Performance Verification of Microturbines:

Instrument Selection, Installation, and Field Operation

Sushma Masemore

The GHG Technology Center

Topics Addressed

- Brief Overview of the GHG Center
- Microturbine Test Protocol
  - Verification parameters
  - Measurement instruments
  - Instrument installation, operation, and data quality assessment
- Future Microturbine Verifications

What is The GHG Center?

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV

EPA
U.S. Environmental Protection Agency

SOUTHERN RESEARCH INSTITUTE

ETV Joint Verification Statement

TECHNOLOGY TYPE:	EMISSION CONTAINMENT AND UTILIZATION SYSTEM		
APPLICATION:	SECONDARY SEALING SYSTEM FOR RECIPROCATING COMPRESSOR ROD SEALS		
TECHNOLOGY NAME:	SEAL ASSIST SYSTEM		
COMPANY:	A&A Environmental Seals, Inc		
ADDRESS:	3213 Texas Avenue La Marque, TX 77568	Phone: Fax:	(502) 634-4796 (502) 637-2280
WEB SITE:	http:\\www.aagroup.com/esi		
E-MAIL:	esi.sales@aagroup.com		

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups which consist of buyers, vendor organizations and permitters, and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

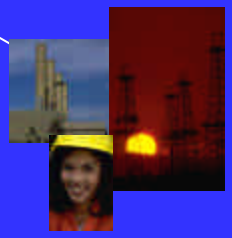
The Greenhouse Gas (GHG) Technology Verification Center (the Center), one of 12 technology areas under ETV, is operated by Southern Research Institute, in cooperation with EPA's National Risk Management Research Laboratory. The Center has recently evaluated the performance of the Seal Assist System. This verification statement provides a summary of the test results for the A&A Environmental Seals, Inc. Seal Assist System (SAS).

Greenhouse Gas Technology Center
Environmental Technology Verification Program
ETV

SOUTHERN RESEARCH INSTITUTE
Affiliated with the University of Alabama at Birmingham

The EPA's Environmental Technology Verification Program ETV

Industry



Industry Focus Areas

- Oil and Gas Production & Distribution
- Distributed Electrical Power Generation (DG)
- Combined Heat and Power (small-scale)
- Large Industrial Commercial Engines
- Municipal Solid Waste Disposal
- Refrigeration

Stakeholder Groups Help Us Focus....

- Executive Group
- Oil & Gas Industry Group
- Electricity Generation Group
- Technical Panels
  - Municipal Solid Waste Panel
  - Distributed Electricity Generation Panel
  - Refrigeration Systems Panel
  - Engine and Fuels Testing Panel

45 Member Electricity Stakeholder Group

- Southern California Edison
- Northern Indiana Public Service Company
- Mitsubishi Power Products, Inc.
- Southern Company
- Solar Turbines, Inc.
- Stirling Energy Systems, Inc.
- Sonat Power Systems
- USEPA-Climate Protection Division
- American Electric Power Company, Inc.
- Capstone Turbine Corporation
- Micro-Turbine Power, LLC
- Chugach Electric Assoc., Inc.
- Distributed Utility Associates
- Tampa Electric Company
- Arizona Public Service Company
- Safe Harbor Water Power Corporation
- Cinergy Corporation
- Cinergy Corporation
- Portland General Electric
- E Source
- The Business Council for Sustainable Energy
- Ballard Generation Systems
- Energy Partners.
- Distributed Power Coalition of America
- Ontario Power Technologies
- Tennessee Valley Authority
- Natural Gas Supply Association
- ABB Power T&D Company
- El Paso Electric Company
- Redding Electric Department
- Elliott Energy Systems
- Williams International
- Vero Beach Municipal Utilities
- Conoco, Inc.
- ARCO Technology & Operational Support
- Velcon Filters, Inc.
- Vermont Public Power Authority
- Eastern Power, Ltd.
- Enron Gas Pipeline Group
- ENCORP, Inc.
- Taunton Municipal Light Plant
- Consolidated Edison Company of New York, Inc.
- AlliedSignal Power Systems, Inc.

