IChemE Energy Centre

Energy and Resource Efficiency Good Practice Guide

Foreword

IChemE

The Institution of Chemical Engineers (IChemE) is the global professional membership organisation for chemical, biochemical and process engineers and other professionals involved in the chemical, process and bioprocess industries. With a membership in around 100 countries, and offices in Australia, New Zealand, Singapore, Malaysia and the UK, IChemE aims to be the organisation of choice for chemical engineers.

IChemE Energy Centre

IChemE Energy Centre was formed in March 2015 with the aim of giving the chemical and process engineering community a coherent voice on energy policy.

IChemE members work across the energy sector: from developing new sources of energy, moving it to where it's needed, improving the efficiency of the processes that use it, and mitigating the environmental effects of its production and consumption. Our systems-thinking approach has a lot to offer to the energy challenges of the 21st century.

The IChemE Energy Centre is a forum for the chemical and process engineering community to provide decision makers around the world with expert advice on energy issues, while highlighting the role of chemical engineers in meeting the energy challenges that society faces.

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Welcome

Welcome to the IChemE Energy Centre Energy and Resource Efficiency (ERE) Good Practice Guide.

One of my favourite books in recent years is Yuval Noah Harari's Sapiens: A Brief History of Humankind. Apart from being extremely well written, educational and engaging, it sets the context for our species on Earth, which is enlightening as we attempt to think about and tackle the single greatest challenge of our time – anthropogenic climate change.

The universe is 13.5bn years old and Earth formed some 4.5bn years ago, with life starting to emerge 3.8bn years ago. The genus, homo, evolved 2.5m years ago and started to use stone tools. Our species, Homo sapiens only appeared around 200,000 years ago. That means we have been here for 0.005% of the time after life first appeared on this planet. The scientific revolution which started 500 years ago gave us huge power to dominate Earth. The industrial revolution of 200 years ago then allowed us to super-size our extractive efforts, in the process replacing family and community with the state and market in the pursuit of economic growth – regardless of environmental consequence.

Since the industrial revolution we have accelerated our consumption of both energy and resources. In October 2018, the Intergovernmental Panel on Climate Change (IPCC) published a special report on the impacts of global warming of 1.5 °C.[1] It is scary stuff. Unlike other threats to our species, global warming is more than likely human made, which makes it all the more perverse if we choose not to correct our course.

The report finds that limiting global warming to 1.5°C above pre-industrial levels would require "rapid and far reaching" transitions in land, energy, industry, buildings, transport and cities. Global net human-caused emissions of greenhouse gases would need to fall by about 45% from 2010 levels by 2030, reaching 'net zero' by 2050.

We can no longer afford to wait. As chemical engineers we are uniquely placed to act in some of the most energy and resource intensive industries to reduce the impact we are having on the life support systems of our single shared planet.

The focus of this report is to provide guidance for chemical engineers looking to implement energy and resource efficiency initiatives within their organisations. I would like to thank everyone who has given up their time to contribute. I hope you will find the ideas in this document helpful and that they inspire you to think differently about what we can all do within our areas of work to make a real difference.

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Energy and Resource Efficiency Task Group Lead
IChemE Energy Centre Board Member

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[1] *The Intergovernmental Panel on Climate Change, October 2018, IPCC Special Report: Global Warming of 1.5°C,* ***http://bit.ly/2R4roQ3***

Introduction

Chemical engineers have the potential to make a significant contribution to reducing greenhouse gas (GHG) emissions to sustainable levels through applying energy and resource efficiency and circular economy principles to the entire supply chains in which we work.

This document describes the underlying principles when carrying out an energy and resource efficiency project in process plants. It includes activities to identify and analyse opportunities for energy and resource efficiency; create business cases for action; design and/or retrofit; install and commission; and operational and maintenance controls.

The term "resource efficiency" is very loosely-defined in industry. For ease of writing this document, we have used energy, water, raw material and waste as examples to illustrate the concepts and the underlying principles of resource efficiency.

Whilst this document explicitly mentions energy, water, raw material and waste separately, these four resources, and others besides, are intimately interlinked. A good way to think about the interactions is to consider the water-energy-food 'nexus' (Figure 1). It is possible to use energy to create water, eg desalination, or to use food to create energy, eg bio-crops, but there are tradeoffs and compromises to consider.

Figure 1. The water-energy-food nexus

The intricate and interconnected nature of various resources means that optimising one resource frequently leads to multiple benefits and/or impacts. This places chemical engineers in a unique position to analyse, identify and develop business cases to give overall organisational benefits. This also extends to reducing GHG emissions, their impacts, and adaptation from climate change requirements.

Principles for energy and resource efficiency

#1: Consider the whole picture

Define the right scope and boundary

#2: Focus on the process

The source of all consumption

#3: If you can't measure it, you can't improve it

Use data to justify business cases

#4: Target the minimum

How little could we use?

#5: Identify all the opportunities

Not just "end-of-pipe" add-ons

#6: Do life cycle analysis (LCA)

Appraise all benefits over the planned life

#7: Make it organisational policy

Align organisations' strategy and culture to deliver energy and resource efficiency as part of a drive towards ethically and socially sustainable business

#8: Be action focused

Recognise and overcome cognitive biases in the organisation

#9: Consider alternative funding options

Unlock efficiency with 3rd party funding

#10: Consider wider environment protection

Think about our Earth system and the planetary boundaries

Principle 1: Consider the Whole Picture

Define the right scope and boundary

When analysing the effective and efficient use of energy, water, raw material, waste and other resources, one of the important aspects is to define the scope and boundary. If the scope and boundary is defined as a single equipment item or unit operation, then the energy and resource savings will be limited to that equipment or unit operation and consequently may reduce the energy and resource efficiency of the overall system.

When the boundary of the analysis covers the whole plant or whole building, energy and resource savings can come from multiple sources. In many cases, trade-offs can be made within individual equipment or unit operations to provide larger overall plant or building savings. But this still may not be the optimal solution for the overall supply chain.

The boundary of the analysis should be extended across the complete supply chain of the organisation, from raw materials, transportation, and final use by customers. Those familiar with GHG emissions reporting may be familiar with the GHG protocol:[2]

- scope 1 (direct emissions from owned or controlled sources);
- scope 2 (indirect emissions from the generation of purchased energy); and
- scope 3 (indirect emissions not included in scope 2, eg extraction and production of purchased materials and transportation of purchased fuels).

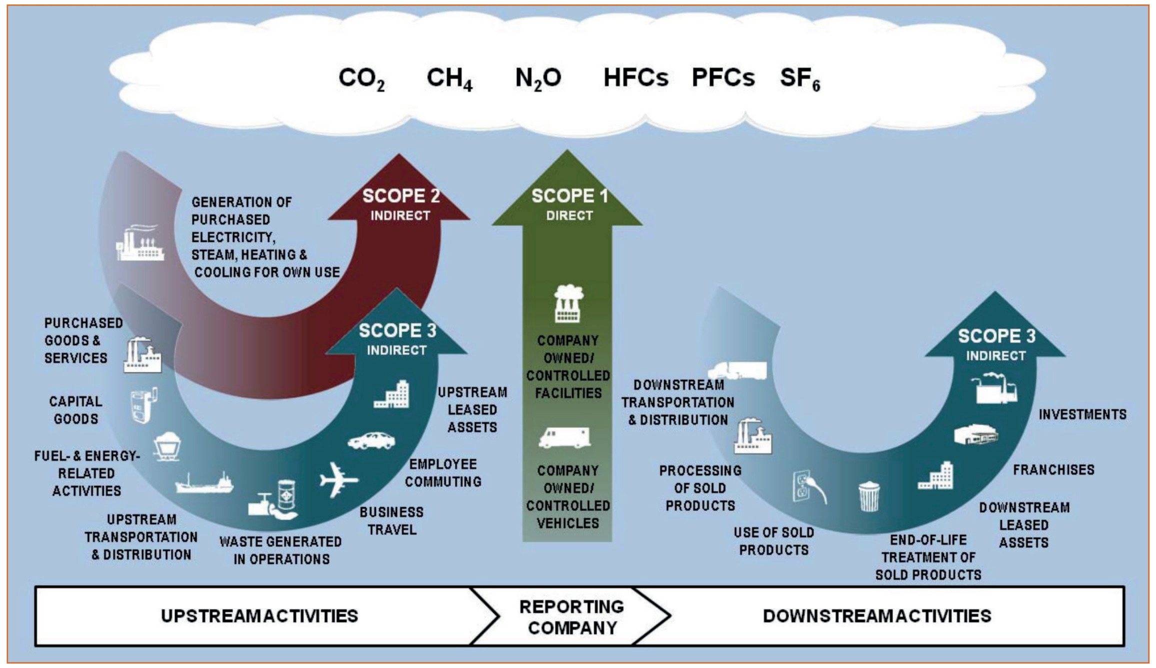

Figure 2. GHG protocol scopes and emissions across the value chain (adapted from GHG Protocol Guidance for Calculating Scope 3 emissions)[3]

