

GREENHOUSE SOLUTIONS

CHP plants with
CO₂ fertilization

JENBACHER
INNIO



ENVIRONMENTAL CONTROL IS KEY

Managing your greenhouse sustainably

You are being asked to do more—with less. More food is needed for a growing population, but that population is taking up more room, limiting the area available to grow its food. In addition, consumers are increasingly concerned about food quality and sustainable production.

Your production systems, therefore, face a demanding challenge: sustainably grow crops that yield a high quantity of quality produce within a limited expanse of land, preferably near urban areas.

With almost one-third of global greenhouse gas emissions coming from food production systems,¹ governmental regulations are increasing. If you have a more advanced greenhouse that provides heat, you are challenged by high carbon dioxide (CO₂) emissions. And high nutrient emissions are a problem for low-tech greenhouses that aren't heated.² In either scenario, you need to increase the efficiency of your horticulture production while meeting new governmental requirements.

When properly managed, greenhouse systems improve the plants' growth conditions, increasing yield and quality and extending the growing season. As a greenhouse manager, it is increasingly important that you take environmental control over your greenhouse.

And with advanced solutions, you can improve the level of environmental control in several ways, including heating—for a longer growing period—and CO₂ supply—for a larger yield.

As a greenhouse owner, you must determine the level of environmental control that works best for you economically, so that you can sustainably yield the largest amount of produce while reducing your environmental footprint.

Controlling the environment

Synonymous terms referring to crop production systems that allow manipulation of the crop environment:

- Protected cultivation
- Controlled environment agriculture (CEA)
- Greenhouse horticulture

¹ Vermeulen, S.J., Campbell, B.M., Ingram, J.S.I., 2012. Climate change and food systems. *Annu. Rev. Environ. Resour.* 37, 195–222. Source: <https://doi.org/10.1146/annurev-environ-020411-130608>.

² Torrellas, M., Ant'ón, A., Ruijs, M., García Victoria, N., Stanghellini, C., Montero, J.I., 2012b. Environmental and economic assessment of protected crops in four European scenarios. *J. Clean. Prod.* 28, 45–55. Source: <https://doi.org/10.1016/j.jclepro.2011.11.012>.

SOLUTIONS FOR LOWER EMISSIONS AND INCREASED CROP PRODUCTION

Food producers have long recognized the advantages of greenhouses, which don't have to be located on ideal farmland and can even be placed near transportation centers and urban areas.³ In them, you can control your heating and cooling using combined heat and power (CHP) with gas engines as you work to economically increase yield.

With CHP, the heat is used for heating the greenhouse, and electricity is used for lighting. Excess electricity can even be delivered to the grid. Efficient operation is possible with approximately 1 hectare (2.47 acres) or larger greenhouses.

With CO₂ fertilization, which is suitable for many crop types, these systems can also help curb emissions. The benefit is two-fold: lower emissions and increased crop production.

All-electric greenhouses providing increased environmental control are likely to continue to grow in number. In the Netherlands, for instance, these systems can be found at many greenhouses, with pipeline gas as the energy source. And other greenhouses around the globe are turning biomass into a biogas energy source to deliver heat and power with significantly lower CO₂ emissions.

The use of renewable gases, such as biogas and hydrogen, is key to facilitating the path to net zero. And, gas engine technology offers an easy transition along that path—from pipeline gas, to biogas, to green H₂ in the future.



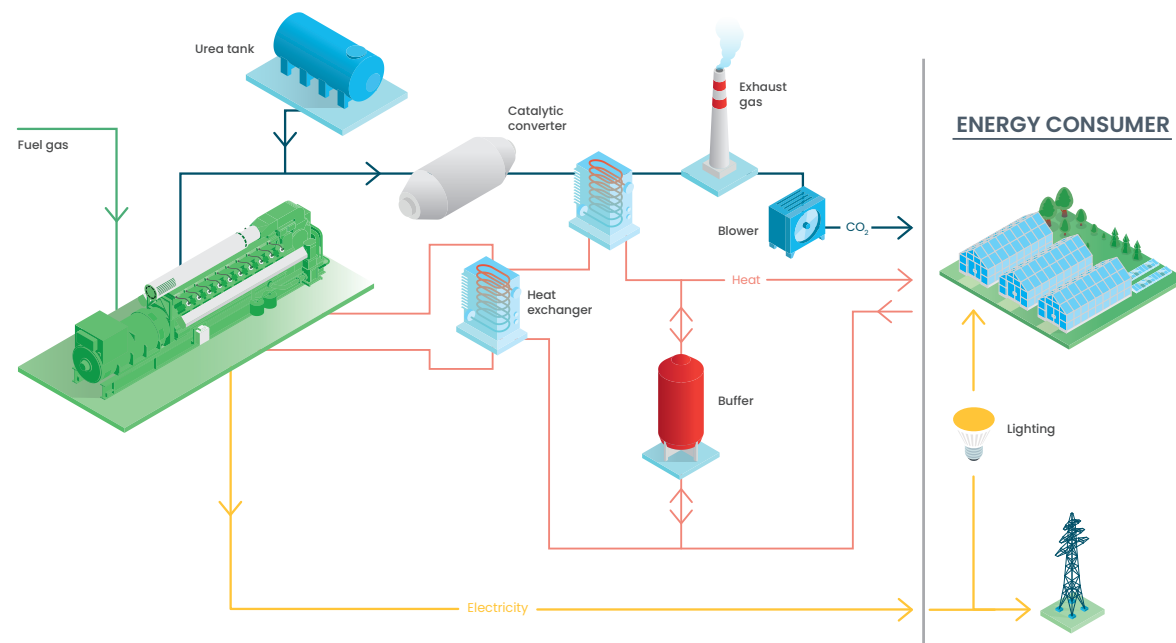
³ Dianfan Zhou, Holger Meinke, Matthew Wilson Leo F.M. Marcelis, Ep Heuvelink, "Towards delivering on the sustainable development goals in greenhouse production systems," *ScienceDirect*, www.elsevier.com/locate/resconrec

