Recovery & Reuse of Water and Carbon Dioxide from Industrial Waste Streams

Final Report

Prepared for the Environmental Protection Agency

by

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This report incorporates the findings of two feasibility studies

Water Recovery Feasibility Study

Project Code: 2010-ET-CP-20

&

CO_2 Recovery Feasibility Study

Project Code: 2010-ET-CP-25

1 Summary

In this project, the feasibility of recovering water and carbon dioxide from industrial waste streams in Ireland was assessed.

Six facilities, from the brewing, dairy ingredients, liquid milk, snack foods and pharmaceutical industries, were examined and the potential for recovery and reuse of water and carbon dioxide was assessed. The results were then extrapolated across similar facilities in each industry to quantify the potential for recovering water and carbon dioxide in Irish industry as a whole.

It was estimated that 34% of water supplied to all IPPC licensed companies is recoverable from individual waste water streams. This equates to 13.9 million m^3/annum. If mains distribution losses are taken into account, which are approximately 44%, the gross savings to the water supply network could be as high as 24.8 million m^3/annum.

Current water prices do not incentivise water recovery and, from the four facilities examined, four opportunities for waste water recovery using membrane filtration were identified as being financially viable.

CO_2 recovery opportunities were identified which could reduce CO_2 emissions from industry in Ireland by 3.2% but these opportunities are limited by the CO_2 sinks available. Identification of applications for recovered CO_2 will be important in making these projects feasible. One sink which has potential for many sites is the use of CO_2 for neutralisation of waste water effluent. A 1.3% reduction in CO_2 emissions could be achieved by this means at one of the sites assessed in the study.

Each opportunity was assessed with respect to environmental and economic impacts. Revenue can potentially be earned through CO_2 recovery from the following sources

- Emissions trading (carbon credits)
- Sale of bulk CO_2
- Displacement of bulk CO_2 or other purchased material

Carbon credits can substantially improve feasibility of emissions reduction projects. It should be noted however that not all CO_2 emissions are covered by the EU Emissions Trading Scheme (ETS); for example, CO_2 produced from fermentation.

Throughout the report, part *A* of each section will deal with the water recovery feasibility study and part *B* will deal with the CO_2 recovery feasibility study. Where neither A nor B is specified, the text is applicable to both studies.

2 Background – Aim & General Description

2.1 Participant Description

FDT is a 100% Irish-owned, independent process engineering consultancy, based in Dublin, serving clients in Ireland, the UK, Europe and Africa. Formed in 1991, the company has a highly skilled team of engineering consultants with professional qualifications and strong technical experience that provide in-depth knowledge of process, utilities & packaging plant.

FDT serve a range of sectors, such as Brewing, Food and Dairy, Pharmaceutical, Healthcare and Chemical industries, with a variety of process engineering solutions and consulting services. FDT provide a range of Sustainability and Resource Efficiency services which help to reduce our client's operating costs and help them meet their compliance obligations.

As part of this, FDT has taken part in Cleaner Greener Production Programme Phases 1, 2 and 4. These include: Pilot Plant for Recovery of Caustic from Spent CIP Solutions, Diageo Dundalk Industrial Scale Spent Caustic Recovery Plant, Galco Spent Pickle Acid Recovery and Reuse, Galco Continuous Flux Treatment System.

Six companies took part in this project in conjunction with FDT. These companies were;

- Dairygold, Mitchelstown
- Largo Foods, Ashbourne
- Diageo, Dundalk (Water project only)
- Rottapharm Madaus, Mulhuddart (Water project only)
- Diageo, Kilkenny (CO_2 project only)
- Glanbia, Ballytore (CO_2 project only)

2.2 Aim of Project

The overall aim of this project was to quantify the potential for Water and CO_2 recovery & reuse in Irish Industry.

2.2 A - Water Recovery Feasibility

The aim of this project was to assess the water recovery potential in Irish Industry. There is currently very little evidence of water being recovered and reused within the production process on large industrial sites in Ireland. Water is an increasingly expensive commodity for many industries. This project aimed to encourage companies to recover water for process use by demonstrating that it is not only technically feasible, but also commercially advantageous.

One of the main barriers to implementing water recovery is perception, i.e. using "dirty" water to make product. If the potential to recover high quality water, while also achieving significant financial savings, can be shown across a range of industries, then this perception can be challenged.

The secondary aim of this project was to investigate the chemical composition of the membrane concentrate to determine if valuable by-products can be extracted from waste streams. The separation of by-products would have the benefit of reducing the effluent treatment requirements, while also reducing procurement costs or adding a revenue stream.

2.2 B - CO_2 Recovery Feasibility

Ireland ratified the Kyoto Protocol in 2002. In this agreement, Ireland committed to limit its growth of greenhouse gas emissions to 13% above 1990 levels. The aim of the study presented in this document was to investigate ways of reducing CO_2 emissions in industry through the use of by-product CO_2 and to assess the feasibility of these opportunities.

CO_2 sources and potential sinks were identified at four sites in the Brewing, Liquid Milk and Snack Foods sectors. The quality of each source and its suitability for recovery and re-use was ascertained through flue gas analysis and use of existing site data. The results obtained at the participating sites were extrapolated to similar industrial sites to quantify the overall potential for CO_2 recovery and re-use in industry in Ireland.

3 Project Implementation

3.1 Investigation of Prevention Opportunities

3.1.1 Strategy to identify Prevention Opportunities

The opportunities for reducing the production of waste water and CO_2 were identified by carrying out the following tasks at each facility.

- Assessment of Sources

  An information gathering exercise was undertaken in conjunction with site representatives, which involved identifying each waste water or CO_2 source and compiling detailed information on its operation.

  Typical information would be equipment design specifications, run hours, site metering data – including chemical or fuel consumption, emissions monitoring and P&IDs. This information was compiled to provide an accurate picture of waste water / CO_2 production on each site.

  Due to the extensive use of water on all sites, a mass balance diagram was generated to illustrate the water flows at each facility.

- Identification of Sinks

  Site water standards, in addition to the mass balance diagram, were used to identify the most appropriate sinks for recovered water.

  Site operations were examined to quantify any current uses for CO_2 and to identify any prospective uses e.g. waste water neutralisation, use of CO_2 by a neighbouring company.

3.1.2 Knowledge of Company Operations

Knowledge of company operations was enhanced in a number of ways, including an increased awareness of the origins of waste, types and costs of waste.

<u>Origins of Waste</u>

Excel spreadsheet documents were generated for both the water and CO_2 recovery projects. These spreadsheets listed every significant source of water / CO_2 at each facility and included the volumes generated by each waste source.

A mass balance of the water system was generated for each facility. This is a useful tool for companies to use to understand their water usage and waste water generation. Piping & Instrumentation Drawings can be too detailed to provide real insight into how water is used on site, while graphical representation on control screens usually omit a lot of information and often ignore the flow of waste water. The mass balance diagrams were prepared in Microsoft Excel so they could be modified and updated regularly on site based on metering information. These spreadsheets could be used to calculate project feasibility calculations in the future.

Types of Waste

The Excel spreadsheet documents were also used to track the results of the laboratory and on-site testing of waste streams. This format facilitated comparison between different waste streams. Examples of the data collected are as follows;

CO_2 Waste Stream

- Concentration of O_2, CO and CO_2
- Temperature of flue gas
- Velocity of flue gas (where possible)
- % operating efficiency
- % excess air

Waste Water Stream

- Colour
- Conductivity
- Chemical Oxygen Demand
- pH
- Dissolved Solids
- Hardness

Knowledge of the chemical composition and physical parameters of different waste streams illustrates clearly to personnel that there are varying levels of contaminants across different waste streams. This helps to dispel the misconception that all waste streams are universally "dirty".

Costs of Waste

Each site was issued with a final findings document for water and / or CO_2 recovery. These reports have provided personnel at the facilities with a greater awareness of the costs associated with water use and also the potential savings that can be achieved through reducing water consumption and CO_2 emissions. This knowledge will be useful in planning future projects on the sites

3.1.3 Prioritised Improvement Options

3.1.3 A - Water Recovery Feasibility

Fresh water consumption may be reduced by recycling it in any of the following ways

- Direct Reuse: This is where a waste water stream is reused directly with little or no treatment. This may be possible if the waste water is of adequate quality to meet the site quality requirements of another user.
- Recycle using Coarse Filtration: This may be appropriate where there is a low level of contamination in the waste water stream.
- Recycle water using membrane filtration: While this method of water recycling is more expensive, membrane filtration can be very effective at removing medium or high levels of contamination from waste water streams. An additional benefit associated with membrane filtration is that it may be possible to recover valuable by-products from waste stream on some sites.

In general, water saving opportunities should be assessed on payback period, potential water saving and ease of implementation and this approach was taken in the on-site testing and subsequent analysis.

3.1.3 B - CO_2 Recovery Feasibility

CO_2 emissions can be reduced by reusing CO_2 in the following ways.

- Use in existing application as substitute for purchased CO_2
- Use in new application e.g. neutralisation of alkaline waste water as substitute for mineral acid
- Exported for use off site

Emissions reduction opportunities should be assessed on payback period, magnitude of carbon savings and ease of implementation.

3.1.4 Implemented Improvements

Details of potential improvements were communicated to each site in individual Overview of Findings Reports (see Annexes) and where applicable, next steps were advised. None of the proposed improvements have been implemented at this time.

3.2 Changes in Practices or Processes

3.2.1 Outline Description of Project

3.2.1 A - Water Recovery Feasibility

Four production facilities, with a combined total water usage in excess of 1.6 million m^3 /annum, were identified to take part in the project;

Industry	Production Facility	Annual Water Consumption (m^3)
Dairy Ingredients	Dairygold, Mitchelstown	1,100,000
Brewing	Diageo, Dundalk	500,000
Pharmaceutical	Rottapharm Madaus, Mulhuddart	20,000
Snack Foods	Largo Foods, Ashbourne	70,000

Table 3.1 Details of Production Facilities

The sequence of activities for the project was as follows:

1. Identification of the main effluent sources and sinks on each site

   The main effluent sources and sinks were identified as described in Section 3.1.1. An example of the type of a mass-balance diagram generated for one of the facilities is shown in Appendix 4 . For each site, the potential sinks exceeded the potential sources.