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[2] *The Greenhouse Gas Protocol, March 2004, A Corporate Accounting and Reporting Standard revised edition,* ***http://bit.ly/2S5QVFH***

[3] *The Greenhouse Gas Protocol Initiative, August 2011, Guidance for Calculating Scope 3 Emissions,* ***http://bit.ly/2rHfbST***

The bulk of energy can be consumed in hidden scope 3 activities. Upstream categories in scope 3 include (but are not limited to):

1. Purchased goods and services
2. Capital goods
3. Fuel and energy related activities
4. Upstream transportation and distribution
5. Waste generated in operations
6. Business travel
7. Employee commuting
8. Upstream leased assets

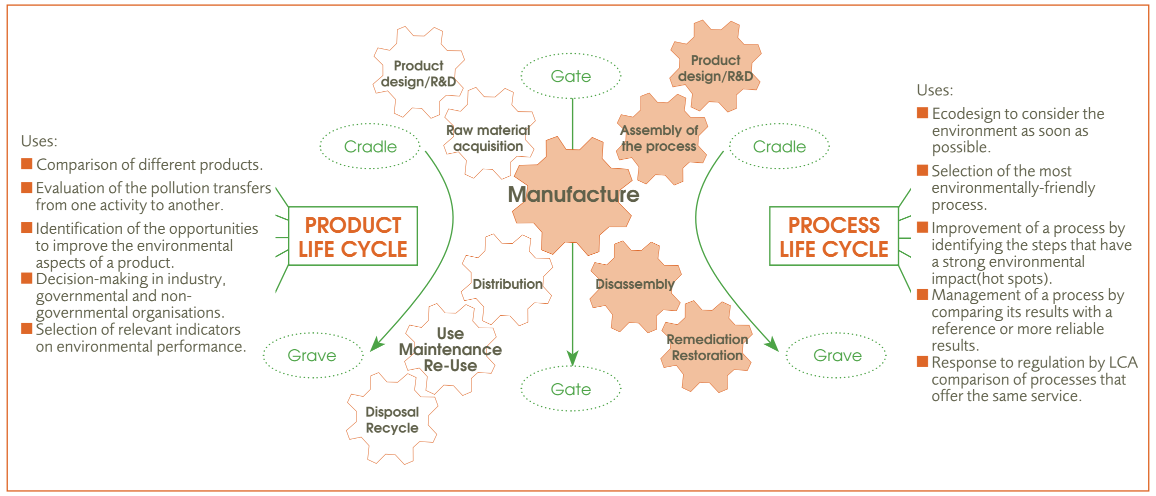
Downstream categories in scope 3 include (but are not limited to):

9. Downstream transportation and distribution
10. Processing of solid products
11. Use of solid products
12. End-of-life treatment of solid products
13. Downstream leased assets
14. Franchise
15. Investments

In the analysis of supply chain, the bulk of energy and other resources can be consumed outside the plant and/or organisational boundaries, thus offering the opportunity to optimise the energy and resource consumption across the whole supply chain. Supply chain boundaries also allow graded materials, waste energy, lower-quality water, and waste in one part of the supply chain to be considered for use in another part of the supply chain.

At the time of writing, energy and resource efficiency initiatives can be analysed from a closed-loop economy or cradle-to-grave perspective. For chemical and process industries, the cradle-to-grave concept can be applied to the materials and equipment used for manufacturing or to its products (Figure 3). It is important to consider the breadth of the process industries. It is not just the traditional chemical manufacturers, but includes food and drink, pharmaceuticals, biotechnology industries, nutraceuticals, fast-moving consumer goods (FMCGs), paints and coatings, textiles, plastics and metals.

In general, the larger the scope and boundary of analysis, the more opportunities for improvements in energy and resource efficiencies can be found, and larger overall savings can be made.



Uses:

- Comparison of different products.
- Evaluation of the pollution transfers from one activity to another.
- Identification of the opportunities to improve the environmental aspects of a product.
- Decision-making in industry, governmental and non-governmental organisations.
- Selection of relevant indicators on environmental performance.

Uses:

- Ecodesign to consider the environment as soon as possible.
- Selection of the most environmentally-friendly process.
- Improvement of a process by identifying the steps that have a strong environmental impact(hot spots).
- Management of a process by comparing its results with a reference or more reliable results.
- Response to regulation by LCA comparison of processes that offer the same service.

Figure 3. LCA applied to the process industry (adapted from Jacquemin et al, 2012)[4]

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[4] *Jacquemin L, Pontalier PY, Sablayrolles C, 'Life cycle assessment (LCA) applied to the process industry: a review', The International Journal of Life Cycle Assessment, vol 17, no 8, 2012. pp1028–1041.*

Principle 2: Focus on the process

The source of all consumption

Universities rightly teach chemical engineering students to see the big picture – to design from the reactor and separation systems before designing energy supply and control systems. This is the concept of the onion model (Figure 4). In reality, many chemical engineers, upon graduation, focus most of their work on addressing specific issues related to specific equipment.

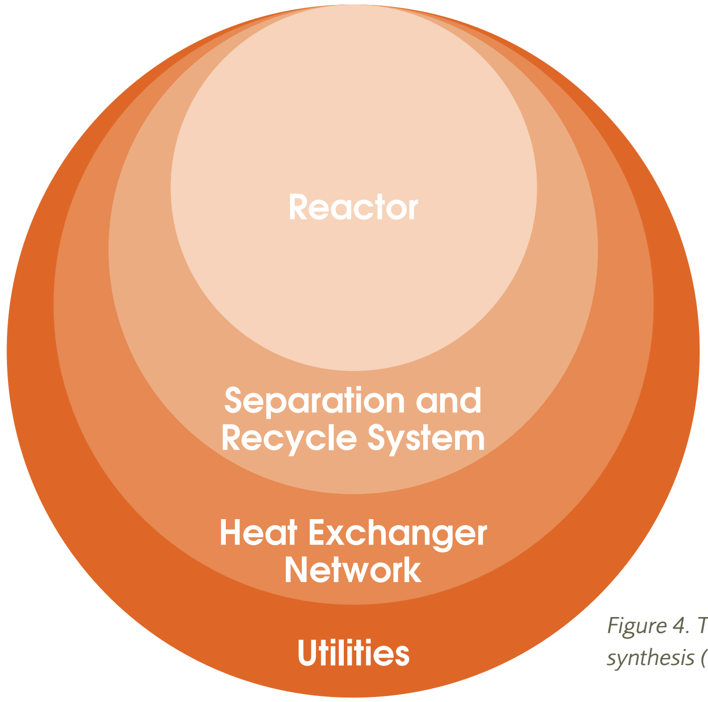

Figure 4. The onion model of chemical process synthesis (adapted from Smith & Linnhoff, 1988)[5]

Take energy as an example, many chemical engineers focus their efforts on reducing energy consumption by looking at their energy plants – their boilers, chillers, air compressors, etc. Optimising the energy plants will result in the energy utilities generating and distributing energy efficiently. However, it does not mean that energy is consumed efficiently by the process. It also does not mean that energy supplied is used effectively to make saleable products.

A good starting point for an energy and resource efficiency project is to get back to basics – understanding the overall mass and energy flow within the scope and boundary of the project. A thorough understanding on the overall mass and energy balance allows process requirements to be matched with the right quality and quantity of energy, water, and raw materials. It provides opportunities to use resources at the right cost levels, and to recycle and reuse other resources elsewhere.

Optimising the whole process does not mean each and every component within the scope and boundary will consume the lowest energy, water, and raw materials and generate the lowest amount of waste. Some trade-offs in individual processes may be required – certain equipment and processes may need to operate sub-optimally – to give the lowest consumption overall.

