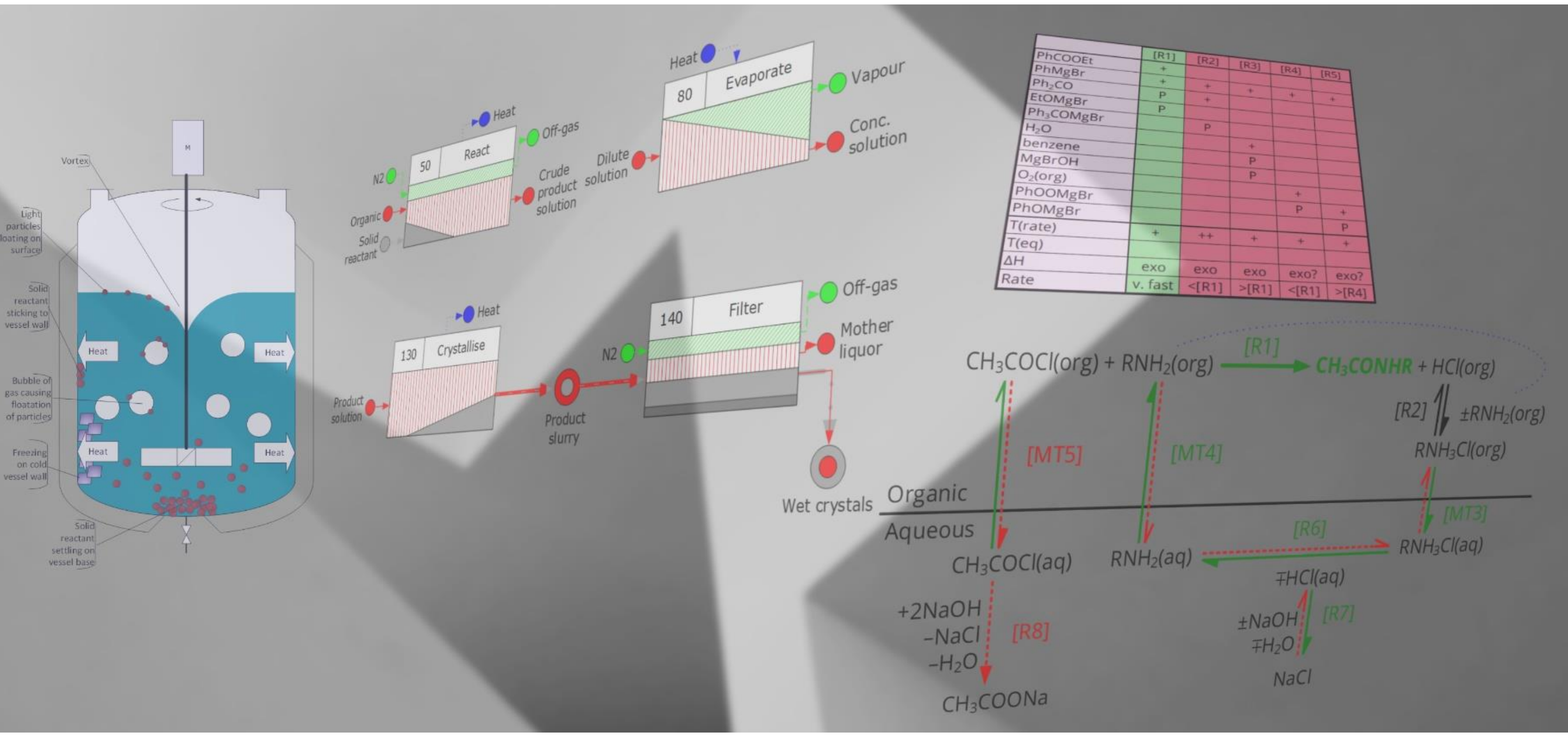
BUILDING A BRITEST TOOLKIT FOR

SUSTAINABLE INNOVATION

BRITEST LIMITED | JANUARY 2022

Generating value from process understanding



Britest is a not-for-profit membership-based organisation and consultancy which champions effective whole process design and open innovation throughout the chemical, biochemical and related process industries.

Britest's specialist technical facilitators help multidisciplinary development and manufacturing teams within companies, across supply chains, and in collaborative projects turn their working knowledge into impactful process understanding capable of driving innovation. Visually rich tools for information capture and structuring enable our clients to assimilate and communicate insight critical to product and process development, successful problem solving, and process improvement. The Britest approach has successfully delivered innovative solutions to key process and manufacturing challenges since 2001.

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SUMMARY

With a clear scientific consensus in place, greatly increased public awareness and growing expectation for action at all levels of society and economic activity, climate change is both our biggest threat and a major opportunity for transformational change for the better.

The chemicals, biotech, pharma, and broader process industries have a key role to play in in this change, but to do so they will need to marry up technological innovation with broader understanding of sustainability drivers and value chains more effectively than ever before.

Current and foreseen developments in the Britest approach are well aligned with these needs in areas including mapping of circular value flows, scale-up and commercialisation of biotechnologies, and process intensification.

