



**EPSRC**

**Centre for Innovative Manufacturing**  
in Continuous Manufacturing and Crystallisation

# Annual Review

2011-2012

**EPSRC**

Engineering and Physical Sciences  
Research Council



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 This EPSRC Centre for Innovative Manufacturing has been co-created with industry to address their long-term manufacturing challenges and emergent market opportunities.

# Vision



This report provides a summary of the EPSRC Centre for Innovative Manufacturing in Continuous Manufacturing and Crystallisation and highlights key events and activities during its first year. Although the Centre is led from the University of Strathclyde the collaborative programme is delivered by a multidisciplinary academic team that also includes colleagues at the Universities of Bath, Cambridge, Edinburgh, Glasgow, Heriot Watt and Loughborough. The vision, scope and programme for the national Centre have been developed

through close collaboration with industry and in particular our founding strategic partners GSK, AstraZeneca and Novartis who have provided significant input and support throughout the last year. With the Centre now established and the flagship research projects and platform activities underway, a key focus in the coming year is the delivery of the research programme and infrastructure supporting our forward plans. Designs for the new continuous manufacturing research facility in the Technology and Innovation Centre at Strathclyde are well advanced and from 2014 will house world-class facilities for collaborative research. Investments by our partner Universities have also made significant contributions to enhance the facilities supporting research in this area. In October 2012 we also welcomed the first cohort of doctoral students joining the new Doctoral Training Centre embedded within the Centre. These are exciting times for the Centre and our partners and we look forward to continue to develop our relationships with the wider national community concerned with Continuous Manufacturing and Crystallisation.

Prof Alastair Florence, Director





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Accelerating the adoption of continuous manufacturing and crystallisation processes, systems and plant for the production of high-value chemical products to higher quality, lower cost, more quickly and more sustainably.

## Introduction

A team that includes three of the world's largest pharmaceutical companies (AstraZeneca, GSK and Novartis) and seven leading UK research Universities (Bath, Cambridge, Edinburgh, Glasgow, Heriot Watt, Loughborough and Strathclyde) have created a unified, long-term vision: to enable a step change from the current batch manufacturing paradigm to fully continuous manufacturing processes, systems and plants for the production of high-value chemical products to higher levels of quality, at a lower cost, more quickly and in a more sustainable manner. In partnership, the academics, industrialists and the Research Council have now established a national EPSRC Centre for Innovative Manufacturing to enable industry to manufacture better particles and high-value chemical products and pioneer the supply-chain for realising this new manufacturing paradigm.

The EPSRC Centre award of £5.9M started on 1st October 2011 and this report summarises the background to the Centre and highlights some of the key areas of progress throughout our first year in operation. The first year has focussed on establishing the Centre and operational structures with key appointments and the initial research programme all now in place. A particular highlight of the year has been the successful £4.3M EPSRC Doctoral Training Centre bid that will support an innovative multidisciplinary training programme for 45 doctoral studentships over three intakes. The initiative has excellent support from a broad range of our industry partners, with over £500k of new support,

and benefits from inputs from all of our academic partners to enable us to deliver a world-class training programme. The Centre's Advisory Board, chaired by Prof Paul Sharratt (ICES Singapore), will provide input to the direction and range of activities we develop over the duration of the grant. A key part of the Centre's success will depend on successful user engagement and through our Industry Director, Craig Johnston, we have developed excellent relationships with a range of end-users and technology providers. These developments will help to ensure the manufacturing research carried out within the Centre continue to meet the demands of industry in this area.

**CMAC**  
Continuous Manufacturing  
and Crystallisation

**gsk** GlaxoSmithKline

**AstraZeneca**

**NOVARTIS**



# Overview of the EPSRC Centre 2011-12

## Demand-led Scope

The research scope of the EPSRC Centre has been defined jointly by the academic team together with our industrial partners. The 10 key challenge areas against the scope are summarised in Figure 1 right and provide a focus for the academic engineering and physical science research activities.

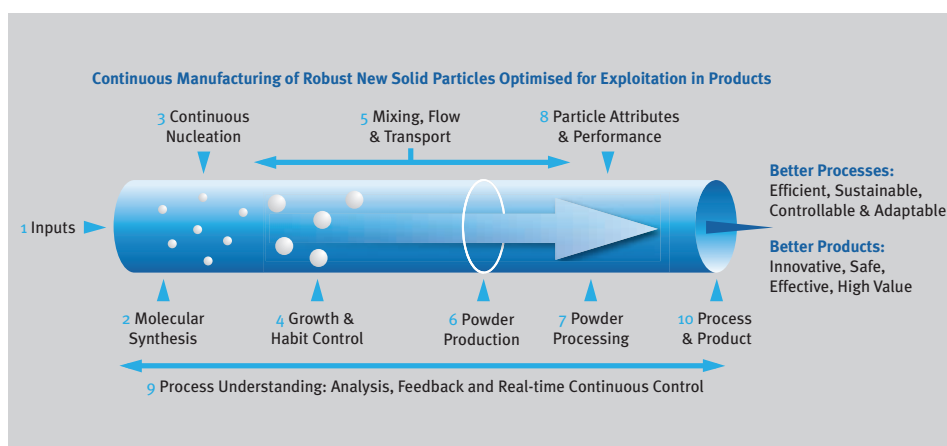


Figure 1. EPSRC Centre research scope highlighting 10 key areas where engineering and physical science research can contribute to accelerate the adoption of continuous manufacturing.

## Centre Mission

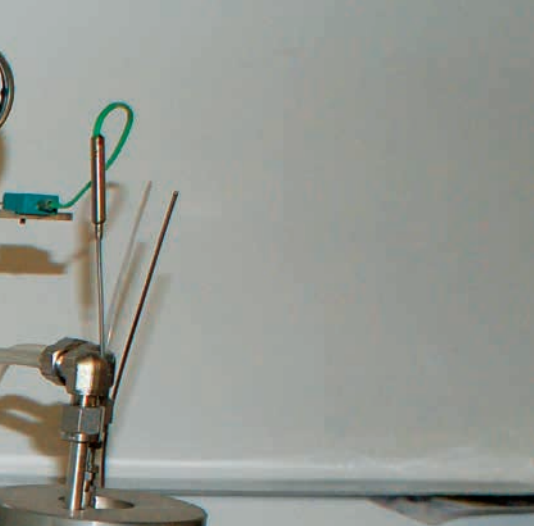
Through partnership and collaboration between academia, industry and public sector stakeholders we will establish a world-class Centre of Excellence in continuous

manufacturing and crystallisation research. The programme will deliver continuous manufacturing research across three main thematic areas that are developing new

understanding and supporting innovation across a range of products, processes and operations (Figure 2).