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[5] *Smith R, Linnhoff B, 'The design of separators in the context of overall processes', Chem. Eng. Res. Des, vol 66, no 5, 1988, pp 195–228.*

Principle 3: If you can't measure it, you can't improve it

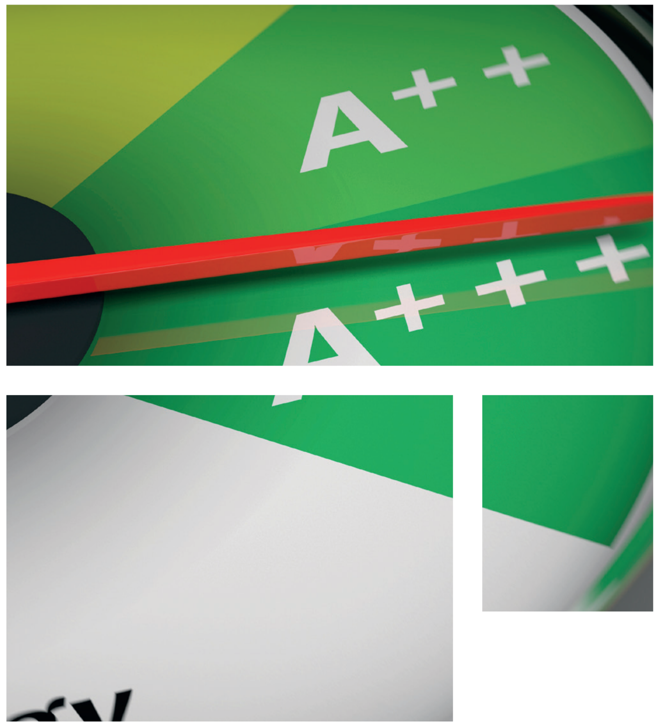
Use data and measurements to justify business cases

Like all things related to engineering and physical sciences, the key to an accurate and repeatable energy and resource efficiency project is to base the business case on measurements and data from the organisation. Using accurate and repeatable measurements and data is also paramount to manage the use and consumption of energy and other resources. As the saying goes, you cannot manage what you do not measure.

> "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."
>
> Lord Kelvin, 1883

When it comes to metering for energy, water and other non-core materials and resources, the quality of metering and analysis is significantly worse than the process-related metering and measuring systems. However, there are many uses of accurate and repeatable energy, water, raw materials and waste measurements:

1. The direct measurement of how effectively we are consuming these finite and precious resources can help. It tells us how much stock we have, how much or how fast we are consuming or generating. It is a good indicator if the consumption is proportional to the productions of saleable products. If the use of energy or water, for example, is constant regardless of production levels, then there is wastage or unaccounted consumption in the organisation and therefore a potential opportunity for savings.
2. Measurement at all stages of consumption and production can identify if there are leaks of these precious resources between the supply and end-use. A leak may indicate pipe integrity issues and potential area of waste. A good example is from the water supply and effluent piping where pipes with poor structural integrity, leaks, may lead to unintended consequences such as land bulging and/or subsidence.
3. Accurate and repeatable measurement of energy, water, raw materials and waste can also enable a benchmark with other similar plants, determine the energy performance gaps, and speed up progress to close the gaps.
4. Traceability and control of energy, water, raw materials, and waste may also be important in a supply chain perspective, especially when the output from one process may be transferred to another entity for use. For example, waste where graded products may be recycled and/or reused in other parts of the process. Another good example is where process water from the plant may no longer be good enough quality for the process, but could be used in other sites, such as for floor washing or land irrigation.



Principle 4: Target the minimum

How little could we use?

Challenge every step to identify the absolute minimum amount of energy and resources required to deliver the required output. Do not compromise. Calculate the minimum from first principles.

It is not enough to settle for a modest improvement in energy and resource consumption. Given a defined output from a system, work out how to produce the output with the minimum amount of energy and resource both from a product and process lifecycle perspective (see principles 1 and 2).

Cup of tea anyone?

Consider the simple example of boiling water to make a single cup of tea. There is a minimum amount of energy required to raise the temperature of a fixed volume of water from ambient to 100°C at atmospheric pressure, but how close are we to achieving the minimum?

Upstream there is energy associated with collecting, treating and pumping water to our location. There are different ways to provide the heat energy: grid electricity, gas, coal, wood, solar. Each has different energy losses associated with them. How efficient is the device for converting supplied energy into boiling water? How easy is it to boil more water than required? How easy is it to extend the heating time beyond the required minimum? On the downstream side, what energy is required to treat any wasted tea poured into the drain? What energy is needed to clean the cup? This is before considering the tea bag and any milk or sugar. Do you really need that cup of tea?

Work out what the minimum is and set that as your target. Measure progress, and therefore success against this minimum target.

Principle 5: Identify all the opportunities

Not just "end-of-pipe" add-ons

Once the plant has been compared with the minimum benchmark and the improvement gap determined, the next step is to find opportunities for improvements. If the plant used an energy and resource profile (trend) and baseline analysis, there would be some ideas as to where to look for improvement opportunities.

The activity of finding opportunities for improvement based on data, turning that conceptual thought into an implementation plan, and calculating the cost-benefit is an audit and can be both internal or external. Some other organisation may have different names for this process. Names range from assessment, scan, study, review, kaizen, treasure hunt, audit and so on but the concept is the same.

When setting up energy and resource audits it is fundamental to consider the following:

- an audit is always a team activity – make sure the right, competent team is in place;
- clearly define the scope and expected deliverables upfront;
- gather the relevant energy and resource consumption data upfront;
- define criteria for evaluating opportunities;
- visit the site/process and have a clear understanding of the internal and external links in energy and resource consumption for the overall system; and
- identify all improvement opportunities which can then be fully evaluated and ranked.

Regardless of what the activity is called, it is common for the organisation to focus on end-of-pipe solutions, ie identifying equipment add-ons to the existing process, and/or replacing the existing equipment with a more efficient variant.

As a chemical engineer, armed with the overall mass and energy balance, a range of opportunities are available, many of which do not involve major changes or investments. A chemical engineer may also be able to work out the minimum energy and resource consumption to produce the quantity of saleable products. These opportunities can come from:

- Operational and maintenance controls: Ensuring the operations match design specifications, matching output specifications with specifications, operating minimising leaks, match demand with supply, minimising idle time, minimise work in progress inventory, minimise finished inventory, etc.
- Improving controls: Control tuning, tightening set points, making specification trade-offs on one area to give larger overall savings, etc.
- Recover, recycle, and reuse energy and other resources in-situ or in other parts of the process.
- Replace and retrofit with more efficient equipment and/or unit operations.
- Design of alternative processes: Introduce alternative sources of energy supply, energy technologies, alternative route for manufacturing (green chemistry), etc.

Principle 6: Do life cycle analysis (LCA)

Appraise all benefits over the planned life

LCA, in general, is a technique to assess the potential environmental impacts of products, processes, and systems, or services at all stages in their life cycle.[6]

Once a portfolio of improvement opportunities has been identified, it is common mistake to quantify only the benefit related to the initial project. For example, if it is an energy-saving project, only the energy-saving benefit is quantified. If it is a waste-reduction project, only the waste-reduction benefit is quantified.

It is important to identify, analyse, and quantify all the benefits to be gained from each opportunity as set out within the boundaries (Figure 5). The most common benefit may come from energy savings, water savings, waste savings, raw material savings, maintenance reduction, quality improvement, penalty reduction, and more possibilities. These benefits should be appraised over the planned life of the opportunity.

