Data</u>

- 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)

<u>Items affecting future SWRP Gas Production</u>

- 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

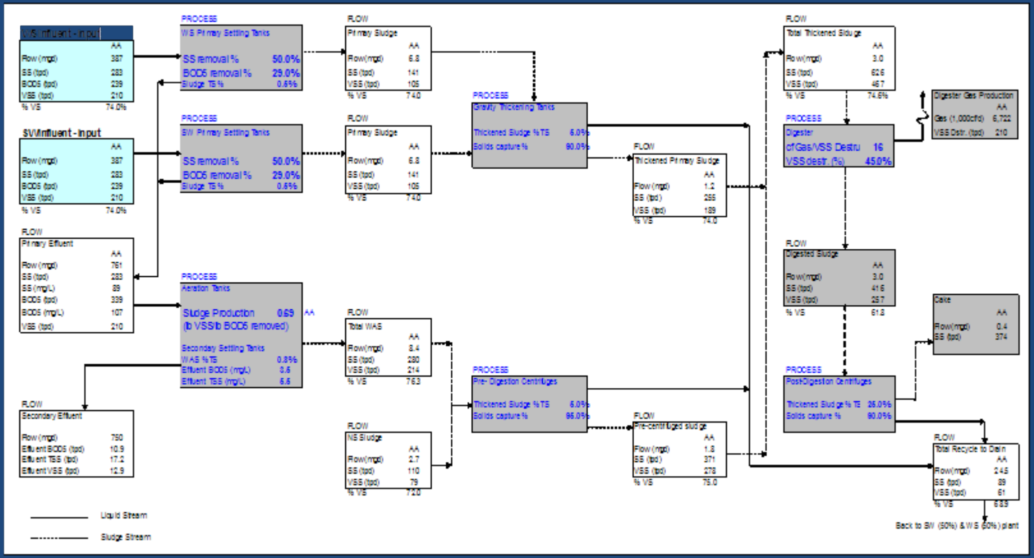
Digester Gas Production Modeling

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

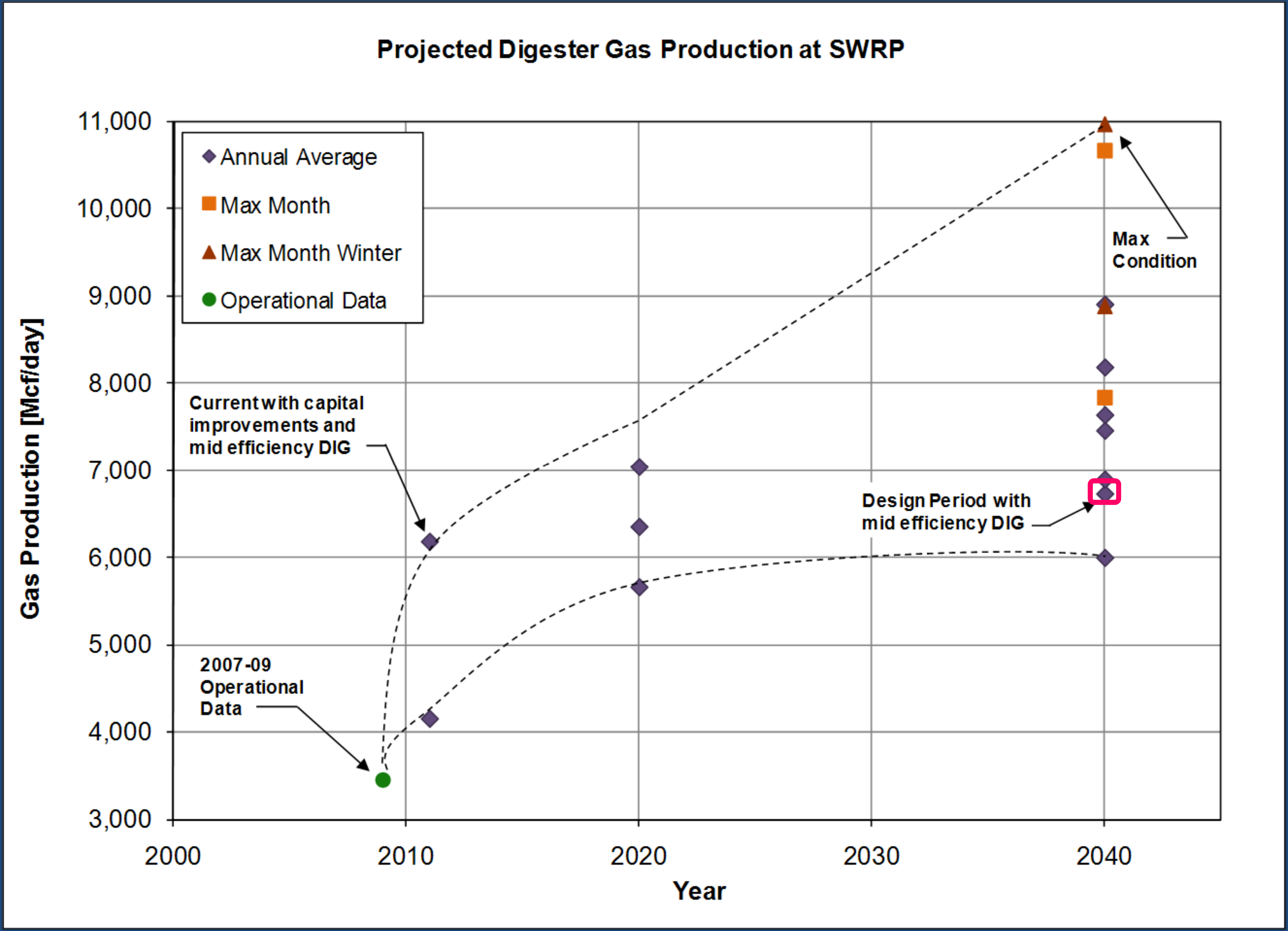
Primary Clarifier SS Removal

- 50% Removal (standard), 60% Removal (enhanced)

VSR

- 40% (low efficiency), 45% (mid efficiency), 50% (high efficiency)
- 55% (digester improvements), 60% (multiple digester improvements)

Digester Gas Production – Modeling Results

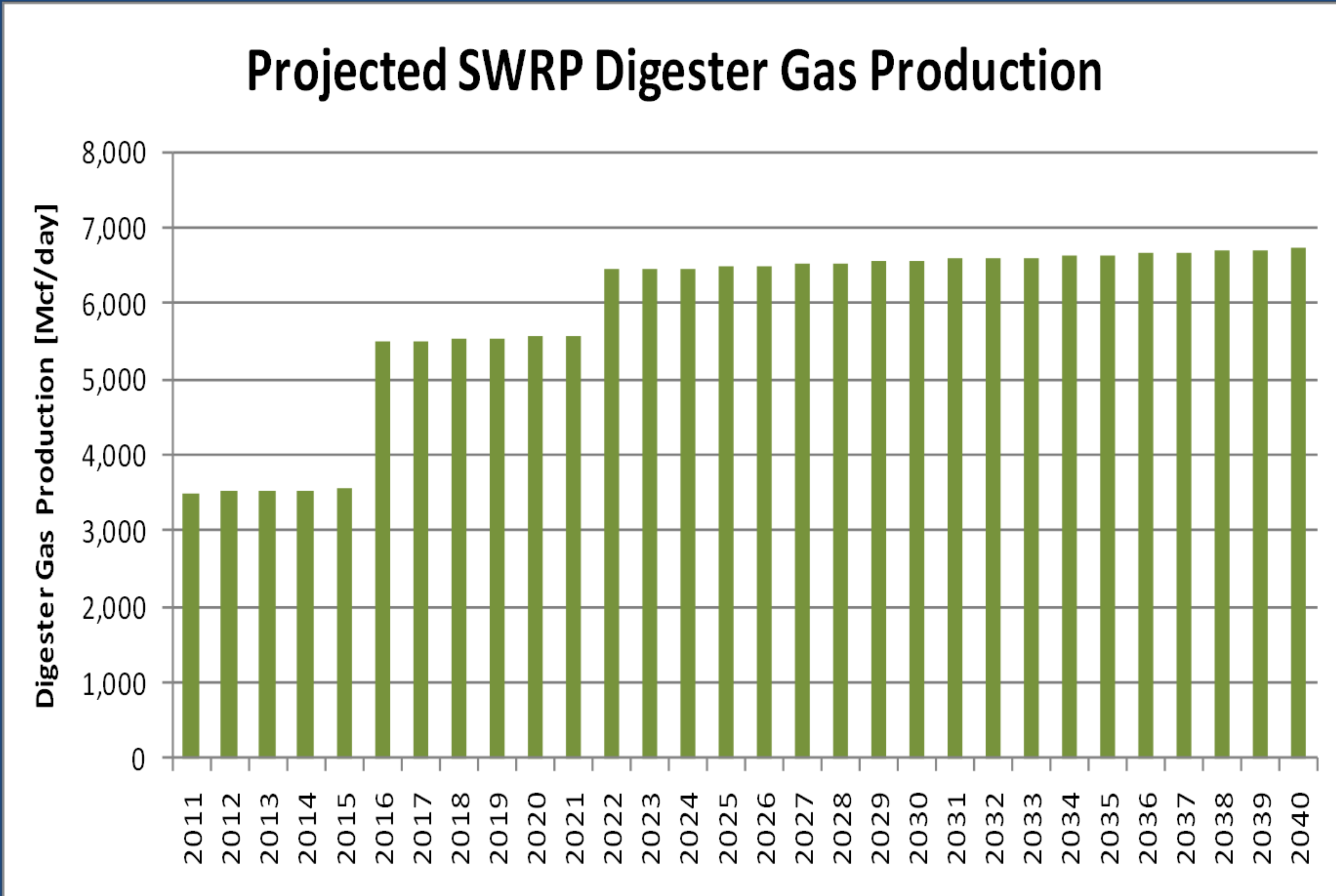


Selected Future Gas Production Value

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]
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
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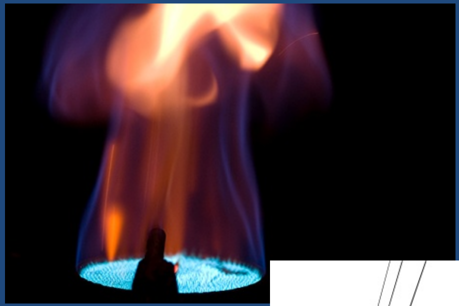
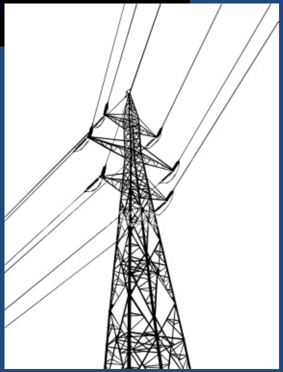
2040

