8. SUMMARY AND CONCLUSIONS

The objectives of this report were to establish the potential risk of operating problems due to carbon deposition and metal dusting in advanced coal-gasification processes and to identify mitigation methods. Metal dusting is a pernicious form of degradation, primarily of iron, cobalt, and nickel. In metal dusting, the metal, or alternatively, a metal compound, functions as a catalyst for the disproportionation of CO when carbon activities exceed unity. Under the appropriate environmental and material conditions, the end result is a breaking up of the metal structure to create powdery carbon and fine particles (thus the term "metal dusting"). The results of the present effort may be summarized as follows:

1. A review of the literature relating to carbon deposition and metal dusting was conducted. Key sources of information were from research on (a) metal dusting, (b) CO disintegration of refractories, and (c) carbon deposition, including formation of filamentous carbon. Although the literature in each of these areas proved very useful for this review, cross-referencing among the three appeared incidental, at best.

2. The product gas compositions of eight representative gasifier systems were examined with respect to the carbon activity of the gases at temperatures ranging from 480 to 1090°C (900 to 2000°F). The composition of the product gas, in particular the CO concentration from the gasification processes considered, is such that carbon deposition is essentially guaranteed when the gas is cooled after exiting the gasifier. Assuming that all of the gas components are in thermodynamic equilibrium, calculations show that carbon activities greater than unity would result at temperatures below 800 to 870°C (1470 to 1600°F) in the case of air-blown gasifiers and at considerably higher temperatures in the case of oxygen-blown gasifiers containing greater than 54 vol % CO.

3. Phase stability calculations indicate that Fe_3C is only stable under very limited thermodynamic and kinetic conditions and that FeO and $Fe_{0.877}S$ tend to form instead of the carbide. As formation of Fe_3C is a necessary step in the metal dusting of steels, there are numerous gasifier environments where this type of carbon-related degradation will not occur, particularly under conditions associated with higher oxygen and sulfur activities. These calculations also indicated that the removal of H_2S by a hot-gas cleanup system may have less effect on the formation of Fe_3C in air-blown gasifier environments, where the iron oxide phase can exist and is unaffected by the removal of sulfur, than in other gasification systems where iron sulfide provides the only potential barrier to Fe_3C formation.

4. In current gasification systems, significant problems resulting from carbon deposition have not been experienced, or, if they have, they have not been reported. The main factors militating against carbon deposition and/or metal dusting in these systems are thought to be (a) the presence of sufficient sulfur in the raw gas leaving the gasifier to inhibit the relevant reactions by poisoning catalytic surfaces; (b) rapid cooling of the product gas, which reduces the residence time of the gas at temperatures at which carbon deposition is favored; and (c) the gas compositions being outside the range of thermodynamic stability of Fe_3C.

5. The adoption of hot-gas desulfurization strategies will probably increase the significance of the carbon-related degradation, since H_2S will then be removed in a temperature regime where carbon deposition and metal dusting are possible.

6. Alloy selection can be an important consideration relative to process performance and economics. With respect to prevention of carbon deposition and metal dusting, alloy selection is reduced to two general alternatives: carbon or low-alloy steels, provided certain criteria are met (see no. 7 below), and higher-

alloyed steels or heat-resistant alloys. As stated in conclusion (2), temperatures prevailing in gasifiers employing hot-gas cleanup essentially guarantee conditions that will support carbon deposition on carbon- and low-alloy steels. Metal dusting is then possible when a metastable carbide (normally Fe_3C) can form and then decompose.

7. The use of carbon steels and/or low-alloy steels will dictate that the process gas composition be such that Fe_3C cannot form if the potential for metal dusting is to be eliminated. Alternatively, process modifications could include reintroducing hydrogen sulfide (to poison the carbon deposition reaction or to form iron sulfide at the expense of Fe_3C), quenching the gas to perhaps as low as 400°C (750°F), and/or injecting steam.

8. If higher-alloy steels (those that form and maintain a protective chromia film on the surface) are used, a hydrogen sulfide-free gas (or a gas with very low hydrogen sulfide content at higher temperatures) may be processed without concern about carbon deposition and metal dusting.

9. It is considered prudent to conduct some testing, preferably under prototypical coal gasification conditions, to experimentally validate the thermodynamic calculations and assumptions about kinetic limitations that are key to developing a predictive capability with respect to carbon formation and metal dusting.