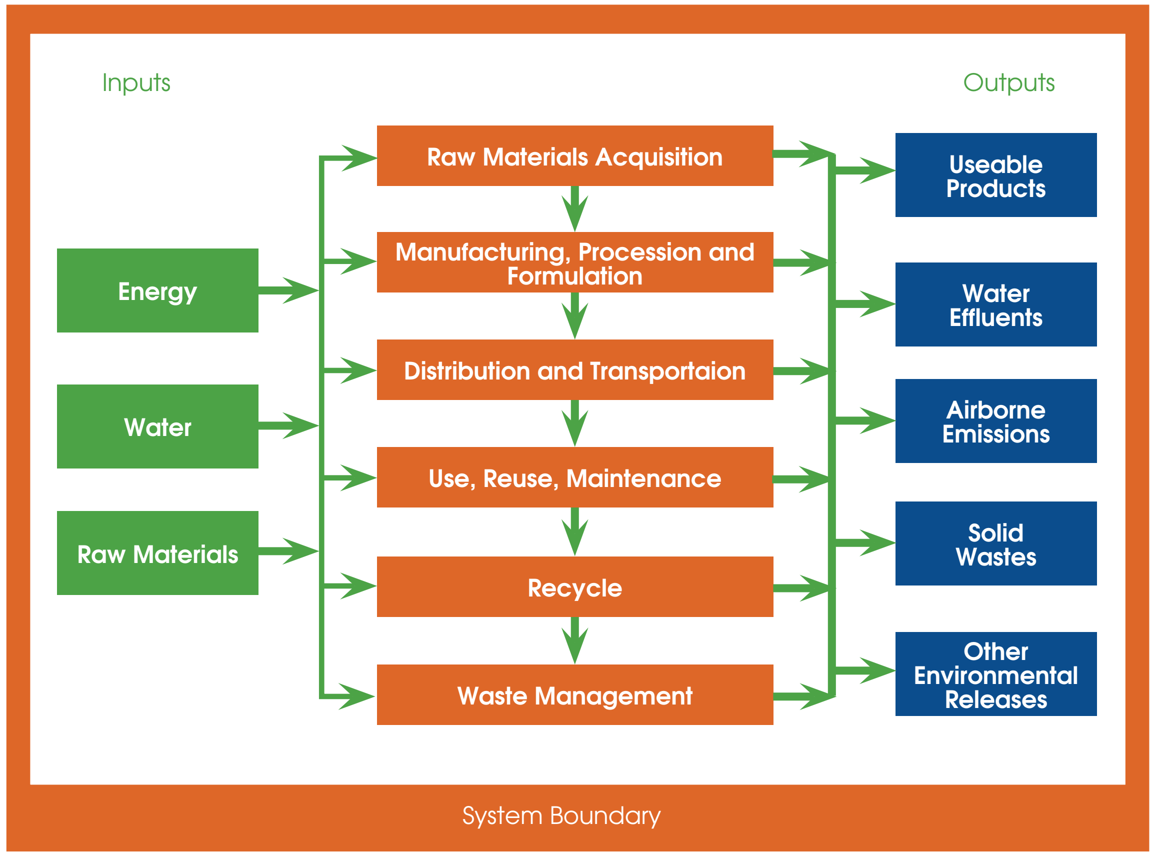


Figure 5. Defining LCA boundaries (adapted from US DOE LBL Life-Cycle Analysis)[7]

It may not be feasible to implement some of the opportunities immediately, perhaps due to longer-term strategic plans. However, these opportunities should still be recorded and regularly reviewed, as they may be implemented in future new designs, major plant modifications and retrofits.

As a chemical engineer it is essential to consider sustainable design and full product lifecycle when designing a new plant or developing a new product, not just partial product life cycle from resource extraction to the factory gate. Therefore, for you as a chemical engineer, defining LCA and its system boundary conditions should be a crucial first step in your area of business.

According to ISO 14040:97,[8] LCA is defined as a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle". There are several different approaches (Figure 6) but you should also be familiar with the core idea of LCA approaches such as:

- Gate to gate: (partial LCA) looking at everything from receiving to shipping gate
- Cradle to gate: (partial LCA) considers raw materials to finished good (no use and disposal phase of the product in considerations)
- Cradle to grave: the full LCA from resource extraction ('cradle') to use phase and disposal phase ('grave')

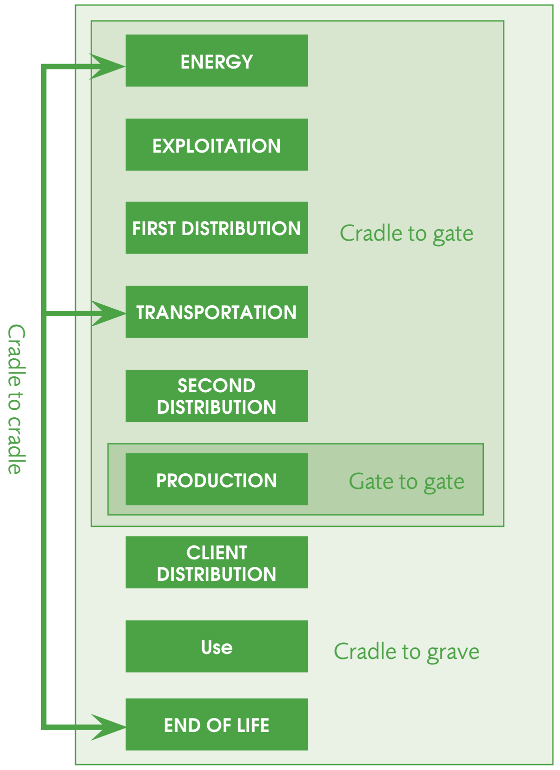


Figure 6. Different LCA approaches (adapted from Fuelfromwaste.eu, 2014)[9]

Hence, in the early phase of product design, when most impact can be made, chemical engineers should incorporate a more holistic approach with emphasis to reduce its environmental effects as well as **minimise raw materials inputs** and **waste output**. To do so, a "closed loop", circular economy approach or cradle-to-cradle (C2C) method should be embraced by chemical engineers and their organisations. This considers every impact of the product, including a potential 4 Rs to minimise the waste:

- recycle
- reduce
- reuse
- recover

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[6] *International Standard ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines,* ***http://bit.ly/2S7Ka6r***

[7] *Department of Environment and Lawrence Berkeley National Laboratory, Life-Cycle Analysis, April 2008* ***http://bit.ly/2Ex70Aa***

[8] *ISO 14040:2006, Environmental management – Life cycle assessment – Principles and framework,* ***http://bit.ly/2Eukc9e***

[9] *Fuelfromwaste.eu., 2014, LCA scope and analysed system boundaries,* ***http://bit.ly/2QA3egK***

Shifting to the circular economy approach

In industry there is an ongoing shift towards a sustainable future. Chemical engineers and their organisations are encouraged to go beyond the normal approaches, to more innovative techniques such as the circular economy and C2C where applicable (Figure 7). This can be achieved through circular economy concepts by revolutionising good practice, design, and focussing on building research and development capabilities to ensure ecologically friendly and sustainable design is embedded in their business.

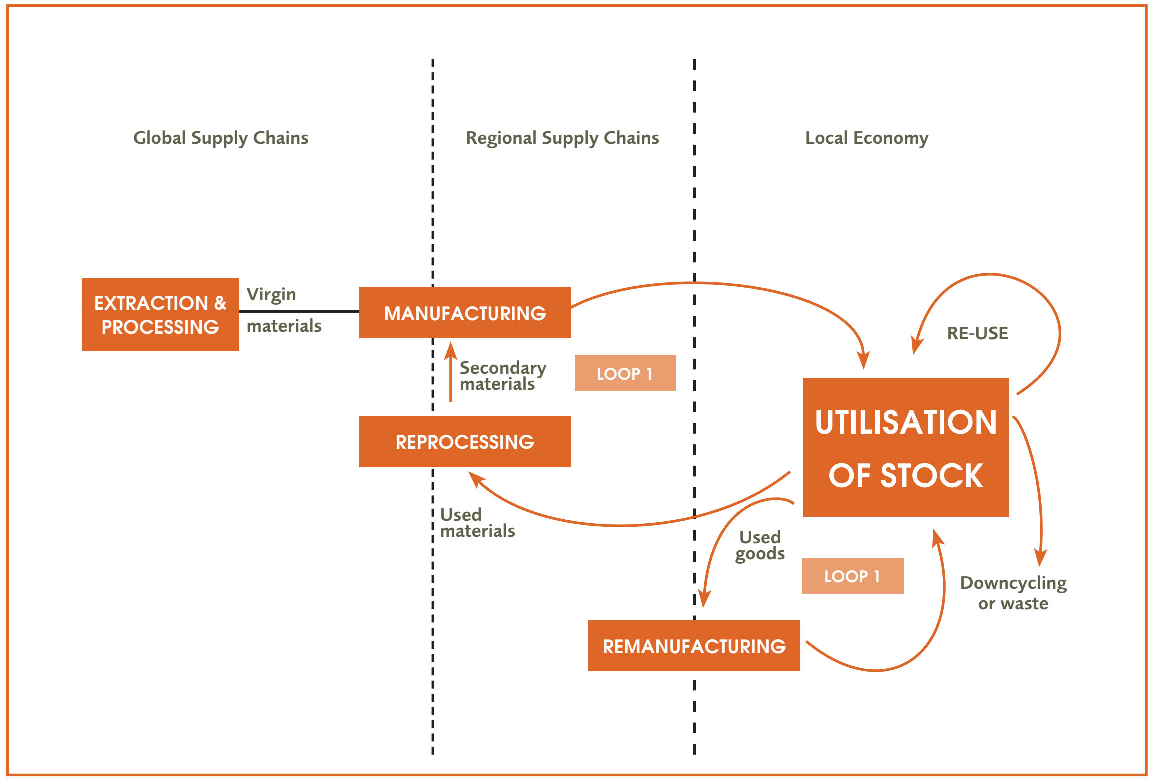

Figure 7. The circular economy (adapted from Stahel & Clift, 2016)[10]

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[10] *Stahel WR, Clift R, 'Stocks and Flows in the Performance Economy'. Taking Stock of Industrial Ecology. Springer, Cham, Switzerland. 2016, chapter 7, pp137–158*

Principle 7: Make it Organisational Policy

Align organisations' strategy to deliver energy and resource efficiency

When an opportunity to save is logical, and makes financial sense, many assume that management and leadership of the company will (and must) implement it. There are many reasons why the opportunities may not be implemented.

