

## TOWARDS MULTI-SOURCE MULTI-PRODUCT ENERGY SYSTEMS

K. HEMMES and J. Leslie ZACHARIAH  
Department of Energy & Industry  
Delft University of Technology, The Netherlands

M. GEIDL and G. ANDERSSON  
Power Systems Laboratory  
Swiss Federal Institute of Technology (ETH) Zurich, Switzerland

Historically, energy conversion was seen as a one-dimensional system, in the sense that one form of energy was converted into another form. By-products of the conversions such as heat were disregarded and/or treated as waste. For example, central power plants had – and mostly still have – one source of energy, such as coal or natural gas, which is converted into electric power. Efficiency loss appears in the form of waste heat that is dissipated into the environment (for instance, via cooling water).

Cogeneration is a first step towards system improvement since the ‘waste heat’ is recovered and used as a valuable product. Tri-generation systems, which take the concept even further, are proposed for the simultaneous production of chemicals, power, and heat, and are integrated into larger systems, such as chemical plants, to achieve increased overall performance. In these systems electricity may just be a by-product. However, co- and tri-generation systems are still characterized by one energy input source. In this paper we explore the concept of *multi-source multi-product (MSMP) systems*.

In a new concept that can be called electrochemical gasification of carbon, it can be derived thermodynamically that heat is converted into electric power together with the enthalpy of the gasification reaction. The heat for this conversion system can be provided, for example, externally by concentrated solar or nuclear reactors. The converter produces carbon monoxide that can be shifted with steam into hydrogen. Thus a ‘fuel cell’ is conceptualized that (i) produces hydrogen in addition to power instead of consuming hydrogen and (ii) converts heat into power instead of dissipating heat. Thus, in this MSMP system, two energy sources – carbon and heat from fossil and renewable and/or nuclear sources – are combined to produce two outputs, namely power and hydrogen (and some heat in practical systems).

So far MSMP systems have been considered as a single device. However, we extend this concept and generalize to include a combination of connected devices called ‘*energy hubs*’. These energy hubs represent an interface between a number of power sources and loads – demands for different products or energy carriers. The basic features of energy hubs are input and output, conversion, and storage of multiple energy carriers and products. Energy hubs can be modeled mathematically by stating input and output vectors containing different flows and products. A typical input vector, for example, contains flows of natural gas, water, air, and electricity; the output vector can include electricity, heat, compressed air, and/or any other energy carrier or product. The vectors can be related to each other by stating a coupling matrix which connects the input with the output. The coupling matrix can be derived from the hub-internal topology and device-specific characteristics of the hub elements. The energy hub model provides a tool for *system analysis and optimization*.

A major consideration for these MSMP systems is the definition of efficiency, which may be a bit problematic because output and input have become multidimensional. We explore the concept of *exergy* system efficiency as one possible approach to achieving a clear and unique definition.

The advantage of MSMP systems is their large degree of flexibility to fluctuations in supply and demand. In this paper we present concrete examples of MSMP systems, clarify their advantages and put forward a robust and transparent framework for modeling them.