2. Conduct laboratory analysis on each of these effluent sources

3. Identification of the most appropriate sources for water recovery and by-product recovery

   The results of the laboratory tests were analysed to determine whether or not a particular waste stream was suitable for membrane filtration and, if so, which membrane should be used in the trial.

4. Conduct pilot membrane trials

   A second sample was taken from the waste streams for which membrane filtration was deemed to be an appropriate treatment process. Each sample was pre-filtered, using filter paper of pore size 8µm, in order to remove coarse impurities and suspended solids.

   Reverse Osmosis filtration of the samples was carried out using a Koch KMS Laboratory Cell CF-1, shown in Figure 3.1. Each membrane filtration trial was initiated with 500ml of the pre-filtered sample in the process tank of the laboratory cell. The pump was turned on, to circulate the sample around the loop, and pressure was applied by means of bottled Nitrogen gas.

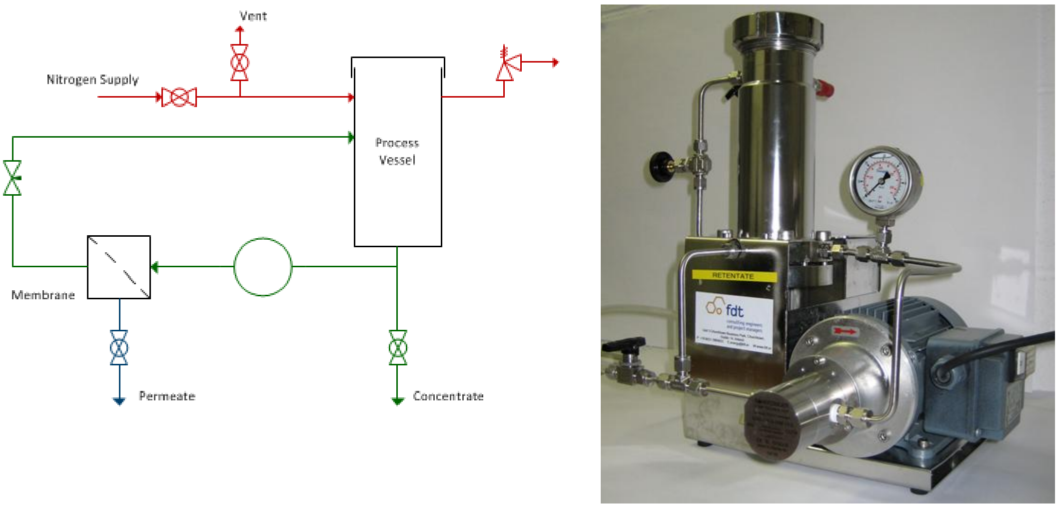


Figure 3.1 Koch KMS Laboratory Cell CF-1 used in water trials

Figure 3.2 shows an example of the concentrate and permeate collected from membrane filtration of a waste water stream. The plant operating conditions, flux rate and VCF were measured regularly throughout each trial so that the membrane performance could be assessed.

Figure 3.2 Example of Concentrate and Permeate resulting from Membrane Trials on Waste Water from Potato Peelers at Largo Foods

5. Conduct laboratory analysis on each of the permeate samples

6. Analysis of the results of the pilot trials and assessment of the potential for water and by-product recovery on each site

   The results of the laboratory analysis were used to assess the effectiveness of membrane filtration in cleaning each waste water stream. Based on these results, it was determined whether or not the permeate was of suitable quality to be reused at the facility. The specification required for water reuse varied between each facility and between each potential sink for recovered water.

   The flux rate and Volumetric Concentration Factor (VCF) were used to indicate the efficiency with which the membrane filtration cleaned the sample. Two examples of flux rate vs. VCF trends are shown in Figure 3.3. This information was utilised in the payback period calculations.

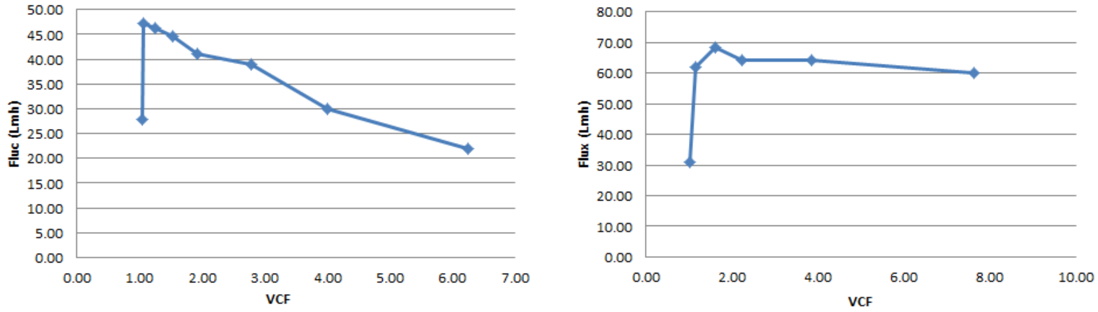


Figure 3.3 Examples of Flux vs VCF trend for (1) Waste Water from Potato Peelers at Largo Foods and (2) Waste Water from Bulk Pharmaceutical Area at Rottapharm Madaus

7. Extrapolate the results to identify the potential for water recovery and by-product recovery in each of the industries identified

   Where the permeate quality met site water requirements, the waste water stream was deemed to be "recoverable using membrane filtration". The efficiency of the membrane filtration was not factored into this assessment.

   Where the permeate quality was not sufficient to meet site water requirements, the waste water stream was deemed to be "unrecoverable".

   The results from each site were extrapolated across the industry in which it operates and for IPPC industries that were not included in the project, the average figure was assumed. In this way, the total potential for water recovery using membrane filtration in Irish industry was estimated.

3.2.1 B - CO_2 Recovery Feasibility

Four production facilities, with combined CO_2 emissions of 67,830 T /annum, were identified to take part in the project;

Industry	Production Facility	Annual CO_2 Emissions
Dairy Ingredients	Dairygold, Mitchelstown	58,600 tonnes
Brewing	Diageo, Kilkenny	4,000 tonnes
Dairy (Liquid Milk)	Glanbia, Ballitore	730 tonnes
Snack Foods	Largo Foods, Ashbourne	4,500 tonnes

Table 3.2 Details of Production Facilities

The sequence of activities for the project was as follows:

1 Identify the main CO_2 sources on each site and quantify using site data, such as previous emissions testing, fuel usage and run hours of equipment.

2 Identify (and quantify if possible) any existing or potential CO_2 sinks on each site.

3 Obtain details of existing CO_2 recovery system on site, if applicable.

4 Generation of schematic for each site showing details of CO_2 production and use.

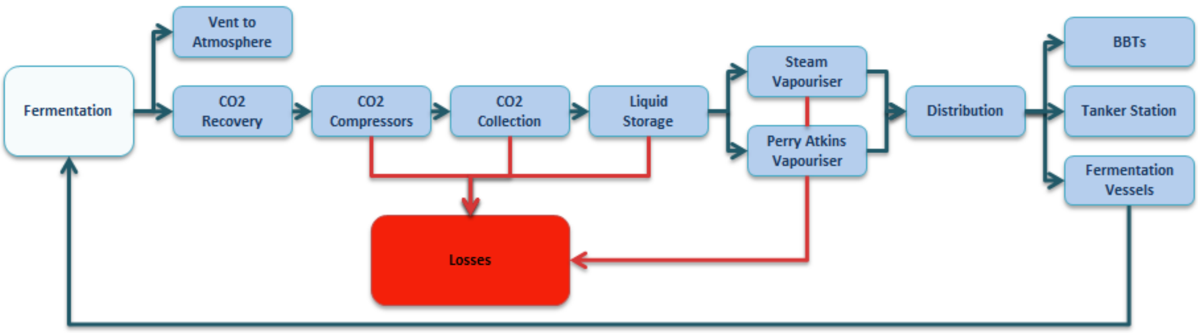


Figure 3.4 Schematic of existing CO_2 system in Diageo, Kilkenny

5 Assess financial benefit of emissions reductions to each site.

6 Access IPPC license and EU Emissions Trading Scheme data online for each site.

7 Specify and purchase emissions testing equipment

Emissions testing was carried out using a Testo 340 Flue Gas Analyser (shown in Figure 3.5).

Figure 3.5 Testo 340 Flue Gas Analyser

8 Perform flue gas testing at each significant CO_2 source (Figure 3.6).

Most boilers and CHP turbines have dedicated ports for flue gas testing. The emissions analyser was used to measure the concentration of oxygen and carbon monoxide in the flue gas stream and, where the sample point was large enough, a pitot tube was used in conjunction with the flue gas analyser to measure the velocity of the stream.

Figure 3.6 On-site CO_2 Testing

9 Analyse emissions testing data and quantify the potential for emissions reductions on each site.

The oxygen and carbon monoxide concentrations were used to calculate the concentration of CO_2 in the flue gas stream.

The velocity of the flue gas stream, in addition to the diameter of the exhaust was used to determine the total flue gas flow rate.

10 Size CO_2 dosing equipment for pH balancing and CO_2 recovery plants and obtain budget pricing from vendors.

11 Perform payback analysis including carbon credits where applicable, to assess economic feasibility for each plant.

12 Extrapolate the results to examine the potential reduction in CO_2 emissions in each of the industries/technologies assessed.

3.2.2 Project Management

Both projects were run by the Project Co-ordinator at FDT (see section 2.1), Michael Clancy. He had responsibility for liaising with the EPA, FDT project engineers, FDT technical specialists, FDT Financial Controller and the companies taking part in the projects. The FDT Project Engineers, Aoife Hamill and Fiona Murray were the main client points of contact and carried out the bulk of the site work and subsequent analysis.

