Grower Summary

PE 003

CO2 enrichment in the future: a technical and economic analysis of alternative CO2 sources

Final 2011

Disclaimer

AHDB, operating through its HDC division seeks to ensure that the information contained within this document is accurate at the time of printing. No warranty is given in respect thereof and, to the maximum extent permitted by law the Agriculture and Horticulture Development Board accepts no liability for loss, damage or injury howsoever caused (including that caused by negligence) or suffered directly or indirectly in relation to information and opinions contained in or omitted from this document.

No part of this publication may be reproduced in any material form (including by photocopy or storage in any medium by electronic means) or any copy or adaptation stored, published or distributed (by physical, electronic or other means) without the prior permission in writing of the Agriculture and Horticulture Development Board, other than by reproduction in an unmodified form for the sole purpose of use as an information resource when the Agriculture and Horticulture Development Board or HDC is clearly acknowledged as the source, or in accordance with the provisions of the Copyright, Designs and Patents Act 1988. All rights reserved.

AHDB (logo) is a registered trademark of the Agriculture and Horticulture Development Board. HDC is a registered trademark of the Agriculture and Horticulture Development Board, for use by its HDC division. All other trademarks, logos and brand names contained in this publication are the trademarks of their respective holders. No rights are granted without the prior written permission of the relevant owners.

The results and conclusions in this report may be based on an investigation conducted over one year. Therefore, care must be taken with the interpretation of the results.

Use of pesticides

Only officially approved pesticides may be used in the UK. Approvals are normally granted only in relation to individual products and for specified uses. It is an offence to use non-approved products or to use approved products in a manner that does not comply with the statutory conditions of use, except where the crop or situation is the subject of an off-label extension of use.

Before using all pesticides check the approval status and conditions of use.

Read the label before use: use pesticides safely.

Further information

If you would like a copy of the full report, please email the HDC office (hdc@hdc.ahdb.org.uk), quoting your HDC number, alternatively contact the HDC at the address below.

HDC
Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

Tel – 0247 669 2051

HDC is a division of the Agriculture and Horticulture Development Board.

© Agriculture and Horticulture Development Board 2011. All rights reserved.

Project Number:	PE 003
Project Title:	CO_2 enrichment in the future: a technical and economic analysis of alternative CO_2 sources
Project Leader:	Tim Pratt, FEC Services Ltd
Contractor:	FEC Services Ltd
Industry Representative:	Hugh Verey, Wight Salads Group Ltd
Report:	Final Report August 2011
Publication Date:	21st September 2011
Previous report/(s):	None
Start Date:	01 September 2010
End Date:	31 August 2011
Project Cost:	£21,620

Headlines

- Natural gas combined heat and power (CHP) offers the cheapest source of CO_2 for greenhouses.
- Technology allowing CO_2 enrichment from biomass boilers is available now. The investment cost is likely to be significantly less than the £155 per tonne required to make it viable.

Background

Enhancing CO_2 levels is an important part of improving the growing environment for many crops. Most growers using the technique source CO_2 directly from the exhaust gas of their natural gas (NG) fired boiler. As NG burns cleanly and has low pollutant levels, the cost of doing this is low. CO_2 derived in this way is regarded as a ‘free’ by-product of NG boiler operation.

Two major things are affecting the status of CO_2 for this use. Firstly, the efficiency of energy use for heating is getting better. Thermal screens, better controls and better structures are reducing heating fuel use and this means there is less CO_2 available for enrichment. Secondly, there is likely to be a significant shift away from fossil fuel fired boilers as a result of Government subsidies for biomass systems. Because biomass boilers do not produce a clean exhaust gas, investment may be required in cleaning technology to enable CO_2 to be derived from this source.

Beyond the move to biomass, increasing global demand for fossil fuels and the prospect of carbon taxes are likely to push up gas costs, forcing growers to look at alternatives for heating and CO_2.

