Process analytics support higher yields in biogas plants

Case Study · August 2010

Biogas production

The production of biogas by means of the anaerobic, microbial breakdown of organic substances in "biogas plants" is growing in significance, especially against a background of increasingly scarce and expensive fossil fuels.

The key energy-generating element is methane. Depending on the baseline conditions, biogas also contains small quantities of water vapor, hydrogen sulfide (H_2S), ammonia (NH_3), hydrogen (H_2), nitrogen (N_2) and traces of lower fatty acids and alcohols.

To date, biogas has primarily been used for power generation and simultaneous provision of thermal energy at the location of the biogas plant.

In the majority of biogas plants constructed in recent years for the production of methane gas from biomass, a host of materials have been utilized simultaneously. In this respect, both renewable resource plants and co-fermenters (common fermentation of animal waste with biomass) are used.

The composition of the input materials and the effectiveness of the fermentation process have a decisive influence on the quality of the biogas produced and on the associated methane yield. A high methane yield is positively reflected in the high efficiency when generating power in combined heating and power plants (CHP) and in the supply to the public gas network.

The ULTRAMAT 23 gas analyzer with integral H_2S sensor is ideally suited to the simple and continuous monitoring of biogas plants.

Biogas

Answers for industry.

SIEMENS

Biogas – the natural source of energy with a balanced CO_2 offset

A biogas plant requires daily support and control, as it involves a sensitive biological process. Key process characteristics are, for example, the temperature, the dwell time and rearrangement of the substrate, as well as the quantity and frequency of the substrate feed. In order to optimize and control the plant, it is absolutely essential to analyze the gas composition on a continuous basis.

Table 1 shows the typical compositions of the main components of biogas in the fermenter prior to purification.

Biogas composition	Fluctuation range	Average
Methane	45 ... 70%	60%
Carbon dioxide	25 ... 55%	35%
Water vapor	0 ... 10%	3 ... 10%
Nitrogen	0.01 ... 5%	1%
Oxygen	0.01 ... 2%	0.30%
Hydrogen	0 ... 1%	< 1%
Ammonia	0.01 ... 2.5 mg/m³	0.7 mg/m³
Hydrogen sulfide (raw measurement)	10 ... 30 000 mg/m³	< 500 mg/m³
Hydrogen sulfide (pure measurement)	10 ... 30 000 mg/m³	< 50 mg/m³

Table 1 Typical biogas composition

Process description

Essentially, the process of biogas production consists of fermentation, processing and purification.

The fermenter is the heart of the plant, as this is where the majority of the biogas is produced. The typical agricultural fermenters are tower constructions, usually with a capacity of at least 1 000 m³, part of which is som etimes below ground level. Inside the fermenter an agitator ensures the necessary homogeneity of the substrate and prevents the formation of sinking and floating layers.

In conventional biogas plants, condensate separators and pollution filters are used in the preparation and purification stage, in order to not only to remove solids carried by the gas flow, but also to prevent the icing of gas lines and to avoid corrosion.

The desulfurization (H_2S removal) is also an important element of the gas purification. The H_2S in the gas can be separated by means of chemical, physical or biological procedures. In agricultural renewable resource biogas plants, the H_2S components are usually removed by blowing in air.

Apart from the legal requirements for infeed into the gas network and the requirements for the protection of the motor when generating electricity (see section on "Analytics"), it is necessary to remove the hydrogen sulfide (H_2S) for the general protection of the materials used in the overall plant, since H_2S has a strongly corrosive effect in combination with water.

In addition, higher concentrations of hydrogen sulfide in the biogas are problematical, as sulfur oxides are created during the combustion. These also have a greater corrosive effect on metallic plant components and also acidify the motor oil used in combustion engines. As a rule, for safe CHP operation, limit values of between 100 and 500 ppm H_2S in the biogas must not be exceeded. Considerably more stringent requirements apply to the feeding of gas into the network and for the protection of gas-fueled engines (see section on "Analytics").

In principle, there are various options for using biogas obtained from the fermenter. Apart from conversion into heat, fuel and/or electricity, it can also be fed directly into the gas network.

The biogas production is ideally monitored and controlled by a continuous measurement of methane (CH_4), carbon dioxide (CO_2), oxygen, and hydrogen sulfide.

