LANDFILL GAS SOLUTIONS

Putting waste to work as an energy source

JENBACHER

INCREASING WASTE WORLDWIDE

Means more greenhouse gas emissions

As the world's population continues to grow, so does the waste we produce. And along with waste comes ever-increasing greenhouse gas emissions.

The World Bank estimates that each individual generates an average of about three-quarters of a kilogram of waste per day, with higher income countries accounting for more than a third of the total 2.01 billion metric tons generated each year.[1] These numbers will continue to rise.

A major by-product of biodegradable waste is methane gas, which is 25 times more harmful to the environment than carbon dioxide (GWP 100[2]) and makes up about 16% of all greenhouse gas emissions worldwide[3]. The waste sector alone is responsible for one-fifth of all methane emissions and 3.3% of total greenhouse gas emissions[4].

In fact, methane emissions from municipal solid waste landfills in the U.S. in 2020 were approximately equivalent to greenhouse gas emissions from about 20.3 million passenger vehicles[5].

All of these numbers add up to real opportunity to capture and use a significant, renewable energy resource—landfill gas.

[1] The World Bank, What a Waste 2.0, A Global Snapshot of Solid Waste Management to 2050, www.datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html

[2] www.ecometrica.com/assets/Understanding-the-Changes-to-GWPs.pdf

[3] United States Environmental Protection Agency (EPA), Global Greenhouse Gas Emissions Data, www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

[4] The Global Alliance for Incinerator Alternatives (GAIA), Zero Waste to Zero Emissions: How Reducing Waste is a Climate Gamechanger, www.no-burn.org/resources/zero-waste-to-zero-emissions-how-reducing-waste-is-a-climate-gamechanger/

[5] United States Environmental Protection Agency (EPA), Basic Information about Landfill Gas, www.epa.gov/lmop/basic-information-about-landfill-gas

LANDFILL GAS AS A VALUABLE ONSITE ENERGY SOURCE

Putting landfill gas to work while cutting greenhouse gas emissions

The good news is that proper waste management can help the world reach sustainability goals. As landfills fill up with municipal solid waste as well as commercial and industrial wastes, organic components of that waste decompose and leave behind the natural byproduct of landfill gas.

This landfill gas is composed of about half methane, half CO_2, and a small amount of non-methane organic compounds[6].

Instead of letting this potent greenhouse gas escape into the atmosphere, it can be collected and used as a valuable energy source. With a clear vision and political will, thousands of landfills around the world can be part of the energy transition solution, delivering significant renewable power generation.

[6] United States Environmental Protection Agency (EPA), Basic Information about Landfill Gas, www.epa.gov/lmop/basic-information-about-landfill-gas

Harnessing significant potential

Municipal waste contains 150 to 250 kg of organic carbon per ton, which microorganisms convert into landfill gas through an anaerobic process. The gas formation is influenced by a number of factors such as waste composition, landfill storage height and density, air temperature, atmospheric pressure, and precipitation levels. Decomposition starts one to two years after the waste is deposited in the landfill and lasts 15 to 25 years. The continuously decreasing gas volume can be compensated by the disposal of additional waste during this period.

With a calorific value of 3.5 to 5.5 kWh m^3_N, landfill gas constitutes a high-value fuel for gas engines that can be effectively harnessed for power generation:

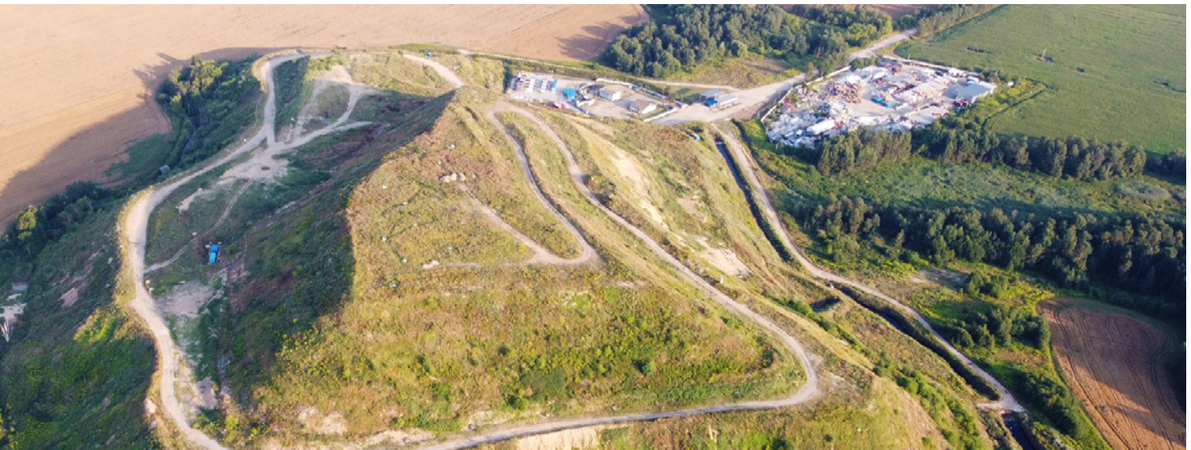
Methane (CH_4) (methane has 25 times the global warming potential of CO_2)	35%–55% by vol.
Carbon dioxide (CO_2)	30%–44% by vol.
Nitrogen from air (N_2)	5%–25% by vol.
Oxygen from air (O_2)	0%–6% by vol.
Water vapour (H_2O)	saturated

Just 1 million tons of municipal solid waste generates about 1.7 to 2.5 million m^3 of collectable methane, enough to fuel a gas engine capacity of 850 to 1,250 kW producing 6,500 to 10,000 MWh of electricity per year. That roughly corresponds to the average power demand of 1,800 to 2,800 EU households.

Turning landfill gas into renewable natural gas

Treatment processes are available to increase the amount of methane and reduce the CO_2, nitrogen, and oxygen in the collected landfill gas. These processes deliver a high-BTU (British Thermal Unit) gas known as renewable natural gas (RNG), which can be used to generate electricity or heat. The RNG is comparable to fossil natural gas, pipeline gas, compressed natural gas (CNG),or liquefied natural gas (LNG), and can be used onsite or added to natural gas pipelines. In the U.S., about 15% of landfill energy projects convert the landfill gas into RNG[7].

[7] United States Environmental Protection Agency (EPA), Basic Information about Landfill Gas, www.epa.gov/lmop/basic-information-about-landfill-gas



LANDFILL GAS–FUELED JENBACHER GENSETS

Turning waste byproduct into power

An efficient power solution, INNIO's Jenbacher gensets offer large output with a small footprint, high efficiency and availability, and low NOx emissions.

Instead of venting methane-laden landfill gas into the atmosphere, our Jenbacher power plant solution uses this gas for power generation, reducing greenhouse gas emissions and creating financial value for you. When the methane is combusted in engines, it converts to CO_2, which is approximately 25 times less harmful to the climate than methane.

While landfill gas has many potential applications, its use in a Jenbacher genset delivers high profitability with exceptional overall efficiencies of up to 86% in combined heat and power (CHP) applications and up to approximately 44% with power generation alone.

Supporting your energy transition journey

Our landfill energy solutions support your community as it transitions to net zero. By generating electricity—and optionally capturing the thermal energy through a Jenbacher CHP solution—our technology works for you today while accelerating a cleaner tomorrow.

Due to its economic advantages, high efficiency, and flexibility to fit different gas output scenarios, technology like our Jenbacher gensets is the most commonly used conversion technology for landfill gas power generation worldwide.