This project takes a broad look at the choices growers have if they wish to use CO_2 enrichment. As well as putting costs against conventional sources to provide a benchmark, the project looks at a wide range of alternative solutions, from boiler exhaust gas cleaning, to novel boiler design, gasification, fuel cells and even CO_2 extraction from the air.

Summary

Current sources and economics

At the moment growers don’t often analyse the costs and benefits of CO_2 enrichment largely because CO_2 has been readily available as a ‘free’ by-product of heating. But as it becomes necessary to invest more in CO_2 enrichment and gas cleaning technology, understanding the value and costs of CO_2 and being able to compare costs of delivery systems becomes more important.

Understanding the true cost of CO_2 is not easy. It depends how it is valued against the heat and power which go hand in hand with its production. Clearly, if heat and power need to be generated and CO_2 is produced as a consequence, it effectively comes as 'free'. But if CO_2 is required when no heat is needed, then fuel cost for CO_2 production has to be apportioned to the CO_2 itself.

Similarly, when extra investment has to be made to allow, what would otherwise be unsuitable boilers, to deliver CO_2, then this capital has to be apportioned to the cost of CO_2 over an acceptable time.

The project has addressed these issues and produced some cost benchmarks to allow growers to gain a general idea of how much can be spent on CO_2 generation whilst working within the costs of a conventional system.

Table 1 below gives the most fundamental benchmark; that being the cost of CO_2 from burning gas where the heat from the process is not required in the greenhouse.

Table 1. Cost of CO_2 from NG boilers

Cost of natural gas		**Cost of CO_2**
Pence/therm	**Pence/kWh**	**£/tonne**
30	1.02	55.65
40	1.37	74.19
50	1.71	92.74
60	2.05	111.29
70	2.39	129.84
80	2.73	148.39
90	3.07	166.94

In terms of conventional fossil fuel combustion, the next step is to adopt combined heat and power (CHP) which has a higher capital cost, but a greater capacity to produce CO_2 (per unit heat required). The following graph relates CO_2 costs, to payback time on capital invested in CHP, and 'spark spread' – the difference between electricity cost and the gas required to generate it.