For the various measurement points used in biogas applications, the continuous-measurement ULTRAMAT 23, ULTRAMAT 6, OXYMAT 6, the gas chromatographs MicroSAM and SITRANS CV, and for special applications the MAXUM Ed II are used for analytical purposes.

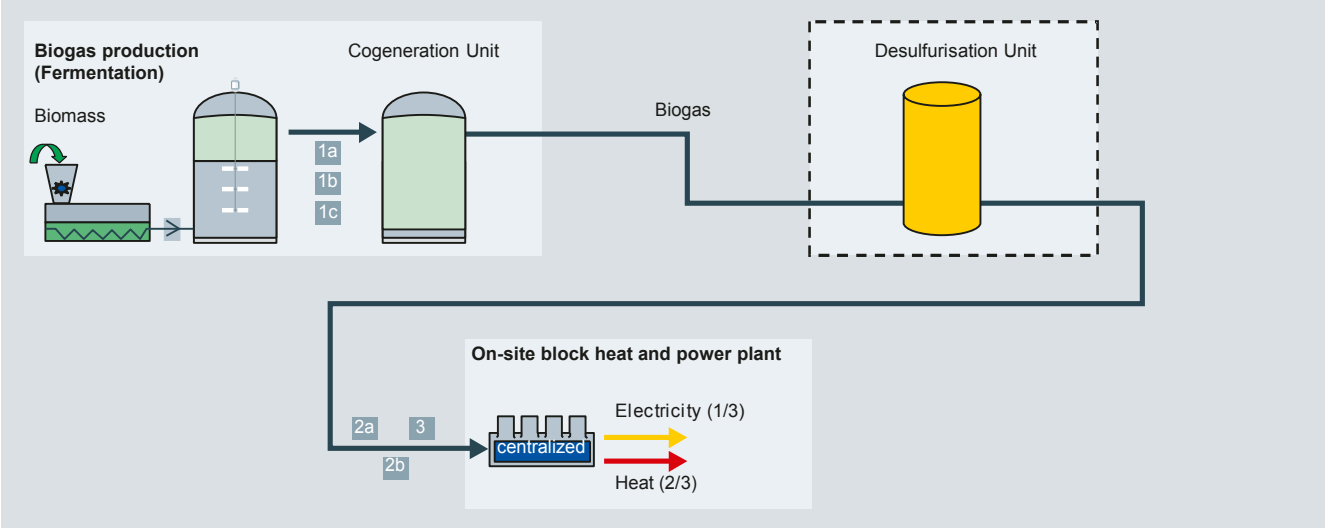

Fig. 1 Power generation from biomass

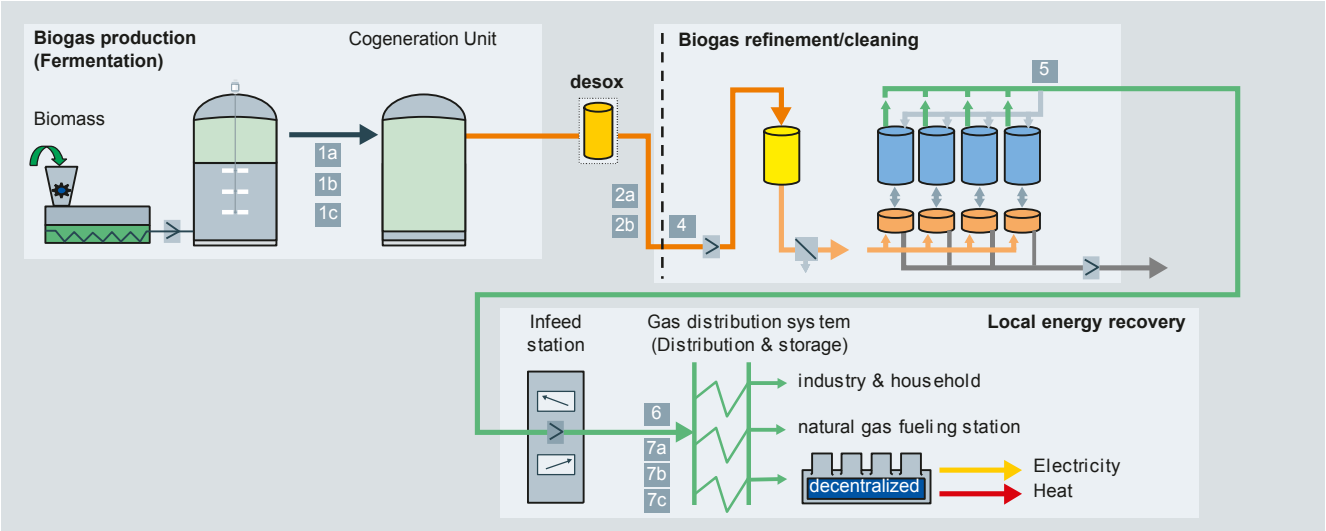

Fig. 2 Feeding of biomethane into the public gas network

Plant	No.	Measurement point	Analyzer
Fermenter	$	Raw gas monitoring for hydrogen sulfide and process control for optimizing the yield	1a) ULTRAMAT 23 (standard) 1b) MicroSAM 1c) Maxum (complete analysis of C_nH_m, H_2 and H_2S)
Biogas power generation / feeding to gas network	%	Pure gas analysis for protection of the gas motor 2a) Desulfurization by injection of air, alternatively 2b) to desulfurization plant	ULTRAMAT 23
	&	Explosion protection on long gas routes (> 500 m) between fermenter and CHP (combined heating and power plant)	OXYMAT 6
Gas network infeed	(	Determination of heating value when fermenter and purification are operated separately	ULTRAMAT 6
	)	Oxygen measurement as dilution check	OXYMAT 6
	*	Option: Monitoring of the liquid petroleum gas (LPG) – admixture to adjust calorific value	ULTRAMAT 6
	+	Purity monitoring and determination of calorific value for Bureau of Standards	7a) ULTRAMAT 23 (H_2S monitoring) 7b) Maxum (complete analysis incl. C_nH_m) 7c) Approved, tested system with MicroSam for calorific value calculation

Table 2 Measurement points in biogas plants

Analytics: Fermenter (biogas extraction)

The aim of biogas extraction is to achieve the greatest possible yield of the high-value energy source methane, whose energy content is about 10 kWh/m³. Depending on the design of the plant and the loading, the target yield in the fermenters is between 45% and 70% CH_4.

In addition to methane, carbon dioxide is created as a by-product. To increase the methane content, the carbon dioxide is removed from the raw gas in downstream purification systems.

Hydrogen sulfide also occurs as a by-product. Due to its toxicity and corrosive effects, H_2S is an undesirable contaminant in the entire biogas process. Too high a concentration can stop the anaerobic process in the fermenter.

