Agri - Food

Chemicals

Geo - Environment

Energy

Application Note

Waste to energy: solid waste characterization

Instrument: ECS 8020, 8070 AIR CO_2 + 14C SCAR
Mode: CHN

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NC TECHNOLOGIES
Innovative Elemental Analysis

Energy increasing demand

People across the globe continue to move to cities, accelerating the demand for housing and transport infrastructure such as railways and electric vehicles charging networks.

The annual production of cement has quadrupled from 1 billion to over 4 billion tons since the 1990s, primarily driven by developing countries such as China and India.

Over the last 15 years, demand for steel has increased by over 40% and continues to grow, particularly in emerging economies.

These are only few examples of why the energy demand is increasing.

**The greater the demand for energy,
the greater the attention must be paid to CO_2 emissions into the atmosphere.**

The challenge lies not only in meeting this demand, but also in doing so without increasing the climate burden – and, eventually, even reducing it.

Introducing circular systems and redesigning products to increase their longevity and efficiency will reduce the demand for raw materials.

Growth in energy demand: 2017 -2040

The energy-intensive industries (EIIs)

Energy-intensive industries (EIIs) are sectors like steel, chemicals, cement, waste incineration, and pulp that require massive amounts of energy to operate.

For historical and economic reasons, these industries have traditionally relied on fossil fuels for energy generation.

The central challenge for EIIs is balancing climate-neutrality goals with economic survival. Transitioning to low-emission technologies requires immense capital and access to affordable, green electricity.

Biomass and solid waste generate energy through combustion, gasification, or anaerobic digestion, turning organic matter into electricity and heat. This process—often called waste-to-energy—reduces landfill volume and lowers greenhouse gas emissions.

The use of these resources offers significant advantages, including local energy self-sufficiency, efficient solid waste management, and reduced net carbon dioxide emissions, as they are generally considered carbon-neutral.

However, these facilities require advanced flue gas treatment systems to prevent the release of particulate matter and other harmful pollutants into the atmosphere. In addition, they rely on short supply chains to ensure genuine environmental sustainability.

The range of application can be:

Steel plants

Cement plants

Fuel plants

Waste incineration plants

The circular economy

Waste incineration and thermal utilization of wastes for energy production are gaining importance in several countries, mainly because of environmental protection and resource management regulations which aims to promote a higher contribution from renewable energy resources in the production of electricity in the relative domestic markets.

Systems able to recover energy lowering the pollutant emissions with respect to conventional plants, are the basis of a society that points to circular economy

Waste management systems today, primarily emphasizes the reduction in waste production.
The more intuitive and sustainable thing to do with waste is the reuse or recycle: unfortunately, this is not always possible, and that's when waste-to-energy plants assume relevance.

The challenge of climate change is no longer just a warning; it is a present-day reality. Meanwhile, the demand for materials, goods and services that account for the largest proportion of CO_2 emissions continues to rise.

Collaboration with leading industrial players is key to replacing fossil fuels with fossil-free electricity, hydrogen and heat, while ensuring competitiveness and affordability.

Characterization of solid waste

Renewable energy resources become an alternative to fossil fuels and help to mitigate the issues relevant to environmental sustainability.

The use of solid waste generated by manmade activities may be considered as an alternative source of energy which may also contribute to the 50% reduction of CO_2 by 2050.

Solid waste principally consists of biomass waste, agricultural waste, and municipal solid waste.

Waste-derived fuels qualified as Solid Recovered Fuels (SRF) can be used directly in energy conversion processes, such as in incineration, combustion, and pyrolysis, where energy is used for supplying heat and/or electric power. For instance, the cement industry is widely adopting SRF to lower greenhouse gas emissions, preserve natural resources, and promote sustainable waste management practices.

Understanding the composition of the organic elements in SRF, particularly Carbon (C), Hydrogen (H), Nitrogen (N), Sulfur (S), and Oxygen (O), is essential for evaluating its combustion efficiency, energy potential, and environmental impact.