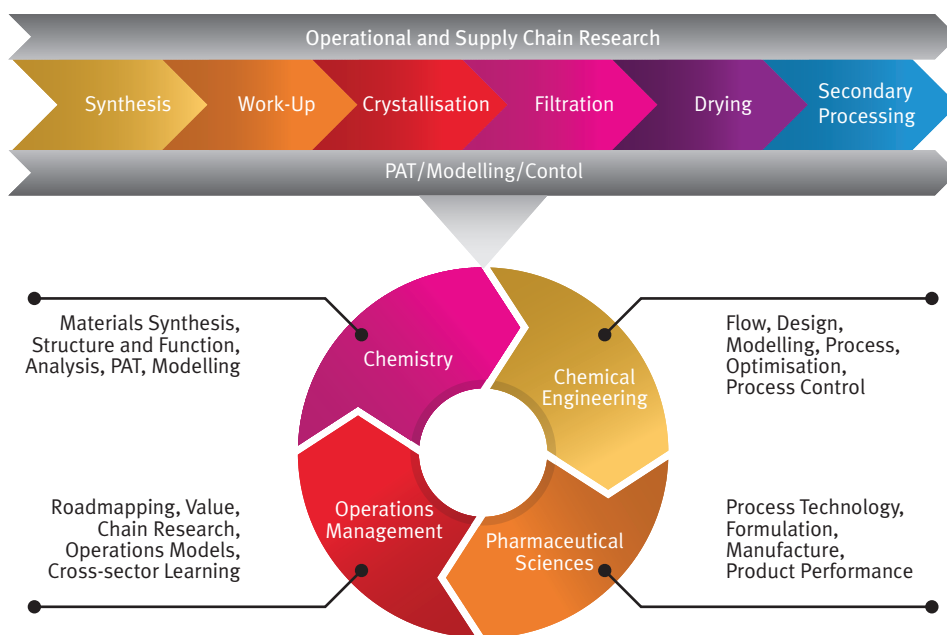
Products	Processes	Operations
<p><b>Better particles through understanding particle formation and performance in continuous processes</b></p> <ul style="list-style-type: none"> <li>• Innovative, safe, effective, high-value</li> <li>• Nucleation, growth, agglomeration, breakage</li> <li>• ‘dial-a’ ...form, size, shape, purity</li> <li>• Tailored bulk and surface structure and function</li> </ul>	<p><b>Better technologies for continuous control, formation, isolation, and processing of particles</b></p> <ul style="list-style-type: none"> <li>• Fast, efficient, sustainable, safe</li> <li>• Controllable, scaleable, adaptable and agile</li> <li>• Predictable, optimised</li> <li>• Reconfigurable, modular, plug-play</li> </ul>	<p><b>Optimised high-value chemical manufacturing operations across the value chain</b></p> <ul style="list-style-type: none"> <li>• Economic, efficient, lean, world class</li> <li>• Wealth creating, sustainable</li> <li>• Deliver regulatory compliance</li> <li>• Reduced time to market</li> </ul>

Figure 2. Key areas for research within the Centre to enable continuous manufacturing of high value chemical products.



## Multidisciplinary Research

Key to the success of the Centre is the multidisciplinary academic team supporting the research programme. Our initial team involves 13 academic investigators from seven institutions working with nine RAs, eight PhDs plus technical and administrative support and harnesses expertise in chemical and process engineering, synthetic, physical, analytical, structural and materials chemistry, crystallisation science, pharmaceutical science, manufacturing and operations management, [Figure 3](#). The programme will adapt to meet the challenges of the scope in years 3-5. The academic team will also contribute to the innovative training programme developed for the new EPSRC Doctoral Training Centre in Continuous Manufacturing and Crystallisation that will train 45 doctoral researchers starting in 2012.



*Figure 3. Key disciplines contributing to the initial EPSRC Centre research programme and Doctoral Training Centre programme.*



*Figure 4. EPSRC Centre flagship research projects in initial programme.*

## Flagship Projects – Years 1-2

Our foundation research activity is delivered via our flagship research projects against key areas of the research scope ([Figure 4](#)). As the national Centre for manufacturing research in this area, we work with a large team of researchers and students and staff have been recruited across the seven universities throughout the first year. A platform RA and technician have also been appointed to carry out short-term feasibility projects and assist in evaluation of new technologies.

# CMAC: Industry engagement

Sustainability is key to the Centre's success and ability to impact in this field through strong industry engagement and leadership. Following the award of the EPSRC Centre, an industry led membership organisation (CMAC) has been created to steer the development of user-led activities in this area, to inform basic research and develop higher Technology Readiness Levels (TRLs) activity (Figure 5). The first CMAC board meeting was held in April 2011 and the sixth board meeting recently took place. In accordance with the Centre's business plan, the aim is to populate the innovation landscape with parallel research activities across the TRLs using a range of appropriate funding mechanisms to address industry needs in a structured manner.

The membership organisation operates under a pre-competitive, collaborative research and development model with senior level company support. The CMAC board (Figure 6) is chaired

by Dr Clive Badman, OBE. A separate Technical Committee comprising industrial experts and representatives of the EPSRC Centre defines the core programme. The EPSRC Centre Director and Industrial Directors are members of these committees to ensure that optimal alignment of the programmes across TRLs is maintained.

In addition to our Tier 1 partners, we are also working with a range of technology providers and companies from other chemical sectors who are contributing to the technical programme, for example, through access to new processing and measurement technologies (Figure 7). We are also continuing to develop further links with other companies that can contribute their expertise to advance the developing programme in continuous manufacturing research.

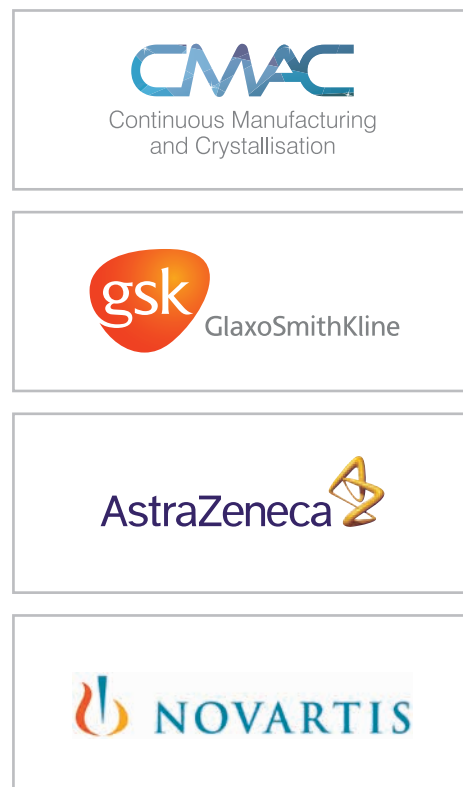


Figure 5. CMAC industry membership organisation and company logos for the Tier 1 founding strategic partners.



Figure 6. CMAC Tier 1 founding members. From left to right: Craig Johnston (EPSRC Centre Industry Director), Prof Sir Jim McDonald (Principal, Strathclyde University), Dr Berthold Schenkel (Novartis, Switzerland), Prof Graham Wren (Strategic Projects, Strathclyde University), Dr Jon-Paul Sherlock (AstraZeneca, UK), Dr Maureen O'Shea (GSK, Ireland), Dr Clive Badman, OBE (GSK, UK).