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)

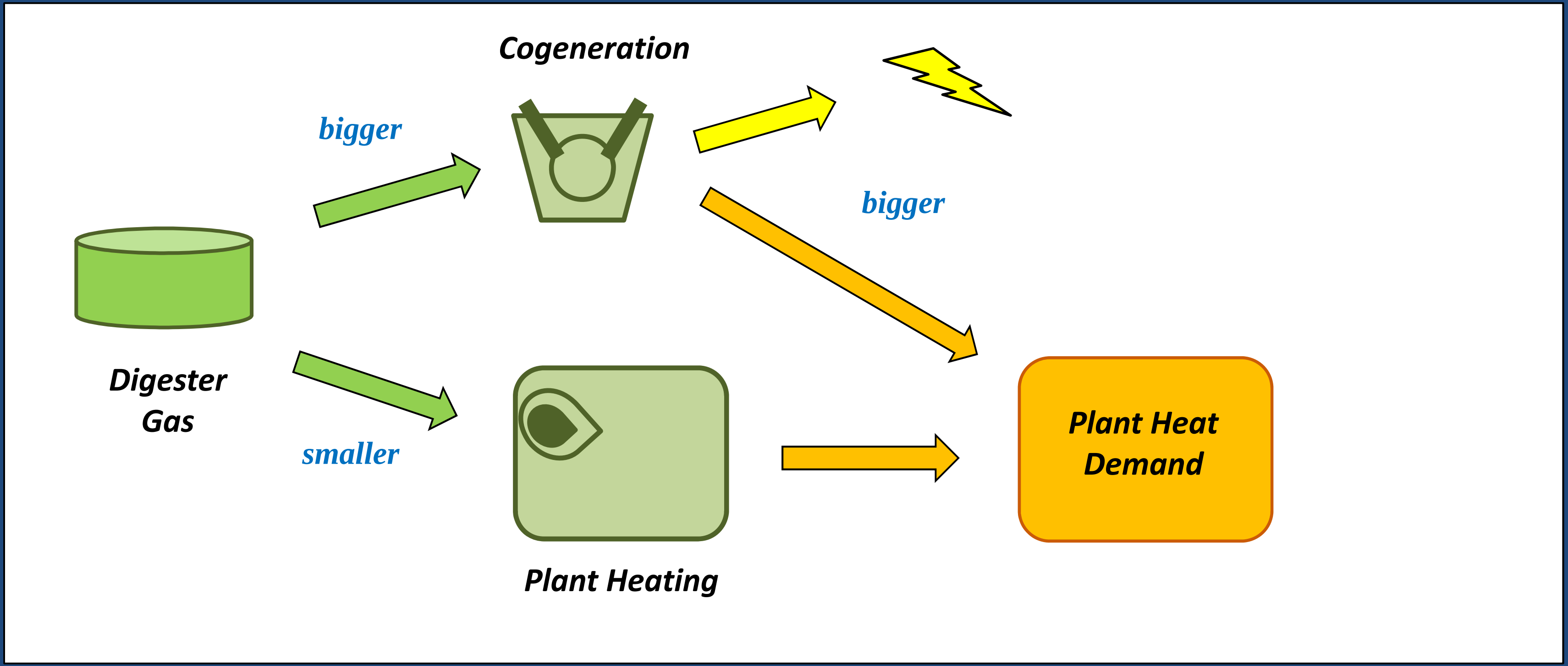
External Utilizations Not in Scope

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_2S 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
- H_2S removal required. SiO removal recommended

Components

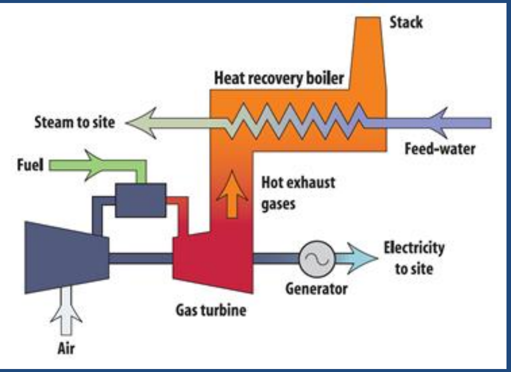
- Engine Generators
- Hot water loop to heat digesters
- Electrical Infrastructure
- New Building
- Gas Cleaning System

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
- H_2S removal required. SiO removal recommended



<u>Components</u>

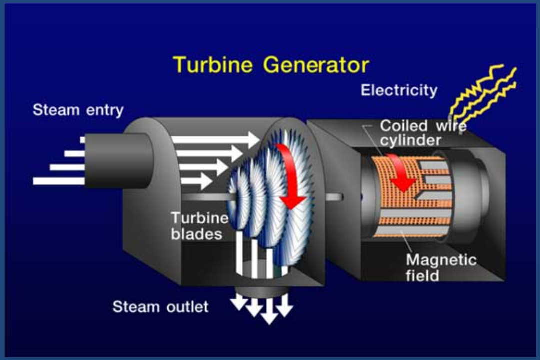
- Gas Turbine Generators
- Gas Compressors
- Electrical Infrastructure
- Heat Recovery Steam Generators (HRSG)
- New Building
- Gas Cleaning System

<u>Benefits</u>

- Electricity generated reduces plant electric bill
- Recovered steam can be used for plant heating

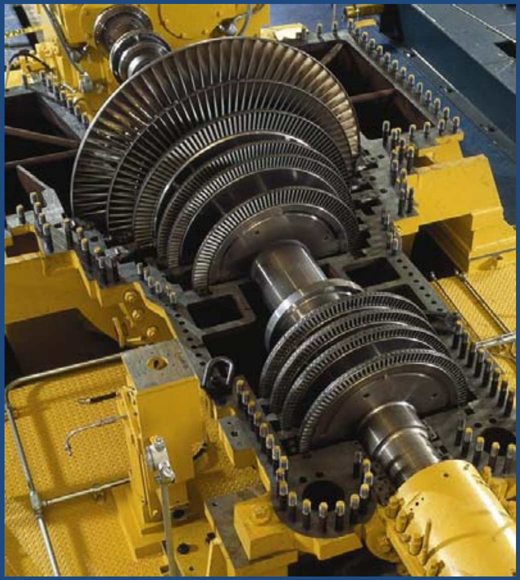
Cogeneration - Steam Turbine

- 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

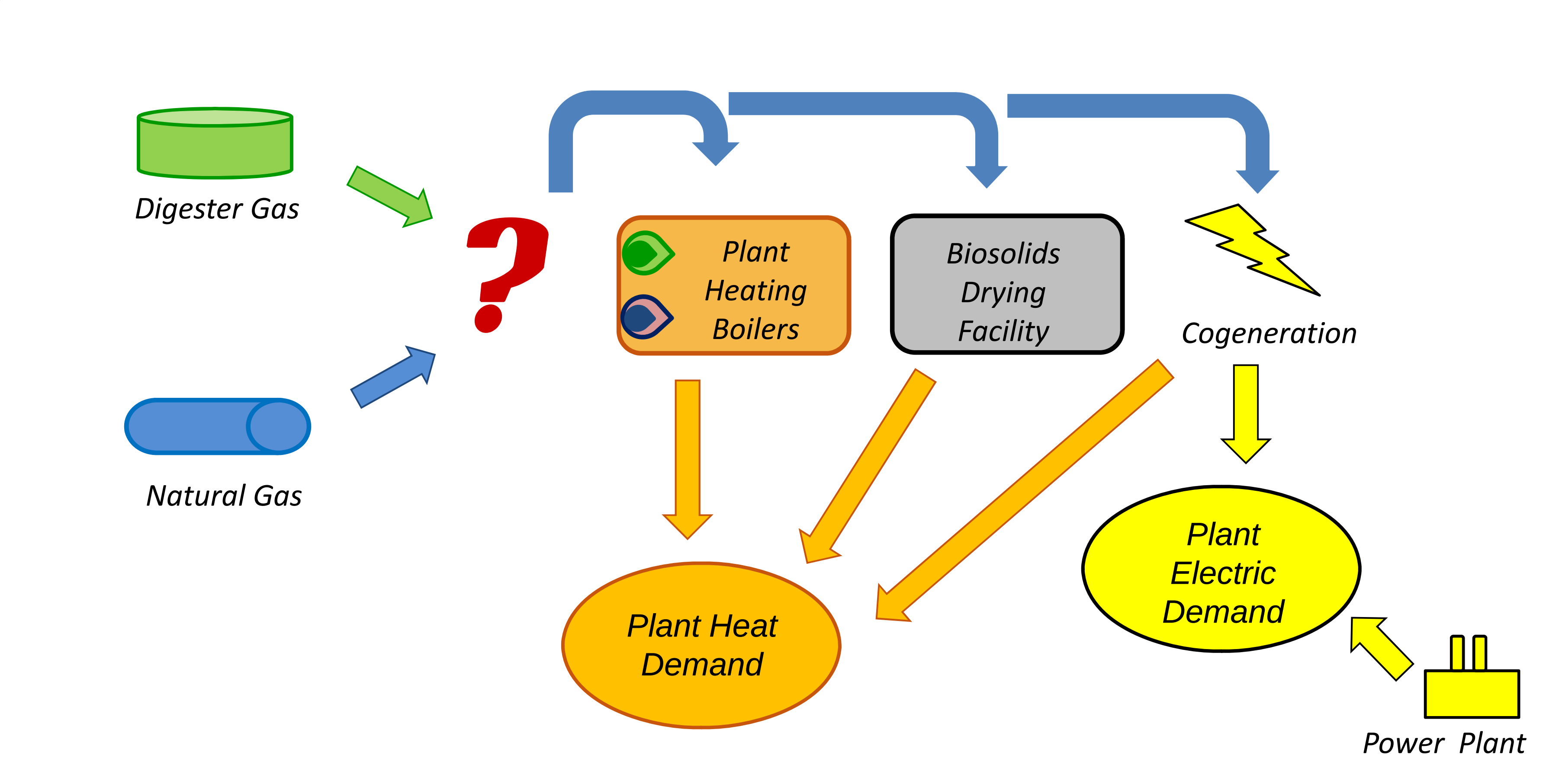
- Electricity generated reduces plant electric bill
- Recovered steam can be used for plant heating