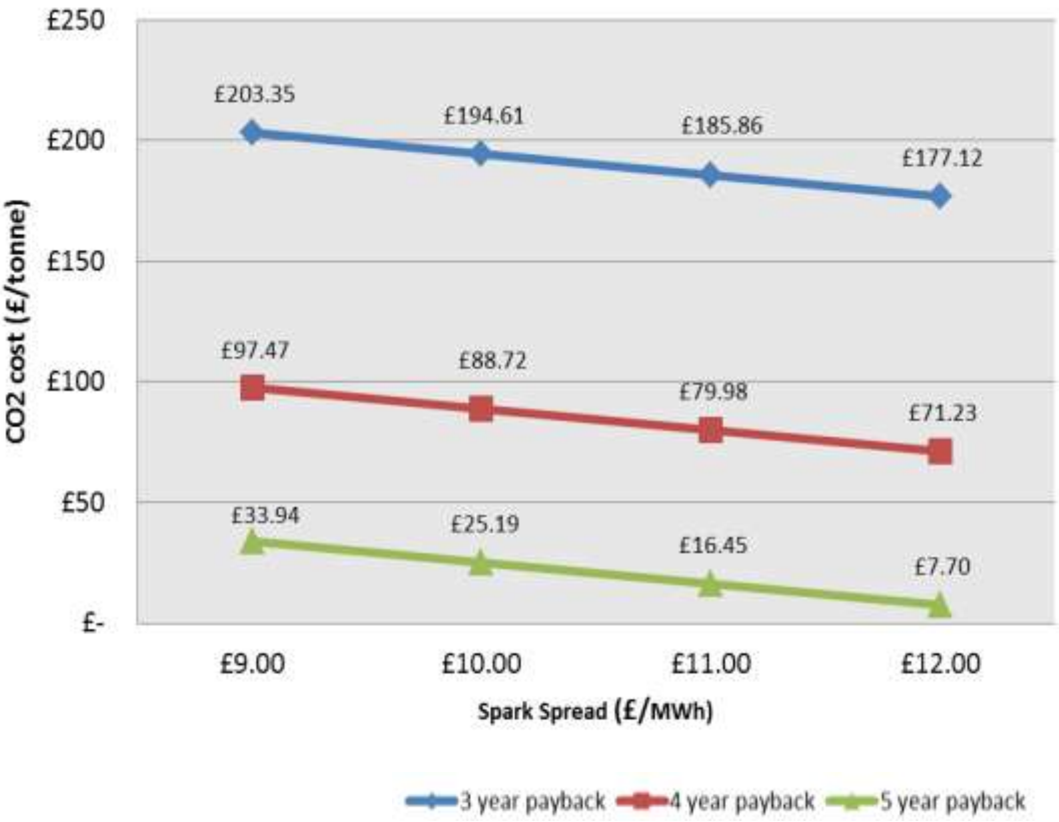

Figure 1. Cost of CO_2 from natural gas CHP

These figures, together with the raw energy costs for the generation of CO_2 set out in Table 1 give a set of benchmark costs against which other technologies can be compared.

Biomass boiler CO_2 economics

When considering biomass boilers it is possible, by starting with fuel cost savings, to state a notional saving per tonne of CO_2 produced and hence derive how much a grower could afford to spend on exhaust gas clean up whilst still producing CO_2 at a lower price than would be possible using gas.

Table 2. Biomass boiler CO_2 economics

Technology	Fuel cost per tonne of CO_2 minus RHI (where applicable)	Annual cost for 5 Ha greenhouse (1,780 tonnes of CO_2)	5 year saving over gas for 5 Ha site	Saving per tonne of CO_2 compared with gas
NG boiler	£111.29	£198,096	-	
Wood chip boiler	£24.91	£44,339	£768,765	£86.38
Straw boiler	-£43.85	-£78,053	£1,380,745	£155.14

Note. Straw is significantly cheaper than wood chip but only if it can be sourced close to the nursery.

So, a 5 Ha site with a straw boiler could afford to spend £1.38 m on gas clean up and still produce CO_2 as cheaply as burning gas (assumes five year payback). A further factor that has significant potential value is that you get at least twice as much CO_2 per MWh of heat from a biomass boiler than you do from a natural gas boiler i.e. similar to a conventional CHP installation.

How clean do CO_2 sources need to be?

This was investigated in detail in HDC Project PC 287 (2009) and identified NO_x, SO_x and ethylene as the main problem gases. Empirical relationships derived by PC 287 allowed a table of broadly 'safe' (economically tolerable) pollutant levels to be produced.

Table 3. 'Safe' concentration of pollutants in flue gas using volume ratio (CO_2:pollutant)

By volume	**Threshold**	**CO_2 concentration**	
		600 ppm	**1,000 ppm**
NO_x	250 ppb	2,000	3,809
	400 ppb	1,250	2,424
SO_x	100 ppb	5,000	10,000
	200 ppb	2,500	4,705
Ethylene	10 ppb	50,000	100,000
	20 ppb	25,000	47,058

By mass	**Threshold**	**CO_2 concentration**	
		600 ppm	**1,000 ppm**
NO_x	250 ppb	1,913	3,681
	400 ppb	1,193	2,301
SO_x	100 ppb	3,482	7,158
	200 ppb	1,741	3,221
Ethylene	10 ppb	80,526	161,052
	20 ppb	40,263	75,789

Note - these figures are approximations, given the accuracy of data available and assumptions made to convert them to a common format.

Current CO_2 enrichment requirements

To be able to specify / compare alternative CO_2 supplies it is useful to know:

The design delivery rate tonnes/hour.

The annual consumption tonnes/Ha.

Table 4 details CO_2 delivery capacities currently found on UK nurseries.