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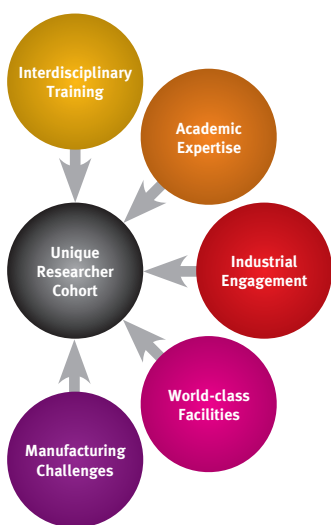
The centre is user led with significant senior industry commitment.



Figure 7. A selection of companies working with the EPSRC Centre.



# Doctoral Training Centre in Continuous manufacturing and crystallisation



## Cohort Building

- Induction
- Residential Training
- Open Day
- Industry Days
- Team building events
- Student forums
- Summer Schools
- Annual Colloquium/Dinner

Figure 8. The new DTC will create a new community of continuous manufacturing researchers.

The Centre team was successful in securing funding from EPSRC to establish a new Doctoral Training Centre (DTC). Through combined support from a £4.2M award from EPSRC, a £50k contribution towards training costs from GSK, AstraZeneca and Novartis and significant support for studentships, training and infrastructure from the participating universities, 45 PhD doctoral researchers will be trained across three cohorts starting in 2012. The DTC benefits from inputs to the training and research programmes from all of the EPSRC Centre member universities (Bath, Cambridge, Edinburgh, Glasgow, Heriot-Watt, Loughborough and Strathclyde).

The DTC provides a cohort approach to deliver the required skills with:

- **Interdisciplinary training** – fresh approach to problems
- **Team working** – e.g. group design project, summer schools
- **Meeting student aspirations** – industry relevant, excellent facilities, exciting projects
- **Establish life-long links** – create a community of practice in continuous manufacturing

## The DTC PhD Training Programme

The DTC four year programme combines a dynamic, multi-disciplinary training spanning the breadth of the Centre’s research scope. The programme combines taught formal training and research (Figure 8). There are three elements to the taught component: (i) a range of taught modules covering the different aspects of the programme; (ii) individual and group miniprojects; (iii) transferable skills training.



## DTC Project themes

- 1 Bridging the gap between compact flow and OBR systems
- 2 Inducing layered solid-forms and controlling crystalline defects in multi-component continuous crystallisation
- 3 Continuous crystallisation of energetic materials
- 4 Model based optimisation of continuous crystallisation
- 5 Comparative investigation of continuous crystallisation approaches with the use of process analytical technologies
- 6 Methods of inducing nucleation for control of crystal properties in continuous manufacture
- 7 The early stages of crystal nucleation and polymorph control
- 8 Continuous seeding in a continuous oscillatory baffled reactor
- 9 Exploring supply network reconfiguration opportunities arising from more continuous processing in pharma
- 10 Exploring the continuous manufacturing lessons from other sectors
- 11 Influence of solid form properties on formulation and extrusion processing
- 12 Development of quality by design and regulatory parameters for continuous manufacturing
- 13 Real-time analytical technologies for optimisation and control of continuous processes
- 14 Lab-scale continuous crystallisers for polymorph and particle control
- 15 Laboratory scale equipment for continuous work-up

Research areas include: crystallisation control and particle engineering; process analytical technologies; powder processing and formulation; process modelling and pharmaceutical regulation and operations management and supply chain research. Students will benefit from support from internationally leading supervisors and expert industry practitioners and opinion leaders. Successful candidates will emerge with an international reputation for excellence in continuous manufacturing and crystallisation research. Further details can be found at: [www.cmac.ac.uk/dtc.aspx](http://www.cmac.ac.uk/dtc.aspx).

## EPSRC Centre 1st Year – Summary Timeline of Key Events

<b>March 2011</b>	Centre awarded
<b>April 2011</b>	First CMAC membership organisation board meeting, chair Dr Clive Badman, GSK
<b>April 2011</b>	Detailed industry engagement, detailed problem statements, workshops, visits, precompetitive technical discussions e.g. CMAC technical committee
<b>May 2011</b>	Industrial Director, Craig Johnston, appointed
<b>Oct 2011</b>	EPSRC Centre grant start
<b>Oct 2011</b>	Co-location of local Strathclyde researchers from pharmaceutical sciences, chemistry and chemical engineering departments into a shared, customised laboratory.
<b>Nov 2011</b>	1st Management Committee held
<b>Nov 2011</b>	Centre Manager, Dr Andrea Johnston, appointed
<b>Dec 2011</b>	Academic Kick-off meeting
<b>Dec 2011</b>	First equipment from technology companies arrived
<b>Feb 2012</b>	Signed collaboration agreement available, funds available, recruitment initiated (some in Oct others spanning Oct-date)
<b>Feb 2012</b>	Doctoral Training Centre bid submitted / Interview and award March 2012
<b>Feb 2012</b>	Delivered workshop on continuous crystallisation at IQPC Amsterdam
<b>Feb 2012</b>	National Centre Strategy Supplement application
<b>Feb 2012</b>	First National Centre Committee
<b>Feb 2012</b>	Discussions and visits with external groups initiated e.g. Imperial (Chem Eng), Leeds (iPRD), Southampton (Maths), UCL (Chemistry), Directed Assembly Network, HVM Catapult (CPI, Wilton).
<b>March 2012</b>	Strathclyde Global Engagements bid to EPSRC successful, March 2012 - ~£100k for this area to develop international engagements targeting US and Far East
<b>March 2012</b>	Outline of £10M capital request to EPSRC submitted
<b>March 2012</b>	CMAC sponsor and joint organiser with RSC Flow Chemistry 2 day conference in York. Speakers included 2 Centre academics and the Industry Director
<b>March 2012</b>	EPSRC Centre contributed to CIKTN scaling-up flow chemistry webinar
<b>April 2012</b>	Specification of dedicated EPSRC Centre Continuous Processing Laboratory in £100M Strathclyde Technology & Innovation Centre building opening early 2014.
<b>May 2012</b>	DTC themes agreed and recruitment initiated
<b>June 2012</b>	Director visits to all academic sites and other EPSRC Centres
<b>June 2012</b>	Cohort of 9 students funded by Scottish Funding Council brought into CMAC fold for efficiency and learning
<b>June 2012</b>	3 month student exchange with MIT
<b>June 2012</b>	European Conference for Crystal Growth (ECCG-4) held at Strathclyde, discussions with EU groups to progress future funding, Director on executive committee, 4 student posters, 2 sessions chaired by Centre academics.
<b>July 2012</b>	DTC grant award starts
<b>July 2012</b>	Consortium building and two subsequent successful TSB Collaborative R&D applications (£1.76m)
<b>July 2012</b>	1st Advisory Board teleconference (including members from Singapore, US, Ireland, UK)
<b>Aug 2012</b>	Global engagements visits to MIT and Purdue to discuss potential collaboration mechanisms between pharmaceutical manufacturing activities in UK and US.
<b>Sept 2012</b>	Participation in EU Cost Action submission on nucleation
<b>Sept 2012</b>	Branding complete, publicity material available and new website ready for launch in October.
<b>Sept 2012</b>	1st Annual Open Day 130 delegates from academia and industry, 33 posters, 12 technology companies exhibiting. Very positive feedback.



