From net zero to CARBON

Parts of the modern economy such as aviation and agriculture are extremely challenging in terms of emissions reduction, so to achieve overall net zero will require other sectors to adopt technologies that are capable of removing carbon from the atmosphere. **Anthony Smith** speaks to experts at Ricardo who are collaborating with Bluebox Energy on a highly innovative combined heat and power concept that sequesters carbon in the form of biochar

Combined heat and power (CHP) systems have long been recognized as having the potential to deliver considerable improvements in efficiency compared with the separate production of conventional electricity and thermal energy. According to the United States Environmental Protection Agency (EPA), the average efficiency of the country's fossil-fuelled power plants is just 33 percent, meaning that a full two-thirds of the energy used to produce electricity is wasted in the form of heat discharged to the atmosphere.

CHP plants act as a combined production system for both electricity and thermal energy, for example for district heating schemes or for industrial processes requiring heat; this allows them to achieve total system efficiencies, according to EPA figures, of between 60 and 80 percent for producing electricity and useful thermal energy. Some systems achieve efficiencies approaching 90 percent. Moreover, as CHP systems are typically developed at a scale appropriate to the immediate demands of an industrial facility or local community, they can also avoid the transmission and distribution losses and capital costs that would otherwise be incurred through centralized power generation.

The use of biomass as feedstock for CHP systems is particularly attractive as a potential low-carbon option, especially if the material is either derived from waste timber or from resources which will be replaced with the cultivation of further forested crops. "Biomass is being widely recognized as a major contributor to the national grid power mix," explains Dipak Mistry, director for infrastructure & utilities at Ricardo Energy & Environment.

Yet, continues Mistry, biomass also has a major role to play in the more localized CHP sector. "In the UK, major multi-gigawatt power plants show that alongside nuclear energy and renewables such as wind and solar, biomass can play an extremely valuable role in reducing the carbon intensity of grid power supplies. But we also need to focus on smaller-scale co-generation technologies, for in many industrialized societies the greater imperative is the challenge of achieving net zero through decarbonizing heat."

While conventional large-scale power and CHP plants use the conventional steam Rankine cycle, current small-scale CHP installations are often based upon the Organic Rankine Cycle (ORC). Rather than using water as the working fluid, these systems have a closed circuit filled with an organic compound with a much lower boiling point: liquids such as toluene, isobutene, isopentane or silicon fluid can be employed. The lower boiling point allows power to be generated from much lower grade heat sources across a wide range of potential biomass feedstocks. A major drawback of ORC-based small-scale CHP systems is their complexity, which attracts a comparatively significant capital cost.

Pyrolysis and FLOX combustion

Based near Portsmouth on England's south coast, Bluebox Energy is a specialist in hot air turbomachinery. The company has developed a CHP concept that promises improved efficiency and lower installed costs than current ORC systems. But that's not all: the concept also sequesters approximately 50 percent of the carbon content absorbed by the timber during its growth, and delivers it in the form of a potentially valuable by-product: biochar.

In the Bluebox concept, the biomass fuel is pyrolyzed rather than combusted. This

NEGATIVE

The use of sustainably grown or waste biomass as an energy source provides an opportunity for negative carbon emissions if carbon is sequestered in the form of biochar, separated from the flue gas

is done by heating it to a temperature at which it decomposes to form a combustible synthesis gas, together with residual carbon biochar as a by-product. The syngas produced through pyrolysis is then fed to a flameless oxidation (FLOX) combustor. A small proportion of the heat released is used to feed the pyrolysis process, while the remainder is used, via a heat exchanger, to feed a turbo-compressor and power turbine to provide clean hot air and electrical power respectively. Some of the clean hot air is used to dry the feedstock, while the remainder is used for direct air heating and industrial drying processes, or to produce hot water or steam supplies. The flue gas produced by the FLOX combustor is already very low-NOx by virtue of the lower temperature of the combustion. It is then passed through electrostatic filters to eliminate particulate matter before being exhausted to the atmosphere.

