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Editorial

ENERGY POLYGENERATION AND CIRCULAR ECONOMY

Polygeneration (sometimes called multigeneration) is an energy process which extends simple generation systems for two products (e.g., cogeneration) and three products (e.g., trigeneration) to four or more products.

Polygeneration classifications of various types have been reported, including classifications by input (renewable energy, fossil fuel, waste, etc.) as well as classifications by outputs (electricity, heat, cool, desalinated water, synthetic fuels, etc.).

Polygeneration has considered as a component of sustainable engineering and has been examined from exergy, energy, environment and sustainable development perspectives.

Recent technology advances of various types have occured for polygeneration energy systems, and reported in many countries.

Some of the more noteworthy of these follow:

- Advances in energy storage technologies to support polygeneration (e.g., thermal energy storage, batteries, pumped storage, hydrogen storage)
- Advances in district energy systems and distributed energy systems, that allow advantageous inputs to be selected, and products to be transported to where they are in demand and utilized in an effective manner.
- Developments in systems for waste-to-energy and renewable energy. The latter include systems that use biomass energy, solar energy geothermal energy wind energy and combinations of these.
- Development and commercialization of new technologies that can support polygeneration, including fuel cells (solid oxide fuel cells, PEM fuel cells, alkaline fuel cells, etc.) artificial intelligence and machine learning desalination technologies and nanotechnology systems.

Integration of polygeneration within Circular Economy strategies

Sometimes, the inputs of polygeneration energy systems include waste in ways that yield viable systems that are often advantageous to more conventional systems.

Some examples of such systems follow:

- Jasim et al. (2024) performed a thermodynamic, environmental and economic assessment of a polygeneration system with waste heat recovery. The system for polygeneration includes CO2 separation and water desalination sections. Fresh water is produced by the system at a rate of 3560 kmol/h while electricity is produced at a rate of 43 MW. The polygeneration efficiencies were reported to be 32% energy based on and 88% based on exergy.
- Taheripour et al. (2024) proposed and analyzed a polygeneration system for electricity and hydrogen from waste heat. The waste heat is sourced and recovered from a steel manufacturing plant. Components of the polygeneration energy system are: electrolyzer (proton exchange membrane type), Kalina power cycle and Rankine power. The economic return period for the polygeneration energy system is projected to be seven years. That projection is based on expected annual revenues of 3.6 MM$ from sales of electricity and 3.8 MM$ from sales of hydrogen is 3.6. The system exhibits an energy efficiency of 26%, but a much higher exergy efficiency, at 57%.
- Ratlamwala et al. (2024) examined for a community a polygeneration system. The outputs of the polygeneration energy system follow: electricity, desalinated water, space heating, space cooling, hot water, and waste heat for industry. The system is fed with non-renewable and renewable energy sources. Desalinated water is generated at a rate of 10.5 kg/s of for one of the working conditions considered.

The approaches and methods to attain such integrated polygeneration energy systems are varied, and often creative. For instance, Kalina and Pohl (2024) assessed technically and economically a polygeneration energy hub for buildings that addresses well multi-temperature heat demands. Important facets of the design were noted to be integration of waste and renewable energy inputs, as well as energy storage and decentralization. The system components include high-temperature heat pumps among other devices.

Advances in polygeneration energy systems and waste utilization often rely on economic methods to enhance economics. For example, Taheripour et al. (2024) performed a technoeconomic analysis of polygeneration using heat recovered from steel plant waste in order to provide electricity and hydrogen. The system initial capital cost was found to be $36.6 million, while its annual revenues are $3,600,000 from the sale of electricity and $3,800,000 from hydrogen, respectively, leading to a return period of sevenyears.

The complexity of the design and operation of polygeneration systems integrated with waste often benefits from astute use of optimization. Ren et al. (2022), as a case in point, reviewed the optimization of distributed polygeneration energy systems. They considered numerous applica-

Editor in chief:
Raffaello Cossu
email: raffaello.cossu@gmail.com

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tions (cities, districts, neighborhoods and others) as well as relevant technologies (waste recovery, renewable energy, energy storage and others).

Benefits of integrating polygeneration and waste recovery

There are many potential benefits of integrating polygeneration and waste recovery in appropriate manners. These include higher efficiencies than stand-alone processes for the corresponding separate products, as well as enhanced environmental performance and economics, and ultimately greater sustainability.

A good example is the investigation by Jasim et al. (2024) of a polygeneration system integrated with waste heat recovery. The system incorporates a carbon dioxide separation/liquefaction cycle, and seeks to reduce pollutants emissions and environmental impacts. Multiple factors are examined economics environmental impact, and energy and exergy usage. The system was shown to have a unit carbon dioxide release of 0.034 kg/kWh.

Another instructive example of the potential benefits of integrating polygeneration and waste recovery is for an application in industry. In particular, a steel manufacturing plant with waste heat recovery was investigated by Taheripour et al. (2024) for the incorporation of polygeneration of electricity and hydrogen.

With the system, 262 MW of waste energy is recovered from the steel plant, with an energy efficiency of 26% and an exergy efficiency of 57%, and with an economic investment payback period of about 7 years.

Given the steel industry constitutes a major portion of the industrial sector, the results can be extrapolated and seen as important.

Conclusions

Polygeneration systems are increasingly applied across energy utilities, communities, industries, and other sectors of the economy. When well-designed, these systems offer cleaner and more efficient alternatives compared to using separate processes for each output. In some cases, they also deliver improved economic performance.

However, the full potential of polygeneration is not always realized in practice. One effective way to enhance its performance is to integrate it into circular economy strategies by utilizing waste as an energy input. Such integration can significantly contribute to environmental protection and the transition toward sustainability.

Optimization plays a key role in advancing polygeneration, enabling the balancing of multiple objectives, including environmental impact, energy efficiency, and economic viability.

Marc Rosen *

University of Ontario Institute of Technology, Mechanical and Manufacturing Engineering
* *marc.rosen@ontariotechu.ca*

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