Table 4. CO_2 delivery capacity

	m^3/hr/Ha of natural gas burnt	kg/hr/Ha of CO_2 delivered	tonnes/hour required by a 5 Ha nursery
NG boiler	100	209	1.0
	150	314	1.6
NG fuelled CHP	200	418	2.1
	250	523	2.6

HDC Project PC 265, (2007) determined a CO_2 use of 356 tonnes per Ha p.a. on a nursery where the CO_2 enrichment policy was to only derive CO_2 from the boiler when heat could either be usefully used or stored.

Potential sources of CO_2

Natural gas fuelled reciprocating engine CHP

This may not seem like an alternative source of CO_2 but few growers have a CHP installation. A new CHP installation can produce CO_2 at a relatively low cost per tonne. See Figure 1 above.

Biomass – combustion

Biomass combustion (wood chip and straw in particular) is becoming an important technology because of subsidies provided by the Renewable Heat Incentive. However, the flue gases are not clean enough to use for CO_2 enrichment without further treatment.

Investment in a high quality boiler/combustion system is vital to ensure the lowest possible pollutant levels in the first instance. This will reduce and possibly even eliminate the cost of any further treatment. Key design features are:

- Moving stepped grate – to deliver the most uniform combustion possible.
- Combustion air control – independent control of primary and secondary combustion.
- Well-designed combustion chamber – to ensure complete combustion of organic compounds.

Table 5. Biomass boiler: flue gas cleaning requirements

Particulates	A high standard of particulate removal is recommended. Bag or ceramic filters are best suited to this.
NO_x	A good quality wood chip boiler might deliver acceptable NO_x levels. A straw boiler will not. Ceramic filters impregnated with a selective catalytic reduction catalyst are a possible solution.
SO_x	SO_x removal is advisable. Dry scrubbing with sodium bicarbonate is possible.
Ethylene	The worst case ethylene concentration is borderline acceptable so should be checked.
Tars & other volatile compounds	Detailed flue gas analysis is required to determine if these are likely to be a problem. A flue gas condenser may provide sufficient removal.

Biomass – anaerobic digestion

The greatest problem with anaerobic digestion (AD) is the presence of hydrogen sulphide in the digester gas which leads to SO_x in the CHP engine flue gas. This significantly reduces the lifetime of selective catalytic reduction (SCR) NO_x removal equipment. The removal of SO_x using dry scrubbing techniques combined with a catalyst for NO_x removal seems possible. AD plants are not likely to become popular for greenhouses because of feedstock demands and digestate disposal issues.

Biomass – gasification

Gasification converts dry biomass into a combustible gas using heat in a low oxygen environment. The gas is partially cleaned and then burnt in a reciprocating engine CHP installation. This has similar pollutant removal issues (and solutions) to combustion and AD. Gasifiers of an appropriate scale are increasingly common in India and China. However, few are found in Europe. CO_2 enrichment aside, growers considering this option should include performance guarantees with associated penalties in any equipment supply contract.

Fresh air

Trials have demonstrated a small but practical wet scrubbing and heat driven regeneration concept which could be scaled up for horticulture. The inferred running cost (pumping and air compression) was £18.99 per tonne of CO_2. This excludes heat for regeneration which is expected to be low.

Gas cleaning technology

Particulates. A high level of particulate removal is recommended in all situations. In addition to removing some pollutants it also increases the lifetime/reduces the cost of many follow-on gas cleaning technologies.

Bag and ceramic filters offer the best potential for horticultural applications, especially biomass boilers. The ability to combine SCR NO_x removal with ceramic filters is particularly interesting.

NO_x and SO_x. The amount of NO_x and SO_x are largely determined by the amount of sulphur in the fuel. Subject to cost, low sulphur fuels should be the first step in any NO_x / SO_x reduction process. Straw contains much more nitrogen and sulphur than wood chip so the flue gases require more treatment to enable CO_2 enrichment.

SO_x can be removed by dry scrubbing using calcium hydroxide or sodium bicarbonate. NO_x can be removed by selective non catalytic reduction (SNCR) with ammonia. However, this requires a gas temperature of 850-1,000 °C (140 °C from a biomass boiler). Selective catalytic reduction (SCR), as used in conventional CHP installations, works best at around 400 °C. Conventional SCR material is easily 'poisoned' by SO_x and some other chemicals. However, the development of catalyst impregnated ceramic filters appears to have solved this problem and they claim to work at 250 °C.