CHP SOLUTIONS WITH CO₂ FERTILIZATION

In today's greenhouses, you can simultaneously increase your crop yield and effectively control CO₂ emissions. INNIO's Jenbacher technology can provide you with heat, electricity, and CO₂ fertilization, increasing your greenhouse's total efficiency, profitability, and plant production. Today, approximately 1,700 Jenbacher CHP units have been installed in greenhouses worldwide, providing more than 3,800 MW of power.

Faster growth with gas engines

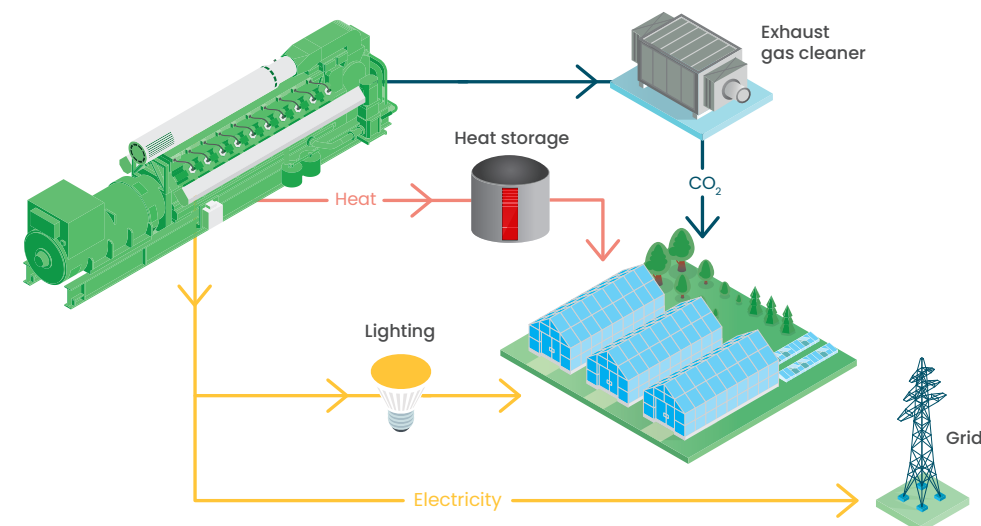
INNIO's Jenbacher CHP systems not only provide electricity for onsite or public grid use, but also heat and CO₂ to fertilize plants and meet the requirements of an efficient greenhouse. By increasing the intensity of the artificial grow light that is found in some greenhouses, plants absorb even more CO₂. Plant growth and the subsequent harvest yield can be significantly increased by enriching the greenhouse environment with CO₂, keeping the temperature constant, and providing sufficient lighting.



The Jenbacher concept

The energy created by gas engine cogeneration systems in greenhouses can be used in various ways. The electricity can provide the power for artificial lighting and/or be fed into the public grid. And while the heat can efficiently meet the greenhouse's requirements, the CO₂ from the engine exhaust gas can help fertilize the plants.

After the purification of the exhaust gas with special SCR and oxidation catalytic converters, it is cooled down by heat exchangers to approximately 50°C or even less and supplied to the greenhouse for CO₂ enrichment. A device that constantly measures the exhaust gas levels helps ensure the safety of both vegetation and workers. With ultra-low emissions, total efficiency is more than 95% at 100% heat utilization.



CONVINCING ADVANTAGES



Higher efficiency

Jenbacher CHP systems can achieve overall efficiency levels of 95% or more.



Increased productivity and production

Achieve higher yield (kg per m² p.a.), consume less water (l per kg), and benefit from a longer harvest season



Flexible power

Produced thermal energy can be stored for use as needed. Electricity can be used to power the facility, including artificial grow lights—and we offer an optional full island lighting control system for this. In addition, surplus power can be fed into the public grid with attractive feed-in tariffs at market rates in several countries.