# A national EPSRC Centre

As a National Centre we have a role to work with and on behalf of the wider community e.g. to influence policy, facilitate and support workshops, meetings on topics within scope, support feasibility studies, develop national expertise and facility registers (Figure 9).

The EPSRC Centre holds an important position in the collaborative Research and Innovation Landscape in the UK (Figure 10). The national Centre Strategy is to foster and support an inclusive, collaborative approach to accelerate progress across the TRLs involving academia, industry and other research organisations.

To support this we are involved in a range of outreach activities to raise the profile of the Centre and work with colleagues across the UK from different sectors. The Centre is linking with the external academic research community (1), and will continue to evolve and grow the research programme over time to meet the needs of the scope (2). We have established a new DTC to meet the needs for skilled researchers in this area with 45 new PhD graduates establishing new capabilities and capacity in the UK (3). Also through the CMAC industrial membership organisation and the HVM Catapult, the EPSRC Centre is contributing to complementary applied and closer to market research in this area.

## National Centre Roles

The Centre has established mechanisms to support the following activities as part of our National Centre Strategy. We continue to work with colleagues to ensure an effective programme that meets the needs of the wider community.

- Advocate the area and highlight opportunities to interested parties
- Support networking activities across the community
- Engage with researchers outside the Centre with interests in this area
- To act on their behalf e.g. to influence policy
- Facilitate and support workshops and meetings on topics within scope
- Support feasibility studies,
- Researcher exchanges
- Provide access to facilities and training
- Share knowledge and promote collaboration
- Develop national expertise and facility registers, act as point of contact

We will continue to develop the profile and wider awareness of these activities via our website, newsletters, LinkedIn and Twitter presence.

Figure 9. The EPSRC Centre engages in a wide range of activities as part of our National Centre Strategy.

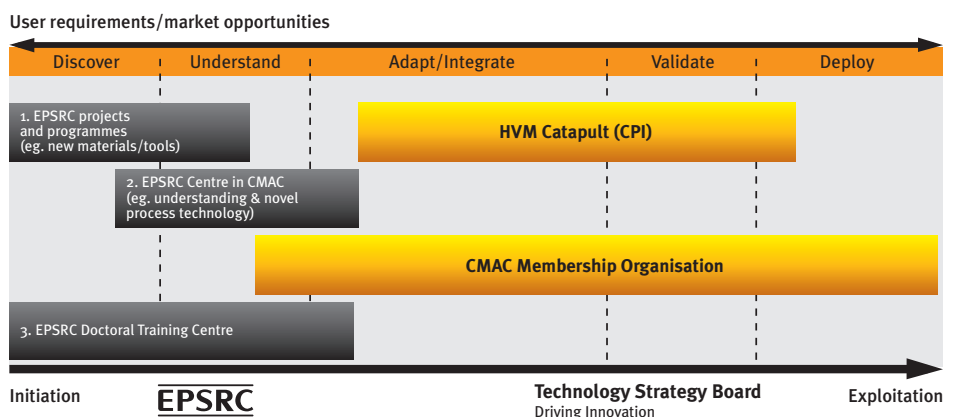


Figure 10. The research and innovation landscape for continuous manufacturing and crystallisation.



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EPSRC Centres for Innovative Manufacturing will provide a national focus for areas of early stage basic research that will feed through to Catapult Centres and Industry.

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## Consortium Building

**Industry** – This is a vital component to overall plan and key to delivery of the overall business plan. A world leading membership organisation (see above) has been established comprising Tier 1 (GSK, AstraZeneca, Novartis) and Tier 2 (mainly technology companies) members. There is a targeted approach to increasing membership underway. The organisation has a leading role in informing basic research needs, developing problem statements, supporting EPSRC activity (cash and in-kind), executing other projects at higher TRLs and driving the end-user agenda to accelerate introduction of continuous processes.

**Academic** – The Centre has had preliminary discussions and visits with external groups including Imperial (Chem Eng), Leeds (iPRD), Southampton (Maths), Strathclyde (EEE/Maths), Reading (Pharmacy), Bradford (Pharmacy) and Sheffield (Chemistry) on the Centre's scope and research challenges and potential opportunities for cooperation and future collaboration. We have also had discussions and joint workshops with the HVM Catapult (CPI Wilton) over possible collaborations and both the Centre and CPI are now involved in a TSB collaborative

R&D project. The Centre has worked with Prof F. Muller (Leeds) and Dr Steve Hillier (CIKTN) to deliver a flow chemistry webinar to build support for further activities in this community. The Centre hosted a young researchers 'DREAMS' event run by the EPSRC Directed Assembly Grand Challenge Network. Discussions with Southampton have led to a submission being developed for the EPSRC Mathematics in Manufacturing call that would introduce new activity through novel mathematical approaches to specific challenges in the continuous manufacturing domain. Also, Prof Chick Wilson has had notable success attracting new EPSRC programme grant funding of £3.2M in the aligned area of Functional Materials.

**International** – We have been very active in the last 12 months to establish the profile of the Centre and build links with international colleagues. The drivers for our efforts to develop global engagements in manufacturing research are to increase the strength and productivity of current links and/or build new links in regions where none previously existed. Collaborative research also enables pooling of research capabilities, sharing of expertise and facilities as well

as access to new environments for impact and exploitations of research outcomes. It is also a stated aim of EPSRC that researchers sponsored by them should have the opportunity to collaborate with an overseas researcher or researchers where this adds value to their research or training.

The Centre Director attended a joint EPSRC Indian DST workshop on Advanced Manufacturing Challenges in Delhi and Mumbai in January 2012, contributing to the definition of a subsequent call for joint UK-Indian manufacturing research projects. The Industry Director was involved in a TSB mission to Singapore to look at manufacturing research activities in the process industries. The Centre has also been able to develop further links with overseas research institutions due to support from EPSRC. Our aims are to escalate existing links with leading international researchers in the US and Far East over the next 12 months through a range of activities including research roadshows, joint research meetings and seminars and research exchanges. To date we have had events at MIT, Purdue with further activity at ICES and NTU in Singapore planned.



# Knowledge transfer and events

## Knowledge Transfer

**KTA** – The Centre has been involved in three Strathclyde EPSRC KTA funded projects to date that have funded Research Exploitation Partnerships with a range of companies. These include AstraZeneca, GSK, Syngenta, Fujifilm Colorants.

**Consultancy** – Several contract projects have been successfully delivered in this area with industrial clients. Where agreed, sharing generic learning with other academics or industries, to best develop the work and impact of the Centre.

**Researcher placements** have taken place between academic centres and with industry, as well as a programme of academic/industrial secondments as offered by our project partners are progressing, especially as part of DTC planning.

**Secondments** of colleagues from industry into projects to contribute critical expertise in an efficient and timely manner, also ensuring the solutions maintain focus on the needs of our industrial manufacturing base. This has been demonstrated on a one to one basis and on industry hosted workshop events e.g. Work-Up in flow. Company site visits involving academics and researchers with our Tier 1 members have been taking place throughout the year to deepen engagement. Two SMEs have also used the Centre's laboratory facilities at Strathclyde and expertise to develop product concepts and business ideas. This type of engagement provides excellent potential to develop further, in particular through the new TIC facility.

