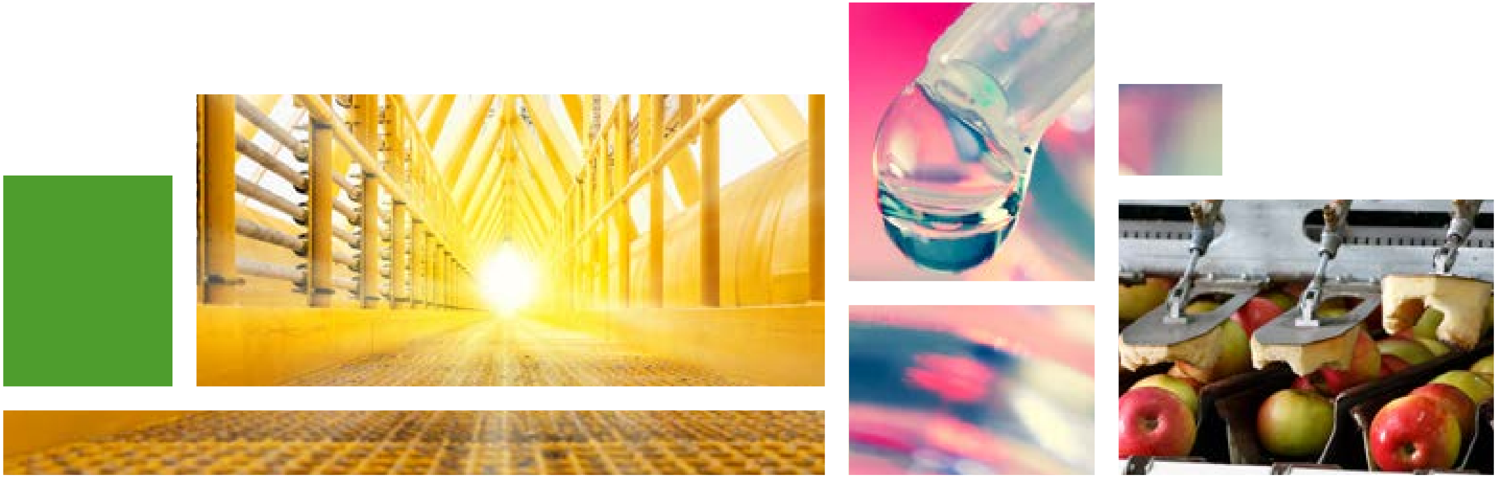
IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

# Chemical Engineering Matters for a modern world



The Institution of Chemical Engineers (IChemE) is the global professional membership organisation for people with relevant experience or an interest in chemical engineering.

Founded in 1922 as the professional Institution for chemical, biochemical and process engineers, IChemE has grown to over 44,000 members in over 120 countries. We currently have offices in Australia, Malaysia, New Zealand, Singapore and the UK.

IChemE is striving to ensure that the message *Chemical Engineering Matters* is spread far beyond the chemical engineering community.

# Foreword from the Chair

It makes me truly proud of my profession to present this collection of case studies, celebrating the impact of chemical engineering research. You will find that all of the case studies demonstrated here show how chemical engineering impacts the world around us.

We are often asked 'what is chemical engineering?'. Therefore, our community must work to improve public understanding of the discipline. This booklet does just that, for it shows how food, water, wellbeing, manufacturing and energy all rely on excellent chemical engineering research.

Our definition of impact is borrowed from the adopted definition in Research Excellence Framework (REF) 2014; 'an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia'. The case studies showcased here are among those submitted by the chemical engineering academic community to the REF exercise.

However, the work presented goes beyond chemical engineering and is an opportunity to look at the scope of knowledge and competency required of chemical engineers as practitioners in a social context. These case studies show that chemical engineering draws on many different experiences and, in a holistic vision of the profession, interface and complement technical competence with a wider socio-economic perspective.

Selecting ten case studies for inclusion in this booklet has been a difficult job; we faced the challenge of choosing between a large number of equally impactful cases. I would like thank my colleagues from IChemE's UK Research Committee who took on the difficult challenge of choosing the cases with me. The choice is by no means definitive as there are so many excellent examples of impactful chemical engineering research to be found.

Each one of these case studies will demonstrate to you that *Chemical Engineering Matters* across the breadth of energy, food, manufacturing, water and wellbeing. It should also be noted that many are cross-cutting and, in line with the nature of chemical engineering, they impact upon more than one aspect of our lives and indeed contribute to the whole spectrum of challenges that the world is facing.

We would like this booklet to provide inspiration to the wider world. From the students yet to study chemical engineering; to professionals who work in engineering; and the public to help develop their understanding of the role of chemical engineering in society. This booklet should be recognised not as an exhaustive piece of work, but rather as the starting point of a long journey of exploitation and realisation of chemical engineering research impact.

I would like to take this opportunity to thank the Baroness Brown of Cambridge, Professor Dame Julia King, for kindly hosting the launch of this work.