Summary – Economics and Performance

Short List Option	Capital Cost	O&M Cost (Annual)	Electrical Efficiency	Heat Recovery Efficiency
Reciprocating Engines (with siloxane cleaning)	$48.4 million	$2.8 million	42%	43%
Gas Turbines (with siloxane cleaning)	$32.1 million	$2.9 million	28/33%*	44%
Steam Turbines (no gas cleaning)	$22.5 million	$250,000	17%	65%
Send Digester Gas to MBM	$0	$0	NA	NA

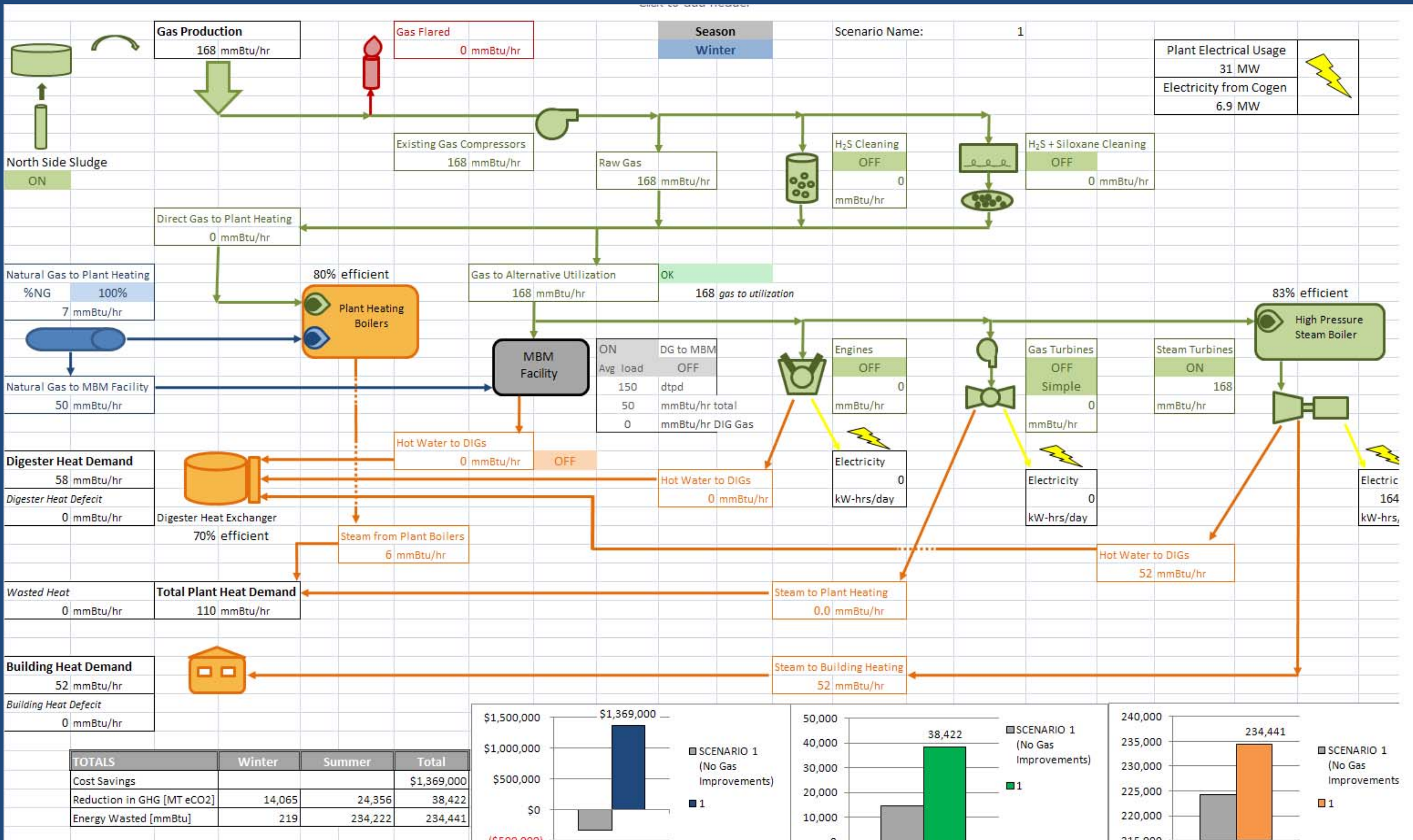
** Due to the compressibility of air, electrical efficiency differs from summer to winter*

Energy Flow Scenarios:



Build a Model !

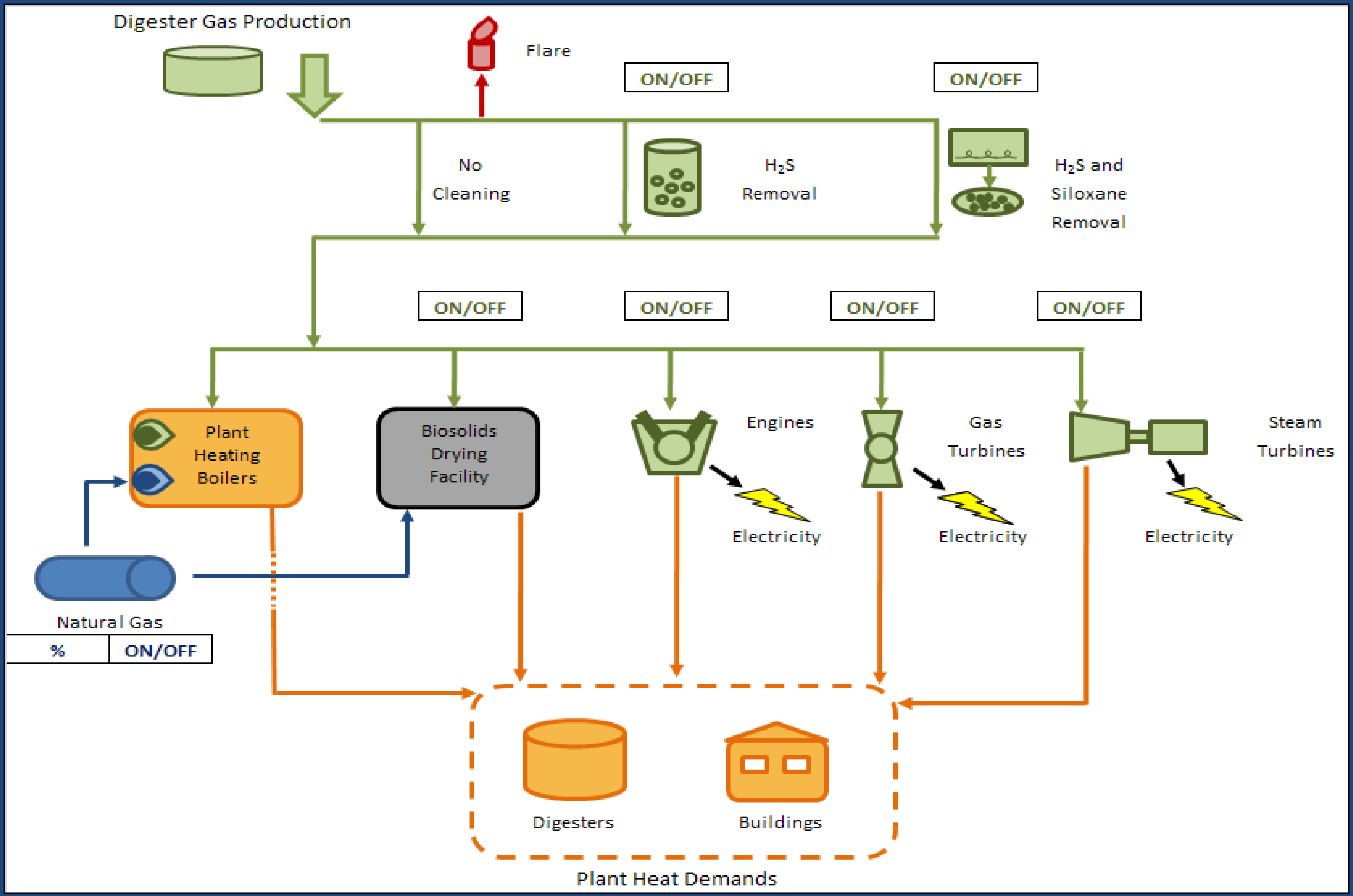
Energy Flow Model



TOTALS	Winter	Summer	Total
Cost Savings			$1,369,000
Reduction in GHG [MT eCO2]	14,065	24,356	38,422
Energy Wasted [mmBtu]	219	234,222	234,441

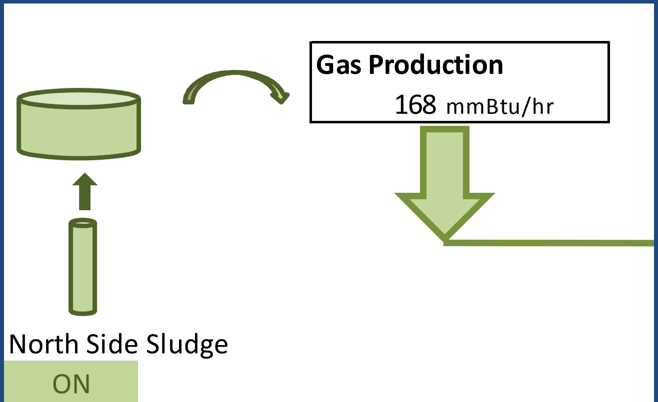
- Outputs = Annualized Cost, GHG Reduction, Unused Energy