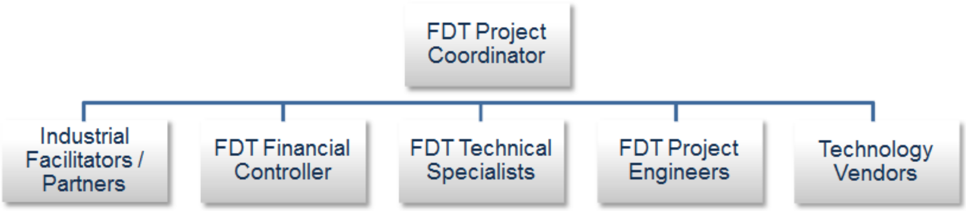


Figure 3.7 Project Organisation

A series of project meetings were held throughout the life of each project in order to ensure that all parties were aware of progress and any new developments. These meetings took place at each major stage of the process and progress was tracked against the Gantt chart in the initial project submissions.

3.2.3 Operating History

The Water Recovery project commenced in December 2010 and the final report was submitted at the end of January 2012, so it had a fourteen month span.

The CO_2 recovery project commenced in January 2011 and therefore had a thirteen month span.

Both projects took place during normal site operation and thus did not have any impact on normal production.

Water Recovery Project

CO_2 Recovery Project

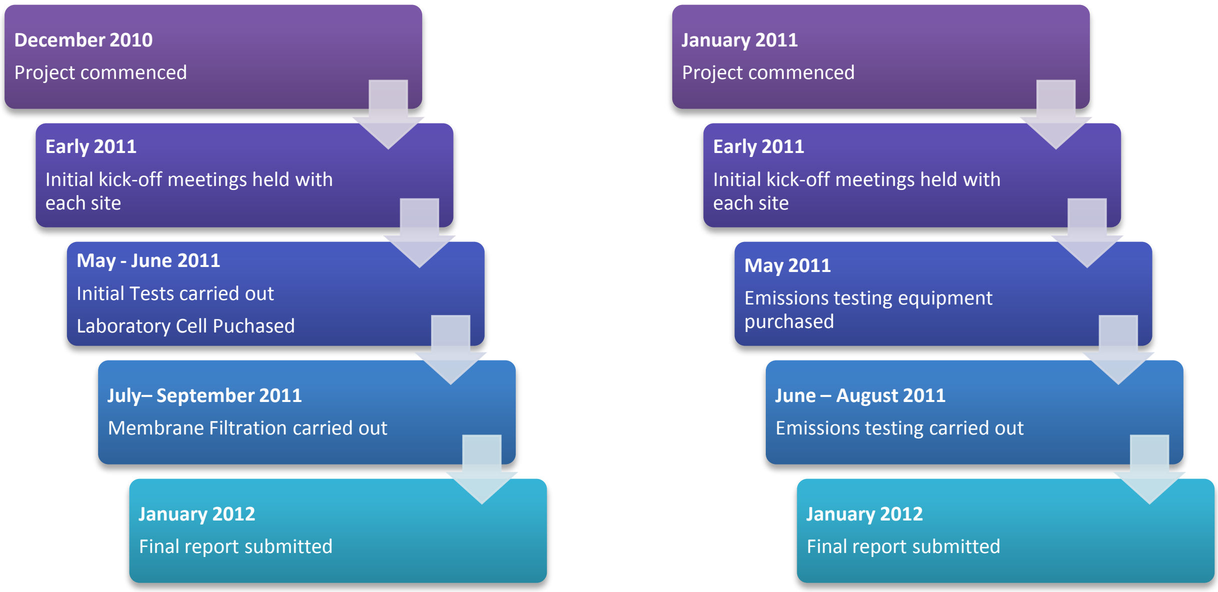


Figure 3.8 Project Timelines

3.2.4 Implementation Experiences

Information Collection: It was difficult to get information from some of the sites, particularly in cases where personnel need to calculate or collate data. This was one of the stated reasons why a company who initially committed to the project, was unable to proceed.

Scheduling: There were some issues with scheduling production operations during site visits to facilitate sampling of waste streams and flue exhaust streams. It was therefore necessary to visit some sites several times in order to obtain all samples.

Capital investment: In the current economic climate, most companies require short payback periods to justify projects.

Water Costs: Water was particularly inexpensive for some sites. This resulted in lengthy payback periods for water reduction opportunities which may have been viable if the water price was higher. Sensitivity analysis was applied to these opportunities to illustrate the effect of rising water price.

EU ETS Participation: Not all of the sites in the CO_2 Recovery Project are required to participate in the EU ETS. Participation in the EU ETS provides a strong motivation to reduce CO_2 emissions. If the rates for carbon credits were to increase above current levels, the economic viability of several of the opportunities, which were not found to be feasible, would be improved. Sensitivity analysis was applied to illustrate the effect of increased carbon credit prices.

3.2.5 *Equipment Performance*

3.2.5 A - Water Recovery Feasibility

The membrane filtration was carried out using the Koch KMS Laboratory Cell CF-1. This equipment is shown in Figure 3.1. It performed well and no issues were experienced during membrane trials.

Several different membranes were used in the course of this project. These membranes are listed in Table 3.3.The performance of each membrane was in accordance with its datasheet.

Table 3.3 Membranes utilised in Membrane Trials

Koch Membrane Systems		
Part Number	**Description**	**Membrane Type / Material**
8150001	TFC®-HR	TFC® RO
0030887	HFM-180	PVDF UF
8150002	TFC®-SR100	TFC® NF
0770002	SelRO® MPF-34	Acid/Base stable NF
0770007	SelRO® MPF-36	Acid/Base stable NF

On-site pH and conductivity measurements were taken using a Hanna Instruments meter, HI9811-5N. Some readings exceeded the conductivity range of this meter so a meter with a broader range would have been useful. In these cases, the laboratory tests results were required to assess conductivity.

3.2.5 B - CO_2 Recovery Feasibility

The equipment shown in Figure 3.5 was used for site-based testing. All equipment was found to be fit for purpose. No problems were experienced with the equipment during testing.

Table 3.4 Equipment utilised in Flue Gas testing

Part Number	Description
0632 3340	Testo 340 Flue Gas Analyser with O2 and CO cells
0600 9766	Flue Gas Probe (500°C) 335mm
0635 2145	350mm pitot tube

3.2.6 *Modifications*

Overall both the CO_2 and Water Recovery projects ran according to plan and within budget; however some minor modifications were made to the schedule, participants and sampling regime over the course of the project.

- Scheduling: The extreme weather conditions in January 2011 resulted in maintenance issues and production downtime on many of the sites involved in this project. As a result, the initial site meetings were delayed until the end of February and March.
- Participants: It was planned that a second pharmaceutical company would take part in both projects. Despite a high level of interest initially, it was not possible to proceed in the project with this company due to a lack of personnel availability and information.

- Sampling Regime: It was not possible to sample all of the waste water streams requested due to conflicting production schedules or inaccessible pipework layout.

3.2.7 Measurement / Monitoring Procedures

Detailed trial protocols were agreed at the start of both projects and these were used as the basis for on-going measurement and monitoring during the onsite trials. A summary of the contents of these protocols is shown in Appendix 2.

3.3 Capacity Building

3.3.1 Training of Staff

Method Statements were prepared, which incorporated the entire scope of sampling and testing to be carried out on each site. This activity highlighted the potential risks and also the risk mitigation measures to both site personnel and FDT project engineers.

3.3.1 A – Water Feasibility Study

Koch Chemical Technology Group conducted office-based training with all members of the project team on the 19th of July. The focus of this training was the operation and maintenance of the Laboratory Cell and the specific functions and operating ranges of each type of membrane.

In addition, Koch also carried out the first day of on-site testing with the FDT Project Engineer. This involved the practical application of the classroom training and was adequate to fully familiarise the FDT project engineer with the membrane trial procedure.

3.3.1 B – CO_2 Feasibility Study

The emissions tester was relatively straightforward to use. No special training was required beyond that provided in the O&M manual and accompanying CD.

3.3.2 Integration of Knowledge from External Assistance

External assistance was provided to FDT from a number of sources over the life of this project. The knowledge gained from these sources, as well as from the extensive literary review undertaken, has been integrated into FDT's Resource Efficiency service offering.

The contacts on each of the participating sites disseminated the results of this project to their colleagues and also to other sites within their organisations.

3.3.2 A – Water Feasibility Study

Koch Chemical Technology Group provided the following input to the project;

- Guidance on trial protocols
- Guidance on method statements
- Consultation on initial sampling results
- Consultation on payback calculations

3.3.2 B – CO_2 Feasibility Study

CO_2 vendors (Buse, TPI and Union) provided the following input to the project

- Guidance in identification of possible CO_2 sources and potential issues arising from each of these sources prior to testing
- Guidance in selecting appropriate test equipment. It was critical that the CO_2 emissions tester would be sufficiently accurate for the level of analysis being carried out.
- Following the on-site testing, detailed meetings were held with several CO_2 recovery vendors regarding the feasibility of CO_2 recovery for each application. These discussions were a direct input into the cost estimates for CO_2 recovery equipment for each site.
- Guidance on the size of the European CO_2 market and also on the pricing of CO_2.

4 Project Outcomes

4.1 Environmental Impact

4.1 A - Water Recovery Feasibility

In this study, water is considered “recoverable” if it is technically possible to recycle the waste water stream, using either membrane filtration or a lower grade of filtration, and reuse it in place of fresh water.

“Unrecoverable water” is water that cannot be recovered because it is consumed in the production process, the permeate does not meet site requirements to replace fresh water for a given user, the flow in the waste stream is extremely small or the contaminants in the waste stream could damage the membrane. Examples of these contaminants are oxidising agents, oils and solvents.

Based on information reported in companies’ Annual Environmental Reports (Environmental Protection Agency, 2011) across all of Irish Industry, it was estimated that a total of 41 million cubic metres of water was used in IPPC regulated industry in Ireland during 2010. The spread of water consumption across industries, determined from these reports, is illustrated in Figure 4.1. The sectors included in the *Other Industries* section account for 36% of water supplied to IPPC licenced industries and include the metals, electronics, power generation and beverage industries.