Professor Raffaella Ocone FREng, FRSE, FIChemE, FRSC
Chair of the IChemE UK Research Committee

# Chemical engineering formulates low fat products for improved health

**Research focused on designing soft solid microstructures, including emulsions and fluid gels, has enabled the production of a range of novel, low and zero fat foods.**

## What is the problem?

There is an exponential rise in obesity, nearly 40% of adults are overweight (WHO 2014), which poses a significant risk of morbidity and mortality. There is an increased awareness of the relationship between diet and health that has led to an upward demand for healthy, low and zero fat foods. The food industry is constantly seeking ways to improve the quality and palatability of such products, by understanding the fundamental science that underpins manufacturing and performance of these foods. However, replacing fat with non-fat ingredients, such as water, water-soluble components or air, without compromising the full-fat sensation, requires accurate control of the microstructure in order to achieve the desirable safety and sensory attributes. This in turn requires in-depth knowledge of the principles of microstructure formation and its role on functionality.

## Why do chemical engineers make a difference?

Research at the School of Chemical Engineering, University of Birmingham, has focused on microstructure engineering of soft solids for food use. These are highly complex materials with detailed microstructures and rheological behaviours, meaning that they are neither simply solids nor liquids; such as butter, margarine, mayonnaise, and yoghurts. This research looks at the fundamental mechanistic understanding of dispersions of oil and water phases (also known as emulsions) under flow. Flow is important in the manufacturing of fat-continuous products such as butter and margarine, in which fine water droplets are dispersed in a fat continuum. This research has enabled production of spreads with fat content of less than 50%.

Another research area involves use of hydrocolloids (thickeners) to control the viscosity of the water phase for increased emulsion stability. A major challenge in this area is the understanding and control of the effect of added thickening agents, on the taste and texture of the final product. This work has led to the ability to produce zero fat spreads, which are stable on storage and breakdown when consumed to give the physical properties and flavour release expected from margarine.

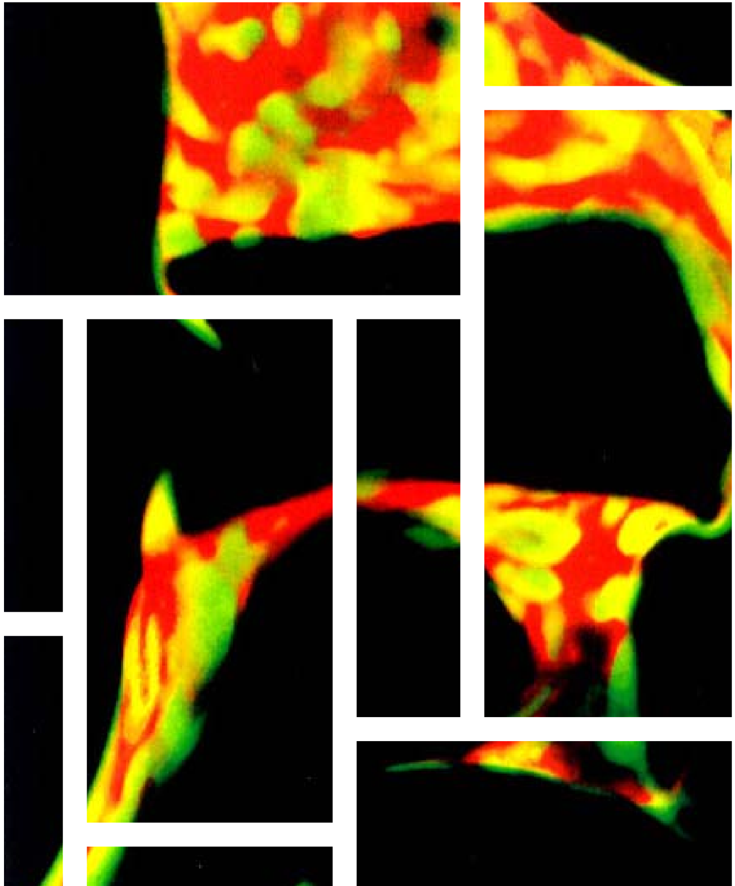
## How has this made an impact?

Research on designed soft solids microstructures was carried out with the aim to engineer reduced fat foods, involving chemical engineering and a number of multinational food industries (including Unilever, Cargill, and PepsiCo). This research has led to the successful manufacturing of an expanded range of novel products with "reduced fat" claims such as low fat spreads, dressings, margarine, sauces, and mayonnaise, which would be much reduced without the engineering work. At least 10 patents have been filed directly related to the research.

Overall, low fat foods contribute to the reduction of fat consumption. It is worth keeping in mind that the risks associated with increased mortality and morbidity are currently estimated at £1.6 trillion (McKinsey & Company statistics). These products are a significant and growing market segment (eg low fat substitutes now outsell margarine/butter in a number of countries and are estimated to be worth globally £8B per year). These products also have a significant impact on the industries' profitability and innovation, and result in inward investment within the UK. From the application of this research, Unilever and Kraft foods have been identified amongst leading names in innovation in reduced fat products.

"The understanding developed by Birmingham has enabled us to manufacture and develop superior quality low-fat foods. In the absence of this research we would have had considerably reduced ability and arguably many products may not have been produced at all."