Energy Flow Modeling Framework

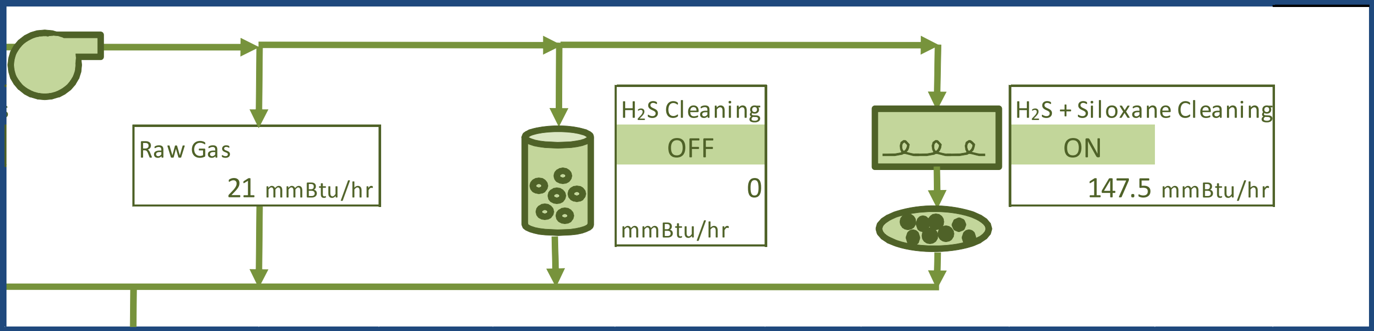


Model Components – Gas Production

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

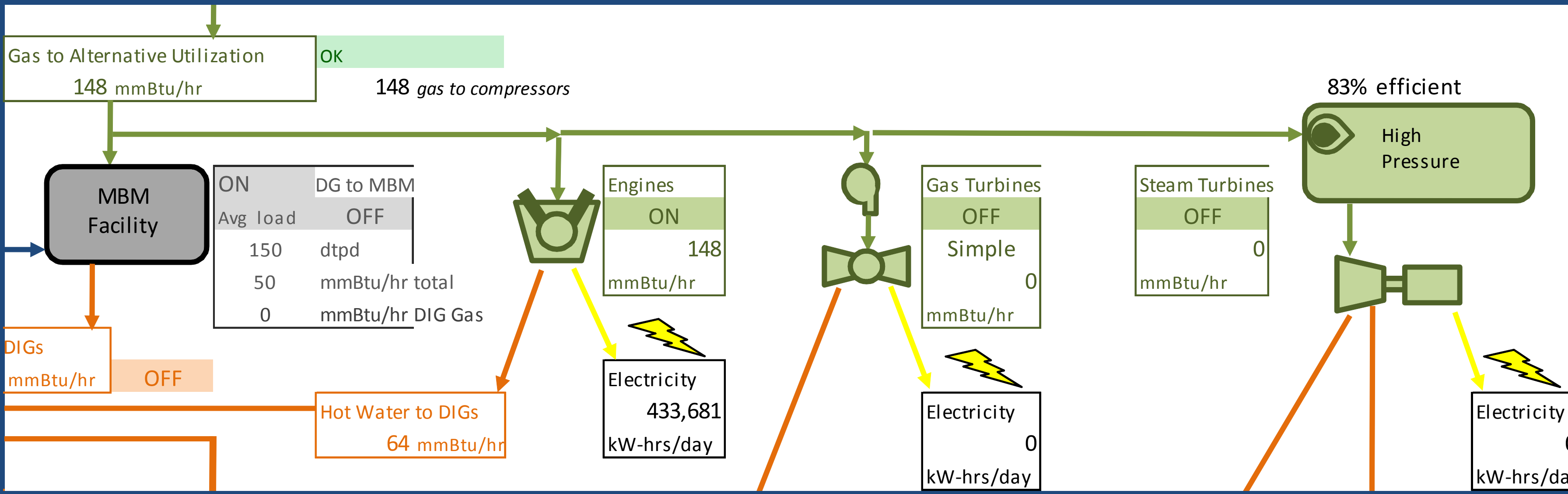


Model Components – Gas Cleaning



- Turn H_2S 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

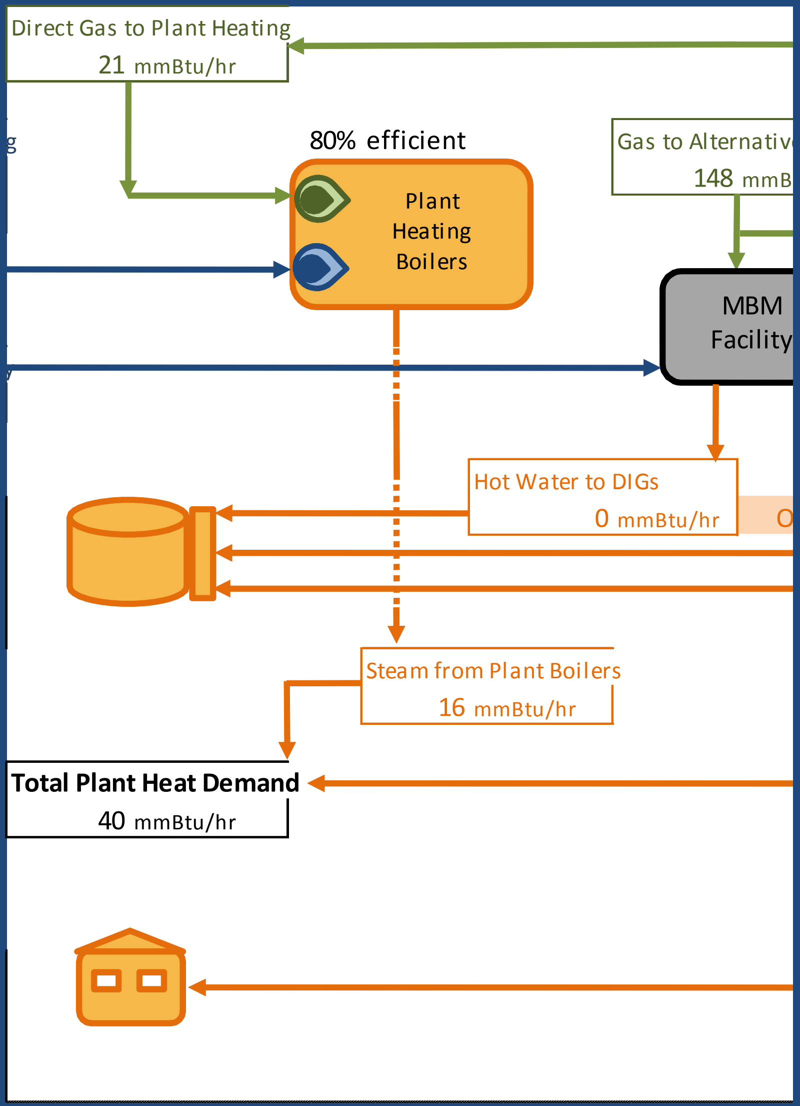
Model Components – Gas Utilization Options



- 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

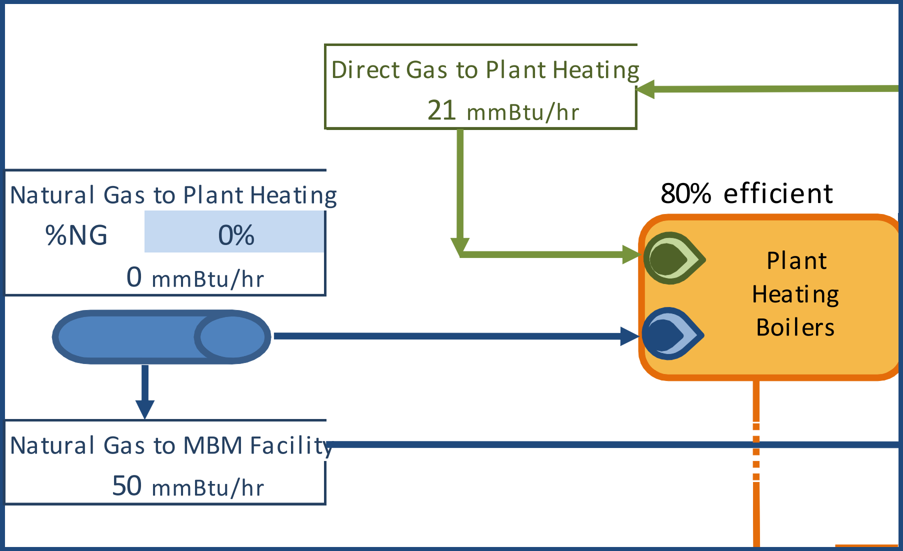
Model Components – Plant Energy Demands

- 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

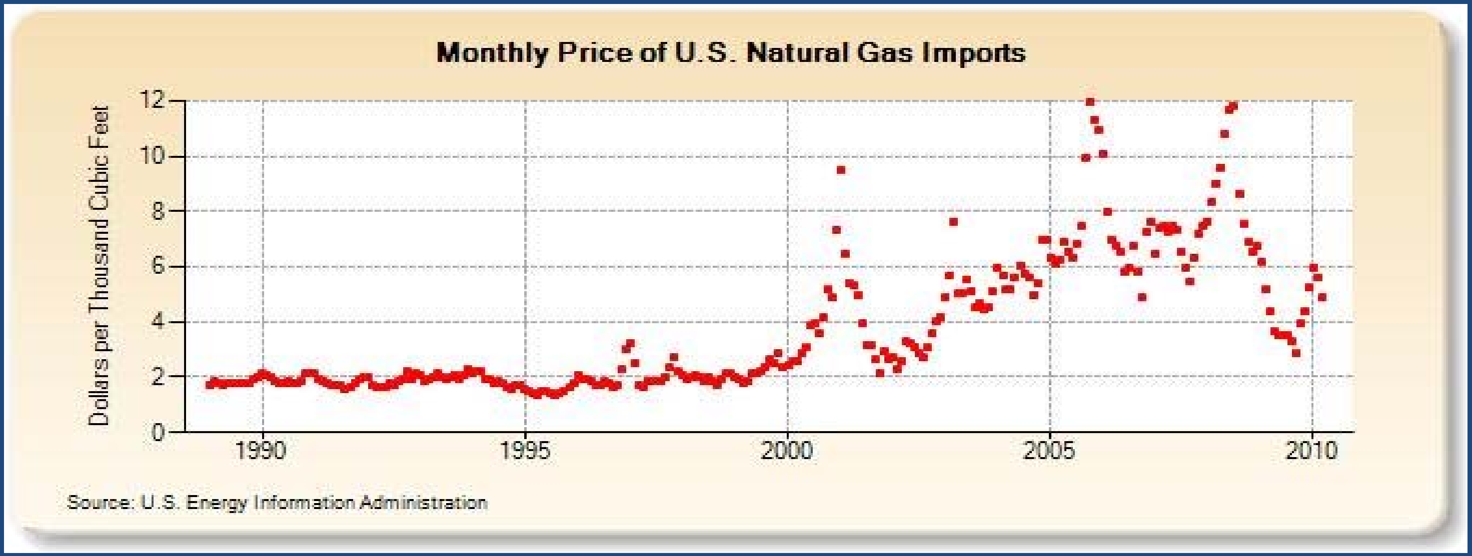
- Natural gas from utility can be input as additional energy
- Natural gas to either plant heating and/or MBM
- Variable amounts of natural gas can be provided to balance plant heating demands
- Natural gas prices can be varied (as well as electricity prices)
- MBM contract pricing is considered



