CARBON MANAGEMENT STRATEGIES FOR EXISTING U.S. GENERATION CAPACITY: A VINTAGE-BASED APPROACH

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ABSTRACT

This paper examines the existing stock of fossil-fired power generation capacity in the United States within the context of climate change. At present, there are over 1,337 fossil-fired power generating units of at least 100 MW in capacity, that began operating between the early 1940’s and today. Together these units provide some 453 GW of electric power, and simply retiring this stock early or repowering with advanced technology as a means of addressing their greenhouse gas emissions will not be a sensible option for them all. Considering a conservative 40-year operating life, there are over 667 fossil-fired power plants, representing a capacity of over 291 GW, that have a minimum of a decade’s worth of productive life remaining. This paper draws upon specialized tools developed by Battelle to analyze the characteristics of this subset of U.S. power generation assets and explore the relationships between plant type, location, emissions, and vintage. It examines the economics of retrofit capture technologies and the proximity of these existing power plants to geologic reservoirs with promise for long-term storage of CO₂. The average costs for retrofitting these plants and disposing of their CO₂ into nearby geologic reservoirs are presented.

INTRODUCTION

The ultimate objective of current international efforts to address climate change, stated succinctly by the United Nations Framework Convention on Climate Change (UNFCCC) [1], is the “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.” Wigley et al. [2] have shown that in order to achieve this goal, carbon emissions must be substantially reduced over the course of this century, and must be virtually eliminated going further into the future. Fulfilling the objective of the UNFCCC will require a long-term and fundamental transformation of the global energy system.

Progressing towards this long-range goal of a net zero-emitting global energy sector requires that some actions be taken in the near term to slow the increase in global CO₂ emissions. It is not unreasonable to believe that a significant fraction of this early mitigation effort can be achieved through aggressive deployment of existing renewable energy technologies and continued advancements in energy efficiency. Yet a growing body of research suggests that these steps alone will not be enough to move the global energy system onto a pathway towards stabilizing atmospheric greenhouse gas concentrations (see [3], for
example). Particularly in the U.S., where over 40% of total CO2 emissions are attributable to the electric power sector [4], it can be expected that some attention will need to be paid to reducing the CO2 emissions from existing power plants. Geologic disposal of CO2 is one such method that holds significant potential for addressing these emissions [5].

U.S. FOSSIL-FUELED POWER GENERATION STOCK

According to the most recent data contained within the Battelle CO2-GIS [6], there are currently more than 1,337 large fossil-fired generating units operating in the U.S. with a total capacity of 453 GW. Total annual CO2 emissions from these plants exceed 2.27 billion tons. The range of vintages for these plants spans the period from 1941 to 19991. Figure 1 shows the breakout of fossil-fueled power generation capacity by unit vintage and fuel type. The number in parentheses above each bar indicates the total number of operating units within each vintage category.

This figure illustrates the dominant role that coal plays in U.S. fossil-fired power generation. The majority of new plants that came on-line from the 1950’s through the 1980’s were coal fired, with average plant sizes increasing over that time period. However, beginning in the 1990’s a trend towards the increasing use of smaller natural gas fired technology developed and has continued through today. Projections of planned capacity additions through the end of this decade, using data compiled for a separate analysis [9], indicate that this trend is likely to continue. Although it remains to be seen how many of these plants will actually be built, the data indicate a possible resurgence in power plant construction over the coming decade, with most units being natural gas fired.

While it may be quite realistic to assume that many of the older power plants will be shut down, replaced, or repowered with new advanced technology (such as IGCC) in the face of climate and other environmental concerns, it is naïve (and would prove terribly disruptive to the U.S. economy) to believe that the entire stock of existing fossil-fired plants will be replaced or upgraded in this fashion. A large portion of the

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1 The last complete update of the Battelle CO2-GIS power plant database occurred in July 2000, covering fossil-fired generating units with a capacity of at least 100 MW, operating within the United States as of early 1999. EIA data [7,8] suggests that over 152 additional units have been built and begun operating since, and plans are underway to update the Battelle CO2-GIS to reflect these more recent data.
existing stock is less than 30 years old and will be around for many years to come; therefore the owners of these existing power plants will most likely need to explore other options for reducing their emissions.