Vice President Biological Sciences, Unilever R&D



Impact

**38% of consumers eat low fat versions of food**

DEFRA's annual summary of food-related data reported that nutritional content is widely influential on shoppers' purchase decisions; particularly the level of fat within the food. 38% of people who were asked about how they obtained or maintained a healthy lifestyle, said they would eat low fat versions of food.

# Biochemical engineering creates technologies for a greener pharmaceutical industry

**Research has been instrumental in creating critically needed, new biocatalysts and bioprocess technologies, to deliver environmental benefits and reduce waste in the pharmaceutical industry.**

## What is the problem?

It is widely recognised in the chemical and pharmaceutical industries that biocatalysis delivers environmental benefits when used to replace chemical approaches that require multiple steps and the use of protection/deprotection reagents. For example, replacing chemical approaches that require the use of hard-to-dispose-of organic solvents. The challenge is to develop robust, high yielding bioprocesses to make pharmaceutical drugs.

## Why do biochemical and chemical engineers make a difference?

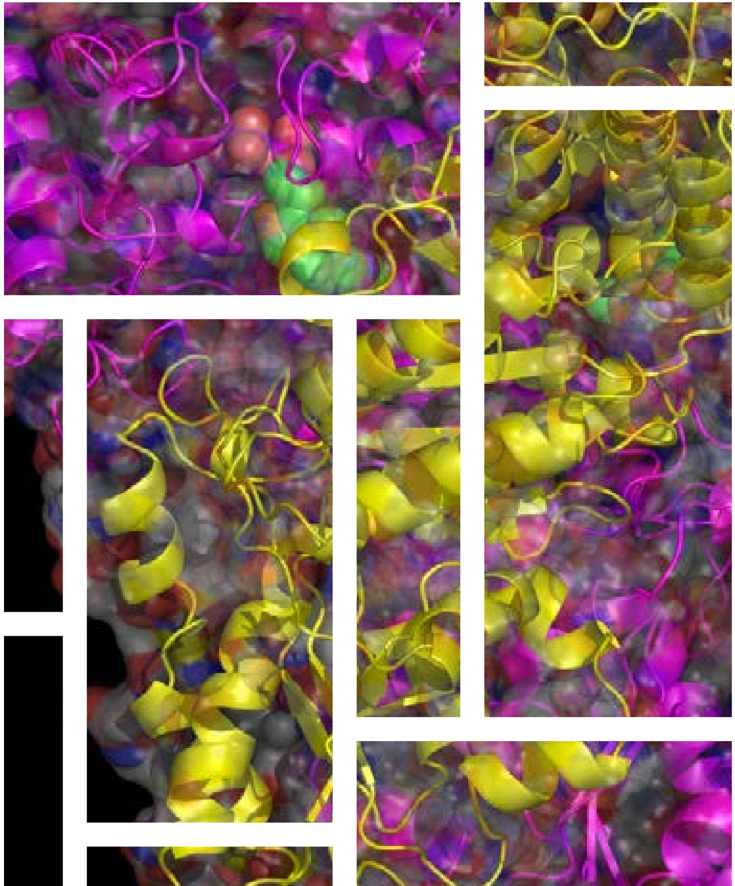
University College London's Biocatalysis Integrated with Chemistry and Engineering (BiCE) research group has developed a framework, and tools, for constructing multi-step enzyme-catalysed processes rapidly and efficiently. They combine synthetic chemistry, molecular biology and process engineering to create libraries of engineered enzymes. This new integrated approach generates novel biocatalysts with increased productivity, for application in the chemical and pharmaceutical industries.

These technologies facilitate the rapid design and scale-up of green, more environmentally friendly, industrial biocatalytic processes. Automated, high throughput methods have been developed for biocatalyst process evaluation, along with novel miniature stirred bioreactor technologies that help facilitate rapid establishment of biocatalytic and chemo-enzymatic routes. This research has enabled the removal of key bottlenecks in the development of novel, industrial processes for the synthesis of amino alcohols – a precursor to many of the pharmaceuticals currently on the market.

## How has this made an impact?

The BiCE enzyme technologies have been exploited through the formation of a spin-out company, Synthace, the UK's first dedicated synthetic biology company start-up. It aims to make high-value, bio-based chemical and biological products. Companies license the libraries of engineered enzymes, saving them the time and costs involved in in-house library generation. For example, Almac has used over 100 of these enzymes in its drug discovery programmes and for customer contracts, and the company used one to convert a client's compounds. Almac reports that not only is the new enzyme process one-third of the cost of the chemical process, but the yield has increased from 10% to over 90%.

Companies involved in the research project have adopted many of the new bioprocess tools for their own use, speeding the design of new biocatalytic processes. These include Lonza, Merck & Co, Evonik and DSM. Merck & Co reported a three- to five-fold productivity improvement by applying microscale-based techniques. This shortened the duration from catalyst screen to delivery of milligram quantities of initial material by 70%, enabling an increase in the number of projects that can be handled by a single scientist and widening the catalyst library that can be rapidly screened.



"Companies like Synthace can help the UK exploit the massive potential that synthetic biology has both here and abroad. By making investment in technology now, it will ensure that in ten years' time the UK is at the forefront of the global race when it comes to commercialising new technologies."