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. [Plant Heating Boilers] 2. [MBM Facility]

Scenario Group 2 (No Cogen)

– DG Priority = 1. [MBM Facility] 2. [Plant Heating Boilers]

Scenario Group 3

– DG Priority = 1. [Plant Heating Boilers] 2. [MBM Facility] 3. Cogeneration

Scenario Group 4

– DG Priority = 1. [Plant Heating Boilers] 2. Cogeneration 3. [MBM Facility] = NG

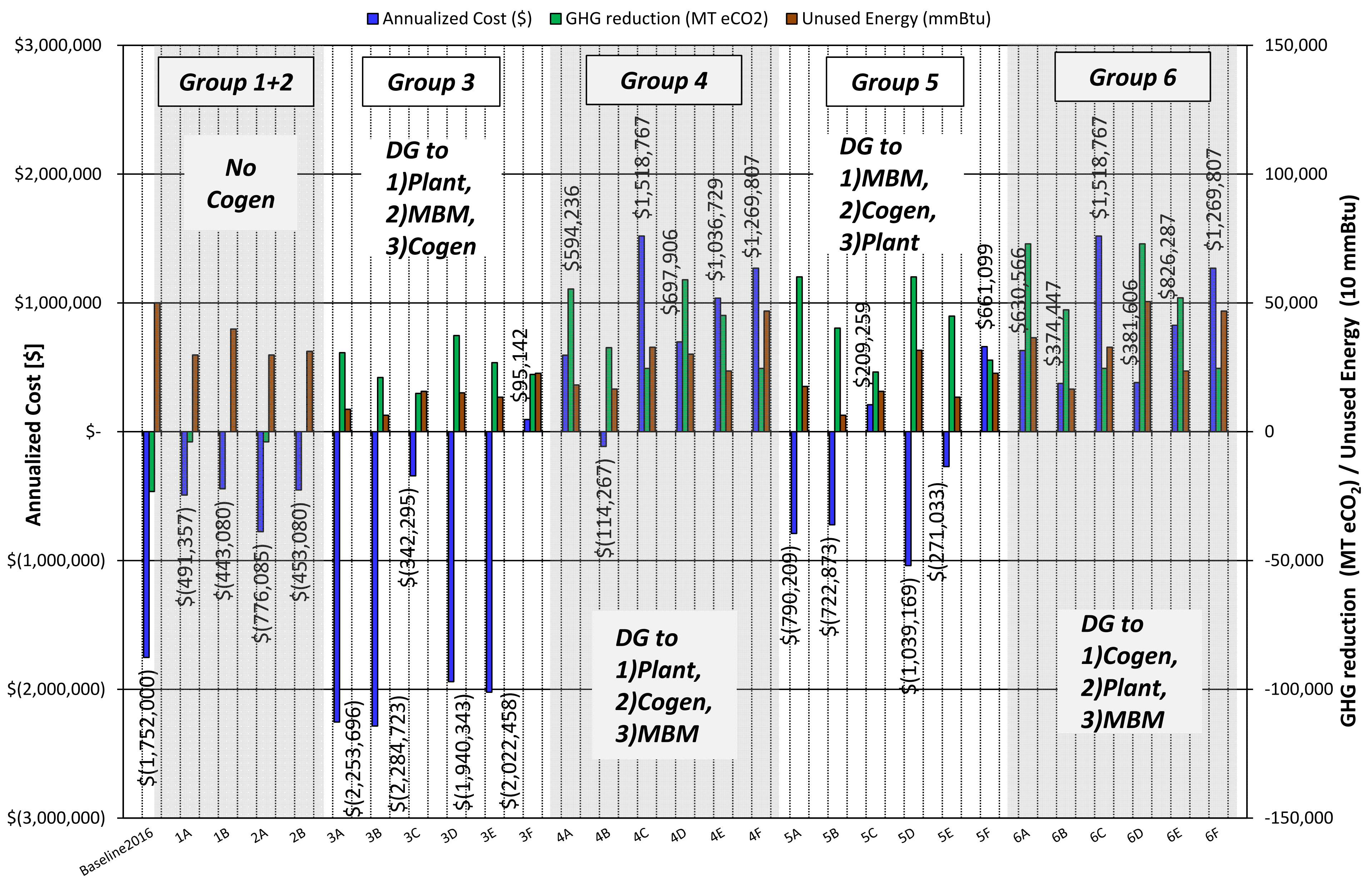
Scenario Group 5

– DG Priority = 1. [MBM Facility] 2. Cogeneration 3. [Plant Heating Boilers]

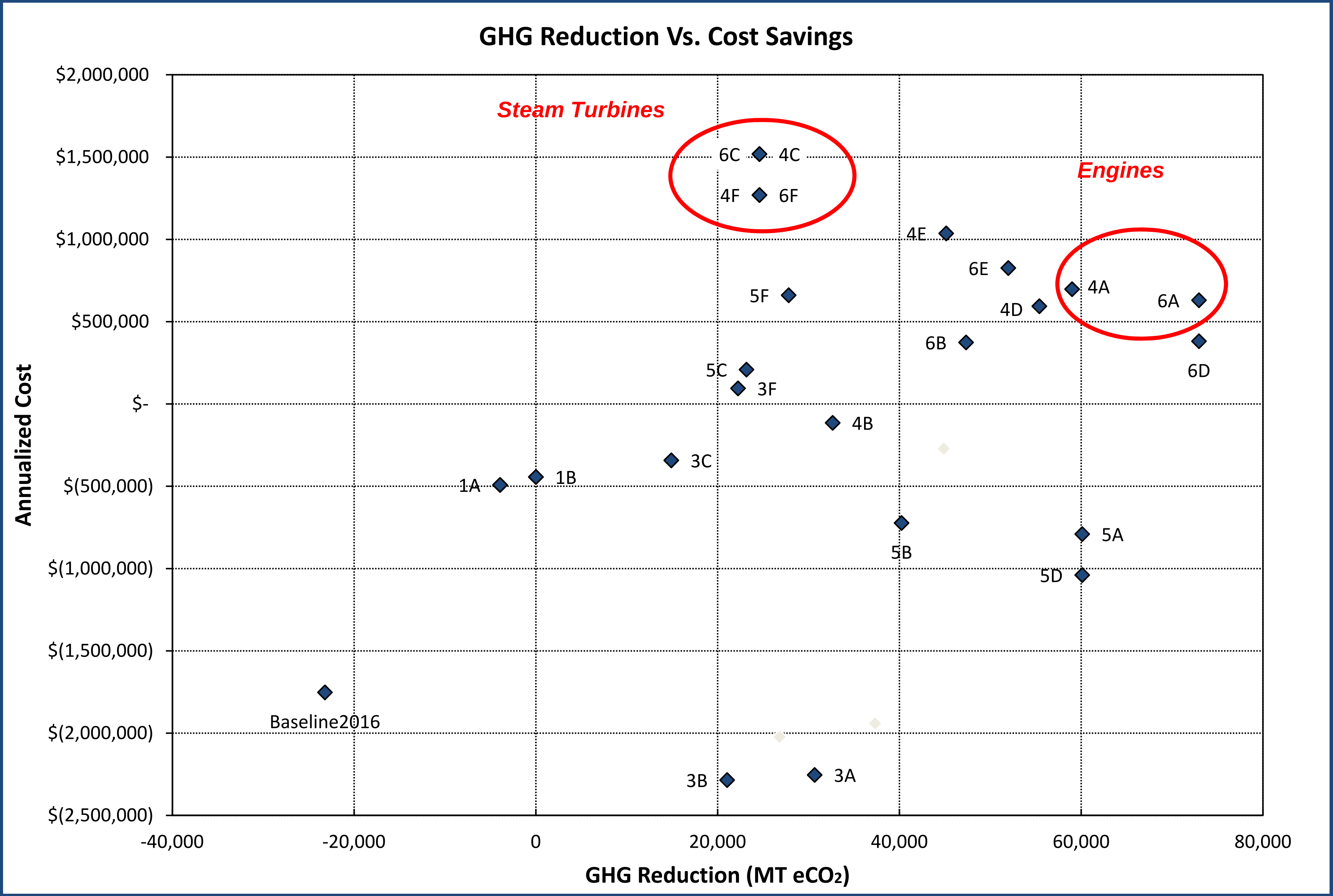
Scenario Group 6

DG Priority = 1. Cogeneration 2. [Plant Heating Boilers] 3. [MBM Facility] = NG

Energy Flow Model - Results



Energy Flow Model - Results



Selected Scenarios for Further Evaluation

Scenario	Cogeneration System	Digester Gas 1st Priority	Digester Gas 2nd Priority	Digester Gas 3rd Priority
4A	Engines	Plant Heating	Cogeneration	MBM (Fueled by NG)
4C	Steam Turbine	Cogeneration	Plant Heating (Plant heated entirely by recovered cogeneration heat)	MBM (Fueled by NG)
6A	Engines	Cogeneration	Plant Heating (Supplemental NG needed)	MBM (Fueled by NG)

Engine Operation Alternatives

- Balance DG

  Digester gas first routed to heating boilers then balance to engines.