The remaining issue is that flue gases from a biomass boiler are not hot enough to work with SCR. However, modifying the boiler or even re-heating the flue gases seems a viable solution.

All the technologies reviewed are:

- Available commercially.
- Proven in various applications and industries.
- Some are already proven in horticulture, albeit not specifically for CO_2 enrichment from biomass in particular.

The level of technical risk associated with these technologies, if correctly applied, should therefore be low. We have been unable to source indicative costs, for all of these technologies.

Carbon capture and storage (CCS)

CCS is subject to massive research and development investment to help decarbonise the power generation industry.

There are three main carbon capture technologies:

1. Absorption.
2. Adsorption.
3. Membrane separation.

Adsorption is closest to commercial application. CO_2 is absorbed by a solvent, typically an amine solution, and is then released by heating the solvent to around 140 °C. The solvents in question are not 100 % CO_2 selective, so some pollutants are absorbed as well. However, research suggests that they can be separated by 'boiling them off' at different temperatures.

Financial benefits

As this project was only intended to provide a broad overview of technologies, specific financial guidance is not provided.

However, in the "Current Sources" section of the grower summary the investment case for a natural gas fuelled reciprocating engine CHP installation is made. At a very competitive CO_2 cost of £30 per tonne a CHP installation will give a payback on investment within five years.

The financial case for investment in gas cleaning technology for a biomass boiler is much less certain. However, based on a five year payback our 'typical' 5 Ha nursery could afford to spend up to £1.4 m on capital and running costs to achieve this with a straw fuelled boiler. Ballpark capital costs provided by one equipment supplier to remove SO_x and NO_x using catalyst impregnated ceramic filters was £500 k. This provides sufficient room for on-going running costs and higher capital costs to remain interesting.

Extracting CO_2 from fresh air may be financially viable. A greenhouse scale system might cost upwards of £250 k and incur variable costs of £30 per tonne. This adds up to £517 k over five years for our 5 Ha nursery. So again, this leaves sufficient room for higher capital and running costs to remain interesting.

Action points

Key points for growers:

- Try to gain a greater understanding of true CO_2 generation costs and also the value derived from CO_2. This will help in the future when assessing capital investments on CO_2 enrichment and cleaning technology.
- Have a close look at natural gas (NG) driven combined heat and power (CHP) plant economics in tandem with the benefits of the extra CO_2 that can be derived.
- If a move towards biomass boilers is intended don't forget to consider the suitability of the plant for CO_2 enrichment. Ensuring the cleanest possible flue gas at this stage will reduce the cost of cleaning equipment in the future.
- Obtain flue gas analysis for plant using the same fuels you will be using and assess the minimum amount of gas treatment you'll need to do to make CO_2 extraction possible.
- With biomass boilers, consider using a cleaner fuel during the CO_2 production season to avoid or minimise the need for flue gas cleaning equipment.
- Keep an open mind to novel technologies. Interesting developments are taking place in combustion design, alternative fuels, gas cleaning and even CO_2 extraction. It's a fast changing area of technology - so keep up to date.

Further work

CO_2 from fresh air shows significant potential as a novel technology. The capital and running costs of a greenhouse scale installation should be explored in detail.

Biomass boilers will become a mainstream heat source in the near future. Comprehensive flue gas analysis should be carried out on commercially operated biomass boilers in the UK.

Detailed specifications and costs should be obtained from flue gas cleaning equipment suppliers. This will provide growers with greater certainty over likely costs and performance.

The economically optimum rate of CO_2 delivery. Growers lack readily interpreted information that allows accurate decisions to be taken. This is an issue with current CO_2 sources but even more so with alternative sources as it could have a significant impact on the capital investment required. As this is such a complex subject and it did not fall within the scope of this project means it is difficult to make specific recommendations as to how this might be addressed. However, it is clear that further work is required.