INTRODUCTION

The first instalment of the IPPC's Sixth Assessment Report[1], released amidst global attention and stark headlines in August 2021, laid out the scientific consensus around climate change and the threats and choices before humankind in blunt terms. Human influence has unequivocally warmed the atmosphere, ocean, and land. The scale of recent changes and the present state of the climate system are unprecedented over the timescale of hundreds to many thousands of years. Human-induced climate change is already affecting many weather and climate extremes in every region across the globe and, left unchecked, catastrophic global temperature rises are confidently forecast. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide and other greenhouse gas emissions occur in the coming decades.

Such is our collective challenge, and surely it could not have been more clearly presented to the global leaders and negotiators gathering in Glasgow just months later for the 26th UN Climate Change Conference of the Parties, COP26. Whatever your views of the adequacy or otherwise of the outcomes of COP26[2], and of the rate of progress of the COP process overall, it is surely true that the broader optics around events in Glasgow demonstrated that, at some level, broader society's tolerance for a gap between words and actions on the response to climate change is diminishing rapidly.

Marchers at COP26 Glasgow. (Image Credit: The Left https://flic.kr/p/2mGT1WR)

Whilst one cannot simply equate impressively large marches of the committed (on behalf of any cause) to widespread public acceptance of their argument, viewed over a longer timeframe "green" and "environmental" issues have unquestionably become established within the norms and indeed priorities of public discourse and democratic debate. From their origins within pressure groups in the 1970's, and the development of fringe political parties in the following decades, Greens are now parties of significant influence and even of government. The first Green MEPs entered the European Parliament in 1984 as part of a small "Rainbow Alliance". At the time of writing, today's Green/EFA group consists of 73 MEPs from 17 countries, making it the fourth largest bloc in the Parliament.[3] [4] Back in the country where COP26 was held, a 2021 cooperation agreement between the Scottish Green Party and the minority SNP government paved the way for two Green cabinet appointments in the devolved government.[5] High profile figures such as Greta Thunberg and David Attenborough, in their very different styles, serve as effective public faces for a widespread and established base of NGOs, charities and pressure groups intent on keeping climate and justice issues to the fore. As public awareness of climate change as a clear, and increasingly imminent and personal threat grows, so inevitably will political pressure. Kicking the climate can down the road is simply no longer acceptable to more and more people.

KICKING THE CLIMATE CAN DOWN THE ROAD IS SIMPLY NO LONGER ACCEPTABLE TO MORE AND MORE PEOPLE.

Addressing climate change and, more broadly, constructing fair and sustainable future social and economic systems[6], is of course not just a matter for policy makers. "Government billions are important, but unleashing private trillions is vital" was something of a COP26 mantra[7], as part of the choreography around the Glasgow Financial Alliance for Net Zero's announcement of over $130 trillion of private capital to transforming the economy for net zero over the next three decades.[8] Whilst there will inevitably be debate around the signatories, absentees, and details of this[9] and other COP commitments [10] [11] [12], they will all ultimately be judged by deeds not words.

One challenge amongst many. Climate Action is No. 13 on the UN's list of Sustainable Development Goals.[6]

For those at the sharp end of running businesses and securing backing to pursue innovation for sustainability in industrial processes, products and systems, the direction of travel in the investment community is at least clear. To quote UN Special Envoy for Climate Action and Finance, Mark Carney, "We now have the essential plumbing in place to move climate change from the fringes to the forefront of finance so that every financial decision takes climate change into account." With this come expectations of transparent reporting and following credible, science-based pathways to demonstrably reach net zero.[13] This ultimately means that for innovations to be taken up by the market, robust technological advances must be accompanied by sound, credible, and compelling techno-economic, environmental, and social impact analyses. For innovators the challenge can often be to balance the need for rigour with the need for speed, especially early in the development cycle where many uncertainties and data gaps can exist in any development team's knowledge base. Can Britest methodologies help with any of this, and how are we innovating to extend our toolkit and capabilities to meet these emerging needs?

POSITIVE THINKING: RIGHT TIME, RIGHT PLACE, RIGHT SCALE

"Think global, act local" [14] has been a long-standing watchword for those seeking to form a strategy for responding to environmental issues: when faced with an all-pervasive global threat that seems way too big for you to deal with, do what you can within your sphere of influence to make things better there. The phrase has also come to be applied to the need for multinational globalised businesses to recognise the importance of tailoring products and services to local conditions.[15] [16] In this case the message is to be true to your global brand values but don't expect one size to fit all across multiple markets. There is an interesting space where these two aspects of the phrase come together; effective localisation in the marketing sense relies upon creating goodwill and establishing credibility within local markets, whilst opportunities to innovate for sustainability will increasingly be found in areas like flexible and distributed manufacture, process intensification, localised circular economies, industrial symbiosis, and clean energy campuses, all of which draw on the importance of place and local systems integration to deliver economic benefits with reduced environmental footprint.

As anyone who has ever taken part in a Britest study will know, starting with the big picture, Initial Screening Analysis to establish the context within which a problem or innovation sits prior to drilling into the detail, has always been the basis of how such a study is approached. Constructing a Process Information Summary Map (PrISM) identifies high level whole process costs and material flows, including where these flows represent wastes, or low/no value-added activities. Whilst conventionally framed as a means of "chasing the money" through a manufacturing system, the PrISM is increasingly being understood as means of mapping value flow, and value leakage from the system, in more holistic terms; "Chasing the impact" if you will: loss of materials and the embedded energy bound up in them, creation of emissions and the costs of dealing with them, excessive consumption of reagents and solvents in non-value added steps like cleaning, and excessive variability and lost time at any stage of the process.