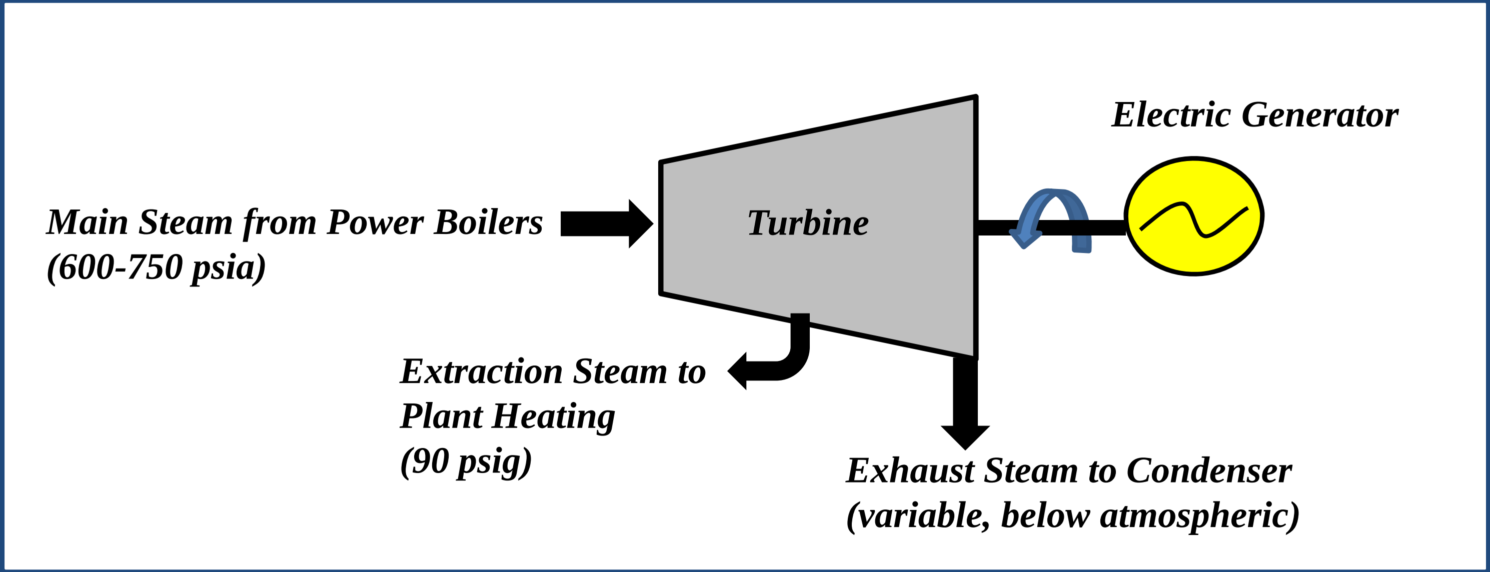
- Max with NG

  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

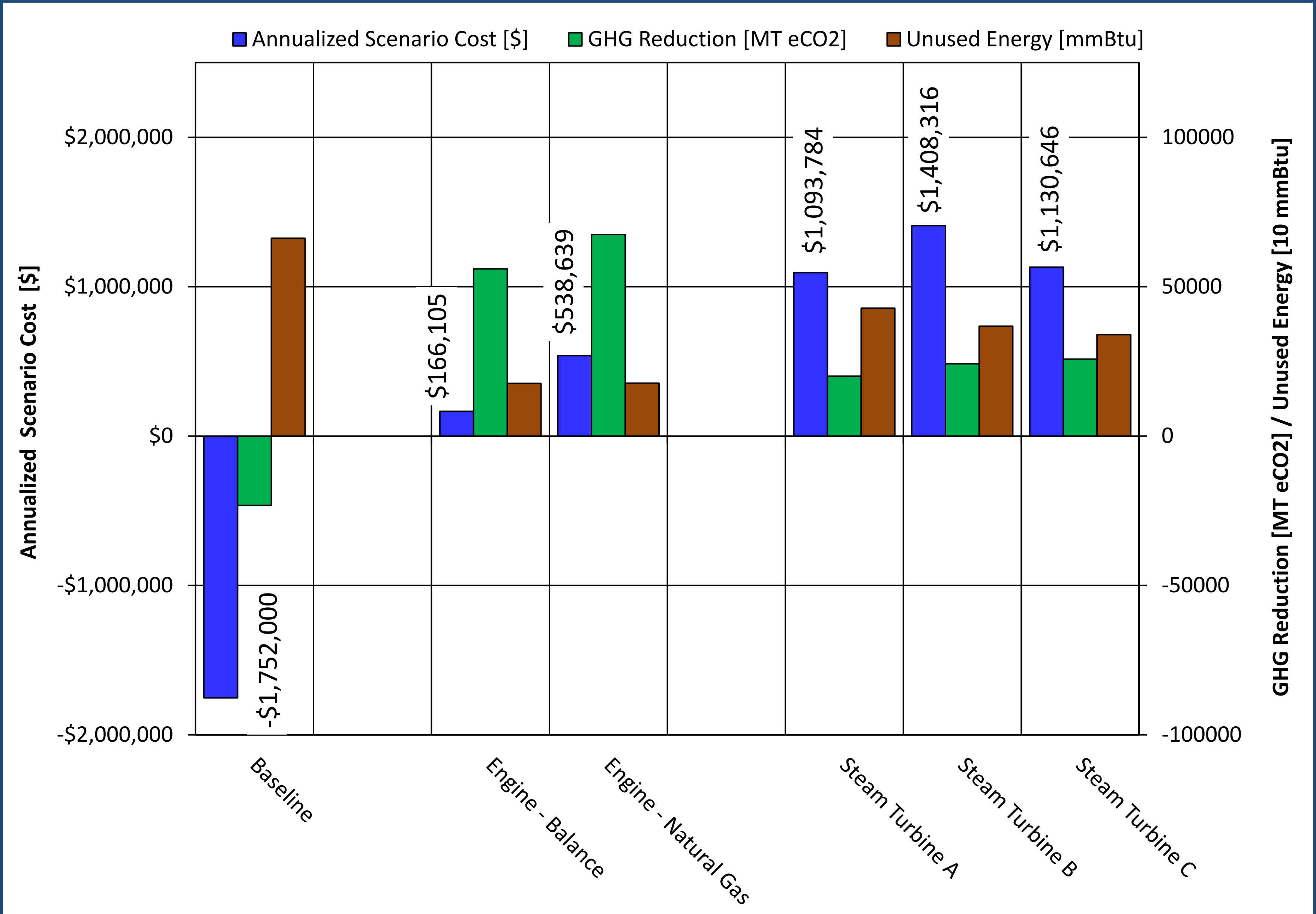


- ST – A = Use extraction steam for building and digester heat
- ST – B = Use extraction steam for building heat, condenser water heats digesters via recirculation line
- ST – C = Use extraction steam for building heat, condenser water pre-heats influent sludge to digesters