The Centre has had a significant presence at relevant conferences e.g. Director and Industrial Director ran a continuous crystallisation workshop at international IQPC conference in Amsterdam, Co-Investigator (Prof Wilson) gave a keynote talk at the Crystal Growth of Organic Materials meeting (CGOM) in Ireland; our Industry Director and a Centre RA delivered a workshop on Economics at the international Flow Chemistry conference in Lisbon. The Centre will continue to be well represented at various conference and events over the coming year covering both technology and application areas such as product development, manufacturing and supply chain.

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130 delegates attended the Centre's first Open Day

2012



## Centre Open Day

The Centre's first annual Open Day took place in September at the Barony Hall, Glasgow with over 130 delegates including all Centre researchers. The programme included poster sessions keynote talks from industry and invited academic speakers from Durham University (Prof Ian Baxendale) and Purdue University in the US (Prof Jim Litster). Over 30 companies participated in the event with several running equipment exhibits during the day.

## Research Outputs

All Centre researchers presented posters at the Open day (Figure 11). Also one of the Centre RAs, Dr Cameron Brown from Heriot Watt University, gave an oral presentation. Several students also presented posters at the ECCG4 conference in Glasgow in June. Outputs are now emerging via conference attendance (oral presentations/poster), applications notes, company project reports and publication showing early results.

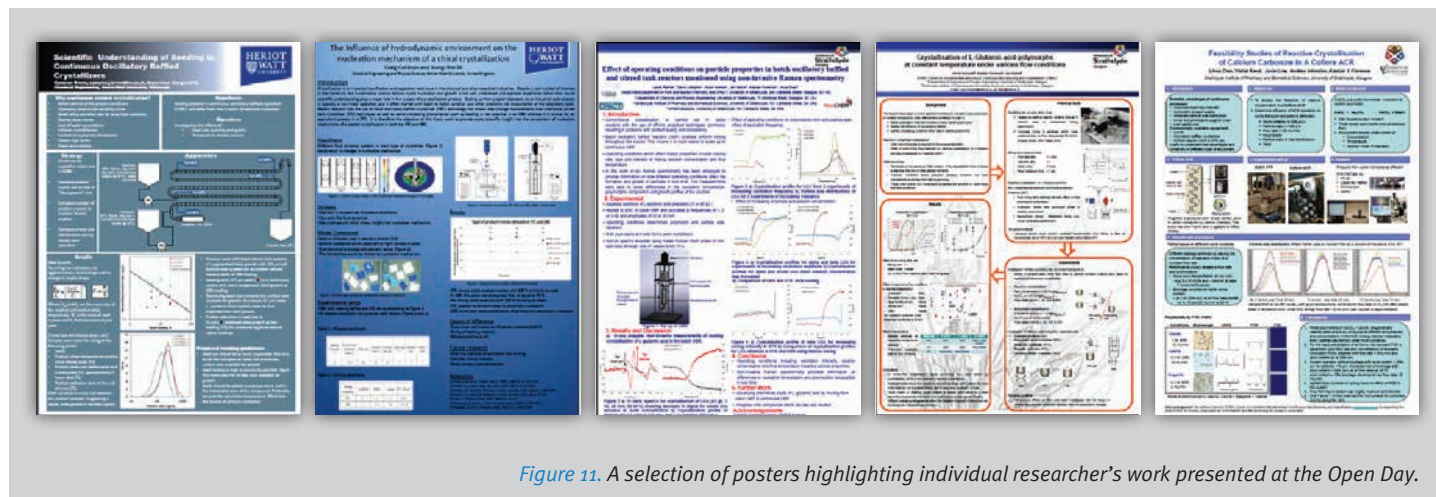


Figure 11. A selection of posters highlighting individual researcher's work presented at the Open Day.



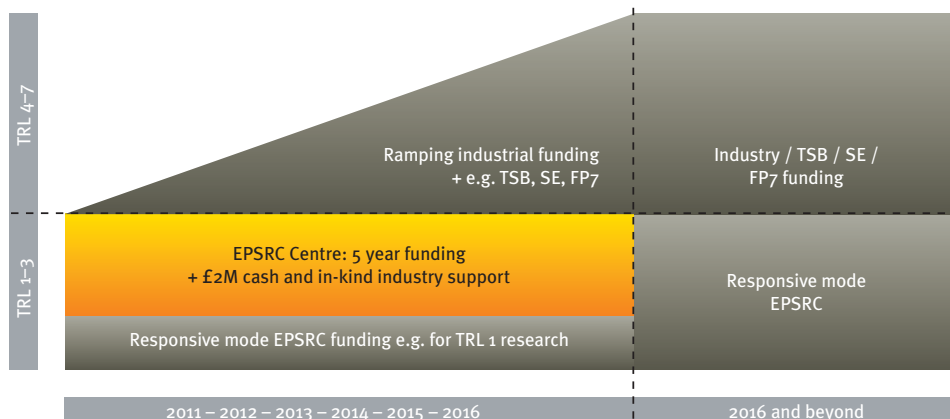
# Funding highlights 2011-12

## Building a Sustainable Centre: Funding Highlights

The Centre is working to establish a sustainable programme of manufacturing research beyond the initial five year Centre for Innovative Manufacturing award (Figure 12). The business plan, as outlined in the original proposal, seeks to deliver this

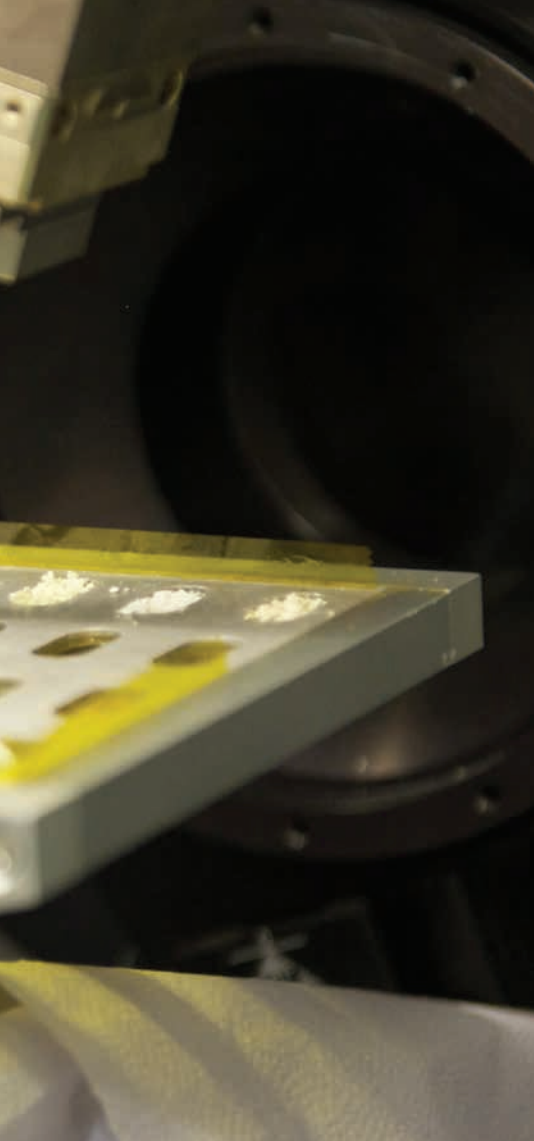
through growing the funding base from EPSRC, TSB, industry, EU and other relevant funding sources. To date there has been strong progress with over £20M of cash and in-kind support including closely related projects, summarised below.