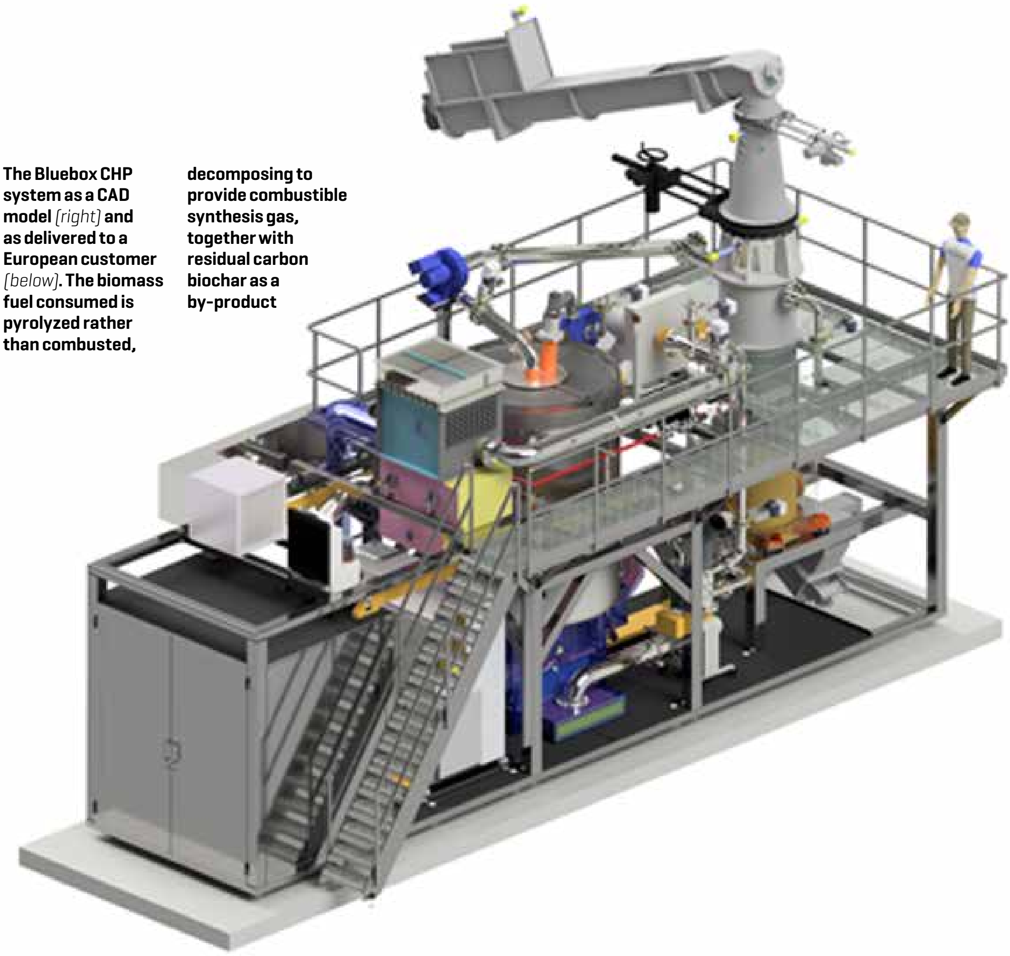
Key advantages of the Bluebox CHP concept also include its competitive cost: the turbomachinery system is based on the use of commercially available off-the-shelf components from the truck, shipping and power generation sectors. In addition to their competitive cost and easy availability, such components are also well proven in terms of robustness and reliability. This pragmatic use of available components is a major factor in Bluebox Energy's claim that its concept is between 20 and 40 percent cheaper to build than competing CHP systems based on established technologies.

Valuable biochar

In the wider context of efforts to move towards net zero, however, one of the most decisive advantages of the pyrolysis and FLOX CHP concept is its ability to sequester fully 50 percent of the CO_2 contained in the biomass fuelling the process in the form of biochar. Biochar is a product that the Intergovernmental Panel on Climate Change (IPCC), as well as the Royal Society and Royal Academy of Engineering have since 2018 recognized as one of the key available solutions for CO_2 capture in a chemically stable form.

But biochar is much more than just an attractive carbon store and effective carbon dioxide removal (CDR) technology, and has many potential valuable downstream uses. According to the European Biochar Industry Consortium, such applications even include improving the quality of construction materials such as concrete or asphalt. Biochar is also being actively investigated as a soil conditioner for horticulture and agriculture, and positive effects already reported include improving plant health through neutralizing acidity, providing better water and nutrient retention – especially in sandy soils – and improved drainage and aeration. Due to its highly porous structure, each biochar fragment also provides a habitat for beneficial soil microbes.

Biochar is also widely used as an animal feed additive, particularly for ruminants where it has been used with the aim of reducing enteric methane emissions, thus providing a potential further greenhouse gas reducing benefit. Despite its chemical stability and its high elemental carbon content of up to 90 percent, not all biochar is identical. Care has to be exercised in the selection of a pyrolysis feedstock appropriate to the intended use of the biochar - for example in the case of its use as a soil conditioner, where it is vital to ensure that the pH is acceptable. However, if the inputs and outputs of the CHP system can be balanced according to availability of the feedstock, the electrical and heat energy requirements and the intended application of the resulting biochar, the Bluebox pyrolysis/FLOX system offers considerable potential for net-negative carbon emissions.



The Bluebox CHP system as a CAD model *(right)* **and as delivered to a European customer** *(below)*. **The biomass fuel consumed is pyrolyzed rather than combusted, decomposing to provide combustible synthesis gas, together with residual carbon biochar as a by-product**

Collaboration with Ricardo

In June 2020 Ricardo and Bluebox Energy announced that they had drawn up a memorandum of understanding that will see the two companies collaborate on innovation in heat and energy technologies. The agreement follows an initial period of less formal collaboration which, as Bluebox Energy CEO Jonathan McGuire explains, has proven to be very promising: "Even in the short time we've been working together, we've already seen a number of opportunities for us to develop innovative technology-based solutions that can drastically reduce carbon. The combined expertise of both companies will enable us to make the ambitious carbon reduction targets achievable. We're now looking forward to making a real difference together."