Organisations need not wait for governments to set out energy, water and waste targets as a reason to take action. The organisation's aspiration to improve its energy and resource consumption as compared to its competition is key to driving and sustaining self-perpetuating management activities.

Many organisations already have management metrics in place for safety, health and environment (SHE). It would be relatively easy to build on these foundations and align the business case with the SHE objectives and strategic intents of the organisation. Once there is alignment, engaging with top management becomes easier. The sponsorship and direction of top management automatically resources and drives the opportunities and behaviours throughout an organisation.

From a strategic planning perspective, decision makers should consider the whole picture of the policy path from planning and implementing the energy efficiency strategy to monitoring and evaluating it in any organisation to achieve long-term continuous improvement. They should know that improving energy efficiency "is a process of technical and behavioural change that is driven by technological, financial, management, social and policy drivers and constraints." Owens Corning[11] IBM[12] and Dow Chemical[13] (Dow Chemical achieved US$27bn in cost savings) are good examples of organisations with impressive track records in energy saving. Figure 8 shows how Dow's energy intensity was reduced from 1990 and the cumulative savings impact of acting early to reduce cost of goods in the business. This is an example of good management policy.

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[11] *Owens Corning, Sustainability,* ***http://bit.ly/2Bvwl5k***

[12] *IBM, IBM and the Environment – Voluntary environmental initiatives,* ***https://ibm.co/2PMkVo0***

[13] *US Department of Energy, Dow Chemical Company: Assessment Leads to Steam System Energy Savings in a Petrochemical Plant,* ***http://bit.ly/2SPYd0e***

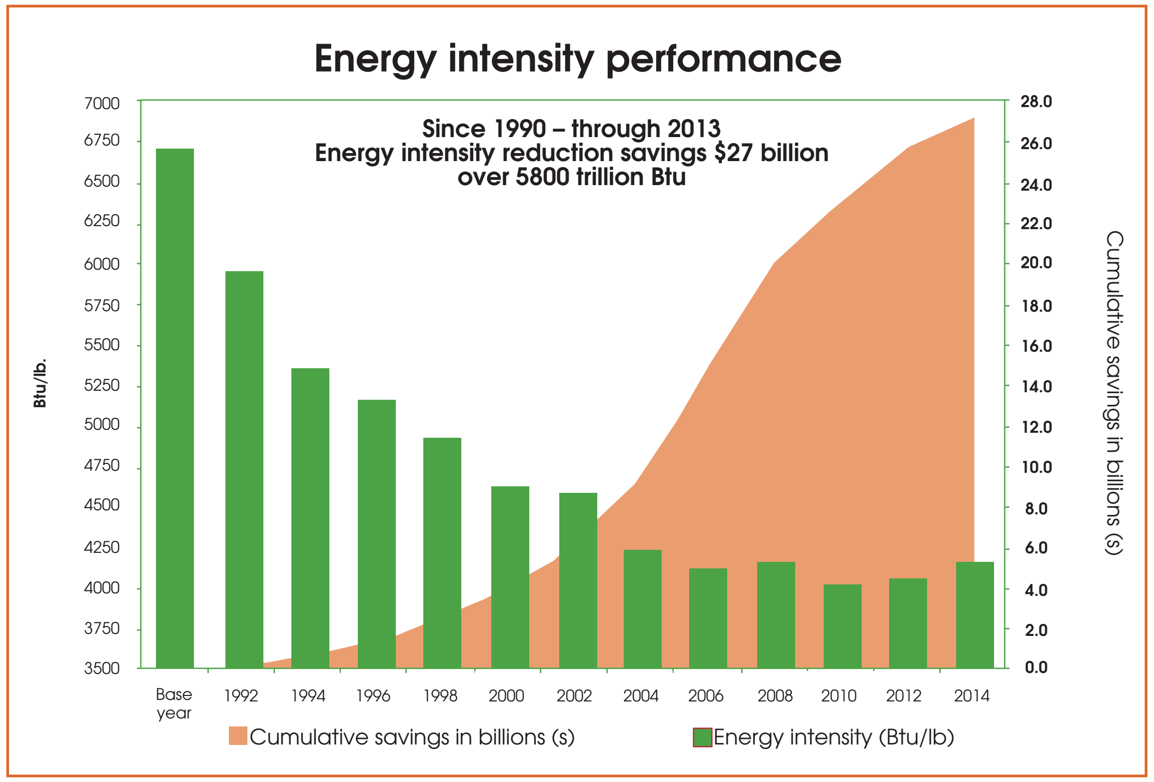

Figure 8. Dow Chemical's energy intensity performance 1990–2013 (adapted from Almaguer, 2015)[14]

The International Energy Agency (IEA) has developed an approach to creating a successful energy management programme in industry that follows a cyclical process of Plan-Implement-Monitor-Evaluate (Figure 9). Every organisation will have its own methods to implement policy change for the benefit of the organisation, but the important thing is that an energy management policy is implemented with sponsorship at the highest level to support real cultural change.

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[14] *Almaguer JA, 'The Dow Chemical Company: Energy Management Case Study', Energy Management and Efficiency for the Process Industries, John Wiley & Sons, Inc., Hoboken, New Jersey, 2015, pp25–36.*

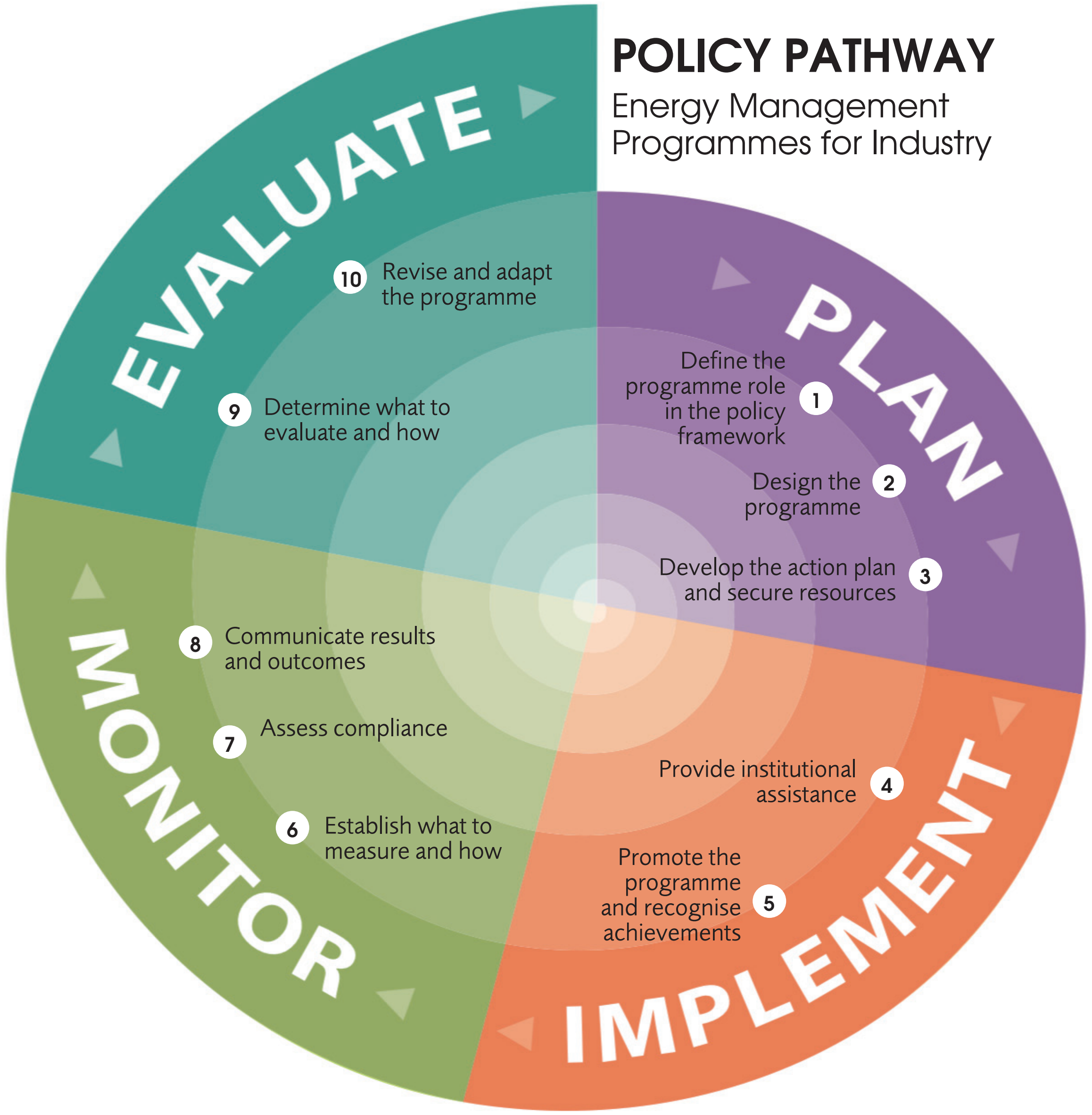

Figure 9. Policy pathway – energy management programmes for industry (adapted from IEA, 2012)[15]