Figure 12. The Centre's initial business plan aims to develop a sustainable funding base across the TRLs for continuous manufacturing research.



## EPSRC

- National Centre strategy funding (£750k) as a supplement to the original award enabling the Centre to support outreach and national centre activities across the duration of the award.
- Global - Promoting Research Partnerships: Strathclyde Escalator for Global Engagements in Research (EP/K004670/1; £500k). This award to a range of themes at Strathclyde includes ca. £100k to support international research engagements across the EPSRC Centre. To date it has supported research meetings at MIT and Purdue Universities and with ICES and NTU in Singapore with further research exchanges planned for early 2013. The aim is to identify mechanisms to support sustained collaborative activity.
- Doctoral Training Centre in Continuous Manufacturing and Crystallisation (DTC, EP/K503289/1) described in detail above, but £4.3M award with £0.5M industry and £1.2M university support to support 45 four year PhD studentships over three cohorts.



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The Centre has benefited from significant industry support with £20m funding. Our ambitions are set at £50m and are ahead of target.

- EPSRC ICT bid for a five year programme on intelligent decision support for continuous manufacturing, involves a multidisciplinary team to deliver new tools for the control of continuous manufacturing processes. This proposal, led by Prof Ivan Andonovic, Strathclyde with colleagues at Strathclyde, is through to the final round of the call with a decision due in November 2012 and secured strong industry support.
- A significant capital request of £10M has been submitted to EPSRC for consideration to provide the world-class infrastructure to support the growing activity across the Centre partners and at the new physical hub which will be located at the University of Strathclyde (see below).
- Several Strathclyde KTA funded projects.
- creativity@home funding (£20k) to facilitate the Centre to discuss and explore innovative approaches to tackling research challenges within the Centre scope.

## TSB projects

- Initiated through discussions at the National Centre Committee, the Centre was involved in various brainstorming, research discussions and project proposals around the TSB sustainable manufacturing call. After many iterations, two projects were funded, both led by SMEs with direct support and assistance on consortium building. With contributions from EPSRC, the Centre will provide specific input to both projects. “MOPP. Made to Order Process Plants”, led by Perceptive Engineering and “Development of an Innovative Modular System for Continuous Chemical Processing” led by Syrris attracted ca. £1.76M in funding and will begin early 2013.
- The Industry Director and senior Centre researcher (Srai) recently contributed to TSB led ‘Deep Dive’ pharma roadmapping.

## EU

- Industry Director invited by TSB as part of consultation on final FP7 NMP call.
- Centre Co-Investigator (Prof Halbert) is involved in a successful IMI project, Orbito, that is relevant to the EPSRC Centre scope providing fundamental understanding of physic-chemical properties of pharmaceutical particles.
- Going forward final FP7, Cost Action, Marie Curie and future Horizon 2020 will be important with National Centre also able to help influence in broader UK/ EU context.
- Involved in EU Cost Action on nucleation science involving several leading EU academic groups that was submitted September 2012.
- Centre Co-Investigator (Prof Cronin) is involved in a MICREAgents project to make smart chemo-robots.

## Industry

To date across all the initiatives in this area, the Centre has benefited from significant industry support with a total of 24 companies providing £6M cash and in kind support.

Figure 13. Illustration of the new TIC building at Strathclyde that will house the new EPSRC Centre continuous processing facility.

New 500m<sup>2</sup> laboratory facility



## Strathclyde Technology and Innovation Centre

The EPSRC Centre has secured a dedicated new 500m<sup>2</sup> laboratory facility in the new £100M Technology & Innovation Centre building at Strathclyde (Figure 13). The Centre including all researchers and locally based DTC students will move into this facility in mid 2014, which represents a ca. £4M investment by the University, Scottish Funding Council and Scottish Enterprise in infrastructure to support continuous manufacturing research. The TIC lab will act as a physical hub for the national centre and will house world-class capabilities for crystallisation, process development, materials characterisation, secondary processing and analysis. Importantly, this new building will also allow us to co-locate multidisciplinary teams of PGRs, RAs, academics and specifically industrial researchers across projects.

# Technology and Innovation Centre / New research links





## New Research Links – iCON Projects

With support from our National Centre Strategy funding we have developed mechanisms to engage with new researchers and accelerate innovation in continuous manufacturing research. Key to this is our “iCON project” scheme. The Centre will publish a number of priority challenge areas with input from our industry partners and advisory board and proposals from

### iCON Projects

Innovation in Continuous Manufacturing

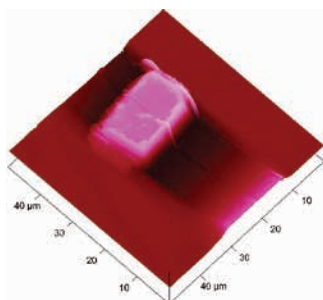
colleagues who are not currently involved in the Centre. We seek to support novel/ complementary research approaches across the EPSRC Centre’s scope that will address key challenges. The EPSRC National Centre can fund up to 10 short term feasibility studies in non-Centre groups.

## Technology ‘scouting’

This activity is vital for platform solution development and to identify new or emergent opportunities in our area. The Centre has made good progress with technology companies including Amtech, Nitech Solutions and Cambridge Reactor Design, including equipment siting (e.g. CoFlore system) and trials on novel equipment including beta machines. Work with Mettler-Toledo for example has explored the implementation of PAT in continuous crystallisation platforms (Figure 14).



Figure 14. Continuous oscillatory baffled reactor (above) and AFM image of crystal growth on crystal surface (right).





# Centre Management and Committee Structures

## Centre Management and Committee Structures

The senior management roles and governance structures of the Centre are shown in [Figure 15](#). Oversight of the key Centre activities is provided by the Centre Management Committee, Advisory Board and National Centre Committee whose functions are also summarised in [Figure 16](#).