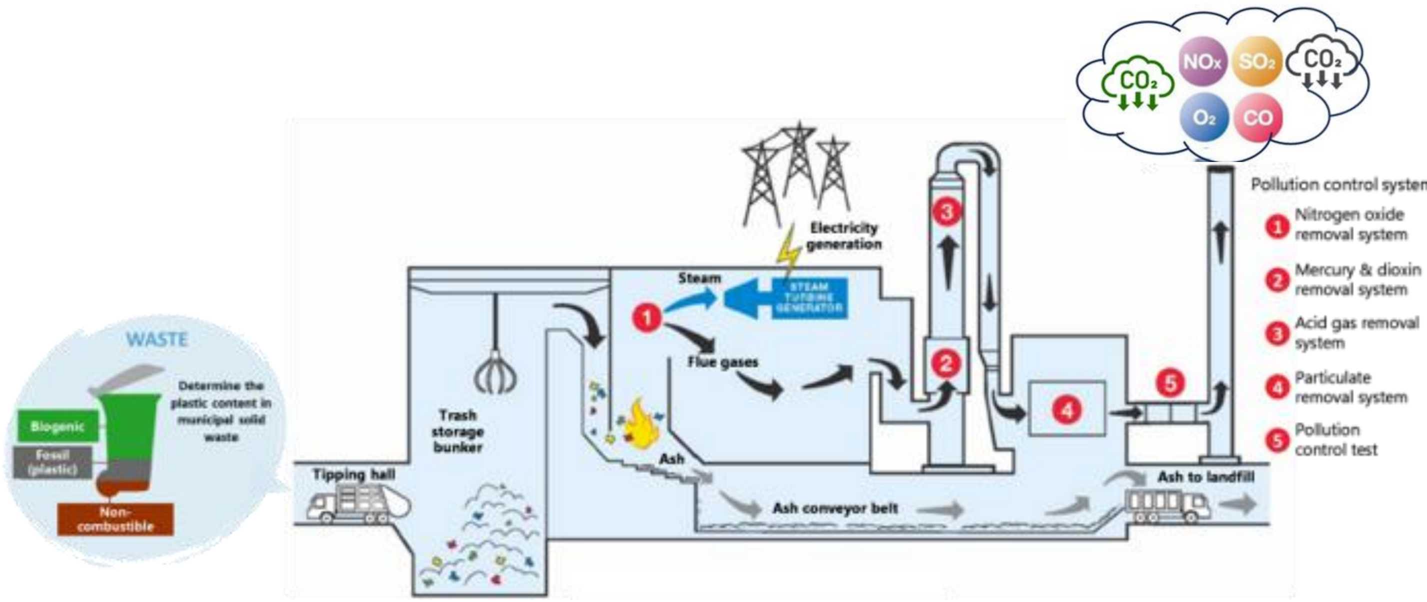
Carbon, Nitrogen, and Sulfur contents are particularly significant when applying thermal treatments due to the formation of CO_2, NO_X and SO_2, which contribute to the greenhouse effect, acid rain, and photochemical smog.

Accurate CHNS analysis begins with proper sample preparation, as the degree of chemical homogeneity significantly affects the reliability of the results.

Not only elemental analysis

Solid waste material typically contains a mix of both biogenic carbon and fossil-derived carbon (e.g., plastics).
Because waste-to-energy facilities release large volumes of combined emissions, identifying the exact biogenic fraction is vital for complying with environmental regulations, avoiding carbon taxes, and trading green fuels.

It is therefore essential to determine the amount of biogenic CO_2 emitted during combustion or to verify the amount of biogenic portion of the solid waste to burn or both.



Typical Waste to Energy plant incinerates

The type of process shown above is used by facilities other than incineration plants as well: in other words, alternative fuels, such as solid recovered fuel (SRF), are used not only in incineration plants but also in industrial facilities such as steelworks, cement plants, and other manufacturing plants.

All these facilities therefore require the chemical characterization of the materials used for energy generation, including not only elemental analysis but also the determination of their biogenic fraction.

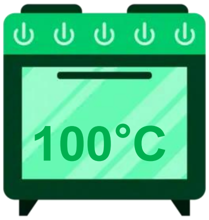
The determination of the biogenic fraction is often carried out not only for assessing CO_2 emissions to the atmosphere but also for to determine the biogenic fraction of the materials used as combustion fuels.

Sample preparation

The collected samples must be free of any non-combustible materials such as stones, metals, glass, etc. The sorted samples must be dried in an oven at around 100 °C to remove surface moisture.