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[15] *Institute for Industrial Productivity and International Energy Agency, April 2012, Energy Management Programmes for Industry – Gaining through saving,* ***http://bit.ly/2GB6rIe***

Principle 8: Be Action Focused

Recognise and overcome cognitive biases in the organisation

Having top management buy-in and sponsorship is only the beginning. The opportunities do not automatically implement themselves, and don't magically appear overnight.

There are many steps to turn opportunity into reality, but they are always similar. Figure 10There are six typical steps from initial opportunity assessment through to construction and commissioning, and ultimately operation when the savings are actually realised. Each of these can have their own typical barriers (Figure 10).

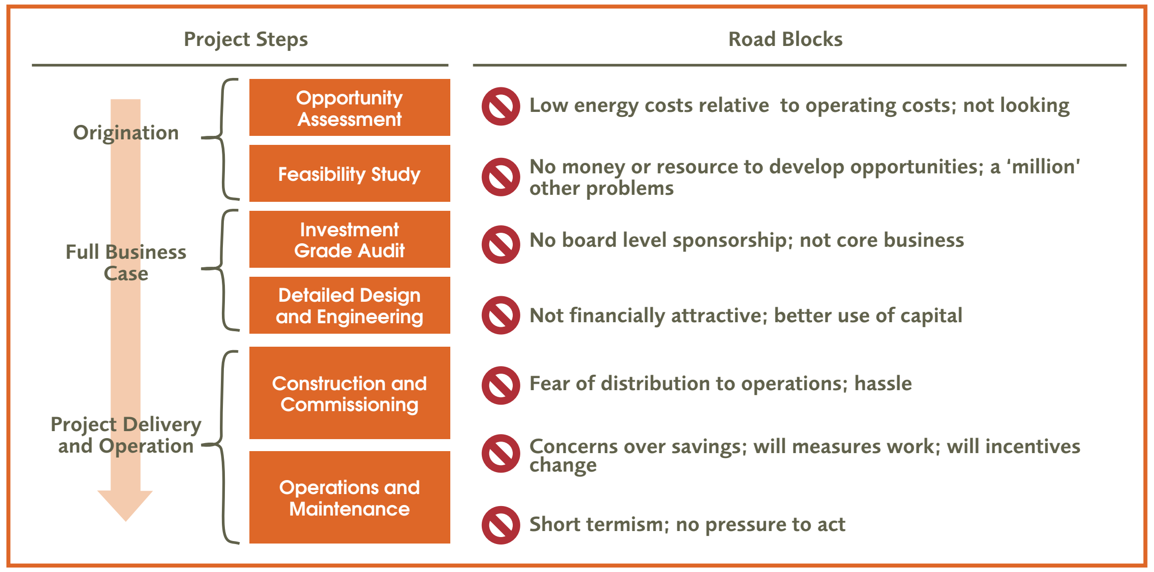


Figure 10. Typical projects steps and blocks to implementation

Each of these stages from conception to project realisation, involves many stakeholders. Many of them have their own objectives which may or may not support the opportunity at hand. These so called "blockers" or "cognitive biases" may include:

- low energy costs relative to overall operating costs;
- competing interest, eg unwilling to allocate time for implementation due to an interest to run production for as long as possible;
- unwillingness to allocate money or resources not dedicated to non-core operations; or
- fear of disruption of operations.

In the 2018 member survey, the requirement of short-term investment returns was cited as the leading barrier to implementing energy and resource improvement, followed by only adopting the regulatory minimum and lack of priority (Figure 11).

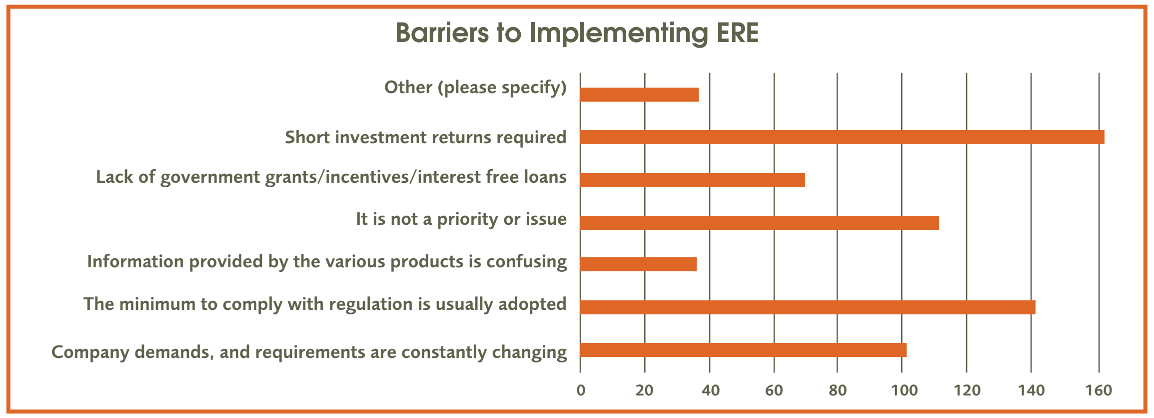


Figure 11. Barriers to implementing energy efficiency improvements, (IChemE Member Survey 2018)

As chemical engineers, it is easy to get caught up in the science of the solution. Care and time should also be allocated to detect these blockers, address the issue and underlying causes, and actively manage the project through its implementation.

Some of the solutions to unblocking barriers, as suggested by IChemE members, include implementing best-practice business processes and balanced case studies or how-to guides to help identify opportunities (Figure 12).

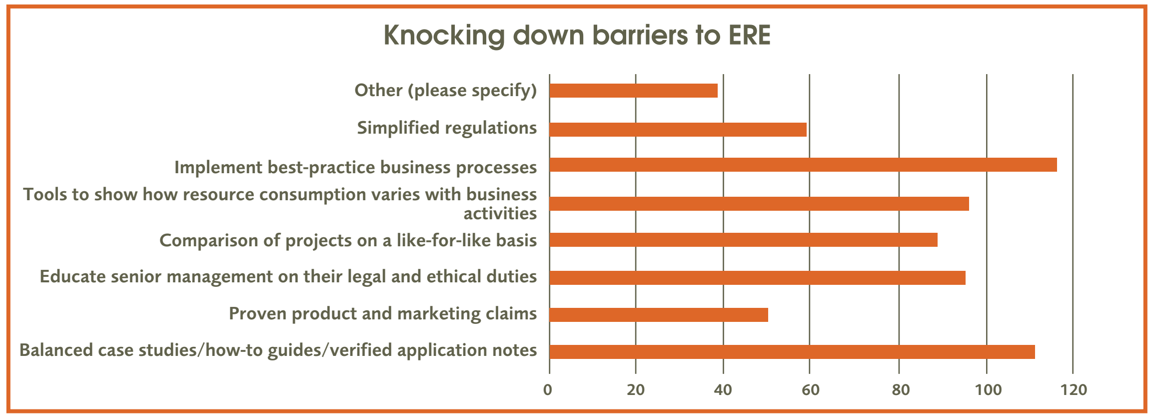


Figure 12. Unblocking barriers to implementing energy and resource efficiency improvements (IChemE Member Survey, 2018)

Principle 9: Consider alternative funding options

Unlock savings with 3rd party funding

Making a business case and funding energy- and resource-saving projects need not follow the conventional balance sheet (capital and/or revenue) funding mechanism. Sure, if you have the funds it is better to invest in energy and resource efficiency projects within your organisation directly. However, as often happens, energy and resource efficiency projects can have longer paybacks than other opportunities for capital deployment in an organisation and therefore can fail to meet investment hurdles.