INNIO'S JENBACHER EXPERTISE FOR GREENHOUSE APPLICATIONS

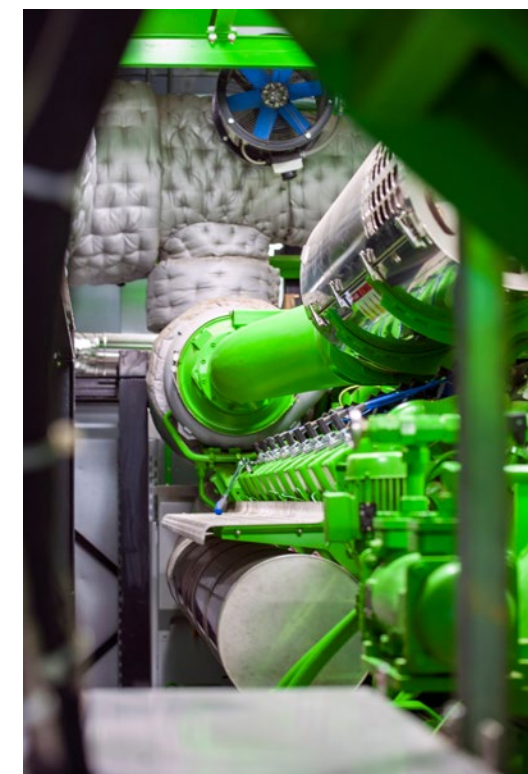
INNIO offers more than just technology. With a focus on delivering you peace of mind, our Center of Excellence (CoE) in the Netherlands can support your greenhouse needs from project initiation through maintenance. We provide greenhouse technical support, high-level project management, and supervision from specialized greenhouse project managers, as well as commissioning from expert greenhouse service engineers. Our CoE team, backed by more than two decades of experience, helps ensure optimal concept integration to your greenhouse and even the public grid.



OUR GREENHOUSE PACKAGE

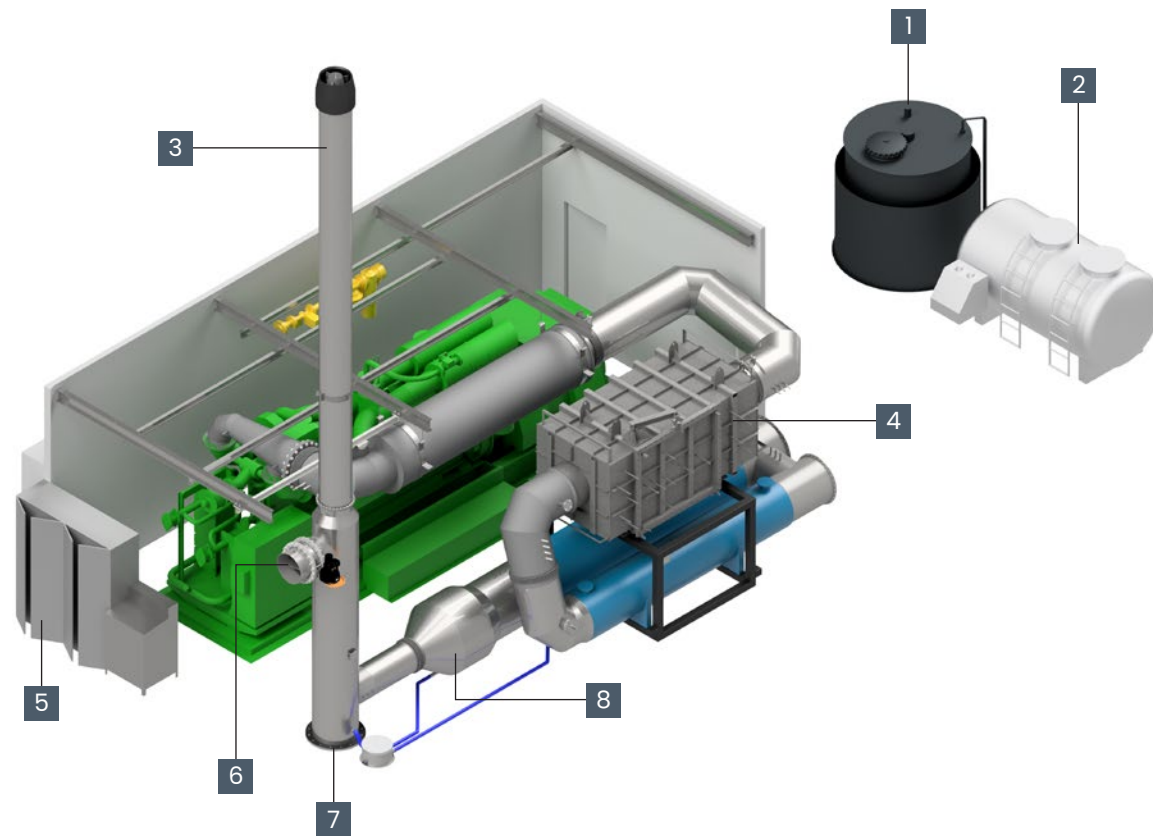
With our standardized greenhouse CHP technology, the Jenbacher engine, catalytic converter, heat exchanger, and all balance of plant equipment and controls are provided in one convenient package. INNIO's Center of Excellence can help develop your balance-of-plant specifications as well as perform engineering and site and design work to meet your spatial requirements. Our standardized package makes your service experience easier, too, since the generator and all other installations can be removed at the same time.

To increase crop yield, it is possible to raise the CO₂ level in the greenhouse twice as high, as compared to a conventional boiler with the same heat output. Our solution uses an exhaust gas cleaning system in combination with our engine.



