Power Systems Modeling: Common Methodologies to Address Fuel, CO_2 and Water Needs

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Overview

Fossil energy power systems modeling has been growing over the last decade as analyses look to understand economically-tractable methods to manage CO_2 emissions from the power sector. Building on the lessons from multiple disciplines including power systems engineering, energy economics, and similar tradeoff analyses, several types of modeling methodologies continue to evolve and integrate the growing body of literature on emissions management science. Specifically, building from much of the modelling work developed to address SOx and NOx emissions during the 1960s – 1980s, more recent developments in CO_2 storage (CCS) or management are building from similar methods to address increasing efficiencies and scrubbing technologies. A few modelling methodologies include recently developed examples include the CO_2 Saline Storage Cost Model, characterization of Capture Transport Utilization and Storage within the National Energy Modeling System, benefits assessment methodology of research and development with the MARKAL modeling platform, and the Water, Energy and Carbon Sequestration Model (WECSsim™). Between these types of models, questions may be addressed such as, 'What will be the cost and performance effects across the U.S. power plant fleet if CCS or fuel switching changes the underlying power sector's efficiency?' This paper illustrates select scenarios to address this and related questions using both the MARKAL-based model and WECSsim.

Methods

In this paper, we analyzed the results from a number of models which have differing scopes but have the capability of analyzing the impacts of some or all portions of the CCS process. We used the US EPA MARKAL nine regions model (EPAUS9r) to evaluate the impacts of CCS R&D, on a national scale with regional detail. We adopt MARKAL because it is the most widely applied energy-economy model in the literature, and can be driven by the latest, 2012, EPAUS9r2012 database [EPA, 2005; EPA, 2006; EPA, 2013]. MARKAL is a bottom up linear programming energy systems model with detailed representation of energy technologies. MARKAL has energy production, conversion, and use activities; capacities as decision variables, and constraints representing energy balances, capacity limits, and various policy considerations [Fishbone, Abilock, 1981; Loulou et al, 2004; Rafaj et al, 2005; Balash et al, 2013].

We also assessed the results from more detailed models which examine specific portions of the CCS process in more detail. The CO_2 Saline Storage Cost Model incorporates reservoir geology to estimate detailed capital and operating costs to locate, characterize, develop, operate and close a storage operation in compliance with Class VI and Subpart RR regulations. The Capture Transport Utilization and Storage model contains representation of the variable costs and storage capacities of saline storage and enhanced oil recovery (EOR) sites across the U.S. and is in turn integrated within the NEMS platform.

Additionally, WECSsim™ combines the National Energy Technology Laboratory's saline water-bearing formations database (NatCarb, 2008) and the Environmental Protection Agency's (EPA) national power plant database (EPA, 2007). WECSsim™ is a bottom-up, system dynamics based national-scale integrated assessment model. It includes interconnected modules specific to power plants, CO_2 capture technologies, CO_2 storage in saline formations, extracted and treated water, and power costs. WECSsim© can be used to evaluate the entire 2005 U.S. fleet of coal- and gas-fired power plants. One perspective the model provides is how extracting saline water from the target storage formation may help manage pressure build up and increase the efficient use of the reservoir. Figure 1 illustrates the modular structure of WECSsim that can easily incorporate new assumptions or import the results from other modeling platforms (such as TOUGH2 in the CO_2 Storage Module).

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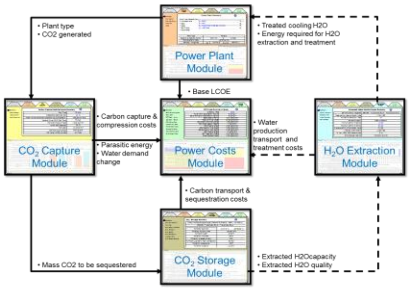

Figure 1. Topological architecture of the WECSsim model's underlying topical modules.

Results

We compared relevant results from each of the models across a variety of scenarios in order to find areas of agreement and conflict. Results from these models can be presented in scenario format at the national and regional levels. The modelling scenarios results are compared to each other and a base case scenario in order to assess the impacts of the changes made in inputs from scenario to scenario. Model results such as costs, emissions, water use and fuel consumption provide the analysts with the data to determine the effectiveness of R&D and what areas have critical needs for improvement. MARKAL results cover the entire country with regional specifications for major parameters such as prices, fuel production and consumption, emissions and water use. However, since it is a national-level model, MARKAL does not model details such as power plants or pipeline routes. More detailed models such as WECSsim focus primarily on the performance and cost effects of installing CCS technology on coal and natural gas-fired power plants to develop single plant analyses or national-level CO_2 storage supply curves. Where applicable, we suggest explanations for substantial differences in results. We further make recommendations for future model operation and development methods in order to incorporate information from the broad range of related models. This informational integration will improve the accuracy and robustness of future model development and analysis.

Conclusions

Reducing CO_2 emissions from the U.S. energy sector will require creativity and innovation from both government and industry. Modeling of the costs and impacts of R&D across a variety of platforms provides critical insights into the strengths, weaknesses and opportunities of the overall R&D portfolio. By comparing the results of a variety of related models, we were able to find potential areas of improvement in both the overall CCS technology adoption modeling process and in our modelling platforms and methodologies.

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