David Willetts, 7 March 2013, (then Universities and Science Minister)

**Impact**

**Yield increases from 10% to 90%**

Reduction in biocatalytic process development times by 70%

A range of enzymes and miniature bioreactor technologies utilised commercially

# Chemical engineering makes oil recovery safer and more environmentally friendly

**Researchers have developed technologies for oil recovery which avoid serious operational and safety concerns.**

## What is the problem?

Despite the world trend to reduce the use of fossil fuels, we are still far from a society which can deliver current living standards without relying on oil and its derivatives. Extending the life and the cumulative production of oil, and directly removing methanol from liquid hydrocarbons, creates large savings and profits.

## Why do chemical engineers make a difference?

Gas hydrates are compounds which form in oil production and processing operations. They can also cause problems for both. Petroleum Engineering within the Edinburgh Research Partnership in Engineering (ERPE) works to better understand and address various aspects of oil flow avoiding gas hydrate, wax and asphaltene problems in the petroleum production and transportation.

From 1993 onwards, ERPE successfully undertook a variety of Joint Industry Projects (JIP) and Government sponsored research projects, focused on developing a method for avoiding hydrate problems in offshore oil and gas operations. These projects involve up to 20-30 industrial partners, investing up to £38.5k per annum per sponsor, into the research. In the last decade the team, led by Professor Tohidi at Heriot-Watt University, firmly established itself within the industrial and academic communities as a leader in flow assurance research, with a reputation for quality experimental work and advanced theoretical studies.

The team discovered that n-propanol takes part in clathrate formation, which is contrary to the general understanding that alcohols prevent hydrate formation. A model of the phase equilibria to predict the hydrate dissociation conditions of methane and natural gases in the presence of distilled water or ethylene glycol aqueous solutions was developed.

## How has this made an impact?

Sequential JIPs have supported the generation of a large in-house library of hydrate equilibrium data, and development of the commercial hydrate predictive software, HydraFLASH®. This software is considered to be the most accurate for predicting hydrate and water hydrocarbon phase behaviour, using the thermodynamic modelling and experimental data generated through various research projects. The software helps major hydrocarbon production and service companies, such as Total, BP and Statoil, in planning their flow assurance strategies.

The work impacted on extending the life of the NUGGETS field (operated by Total) by three years with an increase in cumulative production of 2% (2.8 Million Barrels of Oil Equivalent, value £120M). It resulted in saving £2-6M in costs associated with methanol removal from the liquid hydrocarbon phase, by demonstrating methanol could be removed from Natural Gas Liquids directly by molecular sieve. This played a major role in Total's decision in eliminating a de-propaniser from methanol removal facilities, saving around £50M. Start-up company Hydrafact was created, generating a turnover of £1M in 2012 and employing 8 full-time and 15 part-time staff.

> "It suffices to state that without these results our operations would be non-optimal, resulting in lost value in hundreds of thousands of GBP per year."
>
> Senior Specialist, Flow Assurance at Statoil

**Impact**

**£120M**

Value of extending the life of the NUGGETS field (operated by Total) by three years with an increase in cumulative production of 2%

# Biochemical engineering removes arsenic from groundwater for community use

**This pioneering bioprocess engineering design established how in-situ chemical free treatment of an aquifer can remove arsenic from community water supplies.**

## What is the problem?

Millions of people worldwide are chronically exposed to high levels of arsenic, present in water. In the Indian subcontinent, nearly 70 million people are chronically exposed to high levels of arsenic in rice, milk, vegetables and drinking water. More than 1500 villages in West Bengal in the Gangetic plain are seriously affected by arsenic contaminated groundwater. At least 10 million people living in West Bengal, including about 2.5 million children, were drinking arsenic contaminated ground water containing an arsenic concentration 5-20 times higher than the limits set by the World Health Organization. As a result, almost 3 million people in the region suffered from arsenic related diseases.

## Why do biochemical and chemical engineers make a difference?

A partnership of NGOs and academic institutions led by Professor Bhaskar Sen Gupta, installed world's first chemical and waste free water treatment plant in the arsenic belt of India. The conventional technologies for arsenic remediation are based on 'pump and treat' method involving either adsorption or membrane processes. Such plants are expensive to run and have problems associated with waste disposal and maintenance. In order to design the chemical-free process for resource-poor areas, the following ground conditions were considered: marginalised rural communities may not be able to pay more than $1 for a month's potable water supply; and the technology should be waste-free. The Subterranean Arsenic Removal (SAR) or 'In-situ treatment' developed at Queen's University Belfast neither uses any chemicals, nor produces any waste, making it a very low cost technology option for rural use.

In this process, the underground aquifer is turned into a natural biochemical reactor and adsorber, that removes soluble Arsenic (As), Iron (Fe) and Manganese (Mn) at an elevated redox value of groundwater. This is achieved by returning a pre-calculated amount of the abstracted water under gravity to the same aquifer depth after aeration through shower heads. The oxidation of Fe, Mn and As is accelerated by the autocatalytic effect of the oxidation products and by the autotrophic microorganisms. No added chemicals are used and no sludge is produced in the process, maintaining normal permeability of the aquifer. Every single component used in the plant is available from local hardware shops.