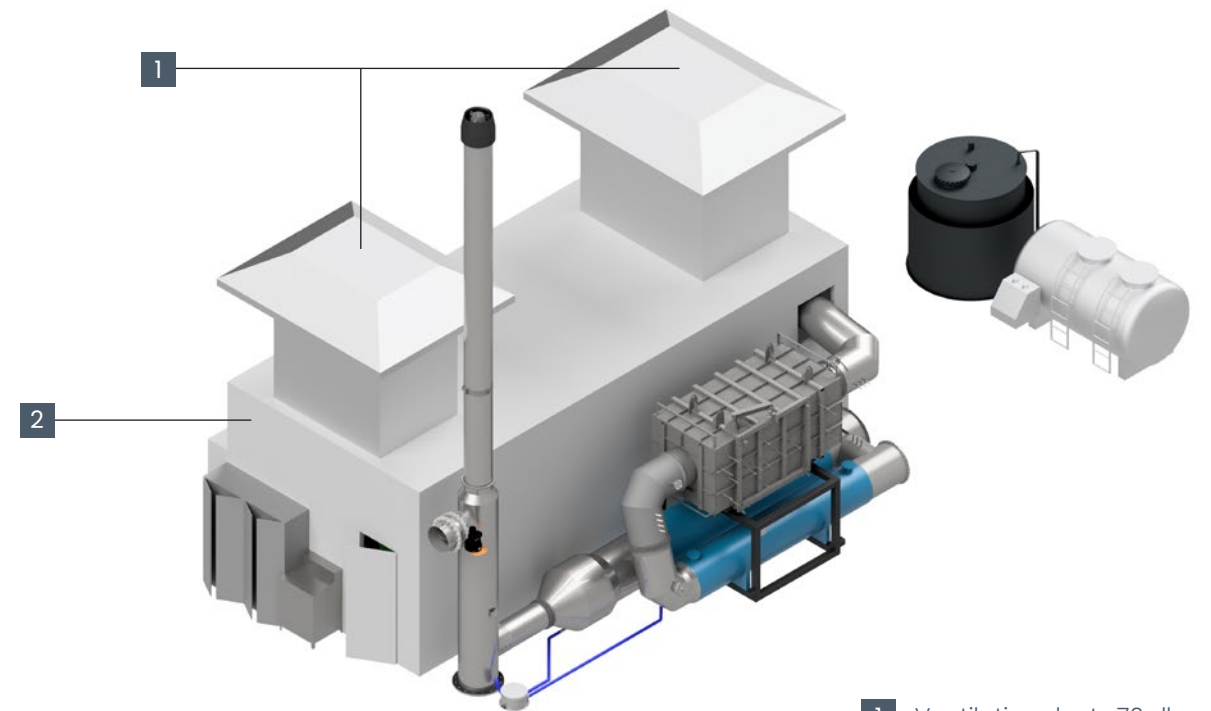
PROVEN, RELIABLE GREENHOUSE SOLUTIONS

INNIO has decades of experience building, installing, and maintaining our modular, standardized adaptable greenhouse solutions. Our integrated Jenbacher approach offers peace of mind with proven solutions backed by significant expertise.



Interior view of the modular system (standard layout)

- | | | |
|---------------------------------------|---------------------|---------------------------------|
| 1 Urea storage tank | 2 Oil storage tank | 3 Exhaust gas stack 70 dba @ 1m |
| 4 Exhaust gas cleaner | 5 Control panels | 6 CO ₂ connection |
| 7 2 nd silencer (optional) | 8 Condensate filter | |



Exterior view of the modular system (standard layout)

- | |
|----------------------------------|
| 1 Ventilation ducts 70 dba @ 1m |
| 2 Acoustic enclosure 75 dba @ 1m |

With a modular Jenbacher solution, greenhouse operators can realize key benefits:

- Less than 12 months of construction time
- Small footprint that can be adjusted to spatial requirements
- Ability to meet your specific greenhouse application needs
- Optimal integration to the public grid
- Maintenance support through Jenbacher greenhouse technical support center
- High-level project management and supervision by dedicated greenhouse project managers
- Optimal integration in new or existing greenhouse construction
- Commissioning by experienced greenhouse service engineers



Modular Jenbacher greenhouse CHP solution with acoustical outdoor enclosure

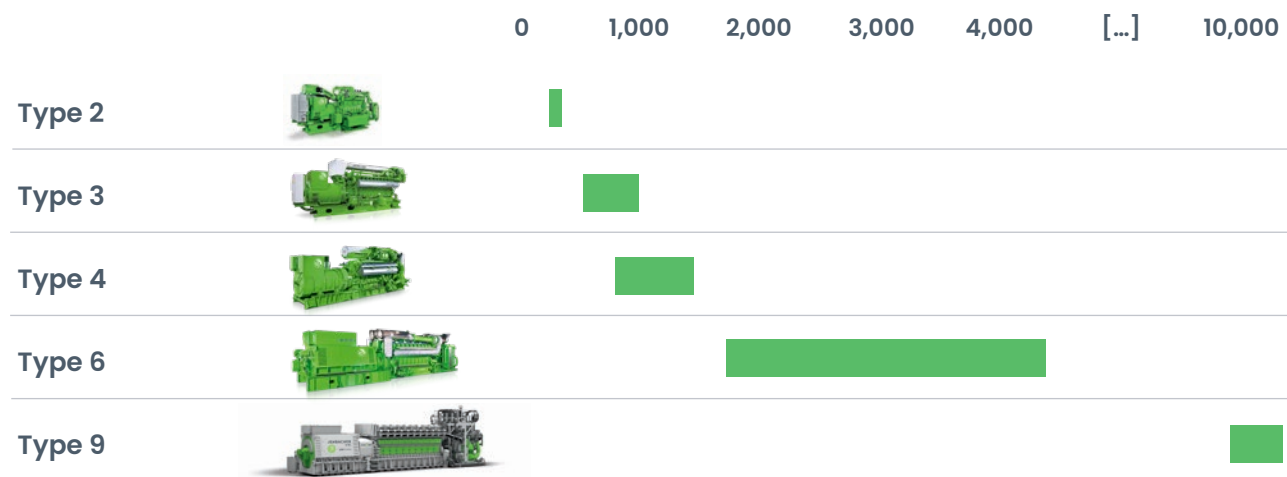
A POWERFUL portfolio

INNIO offers you a comprehensive portfolio from 250 kW up to 10.6 MW of single unit electrical power output. By using multiple gensets in one plant, the power output can be scaled up while part load performance and reliability are significantly increased.