THE ADVANTAGES OF USING LANDFILL GAS IN JENBACHER ENERGY SOLUTIONS

Boosting sustainability... and your bottom line

A Jenbacher solution offers benefits that let you:

- Harness landfill gas as an energy source while simultaneously mitigating greenhouse gas emissions
- Enjoy smooth, reliable operation despite low heating value and fluctuations in gas composition and pressure
- Receive high profitability with overall efficiencies
- Increase revenue by feeding power (and optionally heat with Jenbacher CHP solutions) into the public grid
- Receive carbon credits for reduction of methane emissions or special renewable energy tariffs
- Meet sustainability goals and comply with country-specific emission standards with integrated exhaust aftertreatment CL.AIR for Jenbacher systems
- Achieve quick, flexible installation with low weight, containerized units that are easy to move and adjust to changing project capacity
- Get advanced service support through our extensive remote services and flexible Contractual Service Agreements

PROVEN JENBACHER TECHNOLOGY

For landfill gas power and heat generation

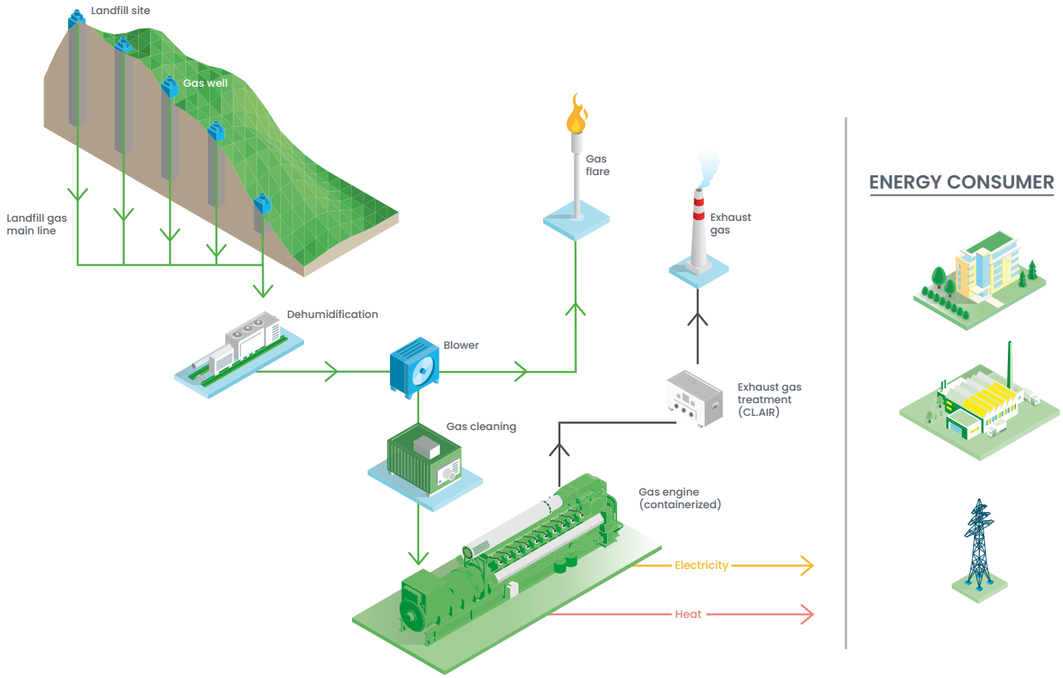
For more than 30 years, INNIO has been using landfill gas to economically, efficiently, and reliably generate heat and power, including warm water for district heating in the winter.

As emission standards continue to increase, the need for improved landfill management becomes more important than ever. That's why INNIO takes a holistic approach to landfill gas power and heat production. We supply a broad range of Jenbacher landfill gas engines specially designed to run at full load with high efficiency, despite a low heating value and fluctuations of gas quality and pressure. Our high-quality engine parts resist the impurities that usually appear in this type of fuel.

To deliver excellent availability with reduced operating and maintenance costs, proper fuel gas conditioning is key. The landfill gas must be dried and compressed, and severe contaminants, such as siloxanes, must be removed or reduced to acceptable levels.