## How has this made an impact?

This technology can replace expensive adsorption or membrane-based processes where disposal of high-arsenic hazardous waste pose a serious problem. Furthermore, very low operating cost makes the process affordable. The concept developed over the period 2004-2007, and was put to practice with six community plants installed in West Bengal; one experimental plant in Washington State, US; one in Kota Bharu, Malaysia; and three in the Prey Veng & Kandal Provinces of Cambodia, based on solar power. The cleaner water has had a remarkable impact on the affected population in six villages in West Bengal, Merudandi, Purbapara, Gotra, Naserkul, Rangapur and Tepul. Most people in an advanced stage of arsenicosis showed signs of recovery in less than a year. From this many more plants have been installed in the Bengal delta, benefitting thousands of people since 2013.

The plants were built from simple plumbing components by local plumbers and electricians. The plants were constructed through funding from the European Commission, the World Bank and DFID. Each plant produced 5000-10000 litres of safe drinking water at a cost of $1 for every 10000 litres or less.

"The low tech nature of the installations, coupled with the minimal waste disposal and energy requirements, set the standard in sustainable remediation to which others should aspire."

Jury of the UK 'Energy & Environment Industry' award in 2011

Impact

**US$1/10,000L safe drinking water**

Plants of 10,000 litre capacity based on the current design cost US$ 6000 (mains supply - India) and US$ 10000 (solar - Cambodia) respectively. Solar plants have no recurring operation cost while conventional plants cost US$ 1 to produce 10,000 litres of water.

# Chemical engineering creates cutting-edge modelling processes

**Research into new process modelling tools and numerical simulation and optimisation algorithms have resulted in a powerful new modelling technology, gPROMS.**

## What is the problem?

The development of process modelling tools, numerical simulation and optimisation algorithms is required to provide associated leading-edge model services. This includes the design of new processes and the optimisation of existing processes. A number of challenges arise in attempting to model these processes, including the need for a comprehensive model description language, and the need for describing operating procedures and solving complex, dynamic hybrid systems models.

## Why do chemical engineers make a difference?

Imperial College London's Centre for Process Systems Engineering (CPSE) has worked to research powerful new modelling technologies. The research is focused on the development of process modelling technology and its application to process design, operations and control. Research programmes were organised into a number of thematic areas including: process synthesis and design; process operations and control; process modelling and numerical methods. In each of these areas, ground-breaking developments in modelling languages, numerical solution techniques, experimental design, dynamic optimisation, and applications to process design and operation, took place.

A team from CPSE established a spin-out company, Process Systems Enterprise Ltd (PSE). This has commercialised the process and energy systems modelling platform - gPROMS. It also provides leading-edge model based services such as the design of new processes and the optimisation of existing processes. These research activities all fed into the development of the gPROMS modelling framework. Another feature of CPSE's research programme was major integrated projects; used to integrate strands of basic research and undertake development activities in collaboration with industry. This enabled rapid evaluation on industrially-relevant problems and refinement of the methods. The research was also oriented to a major project around the design and implementation of a next generation process modelling architecture. The result has been the development of a prototype tool, tested with a group of potential users, based on CPSE's industrial consortium and including Unilever, ICI, Du Pont and Dow Chemical.

## How has this made an impact?

Based on turnover, £400k at launch to £13M today, PSE is now recognised as a leading provider of process modelling technology and modelling platforms, with over 120 employees in high-end jobs. Its customers include most of the world's leading chemical, energy and automotive companies (Dow Chemical, BASF, BP, Shell, ExxonMobil, Toyota, Honda, Ford, Mitsubishi Chemicals) and it has a strong international presence with offices in the UK, US, Germany, Japan and Korea and agencies in China, India, Saudi Arabia and Thailand.

The overall benefit to industry is estimated to be £400M. The software allows customers to model, understand and optimise their processes in an unprecedented manner, leading to improved designs and more efficient operations. The gPROMS software is used in over 200 universities for teaching and research, where it enables research into new chemical and energy processes to take place.

> "We increased total annualised profit by several tens of millions of €/year."
>
> Dr Hilario Rodriguez, Repsol

**Impact**

**£10M**

Based on turnover, £400k at launch to £13M today, PSE is now recognised as a leading provider of process modelling technology and modelling platforms

# Chemical engineering creates novel approaches for environmentally friendlier industries

**New methodology and software for assessing environmental impact throughout the life cycle of commercial products has led to significant potential for its reduction by focusing on carbon hot spots.**

## What is the problem?

All manufacturing processes carry an inherent environmental impact. In a steady state, all the damage caused to the ecosystem would be counterbalanced by the environment's natural recovery mechanisms. However, in present times there is increasing concern that the rate of the damage created exceeds that of the environment's recovery capacity, resulting in net environmental destruction with detrimental consequences to the ecosystem. Reducing environmental impact is an important target globally, set high up in the agenda of many industries and welcomed by the consumers. All stages of production and consumption of commercial goods contribute to the impact and require effective carbon footprint reduction. However, the relevant approaches are often either too simplistic to be effective, too complex to be routinely used, or too limited - estimating the carbon emitted directly by organisations rather than the emissions along the whole supply chain. There is the need for a systematic, holistic approach in order to mitigate climate change more efficiently.