Municipal and industrial waste are materials with an extremely heterogeneous composition, and must be thoroughly homogenized and finely ground by using laboratory cutting mills to obtain a consistent powder with controlled particle size, ensuring the sample is truly representative.

Segregation



Drying

Milling

For the determination of CHNS, the solid sample has to be weighted with an analytical balance (0,001 mg resolution is recommended), packed into a tin foil cup and analysed.

In case of liquid sample, it can be injected into a tin capsule or, depending on the nature of the sample, the LIA (Liquid Injection Autosampler) can be used, increasing the throughput of the system.

Solid sample

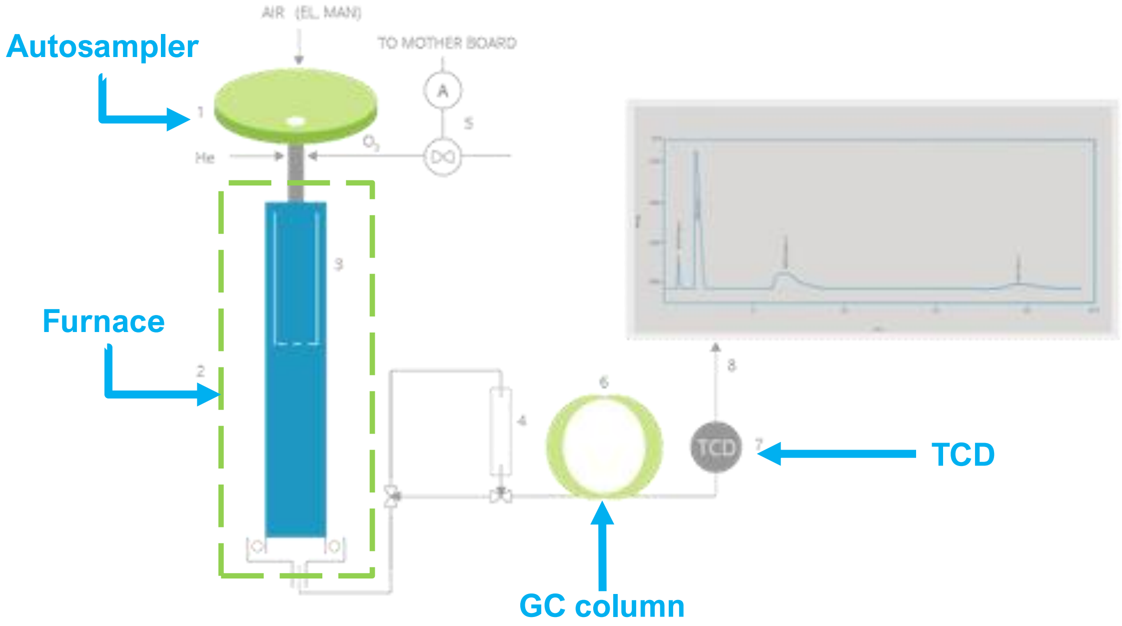
LIA
Liquid Injection
Autosampler

Elemental analysis analytical method for CHNS determination

The analysis is based on high-temperature catalytic combustion technology, which has proved to deliver precise, reliable, and matrix-independent results. The samples are introduced into the combustion reactor via the autosampler after purging with carrier gas.

Here, the samples are introduced into the combustion furnace at high temperature around 1000 °C, in the presence of a catalyst and in excess of pure oxygen gas.

During combustion, the elemental components of the sample are quantitatively converted into gaseous oxidation products (CO_2, H_2O, N_XO and SO_2).
The gas stream then reaches the gas chromatographic column, which ensures homogenous and complete separation of all the elements before the final detection by the Thermal Conductivity Detector (TCD), with no requirement for a reference gas.



The amount of hydrogen, nitrogen and sulfur can vary in different types of municipal solid waste depending upon the nature and type of media from where the solid waste is generated.