INNIO is committed to offering the auxiliary equipment needed to support an integrated landfill gas solution—from the gas flange to the grid connection. We also can install an exhaust treatment device, if needed.

What's more, INNIO can provide basic gas conditioning system design and support as needed.



Collecting & processing landfill gas

The first step of effective landfill restoration requires the continuous, controlled extraction of landfill gas from the site using a well-designed gas collection system that prevents greenhouse emissions from migrating into the atmosphere while avoiding offensive smells and smoldering fires.

A blower sucks the gas through an interconnected system of pipes attached to perforated tubes drilled into the landfill body. The system must be able to handle high temperatures, leachate, condensates, and varying air content while capturing stable, quality gas in a cost-effective way.

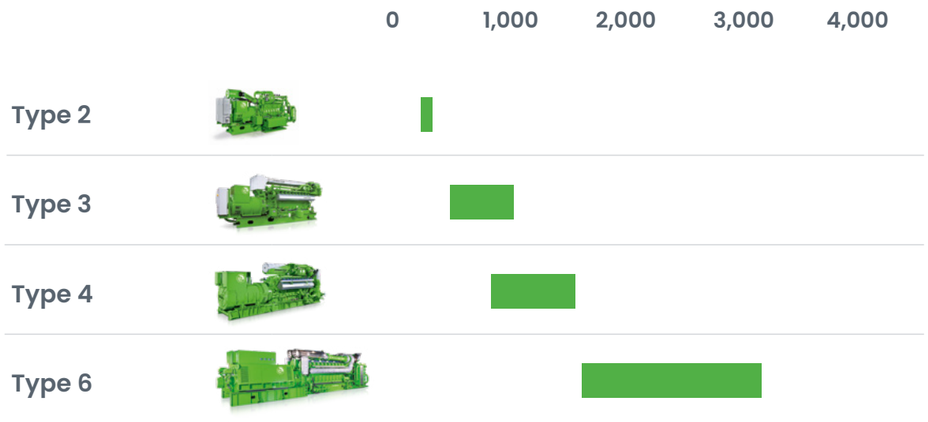
A POWERFUL PORTFOLIO

For a variety of landfill gas-fueled power plant applications

INNIO offers you a comprehensive Jenbacher product portfolio for landfill gas applications, from 330 kW up to 3.1 MW of single unit electrical power output. By using multiple gensets in one plant you can scale up your power output while significantly enhancing part load performance and reliability.

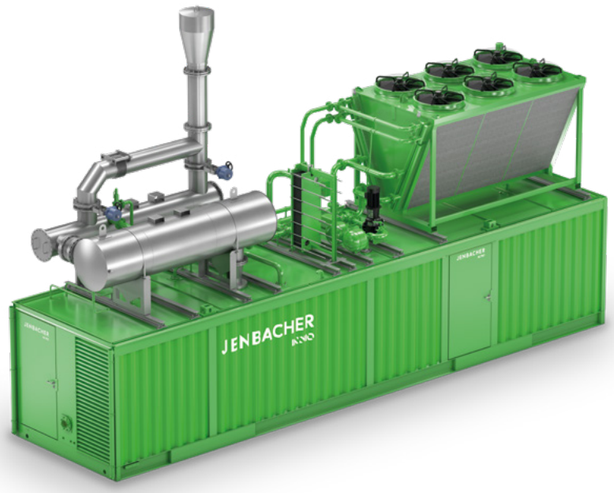
We offer a wide range of available generator voltage levels and flexible hydraulic integration variants for excellent integration into your existing electrical and thermal systems. Depending on your needs and capabilities, we can provide you with the basic module, including its control system, or with an extended supply scope that includes balance-of-plant equipment.

Electrical output (kWel)



JENBACHER CONTAINER SOLUTIONS

Containers are available for Jenbacher Type 2, 3, 4, and 6 engines, with a broad range of options to meet project requirements.