## Why do chemical engineers make a difference?

To fill this gap, researchers at the School of Chemical Engineering, University of Manchester, have developed a novel methodology and a software tool for estimation of environmental impacts of industrial activities and commercial products from 'cradle to grave'. The CCaLC software (Carbon Calculations over the Life Cycle), is free to download and user friendly for non-experts, thus allowing in-house estimation of the footprint.

CCaLC has proved to be a powerful tool for providing new insights on carbon hot spots, often overturning previous assumptions and helping to focus carbon reduction efforts in areas where the greatest improvements can be achieved. It enables significant carbon reductions efficiently across different sectors. In addition, CCaLC considers the effect of reducing carbon emissions on other environmental impacts and/or costs in order to make more sustainable decisions. Overall, CCaLC can be used successfully for engagement along supply chains, raising awareness and disseminating best practice for carbon reduction.

## How has this made an impact?

The impact of CCaLC is evidenced by its global presence, having more than 6000 users in more than 80 countries. The software has won several prizes and has been endorsed by organisations such as BERR (now BEIS), DEFRA and the World Bank. It is used widely by industry across a range of sectors to reduce carbon footprints of their products and increase sustainability.

This has resulted in significant environmental and socio-economic benefits, including estimated climate change mitigation gains in excess of £450M. In one example, Kelllogg's, a leading company in cereal and convenience foods production with £10 billion sales, has been using CCaLC since 2010 to estimate carbon footprint in the life cycle of their entire range of products (about 2000). This has, for the first time, enabled identification of the carbon-intensive stages in the life cycle of different products, demonstrating that a 20% reduction in the carbon footprint is possible across the business. CCaLC can also be valuable tool in product design to help reduce environmental impacts. For example, in the case of Special K, CCaLC has shown that small changes in the product formulation could reduce both carbon and water footprints by up to 20%.

"CCaLC has helped Kellogg's to identify business-wide hot spots and provide focus in terms of future priorities for carbon reductions along the entire value chain."

Kellogg's

**Impact**

**20% carbon footprint reduction**

CCaLC estimates have shown clearly that Kellogg's carbon footprint can be reduced by up to 20% by focusing on key life cycle stages, helping the company meet their sustainability targets.

# Chemical engineering revolutionises the way diabetics monitor their blood glucose

**Research into electrochemical biosensors creates health products targeted directly towards patients.**

## What is the problem?

Diabetes is an emerging global epidemic. The World Health Organization (WHO) estimates that 347 million people worldwide will suffer from diabetes between 2005 and 2030, and deaths from diabetes will double, 80% of which will be in poorer countries. Diabetes is a leading cause of blindness, amputation and kidney failure, and is a massive burden on global healthcare systems. Controlling diabetes well depends on precise monitoring of patients' blood glucose levels, but traditional blood glucose monitors – which rely on so-called static electrochemistry – are accurate only to plus or minus 20%. Many factors – from paracetamol to vitamin C – can distort blood samples. The challenge is how to improve the accuracy of blood glucose monitors, something Cambridge research has achieved thanks to innovative electrochemistry.

## Why do chemical engineers make a difference?

Research on electrochemical biosensors in Professor Lisa Hall's lab in the Department of Chemical Engineering, University of Cambridge, has examined existing systems of blood monitoring, mostly applied fixed voltage stimulus to the electrochemical sensor and measured a steady-state current. Although this is a simple way to measure glucose concentrations, it is not accurate enough. This research applies a variable, wave-like signal instead. Together with some clever advanced processing this has allowed the biosensor to compensate for electrochemical reactions due to interfering substances such as paracetamol or vitamin C, as well as the glucose reaction itself.

This novel approach focuses on time-varying sinusoidal voltage waveforms to stimulate the electrochemical glucose sensor and generate a reciprocal sinusoidal response current. This enables the extraction of time constants related to the electrochemical reactions that are either specific to the glucose reaction or to an interfering substance (such as vitamin C). The time-varying nature of this approach inherently generates a measureable signal that contains more rich information (as compared to a steady-state response), and thus enables separation of the desired glucose signal from the interfering signal.

## How has this made an impact?

AgaMatrix was founded in 2001. Its innovative technology – WaveSense™ – has now been built into a range of diabetes products including the diabetes iPhone App, iBGStar. Approved by the US FDA in 2011, iBGStar was the first smartphone-linked diagnostic device to gain FDA approval. It also won the Red Dot and Good Design awards – an honour shared with Apple, Mercedes and Bose products. As well as its iBGStar, AgaMatrix has developed more than 10 FDA-cleared products protected by more than 120 pending and granted patents worldwide.

By 2012, AgaMatrix had sold 3 million glucose meters and test strips, and today its products are sold in over 20,000 pharmacies worldwide. In 2013, the NHS in Staffordshire decided to give WaveSense™ Jazz meters to patients, saving the NHS £350,000. If the NHS adopted WaveSense™ nationwide, cost savings could top £4 million a year.