Analytical method for biogenic fraction determination

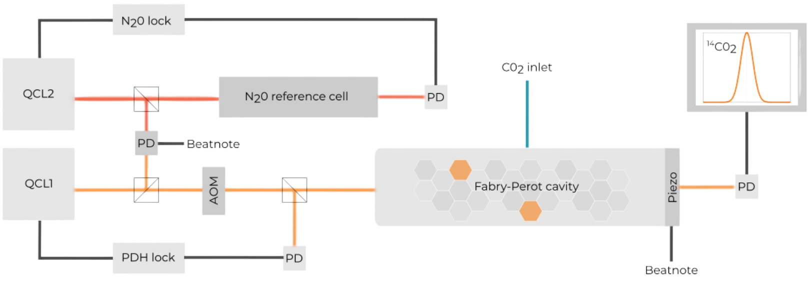
One of the most accurate ways to study a material's bio-based vs. petroleum-based composition is to analyze the carbon in the product.
Bio-based carbon originating from plants is radioactive, whereas carbon originating from fossils no longer is.
The amount of radioactive carbon in the sample can thus be used to determine the amount of biogenic fraction in the material.

The content of radioactive carbon in the organic material can be determined using a dedicated analytical instrument by measuring the 14C carbon isotope in the sample. This method is commonly used to assess the age of organic material, but it can also be used to evaluate how much of the carbon in the material originates from renewable biomass and how much from fossil origin.

By measuring the presence of carbon-14 (or radiocarbon), we can determine the fraction of the sample that is biogenic compared to the fossil fraction.

The detection of 14C is really challenging, due to its extremely low concentration in nature: the required sensitivity is of 1 part in 10^{15}.
Therefore, the use of a dedicated detector with high sensitivity and accuracy is required to ensure reliable determination.

The 14C SCAR (**S**aturated-absorption **CA**vity **R**ing-down) spectrometer is a new and innovative spectrometer for the 14C measure.



Schematic of the optical and optoelectronic setup of the radiocarbon detection part of 14C-SCAR.

Since the 14C SCAR requires the sample to be introduced in gaseous form, it must be coupled with a peripheral.

The type of peripheral to be connected to the 14C SCAR depends on the nature of the sample to analyse.

1° CASE – SOLID SAMPLE

If the goal is to determine the biogenic fraction of the feed material entering an incinerator, a cement plant, or a steel plant, the Solid Recovered Fuel (SRF) must be converted into a gaseous form before being introduced into the 14C SCAR detector.

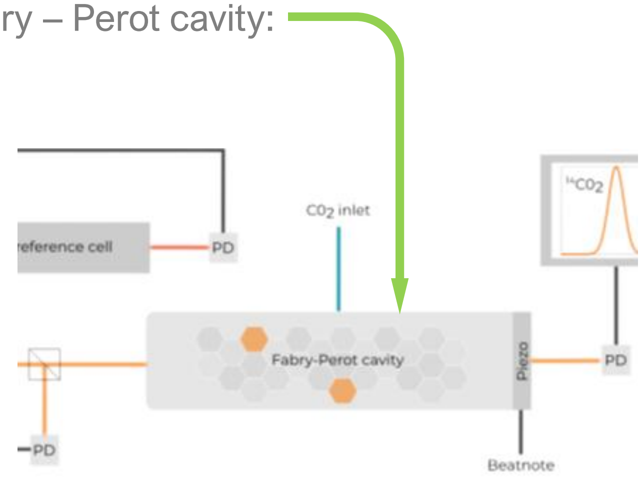
The conversion from the solid to the gaseous phase is carried out by an elemental analyzer.

To proceed with the analysis, the sample must be prepared (see the *Sample Preparation* section) and then loaded into the elemental analyzer.
The elemental analyzer is directly interfaced with the 14C SCAR detector. Once the analysis is started, the biogenic fraction of the sample is automatically determined, since the combustion gases generated by the elemental analyzer are directly transferred to the detector for radiocarbon analysis.

14C SCAR exploits the latest photonics solutions, such as Quantum Cascade Lasers (QCLs), provides room-temperature operation with no moving parts.

The main part of the 14C – SCAR is the Fabry – Perot cavity:

- ✓ the sample gas to measure is introduced into the cavity
- ✓ a system of high-tech mirrors, on both sides of the cavity, reflects a laser beam
- ✓ the laser scans the molecule of the sample gas several times; the more the scanning time, the more the accuracy will be (1 hour time analysis is enough to get a good accuracy).