Jenbacher solutions offer fuel flexibility with engine versions that can handle different gas qualities. Moreover, they are suitable for high ambient temperatures and elevations.

There is potential for an even more sustainable solution: INNIO's Jenbacher energy systems can use a mixture of pipeline gas and CO₂-free hydrogen as an energy source today and be converted to 100% hydrogen (H₂) operation once H₂ becomes more available.

Electrical Power Output (kWel)



Jenbacher Type 2, 3, 4 and 6 engines are available as stationary and containerized solutions. Type 9 is offered as a stationary and modular powerhouse solution.

Want to prepare for a greener future?

Visit innio.com/hydrogen to learn more about INNIO's hydrogen solutions.

"Ready for Hydrogen" = optional scope on demand



JENBACHER CHP SOLUTIONS PAY OFF

The following generic use case shows the convincing economics of a Jenbacher CHP solution with CO₂ fertilization for a Dutch greenhouse 4 ha of sizes of illuminated tomato growing. The greenhouse is equipped with 220 umol/m²/s LED light.

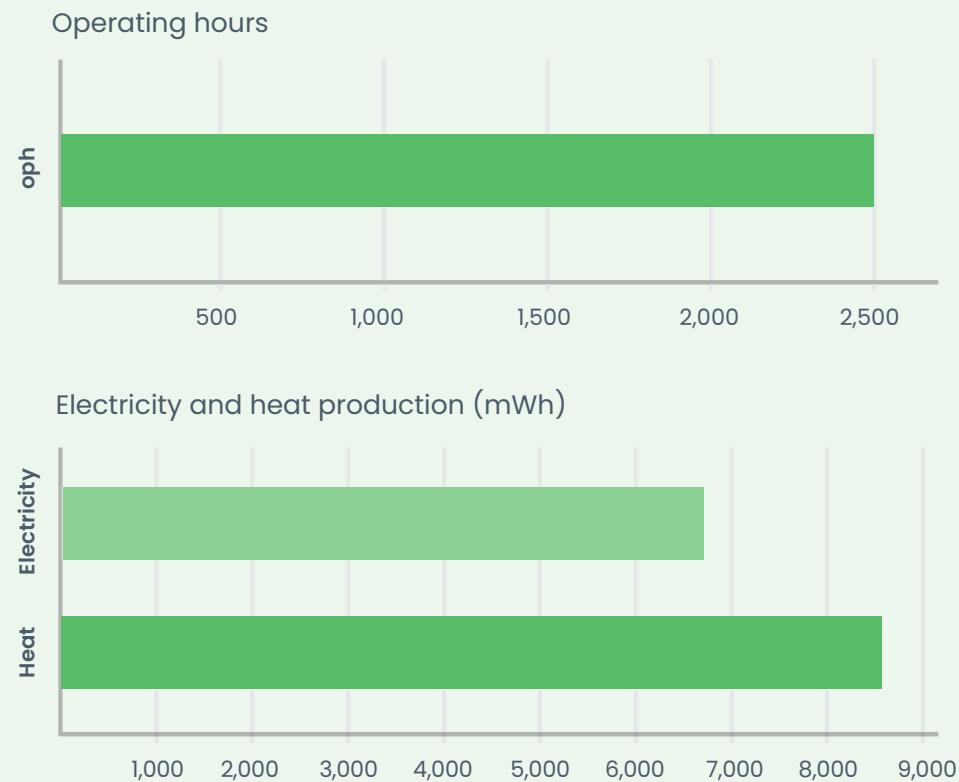
All values rounded and including depreciation.

