Economic and environmental evaluation of flexible integrated gasification polygeneration facilities equipped with carbon capture and storage

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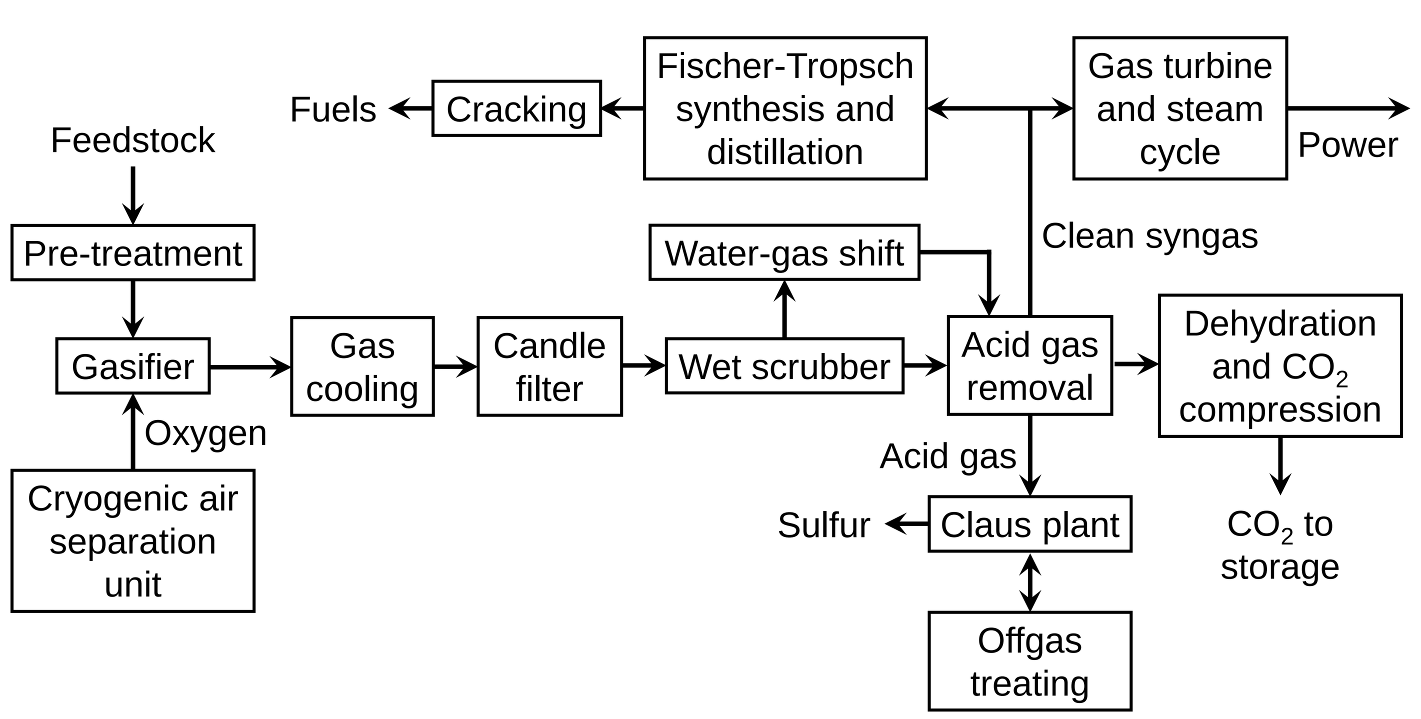
Abstract

One innovative option for reducing greenhouse gas (GHG) emissions involves pairing carbon capture and storage (CCS) with the production of synthetic fuels and electricity from co-processed coal and biomass. In this scheme, the feedstocks are first converted to syngas, from which a Fischer-Tropsch (FT) process reactor and combined cycle turbine produce liquid fuels and electricity, respectively. With low concentrations of sulfur and other contaminants, the synthetic fuels are expected to be cleaner than conventional crude oil products. And with CO_2 as an inherent byproduct of the FT process, most of the GHG emissions can be eliminated by simply compressing the CO_2 output stream for pipeline transport. In fact, the incorporation of CCS at such facilities can result in very low—or perhaps even negative—net GHG emissions, depending on the fraction of biomass as input and its CO_2 signature.