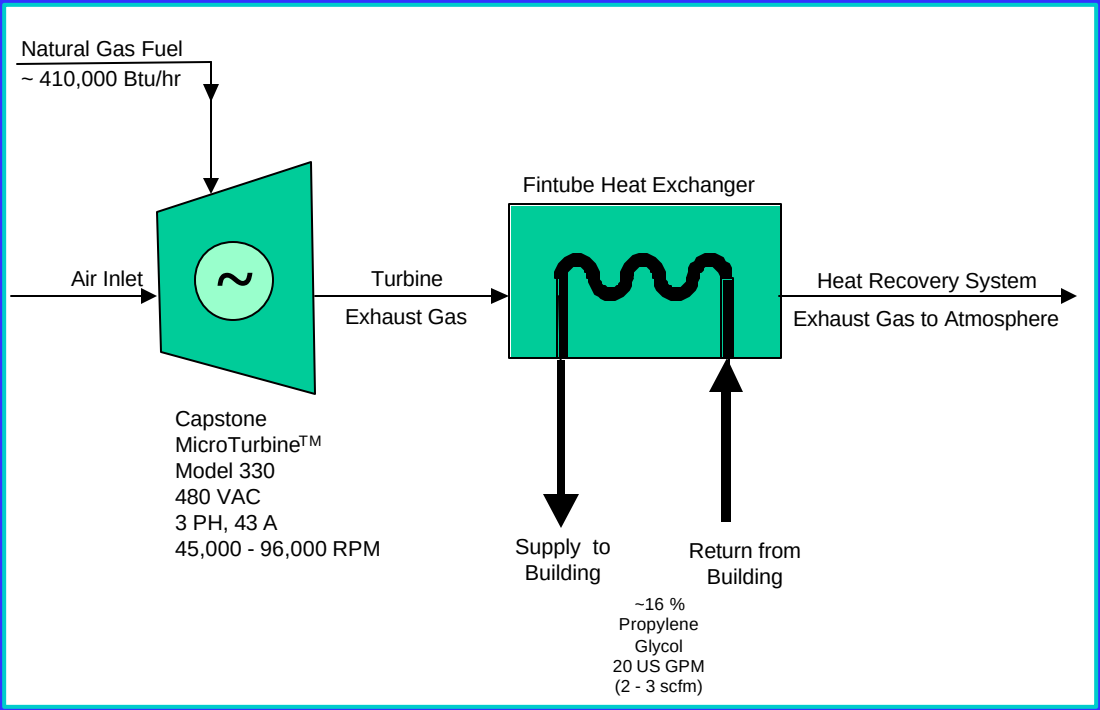
Verification Parameters

- Heat & Power Production Performance
  - Electrical power output and heat recovery rate
  - Electrical, thermal, and total system efficiency
  - Total electrical energy generated and used
  - Total thermal energy recovered
- Power Quality Performance
  - Electrical frequency
  - Voltage output
  - Power factor
  - Voltage and current total harmonic distortion
- Concentrations & Emission Rates For...
  - Nitrogen oxides (NO_X)
  - Carbon monoxide (CO)
  - Volatile organic compounds (VOC)
  - Carbon dioxide (CO_2) and methane (CH_4)
- Emission Reduction Estimates
  - Compare CHP to “baseline technology” at test site (grid supplied power, gas-fired boiler supplied heat)
  - Estimated GHG emission reductions for other “model sites” in USA

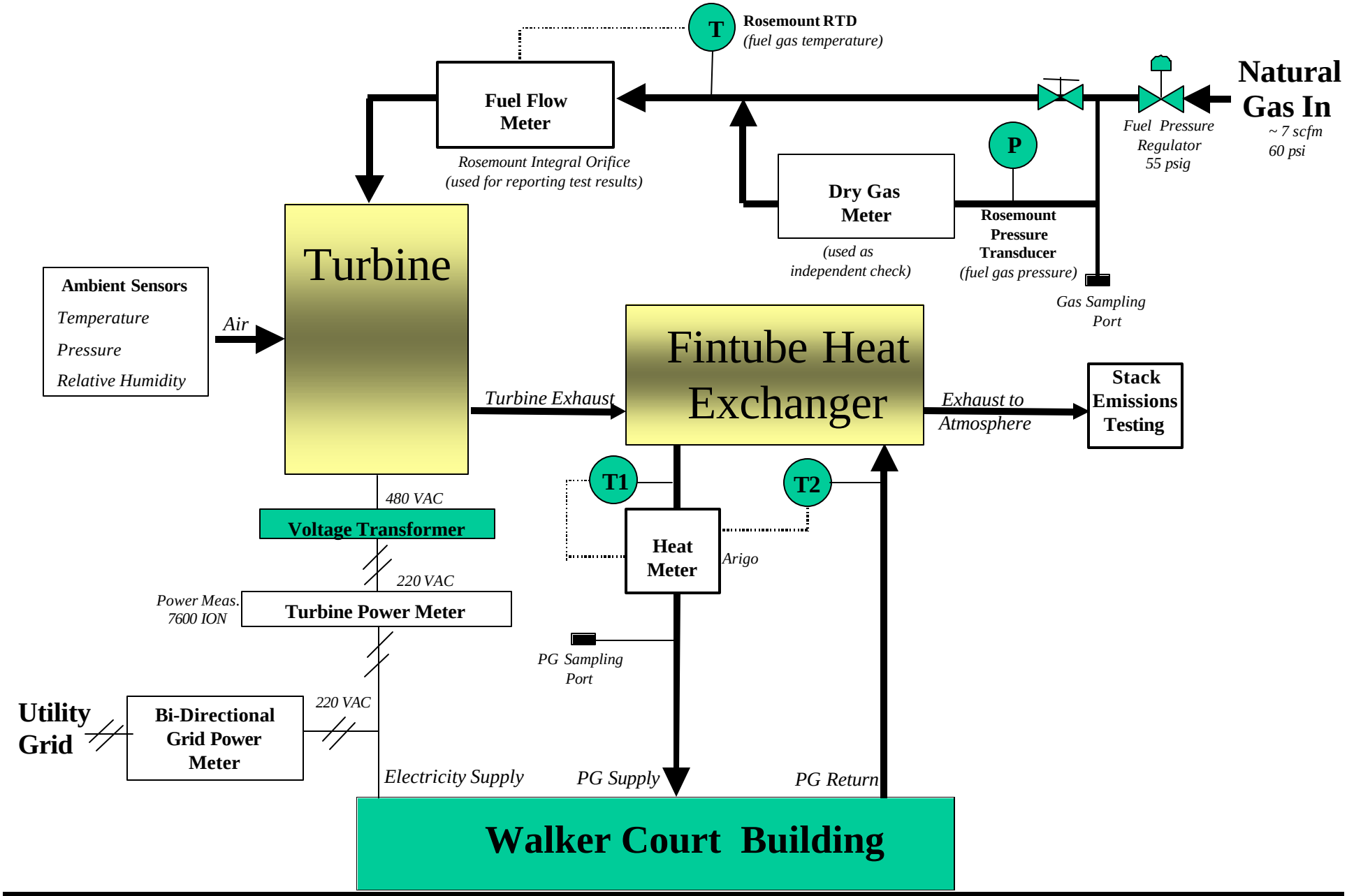
Honeywell Test Site

Mariah Energy

Microturbine Combined Heat and Power System



Measurements System



Electrical Efficiency Method:
ASME PTC 22

- 30-Minutes Each
- Loads (3 runs each):
  - 100%
  - 90 %
  - 75%
  - 50%

$$h_E = \frac{3412.14\, kW_e}{HI}$$

where :

?E = electrical efficiency (%)

3412.14 Btu/hr per kW_e

kW_e = *MEASURED* electrical power output, (kW_e)

HI = *MEASURED* heat input, (Btu/hr); *MEASURED* mass flow rate of natural gas times *MEASURED* natural gas LHV times 60

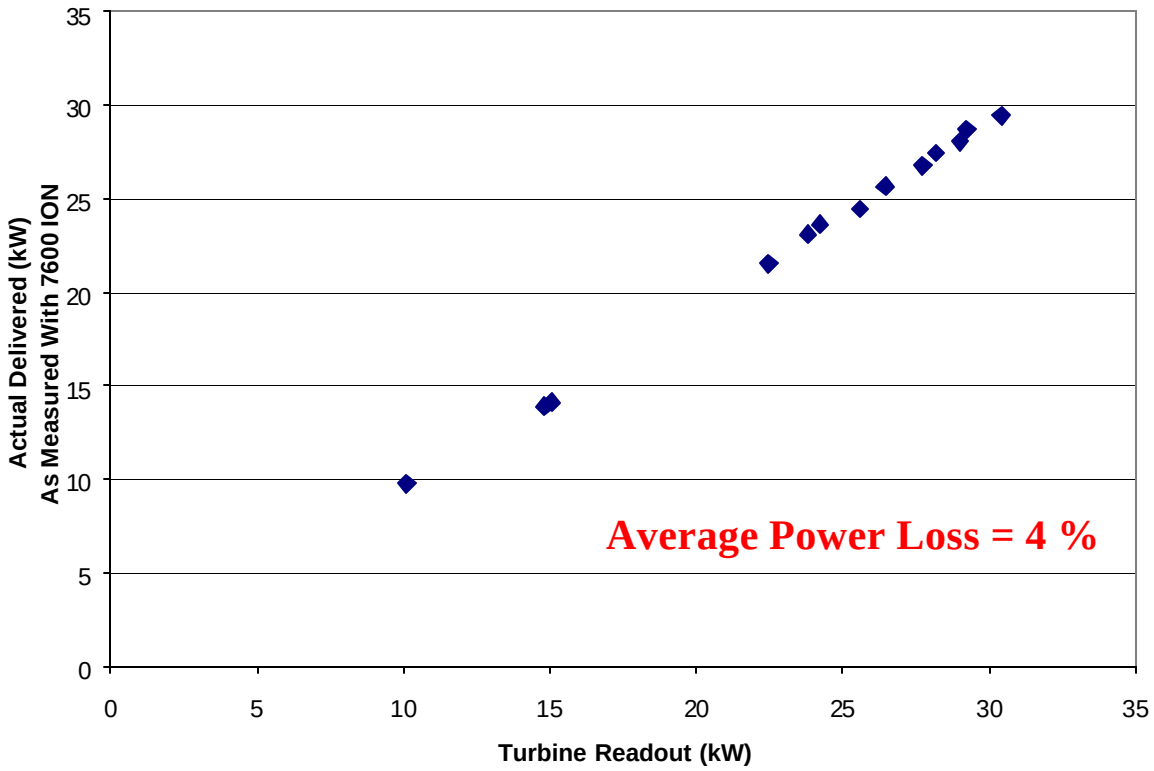
Electrical Power Measurement

- Power Output
  - Digital watt meter by Power Measurements (± 0.20 %)
  - Quantified actual power delivered (including voltage transformer losses)
  - 1-minute average readings
- Booster Compressor Electricity Consumption
  - 2nd digital watt meter

Booster Compressor Electricity Intake

Test Condition		With Compressor		Without Compressor		
		Average Power Delivered (480 volts)	Average Electrical Efficiency	Power Consumed by Compressor (275 volts)	Estimated Total Power Delivered (480 volts)	Estimated Electrical Efficiency
% of Rated Power	Power Command (kW)	(kW)	(%)	(kW)	(kW)	(%)
100	75	71.26	23.45	4.36	75.53	24.85
90	68	64.71	23.22	4.15	68.78	24.68
75	56	53.36	22.71	3.77	57.05	24.28
50	38	35.90	19.81	3.28	39.11	21.58

Comparison of Power Readings



Power Quality Measurements

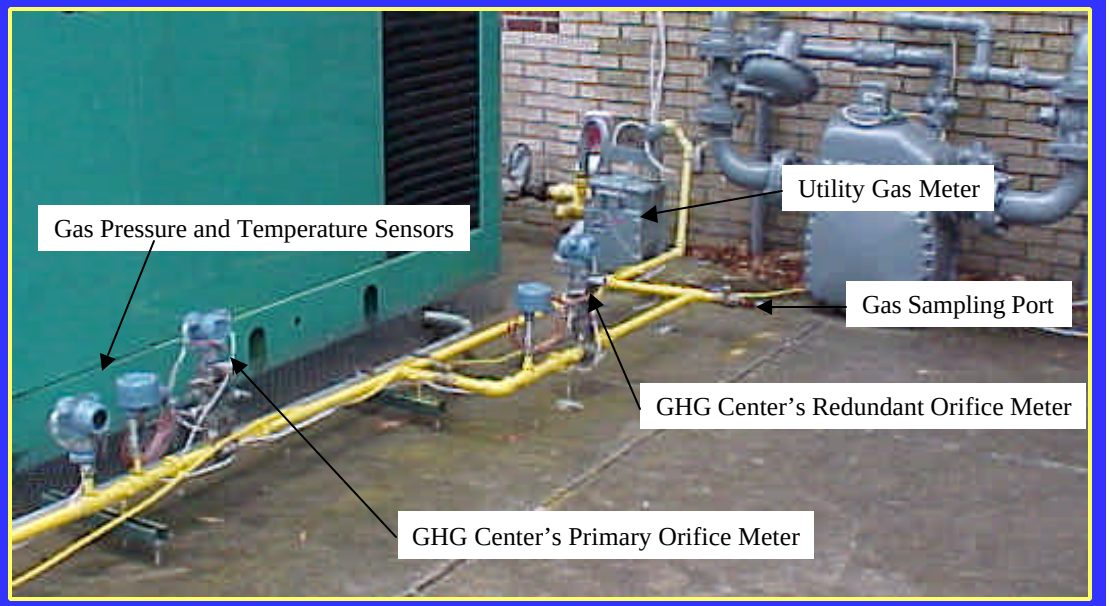
- Same 7600 ION Used (magnitude and no. of incidents over set-point)
  - Voltage and Frequency
  - Power factor
  - Voltage and Current THD
- Comparisons With Grid (before, after, and during microturbine operation)
  - 7500 ION

24 Day Summary of Continuous Monitoring

	Voltage Output (volts)	Frequency (Hz)	Power Factor (%)	Current THD (%)	Voltage THD (%)
Average	487.27	60.000	99.98	3.56	0.94
Maximum	494.29	60.045	100	2.53	0.25
Minimum	478.22	59.942	91.5	4.98	1.82
Std. Deviation	2.36	0.014	0.1	0.4	0.25

Fuel Delivery System

- Fuel Flow Rate
  - Integral orifice meter by Rosemount (± 1 %)
  - Sized to measure steady- state fuel consumption
  - Temperature/pressure compensated
  - 1-minute average readings
  - Backup orifice/dry gas meters
- Fuel Heating Value
  - On-site sample collection
  - LHV analysis per ASTM D1945 and D3588



Comparison of Fuel Flow Measurements

Test Condition (% of Rated Power)	Power Delivered (kW)	Integral Orifice Meter Reading (scfm)	Gas Pressure (psia)	Gas Temperature (°F)	Dry Gas Meter Reading (scfm)	Difference[a] (scfm)
100	28.45	7.16	52.77	46.65	7.15	0.01
	28.32	7.12	52.54	50.42	7.17	-0.05
	28.47	7.22	52.86	54.05	7.07	0.15
	28.45	7.20	52.62	54.73	7.08	0.12
	28.38	7.19	52.79	55.73	7.04	0.15
90	26.44	6.73	52.71	48.57	6.68	0.05
	26.47	6.71	52.86	49.38	6.64	0.07
	26.32	6.73	52.83	50.25	6.67	0.06
	26.46	6.75	52.78	54.18	6.64	0.11
75	22.04	5.76	53.24	50.63	5.73	0.03
	22.05	5.74	53.25	51.25	5.73	0.01
	22.02	5.79	53.09	54.38	5.75	0.04
50	14.54	4.19	53.76	52.46	4.13	0.06
	14.52	4.19	53.48	52.30	4.12	0.07
	14.54	4.19	53.63	55.00	4.14	0.05
					Overall Average	± 0.69 scfm or ± 1.07 %

[a] = (Integral Orifice Reading – Dry Gas Reading)

Natural Gas Audit Analysis

Gas Component	Certified Component Concentration (%)	Analytical Result (%)	Combined Sampling and Analytical Error (%)[a]	Duplicate Analytical Result (%)	Analytical Repeatability (%)[b]
n-butane	0.386	0.43	11.4	0.40	7.0
carbon dioxide	3.01	3.20	6.3	3.18	0.6
ethane	3.52	3.52	0.0	3.50	0.6
n-heptane	0.020	0.02	0.0	0.02	0.0
n-hexane	0.049	0.05	2.0	0.06	20.0
Iso-butane	0.396	0.40	1.0	0.40	0.0
Iso-pentane	0.150	0.15	0.0	0.15	0.0
n-pentane	0.150	0.15	0.0	0.15	0.0
nitrogen	2.50	2.53	1.2	2.57	1.6
propane	1.00	1.01	1.0	1.01	0.0
methane	88.72	88.53	0.2	88.48	0.05

Calculated as: Error = (certified conc. – analytical result) / certified conc. * 100
Calculated as: Error = (initial result – duplicate result) / initial result * 100

Thermal Energy Metering

- Kamstrup - Maxical III, or equiv.
- Directly Measure Volumetric Flow Rate
- Directly Measure Inlet/Outlet Temps.
- Obtain Direct Samples of Heat Transfer Fluid and Analyze for Composition
- Use ASHRAE Charts to Select Density and Enthalpy at Actual Operating Conditions

Heat Recovery Rate and Thermal Efficiency Methods

Heat Recovery Rate (Btu/min) = Vr Cp (T1-T2)

where:

V = *MEASURED* volume of liquid per minute

r = *MEASURED* density of PG solution at the average temp. (T2+T1)/2

Cp = specific heat of liquid (Btu/lb oF) at the avg. temp. (T2+T1)/2

T1 = *MEASURED* temperature of heated liquid exiting heat exchanger (oF)

T2 = *MEASURED* temperature of cooler liquid entering heat exchanger (oF)

11 Measured Variables Required

$$h_{Th}\ Efficiency = \frac{60\ Heat\ Recovery\ Rate}{HI}$$

where :

$?_{Th}$ = *thermal energy* efficiency (%)

Heat recovery rate = average one minute rate (Btu/min)

HI = average heat input, (Btu/hr); same as eariler

Air Intake Measurements

- Remote Meteorological Station Erected Near Turbine Air Inlet
- 1-Minute Average Readings
  - Ambient temperature
  - Barometric pressure
  - Relative humidity
- Used to Meet ASME PTC-22 Stability Criteria

Electrical Efficiency Method:

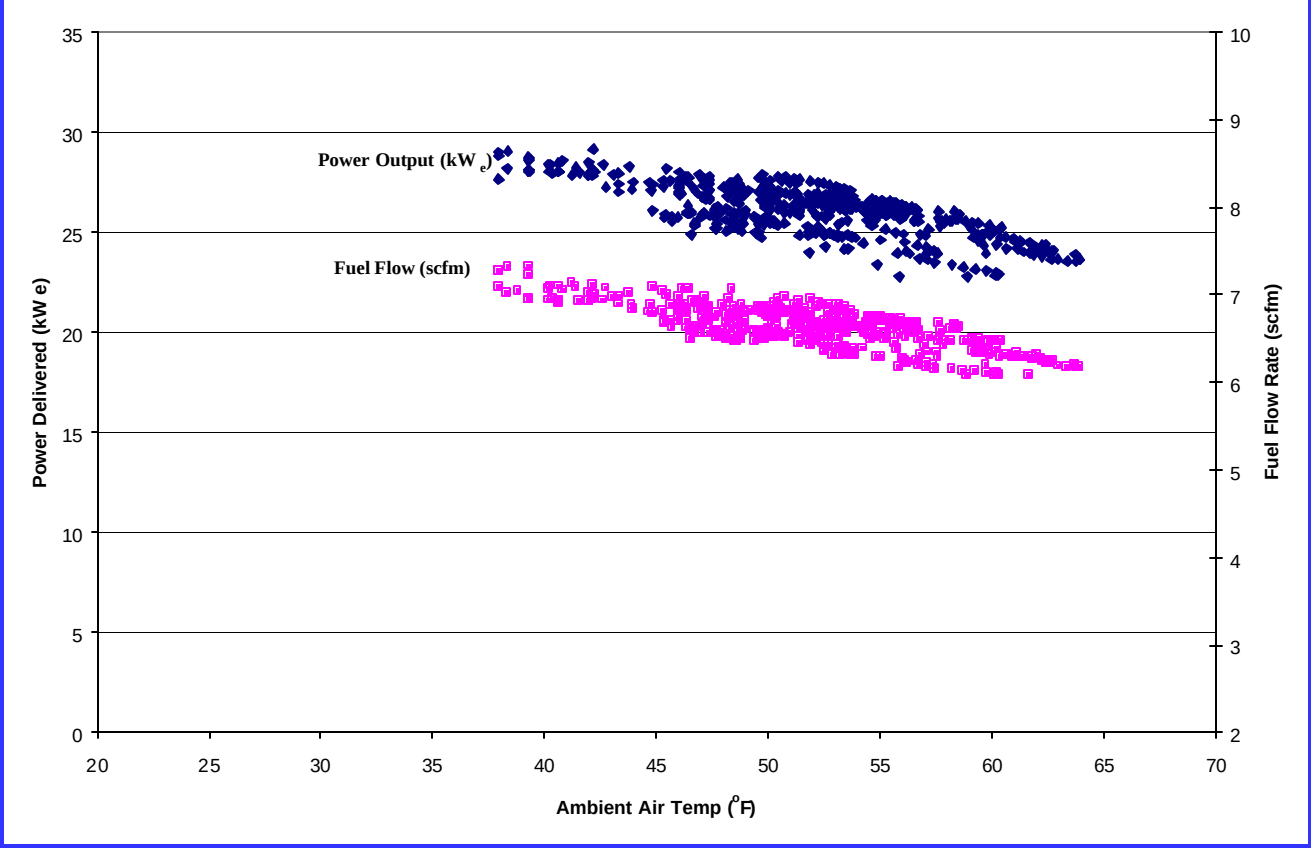
ASME PTC 22

- Stability Monitoring:

Measured Parameter	Allowed	Actual[a] (Run Number)											
		1	2	3	4	5	6	7	8	9	10	11	12
Power Output (%)	± 2	0.08	0.17	0.11	0.09	0.12	0.18	0.12	0.10	0.11	0.17	0.18	0.17
Power Factor (%)	± 2	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.02
Fuel Flow Rate (%)	± 2	1.40	1.26	1.71	1.87	1.86	1.37	1.63	1.57	2.06	0.82	0.48	0.42
Inlet Air Pressure (%)	± 0.5	0.05	0.05	0.05	0.05	0.05	0.06	0.10	0.07	0.06	0.07	0.07	0.08
Inlet Air Temperature (F)	± 4	0.46	0.90	0.33	0.37	1.53	1.50	2.30	1.07	1.02	0.84	1.02	0.67

[a] = (Average of Test Run – Maximum Observed Value) / Average of Test Run * 100

Ambient Temperature Affects



Emission Rate Methods:

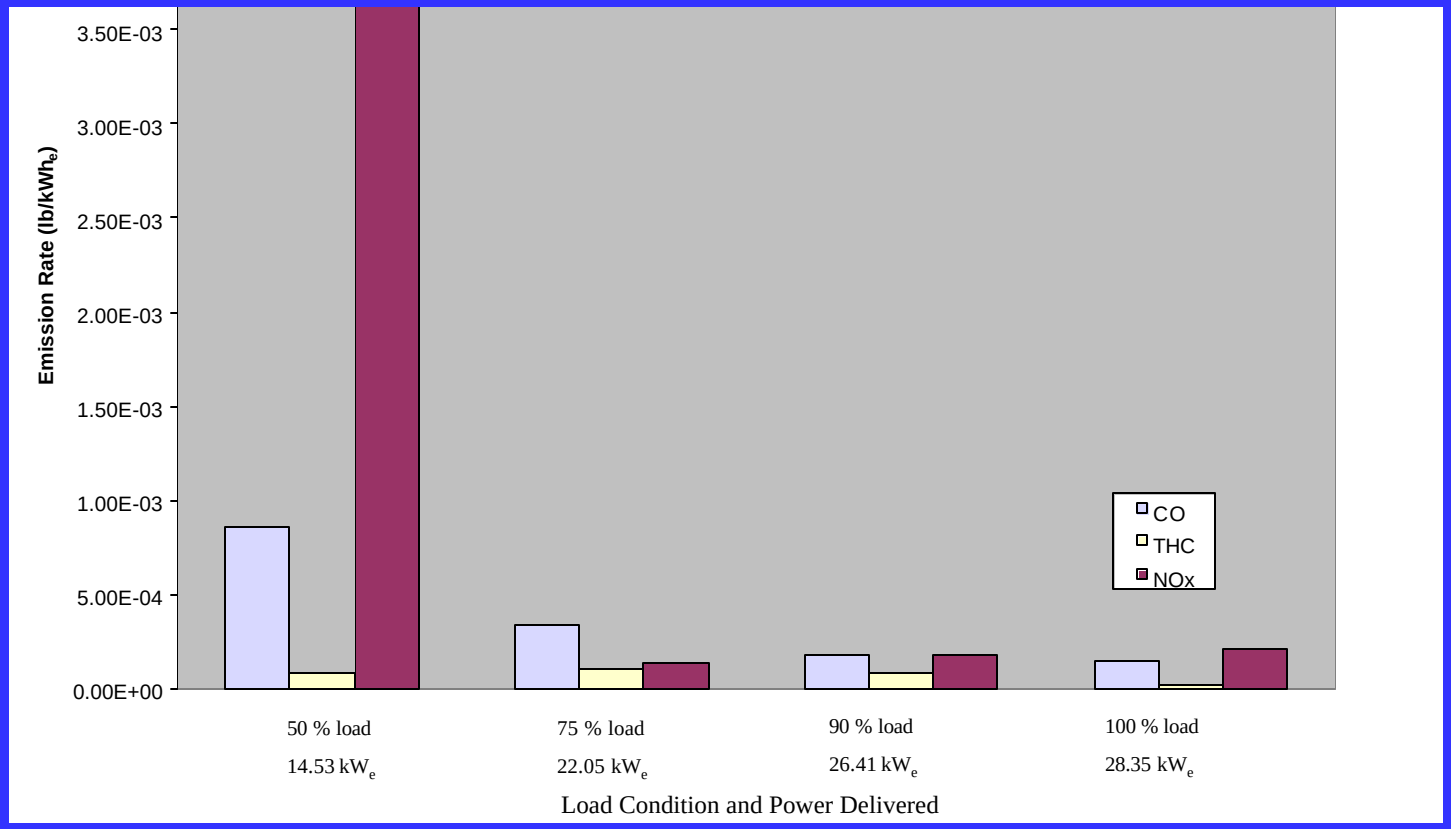
U.S. EPA Reference Methods

Exhaust Stack			
Pollutant	**EPA Reference Method**	**Number of Loads Tested**	**Number of Tests**
NO_X	20	4	3 per load (30 minutes each)
CO	10	4	3 per load (30 minutes each)
THC[a]	25A	4	3 per load (30 minutes each)
CO_2	3A	4	3 per load (30 minutes each)
CH_4	18	4	3 per load (30 minutes each)
O_2	3A	4	3 per load (30 minutes each)

Emission Rate Methods:
U.S. EPA Reference Methods

- CEMs Located in Mobile Laboratory
- Pre-test Screening Recommended
  - Analyzers calibrated to site range
  - Appropriate range of audit gases selected
- Leak Screening Must be Performed on Stack Extension
- Measurement of Stack Flow Rate Not Recommended per Method 2, Method 19 Used Instead

Emission Rate vs. Operating Load



Pollutant Concentration Profile

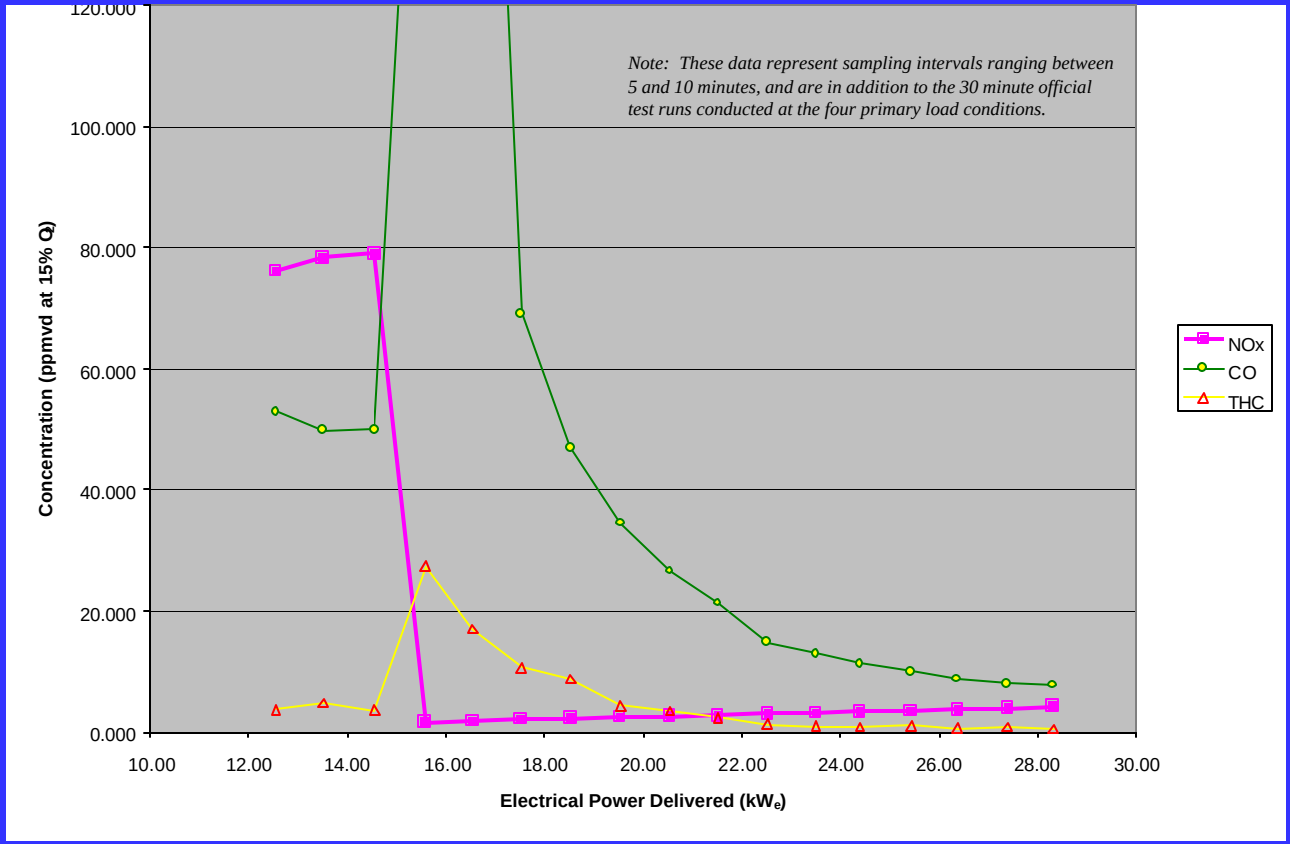
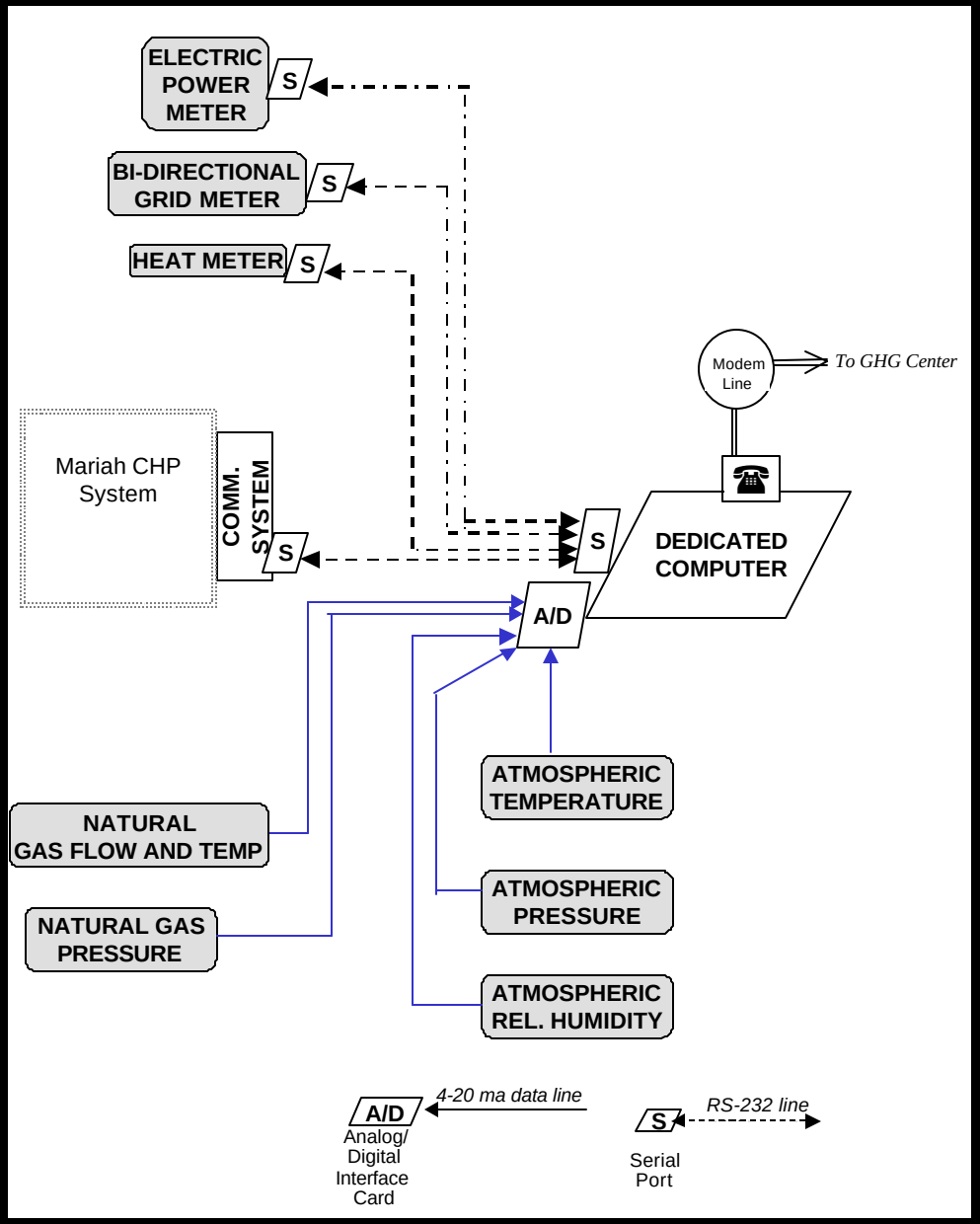


Table 3-2. Summary of Data Quality Goals and Results

Measurement Variable		Instrument Type / Manufacturer	Instrument Range	Range Observed in Field	Accuracy			Completeness	
					Goal	Actual	How Verified / Determined	Goal	Actual
Mariah CHP Power Output and Quality	Power	Electric Meter/ Power Measurements 7600 ION	0 to 100 kW	0 to 29 kW	± 0.20 % reading	± 0.05 % reading	Instrument calibration from manufacturer just prior to testing	load tests: 3 valid runs per load using PTC 22 criteria extended test: 1 minute readings for 25 days	load tests: 3 valid runs at all loads extended test 1 minute readings for 38 days
	Voltage		0 to 600 V	0 to 220 V	± 0.1 % reading	± 0.1 % reading			
	Voltage Transients		600 to 8000 V	none	not defined	NA			
	Frequency		49 to 61 Hz	59.908 to 60.070 Hz	± 0.01 % reading	± 0.01 % reading			
	Current		0 to 100 Amps	0 to 80 Amps	± 0.1 % reading	± 0.1 % reading			
	Voltage THD		0 to 100 %	0 to 100 %	± 1 % FS	± 1 % FS			
	Current THD		0 to 100 %	0 to 100 %	± 1 % FS	± 1 % FS			
	Power Factor		0 to 100 %	0 to 100 %	± 0.5 % reading	± 0.5 % reading			
Mariah CHP Heat Recovery Rate	Inlet Temperature	Arigo Meter RTDs	37 to 356°F	120 to 135°F	RTD differential temps must be ± 1.8°F of ref. thermocouples	±0.3°F	Independent check with calibrated thermocouples	load tests: 3 valid runs extended test: 1 minute readings for 25 days	load tests: 2 runs at @ 75%, and 1 run @ 90 and 50 %, load condition invalidated extended test 1 minute readings for 38 days
	Outlet Temperature		37 to 356°F	135 to 155°F					
	PG Flow	Arigo Meter Liquid Flow Sensor	2.53 to 5.89 cfm	2.5 to 3.0 cfm	±1.0 % reading	± 1.0 % reading	Instrument calibration from manufacturer just prior to testing		
	PG Concentration and Specific Heat	GC/FID	PG Conc: 10 to 20 %	PG Conc: 15.7-16.5 %	PG Conc: ±3 %	PG Conc: ±0.7 %	Independent check with blind sample		
			PG Sp Ht: 0.900 to 0.981 Btu/lb F	PG Sp Ht: 0.962 to 0.971 Btu/lb F	PG Sp Ht: ±0.2 %	PG Sp Ht: ±0.1 %	Using specific heat versus concentration charts published by ASHRAE		
Ambient Conditions	Ambient Temperature	RTD / Vaisala Model HMP 35A	-50 to 150 °F	25 to 65 ° F	± 0.2 °F	± 0.2 °F	Instrument calibration from manufacturer just prior to testing	load tests: 1 minute readings for all runs extended test: 1 min readings for 25 days	load tests: 1 minute readings for all runs extended test 1 min readings for 38 days
	Ambient Pressure	Vaisala Model PTB220 Class B	14.80 to 32.56 in Hg	28 to 31 in Hg	± 0.1 % FS	± 0.1 % FS			
	Relative Humidity	Vaisala Model HMP 35A	0 to 100 % RH	40 to 95 % RH	± 2 % (0 to 90 % RH) ± 3 % (90 to 100 % RH)	± 2 % (0 to 90 % RH,) ± 3 % (90 to 100 % RH)			

Measurements Data Acquisition System



Data Quality Goals and Reconciliation

Verification Parameter	Required	Achieved
Electrical Power Output	± 0.2 % of reading or ± 0.06 kW at full load	± 0.05 % of reading or ± 0.01 kW at full load
Electrical Efficiency	± 0.38 % at full load	± 0.35 % at full load
Heat Recovery Rate	± 2.18 % at full load	± 2.73 % at full load
Thermal Efficiency	± 1.86 % at full load	± 1.97 % at full load
Total Efficiency	± 1.11 % at full load	± 3.21 % at full load
Emission Levels		
NO_X	± 0.50 ppm	± 0.40 ppm
CO	± 1.00 ppm	± 0.50 ppm
CO_2	± 1.00 %	± 0.40 %
VOC	± 1.50 ppm	± 0.80 ppm

QA/QC Checks on Emission Measurements

Parameter	QA/QC Check	When Performed/Frequency	Expected or Allowable Result
Sampling System	System leak check	Before and after each test run	$\leq$ 1.0 % O_2 while sampling pure N_2
NO_X	Analyzer interference check	Once before testing begins	± 2 % of analyzer span or less
	NO_2 converter efficiency	Once before testing begins	98 % efficiency or greater
	Audit gas (approximately 10 ppmvd NO in N_2)	Once before testing begins	± 2 % of analyzer span
CO, CO_2, O_2	Analyzer calibration error test	Daily before testing	± 2 % of analyzer span or less
CO	Audit gas (9.06 ppmvd CO in N_2)	At the end of test after low NO_X levels were measured	± 5 % of analyzer span
CH_4	Calibration with reference gas standard	Prior to analysis of each lot of samples submitted	± 2 % for CH_4 concentration

GHG Technology Verification Guideline Document
Review Tracking Form

Company Name:

Technology Name: **Natural Gas Compressor Leak Mitigation Technologies**

SRI Person Responsible for Tracking: **Steve Piccot**

	Reviewers	Submittal Date	Due Date	Received Date	Comments
	Previous Reviewers of Test/QA Plans				
7 Industry Peer Reviews	**ANR Pipeline Company** Curtis Pederson Ron Sanders **CMS Panhandle Eastern Pipeline Company** Gary Swan **Hanover Compressor Co.** John Snow **Enron Gas Pipeline Group** Michael Terraso James Peterson **C. Lee Cook** Robert Borders **France Compressor Products** James Maholic **A&A Environmental Seals** Harold Johnson **Transwestern Pipeline Group** Jonny Hendricks	----- ----- ----- ----- ----- ----- ----- -----

Future Verifications

- Microturbine CHP Firing Natural Gas and Supplying Hot Water
- Microturbine Using Anaerobic Digester Gas at Dairy Farm
- Microturbine CHP for Desiccant Drying and Space Heating

Thank You.

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