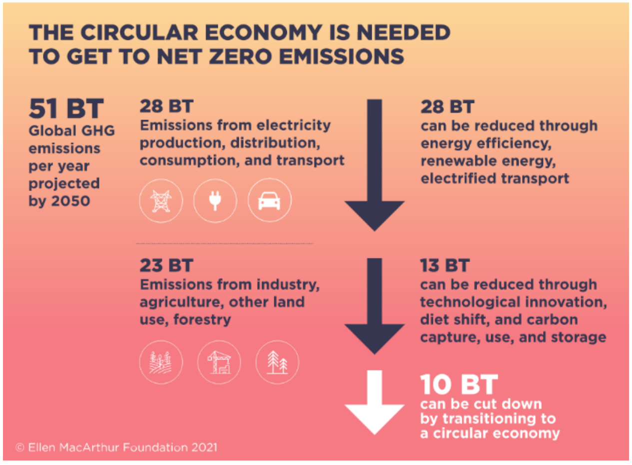
However, we need to step back, think global. Manufacturing organisations in the process industries are rarely short of technical issues competing for their attention and capacity to solve problems. Shorter-term priorities now have to be set with an eye on the longer-term destination that will minimize the damage we are already handing on to future generations - Net Zero (everywhere and ASAP). How can we individually, corporately, and within communities, figure out which are the changes within our current grasp that are best aligned to the global ambition?

WE CAN'T RELY ON OLD SYSTEMS AND THINKING IF THE NECESSARY CHANGE IS GOING TO OCCUR FAST ENOUGH.

To get there (broadly speaking) everything must link back to reducing greenhouse gas emissions. These (broadly speaking) are the result of humanity's appetite for energy. We use energy in pursuit of economic growth: to make, grow transport and consume stuff, and to live and travel in safety, comfort, and at our convenience. We currently do so (more or less) with scant regard for the planet's finite material or restorative limits and tolerating gross inequities in how the wealth and lifestyle benefits are shared, and when and where the impacts of climate change are felt. It would be easy to despair in the face of such a track record but a positive attitude to opportunity spotting tells us that change is possible. Solutions to different parts of the jigsaw are everywhere and to varying degrees gaining traction, however we can't rely on old systems and thinking if the necessary change is going to occur fast enough and be as widespread as is needed.

VISUALISING VALUE CHAINS IN THE CIRCULAR ECONOMY

The concept of the Circular Economy, whilst hardly new[17], has come to prominence in recent years and is now an integral part of development strategies in more than one of the globe's major economic blocs.[18] [19] As in much else in this field, the Ellen Macarthur Foundation has comprehensively articulated how the Circular Economy tackles climate change.[20] [21] The message is most succinctly summarised in the diagram opposite. Given current projections we can't reach Net Zero through energy efficiency, renewables, and mitigating the emissions arising from industrial activity alone. To bridge the gap, we also need to reshape our linear "take, make, forsake" approach to life, minimizing primary extraction and waste generation by retaining the value and embedded energy of the goods we consume in closed supply loops.



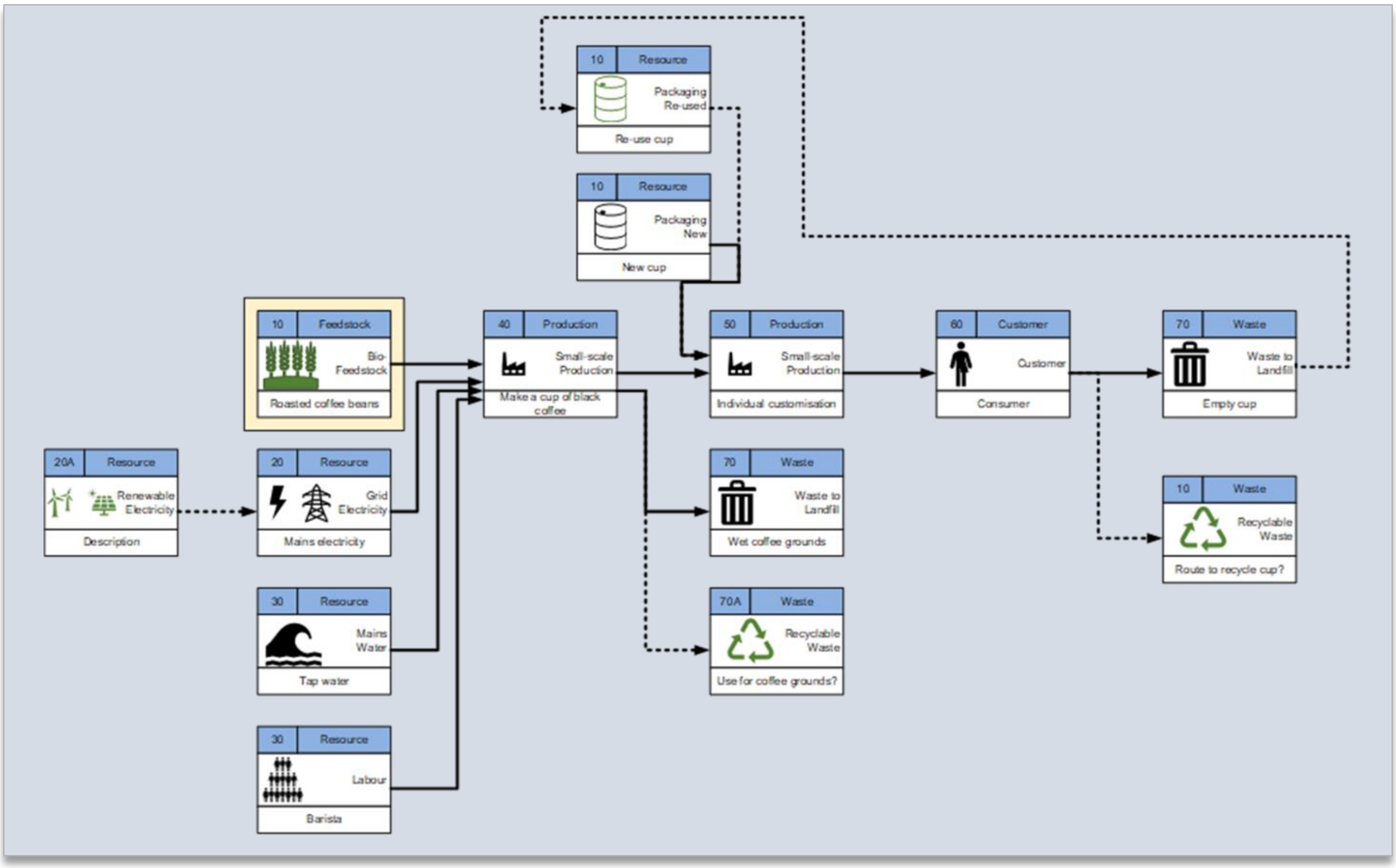
Mind the gap! The Circular Economy is a vital enabler if we are to reach Net Zero[21]