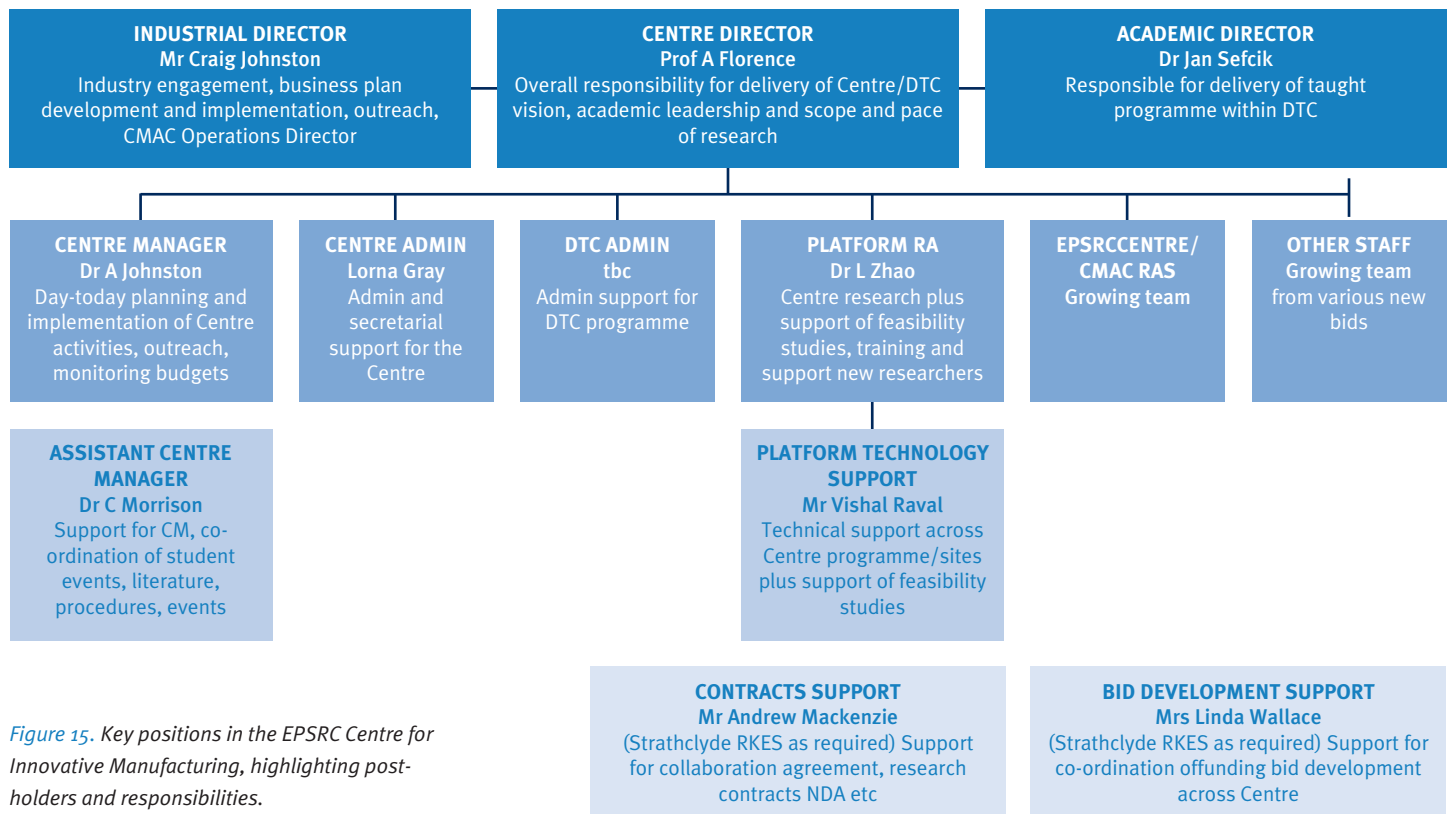


Figure 15. Key positions in the EPSRC Centre for Innovative Manufacturing, highlighting post-holders and responsibilities.



The **Management Committee** consists of the core management team plus co-investigators. The committee meets monthly and responsibilities of the committee include:

- 1) Review project progress against milestones;
- 2) Refine and shape the vision and research programmes in line with user needs
- 3) Conduct an annual review and assess proposals for future work packages/DTC themes;
- 4) Responsible for wider functions such as ensuring that the work of the Centre is appropriately disseminated/published and ensure exploitation pathways are optimised;
- 5) Oversee the financial aspects of the programme;
- 6) Grow activities and secure future funding towards delivering the Centre vision.

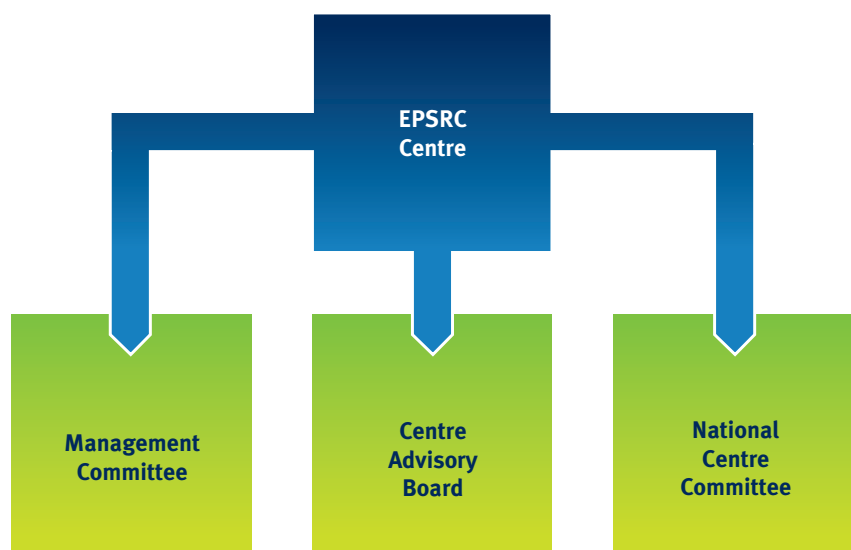


Figure 16. Summary of committee structures within the EPSRC Centre.

# Research team and projects

## EPSRC Centre Academic Team

- Prof Umit Bititci, Strathclyde University
- Prof Lee Cronin, Glasgow University
- Prof Alastair Florence, Strathclyde University
- Prof Sir Mike Gregory, Cambridge University
- Prof Gavin Halbert, Strathclyde University
- Prof David Littlejohn, Strathclyde University
- Prof Zoltan Nagy, Loughborough University
- Prof Xiongwei Ni, Heriot-Watt University
- Prof Colin Pulham, Edinburgh University
- Prof Chris Rielly, Loughborough University
- Dr Jan Sefcik, Strathclyde University
- Prof Graeme White, Heriot-Watt University
- Prof Chick Wilson, Bath University

The multidisciplinary academic team brings collective expertise in:

- nucleation and particle formation
- reactor design and applications testing
- process design and manufacture
- flow chemistry
- continuous processing and crystallisation
- polymorphism, salt selection and multicomponent crystallisation
- process scale up and optimisation
- nanoscale materials and technology
- pharmaceutical processing and formulation
- particle surface characterisation and analysis
- structural characterisation and phase surveys
- Process analysis technologies and control
- amorphous/nano-crystalline materials
- physical and chemical stability
- statistical and theoretical chemical and process modelling
- Supply chains analysis and operational management

The Centre provides access to a range of facilities in support of the research programme, including:

- Crystallisation - from small scale screening to batch STR and continuous crystallisation capabilities including CSTR, OBR, COBC, ACR and networked flow systems.
- Physical characterisation - microscopy; DSC/TGA; powder and single crystal diffraction; mid-FTIR; Raman; DVS; particle sizing/light scattering.
- Chemical characterisation – HPLC; GC; NMR; UV-Vis
- In Situ Measurement Techniques - ATR UV/Vis; Raman; mid-FTIR; FBRM; imaging and DLS
- Secondary Processing – filtration; drying; milling; spray-drying; mixing; granulation; tableting; extrusion
- Process Modelling and Control – DoE; PCA/PLS; Random Forest; CFD; PBE; CryPRINS, iLabber



## Research Theme 1 – Continuous Manufacturing of Solid Particles

- Dr Lihua Zhao, University of Strathclyde, Senior Research Associate, Centre Platform RA. Feasibility Studies and continuous crystallisation projects.
- Vishal Raval, University of Strathclyde, Researcher, Centre Platform Technology Support of continuous crystallisation projects across the Centre.
- Dr Anna Jawor-Baczynska, University of Strathclyde, Research Associate, Modular Test Bench for Continuous Nucleation.
- Rachel Sheridan, University of Strathclyde, PhD Researcher, Investigation of Deposition and Fouling in Continuous Crystallisation.
- Denise Logue, University of Strathclyde, PhD Researcher, Analytical Challenges in Continuous Manufacturing and Crystallisation, In-situ and Non-invasive Measurements Technologies for Monitoring and Control of Processes.
- Maria Vincenza Anna Dragone, University of Glasgow, PhD Researcher, Synthesis of Organic Molecules in Linear, Parallel and Networked Systems.
- Dr Victor Sans Sangorrin, University of Glasgow, Research Associate, Advanced Systems for Adaptive Crystallisation.
- Dr Cameron Brown, Heriot-Watt University, Research Associate, Understanding and Characterisation of Continuous Crystallisation in COBC.
- Hannah McLachlan, Heriot-Watt University, PhD Researcher, Effects of Mixing, Cooling Rate and Concentration on Crystal Purity in OBC and STC.
- Alasdair McKenzie, University of Edinburgh, PhD Researcher, Application of Laser Induced Crystallisation to Continuous Flow Processes.
- Kate Wittering, Bath University, PhD Researcher, Multi-Component Crystallisation in the Continuous Flow Environment.
- Dr Lynne Thomas, Bath University, Senior Research Associate, Multi-Component Crystallisation in the Continuous Flow Environment.
- Keddon Powell, Loughborough University, PhD Researcher, Improving Continuous Crystallisation Using Process Analytical Technologies.
- Dr Ali Saleemi, Loughborough University, Research Associate, Application of PAT for Monitoring, Control and Comparison of Batch and Continuous Crystallisers.

## Research Theme 2 – Manufacturing Operations and Supply Chain Management Challenges in Continuous Manufacturing of Solids

### Three key themes include:

- Manufacturing operations and supply chain configuration - Analyse and map current state manufacturing operations; Create future state manufacturing operations maps and change over plans.
- Management control systems. Analyse key management control challenges; Specify new management control systems; Specify and document external regulatory.
- Learning from experiences of other industries. Oil and gas, food and drinks, automotive, FMCG.

### Researchers include:

- Dr Aylin Ates, University of Strathclyde, Research Associate.
- Rajan Talati, University of Strathclyde, Research Assistant.
- Dr Jag Srail, University of Cambridge, Senior Research Fellow.
- Dr Tomás Harrington, University of Cambridge, Senior Research Associate.
- Lelia Alinaghian, University of Cambridge, PhD Researcher.

The Centre **Advisory Board** is chaired by Prof Paul Sharratt from ICES Singapore. Full membership is shown below. Centre representation on the board includes the Director, Industry Director and EPSRC. Additional members of the board are an experienced grouping of academics and industrialists. The board meets three times

per year with at least two meetings face to face. Responsibilities of the board include:

- 1) Provide independent input from leading academics and industrialists not directly involved in the Centre;
- 2) Gather views that will influence the running of the research of the EPSRC Centre and DTC;

- 3) Advise on strategy, reporting, project monitoring etc.;
- 4) Provide input from researchers from different fields and from stakeholders from sectors other than pharmaceuticals;
- 5) Carry out an annual review of Centre performance.

Name	Institution	Status
<b>Chair</b>		
Prof Paul Sharratt	ICES, Singapore	International independent academic
Dr Clive Badman OBE (deputy-chair)	GSK	Non-independent industry
<b>EPSRC Centre Representatives</b>		
Prof Alastair Florence	EPSRC Centre	Centre Director
Craig Johnston	EPSRC Centre	Industry Director
<b>Independent Academic Members</b>		
Prof Brian Glennon	University College Dublin (SSC)	International independent academic
Prof Nigel Titchener-Hooker	UCL	Independent academic; EPSRC Centre Emergent macromolecular therapies
Prof Kevin Roberts	Leeds University	Independent academic
Prof William Jones	Cambridge University	Independent academic
<b>Non-independent Industrial Members</b>		
Dr Jon-Paul Sherlock	AZ	Non-independent industry
<b>Independent Industrial Members</b>		
Kenny Gilmour	Victrix	Independent industry
Dr Colin Groom	CCDC	Independent non-academic
Dr Kevin Girard	Pfizer (US)	International Independent industry
Ian Laird	Moorbrook Textiles	Independent industry
Dr Paul Stonestreet	Roche	Independent industry
<b>EPSRC/TSB Members</b>		
Dr Richard Bailey	EPSRC	EPSRC representative
Dr Malcom Hannaby	TSB	TSB representative
<b>Observer</b>		
Dr Andrea Johnston	EPSRC Centre	Centre Manager

The **National Centre Committee** is chaired by the Industrial Director, involving the PI and other academics, representatives from end-user collaborating companies (co-creators of the Centre bid). It meets face to face, by telecon and appropriate project teams. Main objectives are detailed delivery of business plan, dissemination of research outputs to industry and technology exploitation. The remit includes:

- 1) Discuss forward looking plans for expanding the EPSRC Centre's funding as per business plan;
- 2) Open membership to all CoIs, other relevant academics, industrialists and relevant advisory and funding bodies;
- 3) Act as a platform for dissemination of funding opportunities and identification of bid teams;

- 4) Inform the Centre on activities in the wider academic network;
- 5) Discuss and agree common approaches to IP, exploitation and dissemination of research outputs.

## Final Words

“I congratulate the Centre on the great progress made in its first year. That sows the seeds for excellent research outcomes in what is a complex and difficult area. The combination of an impressive academic team, strong industrial engagement and the commitment of the universities and EPSRC to supporting the Centre give a weight and momentum to the activity which I am sure will deliver not only high quality research but also results of tangible value to industry.”

Professor Paul Sharratt,  
Division Head at ICES and Chair  
of the Centre Advisory Board.

“This has been a very encouraging first year in starting to understand and design the supply chain of the future. I have been impressed by the way that Alastair, Craig and the team across the universities have worked with GSK, AZ, Novartis and the other partners to progress innovative research against a well defined, user led scope. In addition to the on-going core focus on continuous crystallisation I look forward to the development of continuous processing research in the interface areas with reaction, work up and into secondary.”

Dr Clive Badman OBE,  
VP Investigative Materials GSK  
and Chair of the CMAC Board.



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