Getting to grips with the water-energy-food Nexus?

An IChemE Green Paper

Global demand for food, energy and water is increasing and these resources cannot be considered in isolation. Chemical engineers play a major role in delivering sustainable solutions at the water-energy-food Nexus. This Green Paper presents a range of case studies highlighting examples where the application of a systems thinking approach has improved our understanding of Nexus.

Water, energy and food are essential to sustain human life. Nevertheless, around a billion of the world's poorest people lack satisfactory access to one or more of these basic needs. All are traded internationally and the demand for each is growing. Regional availability varies and each is heavily regulated. But most importantly water, energy, food production and climate change are intrinsically linked.

In view of this connectivity, these resources must be considered together. The former Chief Scientific Adviser to the UK Government, Sir John Beddington, has described the combined challenges of water, energy and food as 'The Perfect Storm'[1].

More than nine billion people are expected to live on Earth by 2050[2], up from seven billion people today.

Water demand is expected to increase by 40% by 2030[3], energy requirements are expected to increase by 50% by 2030[4] and food needs will increase by 50% by 2030[5]. This is a challenge that cannot be ignored.

The driver for this increasing demand is not just population growth, but also improved standards of living and wellbeing in developing economies.

Poverty reduction programmes are driving lifestyle change in the direction of more consumption, placing further pressure on limited resources, and on the environment.

The debate around water, energy and food resources has highlighted both resource constraints and also the inter-dependencies between them. These relationships are summarised in the "Nexus" concept developed by the Stockholm Environmental Institute in 2011[6]. The Institution of Chemical Engineers (IChemE) is working to improve understanding of these interactions with its international partners, including the American Institute of Chemical Engineers (AIChE).

Chemical engineers have a central role to play in shaping the understanding of the connections between water, energy and food – and, more importantly, in devising practical solutions to address this dilemma through:

1. **Applying life cycle analysis (LCA)**
2. **Working across Nexus boundaries**
3. **Thinking globally but acting locally**

Chemical Engineering Matters

The mission of the Institution of Chemical Engineers (IChemE) is to advance chemical engineering worldwide. We are doing this because chemical engineering matters and it makes a positive impact on quality of life for all. IChemE's technical strategy – *Chemical Engineering Matters* – highlights the need for us to examine the interdependences of water, energy and food together.

The topics discussed in this Green Paper refer to the following lines on the vistas of IChemE's technical strategy document *Chemical Engineering Matters*:

Water
Lines 1, 5, 7-10, 21-26

Energy
Lines 9, 11, 19, 22-24

Food and Nutrition
Lines 2-3, 5, 13-15, 22

Health and Wellbeing
Lines 4-7, 16-17, 27

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Sustainable resources

Providing water, energy and food to the world's growing population is a major challenge and one that must be tackled sustainably. Global populations must have access to secure supplies of water, energy and food, delivered in a way that protects and restores the natural environment, rather than degrades it.

When considering how to design and engineer this sustainable world, the following limits must be accounted for: biophysical limits (what is possible within planetary limits and the laws of nature); economic limits (what is affordable); scientific-technical limits (what is technically possible) and socio-political limits (what is socially and politically acceptable)[7].

Nexus security

Whilst ensuring that we protect and enhance the natural environment, IChemE defines Nexus security as follows:

Food security is...

1. Widespread availability and exchange of food
2. Access to affordable, safe food
3. Food with nutritional and social value

Water security is...

1. Access to water supplies
2. The supply of safe water for consumption
3. Sufficient and affordable water to meet demand

Energy security is...

1. Consistent and reliable energy supply
2. Widespread availability of energy supplies
3. Sufficient and affordable energy to meet demand

The water-energy-food Nexus concept

A growing body of work is being produced by engineers and scientists, including social scientists, which investigates and explains the water-energy-food Nexus. This work clearly demonstrates that these resources are linked and need to be considered collectively. These linkages have always been present, but as pressure on the Nexus grows, the need for better understanding of the interdependencies between vital natural resources becomes paramount.