To examine the potential market penetration and environmental impact of coal and biomass to liquids and electricity (CBtLE), a system-wide analysis was performed using the MARKet ALlocation (MARKAL) energy model. With resource supplies, energy conversion technologies, end-use demands, costs, and pollutant emission rates as user-defined inputs, MARKAL calculates—using linear programming techniques—the least-cost set of technologies that satisfy the specified demands subject to environmental and policy constraints. In this framework, the U.S. Environmental Protection Agency (EPA) has developed both national and regional databases to characterize a comprehensive set of technologies in the industrial, commercial, residential, transportation, and electricity generation sectors of the U.S. energy system. Here, the EPA U.S. nine-region (EPAUS9r) MARKAL database was updated to include the costs and emission characteristics of CBtLE using figures from the literature. Sensitivity analyses were then carried out to investigate the impact of various assumptions and scenarios, e.g., oil prices and CO_2 mitigation targets.

Background: CBtLE Process

A schematic overview of a general CBtLE facility is given in the figure below:



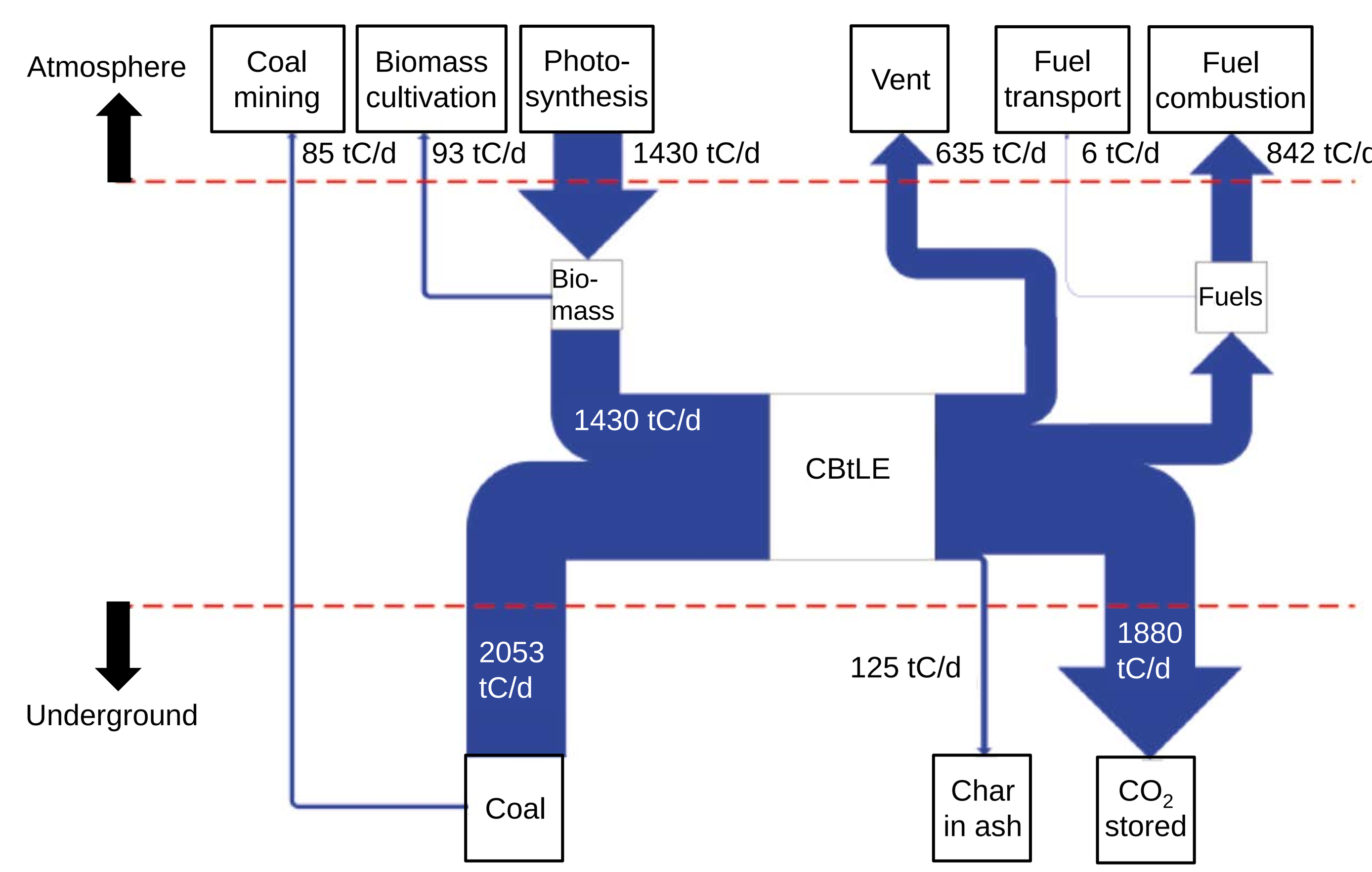
*Process flow diagram reproduced from: Knoope et al. *Int. J. Greenh. Gas Con.* **16**, 287–310 (2013).