The H_2S content is reduced in renewable resource plants by injecting 3 to 5% air into the gas flow and by oxidation of the H_2S into elemental sulfur. The sulfur is conveyed from the fermenter together with the rotted organic material.

In co-fermenters, H_2S develops in considerably higher concentrations (up to 5000 ppm) than in renewable resource plants. The H_2S content is usually reduced by the addition of chemicals (e.g. iron chloride $FeCl_3$).

In both cases, the H_2S concentration must be monitored analytically in order to control the process.

Excellent properties of the ULTRAMAT 23 in biogas plants

- Continuous measurement of CH_4, CO_2, O_2 including H_2S; without dilution unit
- One particularly attractive feature is the auto-calibration with ambient air that does away with the need for expensive test gases and switching valves. A check using test gases is recommended once a year.
- The ULTRAMAT 23 is TÜV-certified for use when introducing and measuring combustible gases, such as occur in Biogas plants (up to 70% CH_4).
- The compact design with the measurement of two IR-active components (CH_4 and CO_2) and measurement of two components (H_2S and O_2) with electrochemical sensors in one device facilitate a very compact and economical design of the individual device and a cost-efficient design of the overall system (Set BGA).

Siemens solution

To monitor the fermenter, the ULTRAMAT 23 is used or the Set BGA as a complete system. By means of gas analysis it is possible to monitor and control the gas composition and thus the effectiveness of the process. For the operator, a higher methane yield means a considerable financial advantage.

ULTRAMAT 23

The ULTRAMAT 23 gas analyzer performs the following functions:

- Monitoring the fermenter for the toxic component H_2S
- Controlling the productivity by monitoring the production of methane gas (CH_4)
- Monitoring the anaerobic fermentation by means of O_2 measurement
- Determining the residual content of CO_2

Measurement ranges (parameterizable)		
CH_4	0 ... 10/100%	NDIR procedure
CO_2	0 ... 10/100%	NDIR procedure
O_2	0 ... 5/25%	Electrochemical sensor
H_2S	0 ... 500/5000 ppm	Electrochemical sensor

Set BGA

With the Set BGA, Siemens is offering a standardized complete solution with the ULTRAMAT 23 for the monitoring of the biogas production – simple to use, high precision and with reasonable investment costs.