"This is a real step forward for patients, GP surgeries, hospitals and pharmacies."

Dr Manir Hussain, North Staffordshire and Stoke-on-Trent Clinical Commissioning Groups

**Impact**

**1 million test strips per month**

Agamatrix UK now supplies over one million glucose test strips per month to the NHS. Agamatrix has developed more than 10 FDA-cleared products, including the first FDA approved smartphone linked diagnostic device.

# Chemical engineering improves the biomass efficiency

**Over the past 10 years there has been a massive expansion in biomass use for power generation. Research has been crucial in addressing the challenges of moving from coal to biomass.**

## What is the problem?

In the UK, electricity generation through biomass co-firing began in 2002 and grew to approximately 28 MWe by 2005. More recently there have been several strategic investments by the UK's power generation industry to replace coal with biomass, driven by legal domestic targets in $CO_2$ reduction and government incentives. Employing biomass will result in at least 70% reduction in green-house gas emissions compared to coal. Increasing incentives could "employ up to 18,000 jobs in the UK by 2020 in the biomass electricity sector alone" (Bioeconomy Consultants NNFCC, 2012).

## Why do chemical engineers make a difference?

Researchers from the University of Leeds, led by Professor Jenny Jones, have worked with Drax to become the biggest renewable power generator in the UK. Drax now operates three fully biomass-converted units and the company has reduced its carbon emissions by 12M tonnes per year. The research is underpinned by four main areas of chemical engineering: fundamentals of biomass combustion; biomass supply and combustion of energy crops; impact of inorganics on combustion properties and ash behaviour; torrefaction of biomass and impact on biomass handling and combustion.

The research involves the characterisation of fuels used in industry for their thermal conversion behaviour and their predicted performance for different technologies. The work stems from the very fundamental to more applied chemical engineering studies of behaviour, at large scale utilisation. This includes milling behaviour and development and application of computational fluid dynamic (CFD) modelling of large boilers and furnaces. The work is significant because it enables control over the combustion characteristics of a biomass resource. It led to further development of industrially important work which linked this to impacts in efficiency versus deposition in boilers and furnaces.

A Knowledge Transfer Partnership explored global wood fuel markets under strict sustainability criteria and widened the fuel portfolio. This directly contributed to the overall strategy of Drax Group PLC by supporting the establishment of new supplies. It also helped to diversify the business away from the historic total reliance on fossil fuel supplies for power generation

## How has this made an impact?

The move to biomass has required changes in policy and practice at nearly every stage in the energy cycle, from fuel procurement and logistics to handling (including milling), burner design, and firing and emission control strategies. Research from the University of Leeds underpins a number of technical challenges the industry has overcome and has also informed policy, in particular the development of energy roadmaps. These impacts occurred as a result of dissemination and direct beneficiary engagement via collaborative R&D, consultancy, CPD and expert advisory roles and capacity building.

One company that has benefitted from technical innovations in the fields of biomass combustion, boiler efficiency, plant operation and emissions is the UK's largest electricity generator, Drax Power, who generate 7% of the country's electricity. The conversion and upgrading of Drax Power Station to use biomass instead of coal has resulted in carbon reductions of over 80% compared to coal, making it the UK's single largest source of renewable power (20% of renewable electricity in the UK in the first half of 2016). The conversion generated in excess of £430 million in GDP (2016 prices) and supported over 7,000 annual jobs. In addition, some £118 million in tax revenue (2016 prices) was generated over the six-year process.

> "[The research allowed] full sustainability to be achieved, opening up new markets to the industry and better managing the world's resources on a global scale."
>
> Drax Power Ltd

**Impact**

**£430M**

The conversion of three units from coal to biomass at Drax Power Station has resulted in: 12M tonnes/pa $CO_2$ reduction; £430M in GDP (2016 prices); 7000 annual jobs and 20% of UK's renewable electricity in the first half of 2016.

# Chemical engineering provides low energy desalination

**The research has led to energy reduction in desalination by more than 30% and spin-out company Modern Water plc. with a market value of £70M.**

## What is the problem?

The Food and Agriculture Organisation of the United Nations (FAO) predicts that by 2025, 1.8 billion people will be living in areas of absolute water scarcity, and two-thirds of the world's population will live in water stressed areas. 97.5% of the earth's water is salt water. Fresh water can be produced from salt water using a semi-permeable membrane and high pressures in a process called Reverse Osmosis. Despite its successful application, the Reverse Osmosis process suffers from problems such as high energy demand, significant corrosion, and fouling, and scaling of the Reverse Osmosis plant components; all of which increase the cost of operation by increasing energy and chemical consumption. Previously, research into reducing the problems has focused on physicochemical solutions, for example the addition of chemicals and frequent replacement of the membranes.

## Why do chemical engineers make a difference?

The Centre for Osmosis Research & Applications (CORA) at Surrey University, founded by Professor Adel Sharif, adopted a different approach by researching the chemistry of seawater, benefiting from a £250,000 award by the Royal Society in 2005 (Brain Mercer Award for Innovation) and the University SEED fund. By building on previous research in membrane separation which was supported by EPSRC, BBSRC and UK industry, they found that by adding osmotic agents to a formulated solution, they could manipulate the osmotic barrier. This allows pure water to move from the seawater side of the membrane to the fresh water side, avoiding the need for high pressures and any of the undesirable corrosive, fouling and scaling properties of seawater.