Data and Methods

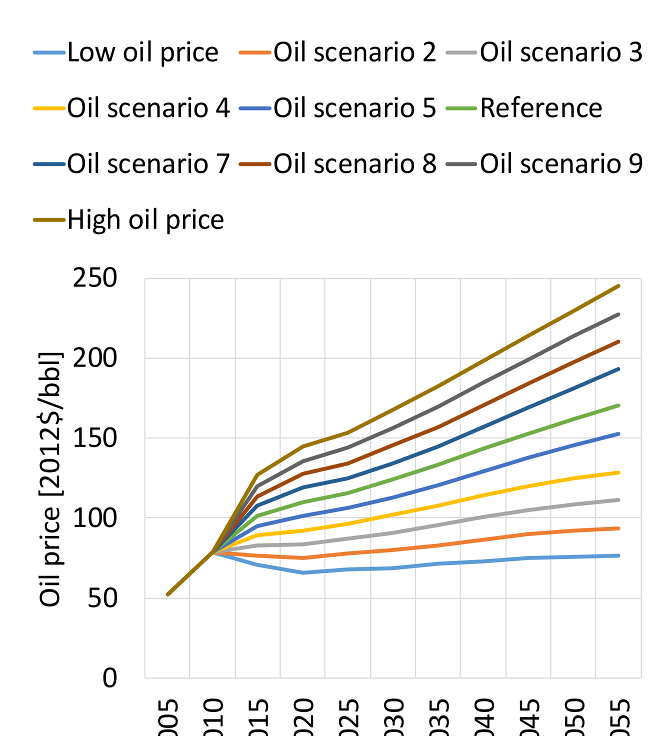
Using figures averaged across 18 sources in the literature—where data was available—the EPAUS9r database was updated to include CBtLE with the following characteristics (costs in 2005$):

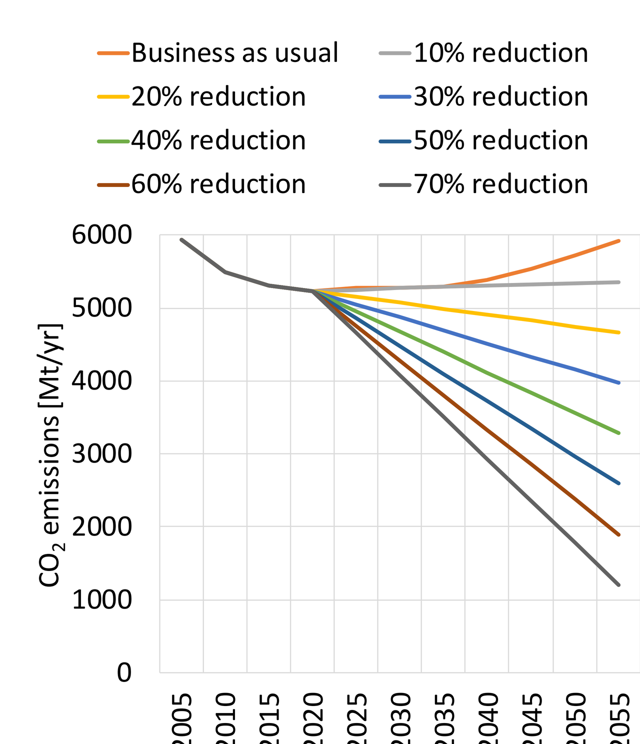
Plant life	25 years
Capacity factor	90%
Efficiency	53%
Input fractions (energy basis)	70% coal | 30% biomass
Output fractions (energy basis)	58% diesel | 22% gasoline | 20% electricity
Capital cost	$2023/kW
Fixed O&M cost	$125/kW
Variable O&M cost	$13/MWh for coal | $23/MWh for biomass
CO_2 emitted	0.07 tonne/MWh
CO_2 stored	0.39 tonne/MWh