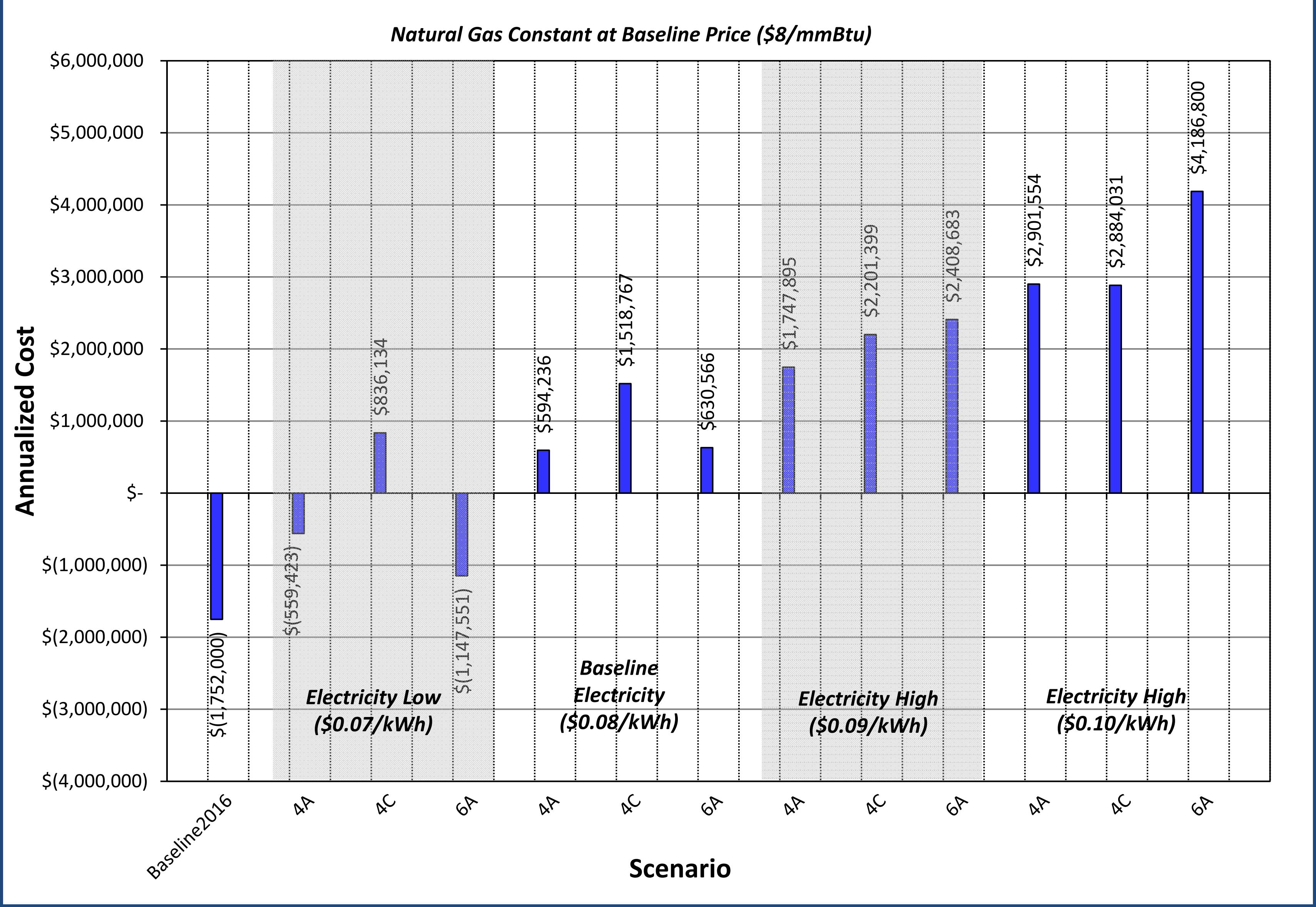
Updated Model Parameters

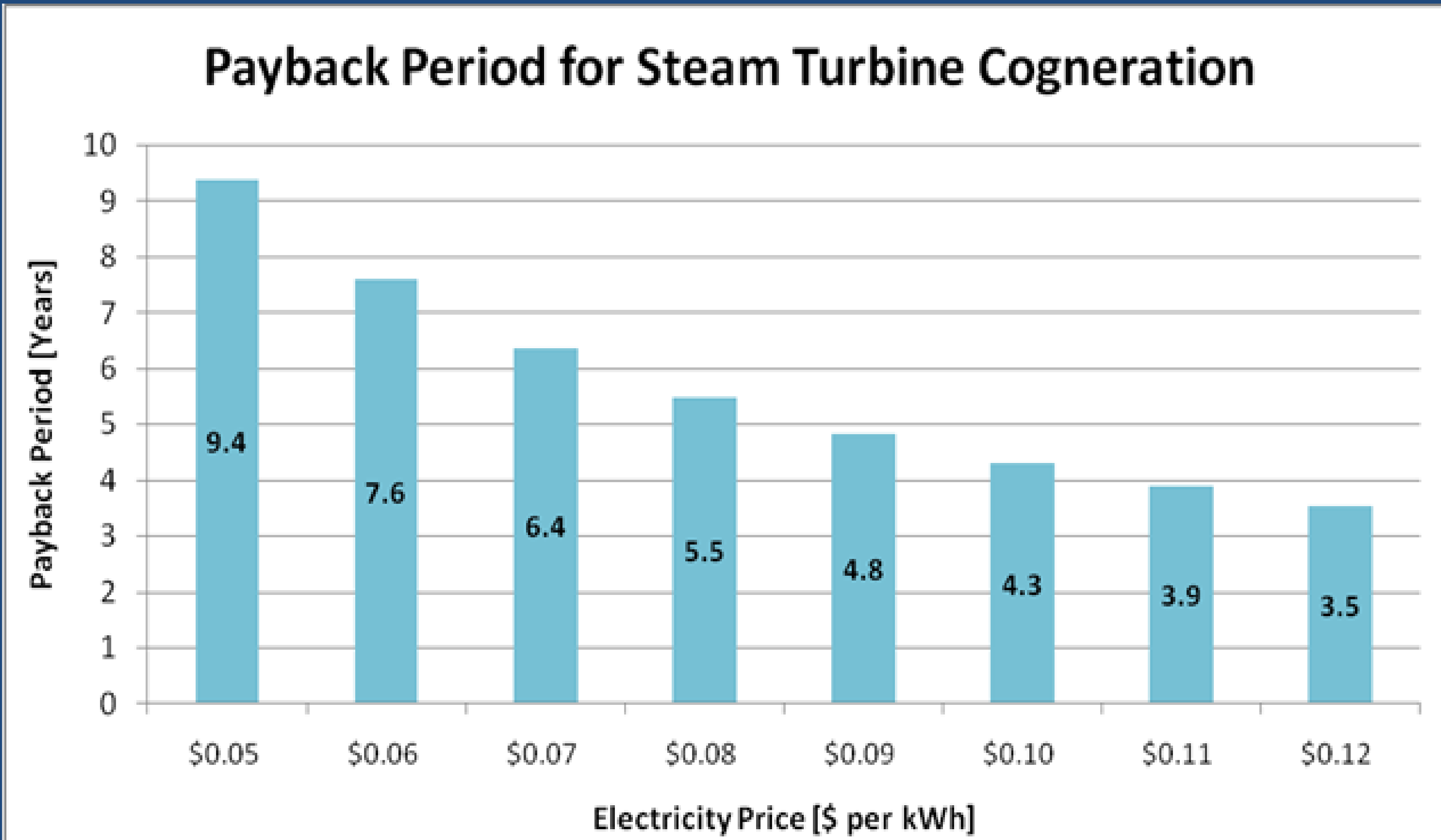
- New Performance for Steam Turbines
- Updated Cost for Heat Recovery Infrastructure
- Updated Cost for Electrical Distribution Infrastructure
- Addition of Digester Gas Storage Costs

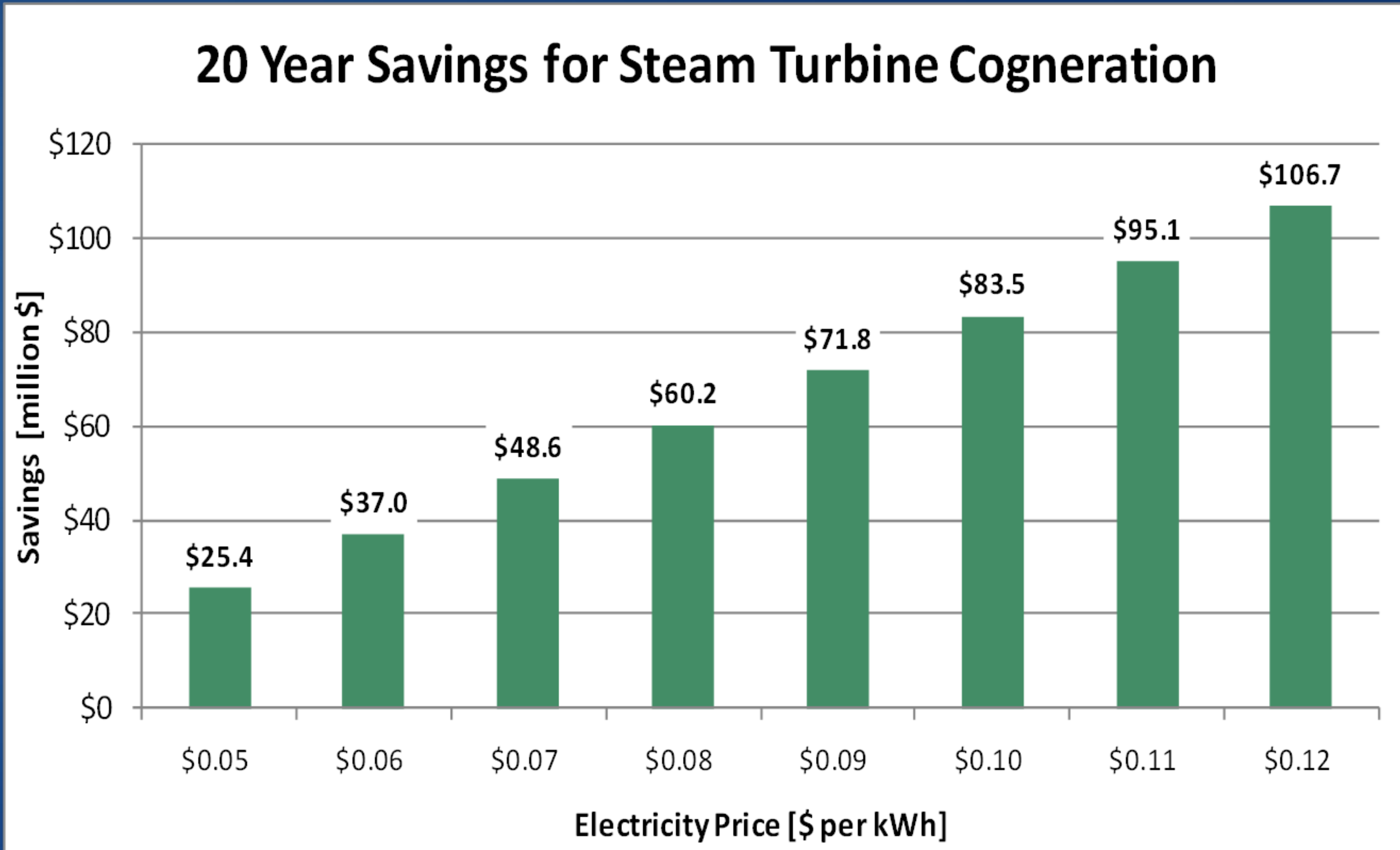
Advanced Energy Flow Model Results



Sensitivity Analysis – Electricity Price




Payback Period for Steam Turbine Cogneration
Payback Period [Years]
10
9
8
7
6
5
4
3
2
1
0
9.4
7.6
6.4
5.5
4.8
4.3
3.9
3.5
$0.05
$0.06
$0.07
$0.08
$0.09
$0.10
$0.11
$0.12
Electricity Price [$ per kWh]