Building in part on thoughts arising from the EU STYLE project's Ideal Toolkit Framework[22] (for project teams in need of a pragmatic tool to check the broader sustainability implications of each technological solution), recently Britest has worked to broaden our conception of 'whole process' design thinking in recognition that innovation for sustainability can and must take place across a broader whole system of which the manufacturing process and its immediate inputs and outputs only form a part. Such supply-process-service systems can be usefully described and explored in the form of a Supply Chain Definition Diagram (SCDD), which takes in relevant upstream and downstream supply chain considerations as well as the physical, chemical, or biochemical processes of manufacture. This can be especially useful in circumstances where the business commissioning or conducting the study is not itself the process operator, but rather (for instance) looking to licence technology or otherwise provide enabling services related to the innovation.

The functional elements of which a SCDD is composed include

- Feedstocks
- Transport (including loading and unloading)
- Production (including packing/unpacking and storage)
- Customers
- Resources – Energy, Water, Labour and Packaging
- Wastes and emissions, and
- Services – Data Management, Process Control, Decision Making, Recovery, Abatement, Disposal etc.

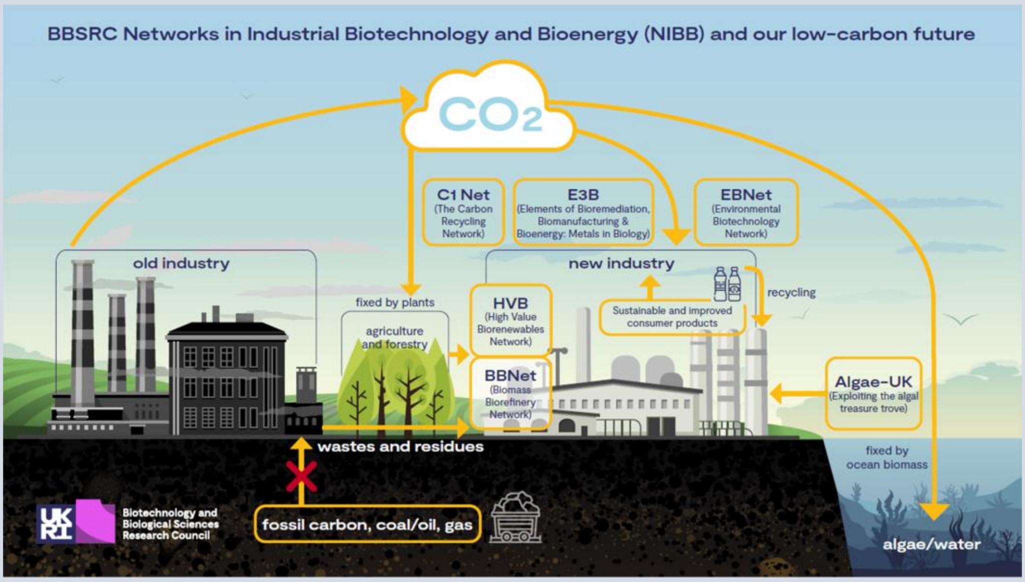
By visually mapping out these elements, their relationships and interdependencies can be assimilated, sparking ideas and debate, which can be captured as annotations to the map. Importantly, the SCDD will amplify how linear or circular the whole system is and can be used to stimulate thinking about the system design changes that will help make the transition from the former to the latter.

