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Underground coal thermal treatment as a potential low-carbon energy source

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ABSTRACT

We evaluate a novel energy strategy, underground coal thermal treatment (UCTT); it involves slowly pyrolyzing coal in-situ, transforming it to a synthetic gas stream containing hydrogen and low molecular-weight hydrocarbons, liquid fuel and char. This evaluation assesses the life-cycle energy and greenhouse gas (GHG) impacts of UCTT for all process stages. It is based on experimental results at two scales, a simple heat-transfer model and literature results. The results show that UCTT can produce a high-quality liquid product and a gas mixture. UCTT's GHG emissions are in the range of those reported for in situ processing of oil shale. Net energy returns (NERs) of 0.48–4.7 are in the range reported oil sands (2.8) and oil shale (0.48–2.6). Product yield at low temperatures, heater temperature, the number of heaters and the moisture content of the coal are key factors in determining the feasibility of the UCTT process.

1. Introduction

With current coal mining technologies and production rates, the US has approximately 270 years of coal reserves [1]. In addition to recoverable coal reserves, the US has vast coal resources, which are currently unrecoverable due to their depth, access, and other factors [2]. This provides an opportunity for an in situ technology to recover otherwise unrecoverable energy from coal. Although natural gas prices are at historic lows in the United States, price increases are projected, and prices will increase more rapidly with US natural gas exports [3]. Furthermore, methane recovery from coal seams is common, but coalbed methane (CBM) produces less than 1% of a coal bed's energy content [4]. In situ pyrolysis offers the possibility of substantially more energy recovery from the resource and the potential to convert the high-carbon content fuel into a lower carbon content, higher heating value syngas or liquid fuel.

Fig. 1 shows an example of the UCTT concept. This novel in situ pyrolysis process, UCTT is proposed and evaluated. By slowly heating coal in-situ, the coal is transformed from long chain geopolymers to a synthetic gas stream containing gas and liquid products, and char. The coal contains native moisture as well as mineral mater, and these components are also heated but do not transform into valuable products. This process has the potential to leave large portions of the carbon from the coal in the ground in the form of char. Although UCTT requires additional energy input compared to CBM, the added resource utilization and carbon management may make this process worthwhile and motivates its evaluation.

UCTT differs significantly from underground coal gasification (UCG); it indirectly heats the coal to pyrolysis temperatures (200–600 °C) rather than injecting air/oxygen mixtures to directly gasify the coal. UCTT offers several potential advantages over UCG including an improved ability to discontinue operations if needed and a reduced risk of subsidence. Several organizations have investigated UCG [5], and pilot studies have been performed in China [6], Australia [5], the US [5, 7], and South Africa [5]. Although UCG research appears to be active in some countries, low oil prices have led to a decreased interest in UCG.

Although peer-reviewed studies of UCTT-type processes are limited, studies evaluating other in situ fossil fuel processes report life-cycle GHG emissions for the production of transportation fuels. These studies include thermal treatment of heavy oil, in situ production from oil sands and the Shell in situ conversion process (ICP) for oil shale conversion. As conventional sources of crude oil become scarce, transportation fuels are increasingly being produced from lower quality resources, like heavy oil and oil sands, and potentially oil shale. Brandt and Unnsach [8] examined the energy intensity of thermally enhanced (steam injection) oil recovery of heavy oils in California. They report well-to-pump (WTP) greenhouse gas (GHG) emissions of 32–47 g CO_2 e/MJ for gasoline produced from this resource (lower heating value, LHV). In comparison, well-to-wheel GHG emissions from conventional petroleum sources in the US are 18.1 g CO_2 e/MJ [9]. Brandt and Unnsach [8] found that the

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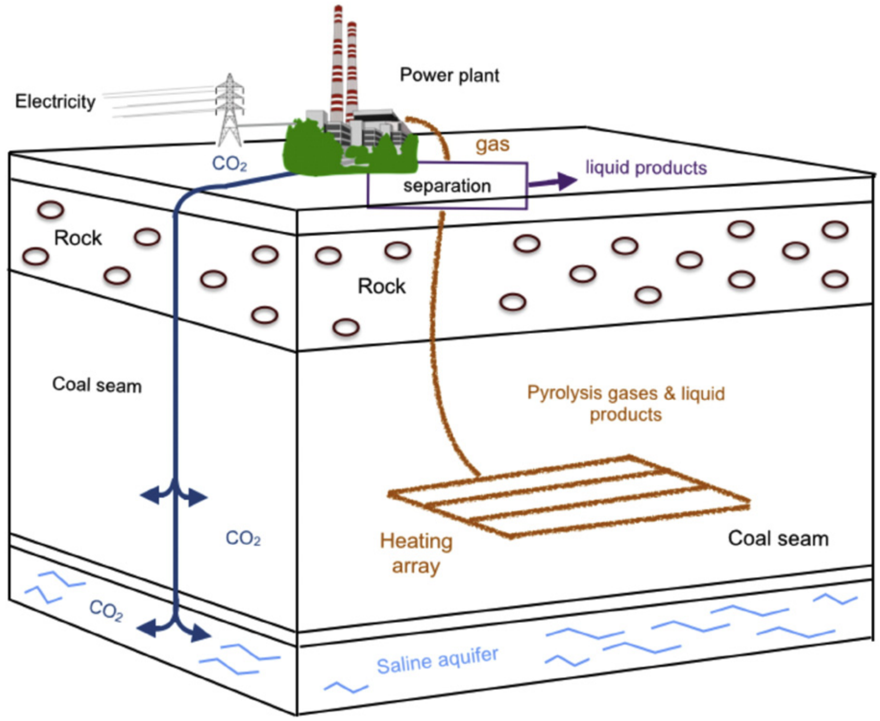

Fig. 1. Example of a UCTT process. The process is not drawn to scale.

GHG emissions vary with energy demand of the heavy oil treatment (i.e., steam to oil ratio), choice of fuel used for steam generation, co-generation of electric power, and the electricity mix.

Brandt [10] evaluated GHG emissions from the production of gasoline using the Shell ICP. This process heats an oil-shale field in situ, releasing liquid- and gas-phase fuels. Concerns over potential groundwater contamination led to the installation of a freeze wall to isolate the processing area from the water table. First, heater and producer wells are drilled. In the heating wells, electrical heaters heat the oil shale to 340–370 °C over a period of several years. The liquid and gas fuels flow to the production wells for recovery. These products are then upgraded, transported, and refined into gasoline. The study reports GHG emissions of 38–63 g CO_2 e/MJ gasoline. Work began on ICP in western Colorado in the 1980s, but activities in the US have ceased. However, work on this process continues in Jordan [11] and Israel [12].

In addition to studies of in situ processes to provide transportation fuels, researchers have proposed electricity production from oil shale with in situ carbon capture (EPICC). This method employs a solid fuel cell underground to heat a shale formation [13]. The produced gas from this process flows back to the fuel cell to provide additional energy to generate electricity and to heat the formation. They report that EPICC's GHG emissions are 51–99 kg CO_2/MWh compared to 92–145 kg CO_2/MWh for pulverized coal with carbon capture. This work is in the conceptual stages, and the authors cite EPICC's potential drawbacks including uncertain operation of subsurface fuel cells, potential geologic impacts without pressure management, and economic concerns associated with the value of stranded energy left in the formation and the long time period for retorting.

The goal of this study is to begin to understand the feasibility of a UCTT process, specifically by estimating UCTT's cradle-to-gate, life-cycle energy and greenhouse gas (GHG) emissions. The analysis includes the impacts of well drilling, heating the formation, recovery, cleanup, and transportation of the UCTT products. The energy required and product yields are based on experimental results and simulations that rely on the properties from the experiments.

2. Materials and methods

This study uses a simplified process model life-cycle assessment approach to determine energy and GHG emissions associated with UCTT. All results are presented on a LHV basis of the coal and products. Fig. 2 shows the processes considered in the UCTT analysis. It is envisioned as a cradle-to-gate analysis with final products being transportation fuel (conventional gasoline) and electricity generated from the gas-phase products. The evaluation does not include the energy and GHG emissions associated with the construction of the refineries and power plant or the manufacture of the drilling rig, the well casing, the well cement, or the associated fittings and equipment. The UCTT process transforms coal in the ground into char and two product streams: a two-phase liquid and a gas stream containing hydrogen and low molecular-weight hydrocarbons (typically less than C4). While several options for heating a candidate formation exist, this analysis focuses on electrical heating of the formation. The gas-phase products are burned to reduce the purchased electricity needed to heat the formation. The liquid products are refined into a transportation fuel, conventional gasoline. As discussed in Section 3.2, UCTT will not likely produce sufficient gas-phase products to permit the sale of excess electricity.

The following subsections describe the resource, life-cycle stages, and other related processes.

2.1. Resource

This evaluation, including the experimental and simulation studies, is based on a Utah Sufco coal, a high-volatile, low-moisture bituminous coal. Table 1 shows the coal properties. The Sufco coal mine is located in Sevier County, UT in the Blackhawk Formation of the Wasatch Plateau coalfield; it is one of the longest continuously running underground long-wall mines in the US. It has approximately 126 million tons of recoverable resource and its annual production in 2012 was 5.7 million tons [14]. Its average thickness is approximately, 3.5 m, although thicker portions of the seam exist, and the overburden depth ranges from 100–600 m [15].