This research has developed a much more sustainable solution. Field trials have confirmed that fouling in the Manipulated (Forward) Osmosis membranes is reversible and can be removed by backwashing, as a result of operating under low pressure and no compacting effect. A commercial plant (with capacities in excess of 200 $m^3$/day) has been operating since 2009 in harsh conditions in Oman producing high quality water to the public, without the membranes requiring replacement or cleaning.

## How has this made an impact?

The University of Surrey has a strong legacy of research into membrane separation and osmosis, culminating the commercialisation of Surrey's spin-out company Modern Water plc. The company is based in Guildford and specialises in desalination and water treatment. The desalination technology was developed, and led to eight patent families being filed. The University, its Seed Fund and a Brian Mercer award funded the early proof of concept and commercialisation, and external investors including the IP Group followed with an additional injection of £685,000. IP Group led the flotation on AIM (London Stock Exchange) raising £30M in cash and with a market value of £70M, with research being the cornerstone of the flotation.

Modern Water plc. has offices in the UK, Middle East and China and employs 52 staff, with a turnover of £3.7 million and plans for further expansion. The company provided successful desalination solutions to the Reverse Osmosis technology in Gibraltar and Oman based on the work's Manipulated/Forward Osmosis technology. The research itself is having direct impact via operating desalination plants in Gibraltar and Oman producing high quality drinking water typically using 30% less energy than conventional desalination plants; because of the poor quality of the feed water in Oman the plant is using 42% less energy, for about 600 people.

"We thought that this would be a good test for Modern Water and its technology; if it is successful at Khaluf, it should work almost anywhere."

Mr Mohammed Al-Mahrouqi
Chairman of the Oman Electricity and Water Public Authority

**Impact**

30% less energy used
Reduction in the energy used for desalination by more than 30% than conventional desalination plants.

# Chemical engineering improves kitchen sinks

**Research and development into polymer-clay nanocomposite materials has led to the successful commercial manufacture of kitchen sinks with enhanced durability, mechanical and chemical properties.**

## What is the problem?

Manufacturing processes are very energy and labour intensive, and product quality is frequently unreliable. The net cost of this to companies comes in terms of lost production time, material wastage and disposal costs. To meet the challenges of achieving reductions in production costs, significant technological challenges must be met. At the same time manufacturing must also focus on improvements in the efficiency of manufacture, energy usage and in the reduction of wastage from spoiled products.

## Why do chemical engineers make a difference?

A trilateral research partnership between the University of Strathclyde's chemists and chemical engineers, and Carron Phoenix Limited was central to the successful design of the new production process leading to the new materials. Together with licensing and significant royalty costs, Carron Phoenix Limited, part of the Swiss Franke Group, sought research expertise to develop new alternative quality processes and products. The research involved carrying out a full evaluation of the chemical processing practices, as well as material and energy audits. Detailed understanding of the mixing of materials, reaction characterisation, and heat and flow properties was also achieved. This led to a radically new approach to processing, which influenced how the workforce was deployed, with the changes fully implemented by the company.

This research was crucial in allowing the team to fully characterise and optimise the new production process and to identify suitable nanoclay fillers and rheology modifiers to allow control of the main processing and materials characteristics that influenced the manufacturing process. Understanding and control of these properties was crucial for the production of synthetic sinks, free from warpage and surface blemishes. It was also to improvements in the efficiency of manufacture and in the reduction of wastage from spoiled products. Research and development of so-called polymer-clay nanocomposite materials has led to the successful commercial manufacture of kitchen sinks with enhanced durability, mechanical and chemical properties, including impact strength, gas and liquid impermeability, and fire retardancy, compared to existing products.

## How has this made an impact?

This research has led to a collaboration with the world's largest manufacturer of composite kitchen sinks, Carron Phoenix Limited, through two Knowledge Transfer Partnerships (KTP), over a six year period. This has resulted in a successful new production process of its high-end synthetic granite kitchen sinks. This led to £4 million of capital investment in new production facilities at their Falkirk site, enabling the company to sustain its leading position in the designer kitchen sink market. The research has led to the manufacture and sale of in excess of one million kitchen sinks, generating sales revenue in excess of over £50M.

The knowledge transfer programmes within this research brought together the complementary expertise of the Strathclyde chemists and chemical engineers with technologists at Carron Phoenix Ltd. The main engineering focus was to ensure that the prior chemistry findings could be fully translated and scaled-up as an industrial production process that delivered a consistent high quality product.

"The nanoclay positively influenced the process behaviour, significantly enabling us to introduce the new manufacturing technology, which delivered significant savings through its greater efficiency. No nanoclay - no new process at that time, it is as 'simple' as that."

Ian Hunter, R&D and Laboratory Manager, Colour Sinks, Carron Phoenix Ltd.

**Impact**

£50M

The research has led to the manufacture and sale of in excess of one million kitchen sinks, generating sales revenue in excess of over £50M.

# Chemical Engineering Matters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