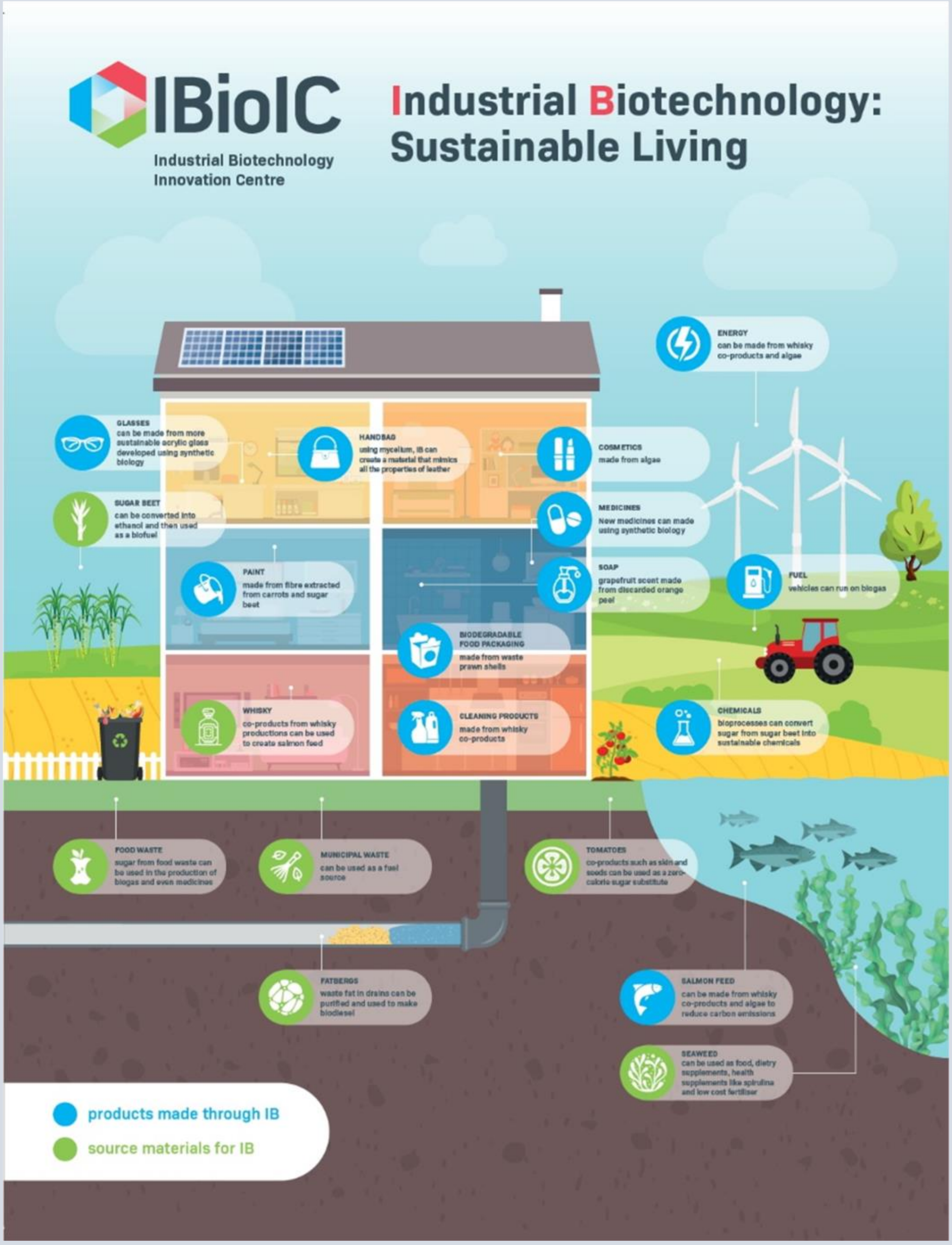


A Supply Chain Definition Diagram extends the Initial Screening Analysis to emphasise the whole system not just the physical, chemical, or biochemical processes and products.

HELPING BIOTECH DELIVER AT SCALE

Innovators in Biotechnology however frequently face significant challenges when scaling up towards commercialisation. Successful proof of concept in the lab and even meso-scale demonstration (often based upon scaling-out – replicating small-scale procedures many times rather than scaling-up) can leave potential investors in new technologies being asked to take a significant leap of faith where robust evidence of commercial process capability and costs is limited. Supply chain considerations also come to the fore: where a bio-derived molecule is proposed as a substitute for a petrochemical-based equivalent, there has to be a credible pathway to provide the necessary scale of raw materials supply, and this must be done recognising potential tensions between competing uses of resources, particularly around the use of agricultural land for non-food crop purposes.[23]