The Set BGA consists of the ULTRAMAT 23 with additional, simple sample preparation in the protective casing. The ULTRAMAT 23 with integral flow meter is fitted in a compact protective casing together with a Peltier gas cooler, pump, shut-off valve, and filters. The system is thereby protected against dust and splash water (IP54).

Flame arresters can be fitted as an option. Likewise, a measurement point selector for several measurement points can be supplied.

The enclosure of the Set BGA can be swiveled in three parts and grants good access to the front and rear for maintenance and service.

Dimensions (H x W x D) in mm:
616 x 615 x 600

The ULTRAMAT 23 or the Set BGA measure the components CH_4, CO_2, H_2S and O_2. The measurement ranges correspond to those used for the fermenter control.

Alternative: SITRANS CV/MicroSAM

SITRANS CV or MicroSAM determine on a batch basis with very short cycle times (max. 150 s) all components of biogas (see Table 1; exception: ammonia and H_2S) with extreme precision and reproducibility.

Analytics: Biogas power generation

Biogas is converted directly into electrical current in CHP plants, for example. Each percent of methane raises the degree of efficiency. An increase in the methane content by 5% results in a rise in the generated electrical power of about 9%.

Power generation by biogas is possible not only in large plants, but also on a smaller scale, where the electrical power is produced by generators driven by special biogas-fueled engines. For the safe operation of these engines, the proportions of methane (45 to 70%), oxygen (0.01 to 2%) and carbon dioxide (25 to 55%) must be measured.

The sulfur in the biom ethane damages the gas-fueled engines, as it forms sediment in the engine oil. By continually analyzing the H_2S content in the biomethane, the oil-change cycle can be maximized, which in turn represents a significant reduction of costs. In addition, sulfur settles in the cylinder head. If the concentrations are too high, the valve seats can be damaged, resulting in considerable repair costs.

The manufacturers of the gas engines demand limit values for the H_2S concentration of between 80 and 300 ppm, these values being subject to a downward trend.

The manufacturers of the gas engines only guarantee their proper function if **gapless** proof can be provided that the H_2S limit has been observed.

After purification, the biogas is delivered to the gas tank from where it is piped to the heating and power plant and in most cases immediately used for power generation on site. The eco energy thus generated can then be fed into the public power network, provided that the plant has been approved as an eco power plant.

Siemens solution

The ULTRAMAT 23 or the Set BGA offer the economical solution based on NDIR photom etry and special hydrogen sulfide sensors for the protection of the gas engines by monitoring the H_2S concentration as well as for maximizing the power generation by monitoring and controlling the methane content, especially in large-scale plants.

Optional: If the gas travels long distances (> 500 m) between fermenter and combined heat and power plant, an oxygen measurement (OXYMAT 6) is used for the detection of leaks and thus for ensuring explosion protection.

Major power plant operators will also use SITRANS CV or MicroSAM as alternatives, as these enable other hydrocarbons and hydrogen to be determined in addition to methane.

Fig. 4 MicroSAM

Analytics: Biogas network infeed

Before the gas is fed into the network, it is necessary to ensure that the biogas meets the quality requirements. This means: the calorific value of the biogas must match that of the public gas network. The energy-bearing hydrocarbons must be clearly identified and determined according to their proportions. This is the basis for determining the calorific value. For corrosion prevention reasons, the oxygen and hydrogen content must be monitored. Due to the embrittlement of steel by hydrogen, i.e. to protect the natural gas carrying pipes from corrosion, the hydrogen content must not exceed the specified limits.

The biogas that has been processed in this way into biomethane is of the same quality as the natural gas in the network into which it is fed. To this end, the solid and fluid elements are removed from the raw biogas and the gas is dried. The gas is then desulfurized and enriched with methane. This methane enrichment refers to the raising of the methane content by removing carbon dioxide. Both the purification and the methane enrichment are parts of the processing of biogas that are performed according to the quality of the raw biogas and required quality of the product biogas.

If necessary, other elements included in the gas can be removed and the calorific value of the gas can be adjusted by the addition of liquid gas.