Post-combustion carbon capture

The initial focus of the collaboration with Ricardo is on the potential integration of additional technologies to the Bluebox CHP system. These technologies would have the potential to extract a significant proportion of the carbon content of the flue gas.

"The system as it stands already captures a full 50 percent of the carbon content of the biomass feedstock and delivers this in the form of a saleable by-product," explains Ricardo's Dipak Mistry. "Our next aim is to provide additional technologies capable of capturing the bulk of the carbon dioxide from FLOX combustor exhaust."

This, Ricardo contends, will provide the opportunity to develop a fourth product

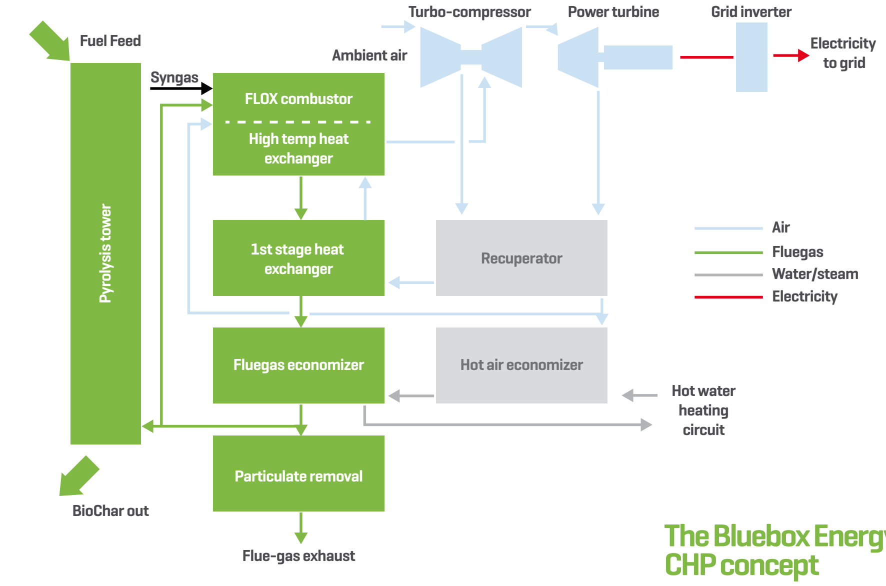
stream – commercial grade bottled CO_2 that can be used in sectors ranging from food and beverages to construction. This could be sold through a well established supply chain in other market sectors, and would complement the CHP system's primary products of electrical power and heat energy, and the existing by-product of biochar.

A number of established technologies are available for carbon dioxide capture from flue gas, each having different efficiencies and capital costs. These include separation methods such as absorption, adsorption and membrane technologies, as well as a proprietary Ricardo concept based on cryogenic liquefaction and fractional condensation. However, as Mistry explains, Ricardo is keeping an open mind on the most appropriate concept for this innovation: "We are currently exploring a range of candidate solutions that we believe could increase the carbon capture from 50 to around 90 percent. To achieve this, we are evaluating a range of possible technical solutions, including due consideration of issues of IP protection and potential commercial exploitation in other sectors."

Beyond zero carbon

The clear overarching theme of Ricardo's collaboration with Bluebox Energy is to go beyond zero-carbon processes to develop expertise in carbon-negative technology.

Where biomass is sustainably forested and harvested, there is already the potential for extremely low-carbon emission production of electricity. Through the pyrolysis and FLOX combustion CHP process that Bluebox Energy has developed, over 50 percent of the carbon absorbed from the atmosphere as the timber



The Bluebox Energy CHP concept

> **"As there will clearly be many aspects of modern life that are not amenable to a fully sustainable future, achieving net-zero carbon at a national or regional scale means that we will also need technologies that are capable of negative carbon emissions"**
> **Dipak Mistry, Ricardo Energy & Environment**

is grown remains sequestered in the form of stable biochar. If successful, the collaboration with Ricardo will see this proportion increase to about 90 percent.

In addition to the immediate carbon-negative CHP process, further indirect greenhouse gas savings may well accrue from the uses to which the biochar is put. These could be in agriculture and horticulture, or in the offsetting of the energy that would otherwise have been required to produce bottled CO_2 for the food and beverage industries.

"As there will clearly be many aspects of modern life that are not amenable to a fully sustainable future, achieving net-zero carbon at a national or regional scale means that we will also need technologies that are capable of negative carbon emissions," concludes Mistry. "In our collaboration with Bluebox Energy we are committed to taking this challenge forward, and demonstrating new and innovative approaches to CDR technology that can remove carbon from the atmosphere while delivering improved CHP performance.

"By applying truly multidisciplinary technologies and working across the boundaries of established market sectors and product lines," he continues, "I believe that we can make significant inroads into decarbonizing the production of electricity and heat and, by doing so, help to deliver a truly net-zero future for society."

Sequestered carbon dioxide can be separated and sold as a by-product, as in the case of this US bioethanol production plant