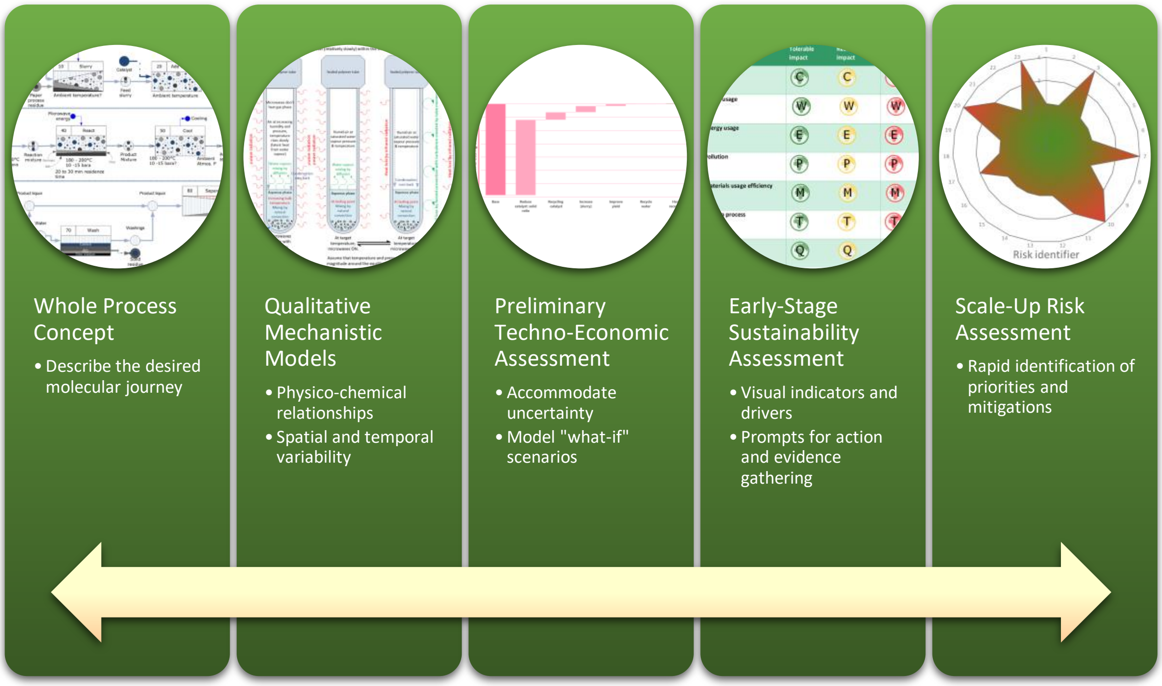




Two recent UK views of an interconnected sustainable future built on industrial biotechnology[24] [25]

Developments in the Britest toolkit arising from several projects in recent years can help innovators take on board the difficulties of developing a viable business case for investment, and identify the risks and uncertainties associated with key techno-economic parameters (a viable business model built upon efficiency, quality, environmental sustainability, social impact, resilience, and supply chain) especially for early TRL offerings. In the TKI project "Business models for flexible modular production", Britest considered approaches to enable the identification and evaluation of business cases for investment in innovative technology. The project delivered a generalised methodology supporting techno-economic decision-making to select business cases based on mixed qualitative and quantitative data, along with a model to simulate the economic cases for each option being considered in the decision problem.[26]

Levwave[27], an Innovate UK / ISCF project provided Britest with the opportunity to road test an understanding-based methodology for setting commercialisation objectives on an innovative route to levulinic acid from the lignocellulosic content of paper sludge using solid-state catalysis and microwave heating. This methodology is specifically designed to accommodate the twin challenges of limited data availability and proliferation of sources of uncertainty in early-stage projects.



Britest Methodology for setting commercialisation objectives for an innovation project

PROCESS INTENSIFICATION

Process Intensification (PI), which may be loosely defined as designing processes to get more or better product from less plant, is a long-established chemical engineering design concept. Whilst early developments in the field were Initially motivated by the prospect of achieving reduced capital or running expenses[28] [29] it fairly rapidly became evident that PI approaches can be readily viewed through the lens of resource efficiency and is intimately bound with aspects of process sustainability on both cost and environmental grounds.[30] More recently the link between sustainability objectives and PI as the enabler to achieve them has been made increasingly explicit in applications as diverse as, on the one hand, pharmaceutical particle engineering, use of microreactors and microfluidics, and extraction and purification of natural therapeutic products[31], through to shale gas treatment, RO-PRO de-salination, other membrane -based systems for water, energy and environment applications, heat and mass exchange networks, and biomass conversion processes on the other.[32] The incorporation of PI principles at the conceptual design stage has been has been considered methodologically using a building block-based approach combined with multi-objective optimisation[33] whilst a large multi-stakeholder expert team writing from a pedagogical perspective has argued directly that PI offers opportunities for attaining the United Nations Sustainable Development Goals in a cost-effective and timely manner (see below).[34]

"Educational PI programs must target renewable energies and feedstocks that correspond to the following UN Sustainable Development Goals…"