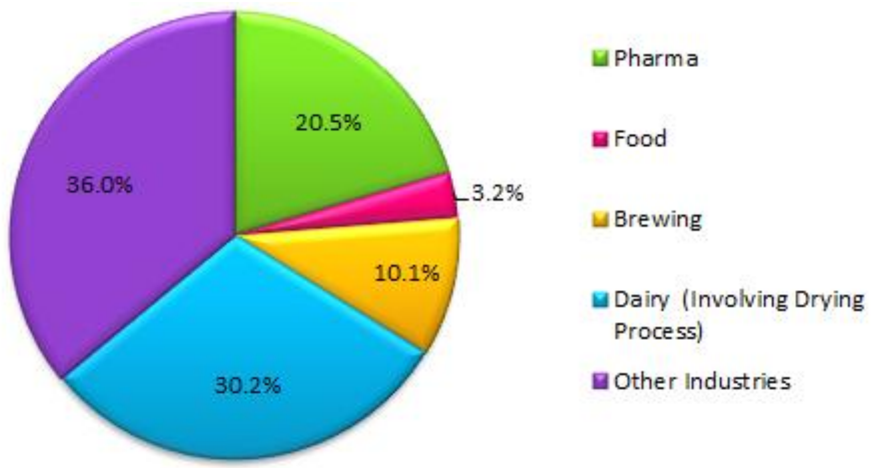
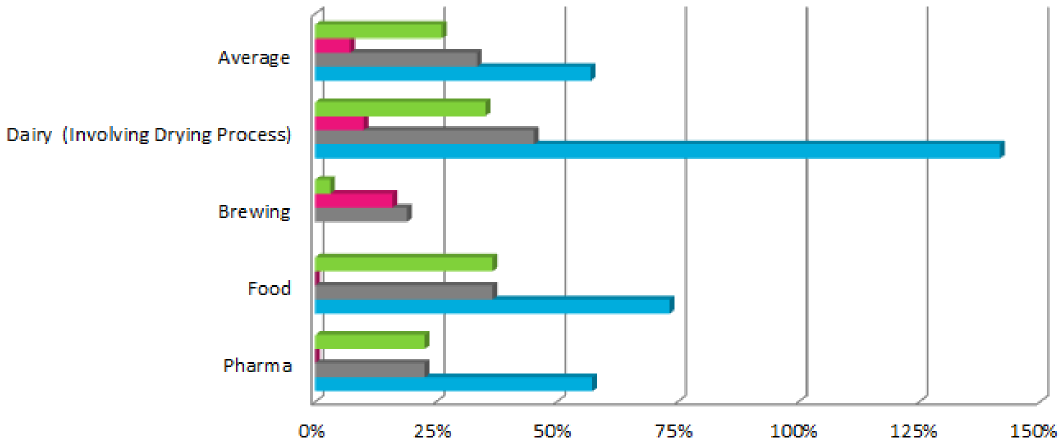


Figure 4.1 Spread of Water Consumption across Irish Industry

As shown in Figure 4.2, it is estimated that, in total, approximately 34% of this water is recoverable from individual waste streams, upstream of the WWTP process on site. This would be the more acceptable option for most sites.

Once waste streams merge, contaminants tend to become more diluted and it was found that, on all sites, the combined waste stream was suitable for RO membrane filtration. Therefore the outflow from the WWTP was a good opportunity for waste water recycling. In relation to water supplied, it is estimated that approximately 57% could be recycled at this stage of the process. This waste stream was tested on all sites except Diageo Dundalk, where there is no on-site effluent treatment (except for pH balancing) and all waste water flows to the local authority treatment plant.



	Pharma	Food	Brewing	Dairy (Involving Drying Process)	Average
% of Water Supplied that is Recoverable using Membrane Filtration	23%	37%	3%	35%	26%
% of Water Supplied that is Recoverable using Lower Grade of Filtration	0%	0%	16%	10%	7%
Total % of Water Supplied that is Recoverable	23%	37%	19%	45%	34%
% of Water Supplied that is Recoverable from WWTP Outflow using Membrane Filtration	57%	73%	N/A	142%	57%

Figure 4.2 Recoverable and Unrecoverable Water by Industry

It is interesting to note that it is possible to recover 142% of water consumed by the Dairy industry, on sites where a drying process is used. This is because, in the production of dairy ingredients, milk is heated to remove moisture, thereby, in effect, generating waste water.

At a recovery rate of 34%, approximately 13.9 million m^3/annum can be recovered from individual waste water streams. If mains distribution losses are taken into account, which are approximately 44% [1], the gross savings to the water supply network could be as high as 24.8 million m^3/annum.

At a recovery rate of 57%, approximately 23.4 million m^3/annum can be recovered from WWTP outflows. If mains distribution losses are taken into account, which are approximately 44%[1], this figure could be as high as 41.7 million m^3/annum. However, it must be considered that water recovery at this stage in the process results in the generation of a concentrate, which is likely to exceed IPPC licence limits for waste water. This concentrate would need to be disposed of in a manner that would not compromise the environment.

[1] Department of Finance, 2009. Report of the Commission on Taxation. [Online]
Available at: http://www.commissionontaxation.ie/downloads/Part%2011.pdf
[Accessed on 08 November 2011]

Opportunities to Recover Valuable Components from Waste Water

The secondary aim of this project was to investigate the possibility of recovering valuable by-products from waste water streams using membrane filtration. Three waste water streams were identified as containing valuable components but only two of these were deemed worthy of membrane treatment, due to the low concentration of the third.

While the desired components were successfully separated from both streams using membrane filtration, the permeate water from one of the trials was not of a high enough quality to be reused. This means that the membrane filtration would provide a valuable product and reduce the loading on the Waste Water Treatment Plant but would not reduce the water consumption on site.

4.1 B - CO_2 Recovery Feasibility

A breakdown of the main industrial emissions in Ireland in 2010 is shown in Figure 4.3[2].

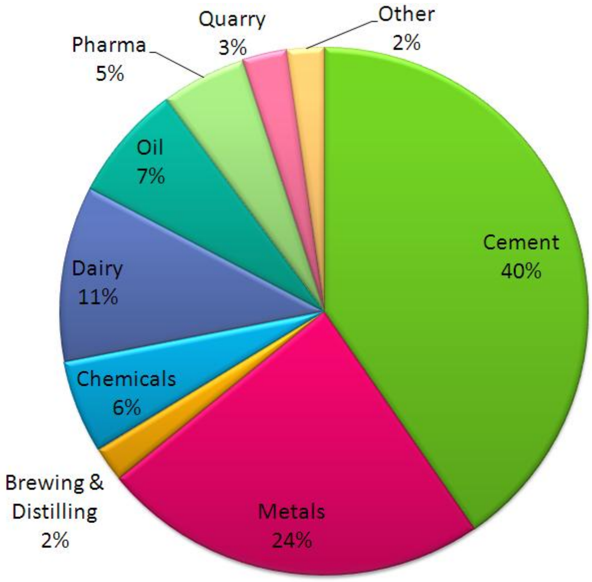


Figure 4.3 Industrial emissions in Ireland by sector, 2010

Cement is clearly the sector with the largest emissions. Dairy is the largest emitting sector[3] of those studied, accounting for 11% of the emissions in the EU ETS registry in 2010 (just under 570,000 tonnes CO_2 per annum). The Brewing and Distilling sector accounted for 2% and food for just over 0.5% of verified emissions in the EU ETS.

A summary of the results of flue gas testing is shown below in Table 4.1. These results, along with the magnitude of emissions per annum were used to assess the suitability of sources for recovery.

Technology	Concentration of CO_2 in exhaust
Natural Gas Boiler	6 - 9%
Natural Gas CHP turbine	3-4%
Natural Gas Fired Thermal Oil Heater	9.4%
Diesel Boiler	13.40%
Natural Gas Fired Dryer	0.60%

Table 4.1 Headline results from flue gas analysis

The Diesel Boiler has by far the highest percentage of CO_2 in the exhaust stream. The example of this technology in the study however was quite small so did not justify recovery. Diesel boilers usually have a

[2] Verified EU ETS emissions in 2010. Emissions from power stations omitted.
[3] Dairy sector as defined in IPPC licensing system. Includes Dairy and Ingredients Manufacturers.

higher level of particulates in the flue gas than those fired using natural gas. Further analysis would be required if recovery from this type of technology were to be pursued.

A summary of the findings for each site in the study is shown in Table **4**.2.

	Annual CO_2 Emissions	Conclusions	Potential reduction in site emissions
Dairygold	58,600T	CO_2 emissions could feasibly be reduced by 38,000T CO_2 per annum using CO_2 recovery plant and exporting liquid CO_2 off site for use. This is subject to discussions with CHP operators.	65% of total site emissions
Diageo	4,000T from combustion 550T from fermentation	Almost 60T of CO_2 per annum could be used for waste water neutralisation which would otherwise be vented to atmosphere. This would remove the need for sulphuric acid on site.	11% of emissions from fermentation 1.3% of total emissions
Glanbia	730T	Flue gas from the diesel-fired boiler at Glanbia Ballitore is not suitable for CO_2 recovery at this time due to economies of scale.	N/A
Largo Foods	4,500T	The CO_2 sources at Largo Foods are not suitable for recovery at this time due to economies of scale.	N/A

Table 4.**2 Summary of project findings**

The main opportunities identified over the course of the project are discussed below.

Recovery of CO_2 from CHP Turbine for use off site

Dairygold's total CO_2 emissions could potentially be reduced by 65% if CO_2 recovery was implemented at the site. The main source of CO_2 on site is two large CHP turbines, with a total rating of 9.8MW, which produce 47,555 tonnes of CO_2 per annum. The onsite testing revealed that this CO_2 is recoverable. Assuming recovery losses of 20%, 38,000 tonnes of CO_2 per annum could be recovered which equates to 3,880 tonnes per MW installed.

The findings from Dairygold would not be applicable to all sites in the same sector however because the CO_2 emissions are not a result of dairy operations but rather are produced by CHP turbines. Therefore, it would be more accurate to extrapolate the findings from Dairygold across other sites which have CHP turbines.

The authors are aware of an additional 53MW installed gas turbine CHP capacity in Ireland[4]. Assuming that these CHP turbines are operated in a similar manner to that at Dairygold, then a total of 243,600 tonnes of CO_2 could potentially be removed from Ireland's total emissions. This represents a reduction of 3.2% of the total emissions from industry (not including power stations) in Ireland[5].