CHP PLANT KEY TECHNICAL DATA

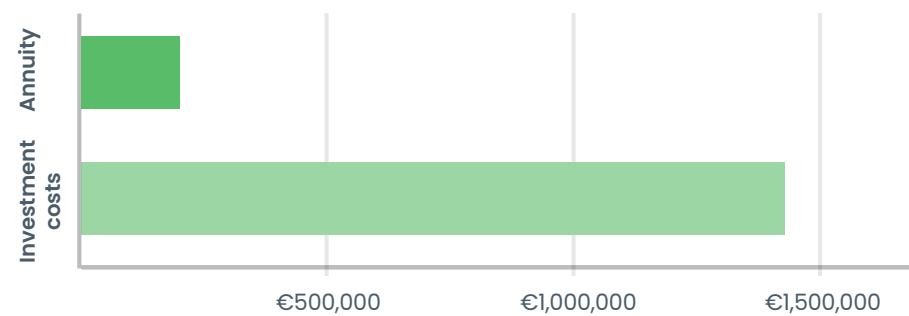
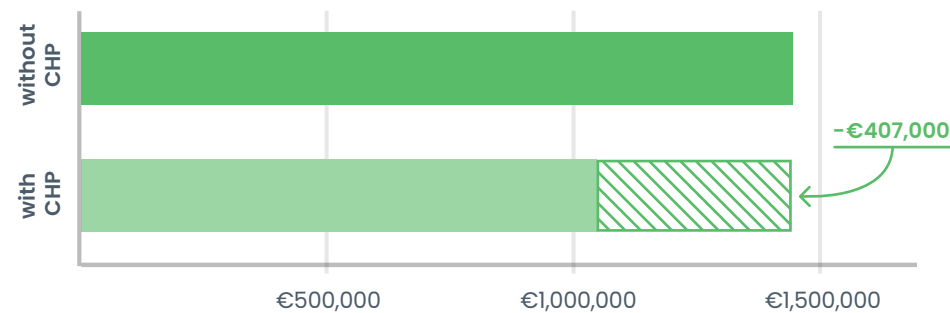
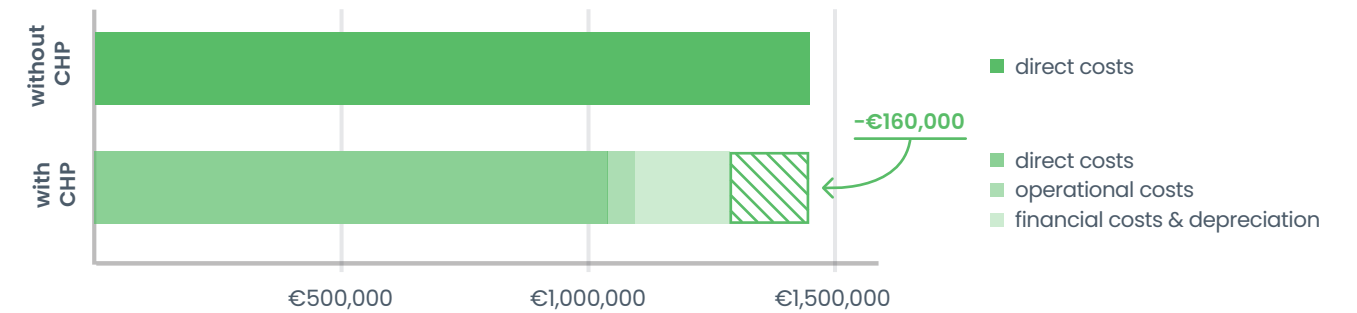
Engine	1 x J616
Energy source	Pipeline gas
Electrical output	2,676 kWel
Thermal output (capacity total)	3,436 kWth
Total efficiency	102.2%



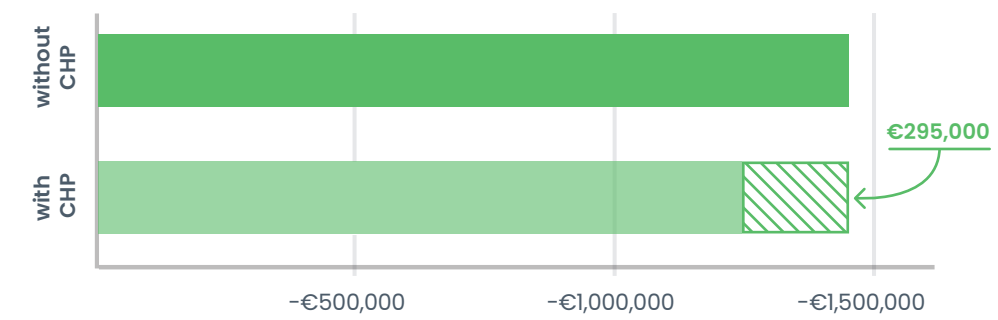
Operating parameters p.a.



CAPEX (CHP solution)

Significant energy cost savings p.a. through CHP solution³Less OPEX p.a. through CHP solution^{2,3}

Higher cash flow p.a. from operating activities



In our example, the CHP solution reduces negative cash flow from operating activities by €295,000 p.a., showing that an investment in Jenbacher CHP technology pays off.

The CHP investment payback time is less than 6 years.⁴

¹ Investment budget for a J616 CHP greenhouse setup including electrical grid connection, heating, and climate computer integration.

² The installation is financed with a bank loan with 4% interest.

³ Gas price €40/MWh; Electricity price €100/MWh (spread 2.5)

⁴ Based on the cashflow from operating activities

Looije Agro Technics is an independent specialized consultancy bureau for the greenhouse horticulture sector whose core business covers the following: feasibility studies and cost forecasts, company design and purchasing guidance, advice on and administration of all relevant legislation and regulations, complete building management and control, development of areas for market gardening, and energy consultancy.

The above presented calculations were kindly provided by Looije Agro Technics B.V.

A PROVEN CONCEPT – CASES IN POINT

The more than 1,700 Jenbacher units delivered to greenhouses around the globe have the potential to generate a total electrical output of more than 3.8 GW and a total thermal output of about 4 GW. This is powerful proof that INNIO's highly efficient CHP systems hold a leading position in the greenhouse industry. And, with optional CO₂ fertilization, our Jenbacher technology is even more beneficial to greenhouse operators.



AGR FENLAND GLASSHOUSE

Delivering low-carbon power at UK greenhouse & energy center

AGR's Fenland Glasshouse and energy center includes a combined heat and power (CHP) plant comprising three high-efficiency Jenbacher engines that deliver electricity, while an exhaust cooling system delivers recovered CO₂ to help the plants grow.