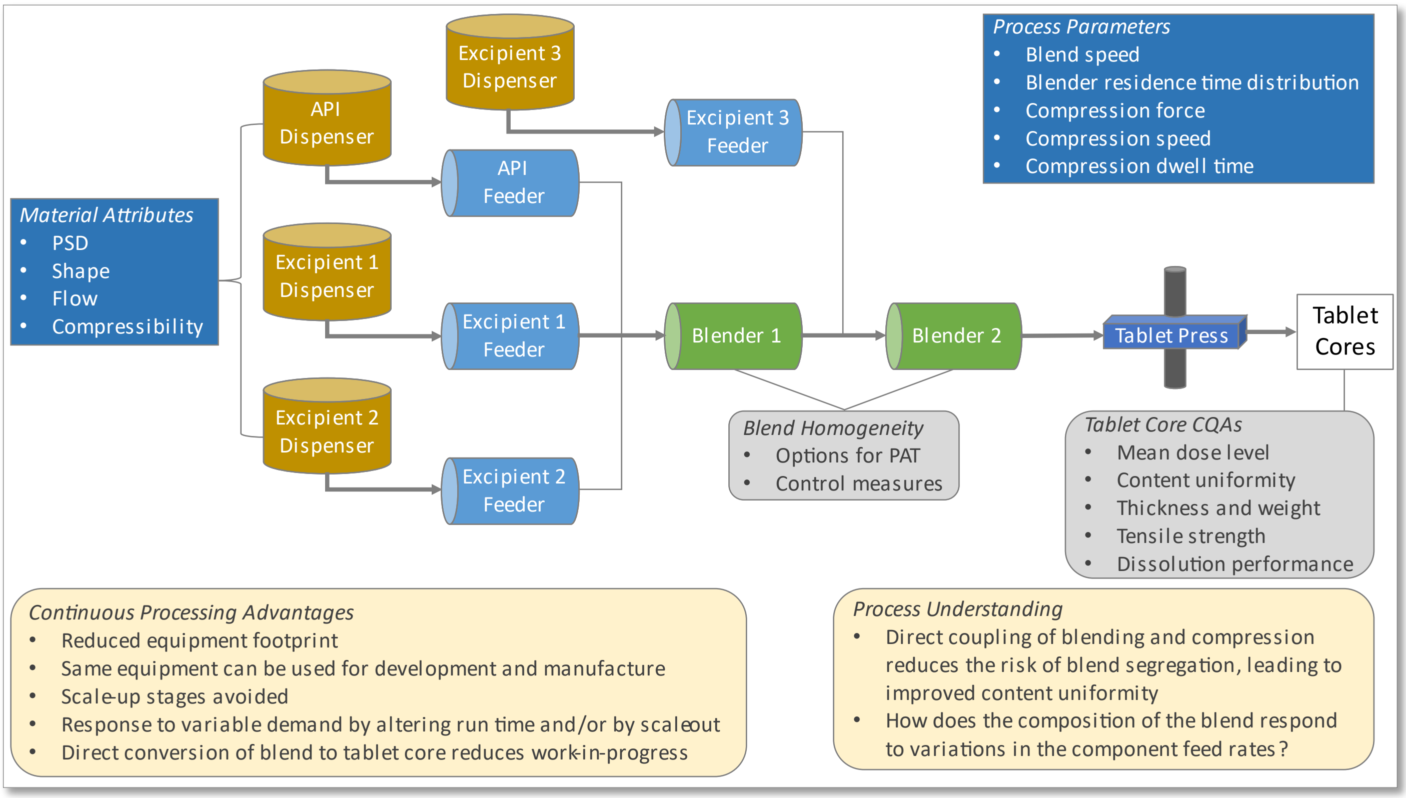
Expert Workshop Output, Lorentz Center, Leiden, June 2019

Quality of education (SDG-4)
Educating on PI allows learners to acquire knowledge to develop more efficient and sustainable technologies
Affordable, clean energy (SDG-7)
PI enables energy savings in large-scale industrial processes and more compact and cost-competitive processes
Decent work and economic growth (SDG-8)
PI fosters opportunities for economic growth in developing and developed countries, thanks to the higher productivity and resource efficiency for medium and small scale plants
Industry innovation and infrastructure (SDG-9)
PI enables cost-effective upgrading of old industrial infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and processes
Responsible consumption and production (SDG-12)
PI can support the development of environmentally sound management of chemicals and their by-products throughout their life cycle by improving process safety, and reducing waste generation
Climate action (SDG-13)
PI can accelerate the incorporation of renewable energy into existing chemical industrial plants, thus reducing greenhouse gas emissions (e.g. with electrochemical reactors, electrical heated micro-reactors, using biomass, etc.)

From a Britest perspective, many chords chime when reflecting on how PI is achieved in practice. Equipment size is often reduced (e.g., as in spinning disc or micro-channel reactors) leading to enhanced mass and/or heat transfer, and so the ability to describe and model these processes at the appropriate scale becomes important. Tasks may be combined (as in reactive distillation, where removal of the product as it is formed drives the equilibrium in the desired direction), so an understanding of both the distinction between process *tasks* and equipment *stages*, and the nature of the process driving forces are both of relevance. Batch processes can be intensified, for example by telescoping sequential synthesis steps in a single vessel without workup, or by reducing the energy demand during work up by emphasising isothermal conditions. Particle design approaches in crystallisation may be thought of as means of achieving process intensification: by targeting the correct particle size/form initially the need for subsequent particle size reduction is removed. There is often an emphasis on giving each molecule the same processing experience, to achieve a uniform product and minimise waste (for example through enhanced mixing, reducing temperature gradients or minimising residence time distributions). In this case, it is highly desirable to be able to define and communicate that molecular experience in a scale independent way.

FROM A BRITEST PERSPECTIVE, MANY CHORDS CHIME WHEN REFLECTING ON HOW PI IS ACHIEVED IN PRACTICE.