[4] Fingleton White & Co. Ltd. www.fingleton.ie/index.php
[5] EU Emissions Trading Scheme Registry www.etr.ie

Use of CO_2 from Fermentation for Effluent Neutralisation

Diageo Kilkenny CO_2 emissions could be reduced by 1.3% through implementation of waste water neutralisation with CO_2. This opportunity could lead to a two-part reduction in CO_2 emissions:

- Direct emissions from the company
- Emissions associated with the production and transport of mineral acids which would be replaced by CO_2

A further environmental benefit of this opportunity would be the reduction in sulphates present in the effluent stream from the brewery.

Neutralisation using CO_2 is a proven technology and because carbonic acid is self-buffering (see gradual neutralisation curve in Figure 4.4), there is an increased level of process control compared with the use of hydrochloric or sulphuric acids. There is also be a health and safety benefit from use of this process arising from a reduction in hazardous chemicals being handled and stored on site.

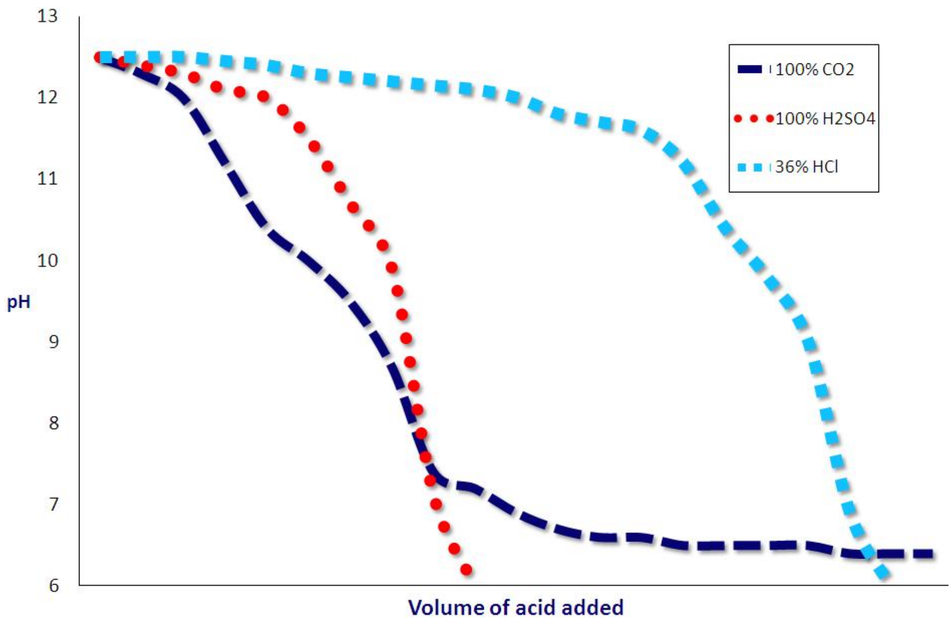


Figure 4.4 Neutralisation curves of CO_2, H_2SO_4 and HCl

Should a similar system be implemented in the other breweries in Ireland, just over 1,100 tonnes of CO_2 could be prevented from entering the atmosphere each year. However, this technology could potentially be extended to other industries that generate alkaline waste water. For instance, if similar figures were applied to the pharmaceutical industry in Ireland, a further 4,000 tonnes of CO_2 emissions could be avoided. Neutralisation using mineral acids is very common in Ireland so there is a lot of scope to reduce CO_2 emissions by implementing this opportunity.

CO_2 does not necessarily have to be liquefied or stored (energy intensive processes) for use for neutralisation but it may (particularly if generated from combustion) have to be scrubbed to remove any flue stream constituents which would negatively affect effluent water quality.

Use of CO_2 for Atmosphere Enrichment in Horticulture / Agriculture

When CO_2 is added to the air in greenhouses at levels of 2-3 times the natural concentration, crop yields can be increased by as much as 15%[6]. A substantial amount of research has been conducted in this area. Greenhouse plants only consume CO_2 during daylight hours (due to the photosynthesis process). A greenhouse would therefore be a particularly suitable carbon sink for an adjacent facility which is most productive during daylights hours (e.g. has no night shift). If a good balance could be found between the CO_2 produced and the CO_2 used in the greenhouse, this may negate the need for more costly recovery methods.

The contents of flue streams from combustion of natural gas have relatively low concentrations of sulphur dioxide and other pollutants so they can often be suitable for CO_2 enrichment in greenhouses. This opportunity could potentially be implemented on all sites but as none of the sites investigated currently neighbour a greenhouse, it was not included in the overall findings shown in Table 4.2.

A further advantage of this initiative would be that waste heat in the exhaust stream could be utilised in the greenhouse. Greenhouses could form a large sink for CO_2. The favourable environmental impact of such a scheme would be two-fold; firstly, the emissions from the industrial site would be significantly reduced and, secondly, there would be a fuel saving, and associated emissions saving, because of the heat provided to the greenhouse.

In a similar way, this technology could be used to enhance growth of algae for biofuels – this is an area where there is a lot of research and development at the moment. Algae would benefit from both higher levels of CO_2 and warmer temperatures.

[6] Aresta M. (2004) The contribution of the utilization option to reducing the CO2 atmospheric loading: research needed to overcome existing barriers for a full exploitation of the potential of the CO2 use, Catalysis Today 98 455-462

4.2 Economic Impact

4.2 A - Water Recovery Feasibility

The costs associated with water consumption varied considerably from one facility to the next depending on the water source used, the necessity for pretreatment and waste water management. As a result of this, it can be more financially beneficial to implement water recycling opportunities on one site than another.

Overall, water supply costs are quite low for Irish Industry. There are currently no charges or penalties in place for water abstraction and the average charge per cubic metre of water supplied in Ireland was €1.71 in 2007. The average charge for water supplied in Europe in the same year was €3.25 per cubic meter. The two European countries that achieved full cost recovery in 2007 were Germany and Denmark, who charged €5.09 and €5.63 per cubic metre respectively[7].

The IMF Memorandum of Understanding [8] states that Ireland plans to "move towards full cost recovery in the provision of water services". Full cost recovery is not currently being achieved in Ireland, with the recovery rate in the non-domestic sector at 74% in 2007 [9].

The undertaking by the Irish government to move towards full cost recovery, in addition to the fact that non-domestic water charges in Ireland are comparatively low, signal that an increase in non-domestic water charges is highly likely over the coming years.

As shown in section 4.2 above, it is technically possible to recycle a high proportion of the waste water generated at the four industrial sites studied using membrane filtration. However in many instances, the waste water streams were too small for the installation of a dedicated RO plant to be financially viable. In these cases, the payback duration was greater than fifty years or didn't exist because annual costs exceeded the annual savings. It should also be noted that payback periods tend to be longer for recovering water from WWTP outflow because this water has already incurred the cost of the WWTP.

However, three of the opportunities identified were financially viable with payback periods of less than fifty years at current water supply costs. These opportunities are shown in Table **4**.3. The fourth opportunity listed, the process rinse, is not financially viable at current waste water volumes, however process modifications mean that the volume of this this waste water stream in will increase by a factor of two by 2013, at which time the payback period for this opportunity will be 13.1 years.

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[7] Forfás, 2011. Ireland Competitiveness Scorecard 2011. [Online]
Available at: http://www.forfas.ie/media/Forfas060911_Irelands_Competitiveness_Scorecard_Report.pdf
[Accessed on 08 November 2011]

[8] International Monetary Fund, 2010. IMF Memorandum of Understanding. [Online]
Available at: http://www.imf.org/external/np/loi/2010/irl/120310.pdf [Accessed on 08 November 2011]

[9] Department of Finance, 2009. Report of the Commission on Taxation. [Online]
Available at: http://www.commissionontaxation.ie/downloads/Part%2011.pdf [Accessed on 08 November 2011]

Waste Water Stream	Recovery Rate	Payback Period	Comments
WWTP Outflow	90%	6 Years	
WWTP Outflow	95%	33 Years	
Nano Filtration Permeate	80%	5.8 Years	
Process Rinse	90%	NA	When this payback assessment is adjusted to include the projected waste water flows, it has a payback of 13.1 years.

Table 4.3 Payback Periods for Opportunities Identified

The payback periods were then stress-tested against the European average cost of water supply, €3.25 and against the cost of water supply in Denmark, €5.63 in 2007. The results of these stress tests are shown in Figure 4.5.

Interestingly, the opportunity relating to the process rinse waste water, which has a negative payback at current volumes, is financially viable at the European average cost of water supply.

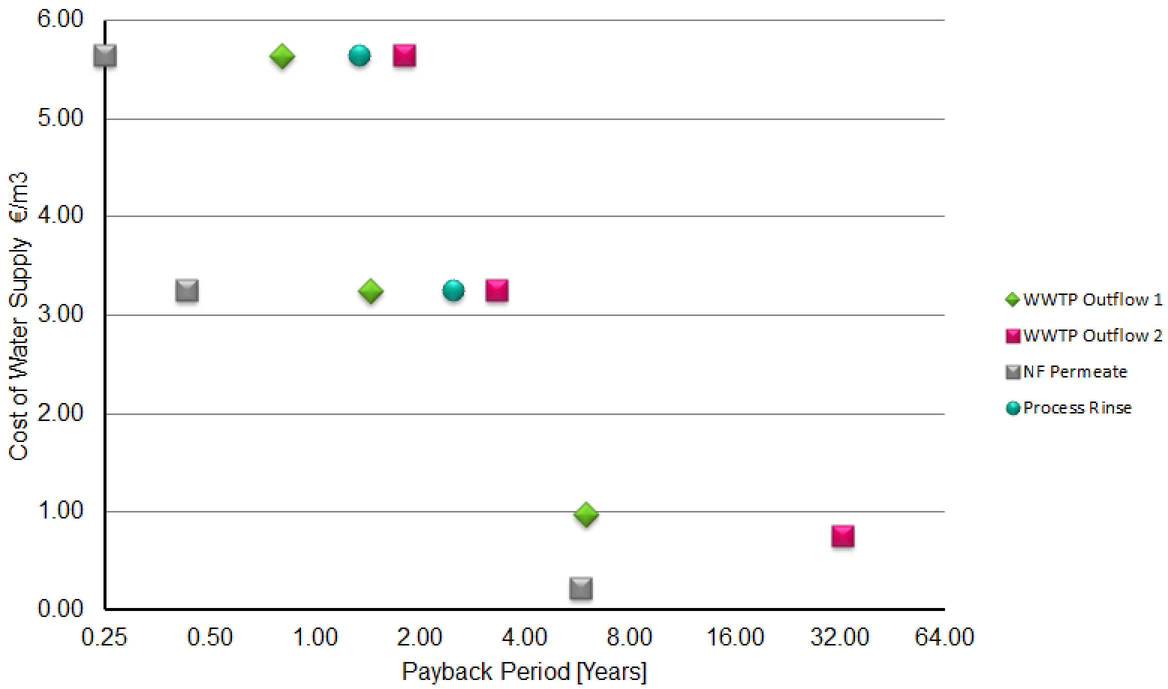


Figure 4.5 Stress Testing of Payback Periods for Opportunities Identified

It is evident from Figure 4.5 that the low cost of water in Ireland does not encourage companies to proceed with water recycling projects. This is particularly true for water recycling involving membrane filtration, which is an expensive technology.