The purified biogas is then piped via the gas network to the consumer where it can be used for power generation, heating purposes, or as a fuel.

This feeding into the public gas network is subject to stringent quality requirements. The quality of the gas is monitored with the aid of a gas chromatograph system. This measuring system basically comprises a sampling point, a chromatograph, and a downstream data processing unit.

One essential factor for the use of such chromatographic analysis systems at infeed points is the fact that these systems have been approved and certified by the PTB (German national meteorology institute providing scientific and technical services) . Only these PTB-certified systems are accepted by the natural gas producers, suppliers and network operators and have legal validity.

Siemens solution

Due to the stringent safety requirements, the supply of gas to the public network is monitored in most cases by the gas network operators. On the one hand, for reasons of personal safety, a limit of 3 ppm H_2S must not be exceeded, while on the other hand, it is necessary to determine the calorific value of the supplied gas. Depending on the calorific value and methane concentration, natural gas m ay be added to the supplied biogas. In addition, the amount payable to the biogas producer is calculated according to calorific and heating value.

The supply of biogas is currently only a lucrative option for large-scale plants, as the purification process requires a very expensive plant. What is more, a corresponding gas pipeline must be available for conveying the gas.

In order to match the biomethane to the calorific value of the public gas network, air can be added to the biomethane. The permissible limit for oxygen of 3% is monitored by the OXYMAT 6. In addition, liquid gas may be added if necessary. The ULTRAMAT 6 is used for monitoring measured values for CH_4 (methane).

SITRANS CV

The stated measurements can be performed very precisely and reproducibly by the gas chromatograph method, using the SITRANS CV and the MicroSAM. They are Ex(d)-encapsulated and can be used in hazardous environments without flushing.

Micro gas chromatography has proven to be very advantageous for this application. By miniaturizing the analyzer components of the SITRANS CV and the MicroSAM, the operating costs are reduced, while at the same time raising the analytical performance. In order to fully exploit the potential of miniaturization, the entire chromatographic concept is optimized with its essential modules for injection, separation, pneumatic column switching and detection.

The range of applications of the SITRANS CV in network infeed extends to

- Controlling the productivity by monitoring all standard biogas components
- Quality control during the infeed (both certified and non-certified as solution package)
- Calculation of calorific value, heating value, specific gravity, relative density and Wobbe Index according to ISO 6976, GOST and AGA 8

Wherever high precision of the quality param eters such as calorific value or specific gravity is required, this compact gas chromatograph is a particularly suitable solution.

Excellent properties of the SITRANS CV in biogas plants

- User-friendly and high-performance CV control software, specially developed for energy calculation
- The use of three different user levels improves the safety of the system
- Internal and external archiving of data possible over a very long period
- Trend analysis facilitates a clear overview of the results over a long period
- Standby mode reduces the consumption of carrier gas
- A particularly attractive feature is the auto-optimization, which automatically optimizes the gas chromatography system. This feature results in a very high analytical performance and increases the availability of the gas chromatograph.
- Can also be used under extreme conditions, e.g. high temperature and in hazardous zones

Fig. 5 SITRANS CV

Set CV

The Set CV is the versatile Siemens complete solution for biogas analysis using the MicroSAM or SITRANS CV gas chromatographs. Set CV is modular, safe and a cost-efficient investment.

Such a system can be used wherever the quality of biogas has to be determined. For example, when feeding gas into the pipeline network, during transportation, and when distributing the biogas in the network. The precondition, however, is that the biogas no longer contains any corrosive components.

Design

With the Set CV (Calorific Value), Siemens offers a system that covers all the requirements of such applications, from sampling to pressure reduction, sample preparation and determination of quality, supplying carrier gases, right through to expansion of the communication interfaces.

The Set offers various modules to cover market requirements. Using the different versions, the Set can be adapted.

The basic version of the Set CV contains a sample preparation unit, comprising shut-off valve, filter, flow sensors and solenoid valves on a mounting plate, together with a Micro GC on the mounting plate. Starting with the basic version the sample processing can be modified and modules for sampling, external pressure reduction, system integration and gas supply, for example, can be added by configuration.

You can find additional information in the Catalog PA 01, Chapter 5.

Option: Measuring point switchover

With this option the Set BGA can monitor as many as eight measurement points. The solenoid valves are controlled externally by the plant operator.