In November 2011, the water-energy-food Nexus concept was discussed in Bonn, Germany[6] with the aim of exploring a visionary method of achieving sustainability. It was recognised that in an interconnected world, solutions will not be found in one area, nor will they be found in one discipline. The international community must come together and focus on the role it can play in supporting the water-energy-food Nexus.

Systems thinking

Chemical engineering makes its professional contribution by understanding how whole systems work, and generating engineered system solutions to meet desired targets. Much ideology and discussion behind the Nexus are in place, but it needs a chemical engineering, systems thinking approach to give it substance.

Life Cycle Assessment

The application of systems thinking through life cycle assessment (LCA) is a useful guide in developing our understanding of the interdependence of the Nexus as it allows for the consideration of the whole supply and value chain.

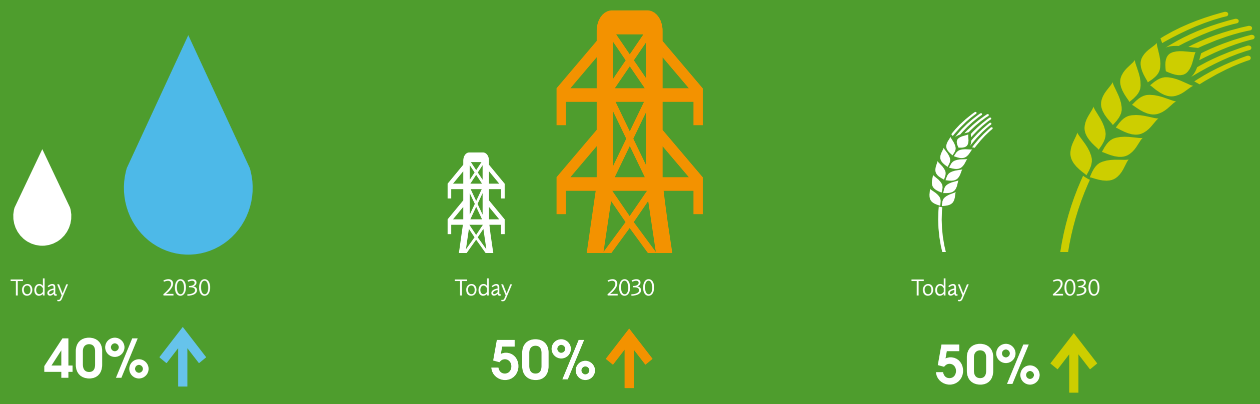
LCA is a methodological[8] framework which involves the analysis of the inputs, outputs and environmental impacts of a process, product, or system throughout its entire life. This enables us to understand and evaluate the magnitude and significance of its impact upon the interconnected resources of water, energy and food.

This methodology is able to support supply chain management within industry to minimise the environmental burdens from extraction and processing of raw materials, through manufacturing, packaging and marketing processes, use, and on to eventual recycling or disposal as waste at the end-of-life of food products.

It should be noted that LCA does not consider social aspects, and only environmental impacts within limiting restrictions. Societal values (such as the need for the production of lifesaving medicines or cultural variety of food supplies) must be factored into LCA when addressing Nexus problems.

The application of LCA to the complexities of the Nexus requires further development.

The world needs more...



Case Study 1 – Water for Energy

Hydraulic fracturing for shale oil and gas in the UK[22]

Hydraulic fracturing (fracking) requires large amounts of water which can be drawn from local aquifers or, in water-scarce areas, trucked in with the concomitant increase in traffic movements. This water, with the chemicals added to aid the fracking process, is returned with the produced oil and gas. It can be treated and recycled to minimise freshwater use and although not universally practised, this will be mandatory in the UK.

Case Study 2 – Energy for Water

Water production in the Middle East and North Africa[17]

Extracting, producing, delivering, purifying and disposing of water requires energy. However, it is essential in some water-scarce regions to use energetically costly processes to ensure a supply of freshwater. Countries in the Middle East and North Africa use an estimated 5-12% of their total electricity consumption for pumping ground water and desalination. Integrated assessment suggests that this could be reduced by greater reuse and recycling of water supplies.