Additionally, an innovative 33 MWth heat pump system provides renewable hot water for the facility, producing 30% less CO₂ than conventionally heated greenhouses. The state-of-the-art greenhouse will grow 10% of the UK's cucumbers, reducing imports and so reducing the food sector's carbon emissions.



Cambridgeshire
United Kingdom

PLANT FACTS

Engines	1 x J416, 1 x J620, 1 x J624
Energy source	Pipeline gas
Electrical output	9 MW
Thermal output	11.2 MW
Total efficiency	101.76%*
Year of commissioning	2022

»AGR are proud to have worked in partnership with Clarke Energy and INNIO in the delivery of the 20ha Fenland Glasshouse, the heat supply for which is based on one of the largest water source heat pump arrays in the UK. Sustainable large scale glass-house developments such as this are vital in an era where energy and food security are under so much pressure.«

Konrad Aspinall,
Director and Co-Owner, AGR Group



*Highest efficiency ratings possible due to exhaust gas utilization below dew point

AMCO PRODUCE

High overall efficiency and less carbon footprint with combined heat and power

To support its energy- and heat-intensive hydroponic production, AMCO Produce turned to a combined heat and power (CHP) solution centered on a single Jenbacher J316 engine powered by pipeline gas.

Equipped with heat recovery systems, the new cogeneration plant delivers 850 kW of power and 1.2 MW of heat to meet the 100-acre greenhouse facility's baseload demand and complement its thermal demand. This cost-effective power solution achieves an impressive overall efficiency of approximately 90% while also reducing AMCO's carbon footprint.

PLANT FACTS

Engines	1 x J316
Energy source	Pipeline gas
Electrical output	850 kW
Thermal output	1.2 MW
Total efficiency	90%
Year of commissioning	2021



DEN BERK DÉLICE

Fueling greenhouse operations with combined heat and power

Meeting Belgium's goal of transitioning to 100% renewables by 2050 requires a stronger focus on power flexibility. At Den Berk Délice's greenhouses in Belgium, small distributed power plants are enabling that flexibility using Jenbacher energy solutions and greenhouse balance-of-plant equipment.

Through multi-year service agreements, the Jenbacher engines also are connected to INNIO's myPlant Asset Performance Management (APM) platform for enhanced reliability, productivity, and performance.

The high-efficiency Jenbacher engines use pipeline gas to provide heat and power to Den Berk's greenhouse complex and carbon dioxide (CO₂) to fertilize the tomatoes. The result of continuous enhancements and extensive experience, INNIO's Jenbacher 1,500-rpm Type 6 engine technology delivers high power density with low installation costs, and its pre-combustion chamber achieves high efficiency with low emissions.

About Den Berk Délice

With 82 hectares of tomato cultivation, Den Berk Délice is an exceptionally reliable, full-service specialist dedicated to growing, marketing, and innovating delicious, top-quality tomatoes. The company strives to build effective long-term relationships with its suppliers and has made extensive use of Jenbacher technology in pursuit of its mission to let its customers enjoy tomatoes 365 days a year.



»For more than a decade, we have been relying on Jenbacher solutions and services to power our multiple greenhouses. Our longstanding relationship with INNIO continues to grow, and we rely on its proven technology and deep domain expertise. The Jenbacher systems provide a bridge to renewable energy and are helping us do our part to help meet Belgium's renewable energy goals.«

Luc Beirinckx, owner, Den Berk Délice

PLANT FACTS: BERKENRIJS

Engines	2 x J624
Energy source	Pipeline gas
Electrical output	9,004 kW
Thermal output	11,220 kW
Total efficiency	103.3% (46.0% electricity, 57.3% heat)
Year of commissioning	2021



PLANT FACTS: BENTELTOM

Engines	1 x J612, 1 x J616
Energy source	Pipeline gas
Electrical output	4,684 kW
Thermal output	5,748 kW
Total efficiency	93.8% (44.8% electricity, 49% heat)
Year of commissioning	2010, 2020



PLANT FACTS: DEN HORST

Engines	2 x J624
Energy source	Pipeline gas
Electrical output	8,994 kW
Thermal output	10,702 kW
Total efficiency	102.6% (46.8% electricity, 55.8% heat)
Year of commissioning	2018, 2022

PLANT FACTS: BEIRINCKX

Engines	1 x J612, 2 x J624
Energy source	Pipeline gas
Electrical output	10,995 kW
Thermal output	12,832 kW
Total efficiency	101.7% (45.8% electricity, 55.9% heat)
Year of commissioning	2013, 2018, 2022



PLANT FACTS: DEN BERK

Engines	6 x J416, 2 x J624
Energy source	Pipeline gas
Electrical output	16,482 kW
Thermal output	20,948 kW
Total efficiency	102.3% (44.5% electricity, 57.8% heat)
Year of commissioning	2017, 2022



PLANT FACTS: LAUWERYSEN

Engines	1 x J616, 1 x J624
Energy source	Pipeline gas
Electrical output	7,175 kW
Thermal output	8,942 kW
Total efficiency	103.5% (45.9% electricity, 57.2% heat)
Year of commissioning	2015, 2022

PLANT FACTS: SALMMEIR

Engines	2 x J624
Energy source	Pipeline gas
Electrical output	8,994 kW
Thermal output	10,886 kW
Total efficiency	102.6% (46.8% electricity, 55.8% heat)
Year of commissioning	2017, 2022

PLANT FACTS: TRUYENBERG

Engines	2 x J612, 3 x J416
Energy source	Pipeline gas
Electrical output	7,617 kW
Thermal output	9,744 kW
Total efficiency	101.0% (44.1% electricity, 56.9% heat)
Year of commissioning	2016

PLANT FACTS: VROUWKENSBLOK

Engines	2 x J624
Energy source	Pipeline gas
Electrical output	9,004 kW
Thermal output	11,220 kW
Total efficiency	103.3% (46.0% electricity, 57.3% heat)
Year of commissioning	2022

OUR COMMITMENT

to you

Flexibility and experience you can count on

For the last 65-plus years, INNIO 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 80 countries and our digital capabilities, we provide life-cycle support for over 40,000 installed units globally, helping to ensure a greater runtime for longer equipment life.