Opportunities to Recover Valuable Components from Waste Water

Recovery of valuable by-products from waste water has many benefits. It provides the opportunity for a new revenue stream, reduction in WWTP loading and also for a reduction in fresh water consumption. Based on the analysis carried out, however these opportunities are not widespread. Payback periods for the two opportunities identified are shown in Table 4.4 as follows;

Industry	Valuable Component	Recovery Rate	Payback Period	Comments
Snack Foods	Starch	85%	5.44 Years	Large variation between results from two grab samples so more testing would be required to confirm this payback period.
Dairy	Caustic	48%	> 50 Years	

Table 4.4 Payback Period for By-product Recovery

The payback periods for these opportunities were calculated based on each site's own current water costs, the market value of dried starch used was €225 / tonne and the market value of caustic at 30% concentration used was €145 / m^3. Rising energy and commodity chemical costs could greatly impact on these payback periods so these should be reviewed when circumstances change.

There may be greater opportunity for by-product recovery in other sectors that were not included in this study, such as active pharmaceutical ingredients, electronics or chemicals as in these industries the by-products would have greater value.

4.2 B - CO_2 Recovery Feasibility

CO_2 recovery can have an economic impact for a company on several levels;

- Financial benefit of carbon credits, assuming the company is an EU-ETS scheme participant
- Revenue from sale of bulk CO_2
- Savings from substitution of CO_2 for a previously purchased material
- Competitive advantage of reduced carbon footprint

Emissions Trading

Carbon credits can substantially improve feasibility of emissions reductions projects. It should be noted however that not all CO_2 emissions are covered by the EU Emissions Trading Scheme (ETS); for example, CO_2 produced from fermentation.

When the EU ETS was introduced, carbon credit prices rose to €30 per tonne but by the end of Phase 1 had dropped to less than €0.01 per tonne due to over-allocation of allowances.

Phase 2 of the EU ETS is currently in progress. In 2011, carbon credits were trading at €16-€17/T [10] but they have dropped significantly in price over the first few months of 2012 to approximately €7.

For Phase 3 (2013-2020) the system for allocating emission allowances will significantly change compared to the two previous trading periods (2005-2012). Allocations will be decided at an EU wide level. Further data will be available also to reduce the incidence of oversizing allowances, thus increasing scarcity and driving demand and value. This development could significantly increase the feasibility of CO_2 reduction/recovery projects.

In reality, while carbon prices are expected to rise in Phase 3, it is difficult to predict what price carbon credits will reach in the coming years. A carbon credit price of €12 was used in payback calculations as an indicative figure.

Bulk CO_2 Market

CO_2 has many physical properties which make is useful for numerous applications. It is a colourless, odourless inert gas at ambient temperature. All forms of CO_2 are incombustible. It is miscible with water, hydrocarbons and most organic liquids. Common applications of CO_2 are outlined in Appendix 3

The sale price of CO_2 varies in Ireland and in Europe but a large component of the final price paid by the consumer is transport. It is therefore unlikely that shipping recovered CO_2 overseas would be

[10] Macken K. (2011) The EU Emissions Trading Scheme: A Review of the First Six Years of Operation, EPA June 2011 http://www.epa.ie/downloads/pubs/air/etu/name,31044,en.html (accessed 7th March 2012)

feasible. Recovery of CO_2 for sale in the Irish market is therefore limited by the size of the CO_2 market in Ireland.

It is difficult to quantify the size of the CO_2 market because of the confidential nature of information regarding usage. In one study in 2004[11], the European merchant CO_2 market was estimated at 2,120,000 tonnes per annum, with the largest consumers being the soft drink and brewing industries. In 2010, Ireland's GDP accounted for 1.25% of the EU total. Thus, a very rough approximation of Ireland's CO_2 market at that time would be in the region of 30,000 tonnes per annum. The market for CO_2 is increasing however. There is currently a large amount of international research into alternative uses for CO_2 with an aim to reducing emissions. These are outlined along with current common uses in Appendix 3

The economic impact of the specific opportunities identified in the course of the project is as follows;

CO_2 Recovery from CHP Turbine for use off site

There is no current use of CO_2 on site in Dairygold. Waste water from the site is usually acidic so the use of CO_2 for neutralisation is not an option in this case. The only possible use of recovered CO_2 therefore is off site. The economics of CO_2 recovery from the CHP turbines in Dairygold (including the benefits available from carbon credits) are outlined below in Table 4.5.

Source	Cost of Equipment	Estimated installation, civil works etc	Plant capacity	Expected annual production	Annual profit (revenue - operating costs)	Payback Years
CHP 1 & CHP 2	€6,000,000	€4,300,000	12000 kg/h	47555 T CO2	€1,997,316	5.2

Table 4.5 Project economics for Dairygold

A payback period of approximately 5 years was calculated for CO_2 recovery in Dairygold using the bulk sale price of €80/tonne CO_2. No allowance was made for costs associated with reduced turbine efficiency, depreciation or interest in the calculation. This payback period encourages further investigation into this opportunity. It should also be noted that if a higher bulk CO_2 sale price were achieved (e.g. €100), the payback for the system would be reduced to less than 3.5 years. The feasibility of this project would be significantly increased if a local consumer of CO_2 exists. Piped transfer of CO_2 is much more economical than the transfer by tanker which as well as running costs would require installation of costly tanker filling and emptying infrastructure.

[11] Aresta M. (2004) The contribution of the utilization option to reducing the CO_2 atmospheric loading: research needed to overcome existing barriers for a full exploitation of the potential of the CO_2 use, Catalysis Today 98 455-462

There is a technical difficulty with recovering CO_2 from CHP. A flue gas concentration of at least 10% CO_2 is preferable when considering recovery from flue gas, so if CO_2 recovery from a CHP exhaust was to be implemented, it would be necessary to reduce the excess air used for firing. This would result in a reduction in firing efficiency so a compromise is necessary to achieve the best possible balance between efficiency and CO_2 production. This difficulty is not insurmountable however - recovery of CO_2 from CHP exhausts has been implemented at several beverage manufacturing sites in Europe, including at the Coca Cola Hellenic site in Lisburn in Northern Ireland. Ideally, for the recovery process to be most efficient it would be integrated into the CHP plant during the design stage.

At a carbon credit cost of €12 per tonne CO_2, the potential emissions savings from CHP turbines in Ireland represent an asset of almost €3 million per annum before any revenue is generated from sales. As discussed previously however, the size of the Irish market for CO_2 could make it make it difficult to realise this potential.

Use of CO_2 from Fermentation for Effluent Neutralisation

CO_2 produced from fermentation does not currently fall under the remit of the EU ETS so the financial benefit of carbon credits was not factored into the payback calculation for this opportunity. The savings achieved were calculated purely on the basis of the cost benefit of using recovered CO_2 instead of purchasing sulphuric or hydrochloric acid at a rate of approximately €180/tonne. This opportunity is thus most economically effective when CO_2 is readily available on site at a low cost. However, if CO_2 were to be produced at another site from a source where carbon credits applied, this could improve economic viability of the opportunity.

Cost of production of CO_2	Cost of H_2SO_4	Annual H_2SO_4 usage	Projected annual usage of CO_2	Annual savings from using CO_2	Supply and installation of dosing skid	Payback
20 €/T	175 €/m^3	40 m^3	58.8 T	€5,824	€44,400	7.6 years

Table 4.6 Payback details Diageo Kilkenny

As outlined in Table 4.6, a payback of 7.6 years was calculated for this opportunity in Diageo in Kilkenny[12]. It should be noted however that the equipment and the control required to operate this type of system are quite simple so it may be feasible to construct a custom, inexpensive version of this system on site. Neutralisation using CO_2 may be worth exploring for other larger sites because of the savings available from the purchase of acid and also the reduction in CO_2 emissions which could be achieved.

[12] It was announced in early 2012 by Diageo that the brewery in Kilkenny will close down in December 2013

Use of CO_2 for Atmosphere Enrichment in Horticulture / Agriculture

The contents of flue streams from combustion of natural gas could be used for CO_2 enrichment in greenhouses or commercial algae growing processes. While, in theory, this opportunity should be applicable to all sites, none of the facilities partaking in the project was in proximity of greenhouses. Therefore the economic impact of the opportunity could not be assessed.

Further investigation would be necessary to ascertain what level of treatment, and therefore investment, would be required to implement this type of scheme. This application is likely to be much less energy intensive than full CO_2 recovery because there is a lower level of processing required and because it is not necessary to liquefy or store the CO_2. This opportunity could be considered as a potential option at design stage of future green field sites.

