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ASSESSMENT OF LEVELIZED ECONOMICS OF FOSSIL-FUEL-BASED POLYGENERATION ENERGY SYSTEMS

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Overview

Meeting the growing energy demand while mitigating climate change necessitates reducing CO_2 emissions from fossil-fuel-based energy systems, which could be achieved through carbon dioxide capture and storage (CCS). However, fossil-fuel decarbonization is one of many alternatives that also include increasing energy savings through efficiency improvements and expanding renewable energy deployment. Given this diverse approach, future fossil-fueled energy and industrial facilities are likely to face more challenging regulatory and market standards at three frontiers: tighter emissions standards, higher efficiency standards, as well as more flexible operational requirements to complement intermittent renewable energy generation and hedge against increasing fluctuations in energy prices.

Polygeneration energy systems with CO_2 Capture (PGCC) provide a promising alternative that can meet all three challenges. PGCC is a multi-input multi-output energy system. Many fuel types have been proposed as inputs for polygeneration, including biomass, coal, natural gas, and heavy oil. Similarly, a wide range of chemical and energy products have been proposed as potential outputs, including hydrogen, liquid fuels (Fischer-Tropsch liquids), methanol, ammonia, and urea (Meerman, Ramírez, Turkenburg, & Faaij, 2011). In addition to realizing lower CO_2 emissions via CCS, polygeneration plants achieve higher energy conversion efficiencies than conventional monogeneration (single-output) plants due to better energy utilization and better process- and heat-integration (Liu, Pistikopoulos, & Li, 2010). Furthermore, diversifying the input and product portfolios of PGCCs allows operational flexibility that exploits the variability in commodity prices and can thus further improve the plant economics.

This study develops a set of levelized-cost metrics that can be used to assess the economics of fossil-fuel-based polygeneration energy systems. At the heart of this work is a new metric referred to as Levelized Cost of Polygeneration, or LCOP. Based on the concept of Levelized Cost of Electricity (LCOE), the LCOP achieves two important goals: (1) it allows consistent comparison of the economic competitiveness of PGCCs to other electricity-generating alternatives (PV solar, natural gas, wind, etc.), and (2) it is used to derive additional economic metrics that quantify the value of real-options associated with the diverse and flexible operation modes of PGCC.

Methods

A generalizable PGCC technical configuration was assumed in this study. The proposed system uses coal as primary fuel, produces hydrogen then ammonia as intermediate products, and produces electricity, CO_2, urea and UAN (fertilizers) as final products. To capture the system complexities, realistic operational constraints are applied. Hydrogen and fertilizers production units should always run at steady-state, whereas electricity and ammonia production units can be dispatchable (run at variable rates) with time. In addition, a minimum production capacity was imposed on each production unit, and, to buffer the variability in production rates, an intermediate-product storage site with limited capacity was designed.

The Levelized Cost of Electricity (LCOE) metric was used to derive the Levelized Cost of Polygeneratioin (LCOP) metric. Consistent with earlier literature, this study defines LCOE as the "lifetime cost to lifetime electricity generated by the monogeneration facility", presenting it as a break-even value per one unit of output ($/kWh) (MIT, 2007). Accordingly, the LCOP was developed to account for: (1) cost of capital, (2) fixed costs, (3) variable costs, (4) and production capacity ratios of the various units within a specific polygeneration facility. The LCOP is expressed in terms of cost-per-unit-of-energy (e.g. $\$/kg_{H2}$), and it could be easily converted to cost-per-unit-of-output (e.g. $\$/kWh_{eq}$) to facilitate comparison to monogeneration facilities.

Results

The following economic metrics were derived and quantified by applying the LCOP on the assumed generalizable PGCC system:

- Levelized cost and profitability for steady-state production of single end-product (electricity only)
- Levelized cost and profitability for steady-state production of multiple end-products (electricity and fertilizers)
- Levelized cost and profitability for dispatchable production of multiple end-products (electricity and fertilizers)
- Value of Diversification (VOD): real-options value associated with producing multiple end-products instead of a single end-product
- Value of Flexibility (VOF): real-options value associated with dispatchable production instead of steady-state production of multiple end-products

The results show that, unlike monogeneration where break-even is solely dependent on the average price of a single output, break-even for polygeneration can be reached through multiple combinations and trade-offs among average prices and generation capacities of the various end-products. The results also show that both VOD and VOF consistently improve the economics of polygeneration.

All economic metrics were validated and applied to a case-study on Hydrogen Energy California (HECA, 2010), which is a real polygeneration project currently under development in Kern County, California, USA. The facility produces 50-150 MW of net power output and 1 million tonnes of urea and UAN. The results show that, under assumed prices and costs, HECA's LCOP is around $2.045\ \$/kg_{H2}$ equivalent to $0.104\ \$/kWh_{\bar{e}}$, which is comparable to the LCOE of coal plants with CCS at $0.1 - 0.12\ \$/kWh$ (Herzog, 2011). Sensitivity analysis was conducted to show the effect of the various input and output prices on the economic attractiveness of the facility.

Conclusions

Polygeneration with carbon capture allows benefiting from fossil fuels for both power and chemicals production without suffering from the negative consequences associated with their emissions. This study develops a comprehensive set of metrics to quantify and assess the economic competitiveness of polygeneration, as compared to that of conventional monogeneration. Polygeneration can be the "plug-and-play" energy technology of the future that hedges against economic uncertainties associated with both volatile energy prices and changing regulations. The fuel-switching and fuel-mixing flexibility, as well as product-substitution flexibility, allows optimizing operations based on market prices. On one hand, this helps avoid (or at least mitigate) the negative consequences of sudden price shocks in energy feedstock. On the other hand, it helps exploit price volatility for end-products. In addition, flexibility in choosing both input-fuels and end-products allows better control over the CO_2 intensity of polygeneration, which in turn could help avoid future costs associated with uncertain environmental regulations. In that regard, polygeneration can be a strategic energy solution in countries and regions that lack local, clean and abundant energy resources with relatively low prices, secure supply, and low carbon footprint.

References

HECA. (2010). *Project Fact Sheet.* Retrieved 2013, from Hydrogen Energy California: http://hydrogenenergycalifornia.com/factsheets

Herzog, H. (2011). Audiences and Uses for CCS Cost Estimates. *CCS Cost Workshop.*

Liu, P., Pistikopoulos, E. N., & Li, Z. (2010). A Multi-Objective Optimization Approach to Polygeneration Energy Systems Design. *AIChE Journal: Process Systems Engineering*, Vol. 56, No. 5.

Meerman, J., Ramírez, A., Turkenburg, W., & Faaij, A. (2011). Performance of simulated flexible integrated gasification polygeneration facilities. Part A: A technical-energetic assessment. *Renewable and Sustainable Energy Reviews*, 2563– 2587.

MIT. (2007). *The Future of Coal.* Boston: Massachusetts Institute of Technology.