Zero-carbon H₂ operation tomorrow

In addition, the same proven and economically viable INNIO equipment can be moved from conventional fuels today to full CO₂-free H₂ operation tomorrow, once H₂ 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 10,000 engines are managed remotely, evaluating more than 900 billion data points 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% H₂ 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

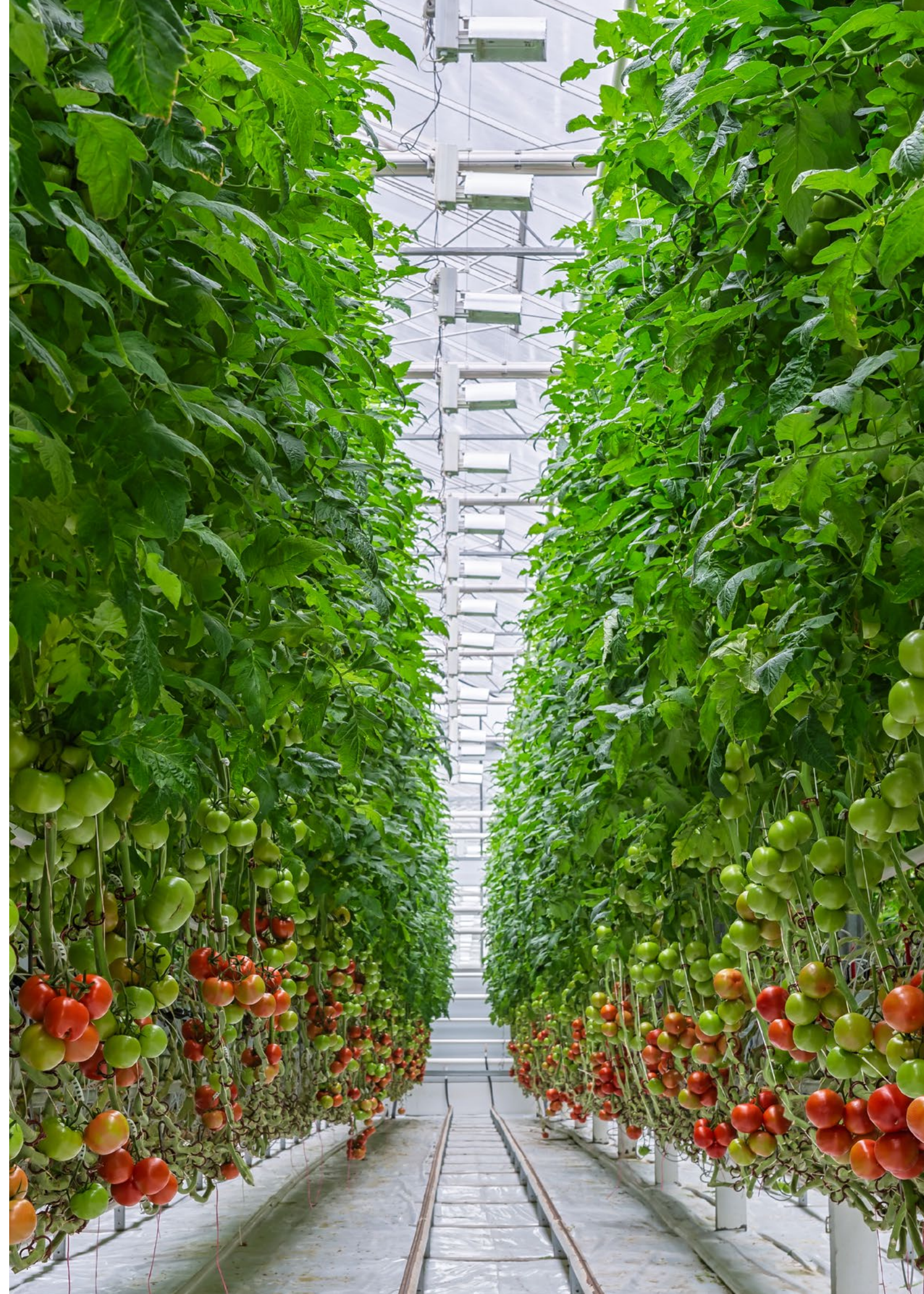
INTERESTED?

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

Let us develop a powerful energy concept for your company.

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

Our greenhouse solution experts 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, INNIO offers 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. We are individual in scope, but global in scale. With our flexible, scalable, and resilient energy solutions and services, we are enabling 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 3,500 experts provides life-cycle support to the more than 54,000 delivered engines globally through a service network in more than 80 countries.

INNIO's ESG Risk Rating places it number one of more than 500 worldwide companies in the machinery industry assessed by Sustainalytics.

For more information, visit INNIO's website at www.innio.com

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