Container for Jenbacher Type 2, 3, and 4 engines

Benefits

- Pre-installed package, completed with auxiliary systems, ensures a quick and easy site installation
- Compact footprint consumes a minimum amount of space on site
- All components perfectly matched and tuned to the specific site requirements by Jenbacher engineering experts to ensure optimal performance

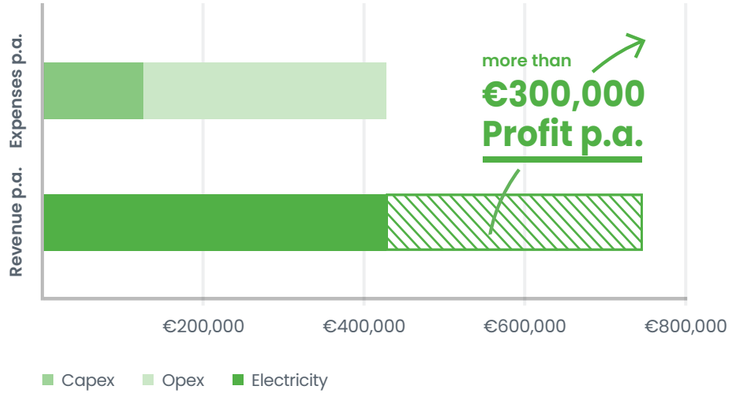
JENBACHER LANDFILL GAS-FUELED CHP TECHNOLOGY

An investment that pays off

With Jenbacher solutions for harnessing landfill gas as an energy source, you gain economically—and so does the environment.

The following example from Turkey details how the use of landfill gas in a Jenbacher power generation plant pays off. In addition to the economics of this application, the environmental aspect of not emitting the methane into the atmosphere is key for decision makers in the industry.

Engine	1 x J420
Electrical output	1,414 kWel
Energy input	3,344 kW
Power generation	27,003 MWh/a



Return on Investment: less than 2 years

All values rounded

Assumptions

- Landfill Gas Fuel Costs: 0 €/kWh; gas extraction required by law.
- Electricity Price: 0.0665 €/kWh
- Based on a review period of 10 years, 8% interest rate p.a.
- Annual operating hours: 8,075

PROVEN EXPERTISE WITH MAJOR EMISSIONS SAVINGS

More than 2,500 landfill gas projects

With more than 30 years of experience in the combustion of landfill gas—and around 2,500 landfill gas systems with a total electricity output of more than 2,700 MW delivered throughout the world—we offer an unparalleled breadth of expertise, references, and solutions.

These plants have the potential to generate about 21 million MW-hours[8] of electricity a year—enough to supply more than 5.6 million EU homes.[9] In addition, by capturing landfill gas instead of emitting it directly into the atmosphere and using it for power generation in place of fossil fuels, these engines can reduce greenhouse gas emissions by about 75 million tons[10] CO_2 equivalent each year.

[8] Based on the number of Jenbacher systems delivered worldwide and assuming 8,000 operating hours p.a.

[9] Based on average electricity consumption per EU household in 2018, www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html

[10] Based on the carbon intensity of power generation in 2021, IEA www.iea.org/reports/tracking-power-2021

BIOMONT ÉNERGIE SEC

Significantly reducing emissions by converting landfill gas into energy

Since 2017, the Biomont Énergie SEC plant at the Saint-Michel Environmental Complex on the island of Montréal has been converting the biogas generated from the landfill there into valuable renewable electricity and thermal energy.