This doesn't mean they have to be left undone.

The energy efficiency sector has developed many financing solutions that can bring investment from outside third-party funders prepared to take a longer-term view. This means deep energy efficiency improvement projects can be implemented and savings for organisation can be realised without internal capital investment – the trade-off being that host organisations have to commit to benefit from these type of contracts over a longer period of time so that investors have the time to recoup their investment.

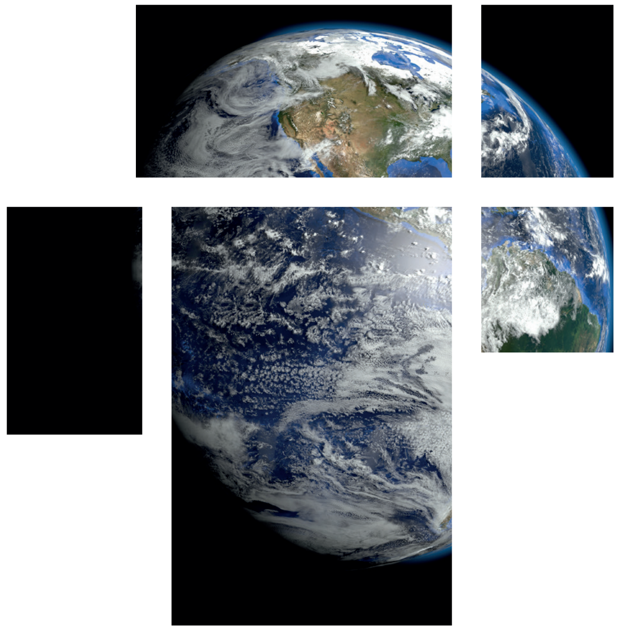
Energy performance contracts (EPCs) are offered by energy services companies (ESCOs) that can guarantee a level of savings that attracts investors whilst simultaneously providing savings to the host organisation.

These contracts can also cover water, waste and many resource efficiency projects and are a great way to finance energy and resource efficiency projects that would otherwise be ignored.

To take advantage of EPCs there are some basic project lifecycle phases to consider:

1. baselining;
2. savings calculation;
3. design, construction, verification;
4. operations, maintenance, monitoring; and
5. measurement and verification

In working through these phases, transparent procedures and documentation are important to bring all parties together



Principle 10: Consider wider environment protection

Think about our system and the planetary boundaries

Whilst this document focuses on energy and resource efficiency, it is important not to forget about the wider environmental impact.

To challenge and improve current processes we must first learn to see the ecological system within which we operate and the safe limits inside it.

Guidelines released by the Stockholm Resilience Centre on the nine planetary boundaries give clear suggestions on how to improve the processes we design and operate, with the health of our planet in mind (Figure 13).

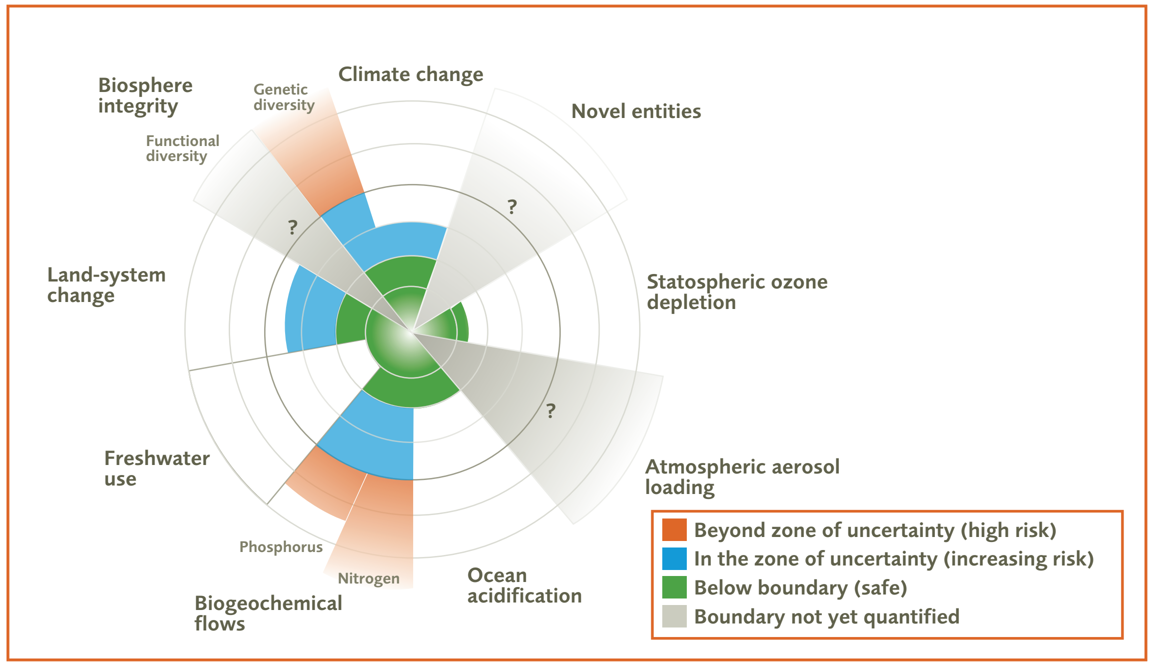


Figure 13. The nine planetary boundaries (adapted from Steffan et al 2015)[16]

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[16] *Steffan W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, Biggs R, Carpenter SR, de Vries W, de Wit CA, Folke C, Gerten D, Heinke J, Mace GM, Persson LM, Ramanthan W, Reyers B, Sörlin S, 'Planetary boundaries: Guiding human development on a changing planet', Science, vol 347, no 6223, 2015, pp1259855,* **http://bit.ly/2Cl5RKI**

1. Climate change

Unarguably the most well-known planetary boundary is climate change caused by GHGs such as carbon dioxide, methane and nitrous oxide being released into the air and acting to trap more heat within the atmosphere. The specific control variable used to measure this boundary is the atmospheric concentration of CO_2 in parts per million (ppm). Work done to-date indicates that the safe planetary boundary for this measure is 350 ppm. Current levels are around 400 ppm and are rising rapidly. In short, we are already exceeding the safe limit for this and need to bring things back under control.

What can chemical engineers do?

- Implement energy efficiency, low-carbon and renewable projects across all processes and factories as quickly as possible.
- Implement circular economy principles to minimise linear processing and the associated resource and energy waste.
- Research and development of carbon-negative technologies to remove CO_2 from the atmosphere.

2. Ocean acidification

Ocean acidification is linked to emissions of carbon dioxide and is caused when the gas dissolves in the oceans to form carbonic acid, which lowers the pH of the surface water. This process reduces the carbonate ions available for marine species to form shells and skeletons, consequently endangering ocean ecosystems and the ocean's food chain. The control variable used for ocean acidification is the average saturation of calcium carbonate at the ocean surface as a percentage of pre-industrial levels. The current value is around 84% and is falling towards the recommended minimum limit of 80%.

What can chemical engineers do?

- Redesign processes to limit the release of carbon dioxide to the environment.

3. Chemical pollution

Ecosystems on land and sea are endangered by the release of persistent toxic compounds such as synthetic organics and heavy metals. These substances can accumulate in the tissue of living creatures, often reducing fertility, causing genetic damage, and affecting multiple generations as they may last longer than the lifecycle of organisms.

As yet, scientists have not identified an appropriate control variable in order to monitor and set a safe limit. Suffice to say, reduced emissions of long-lived toxic compounds is better.

What can chemical engineers do?

- Redesign processes to reduce or eliminate the use of long-lived toxic chemicals.
- Design abatement technologies to prevent release of long-lived toxic chemicals.

4. Nitrogen and Phosphorus Loading

Modern farming with extensive use of fertilisers results in significant quantities of nitrogen and phosphorus running off into rivers, lakes and oceans. Algal blooms can then turn the water green and kill off other aquatic life by starving it of oxygen.

Two control variables for safe nitrogen and phosphorus loading have been identified. Phosphorus can be applied to land with a safe global limit of 6.2m t/y and nitrogen applied to land as fertiliser with a limit of 62m t/y.[17] Both are currently being exceeded by more than double at 14m and 150m t/y respectively. This loading incorporates all fertilised land dressings.