As an example, carbon flows (in tonnes per day) for a 750 MW CBtLE plant are shown below [reproduced from Liu et al. *Energy Fuels* **25**, 415–437 (2011)]:



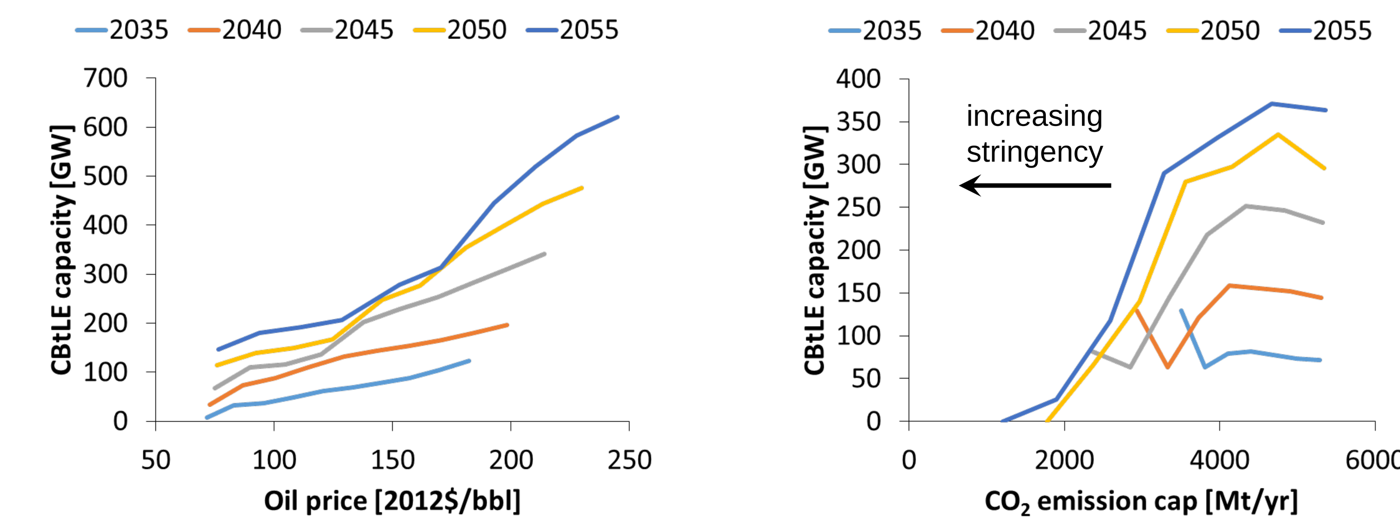
Using the data given above, the relative competitiveness of CBtLE was examined by conducting sensitivity analyses in MARKAL. For example, the effect of the price of oil was studied by running several simulations between the low and high price projections given by the U.S. Energy Information Administration in the Annual Energy Outlook 2014. In addition, the sensitivity of CBtLE buildout to carbon policy was investigated by applying a series of constraints on national CO_2 emissions beginning in 2020, with reductions relative to 2005 levels:



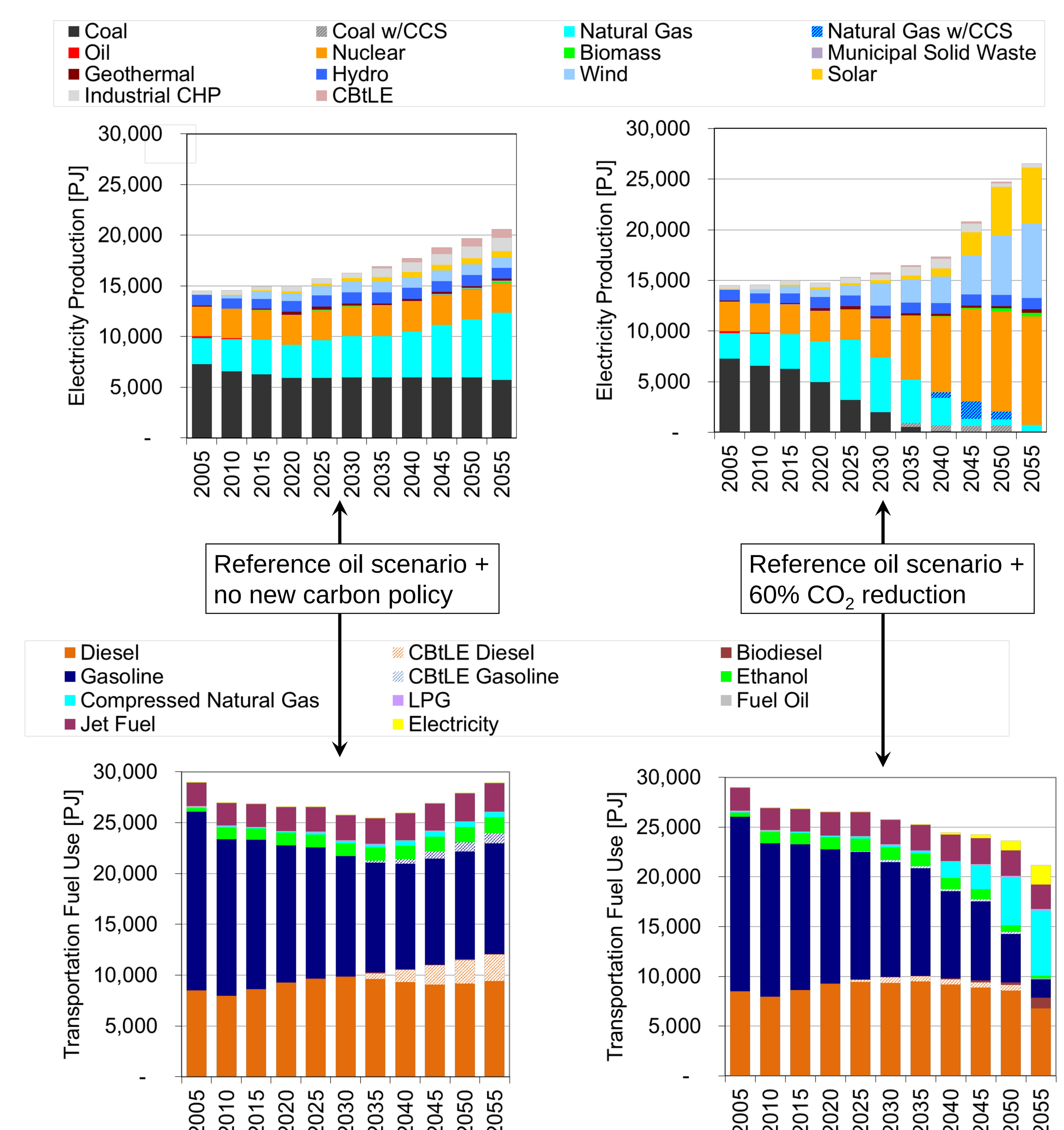


Preliminary Results and Conclusions

Oil price scenarios were run without any constraint on CO_2 emissions, and carbon scenarios were run with oil fixed along the reference price trajectory. The dependence of CBtLE capacity on the price of oil and carbon policy at different time intervals can be seen in the two charts below:



Although more competitive as the price of oil rises, CBtLE capacity falls off as the carbon cap is tightened—despite the inclusion of CCS—because the corresponding liquid fuel products still result in CO_2 emissions when burned. (This effect could perhaps be mitigated by designing CBtLE facilities to accept higher fractions of biomass as input, although there would be an associated cost penalty.) In addition, CBtLE loses market share in scenarios with sharp constraints on carbon pollution because of cheaper clean electricity sources—such as wind, solar, and nuclear—and also because increased efficiency and electrification in the transportation sector reduces demand for liquid fuels, as seen in the figures below:



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