The laser beam travels an effective path length of several kilometers through multiple scans; only in this way the few CO_2 molecules containing ^{14}C can be detected among the much more abundant molecules containing ^{12}C.

2° CASE – GASEOUS SAMPLE

If the goal is to determine the biogenic fraction of the CO_2 emitted through the stacks of incineration plants, cement plants, or steel plants following waste combustion, the CO_2 must be purified and concentrated before being introduced into the 14C SCAR detector.

Stack emissions need to be purified due to their composition:

- fine particulate matter
- nitrogen oxides
- hydrochloric acid
- hydrofluoric acid
- heavy metals

etc.

Following the necessary purification steps, a fraction of the emitted CO_2 is sampled and injected into our purification and concentration unit: the 8070 AIR CO2.

8070 AIR CO2

14C SCAR

Based on a patent, 8070 Air CO2 is a concentrator and purifier of CO_2 contained in atmospheric air. Therefore, through its use, it is possible to obtain purified CO_2 and introduce it into mass detectors to determine the isotopic ratio δ13C or quantify the content of 14C, a radioactive isotope of carbon.

This unit is based on the production of a high volume of pure CO_2 according to the principle of adsorption/desorption, with an innovative purification line that allows the elimination of water, VOC and NOx, leaving only pure CO_2. So, the purified CO_2 will be injected into the 14C SCAR for a complete automatic analysis of the biogenic fraction of the gas.

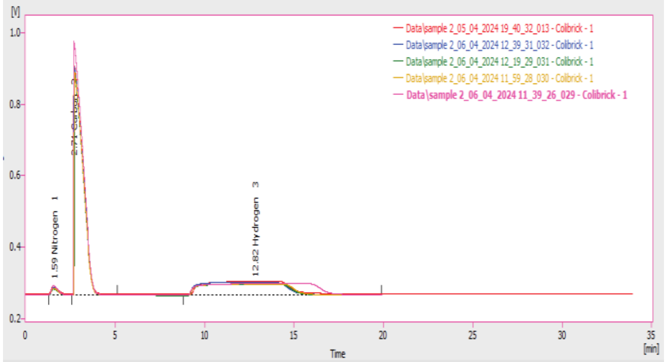
For more information about 14C analysis of CO2 in air, see the Application Note: AN_Biogenic CO2 in atmospheric air

CHN analysis of Solid Recovered Fuels (SRF)

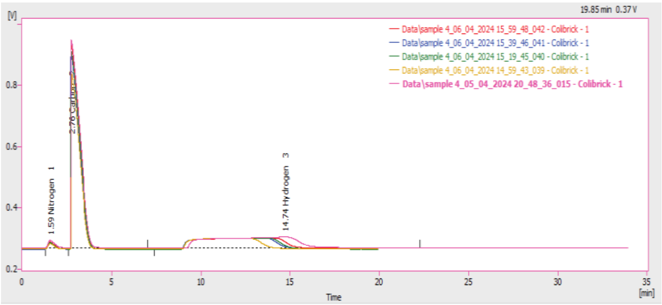
In this study, we analyzed two SRF samples supplied by a cement plant, where this type of fuel is used to generate the energy required for kiln operation.

The samples were supplied in a properly ground and homogenized form (see figure).

Instrument set up	
Instruments	ECS 8020
Operative mode	CHN
Left furnace	WO3+Co3O4 ; 16 mm diam; T = 950°C
Right furnace	Cu 0,5 ; 18 mm diam: T = 650°C
GC column	T = 70°C; 3 m long.
TCD gain	L3
Carrier flow	85 ml/min



Sample ID	Weight (mg)	N %	C %	H %
2	6,95	2,6	41,54	5,81
2	7,10	2,64	41,5	5,77
2	6,45	2,6	41,45	5,73
Average		2,61	41,50	5,77
Std Dev		0,05	0,09	0,08
RDS %		1,77	0,22	1,39



Sample ID	Weight (mg)	N %	C %	H %
4	7,623	2,54	42,3	5,53
4	7,00	2,47	42,36	5,65
4	7,24	2,48	42,11	5,6
Average		2,50	42,26	5,59
Std Dev		0,04	0,13	0,06
RDS %		1,52	0,31	1,08

The analyses were performed using an ECS 8020 elemental analyzer, equipped with an autosampler up to 147 positions, in CHN operating mode and fully compliance to the international standard **EN ISO 21663**: Solid recovered fuels - Methods for the determination of carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) by the instrumental method.