Option: Heated pipeline

in order to keep the measurement gas reliably in its gaseous state and to avoid the formation of condensation if below the dew point, the use of a heated pipeline is recommended.

Maxum and MicroSAM

As in the case of SITRANS CV, the possible uses of Maxum and MicroSAM in biogas applications extend to the fields of application listed above.

SITRANS CV, MicroSAM and Maxum are the devices of choice if the customer accepts high precision with a cycle time in the order of minutes.

MicroSAM and Maxum are characterized by the following points:

- Flexible workstation software: Both gas chromatographs use the same software, enabling the synergies to be exploited to maximum effect
- Universal application of the Maxum conventional high-performance chromatograph, e.g. for sulfur analyses
- The MicroSAM can be freely applied for gaseous samples
- Reduction of the verification limit by means of special software features such as smoothing

Global support

Our broad portfolio of services is divided into the topic areas of consultation, support and service. It encompasses all support-related measures and services that could possibly be required by our customers during the lifetime of an analyzing system.

The services extend from a tour of the construction site to an inspection of the installation, from on-site training to spare parts management, and from FEED for Process Analytics (see below) to the Internet Hotline.

Examples are:

- Site visit
- Checking the installation
- Function test
- On-site acceptance test
- Training at the plant
- Preventive maintenance
- On-site repairs
- Remote diagnostics
- Determining the stock of spare parts
- Spare parts management
- Training centers
- Process optimization
- Hotline via the Internet
- FEED for Process Analytics
- Technical consultation

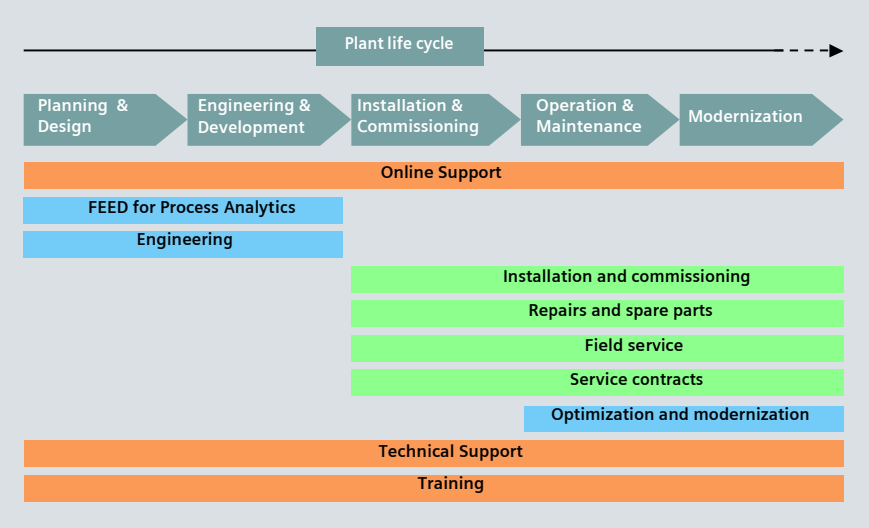

Fig. 6 Services of Siemens Process Analytics

Front End Engineering and Design

Front End Engineering and Design (FEED) is a part of the planning and engineering phase for new construction or conversion projects for process engineering plants. The FEED activities take place after drawing up the concept and prior to the detail design stage. During the FEED phase, the best opportunities exist for cutting costs and optimizing the time requirements of the project, as a majority of the subsequent investments are established at this stage and any changes would only have a minor influence on the project.

Siemens Process Analytics has the best qualifications for executing "FEED for Process Analytics", thanks to extensive knowledge and experience in analytical technology and its applications and in the preparation of complete solutions for numerous sectors of industry.

Based on these qualifications, Siemens Process Analytics offers a wide range of appropriate FEED services, concentrating on analytical procedures, technologies for sampling and solutions for given applications, but also with regard to the networking of the devices in communication systems or consultation relating to the relevant standards for the analytical technology. In this way, we can make an effective contribution to the safety and economy of our customers' projects.

For plant operators and pant constructors alike, benefits can be gained from these "FEED for Process Analytics" services:

- Knowledge of analytics and process engineering available from the start of the project
- Top-class performance capability of the analytics with high availability
- Well-founded studies for realistic investment decisions
- Swift and clear definition of specifications and circuit diagrams for the analyzer equipment
- Low project management costs due to the appointment of just one responsible contact partner

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