Case Study 3 – Energy for Food

Kelloggs, breakfast cereals in Europe[16]

Breakfast cereals are an important international food source, but their environmental impact is rarely considered. Kelloggs have identified that breakfast cereals can produce 2.64 kg CO_2 per kg of the product produced. Life cycle assessment (LCA) has indicated that manufacturing has the biggest energy demand (34%) but that this can be reduced by up to 15% by improving the energy efficiency of manufacturing processes.

Case Study 4 – Food for Energy

Biofuel production from cereal crops[21]

The production of bioethanol from corn and wheat for blending with or as a replacement for gasoline has increased dramatically as a result of government targets in several countries, in an attempt to reduce carbon emissions. There is an immediate conflict with the production of food, and increasing biofuel production from these feedstocks has driven up food prices. Additionally, if land use change is taken into account, the ability of these first generation biofuels to contribute to carbon emissions reduction becomes doubtful.

Case Study 5 – Food for Water

Food as a global transporter of water[18]

When a country imports a water-intensive product, it imports virtual water[23]. Real water trading between water-rich and water-poor countries is limited, but trading water through virtual water products is significant. The development of the water footprint concept has been an important step in understanding the importance of freshwater. Existing methodologies mainly assess the quantity of water used in food production and processing rather than the related impacts.

Case Study 6 – Water for Food

Banana production in Ecuador[19]

The environmental impact of food production varies with its economic importance. The banana is of key economic importance in Ecuador, representing 2.5% of GDP and one third of global banana production. For such an economically important crop, water supply is essential but it takes 330 L of water to produce 1 kg of bananas. Value chain analysis indicates that agricultural methods used can reduce the amount of water required, for example by reducing fertiliser use or through more efficient washing processes.

Towards a circular economy

A circular economy[9] is one that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times – distinguishing between technical and biological cycles.

Business leaders and governments alike are acknowledging that continued long-term value creation requires a new economic model that is less dependent on cheap, easily accessible materials and energy, and that is able to restore and regenerate natural capital.

The Ellen MacArthur Foundation[10] believes that the circular economy has clear value in creating a new way of improving our wellbeing. To test the concept, a toolkit for policymakers was created in Denmark, focusing on five key areas: construction; real estate; machinery; plastic packaging; and hospitals. This found that there are significant opportunities to scale up the transition towards the circular economy, and policymakers can play an important enabling role.

2050 Global Calculator

The 2050 Global Calculator is an open-source model of the world's energy, land and food systems that allows users to design their own version of the future up to 2050 and see the implications for the climate[11].

The Global Calculator is a joint project using the knowledge of experts from ten leading international organisations. It models the world's energy, land, food and climate systems to 2050. It aims to model what lifestyle is physically possible for the world's population – from kilometres travelled per person to calorie consumption and diet – and the energy, materials and land requirements to satisfy all this.

The model, which can be used by anyone, has been tested with experts from more than 150 organisations around the world. The model, its methodology and assumptions are all published freely online[12].

The UN Sustainable Development Goals[20]

17 Sustainable Development Goals and 169 targets have been drawn up to build upon the Millennium Development Goals and complete what they did not achieve. The following goals (drawn from the complete list of 17) can be supported by using a water-energy-food Nexus approach:

Goal 2

End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Goal 3

Ensure healthy lives and promote wellbeing for all at all ages

Goal 6

Ensure availability and sustainable management of water and sanitation for all

Goal 7

Ensure access to affordable, reliable, sustainable and modern energy for all

Goal 12

Ensure sustainable consumption and production patterns

Goal 13

Take urgent action to combat climate change and its impacts

However, despite the fact that the Sustainable Development Goals acknowledge the integrated nature of sustainable development, there is no Goal that clearly states the importance of considering water, energy and food together.

Limits of the world

The earth is only so big

We can only afford so much

We can only do what we know

Community engagement

The challenges presented by the water-energy-food Nexus are global in nature, but solutions must be focused locally on individual systems.