Emissions Trading

Carbon credits are a significant financial incentive to reduce CO_2 where they apply. Figure 4.6 illustrates the payback periods calculated for the opportunities identified on each site for the following carbon credit rates:

- €0 - rate currently applicable to CO_2 from fermentation and at sites that don't participate in EU ETS
- €12 - approximate rate in 2012 for sites that participate in EU ETS
- €39 - rate used in models by International Energy Agency for 2020[13]
- €86 – rate used in models by International Energy Agency for 2030[14]

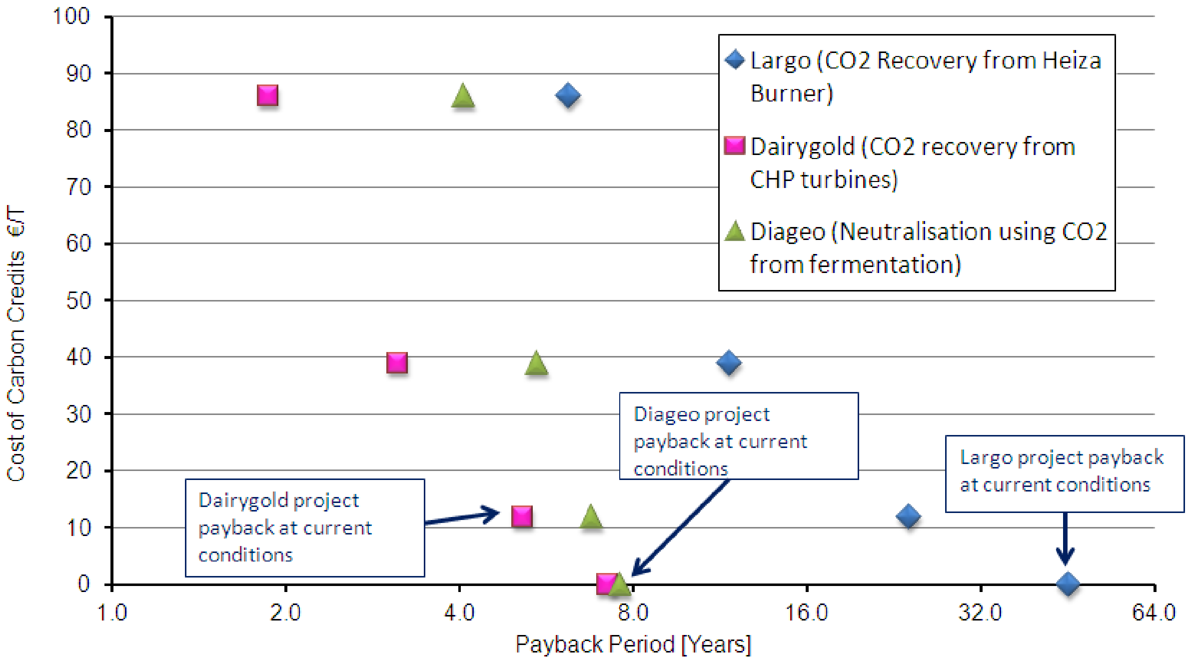


Figure 4.6 Payback periods for opportunities identified

[13] IEA World Energy Outlook, 2009
[14] IEA World Energy Outlook, 2009

The economic viability of every project examined increased substantially with higher carbon credit rates. For instance, high carbon credit rates would much improve the economic feasibility of CO_2 recovery at Largo Foods, if they were to join the EU-ETS scheme or if similar incentives were introduced for smaller sites (e.g. the UK Carbon Reduction Commitment scheme). Should incentives of this nature be introduced in the coming years, opportunities which are currently not feasible should be revisited.

4.3 Other Benefits

In addition to the environmental and financial benefits described in sections Environmental Impact 4.1 and 4.2 respectively, there are strategic advantages associated with recovery of water and CO_2.

Many organisations strive to be socially responsible and often surpass their legal environmental requirements in order to promote a positive company or brand image. Good performance in this area may be rewarded by corporate recognition and / or can be included in marketing literature for the organisation.

4.3 A – Water Feasibility Study

It is critical that companies minimise their reliance on scarce resources. If a company minimises its water consumption, then its operations may not be adversely affected in the event of a water supply issues.

There is increasing pressure on organisations to minimise the water footprint associated with their products. Water Footprint is a measurement of the volume of fresh water consumed to produce a product and it incorporates all stages of the supply chain. By reducing fresh water consumption, companies will have a competitive advantage, as major corporations are beginning to factor in water footprint as a criterion for supply chain partner selection.

At a national level, there is currently huge pressure on the water supply network. This is particularly critical in the Dublin area where there is insufficient capacity to meet the projected future water demand. The Dublin Water Supply Project[15] identified a variety of measures to close the gap between the supply and projected demand, including abstracting up to 350 million litres per day of water from the Shannon to supply Dublin. Water recycling and reuse at manufacturing facilities in Ireland would minimise water consumption and thereby reduce the need for such a large infrastructural project.

4.3 B – CO_2 Feasibility Study

There is increasing pressure on organisations to minimise the carbon footprint associated with their products. Carbon footprint is a measurement of the volume of carbon dioxide emitted to produce a product and it incorporates all stages of the supply chain. By reducing the amount of CO_2 released on site, companies will have a competitive advantage, as major corporations are beginning to include carbon footprint as a criterion for supply chain partner selection.

[15] RPS, Veolia 2010. Water Supply Project – Dublin Region. http://www.watersupplyproject-dublinregion.ie

4.4 Involvement of Other Business

The six facilities that were studied in detail in this project were directly impacted by the project. The opportunities identified can be analysed further and project proposals can be developed.

This study also has an impact on all other companies in Irish industry. It demonstrates the scale of savings that can potentially be made by IPPC licensed companies in Ireland.

Evidence of the potential for recycling and reuse of waste water and CO_2 will act as an incentive for other companies to investigate the feasibility of recovery technology. It will stimulate interest in water and CO_2 recovery in all industries.

5 Promotion and Publicity

5.1 Potential Replication in Other Enterprises

The industries represented in the study were brewing, dairy ingredients, liquid milk, snack foods and pharmaceutical. These industries do not account for all IPPC / EU ETS registered companies in Irish industry.

From a water perspective, the four sectors examined in this study accounted for 64% of the total water consumption in 2010. The savings potential for the remaining 36% was assumed to be the average of the sectors studied.

Similar analysis could be carried out for other industries covered by IPPC licensing, such as beverage, energy production, metals, semiconductors etc.

From a CO_2 perspective, the industries examined accounted for just under 10% of the total industrial CO_2 emissions in 2010. However, the technologies examined in the study (e.g. gas CHP turbines, gas boilers) are used at most industrial sites so the information gained should be valuable to many companies.

5.2 Dissemination of Results

The results arising from these projects will be disseminated through the following channels

- Poster Presentation on CO_2 Project at the Planet Under Pressure Conference "New Knowledge towards Solutions" in London on March 26th, 2012
- Poster Presentation on Water Project at the Planet Under Pressure Conference "New Knowledge towards Solutions" in London on March 27th, 2012
- Poster Presentation on Water Project at the International Water Association Conference "World Congress on Water, Climate and Energy" in Dublin, May 13th – 18th, 2012
- Oral Presentation on CO_2 Project at the International Water Association Conference "World Congress on Water, Climate and Energy" in Dublin, May 13th – 18th, 2012

The results from both projects have already been disseminated in the following manner

- All information and findings have been communicated to the companies that partook in the project
- This report is available for download on the FDT website, www.fdt.ie

In addition, case studies will be submitted to the following publications: *Technology Ireland, Engineers Ireland, The Chemical Engineer, Water and Wastewater Treatment, Pharmaceutical Engineering, Brewer & Distiller International, Irish Times Innovation Magazine, Business & Finance*.

6 Lessons learned for the Future

6.1 Lessons learned

6.1 A – Water Feasibility Study

Several opportunities for water recovery using membrane filtration were identified in the course of this project. However, only some of these opportunities were financially viable due to the fact that water charges in Ireland are currently quite low.

Where it is technically feasible to recover water, there can be significant financial and environmental benefit. Detailed technical and commercial analysis is required to assess these opportunities.

While some opportunities to recover by-products from waste water streams were identified, these were not commonplace and tended to have extremely long payback periods. There may be greater opportunity for by-product recovery in other sectors, such as active pharmaceutical ingredients, electronics or chemicals as in these industries the by-products would have greater value.

Opportunities for further study on this topic are discussed in sections 6.2 and 6.3.

6.1 B – CO_2 Feasibility Study

The amount of CO_2 produced needs to be very large for off-site use to be feasible.

For CO_2 recovery, it is preferable to have a high concentration of CO_2 in the flue gas. Normal operating levels for CHP turbines would not be suitable so some adjustment to operating conditions would have to be made in order to implement recovery. This however involves a reduction in firing efficiency so a compromise would need to be found to achieve the best possible balance between efficiency and CO_2 production.

Neutralisation with CO_2 is feasible if low cost CO_2 is available. Economic viability would be increased if carbon credits could be earned through use of CO_2 from fermentation and also at larger plants with higher volumes of waste water.

The potential for reducing emissions in Ireland by CO_2 recovery is limited by the size of the bulk CO_2 market. It is likely that this will increase given the increasing number of applications for bulk CO_2 (such as formic acid production). The greatest environmental impact a recovery scheme can have if it is actually reducing the total amount of CO_2 in the atmosphere. This means if it is replacing CO_2 that would be generated for this purpose only, replacing inefficiently generated CO_2/ CO_2 that is transported over large distances, or if it is used for a new application for CO_2.

Opportunities for further study on this topic are discussed in sections 6.2 and 6.3.

6.2 Continuation of Project

FDT issued each of the participating sites with a report of findings. This report detailed the testing carried out and any opportunities for recovery identified. Where water or CO_2 recovery were technically feasible, the report set out the recommended next steps to progress these opportunities.

6.2 A – Water Feasibility Study

The recommended next steps for water recovery opportunities involved carrying out a more detailed investigation. This should include

- Sampling the waste water stream over an extended period
- Carry out longer membrane trials in order to obtain a greater volume of permeate and concentrate
- Test the waste water and recovered water streams for a wider range of parameters

Some of the companies involved in this study are actively considering water recovery projects for either the sites involved or for other sites within the company. Building on their experience in this project, FDT are involved in this work and will be carrying out further testing using the membrane test skid purchased for use in this project.

