Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Chemical Engineering

Energy and water interactions: implications for industry

Petar Sabev Varbanov

The constant increase of the world-wide demand for water and energy makes it necessary to make their use more efficient. For supplying energy, so far mainly fossil fuels are used. The apparent link of energy and water supply increases the cost of delivery and, in many cases, causes shortages of all forms of energy and water. This paper reviews the main trends in the global flows of energy and water supply, identifies the inherent limitations and pays attention also to the concept of virtual water. The implications for industry and of some notable recent research efforts are also reviewed, and conclusions are drawn for the directions of possibly promising future research and development.

Addresses

Centre for Process Integration and Intensification – CPI^2, Research Institute of Chemical and Process Engineering – MŰKKI, Faculty of Information Technology, University of Pannonia, Egyetem u. 10, 8200 Veszprém, Hungary

Corresponding author: Varbanov, Petar Sabev (psvarbanov@gmail.com, varbanov@cpi.uni-pannon.hu)

Current Opinion in Chemical Engineering 2014, **5**:15–21

This review comes from a themed issue on **Energy and environmental engineering**

Edited by **Rakesh Agrawal** and **Subhas K Sikdar**

http://dx.doi.org/10.1016/j.coche.2014.03.005

Introduction

Key issues in the world economy are efficient use of energy and water. Within industry this is most visible in power/heat-and-power industry, desalination, energy extraction from primary resources, agriculture, and petrochemicals. Both resources are tightly linked economy-wide [1]. Sourcing, delivery, use of fresh water as well as treatment and disposal of wastewater, require energy. Similarly, energy generation is some of the largest water users.

At global and regional levels, a key task is to deliver the resources to the demand locations. This creates logistic and political problems. At the level of users — industrial sites, farms or municipalities, the constraints imposed for political and logistic reasons create challenges for managers and researchers [2]. Integration of renewables has been studied by a number of researchers — see, for example, Nemet *et al.* [3•].

Fossil fuel sourcing from regions distant from their use has been of paramount importance to industrialised countries and causes considerable struggle and conflicts. Nuclear energy can be generated close to the demands, but raises safety and environmental concerns. Renewable energy resources can be harvested close to the demands too. However, they have problems with variable availability in time, intensity and handling their supply flows.

The energy-water nexus has been addressed at the levels of economies and regions — for example, the US Congress' analysis by Carter [1], the regional modelling study by Dubreuil *et al.* [4], the global virtual water trade flows [5,6] or analysing global energy flows [7]. There have been also studies, caused by the energy-water nexus and its manifestations in various economy sectors, including industry. However, the explicit treatment of the nexus in industrial context is still not very well pronounced. The current article has the goal of reviewing the major issues resulting from the global energy and water flows, their connection and the main recent industrially relevant efforts for addressing these challenges.

Energy demands, flows and supply

The resources for energy supply have been limited. However, the demand trends show a continuous growth. Figure 1 illustrates the trends for United States, China and India [8]. The major sources are still fossil fuels, supplemented by nuclear power and renewables.

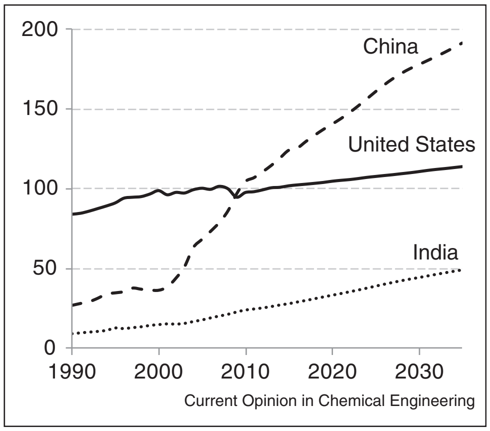
Another crucial problem has been the conversion of the primary energy carriers into utilities and the delivery to the users. A recent source [9] analyses the situation in the USA for 2011, showing that more than 62% of the primary energy resources for electricity generation are losses. Renewable sources harvesting has problems with variable availability in time, intensity and logistics — all interconnected, giving rise to multicriteria optimisation problems [10••].