ECS 8020

Biogenic fraction determination of Solid Recovered Fuels

In this study, we determined the biogenic fraction of SRF samples supplied by a cement plant for energy generation. These samples were different from those analyzed in the CHN study.

The study was carried out using a system consisting of an ECS 8024-C14 elemental analyzer coupled with a SCAR 14C detector.

ECS 8024 – C14

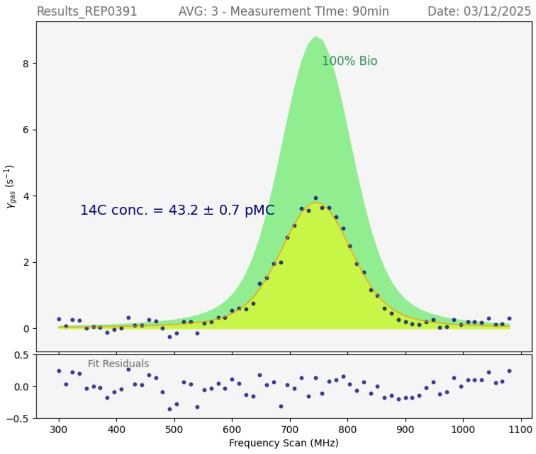
14C SCAR

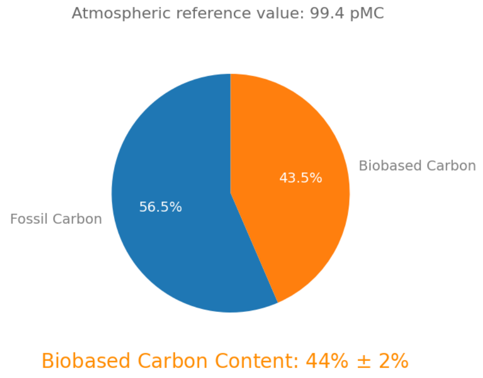
The ECS 8024-C14 is an elemental analyzer specifically designed to be coupled with the 14C SCAR detector, providing CO_2 with the characteristics required for radiocarbon measurement.

Once the samples have been loaded into the ECS 8024-C14 autosampler, the analysis is fully automated.

Application Note – Waste to energy: solid waste characterization

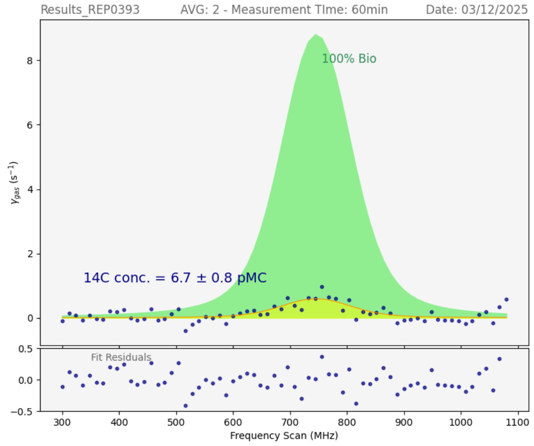
Sample ID: REP0391

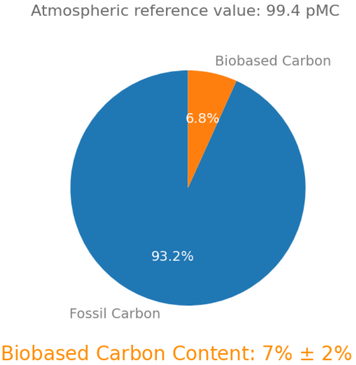




Result: 44% ± 2% Biobased Carbon Content (as a fraction of total carbon)

Sample ID: REP0393





Result: 7% ± 2% Biobased Carbon Content (as a fraction of total carbon)

Conclusions

The elemental and the radiocarbon analysis are powerful tools for the solid waste characterization, not only in term of basic chemical information about the CHN concentration, but to distinguish the biogenic fraction from the fossil one also. This bring highly value to the energy-intensive industries.

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