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

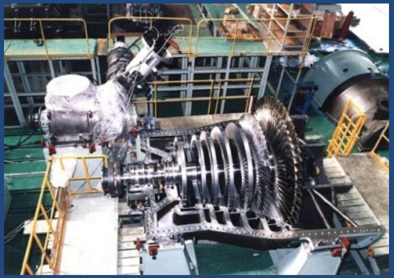
Site Visits

- 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

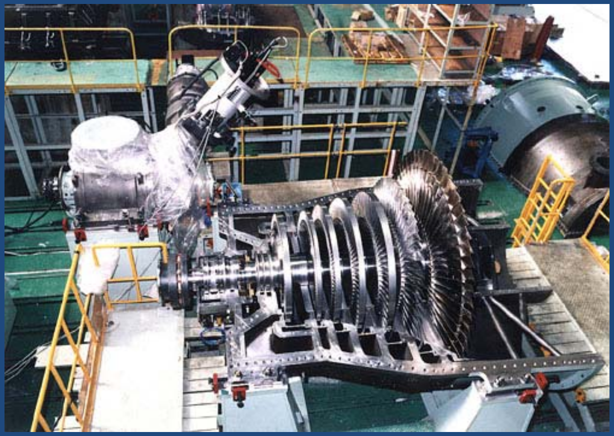
Calls and Field Visits – Steam Turbine



- 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



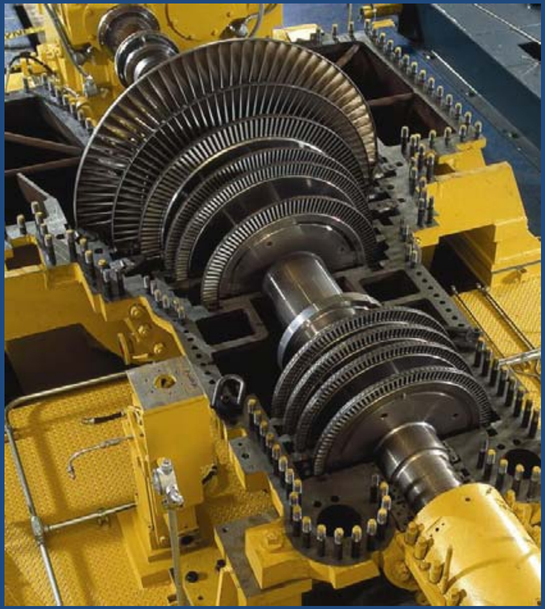
SWRP Specific Advantages

- 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 <u>this</u> plant.
- Slight changes in electricity rates have a significant affect on the economic payback of all co-generation alternatives.

Questions



Protecting Our Water Environment

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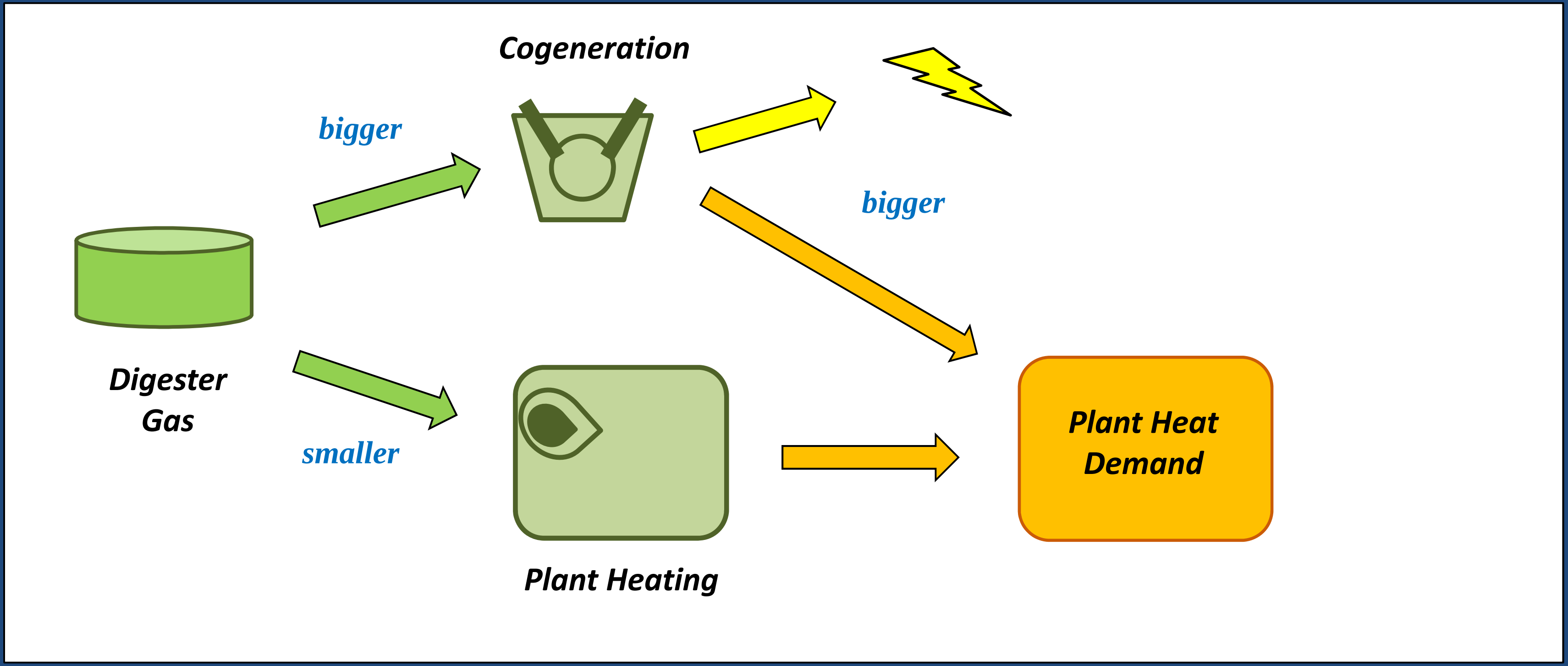
Sizing of Cogeneration Systems

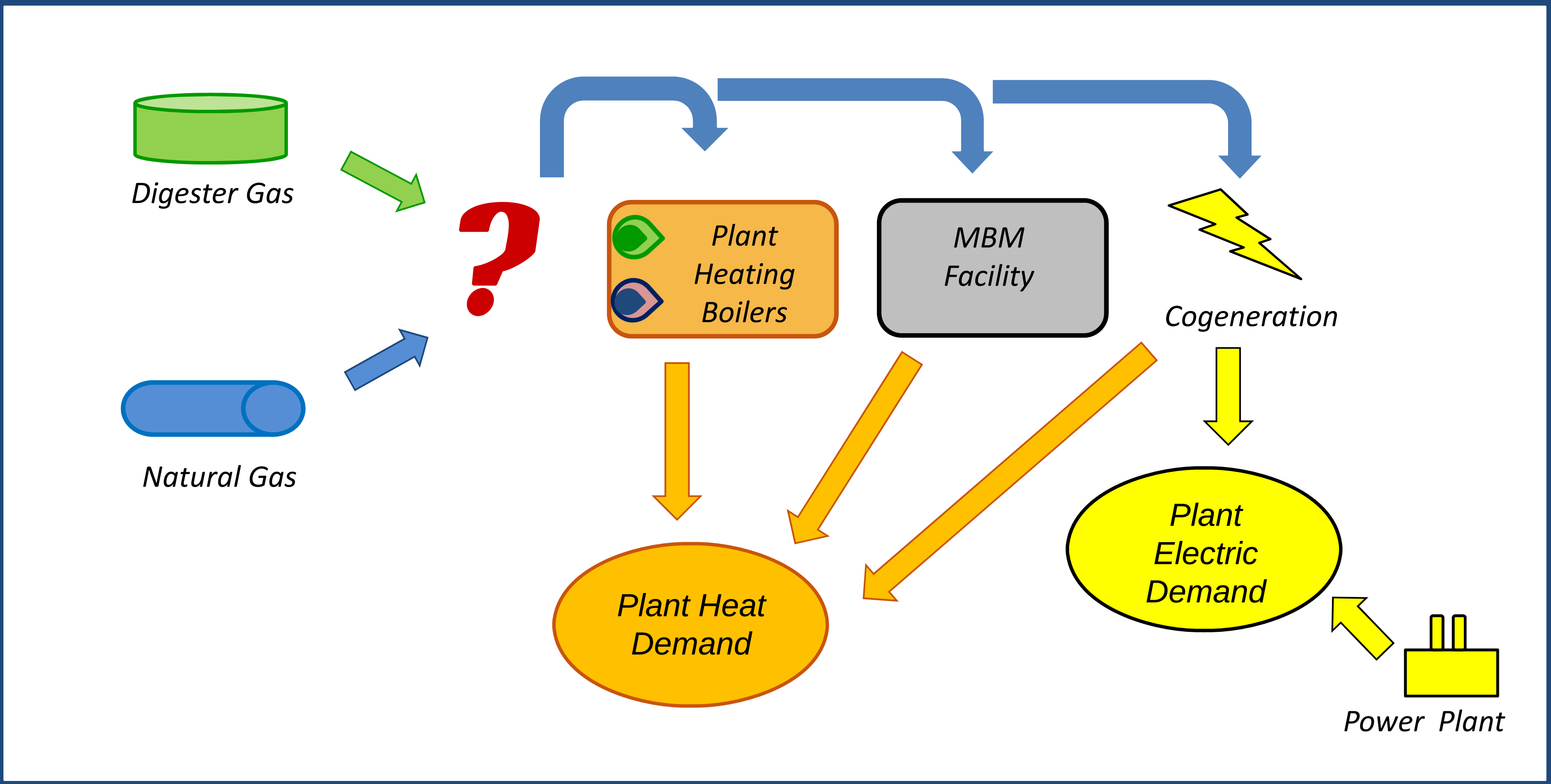
<u>Cogeneration Sizing</u>: Requires iterative loop to size capital equipment (maximum capacity)



- *<u>Average Gas Production</u> used to determine operating costs and economic performance*

Energy Flow Modeling

- Different Operational Scenarios Possible



Triple Bottom Line Scoring

Category	Weight	Sub Category	Max Score	Scenario Score ENG-NG	ST-A	ST-B	ST-C
Economic	50	Cost Savings	8	5.8	7.2	8.0	7.3
		Sensitivity	2	0	2	2	2
		Total Economic	*10*	*5.8*	*9.2*	*10.0*	*9.3*
		Weighted Score	*500*	*290*	*460*	*500*	*465*
Environmental	30	GHG Reduction	4	4.0	1.9	2.1	2.2
		Air Pollutants	6	2	5	5	5
		Total Environmental	*10*	*6.0*	*6.9*	*7.1*	*7.2*
		Weighted Score	*300*	*180*	*207*	*213*	*215*
Social	20	Operability	4	1	4	2	2
		Maintainability	5	1	5	4	4
		Implementability	1	0	1	0	0
		Total Social	*10*	*2.0*	*10.0*	*6.0*	*6.0*
		Weighted Score	*200*	*40*	*200*	*120*	*120*
TOTAL OVERALL SCORE			***1000***	***510***	***867***	***833***	***800***

Model Components