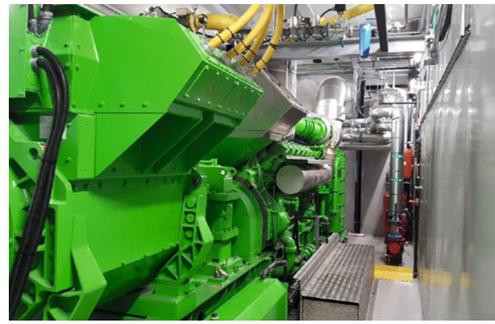
Montréal
Québec, Canada

The cogeneration plant is centered on three Jenbacher J612 engines from INNIO, each with a capacity of 1.6 MW of electrical output. Enerflex—INNIO's authorized Jenbacher distributor in Canada—delivered the complete facility, including all engineering, procurement, and construction under a complete turnkey contract. One of the major Canadian utility companies buys the green electricity produced by the plant under a 25-year power purchase agreement, providing enough electricity to power the equivalent of about 2,000 homes*. At the same time, thermal energy recovered from exhaust gases and the engines' cooling circuits is used to provide 5.2 MW of heat to surrounding buildings, including the TOHU circus stadium and the headquarters of Cirque du Soleil.

PLANT FACTS

Installed engines	3 x J612
Energy source	Landfill gas
Electrical output	4.8 MW
Thermal output	5.2 MW
Total efficiency	85%
Year of commissioning	2017

* The Daily — Households and the Environment Survey: Energy use, 2019, https://www150.statcan.gc.ca/n1/daily-quotidien/220502/dq220502b-eng.htm



ISTANBUL ENERJI

Renewably powering Europe's largest city with landfill gas

Istanbul Enerji's Seymen Biomass Power Generation Plant is turning vast quantities of waste generated in Istanbul—home to more than 15 million residents—into usable energy for the region.

Centered on 26 of INNIO's Jenbacher J420 gensets running on renewable landfill gas, the plant is delivering 37 MW of energy to meet the needs of about 190,000 households, or 760,000 individuals, in the region annually. And, by burning landfill gas, the plant eliminates methane emissions that are equivalent to the greenhouse effect of 1.45 million tons of CO_2 annually. To help improve the operational performance of the facility's Jenbacher units, INNIO's myPlant Performance solution provides live remote monitoring and predictive analytics to detect and correct even the smallest deviations at an early stage.

PLANT FACTS

Engines	26 x J420
Energy source	Landfill gas
Electrical output	26 x 1.4 MW
Total efficiency	41.3%
Year of commissioning	2021, 2022

»By increasing the use of renewable energy sources, Istanbul Enerji's new biomass plant is helping to make Istanbul a cleaner, greener, and healthier city. We are proud of our role in creating more awareness about green industry and green cities while we promote our goal of being a more sustainable, effective, efficient, and environmentally responsible scientific and technologically based energy company. INNIO's technology is helping us achieve our goals in this respect while also helping to ensure the reliable and efficient operation of our power plant.«

Yüksel Yalçın, general manager, Istanbul Enerji

GASGREEN ENERGÍA LANDFILL GAS POWER PLANTS

Turning landfill gas into clean electricity

In 2016, two of INNIO's Jenbacher J320 gensets began delivering 2 MW of power running on renewable landfill gas from the Gasgreen Energía[11] landfill site.

Based on that success, three Jenbacher J420 units producing 3 MW were added in 2017. Today, the power plant is delivering a combined 5 MW of electricity to power more than 25,000 homes in Ecuador and saving 26 million cubic meters of landfill gas from being released into the environment. By turning renewable landfill gas into power, the plant prevents 250,000 tons of CO_2 from entering the atmosphere each year—the equivalent of removing the CO_2-pollution generated by 250,000 cars annually[12].

PLANT FACTS

Engines	2 x J320, 3 x J420
Energy source	Landfill gas
Electrical output	Up to 5 MW
Electrical efficiency	39.6%
Year of commissioning	2016, 2017

[11] www.gasgreen.com
[12] Source: www.emgirs.gob.ec/index.php/noticiasep/398-quito-se-destaca-en-el-ecuador-al-producir-energia-electrica-de-la-basura

OUR COMMITMENT

to you

Flexibility and experience you can count on

For the last 65-plus years, Jenbacher has been an innovator of power generation technology. Today's highly efficient Jenbacher systems deliver energy independence through an efficient, low emission, secure and cost-effective energy solution.