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[17] *Steffan W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, Biggs R, Carpenter SR, de Vries W, de Wit CA, Folke C, Gerten D, Heinke J, Mace GM, Persson LM, Ramanthan W, Reyers B, Sörlin S, 'Planetary boundaries: Guiding human development on a changing planet', Science, vol 347, no 6223, 2015, pp1259855,* **http://bit.ly/2Cl5RKI**

What can chemical engineers do?

- Research and develop new methods of farming to feed the world whilst minimising fertiliser use.

5. Freshwater Withdrawals

Industry, agriculture and households use large quantities of water, and it is essential for life. However, excessive withdrawal of freshwater can alter the hydrological cycle and climate by drying up rivers, lakes and aquifers.

The identified control variable is blue water (freshwater) consumption in cubic kilometres per year. The limit of 4,000 km^3 per year is currently not being exceeded, the withdrawal level currently being 2,600 km^3, but the quantity is rising. However, disproportionate use across the globe currently leads to significant problems at local levels.

What can chemical engineers do?

- Design processes to minimise industrial water use.
- Implement water conservation measures for existing facilities.

6. Land Conversion

Transforming forests and wetlands into cities, farmland and roads for human use destroys habitats, reduces our planet's carbon sinks and undermines the land's role in cycling water, nitrogen and phosphorous.

The control variable in this case is defined as the area of forest covered land as a proportion of forest covered land prior to human alteration and this should be kept at least above 75%. Currently this measure is as low as 62% and falling.

What can chemical engineers do?

- Challenge supply chains, and design processes to use responsibly-sourced materials that do not rely on increasing deforestation.
- Design new factories to occupy brownfield sites.

7. Biodiversity Loss

By some reports we are currently living through the fourth mass extinction event on our planet.[18] The rate of species extinction is accelerating, and the current rate is 100–1,000 species extinction per million species per year. The safe limit is estimated at just 10 species extinctions per million species per year.

What can chemical engineers do?

- Act to protect endangered species wherever they are found when operating and developing new factories or facilities by minimising the impact on local ecosystems.

8. Air Pollution

Emissions to air include smoke, dust and pollutant gases and can have detrimental effects on living organisms. Air quality in cities around the world is now becoming a major health concern for humans. As well as damaging organisms, emissions interact with water vapour and affect cloud formation. Large volumes can also alter regional rainfall patterns.

Whilst air pollution has been identified as a planetary pressure, no control variable has yet been identified.

What can chemical engineers do?

- Rigorously review all emissions to air from processes we design and operate, to minimise releases.

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[18] *WWF, October 2018, Living Planet Report 2018: Aiming Higher,* **http://bit.ly/2Errz18**

9. Ozone Layer Depletion

Concentration of ozone in the stratosphere as measured in Dobson Units (DU) needs to be at least 275 DU to remain within safe limits.[19] The ozone layer filters out UV radiation from the sun and protects us from overexposure to harmful UV rays.

Stratospheric ozone concentrations vary hugely by season and location, as do the associated effects.[20] While they are currently expected to broadly recover, they remain below pre-industrial levels.[21]

What can chemical engineers do?

- Phase out use of ozone layer depleting substances[22] such as chlorofluorocarbons (CFCs) in all processes.[23]

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[19] *Steffan W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, Biggs R, Carpenter SR, de Vries W, de Wit CA, Folke C, Gerten D, Heinke J, Mace GM, Persson LM, Ramanthan W, Reyers B, Sörlin S, 'Planetary boundaries: Guiding human development on a changing planet', Science, vol 347, no 6223, 2015, pp1259855,* ***http://bit.ly/2Cl5RKI***

[20] *Eastham S, Keith D, Barrett S, 'Mortality tradeoff between air quality and skin cancer from changes in stratospheric ozone', Environ. Res. Lett., vol 13, 2018,* ***http://bit.ly/2s9Lf1Z***

[21] *Chipperfield M, Bekki S, Dhomse S, Harris N, Hassler B, Hossaini R, Steinbrecht W, Thieblemont R, Weber M, 'Detecting recovery of the stratospheric ozone layer', Nature, vol 549, 2017, pp211-218,* ***https://go.nature.com/2AtizWA***

[22] *United Nations, September 1987, Montreal Protocol on Substances that Deplete the Ozone Layer,* ***http://bit.ly/2Bum2DV***

[23] *European Environment Agency, September 2018, EEA Report No 10/2018, Data reported by companies in 2018 on 2017 transactions on the production, import and export of ozone-depleting substances in the European Union,* ***http://bit.ly/2rlyVpe***

Further reading

In addition to the references contained in this document, the following resources provide additional information:

International Energy Agency, May 2016, Water Energy Nexus, Excerpt from the *World Energy Outlook 2016*, ***http://bit.ly/2PJ0lVz***

Harari YN, *Sapiens A Brief History of Humankind*, Penguin Random House, London UK, 2011.

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Lovelock J, *The Revenge of Gaia*, Penguin Books, London UK, 2007

MacKay DJC, *Sustainable Energy – Without the Hot Air*, UIT Cambridge Ltd, Cambridge UK, 2008

Anastas P, Zimmerman J, *'The 12 Principles of Green Engineering', Env. Sci. & Tech., vol 37, no 5, 2003, pp94A–101A*

Institution of Chemical Engineers, June 2016, *Chemical Engineering Matters 3rd Edition*, ***http://bit.ly/2A7Jmr0***

Workflow

At the beginning of 2018, the Energy and Resource Efficiency (ERE) Task Group, in conjunction with the Energy Centre Board identified two workstreams that we considered may help chemical engineers address issues of energy and resource efficiency within our areas of influence.

1. an ERE guidance framework document
2. a series of ERE case studies

The workflow followed for the development of the ERE guidance document is shown in Figure 14.

Figure 14. Workflow for ERE guidance document development.

Acknowledgments

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Workshops

The working group held online workshops on particular topics associated with energy and resource efficiency to develop the initial ideas to put into the guidance document that were then further developed through the member consultation survey.

- Energy efficiency, 13 May 2018
- Water efficiency, 6 June 2018
- Waste and raw materials, 13 June 2018
- Environmental impact, 20 June 2018

Consulted Experts

Consultation with IChemE members was carried out through a range of stakeholder groups.

- IChemE Energy Centre Board Members
- IChemE Energy Centre Leadership Forum
- IChemE worldwide member survey, 441 responses (August 2018)

Analysis of the survey shows 441 responses. Respondents represented 45 different countries and had various roles (Figure 15).

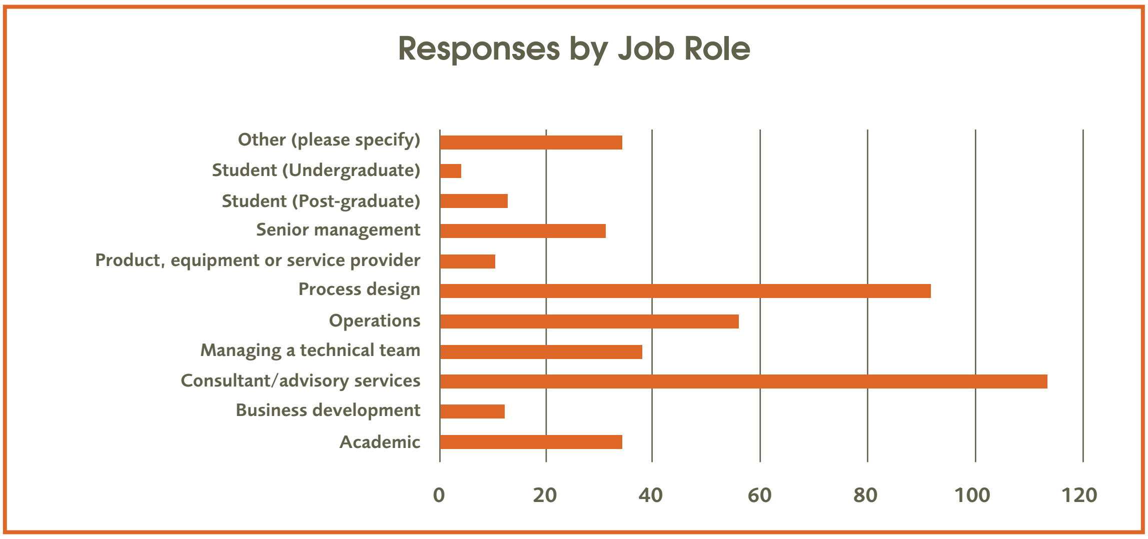

Figure 15. Occupational role of member survey respondents (IChemE Member Survey, 2018)

www.icheme.org

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