Assuming a conservative 40-year useful power plant life, and looking only at the plants built through the 1990’s, 667 of these units, representing more than 290 GW of capacity, will be operating into the next decade and beyond. Most (379) of these are coal-fired units; 243 are natural gas-fired, and 45 are oil-fired. The CO₂ emissions contribution from these units alone is currently about 1.6 billion tons per year (roughly 62% of total U.S. electric utility sector emissions). A projection of future emissions from just these units over the next 40 years is shown by fuel type in Figure 2. The projection here assumes that each unit will be retired after operating for 40 years. If this projection were to hold true, these existing 667 power plants would collectively be responsible for emitting 30.2 billion tons of CO₂ to the atmosphere over the remainder of their hypothetical lifetimes (26.7 billion tons from the coal units alone).

This simplified analysis however does not tell the whole story. It does not include the emissions from units built prior to 1970, nor additional or replacement units that have already come on-line or will through 2040 (most of which will likely continue to employ conventional technology, rather than advanced power generation cycles that might be more amenable to CO₂ emissions control). It also does not consider that many of these units will likely be able to produce economical power years beyond age 40. Assuming that a societal aspiration exists to begin addressing climate change within this decade, a strategy must be conceived to help these existing plants continue to produce affordable power while meeting their CO₂ reduction requirements. Solutions beyond retiring this still valuable and productive stock or attempting to purchase increasingly expensive offsets must be developed to address these plants’ large carbon liability, while maintaining their economic viability.

**OPPORTUNITY FOR GEOLOGICAL SEQUESTRATION**

The Battelle CO₂-GIS currently contains information and spatial extents for some 117 geologic formations that could be amenable to CO₂ disposal. These include current and prospective CO₂ enhanced oil recovery operations, coal basins, and deep saline formations. Figure 3 is a map of the continental U.S. showing locations of the set of existing power generating units built since 1970 superimposed against these disposal reservoirs. Visual inspection reveals that many of these units lie directly above or in close proximity to possible disposal sites. However, it can also be seen that there are many generating units that are far from known CO₂ disposal targets. Using the built-in analysis capability of the Battelle CO₂-GIS, we are able to
evaluate more thoroughly the opportunity that retrofit carbon capture and geologic sequestration offers this stock of plants.

![Image](image.png)

**Figure 3:** U.S. Fossil-Fired Power Generating Units Built after 1970 and Major CO₂ Geologic Disposal Reservoirs

Utilizing the basic spatial analysis capability of the system, we find that of the 379 coal plants built within this time frame, 244 lie directly above either a deep saline formation or a coal basin. Of the 216 such units that began operating in the 1970’s, 146 sit atop a deep saline formation or coal seam and 5 are within 50 miles of an existing or prospective EOR field, representing over 70% of the annual emissions from this group of coal plants. In all, 66% of the total emissions from all 1970’s vintage plants are within close proximity to potential disposal sites. For the 1980’s plants, 61% of their emissions occur within a short distance to a disposal pathway, dropping to 47% for the 1990’s plants’ emissions. Deep saline formations are the reservoirs that underlie the most plants (44% of the total stock) across all vintage categories, reaching as high as 70% of all the 1980’s natural gas fired plants. Coal seams are the next most prominent formation type located close to existing power plants, occurring beneath some 40% of 1970’s vintage coal-fired plants. EOR fields offer the fewest options in close proximity to existing power plants, with only 18 of the 667 plants sitting within 50 miles of an existing or prospective EOR site. Overall, roughly 63% of the total emissions from these 667 units occur within close range of a possible disposal site, offering a promising opportunity for carbon capture and disposal.

The CO₂-GIS also contains an economic screening capability that seeks to optimize the matching of CO₂ source and sink by assessing the costs of CO₂ capture, transport, and disposal for each plant and reservoir combination. A previous paper [10] describes this functionality in greater detail. Expanding the assumed maximum search radius to 100-miles around each unit, we examine the available disposal pathways and identify those that appear most economical. Results of this analysis indicate that of the 667 units, 568 are located within 100 miles of at least one potential disposal reservoir. The results for each class of reservoir,

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2 Additional Legend for Figure 3: Dark solid areas represent major coal basins. Lighter textured areas represent deep saline formations. Black dots indicate locations where CO₂ injection for enhanced oil recovery is on-going. The oil derrick symbol highlights areas with near-term prospects for CO₂ enhanced oil recovery projects.
The majority of generating units elect to sell their CO2 to “value added formations” which include enhanced oil recovery fields and deep coal seams, for which there would likely be an offsetting revenue stream from hydrocarbon recovery. Nevertheless, significant portions of the stock dispose of their CO2 in nearby deep saline formations. There is no direct revenue associated with this type of disposal, so the costs are much greater per ton of CO2 than for the “value added formations”. Recalling that 294 of the total stock of plants sit directly over a deep saline formation, this results in many of these plants electing to build a much longer pipeline to sell their CO2 instead to a revenue-producing formation. This also suggests that many of the 176 plants that do opt to inject into a deep saline formation have no “value added” disposal options within the 100-mile radius. However, both the geographic distribution and storage capacity of deep saline formations is far greater than for enhanced oil recovery fields in particular, which could ultimately reduce the cost differences as the CO2 demand for EOR becomes saturated. While the value of methane produced from coal seams under CO2 injection is not as great as the oil produced from EOR operations, it does help to offset some of the capture and disposal costs. This, along with the broad geographic extent of the coal seams make this also a promising disposal option, accepting the majority of emissions from these units.

### Table 1

RESULTS OF GENERATING UNIT CO2 DISPOSAL ECONOMIC SELECTION ANALYSIS

<table>
<thead>
<tr>
<th></th>
<th>Enhanced Oil Recovery</th>
<th>Deep Coal Seams</th>
<th>Deep Saline Formations</th>
</tr>
</thead>
<tbody>
<tr>
<td># Units</td>
<td>62</td>
<td>330</td>
<td>176</td>
</tr>
<tr>
<td>CO2, million tons/yr</td>
<td>120</td>
<td>950</td>
<td>250</td>
</tr>
<tr>
<td>Req’d Pipeline, miles</td>
<td>4,500</td>
<td>19,800</td>
<td>11,600</td>
</tr>
<tr>
<td>Avg. Cost $/ton</td>
<td>1.50</td>
<td>18</td>
<td>61</td>
</tr>
</tbody>
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In order to transport the CO2 from source to sink, a network of pipelines will be required. Table 1 indicates the total pipeline length needed to deliver CO2 from each generating unit to its reservoir of choice. This figure assumes an average 15% adder to the straight-line distance to account for anticipated routing allowances. It also factors an additional 25 miles from the edge of a chosen coal basin or saline formation to locate an acceptable injection site. That said, these figures also assume that each generating unit builds a separate pipeline to its chosen disposal site. However, if capture and disposal of CO2 were developed on a scale such as envisioned here, a national network of interconnected CO2 pipelines would likely emerge with time. To illustrate the level of savings possible by evolving towards an interconnected national pipeline system, we note that many of the existing power plants in the U.S. have multiple generating units at the same site. By simply allowing a single pipeline to be shared by all the units at a particular location, the total required pipeline length needed to transport the emissions from existing power plants falls from over 35,000 miles to just over 18,000 miles. A more thoroughly coordinated system would reduce this further.

### CONCLUSIONS

Is IGCC paired with carbon capture and disposal the power generation technology bridge to a transformed energy system? Perhaps, although it will likely be years before it is deployed at a wide scale. In the meantime, there are presently over 1,337 large conventional fossil-fired generating units across the United States that together emit some 2.3 billion tons of CO2 into the atmosphere each year. A large number of these plants are quite old and will likely be shut down and replaced with cleaner, more efficient plants (some

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3 The authors believe that the cost numbers presented in this table should be interpreted as relative indicators of the cost of capture and disposal rather than precise engineering estimates.
no doubt with IGCC), rather than be extensively upgraded or overhauled in the face of climate change and other environmental challenges. However, there are a significant number of units that have been built in the past few decades that have plenty of generating life remaining and will continue to operate into a future where carbon emissions are increasingly constrained.

As far as U.S. electricity demand and climate change mitigation efforts are concerned, one cannot simply write off these plants’ power production or resulting emissions; as we move forward and begin to define a sensible strategy for the level of emissions reduction required to help stabilize atmospheric concentrations of greenhouse gases, the continued operation and emissions from these units must be considered. Retrofitting these units with carbon capture systems and disposing of the CO₂ in nearby geologic formations is an option that could help mitigate the large volumes of CO₂ produced by these plants. Yet, this will not be an option for every unit. The 99 units producing 132 million tons of CO₂ per year that cannot easily take advantage of geologic disposal would need to consider other options (including, but not limited to the purchase of CO₂ offsets, repowering with advanced technology, or early retirement). For others, while geologic disposal options may exist, the cost of capture may prove prohibitively high (for small peaking natural gas turbines in particular). In such cases, other options will undoubtedly prove more economical and should be examined. Nevertheless, if we are serious about addressing our climate change mitigation obligations, carbon capture and geologic disposal should be considered in the portfolio of options.

REFERENCES