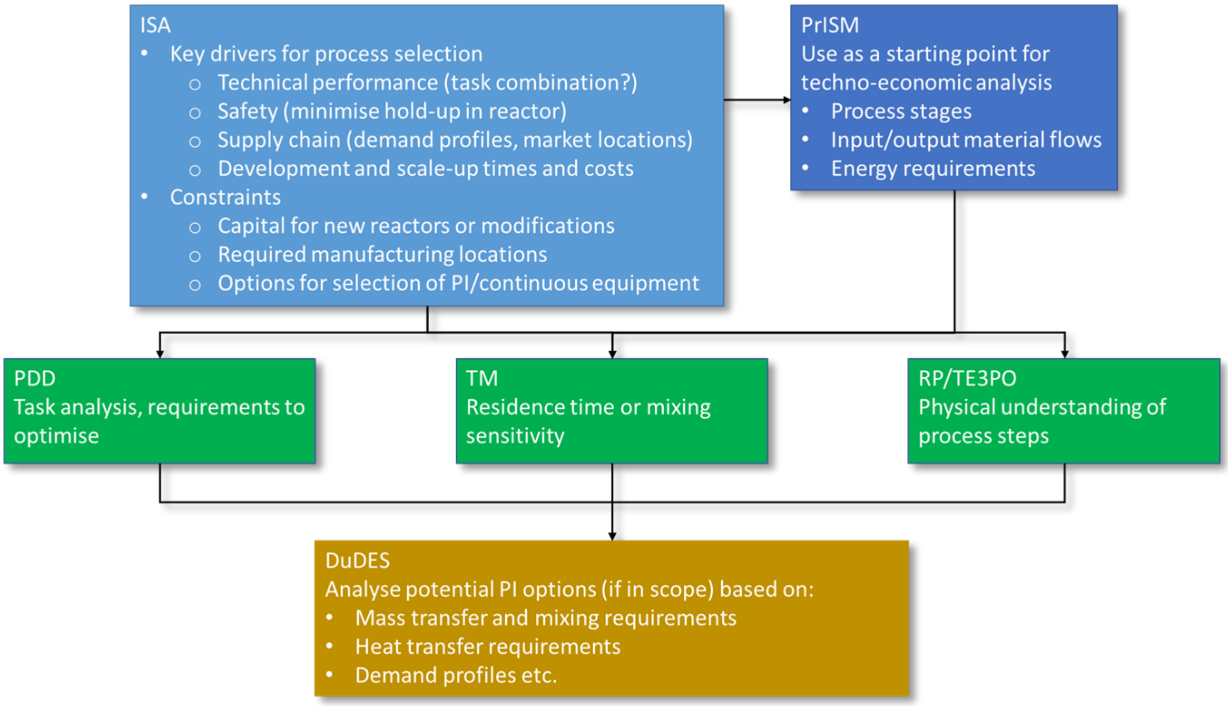
Continuous processing offers many examples of Process Intensification. Generally, equipment size is smaller for equivalent throughput, but a number of other advantages accrue. The same equipment can be used in manufacture as development, reducing the risks of scale-up steps. Increased demand can be met through longer run times or by use of multiple units. Response to variation in demand can be achieved by varying run times and/or the number of units used. Smaller, modular equipment facilitates distributed manufacture, through placing units in different locations, to suit logistical and market requirements. Often continuous equipment is of lower footprint than its batch equivalent and this reduces cost, especially if the equipment is located in a GMP or cleanroom environment. If tasks are combined (e.g., blending and compression in continuous direct compression) costs can be reduced through a reduction in work-in-progress. Technical benefits from continuous processing may arise from the more consistent processing experience and from the high level of monitoring often seen in these processes through use of process analytical technology (PAT), and from the close coupling of continuous tasks (again continuous direct compression provides an example where particle segregation may be prevented by the coupling of blending and compression).



Process Intensification links with Process Understanding to deliver the advantages associated with Continuous Direct Compression of pharmaceutical tablet cores

Britest has extensively explored approaches to developing and documenting process understanding of continuous operations through collaborations at EU and UK level including applications to liquid-liquid systems in structured equipment[35], flexible, modular, continuous manufacture[36 37], continuous pharmaceutical manufacture[38], and continuous microwave assisted processing.[27] There is interesting scope for further development, for example to aid decision making in whether to select a continuous or a batch process and, building on previous work[39], to study how existing batch processes may be converted to continuous operation. Such decisions once again extend to take account of factors beyond the technical arena, pointing towards a holistic evaluation of the process in the context of the business and the business in the context of its market.

From a consideration of all the above features and more, a Britest methodology for Process Intensification may be outlined. This is expressed in terms of recognised, well-proven tools however, as is often the case, the skills and awareness of the facilitator to apply the tools in such a way that the options for PI / continuous approaches are introduced and accommodated where appropriate will be part of the overall recipe for success.



Britest Methodology for Process Intensification

IN CONCLUSION

The areas outlined in this paper represent new strategic pillars of growth for Britest in addition to being key parts of industry's response to the imperatives of the climate emergency. We are already embarked upon a journey, engaging with our Advocates, and working though collaborative frameworks to enrich steadily our whole process understanding methods and develop our understanding of how the technical facilitation approach can be harnessed towards embedding the sort of broader whole systems thinking needed to build transformational change for sustainability in the process manufacturing industries as part of a Net Zero society by 2050.

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