To illustrate the size of energy flows, the international trade of natural gas can be used as an example. According to a study by British Petroleum [7] the overall world flows of natural gas trade are very large — of the order of 10^{11} m^3/y. Flows of comparable magnitude are delivered world-wide by crude oil, refining and petrochemical companies.

Water demands, flows and virtual trade

Clean water availability is limited too and requires energy to be delivered. Some of the first water related studies on the global scale were presented by Allan [5] discussing the concept of virtual water, which has been accompanied by an analysis of the political impacts of water flows [6].

Figure 1



Projected energy consumption in China, the US and India, in 1.055×10^{15} J [8].

Chapagain and Hoekstra [11••] defined water footprints as the volume of water required to produce a commodity or service, and virtual water as the water embedded in an economic good throughout its production and manufacturing process. The main issue raised by these studies has been the possible saving of water by importing a product instead of producing it locally [12•]. The global analysis of water consumption and pollution indicates that some countries rely very much on importing water resources from elsewhere. For instance Mexico depends on virtual water imports from the United States.

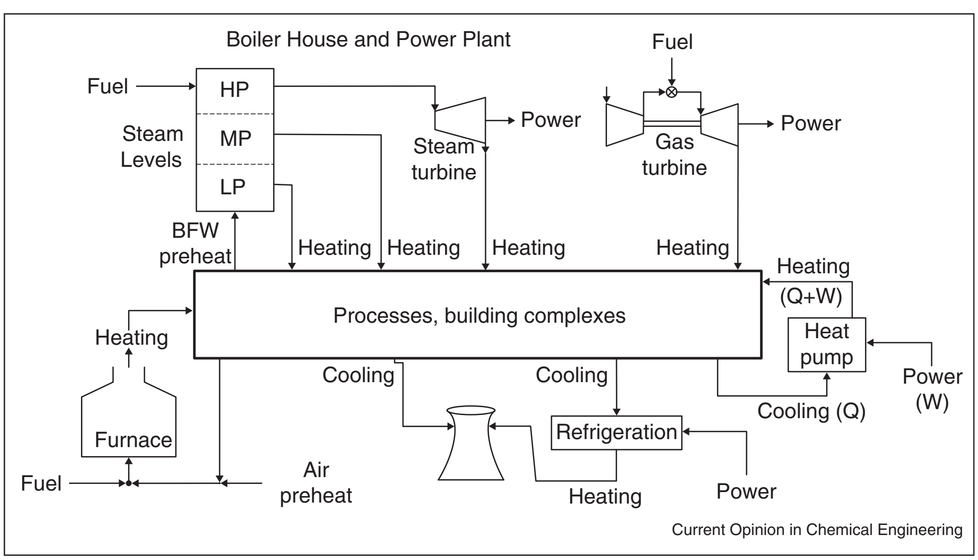
The close connection of water with energy supply and use has been very apparent also for all industrial sectors [13••]. On industrial sites water often is used hot or chilled, requiring energy for generation and transportation. Treatment, delivery, reuse, regeneration and recycling of water demand energy as well. Figure 2 [14] illustrates these flows for an industrial site. However, also the production of biofuels results in a considerable water footprint. For instance, Chiu *et al.* [15] indicated that in producing bio-ethanol, the water needs just for irrigation reach up to 2140 (L water)/(L bio-ethanol).

For the year 2007, the overall water consumption in the EU [16] was approximately — for energy generation: 44%; in agriculture 24%, for public water supply: 17%; and industrial use: 15%.

There are some advantages and disadvantages of the global exchange of goods and services, which from the viewpoint of virtual water trade have been summarised by [17••]:

- To import goods embedding virtual water requires adequate foreign exchange revenue and social absorption capacity, reducing food self-sufficiency.
- Good transport and infrastructure between countries and inside countries is needed, especially in rural areas.
- Besides ecological advantages for the water balance, ecological disadvantages can be expected.

Figure 2



Hot-and-cold-utilities — meeting point of energy and water demands [15].