6.2 B – CO_2 Feasibility Study

Should a participant site decide to pursue CO_2 recovery opportunities, the recommended next steps were as follows;

- Discuss the feasibility of reducing excess air used in firing with CHP operators and the financial impact versus the potential revenue stream from CO_2 recovery.
- Assess local market opportunities for CO_2.
- Make contact with gas supply companies with respect to ESCO opportunities.
- Obtain detailed quotations from CO_2 recovery vendors.

As noted previously, CO_2 recovery is most effective from both economic and environmental perspectives when a local sink exists. A logical step would be to examine the use of mineral acids for neutralisation of alkaline waste waters in Ireland and assess the feasibility of replacing this with CO_2.

6.3 Continuation of Cleaner Greener Production

6.3 A – Water Feasibility Study

Approximately 36% of the water use by IPPC facilities not represented in this analysis, so the water recovery potential was assumed to be the average of those analysed (see Figure 4.1). The water recovery potential in these sectors, namely metals, electronics, power generation and beverage could be assessed as part of future Cleaner Greener Production Programmes.

As part of our focus on water efficiency, FDT have become partners of the Water Footprint Network[16]. This gives FDT access to Best Practice Information and Training, as well as opportunities to exchange information with other WFN partners. Suggested future work, subject to research funding being available, would be to build on this project and consider developing a water footprint for each of the sites studied as a pilot project.

6.3 B – CO_2 Feasibility Study

In 2011, FDT was part of an international consortium which applied for funding under the FP7 Fine Chemicals from CO_2 call. Unfortunately the application was unsuccessful but FDT may be involved in future research projects or commercial activities with the consortium partners.

Future research into the development of small scale CO_2 recovery plant could positively affect the feasibility of the opportunities identified in this study.

As the cement sector has the largest emissions in Irish industry, implementation of CO_2 recovery could provide an effective means of mitigating the CO_2 impact of that sector, particularly if an on-site use for CO_2 could be found.

One of the industrial companies involved in this project, in conjunction with FDT, is investigating the possibility of recovering food grade CO_2 from a new CHP plant on a one of their sites outside of Ireland. This is a direct result of the CGPP Project and has led to additional export business for FDT.

[16] http://www.waterfootprint.org/?page=files/home

Appendix 1 Key Terms & Abbreviations

Permeate – The liquid which passes through the membrane

Retentate – The liquid which does not flow through the membrane. Also called concentrate

Flux Rate – Refers to the rate at which permeate flows through the membrane, units of Lmh

Lmh – Litres per square meter per hour

VCF – The volume concentration factor is used to define how much the feed volume has been reduced during the filtration process (VCF = Feed Volume/Concentrate Volume)

CWF – Clean Water Flux, refers to the rate at which permeate flows through the membranes when the feed stream is clean water

UF – Ultra Filtration

NF – Nano-Filtration

RO – Reverse Osmosis

EU ETS – European Union Emissions Trading Scheme

Appendix 2 Monitoring & Measurement Protocols

Appendix 2 A – Water Feasibility Study

The following information was contained within the membrane trial protocol.

General Trial Information

- Site
- Waste Stream
- Sample Date
- Sample Time
- Trial Date
- Trial Start Time
- Membrane Type
- Details of system clean before trial
- Initial Cold Water Flux (lmh)
- Details of system clean after trial
- Final Cold Water Flux (lmh)

Feed Data

- Conductivity of Raw Sample (µS/cm)
- Conductivity of Pre-filtered Feed (µS/cm)
- Temp of Pre-filtered Feed (°C)
- pH of Pre-filtered Feed
- Volume of Pre-filtered Feed added to System (L)

The following table was then completed during the trial

Time	Inlet Pressure (bar)	Permeate (ml/min)	Flux (Lmh)	Total Permeate Volume (ml)	Feed Tank Volume (ml)	VCF
. . . .						

Appendix 2 B – CO_2 Feasibility Study

The following information was contained within the flue gas testing protocol.

General Testing Information

- Site
- Flue Stream
- Fuel usage
- Annual operating hours
- Sample Date
- Sample Time

Analyser Data

- % O_2
- CO (ppm)
- %CO_2
- Temperature
- Velocity (m/s)
- Flow rate (m3/h)
- % Efficiency
- % Excess air

The following table was then completed during the trial

Time	% O_2	% CO_2	Exhaust Temperature °C	Velocity m/s	Flow m^3/h	% Effn	% ExAir	Fuel use m^3/h
. . . .								

Appendix 3 Uses of CO_2

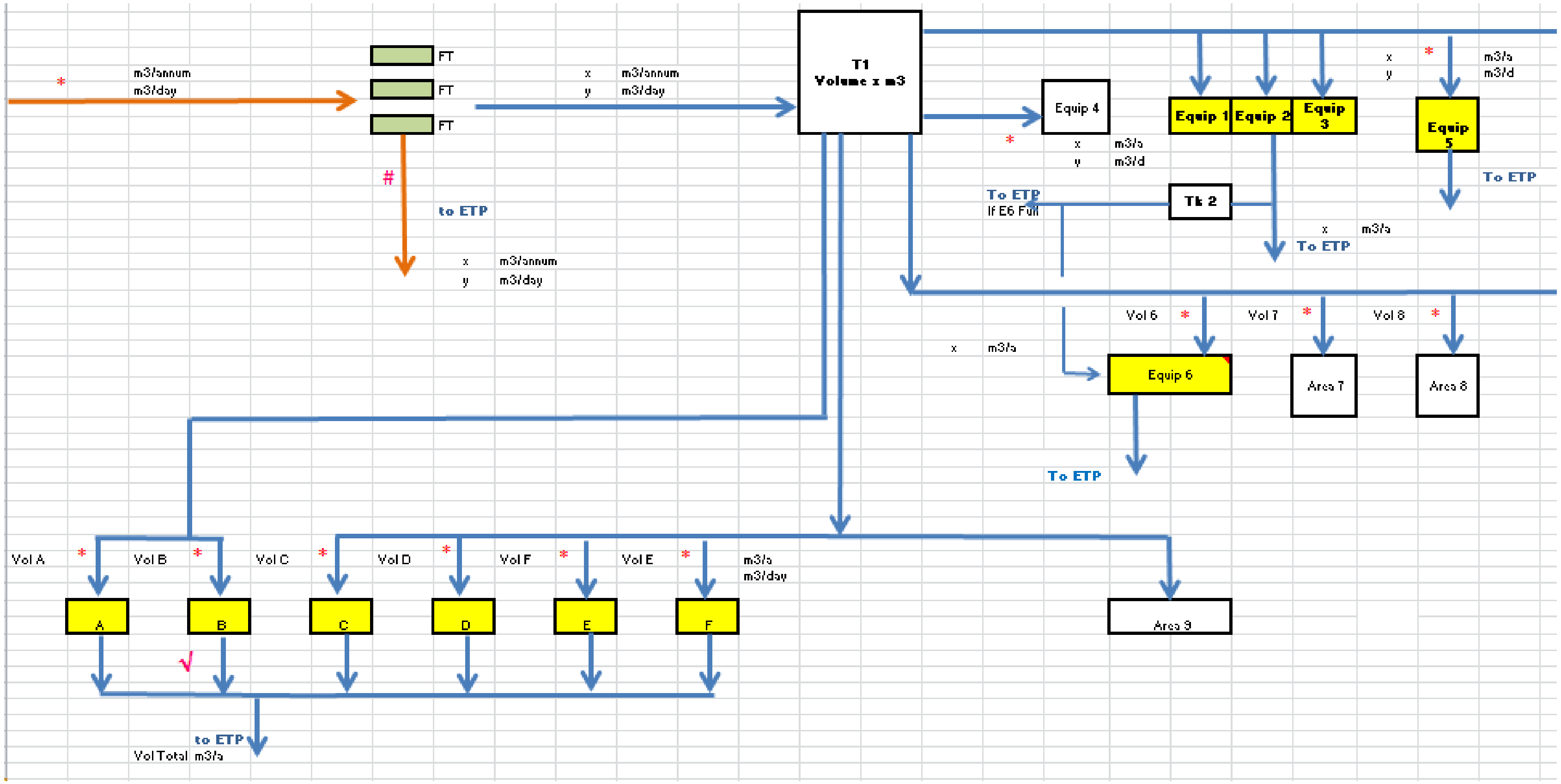
CO_2 is commonly used for the following applications

- Soft drink carbonation
- Water treatment
- Atmosphere enrichment for agriculture/horticulture
- Food Processing - modified atmosphere packaging, sterilisation of food products
- Welding, metal fabrication - used as a shielding gas during welding
- Solvent - used as a propellant in aerosols
- Refrigeration - used as a refrigerant, particularly in the food and the nuclear industries
- Fire fighting - used in fire extinguishers
- Dry ice - CO_2 in its solid state is known as dry ice

Increasing uses and those identified in recent research include:

- Cultivation of algae for production of biofuels
- Synthesis of chemicals e.g. formic acid (widely used as a preservative and antibacterial agent)
- Production of hydrogen (many uses e.g. production of ammonia, direct use as a fuel)
- Production of hydrocarbons from CO_2 and water using a catalyst. A compelling argument for this type of technology is that it could be used as a form of energy storage which may be used in conjunction with forms of renewable energy with variable outputs such as wind power and solar power.

Appendix 4 Example of Water Mass Balance Diagram



Appendix 5 Suppliers

Supplier of Koch KMS Laboratory Cell CF-1:

Koch Chemical Technology Group Ltd

Address: Koch Membrane Systems Division, Units 3-6, First Floor, Greyfriars Business Park, Frank Foley Way, Stafford ST16 2ST, United Kingdom

Supplier of Laboratory Testing Service:

T.E. Laboratories Limited

Address: Loughmartin Business Park, Tullow, Co. Carlow

Supplier of Testo 340 Emissions Analyser:

Emissions & Combustion Instruments Ltd

Address: Cheriton House, Newman Lane, Alton, Hampshire GU34 2QJ, United Kingdom

Annexes

Note: These annexes are confidential to each site and are not to be published.