Local engagement works to explain the links between energy, food and water and how communities can be resilient to change. Research in Australia[13] is focusing on engaging regional communities in climate change action plans and sustainable energy futures.

By examining the inter-relationships between energy and climate policy with communities, chemical engineers are able to highlight the complex interactions and implications of the water-energy-food Nexus.

The Local Nexus Network project[14], funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC) in the UK, examines Nexus issues in local communities. By focusing on local water-energy-food Nexuses they are able to consider the rationale behind resource utilisation, production, and consumption to meet the service demand.

This represents a complex and significant transition, which not only requires "smart" chemical and other engineering, but support from businesses, industries, communities and policymakers, to turn them into an economic and social reality.

The US National Science Foundation (NSF) is working to ensure that contributions to Nexus thinking are made by building upon the fundamental knowledge base. This is reflected in its 2016 budget request to Congress[15] for US$74,960,000 to fund vital research in this area. The NSF aims to invest in integrated research that will create a comprehensive water-energy-food sociotechnical systems model and advance knowledge and technologies for safer, more secure, and more efficient use of resources within the Nexus.

Community engagement is an essential part of developing solutions that meet community needs in a sustainable way. Chemical engineers need to be involved in their communities where they can bring essential knowledge and ethical commitment to public debate.

Recommendations and conclusions

IChemE concludes that applying systems thinking to the interconnectedness of water, energy and food is required to improve the sustainability of human wellbeing and the world in which we live. The following ideas are put forward by chemical engineers for consideration to support the development of the water-energy-food Nexus and to help all those who need to work more sustainably, including decision-makers, manufacturers, companies and regulators:

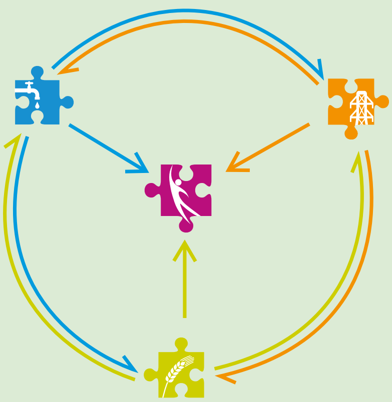
1. **Greater investment is required from funding agencies for systems thinking Nexus research. Stronger collaboration between disciplines is imperative.**
2. **Governments must work together to solve this problem by developing international platforms to promote Nexus-thinking through the circular economy and other novel solutions.**
3. **The role of the Nexus in the new 17 Sustainable Development Goals needs to be explored, and the consequences for policy and commercial activity clarified.**
4. **Operating companies and manufacturers should refrain from making decisions on sustainability and efficiency until they have studied their impact on the water-energy-food Nexus.**
5. **Industry should publicise case studies of effective, good practice chemical engineering solutions to Nexus challenges.**
6. **New tools are required for investigating the interconnectedness of the Nexus at different scales, and developing solutions to Nexus challenges.**
7. **Better understanding is required of the trade-offs between Nexus security and ecosystem health.**

The water-energy-food Nexus is now a key aspect of international development and a recognised problem. Our ability to consider all three aspects of the Nexus together is essential in making decisions about the sustainability of our resources in the future. And chemical engineering is well placed to do this.

Much of the ideology behind the Nexus is now being explored but it needs chemical engineering to give it substance. The applications of the water-energy-food Nexus are reliant on strong messages and tools, and chemical engineering provides the evidence base to do this.

Chemical engineers are working to inform the research surrounding the Nexus by using systems thinking to examine the whole supply and value chains of natural resources. Analysis of this nature is essential to using a Nexus approach to process solutions.

Chemical engineers will continue to make a key contribution towards ensuring that all processes are efficient, cost-effective and sustainable. By applying systems thinking to the water-energy-food Nexus, chemical engineers offer a unique insight into creating, sustaining and improving wellbeing for all.



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Acknowledgements

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To continue the conversation you can engage with us by:

email: chemengmatters@icheme.org

twitter: @ChemEngMatters and #chemengmatters

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