Chris Frey

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DEVELOPMENT OF THE INTEGRATED ENVIRONMENTAL CONTROL MODEL

E.S. Rubin, M.B. Berkenpas and H.C. Frey
Carnegie Mellon University
Pittsburgh, PA 15213

INTRODUCTION

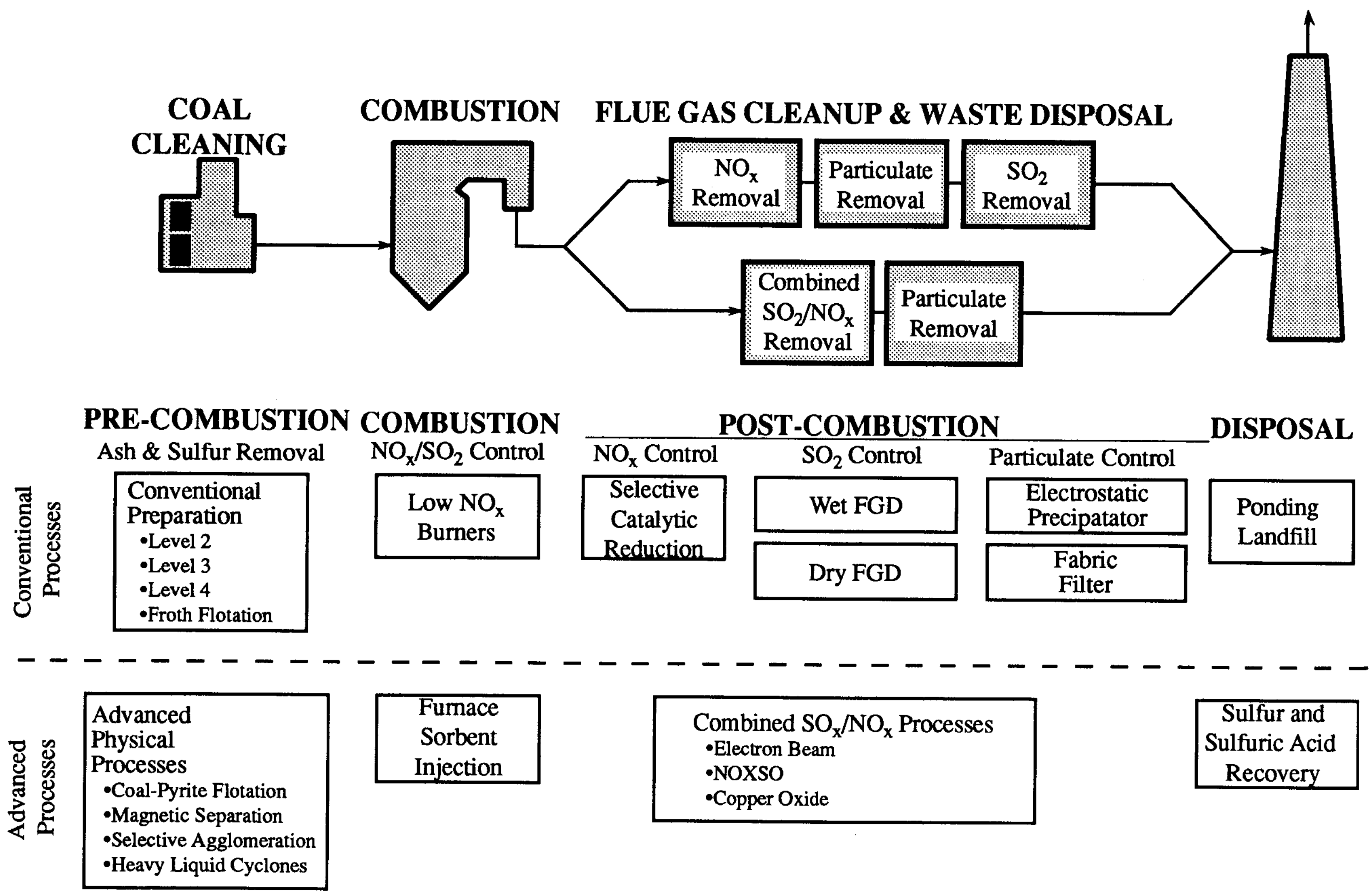
Over the past two decades, environmental regulations have transformed the design of new coal-fired power plants. Requirements for the control of air pollutants, water pollutants and solid wastes have added considerably to plant complexity, while spurring the development of new, more innovative technology for the removal of pollutants before, during and after combustion. The availability of a larger number of options for meeting emission reduction requirements also has increased the need for systematic methods of evaluating and comparing process alternatives. In particular, there is now an increased need to assess the cost and performance of alternative power plant designs involving both conventional and advanced technologies.

This paper describes the Integrated Environmental Control Model (IECM), an analytical model developed for the U.S. Department of Energy's Pittsburgh Energy Technology Center (DOE/PETC) [1,2]. Model development work will continue under a new contract initiated in October 1992. The model quantifies the performance and cost of power plant designs that involve user-specified combinations of pre-combustion, combustion, and post-combustion methods of environmental control. A unique feature of the IECM is the ability to characterize uncertainty in probabilistic terms, in contrast to conventional deterministic analysis. This capability offers special advantages in analyzing advanced technologies at an early stage of development , and in comparing them with conventional systems where uncertainties typically are smaller. This paper reviews the current status of model development and presents an illustrative example of its use. Then, plans for further model development are summarized.

THE INTEGRATED ENVIRONMENTAL CONTROL MODEL

Figure 1 shows the technologies currently included in the Integrated Environmental Control Model. These include a number of commercially available methods of pollution control, as well as several advanced technologies of interest to DOE/PETC. For each of the technologies listed in Figure 1, a process performance model has been developed to account for mass and energy flows associated with that process. Coupled to each performance model, an economic model also has been developed to estimate the capital cost, annual operating cost and total levelized cost of each technology. Details of these performance and cost models have been reported elsewhere [1, 2].

Figure 1. Integrated Environmental Control Model Technologies



Running the IECM involves three principal steps. The first is to configure a power plant for analysis. Here, the user specifies the set of pre-combustion, combustion, and post-combustion technologies of interest, along with associated waste disposal method. Next, the user specifies the values of model parameters related to control technology design, power plant characteristics, fuel specifications, and environmental regulatory constraints. Economic and financial parameters also are specified at this stage. Overall, the IECM contains several hundred input parameters covering all technologies in the model. For a typical analysis, on the order of 50 parameters must be specified. Default values for most parameters are incorporated to assist the user. Finally, once all input parameters are set, the model is executed and the desired output results are specified. Several standard reports are incorporated for economic analysis, though the user may easily call for any performance or economic output parameter of interest.

The model runs on a Macintosh II computer. As discussed later, a particular advantage of the Macintosh system is its capability to support a user-friendly graphical interface to facilitate model use.

As noted earlier, a unique feature of the IECM is its ability to characterize input parameters and output results probabilistically, in contrast to conventional deterministic (point estimate) form. This method of analysis offers a number of important advantages over the traditional approach of examining uncertainties via sensitivity analysis. Probabilistic analysis allows the interactive effects of variations in many different parameters to be considered simultaneously, in contrast to sensitivity analysis where only one or two parameters at a time are varied, with all others held constant. In addition, probabilistic analysis provides quantitative insights about the likelihood of certain outcomes, or the probability that one result may be more significant than another. This type of information is generally of greater use than simple bounding or "worst case" analyses obtained from sensitivity studies.

The ability to perform probabilistic analysis comes from the use of a new software system which uses a non-procedural modeling environment designed to facilitate model building and probabilistic analysis [3]. In addition to a number of standard probability distributions (e.g., normal, lognormal, uniform, chance), the IECM can accommodate any arbitrarily specified distribution for input parameters. Given a specified set of input uncertainties, the resulting uncertainties induced in model outputs are calculated using median Latin Hypercube sampling, an efficient variant of Monte Carlo simulation. Results typically are displayed in the form of a cumulative probability distribution showing the likelihood of reaching or exceeding various levels of a particular parameter of interest (e.g., cost). Examples of model results have been presented previously [1, 4].

MODEL APPLICATIONS

The IECM is intended to support a variety of applications related to technology assessment, process design, and research management. Examples of questions that can be addressed with the IECM include the following:

- What uncertainties most affect the overall costs of a particular technology?
- What are the key design trade-offs for a particular process ?
- What are the potential payoffs and risks of advance processes vis-a-vis conventional technology?
- Which technologies appear most promising for further process development?
- What conditions or markets favor the selection of one system design (or technology) over another?
- How can technical and/or economic uncertainties most effectively be reduced through further research and development?

To address questions like these, a number of case studies have been undertaken using the IECM. As an illustrative example, we show here the case study results for a new 500 MW coal-fired power plant employing the fluidized bed copper oxide process for simultaneous SO_2 and NO_x removal. An integrated system design was assumed in which conventional coal cleaning was used along with power plant controls to evaluate the least cost option. Two options for by-product recovery (sulfur and sulfuric acid) also were evaluated. Finally, the analysis was conducted for two different coals (Pittsburgh No. 8 with 2.2%S and Illinois No. 6 with 4.4%S) to examine the effects of differences in coal quality and cost. The details of the assumptions and results for this analysis are reported elsewhere [5,6,7].

For the copper oxide process alone, there are a number of key design trade-offs affecting overall process economics and potential markets for this technology. Use of the engineering process model allowed the values of several key design parameters to be specified so as to minimize overall costs. Figure 2 displays the results of additional deterministic studies to explore the role of coal cleaning in conjunction with post-combustion emission controls. The results in Figure 2 indicate that for the system configuration using Illinois No. 6 coal, the overall cost of pollution control is minimized when coal cleaning is used to reduce the coal sulfur content by 30 percent below run-of-mine levels (normalized on an energy basis). For subsequent analyses, this least-cost configuration was assumed. For the Pittsburgh seam coal, on the other hand, no coal cleaning proved to be the optimal choice. Although coal cleaning reduces the cost of pollution control at the power plant, the higher cost for the cleaned coal product in this case offset the cost advantage at the power plant.

In addition to applications involving the analysis of a particular technology, another major application of the IECM is for comparing alternative options for a given facility. In particular, the likely cost advantages of advanced process designs relative to conventional technology are of special interest. In the illustrative analysis presented here, the advanced plant design using the copper oxide process is compared to a base-case design employing separate processes for SO_2 and NO_x removal -- a wet limestone scrubber, while NO_x is removed using selective catalytic reduction (SCR), respectively .

Because many of the input parameter distributions are common to both conventional and advanced systems (e.g., financial parameters, base plant characteristics, solid waste disposal, and ammonia cost), there is, in general a positive correlation between the cost distributions for the two systems. Therefore, the probability distributions have been determined for the cost differences between the copper oxide and FGD/SCR systems using paired samples in which parameters common to each had the same value.

Figure 3 shows the differences in levelized pollution control costs between the baseline (FGD/SCR) and advanced (copper oxide) systems for two coals and two sulfur recovery options. In all cases, the copper oxide process is most likely to be less expensive and the FGD/SCR system, since cost savings at the 50 percent probability value are positive. However, for the higher sulfur coal there is still a substantial probability (risk) that the copper oxide process will be more expensive. Taking the case with sulfur recovery and the Illinois No. 6 washed coal as an example, there is nearly a 30 percent probability that the new process will be more expensive than conventional technology, based on the difference in levelized costs. For the medium sulfur Pittsburgh coal, the probability of the new technology being more expensive than the conventional system is negligible. Furthermore, the magnitude of cost savings is likely to be larger for the Pittsburgh coal than for the higher sulfur Illinois No. 6 coal, indicating a more attractive market potential. In all cases, there is considerable uncertainty in the amount of the cost savings. The 90 percent probability range for the Illinois No. 6 coal with sulfur recovery is -5 mills/kWh to 8 mills/kWh in constant 1985 dollars. There is a small probability that the cost savings could be significantly higher.

SCOPE OF CURRENT WORK

The preceding discussion was intended to illustrate some of the potential applications of the Integrated Environmental Control Model. Version 1.0 of the model was transferred to DOE/PETC in 1991 [2,8]. Under the new five year grant initiated in October 1992, twelve new tasks, organized into two main project phases, will be pursued to update and enhance the IECM. Details of these tasks have been elaborated in a project management plan developed during the initial period of the contract [9].

Figure 2. Mean Levelized Pollution Control Cost versus Sulfur Reduction from Coal Cleaning: Copper Oxide/Sulfur Plant with Illinois No. 6 Coal

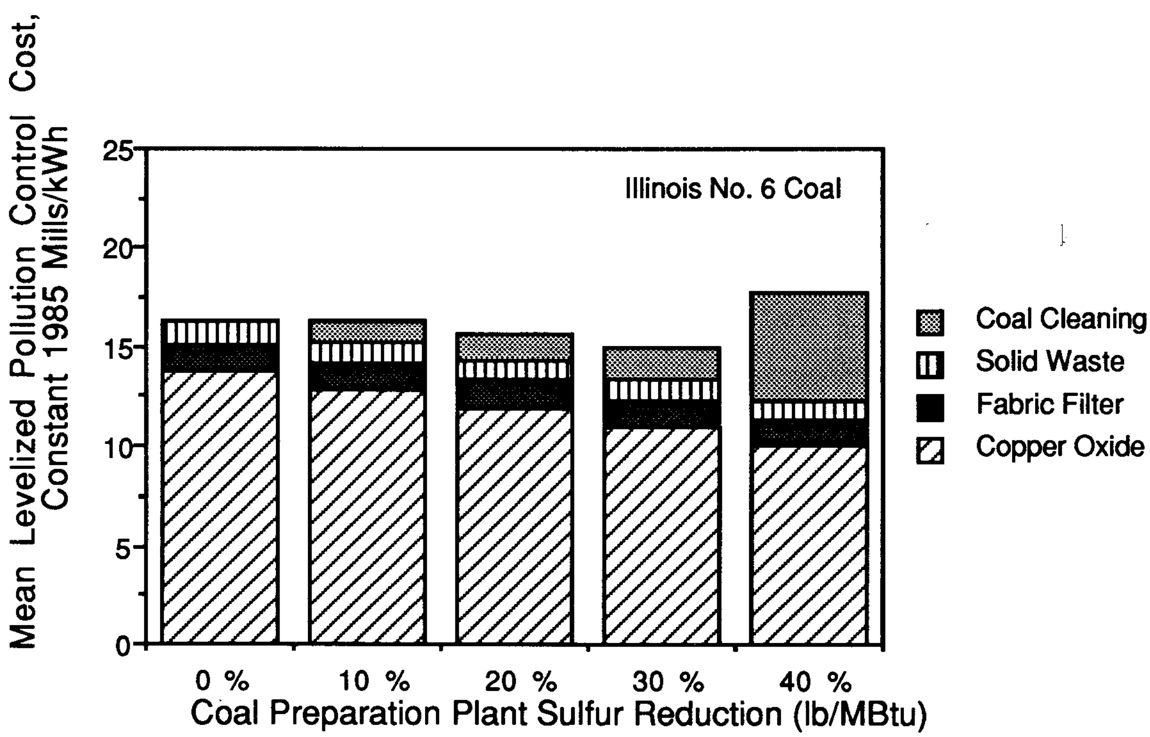
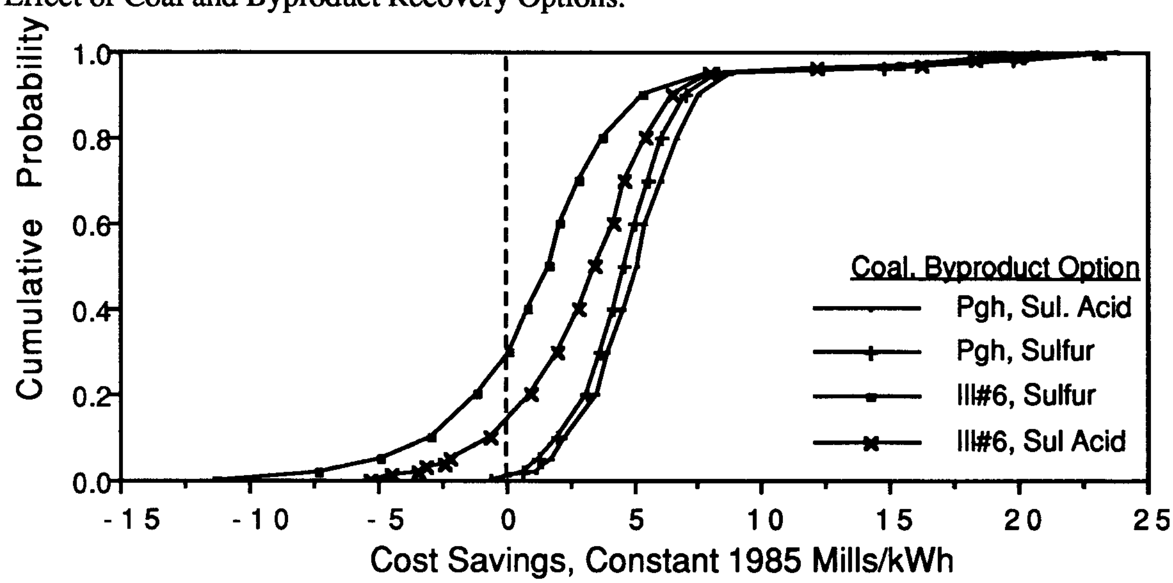


Figure 3. Comparison of Cost of Electricity Savings for Copper Oxide vs. FGD/SCR Systems: Effect of Coal and Byproduct Recovery Options.



Initial efforts include on a comprehensive training program for PETC personnel on the use of both the IECM and the DEMOS programming language. The latter capability will be necessary for developing new models, or making significant revisions to existing ones. The training program was initiated in February 1993 and will continue throughout the contract, on an intermittent basis.

To enhance the usability of the model for routine analyses, Phase I will involve the development of a graphical user-friendly interface which will eliminate the need of most users to master the underlying computer command language. The interface will provide access to all model documentation, a tutorial on model operation, and the capability to execute a model run and obtain results. A prototype demonstration of a graphical user interface, implemented in Hypercard, has been developed in a separate project for the Electric Power Research Institute (EPRI) focused on the modeling of trace chemical emissions from conventional power plants [10]. Although most of the technical and economic models embedded in the IECM are different from the models developed for EPRI, the general approach and software underlying the graphical user interface are expected to be applicable to the IECM. This effort also will involve extensive consultation with DOE/PETC personnel to determine the most common uses and needs of model analyses, in order to design an appropriate and useful interface.

Phase I also will include an extensive technical effort to upgrade and enhance many of the current technology modules in the IECM. In particular, efforts will focus on the existing models for hot-side selective catalytic reduction (SCR), wet limestone flue gas desulfurization (FGD) systems, lime spray dryer systems, fabric filters, electrostatic precipitators, the NOXSO process and the copper oxide process. In each case, existing analytical models for the performance and cost of these technologies will be revised and upgraded to account for recent experience in the U.S.. and elsewhere. In a companion task, all technology options currently embedded in the IECM will be extended to include a series of process retrofit factors that can account for the higher cost incurred when installing the new technology at an existing facility.

Under Phase II, several new technology modules will be developed, along with linkages between the IECM and several existing PETC databases. The specific performance and economic models to be included in the Phase II research will be finalized later in the project, but may include such processes as advanced wet limestone FGD, duct injection technologies, sulfur recovery plants, reburning with coal or gas, cold-side SCR, the Tung process and slagging combustors. Additional personnel training, program debugging, and model documentation will be part of this effort, along with further enhancements of the graphical interface to accommodate the new technology modules.

During Phase II, linkages also will be developed with existing PETC databases to facilitate running the IECM for large numbers of cases. In particular, the PETC power plant database, the coal characteristics database, and the coal washability database will be linked to the model via a new interface capability to automatically read external files into the IECM. This work will be carried out in conjunction with PETC personnel responsible for the existing database. An automated interface with external data sets will allow the IECM to be used more extensively for market studies, technological risk evaluations, R&D management, and other special studies of interest to DOE.

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