Thinking long-term. Thinking circular

With our flexible, scalable, and resilient energy solutions and services, INNIO is embracing the circular economy—recycling, reusing, and upgrading our engines to meet the latest environmental requirements. For example, upgrading to hydrogen operations for a renewed life or using heat that normally would be wasted during power generation are sustainable solutions that can keep entire communities or businesses warm and electrified.

Through our service network in more than 100 countries and our digital capabilities, we provide life-cycle support for our globally installed units, helping to ensure a greater runtime for longer equipment life.

Zero-carbon H_2 operation tomorrow

In addition, the same proven and economically viable INNIO equipment can be moved from conventional fuels today to full CO_2-free H_2 operation tomorrow, once H_2 becomes more readily available.

BENEFIT

from a powerful digital platform

Through our myPlant Performance digital solution, INNIO provides digital remote support for our connected customer-operated systems across the globe. Today, more than 12,000 engines are managed remotely, with more than 1.2 trillion data points evaluated annually—a powerful proof-point of INNIO's knowledge and experience.

Fulfill emission requirements

Our engine and fleet emission monitoring solutions help you more easily comply with emissions requirements—until you can operate your plant with 100% H_2 and become carbon-free.

Improve business planning

Increase your power system's lifespan by taking advantage of self-learning algorithms that analyze component condition and calculate parts lifetime.

Optimize engine management

Real-time engine monitoring and operations provide you with remote access to your assets via desktop or app, whenever you need it, by aligning operational practice with maintenance requirements.

Achieve greater availability

With the ability to solve more than 60% of logged cases remotely, you can reduce the need for travel to your site—saving time and money.

Rely on INNIO's engagement to sustainability

For INNIO, ethics and compliance, along with a sustainable way of conducting business, are front and center of everything we do. By selecting INNIO as your supplier, you enter a long-term relationship with a dependable collaborator. Our fundamental mission to accelerate the world's transition to net zero was recognized with the prestigious EcoVadis ratings. Also in 2021, INNIO joined the "Race to Zero" campaign, initiated by the United Nations, to bring together global leadership for a healthy transition to a net-zero future. Thanks to our efforts in 2021, INNIO's ESG Risk Rating places us number one out of more than 500 worldwide companies in the machinery industry assessed by Sustainalytics.*

*Rating took place in February 2022

INTERESTED?

INNIO is among the world's technological leaders in energy solutions and services for landfill gas applications.

Let us develop a powerful energy concept for your company.

Reach out today by completing the contact form online:
innio.com/contact

Our Sales team will get back to you.

INNIO is a leading energy solution and service provider that empowers industries and communities to make sustainable energy work today. With our product brands Jenbacher and Waukesha and our digital platform myPlant, we offer innovative solutions for the power generation and compression segments that help industries and communities generate and manage energy sustainably while navigating the fast-changing landscape of traditional and green energy sources. INNIO is individual in scope, but global in scale. With our flexible, scalable, and resilient energy solutions and services, we enable our customers to manage the energy transition along the energy value chain wherever they are in their transition journey.

INNIO is headquartered in Jenbach (Austria), with other primary operations in Waukesha (Wisconsin, U.S.) and Welland (Ontario, Canada). A team of more than 4,000 experts provides life-cycle support to the more than 55,000 delivered engines globally through a service network in more than 100 countries.

INNIO's improved ESG Risk Rating again secures the number one position across more than 500 companies globally in the machinery industry assessed by Sustainalytics.

For more information, visit the INNIO website at **www.innio.com**

Follow INNIO on

ready for H_2

ENERGY SOLUTIONS.
EVERYWHERE, EVERY TIME.

Jenbacher is part of the INNIO Group

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