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Permalink
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Publication Date
1989-09-01

Lawrence Berkeley Laboratory
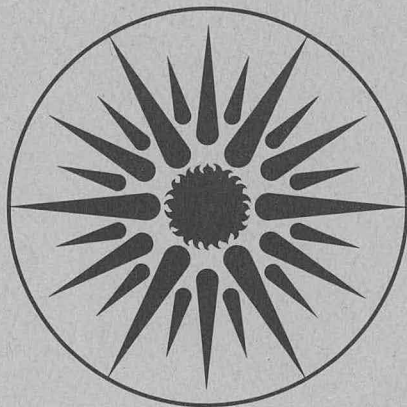## UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Designing a Performance Based Cost-Sharing System
for the Clean Coal Technology Program

E. Kahn and S. Stoft

September 1989

**APPLIED SCIENCE
DIVISION**

DISCLAIMER

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ACKNOWLEDGEMENTS

ABSTRACT

The US Department of Energy (DOE) administers a legislatively mandated program to promote the development of efficient, low pollution coal combustion technology. Most of this is targeted toward the electricity sector which comsumes the vast preponderance of coal in the US. The Clean Coal Technology (CCT) program subsidizes the cost of demonstrating these technologies in commercial settings by co-operating with utilities, equipment vendors, engineering firms and unregulated private producers. Because new technology typically experiences operating problems, particularly in the "start-up" phase, a demonstrated record of performance must be established before the new technology will be adopted.

To encourage participants in the CCT Program to design and operate projects that will demonstrate performance objectives, DOE needs to examine the structure of its subsidy arrangements. The basic proposal examined in this paper is that subsidies ought to be paid in proportion to actual project output, rather than as non-contingent grants. Paying for performance will induce the appropriate behavior from program participants. Under an arrangement of this kind participants meeting certain minimum technical thresholds can be selected by DOE by an auction. Those bidders who will accept the lowest performance subsidies will be selected.

A simple model of bidder behavior is constructed which accounts for credit constraints, technical risk, and market returns. Analysis of this model reveals that credit constraints in the presence of technical risks are very significant. Potential lenders evaluate projects under "worst case" scenarios, whereas bidders make choices under expected value outcomes. Technical risk drives a wedge between these two perspectives. By structuring government subsidies in a purely "market-driven" fashion, i.e. paying only for performance, the cost to DOE of inducing desirable performance is high. A mixed system of grants and performance based subsidies is a more efficient approach of meeting both credit constraints and technology demonstration objectives.

Numerical examples illustrate this theme.

Designing a Performance Based Cost-Sharing System for the Clean Coal Technology Program

Edward Kahn and Steven Stoft†
September, 1989

1. Introduction

The Department of Energy (DOE) has completed two rounds of its Clean Coal Technology (CCT) program, and is in the process of implementing its third round. This report examines the structure of the CCT program and suggests ways in which it might be reshaped for rounds four and five. The basic theme raised here is that the cost-sharing formulas adopted by DOE should emphasize a performance basis. The underlying argument is quite simple. The ultimate goal of the CCT program is the commercial adoption of the technology that has been demonstrated by the program. To encourage that process, DOE must show the potential ultimate adopters of the technology that it can perform as well as competing technology. By structuring the government's cost- sharing in a form that rewards performance, the commercialization objective is attained most efficiently.

This basic argument will be articulated in detail. We will recommend specific ways in which the performance basis of DOE cost sharing should be implemented. The implications for program budgeting will be defined, and the relationship between the proposed modifications and existing procedures will be clarified. The economic efficiency of the performance basis will be demonstrated in a simplified conceptual model. The model accounts for the profit motivation of program participants, their technology choices, the inherent risks of new technology, financial constraints imposed by the credit markets, and the response of participants to different kinds of government incentives.

This report is organized in the following manner. Section 2 is an overview of various types of incentives that government can use to promote the development of technology. The experience of the CCT program will be reviewed in this context. Section 3 explores the relationship between commercialization and performance demonstration. The need to define performance objectives clearly will emerge from this discussion. Section 4 introduces our model of the behavior of potential program participants. We must understand the

technological opportunities and risks facing participants as well as the market environment and constraints they face. Particular attention is given to credit constraints, because capital can often be difficult to raise for risky projects. Section 5 defines our proposed incentive format. It will have some of the properties of an auction. Program participants who meet threshold qualifications will bid for operating incentives. We prove that the proposed format will induce efficient behavior in the selected participants. Section 6 explores the budgetary and administrative aspects of the proposed approach. Finally, Section 7 identifies the unresolved implementation issues raised by the scheme outlined in this report.

2. Overview of Incentive Types

Government has played a wide variety of roles in promoting technology development. Rothwell (1983) has identified twelve different kinds of "technology policy instruments" that have been used by public authorities to influence the path of technological development. These range from publicly owned enterprise to information and education to patent and legal regulation. In the U.S. energy industries, Cone et.al. (1978) have studied the extent and variety of federal programs that have promoted both market and technical development. Our primary concern lies with the class of financial tools that are available to influence the market returns of private companies that invest in new technology. This focus on the financial environment facing private companies best represents the situation of the CCT program.

The inventory of financial incentives includes grants, loans, subsidies, cost-sharing, tax preferences or reductions, and loan guarantees. We will consider most of these in one way or another except for tax effects. The CCT program does not involve tax effects in any particular way, nor does it have any direct mandate of this kind. For convenience, therefore, we will neglect whatever second-order tax effects may accrue to program participants as essentially beyond the control of DOE. To take meaningful account of different financial incentives available in principle to the CCT program, we must differentiate among their effects.

It is convenient to distinguish among incentives by differentiating them with respect to the phase of a project's history at which they are directed. The CCT program has traditionally distinguished between cost-sharing directed at the construction phase of projects from that which is directed at their operating phase. This distinction, however, has more of an accounting meaning than an economic one, because there is little difference in the requirements for obtaining cost-share funds once a project has been selected and a co-operative agreement signed. Essentially, the requirement for program participants to receive funding is a showing of good faith effort.

A more economically meaningful distinction involves the conditions under which cost sharing may or may not occur. We might refer in general to cases where incentives are linked to outcomes as contingent subsidies. These can have very different characters. In the case where subsidies are funded only when economic outcomes are unfavorable, they function as insurance. In technology development programs this approach may be reasonable if the underlying risks are very large. The opposite case is the reward structure. In this

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situation, subsidies or cost sharing occurs when the participating firm succeeds by some measure of economic performance. The government funds are contingent on the firm's successful performance, and therefore act as an incentive to induce that performance.

We will argue that the technology commercialization objective is most consistent with the reward type of contingent incentive. The insurance type is more appropriate to stages of technology development that precede commercialization. Under- writing technology development risk pre-supposes a less mature product and process than one which is ready to enter normal marketplace competition.

Non-contingent subsidies, of which the capital grant is the purest type, can best be thought of as a financial inducement. New technology is often more expensive than competing alternatives due to production economies (e.g. "learning by doing") that have not been captured. Capital subsidies can close the competitive gap, assuming that there is no question of performance differences. Capital subsidies can also play a role in the high risk development phase when performance incentives are insufficient.

Determining what kinds of incentives are appropriate for the CCT program requires some judgments about the state of the technology that is being promoted and the government's goals. This study makes no assertion about either of these issues. Our focus is on the case where commercialization is the program objective. This means, in effect, that first-of-a-kind applications will not be chosen. Replication of innovative technology, presumably demonstrated in previous rounds of the CCT program, is the basic situation we will examine.

We recognize that terms such as "replication" and "first-of- a-kind" are ambiguous, but we leave the resolution of these ambiguities in particular cases to others. Our concern is with the linkage of the commercialization objective with reward-type incentives. In the next section we address the rationale for that linkage in more detail, and specify the kinds of questions that DOE must answer to implement a performance-based incentive structure in rounds four and five of the CCT program.

3. Performance Incentives and the Commercialization Objective

For clean coal technology to compete in the electricity marketplace it must be able to show a record of performance that approximates the standards met by alternatives. In practice, we interpret this to mean that CCT projects must show high capacity factors over a number of years. Capacity factor is the best overall measure of baseload power plant performance. It is measured simply as annual output divided by the output the plant would have achieved if it had run in every hour of the year at full rated capacity. Thus it accounts for both scheduled and forced outages. Most clean coal technologies compete in the baseload segment, so their performance will be compared to the capacity factor achieved by conventional baseload coal and nuclear plants. The EPRI Technical Assessment Guide typically estimates expected capacity factors for new conventional coal plants of about 70%. Nuclear power plants in commercial operation have achieved an average of about 60% capacity

factor. For nuclear units the variance in capacity factors is larger than that for baseload coal plants.

3.1 Marketplace Performance Standards and CCT

It is useful to examine the capacity factor standards that have been established through regulatory action in the electricity marketplace. We begin with the treatment of performance for conventional rate-of-return regulated utility generation. A number of state regulatory commissions have set capacity factor targets for this kind of baseload generating unit. Utilities are rewarded or penalized for performance that deviates from the established target. Joskow and Schmalensee (1986) cite a privately conducted survey which identified fifteen separate programs of this kind. They discuss a typical example where the Arizona Public Service Commission has established standards for the Palo Verde Nuclear Generating Station. The mechanism establishes a "dead band" range of 60-75% capacity factor where there is neither reward nor penalty. For performance above 75% the utility shareholders retain a portion of the fuel savings achieved by the output above that level. Conversely for performance below 60% the shareholders are penalized a portion of the extra fuel costs incurred. In the worst case, where capacity factors fall below 35%, the commission will re-evaluate whether rate-base treatment should be granted at all.

Another class of output standard has been established in the private power market. In this case, Qualifying Facilities (QFs) under PURPA may receive capacity payments as part of their power purchase contracts provided that they meet certain performance standards. In California, QFs must typically maintain an 80% capacity factor during the summer on-peak period (6 hours per day, 5 days per week for five months of the year) to earn their full contract payment. Texas Utilities imposes a performance standard for QF capacity payments that requires an annual capacity factor of 65% and 75% during the June through September period (Texas Utilities Electric Co., 1985). There are many other examples of capacity performance standards in this segment of the electricity marketplace.

These examples illustrate the economic environment in which new technology must compete. As cost and competitive pressures have increased in the electric utility industry, regulators are forcing performance standards on both the regulated firms and the private wholesale suppliers. DOE must respond to this environment by structuring the CCT program in a manner that will persuade potential adopters of the emerging technology that it can meet the performance norms that the market expects.

There will be no automatic assurance that performance standards can be met. Typically new technology experiences operating problems. In the best cases, these may simply involve the start-up phase of a project. In other cases, they may be chronic. Without a demonstrated track record of performance, potential users will be unable to distinguish between thesecases.

The record of clean coal technologies to date is promising but still ambiguous. The repowering technologies have experienced start-up problems, but then settled into

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reasonable operations. There have been a number of cases involving circulating fluidized bed (CFB) boilers at the 50 -100 MW scale where operating problems have been documented (Friedman, et.al., 1989; Moll, et al., 1989; Simbeck and Vejtasa 1989, Power, 1989). The consequences of these vary from case to case. Sometimes there has been significant downtime, equipment replacement costs have been incurred, and there have been cases where capacity has permanently decreased. Despite these events, CFBs continue to be ordered from vendors in this size range particularly by private suppliers operating as QFs.

There is less experience with gasification/combined cycle plants. Interesting results of the Coolwater project were summarized in the application of the Southern California Edison Company (SCE) to the California Energy Commission for a commercial siting permit for this plant. Long term expected capacity factor estimates were made by SCE based on the post- start up record of the plant in its demonstration phase. The result was a projection of just under 61% capacity factor. Three fourths of the downtime was projected to come from forced outages and one fourth from planned maintenance (Litzinger, 1988). This projection is interesting because it is at the lower end of the range of performance standards that have been defined, and it can be expected to be somewhat optimistic.

These examples illustrate the basic point that CCTs are close to meeting the kind of performance standards being required in the marketplace, but still have to establish this ability more definitively and with less uncertainty. To structure rounds four and five of the CCT program toward establishing the necessary market performance level, DOE must implement an incentive scheme that will induce that behavior. The essential point is that the leading edge of the electricity marketplace has accepted performance standards. In general CCT has not yet shown it can meet these standards. It will be most efficient for DOE to use market mechanisms to bring CCT into line with commercial expectations.

3.2 Specifying the Performance Objective

We can summarize the discussion so far by saying that DOE should structure CCT program incentives so that participants will demonstrate high capacity factor operations. This will best meet commercialization objectives. Such a formulation is not sufficiently precise to give much direction to the process. To make the performance objective more concrete we must specify what the economists call "indifference curves." These are precise characterizations of the government's preferences and willingness to pay for specific levels of performance.

The exercise of defining indifference curves requires the government to answer some very particular questions about the value of projects. The answers to these questions may seem imprecise or uncertain. Nonetheless, the process of answering them will help to elucidate the underlying issues. When confronted with perplexity about the process of identifying preferences in this way, the standard response of economics is that the imprecision of the process is better than the incoherence of not even trying to be clear.

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With that pre-amble we can now pose the two central value questions. First, what constitutes a "worthless" project? Second what is DOE willing to pay for a "exceptional" project? