WÄRTSILÄ RENEWABLE GAS/ PUREGAS SOLUTIONS

BIOGAS UPGRADING/ CAPURE TECHNOLOGY

November 19th, 2020

American Biogas Council
Biogas Upgrading Case Studies Webinar

Today's Speakers

Joe Ayala
General Manager

Wärtsilä Puregas North America

George Yavari
Senior Project Manager

Wärtsilä Puregas North America

Fredrik Vigertsson
Service Manager

Wärtsilä Puregas North America

Patrick Serfass (Moderator)
Executive Director

American Biogas Council

Quick Notes

- You should be able to hear me talking now. If you can't, use the questions module to describe your issue.

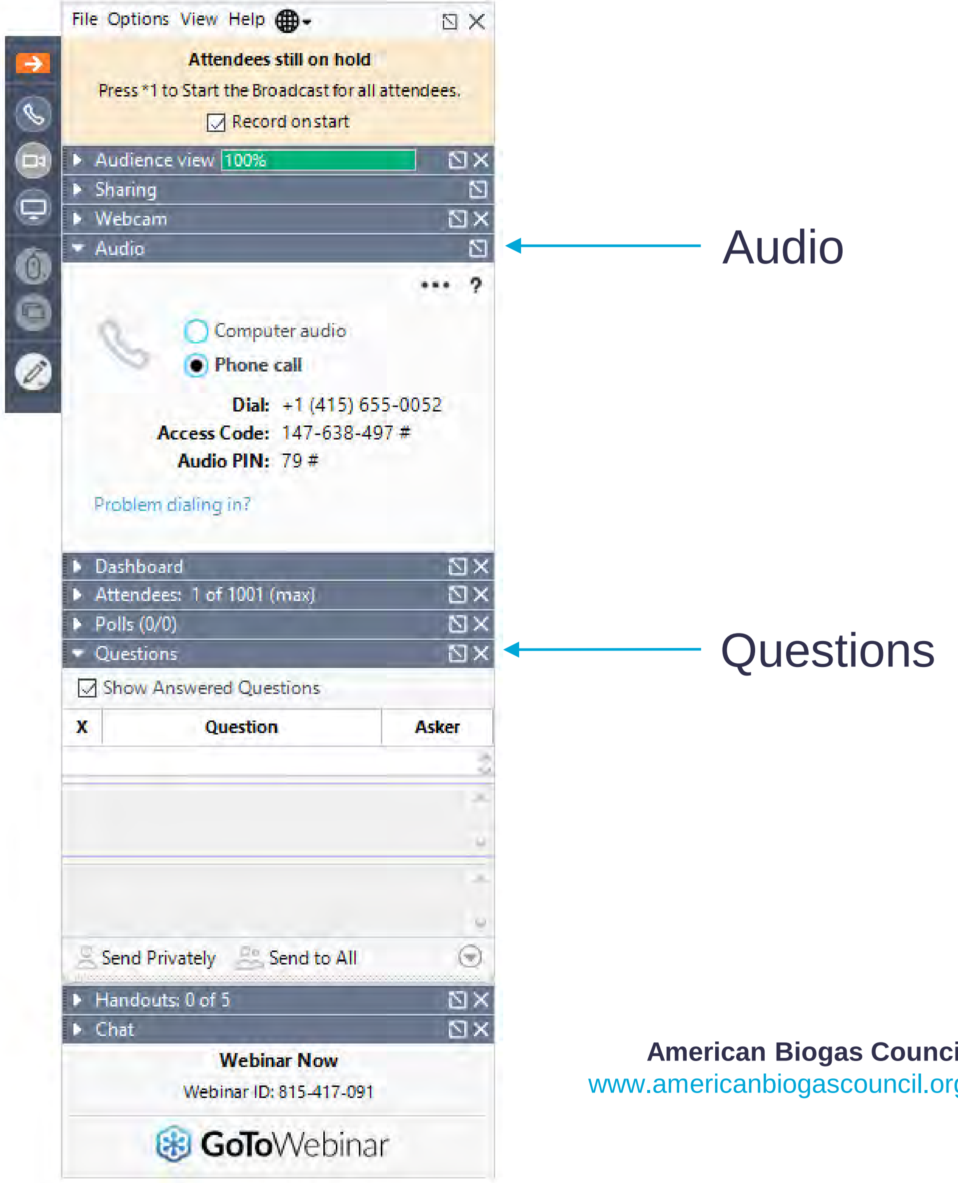
- Two Audio Options: Phone or Computer

  Choose one and connect

- Pro tip: Don't call in on our phone if your audio is set to "Mic and Speakers"

- Ask questions using the Questions Panel on the right side of your screen at any time.

- The recording of the webinar and the slides will be available after the event. We will post them online and send you a link.



American Biogas Council
www.americanbiogascouncil.org

Who we are

The only US organization representing the entire biogas industry

All sectors represented

- Project developers/owners
- Equipment retailers and dealers
- Waste management companies
- Waste water companies
- Farms
- Utilities
- Municipalities
- Consultants and EPCs
- Financiers, accountants, lawyers and engineers
- Non-profits, universities and government agencies

200+ organizations

2,000+ individuals

The US Biogas Market

Current

255 on Farm

1,269 Water

66 Food Scrap

645 at Landfills

Potential

8,300 on Farm

4,000 Wastewater

1,000 Food Scrap

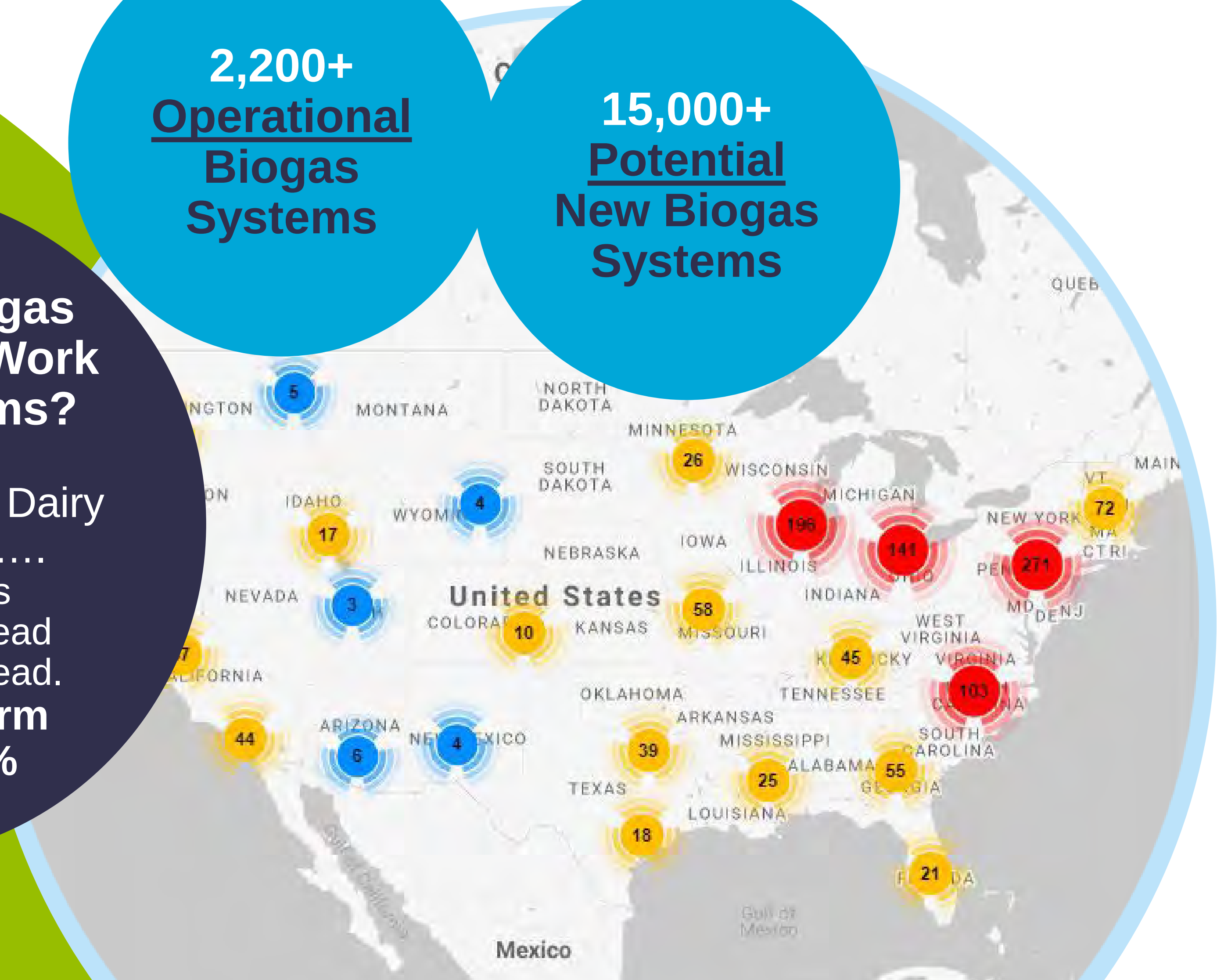
440 at Landfills

Wait, Don't Biogas Systems ONLY Work on LARGE Farms?

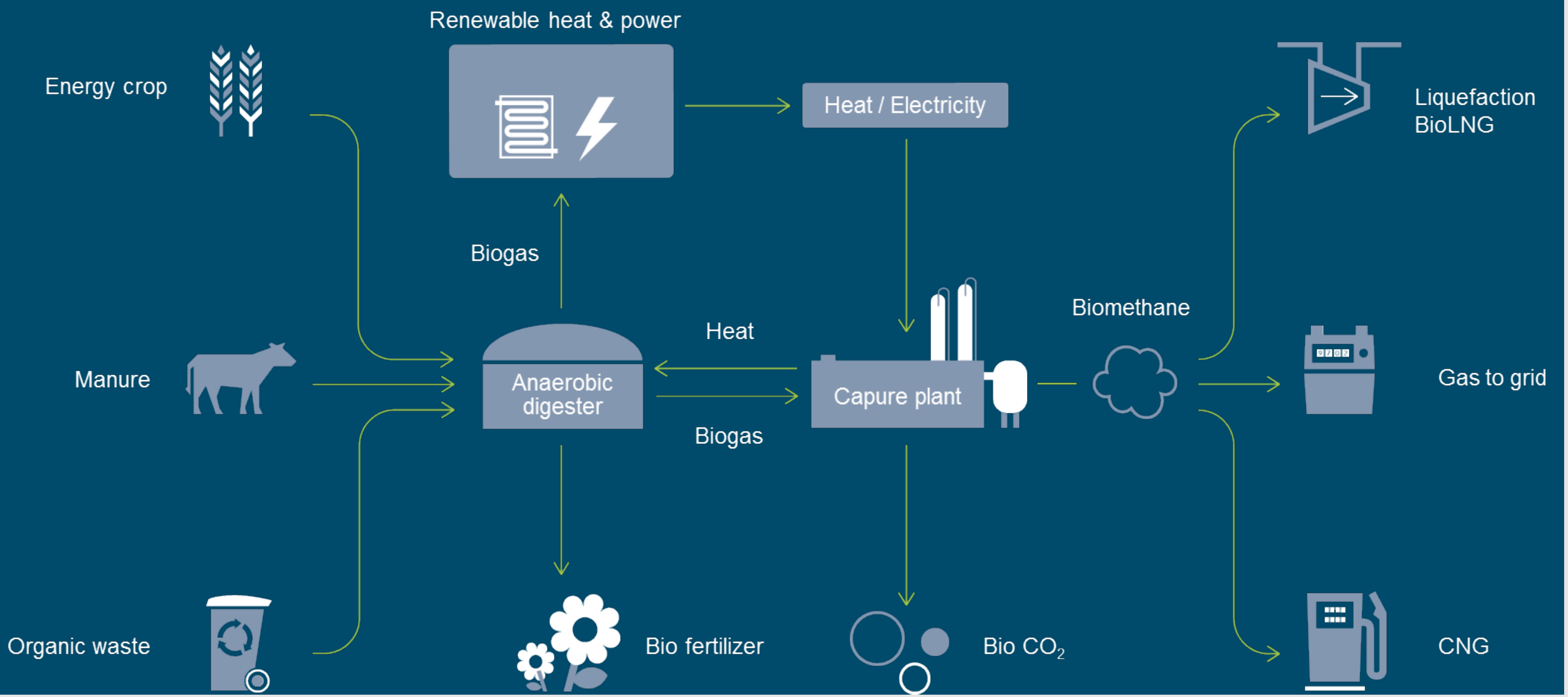
Breaking down 222 Dairy Biogas Systems….
1: > 20,000 cows
6:10,000-20,000 head
16: 5,000-10,000 head.
Total LARGE farm digesters: 10%

2,200+ Operational Biogas Systems

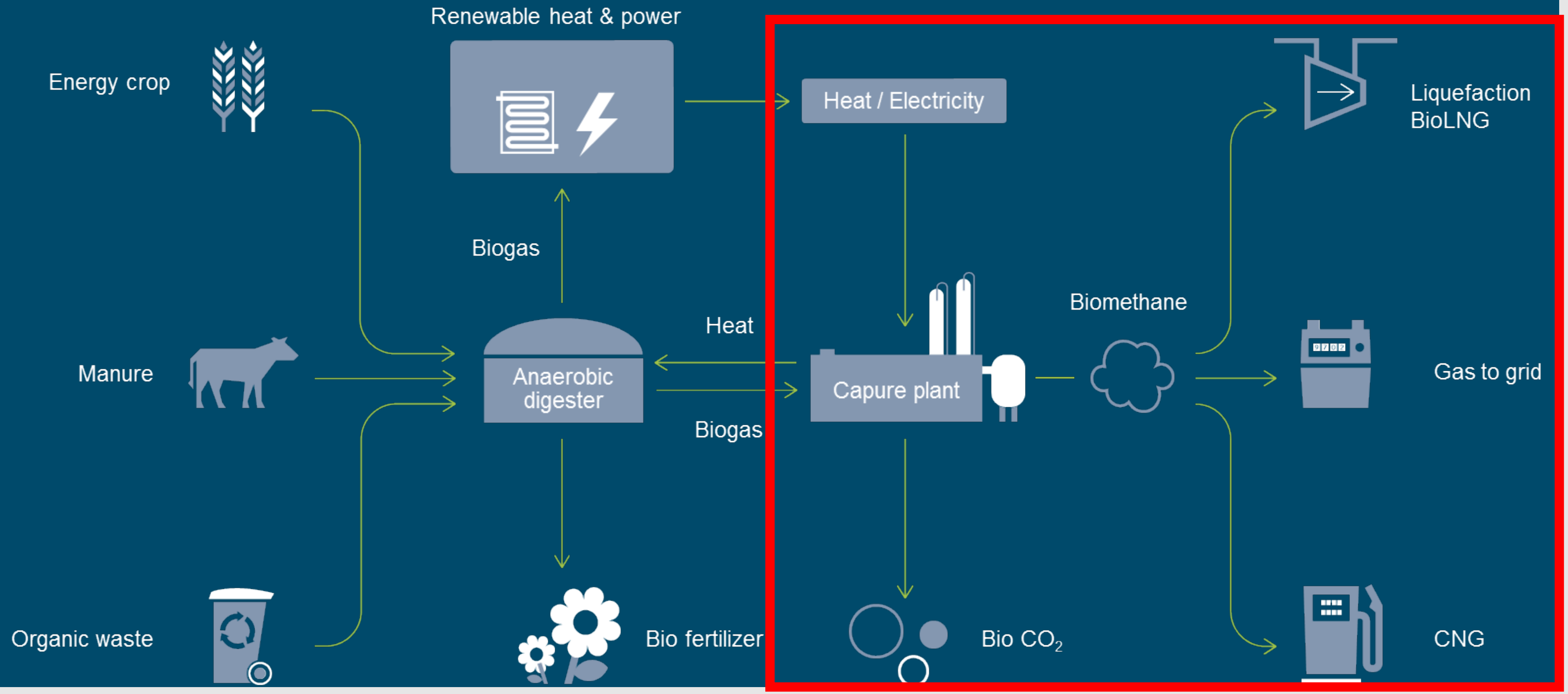
15,000+ Potential New Biogas Systems

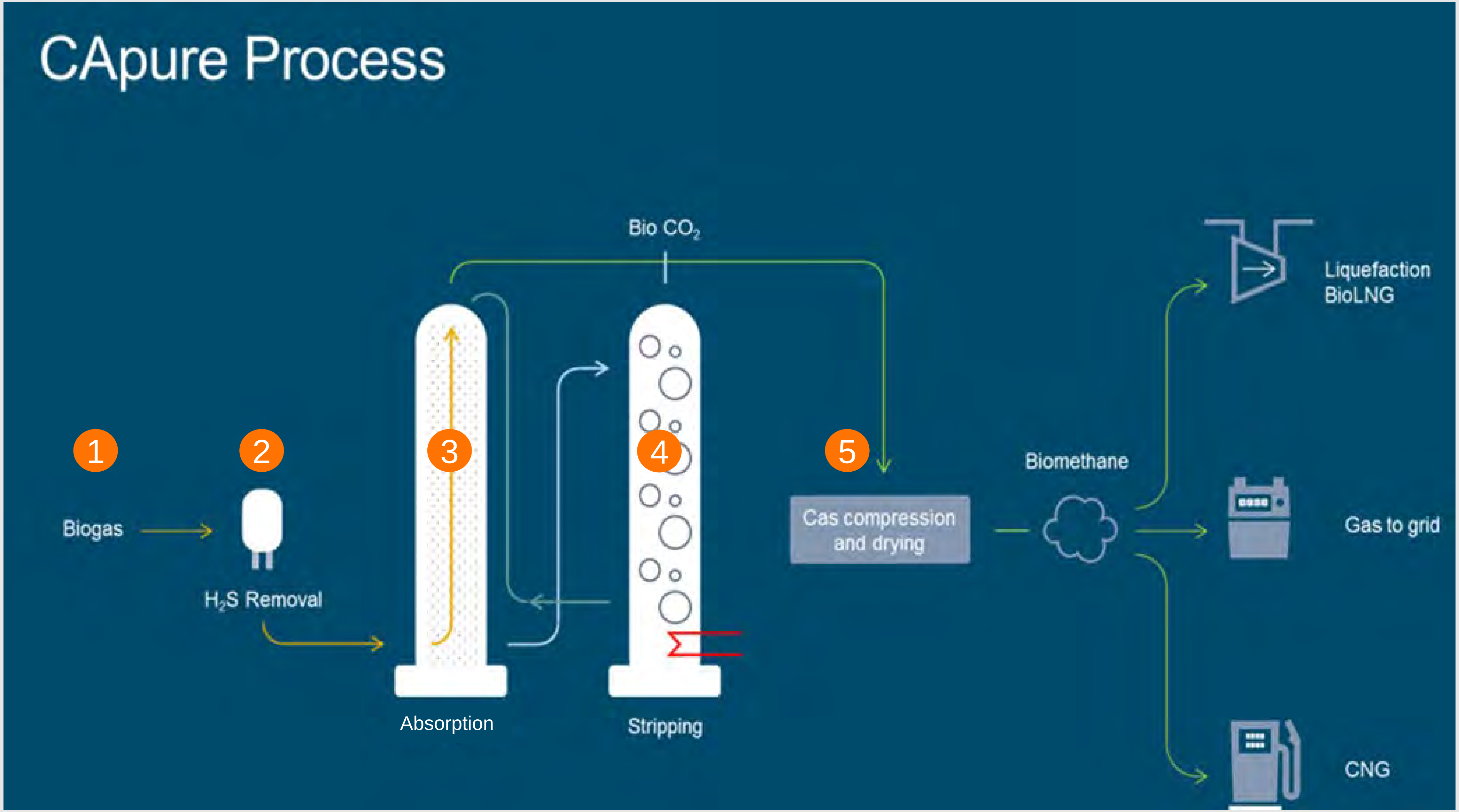


Biogas Process



Biogas Process




CApure Process
Bio CO_2
Liquefaction
BioLNG
1
2
3
4
5
Biomethane
Biogas
Cas compression and drying
Gas to grid
H_2S Removal
Absorption
Stripping
CNG

99.9% of the CH_4 in the biogas can be sold

- Always the highest revenue

CApure Technology

- No affinity for CH_4 / high affinity for CO_2

Best In Class

- No other single technology achieves this efficiency

<0,1% METHANE SLIP

Minimises GHG emissions

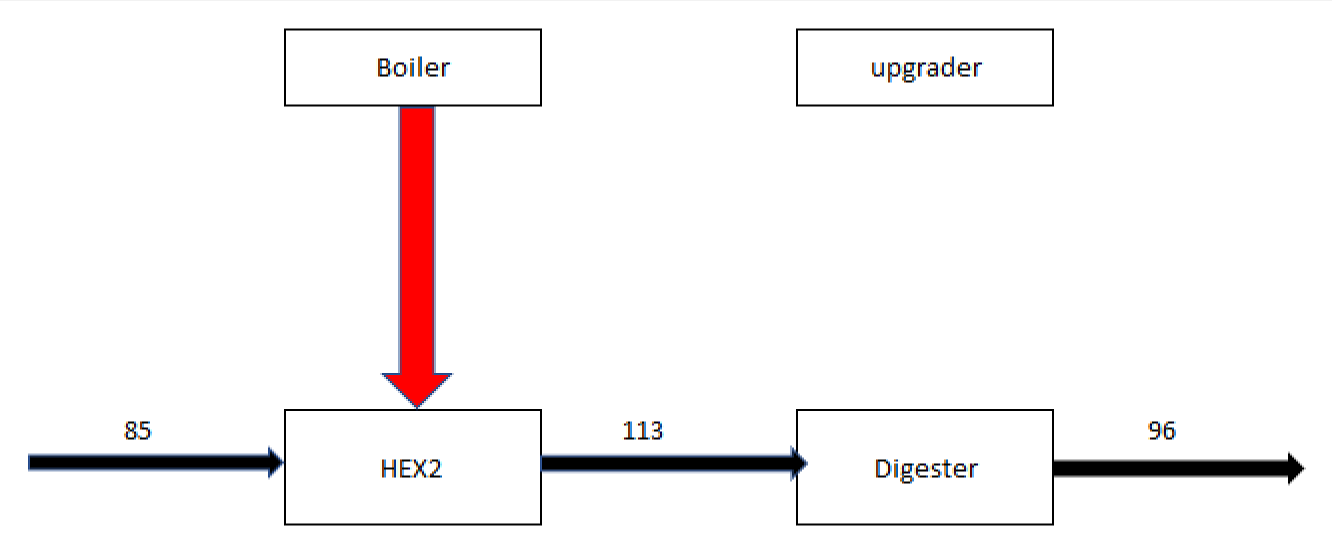
Helps achieve sustainability criteria

CO_2 can be used directly for crop propagation

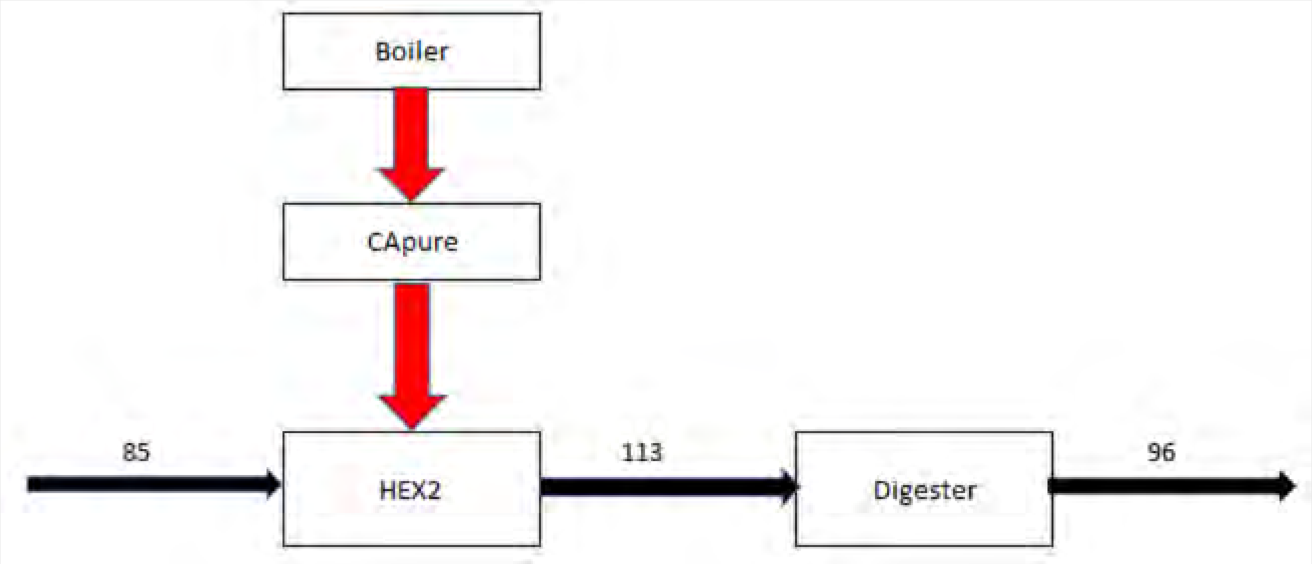
No need for additional exhaust treatment

Easier to recover CO_2 for Food Grade applications

Biogas upgrading without heat integration



Biogas upgrading with heat integration



LOWEST COST OF OWNERSHIP

- < 0.06 kWh/Nm^3 Biogas in electricity consumption
  - CApure process operates at low pressure (only the CH_4 is compressed)
- < 0.1 kWh/Nm^3 Biogas in net heat consumption
  - 95% of the heat used can be recovered
- Low consumption of water and solvents
  - Long life, biodegradable organic solvents used in CApure process are part of a closed-loop system
- Low maintenance cost
  - Robust design, Easy access, 98% uptime guaranteed

Recovered by Wartsila Puregas Solutions unique upgrading process.

Core model	Max Capacity (scfm)
CA30LP	567
CA50LP	800
CA60LP	1521
CA70LP	2276
CA80LP	3780

5 core models - available in 2 versions

- Standard version
- Low pressure version (LP)

HIGHEST BUILD QUALITY AND DESIGN

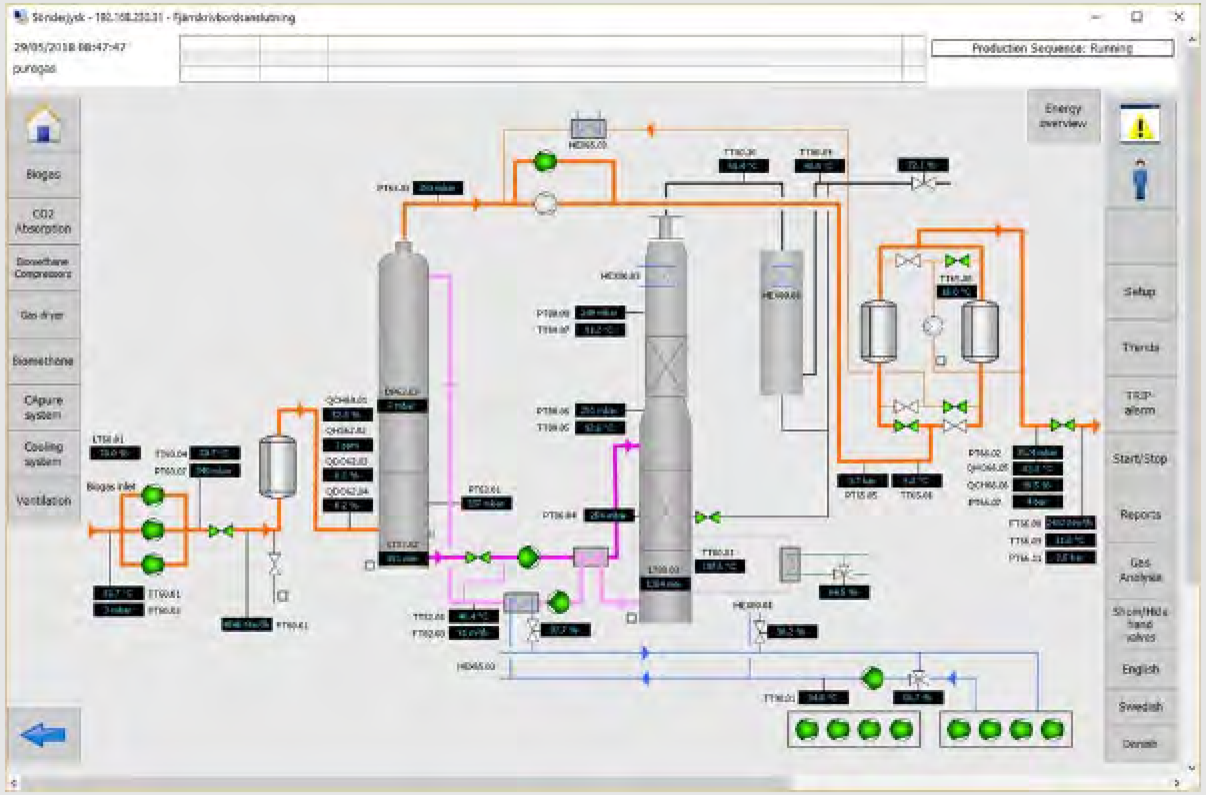
WÄRTSILÄ

- Manufactured and fully tested before delivered to site
- High-Grade Stainless Steel used throughout
- Built-in redundancy of key components such as compressors and blowers
- Easy access for maintenance
- US manufactured in Dubuque, Iowa

CAPURE MANUFACTURING FOOTPRINT

WÄRTSILÄ

- Packages include remote operation, supervision, control, service, maintenance & 24/7 phone support
- Installation, Start-Up, Commissioning and Operator Training included as standard
- Extended warranty packages available
- Remote monitoring and call out available
- 98% uptime guarantee - further improved through optimisation program



- Over 40 operational sites
- Sites in USA, Sweden, UK, Denmark, Germany, Norway, Ireland, Switzerland
- Two new installations in US in 2019/2020
- Range of substrates including food waste, agricultural residues, green crops, WWTP

1. Borås, SWE, 2002, 450 Nm³/h, co-digestion **) FW, MSW
2. Göteborg, SWE, 2006, 1600 Nm³/h, WWTP *)
3. Kalmar, SWE, 2008, 200 Nm³/h, co-digestion **) FW
4. Falkenberg, SWE, 2009, 750 Nm³ h, co-digestion *) FW
5. Stockholm, SWE, 2009, 800 Nm³/h, co-digestion **) FW
6. Stavanger, NOR, 2009, 500 Nm³ /h, co-digestion *) FW
7. Könnern, DEU, 2009, 3400 Nm³/h, green crops *)
8. Oslo, NOR, 2010, 750 Nm³/h, WWTP **)
9. Karlstad, SWE, 2010, 200 Nm³/, WWTP **)
10.Linköping, SWE, 2010, 3400 Nm³/h, co-digestion **) FW, MSW
10. Sävsjö, SWE, 2012, 600 Nm³/h, manure co-digestion **) FW
11. Freiburg, DEU, 2012, 1000 Nm³/h, green crops *
12.Växjö, SWE, 2012, 500 Nm³/h, WWTP **) FW, MSW
13. Weissenborn, DEU 2013, 700 Nm³/h, green crops *)
14. Zürich, CHE, 2013, 1400 Nm3/h, WWTP *) MSW
15. Karlskoga, SWE, 2014, 900 Nm3/h **) FW, MSW
16. Crouchland, GBR, 2014, 2000 Nm3/h *)
17. Kalmar, SWE, 2014, 600 Nm3/h **) FW, MSW
18. Hemmet, DNK, 2015, 900 Nm3/h *)
19. Glenmore, IRL, 2016, 1800 Nm3/h
20. Lindum, NOR, 2015, 600 Nm3/h **) FW
21. Buchan, GBR, 2015, 1250 Nm3/h *)
22. Riverside, GBR, 2015, 2.000 Nm3/h *)
23. Biokraft, NOR, 2017, 2200 Nm3/h with liquefaction **) FW
24. Rybjerg, DNK, Membrane plant, 2016,
25. Grøn Gas Vraa, DNK, 2016, 3000 Nm³/h
26. Sønderjysk, DNK, 2016, 5000 Nm³/h
27. Somerset, GBR, 2016, 1250 Nm³/h
28. Willand, GBR, 2016, 1250 Nm³/h
29. Granville, GBR, 2016, 3000 Nm³/h
30. Ekogas, SWE, 2017, 700 Nm³/h
31. Korskro, DNK, 2018, 5000 Nm³/h
32. Högbytorp, SWE, 2018, 2000 Nm³/h
33. Holsted, DNK, 2019, 3000 Nm³/h
34. Tekniska verken Linköping, LBG, SWE, 2019,
35. Bånlev, DNK, 2019, 3000 Nm³/h
36. GreenLab Skive Biogas, DNK, 2019, 5000 Nm³/h
37. VEAS, NOR, 2020, 2000 Nm³/h
38. Thorsö, DNK, 2020, 2000 Nm³/h
39. Three Mile Canyon Farms, USA, 2019, 6000 Nm³/h
40. Sønderjysk, DNK, 2020, 6000 Nm³/h
41. Junction City Expansion, USA 2020, 6000 Nm³/h

*) Grid injection to natural gas grid,

**) Vehicle fuel filling station or local bio methane grid

Food waste FW, Municipal solid waste MSW

The amine advantage

George Yavari

WHY AMINE?

- Amine has been used since the 1960s by the oil and gas industry for processing and sweetening of natural gas.
- More recently small-scale versions have been developed for the removal of CO_2 from biogas and CO_2 removal (carbon capture) from flu gas.
- Amine is the most energy efficient media for CO2 removal providing the highest CH4 recovery, the highest CH4 purity and the lowest OPEX
- The use of Amine reduces the methane slip to less than 0.1% which is more than a 500% reduction compared to other technologies
- Methane is a harmful GHG - approx 28 times more harmful than CO2. Thereby biogas upgrading by Amine emits much less GHG than other upgrading technologies

Gas Sweetening Plant

IS AMINE DANGEROUS OR POLLUTING?

- Dimethylamine is a BIODEGRADABLE organic solvent with the formula $(CH_3)_2NH$
- A Puregas CA50 will be filled with only 1.8 m^3 of amine and 1.8 m^3 of water
- The solution is in a CLOSED-LOOP SYSTEM and the amine is recycled back into the process. None is consumed in the upgrading process.
- In biogas upgrading plants, handling of the amine needs to follow the same precautions as other liquids such as compressor oils, glycol, condensate etc i.e. wear protective gloves/protective clothing/eye protection etc. Avoid breathing dust/fume/gas/mist/vapours/spray.

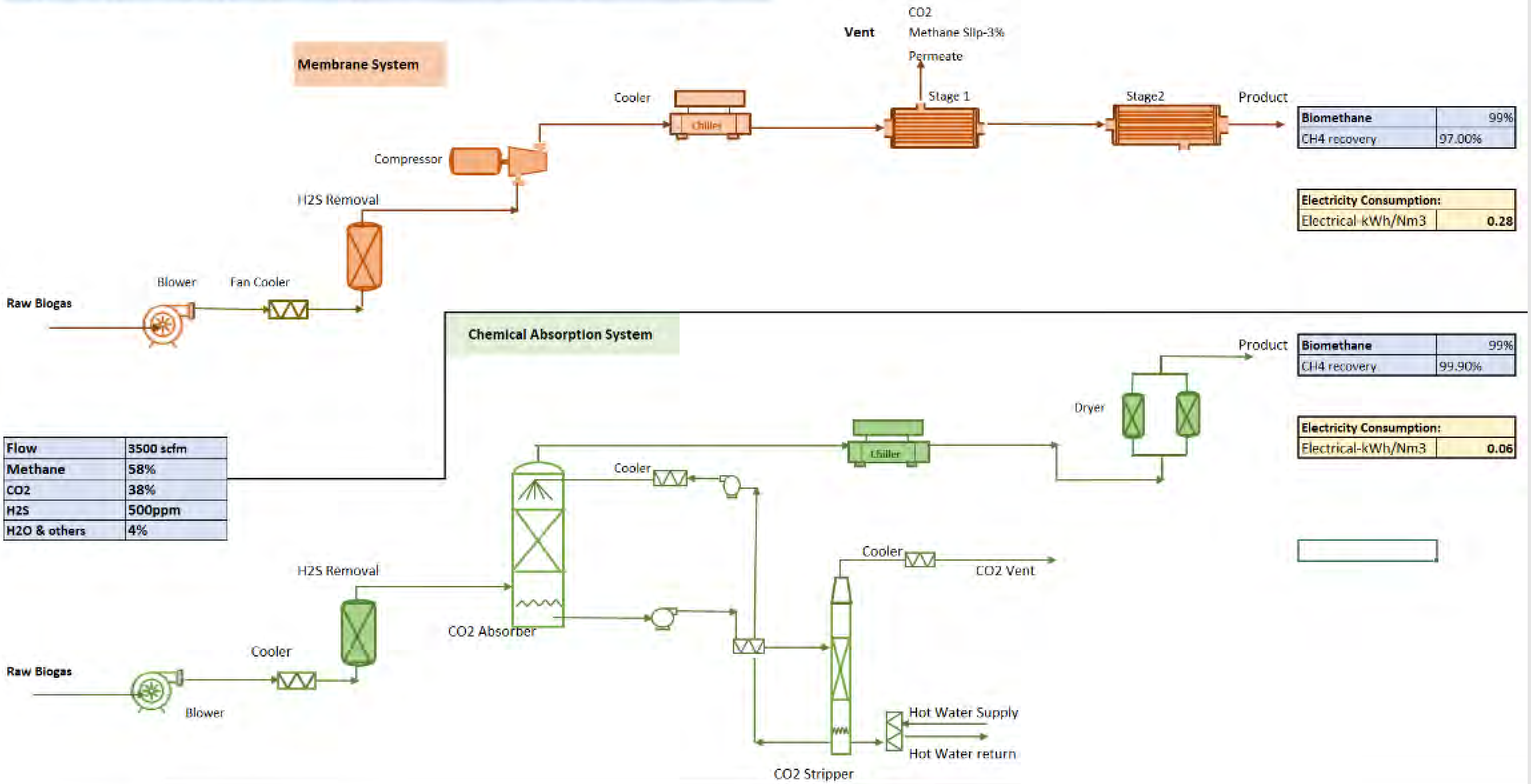
PUREGAS CA Upgrading Plant

How does amine process compare with other upgrading technologies?

Parameters	Amine process	Membrane	Water scrubbers	PSA
Technology -process steps		Pre-treatment needed: VOCs and siloxanes are removed before the membranes		Pre-treatment needed: H_2S & VOC removal + Gas cooler/Chiller
Performance values (electricity consumption)	0,06 kWh/Nm3	0,28 kWh/Nm3 (3-stage)	0,25 kWh/Nm3 (have not met the performance tests on 0,21)	0,3 kWh/Nm3
Operational conditions	Higher temperature than others = The hot streams allow heat integration & heating of substrates.	Low temperatures (excess heat cannot be utilised without a heat pump)	Microbiological growth in the water – capacity decrease & cleaning (fatty substrates) Low Temp (see previous)	Swinging is managed with buffertanks (continuous process) Low Temp (see previous)
Methane slip	<0.1% of inlet CH_4	<2,5% of inlet CH_4	<5% of inlet CH_4	<4% of inlet CH_4
Product quality (remaining CO_2)	<1 vol% CO_2 in product	~1 vol% CO_2 in product (3-stage), 1-stage has higher CO_2 in produc	~2 vol% CO_2 in product	~2 vol% CO_2 in product
Health, environment, safety (HSE): Raw gas impurities are removed in each technology but by different means and the sidestreams need to be treated differently	Solvent: amine Leakages to environment are minimised with process safety Amine traces go out only with off-gas (<150 micrograms/Nm3 CO_2)	A dry system Gas cooler with chiller as pretreatment collecting the impurities (water, VOC, impurities) & AC (VOC, H_2S)	Water treatment – impurities end up in water streams	Gas-cooler will knock-out water and VOC Traces of VOC in the offgas
Utilities & efficiency (cooling water consumption) – heat integration reduces the total low energy consumption for the upgrading)	Efficient heat integration possible and with heat integration no cooling water needed Less water consumption	No water consumption but high electrical consumption	Water consumption and high electrical consumption	No water consumption but high electrical consumption
CAPEX & foot print (large plants, >500 Nm3/h)	Amine CAPEX attractive, less footprint	Higher footprint and CAPEX	Same footprint as amine	Higher footprint
CAPEX & foot print (small plants, < 500 Nm3/h)	Higher footprint and CAPEX	Lower footprint and CAPEX	1000-2500 Nm3/h mid range	1000-2500 Nm3/h mid range

Electricity Consumption Comparison

Comparison of typical Biogas upgrading plant using Membrane and Chemical absorption technology



Membrane System

Biomethane	99%
CH4 recovery	97.00%

Electricity Consumption:	
Electrical-kWh/Nm3	0.28

Chemical Absorption System

Biomethane	99%
CH4 recovery	99.90%

Electricity Consumption:	
Electrical-kWh/Nm3	0.06

Raw Biogas

Flow	3500 scfm
Methane	58%
CO2	38%
H2S	500ppm
H2O & others	4%

Electricity Yearly Consumption

Basis: 3500 scfm of inlet raw biogas flow
Using membrane system increase the electricity cost by 1,260,000 dollars /year.

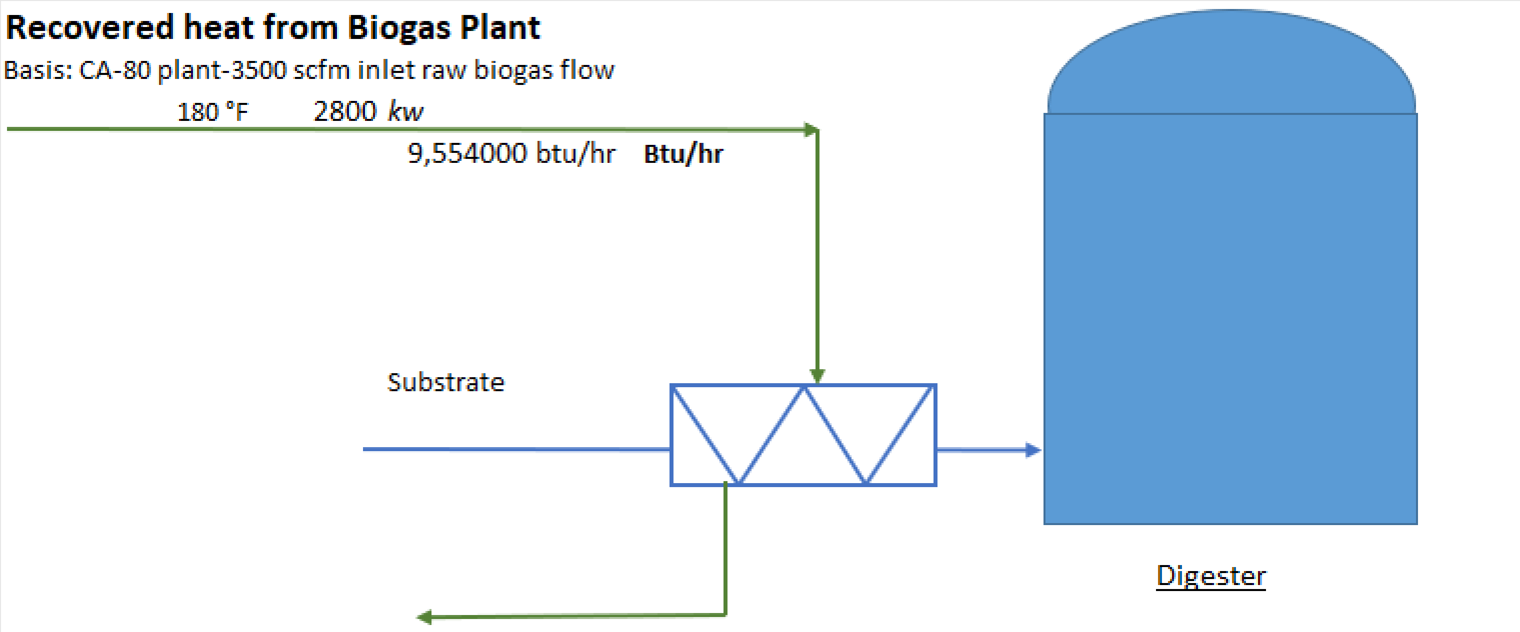
Chemical Absorption	0.06	kwh/Nm3
Membrane	0.28	kwh/Nm3
Difference	0.22	kwh/Nm3
Yearly Electricity usage difference	12,578,834	kw/year
Electricity cost	0.10	dollar / kwh
Total Energy Cost Difference	1,257,883.40	dollars / year

Methane Recovery and Revenue Comparison

Basis: 3500 scfm of inlet raw biogas

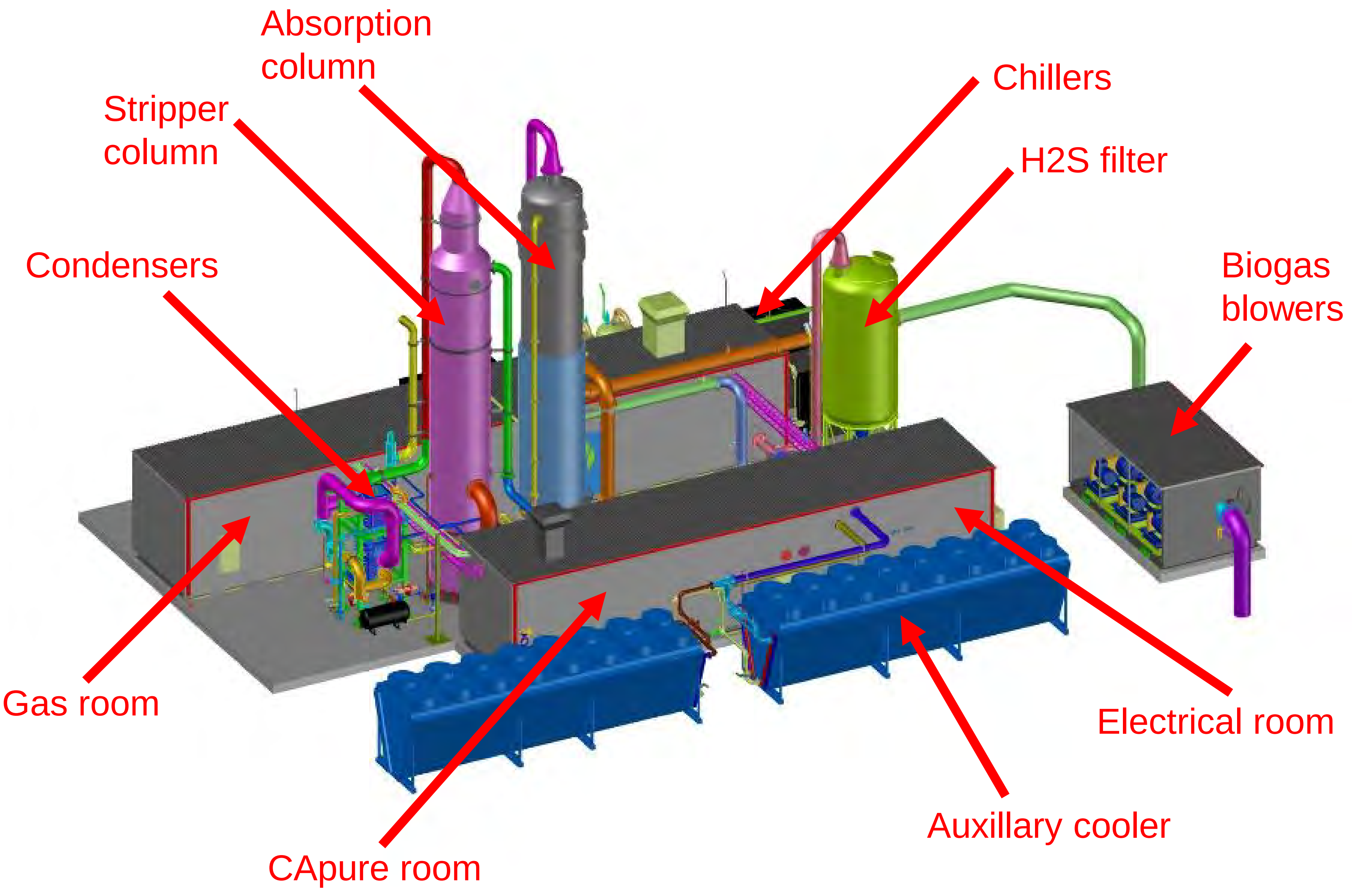
	Methane Recovery	Product biomethane in scfm	Product gas Caloric value btu/ft3	Production Million btu / year
CApure amine process	99.90%	2028	1000	1,065,901
Membrane System	97.0%	1969	1000	1,034,959
Difference	2.90%	59		33,942
Biomethane price	$35 per million btu			
More Revenue in a Year By utilizing Wartsila Puregas CApure amine process technology				$ 1,082,972.52

Integration of heat recovered from biogas upgrader into the digestion process



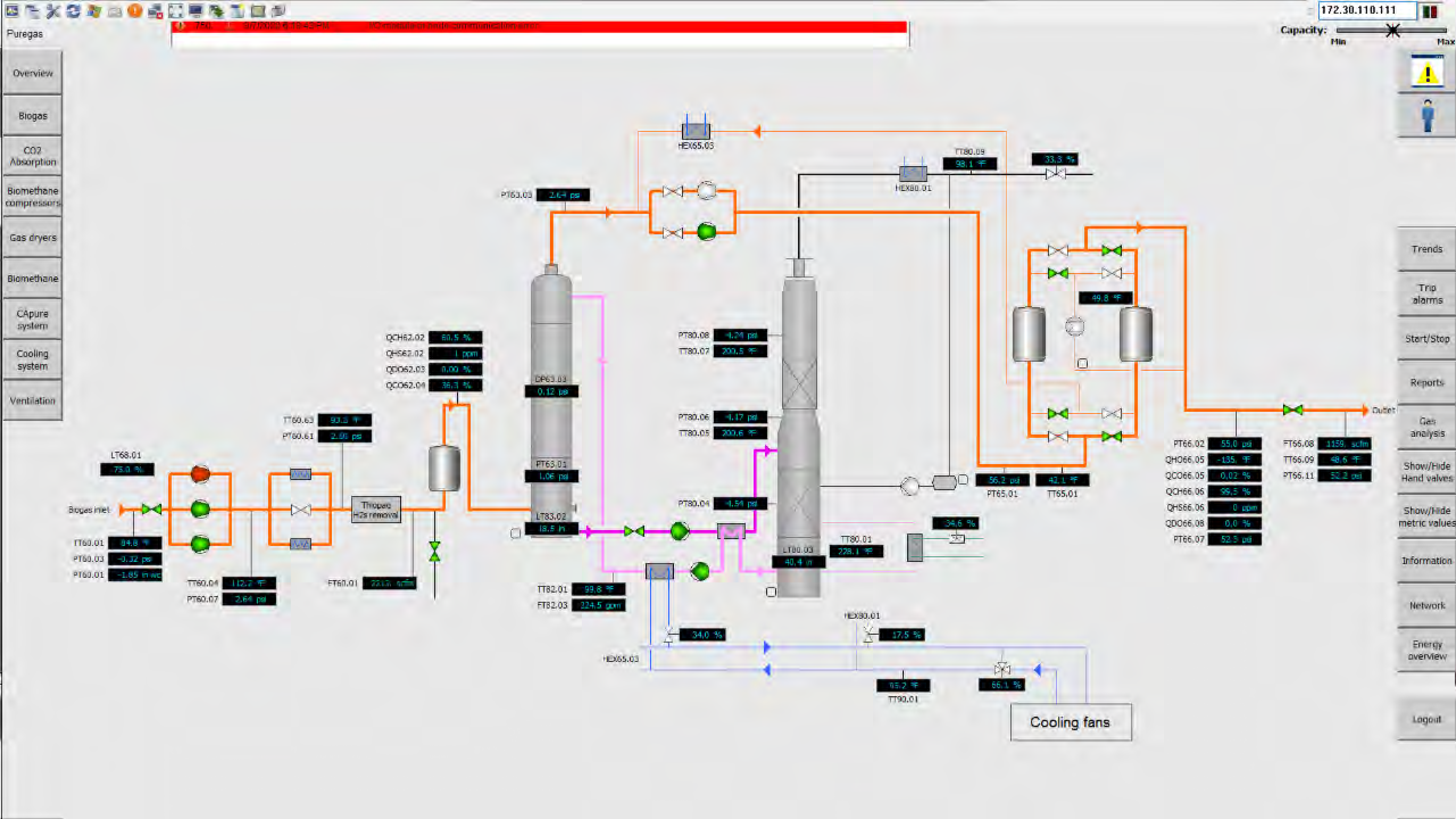
Operation & Automation

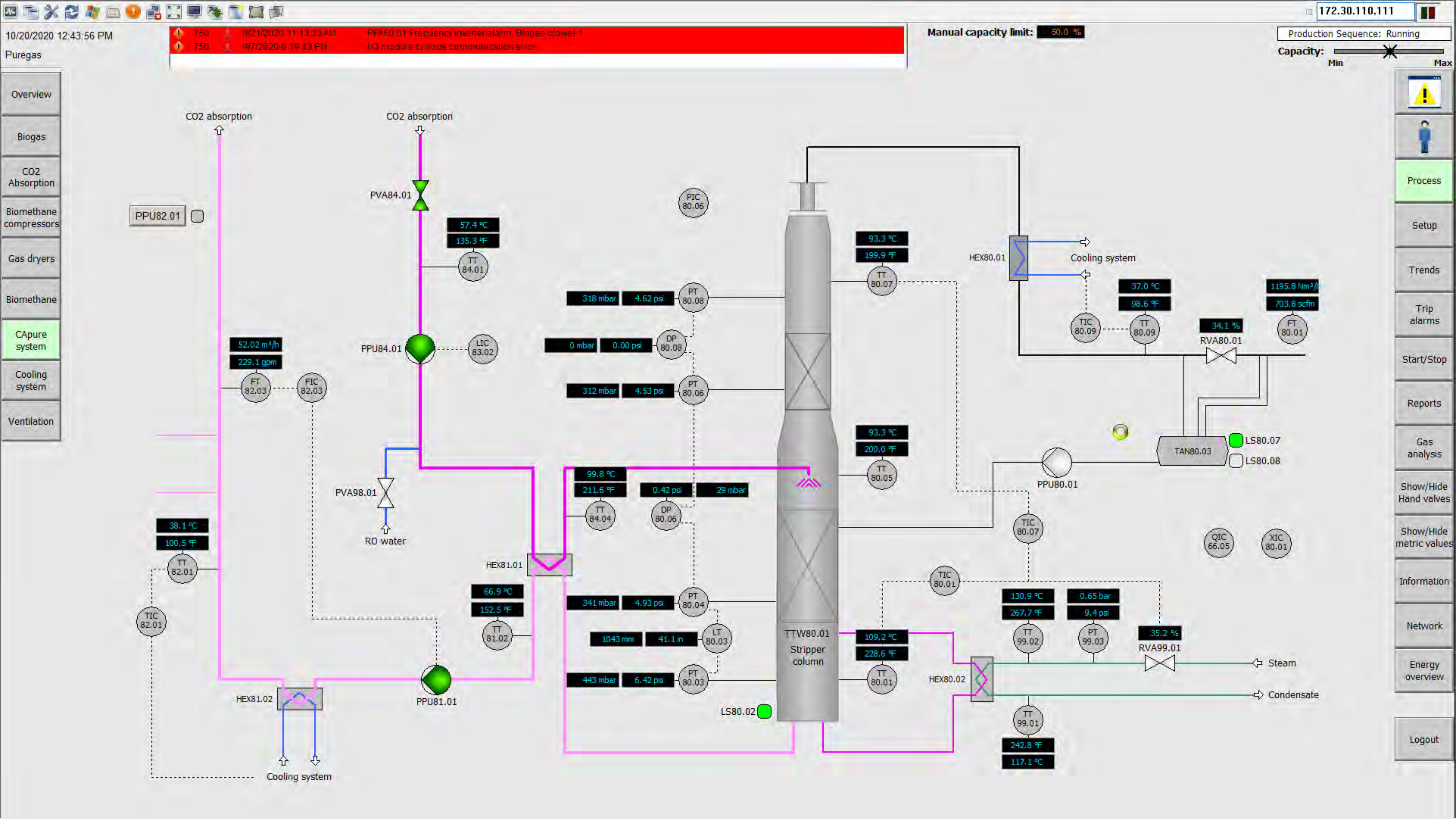
Fredrik Vigertsson


Absorption column
Stripper column
Chillers
H2S filter
Condensers
Biogas blowers
Gas room
Electrical room
Auxillary cooler
CApure room

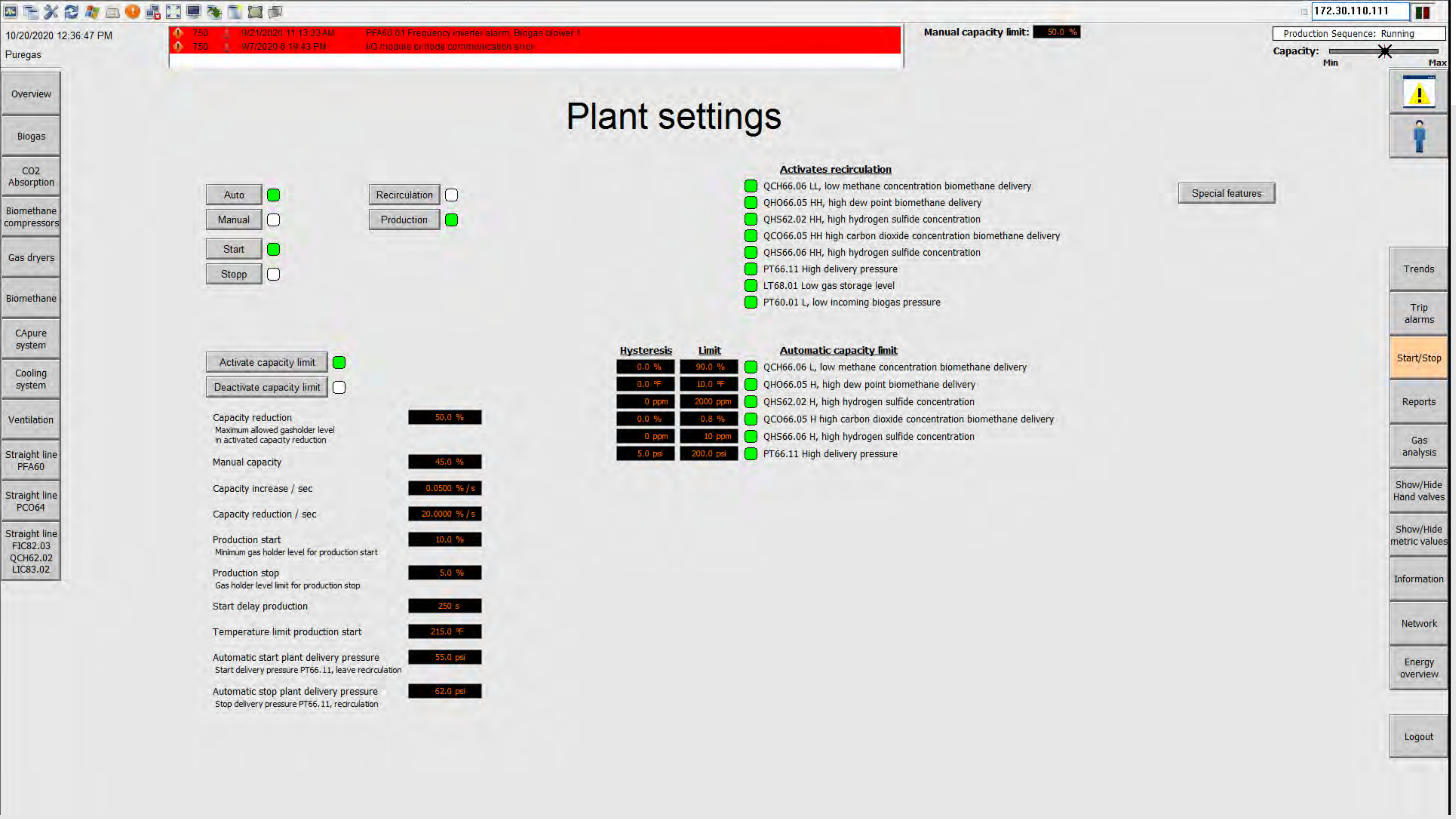
Uptime and Reliability

- Facility is going through a Factory Acceptance Test before being shipped to site
- Well tested PLC program with a long history
- All analog signals are trended
- Easy to use HMI panel with user friendly interface
- 24/7 helpdesk with online support with a skilled Wärtsilä engineer receiving the calls

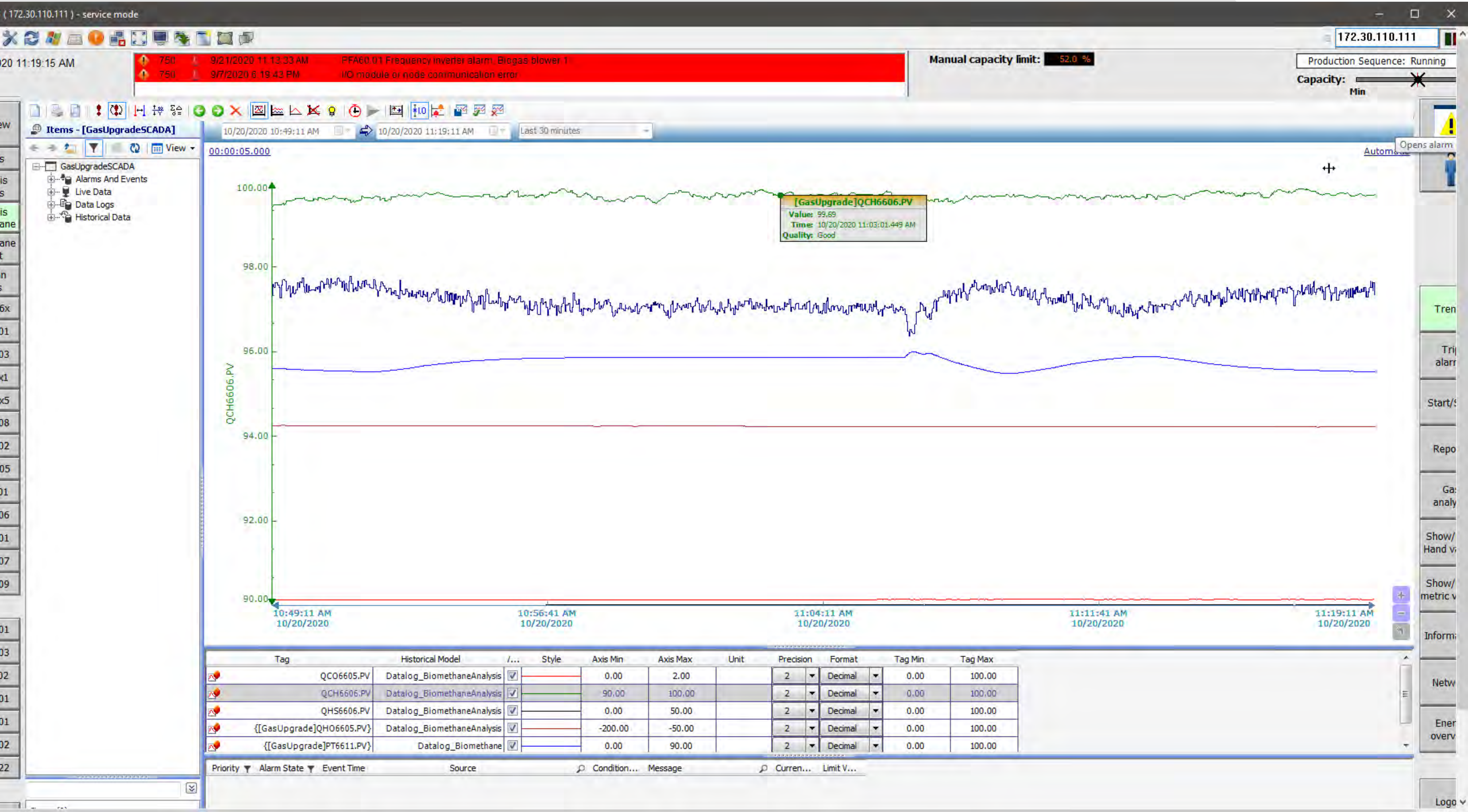

Puregas
172.30.110.111
Capacity:
Min
Max
Overview
Biogas
CO2 Absorption
Biomethane compressors
Gas dryers
Biomethane
CApure system
Cooling system
Ventilation
Trends
Trip alarms
Start/Stop
Reports
Gas analysis
Show/Hide Hand valves
Show/Hide metric values
Information
Network
Energy overview
Logout
Biogas inlet
Thiopaq H2S removal
HEX65.03
HEX80.01
HEX90.01
Outlet
Cooling fans
LT68.01
TT60.01
PT60.03
PT60.01
TT60.04
PT60.07
TT60.63
PT60.61
FT60.01
QCH62.02
QHS62.02
QDO62.03
QCO62.04
PT63.03
DP63.03
PT63.01
LT83.02
TT82.01
FT82.03
PT80.08
TT80.07
PT80.06
TT80.05
PT80.04
LT80.03
TT80.01
TT80.09
PT65.01
TT65.01
PT66.02
QHO66.05
QCO66.05
QCH66.06
QHS66.06
QDO66.08
PT66.07
FT66.08
TT66.09
PT66.11
TT90.01



172.30.110.111
10/20/2020 12:43:56 PM
Puregas
750 9/21/2020 11:13:33 AM PFA60.01 Frequency inverter alarm, Biogas blower 1
750 9/7/2020 6:19:43 PM I/O module or node communication error
Manual capacity limit: 50.0 %
Production Sequence: Running
Capacity:
Min
Max
Overview
Biogas
CO2 Absorption
Biomethane compressors
Gas dryers
Biomethane
CApure system
Cooling system
Ventilation
Process
Setup
Trends
Trip alarms
Start/Stop
Reports
Gas analysis
Show/Hide Hand valves
Show/Hide metric values
Information
Network
Energy overview
Logout
CO2 absorption
CO2 absorption
PPU82.01
PVA84.01
57.4 °C
135.3 °F
TT 84.01
PIC 80.06
318 mbar
4.62 psi
PT 80.08
0 mbar
0.00 psi
DP 80.08
312 mbar
4.53 psi
PT 80.06
93.3 °C
199.9 °F
TT 80.07
HEX80.01
Cooling system
37.0 °C
98.6 °F
TIC 80.09
TT 80.09
34.1 %
RVA80.01
1195.8 Nm³/h
703.8 scfm
FT 80.01
52.02 m³/h
229.1 gpm
FT 82.03
FIC 82.03
PPU84.01
LIC 83.02
PVA98.01
RO water
99.8 °C
211.6 °F
TT 84.04
0.42 psi
29 mbar
DP 80.06
93.3 °C
200.0 °F
TT 80.05
PPU80.01
TAN80.03
LS80.07
LS80.08
TIC 80.07
QIC 66.05
XIC 80.01
38.1 °C
100.5 °F
TT 82.01
TIC 82.01
HEX81.01
66.9 °C
152.5 °F
TT 81.02
341 mbar
4.93 psi
PT 80.04
1043 mm
41.1 in
LT 80.03
443 mbar
6.42 psi
PT 80.03
TTW80.01
Stripper column
109.2 °C
228.6 °F
TT 80.01
TIC 80.01
130.9 °C
267.7 °F
TT 99.02
0.65 bar
9.4 psi
PT 99.03
35.2 %
RVA99.01
HEX80.02
Steam
Condensate
TT 99.01
242.8 °F
117.1 °C
HEX81.02
PPU81.01
LS80.02
Cooling system



10/20/2020 12:36:47 PM
Puregas
750 9/21/2020 11:13:33 AM PFA60.01 Frequency inverter alarm, Biogas blower 1
750 9/7/2020 6:19:43 PM I/O module or node communication error
Manual capacity limit: 50.0 %
172.30.110.111
Production Sequence: Running
Capacity:
Min
Max
Overview
Biogas
CO2 Absorption
Biomethane compressors
Gas dryers
Biomethane
CApure system
Cooling system
Ventilation
Straight line PFA60
Straight line PCO64
Straight line FIC82.03 QCH62.02 LIC83.02
Plant settings
Auto
Manual
Start
Stopp
Recirculation
Production
Activates recirculation
QCH66.06 LL, low methane concentration biomethane delivery
QHO66.05 HH, high dew point biomethane delivery
QHS62.02 HH, high hydrogen sulfide concentration
QCO66.05 HH high carbon dioxide concentration biomethane delivery
QHS66.06 HH, high hydrogen sulfide concentration
PT66.11 High delivery pressure
LT68.01 Low gas storage level
PT60.01 L, low incoming biogas pressure
Special features
Activate capacity limit
Deactivate capacity limit
Capacity reduction 50.0 %
Maximum allowed gasholder level in activated capacity reduction
Manual capacity 45.0 %
Capacity increase / sec 0.0500 % / s
Capacity reduction / sec 20.0000 % / s
Production start 10.0 %
Minimum gas holder level for production start
Production stop 5.0 %
Gas holder level limit for production stop
Start delay production 250 s
Temperature limit production start 215.0 °F
Automatic start plant delivery pressure 55.0 psi
Start delivery pressure PT66.11, leave recirculation
Automatic stop plant delivery pressure 62.0 psi
Stop delivery pressure PT66.11, recirculation
Hysteresis
Limit
Automatic capacity limit
0.0 % 90.0 % QCH66.06 L, low methane concentration biomethane delivery
0.0 °F 10.0 °F QHO66.05 H, high dew point biomethane delivery
0 ppm 2000 ppm QHS62.02 H, high hydrogen sulfide concentration
0.0 % 0.8 % QCO66.05 H high carbon dioxide concentration biomethane delivery
0 ppm 10 ppm QHS66.06 H, high hydrogen sulfide concentration
5.0 psi 200.0 psi PT66.11 High delivery pressure
Trends
Trip alarms
Start/Stop
Reports
Gas analysis
Show/Hide Hand valves
Show/Hide metric values
Information
Network
Energy overview
Logout



(172.30.110.111) - service mode
172.30.110.111
20 11:19:15 AM
750 9/21/2020 11:13:33 AM PFA60.01 Frequency inverter alarm, Biogas blower 1
750 9/7/2020 6:19:43 PM I/O module or node communication error
Manual capacity limit: 52.0 %
Production Sequence: Running
Capacity:
Min
Items - [GasUpgradeSCADA]
View
GasUpgradeSCADA
Alarms And Events
Live Data
Data Logs
Historical Data
10/20/2020 10:49:11 AM
10/20/2020 11:19:11 AM
Last 30 minutes
00:00:05.000
Opens alarm
[GasUpgrade]QCH6606.PV
Value: 99.69
Time: 10/20/2020 11:03:01.449 AM
Quality: Good
100.00
98.00
96.00
94.00
92.00
90.00
QCH6606.PV
10:49:11 AM 10/20/2020
10:56:41 AM 10/20/2020
11:04:11 AM 10/20/2020
11:11:41 AM 10/20/2020
11:19:11 AM 10/20/2020
Tag | Historical Model | Style | Axis Min | Axis Max | Unit | Precision | Format | Tag Min | Tag Max
QCO6605.PV | Datalog_BiomethaneAnalysis | 0.00 | 2.00 | 2 | Decimal | 0.00 | 100.00
QCH6606.PV | Datalog_BiomethaneAnalysis | 90.00 | 100.00 | 2 | Decimal | 0.00 | 100.00
QHS6606.PV | Datalog_BiomethaneAnalysis | 0.00 | 50.00 | 2 | Decimal | 0.00 | 100.00
{[GasUpgrade]QHO6605.PV} | Datalog_BiomethaneAnalysis | -200.00 | -50.00 | 2 | Decimal | 0.00 | 100.00
{[GasUpgrade]PT6611.PV} | Datalog_Biomethane | 0.00 | 90.00 | 2 | Decimal | 0.00 | 100.00
Priority | Alarm State | Event Time | Source | Condition... | Message | Curren... | Limit V...
Tren
Trip alarm
Start/
Repo
Gas analy
Show/ Hand v
Show/ metric v
Inform
Netw
Ener overv
Logo

Case Studies

Fredrik Vigertsson

More Biogas – Kalmar, Sweden

- 750 Nm^3/h raw biogas (65% methane)
- 99.95% methane efficiency
- 30,000 tons pa of food waste, manure and crop residues
- Heat supplied from biomass boiler
- Two high pressure compressors, each compress the biomethane to 250 Barg
- Four trailer filling stations
- Local CNG fueling

Karlskoga Biogas – Sweden

- 900 Nm^3/h raw biogas (65% methane)
- Food and agricultural waste
- 10% landfill gas with 45% methane added
- Two high pressure compressors, each compress the biomethane to 250 Barg
- 10 trailer filling stations
- Local CNG fueling

Riverside Biogas – Glenfiddich Distillery

- 2000 Nm^3/h biogas from spent malt.
- 99.9% methane efficiency
- Heat supplied from CHP
- Back up biogas boiler.
- Injects 1,200 Nm^3/h biomethane direct to the gas grid
- Propane enrichment and gas network entry facility.

Buchan Biogas – Peterhead (SGN)

- 1200 Nm³/h biogas from agricultural waste
- 99.9% methane efficiency
- Heat supplied from biogas boiler
- Injects 720 Nm³/h biomethane direct to the gas grid
- Propane enrichment and gas network entry facility.

Biogas Zurich, Switzerland

- Wastewater treatment facility
- 1400 Nm^3/h biogas from sewage sludge
- Heat supplied from biogas boiler
- Injects 840Nm^3/h biomethane direct to the gas grid
- Propane enrichment and gas network entry facility.

Sønderjysk Biogas, Denmark

- 5,000 Nm^3/h biogas from agricultural waste
- 540,000 tons of manure, straw and agricultural residues
- Injects c. 2,000 Nm^3/h biomethane to the gas grid
- Produces enough energy to heat 15,000 homes or fuel 570 city busses.

Castle Eaton Farm, UK

- 750 Nm^3/h biogas from agricultural waste
- 99.9% methane efficiency
- Chopped straw & agricultural residues
- Virtual Pipeline
- Biomethane injected to the gas grid at high pressure.
- Multiple sites feed into the same injection point.

Three Mile Canyon Farms, Oregon USA



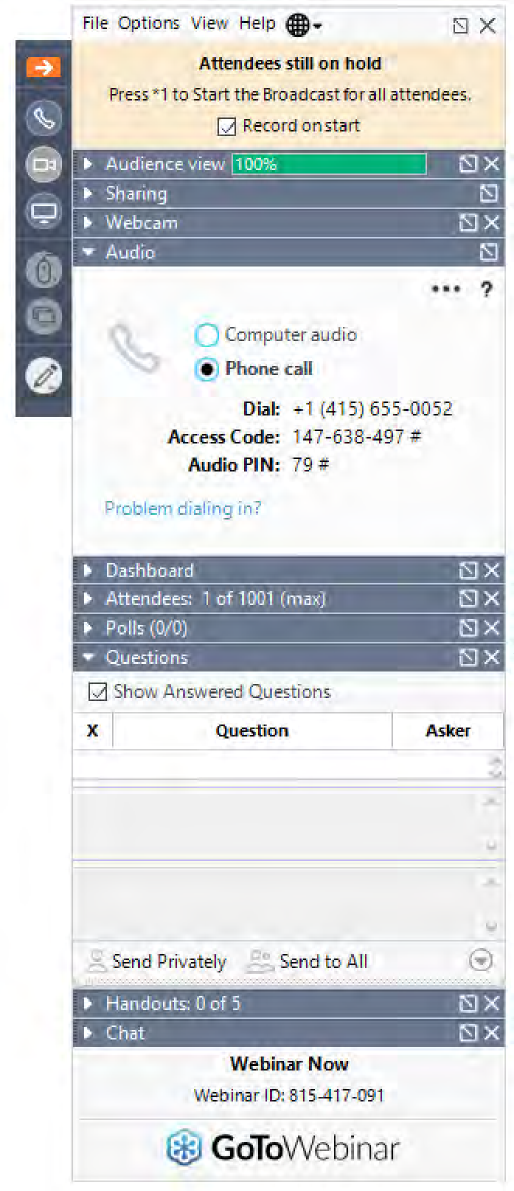
- 6,000 Nm^3/h biogas from dairy waste
- 99.9% methane efficiency
- Feedstock: Cow manure
- Pipeline injection for California market
- Biomethane injected to the gas grid at 900 psig
- Plant operating uptime over 99%
- Largest manure-to-RNG operations in the United States

Junction City Expansion Project, Oregon USA

WÄRTSILÄ

- 6,000 Nm^3/h biogas from agricultural and dairy waste
- 99.9% methane efficiency
- Feedstock: Hay, straw and cow manure
- Injecting on Northwest Natural Pipeline gas for California market
- Biomethane injected to the gas grid at 400 psig.
- Plant to be commissioned this year

Questions?



Audio

Questions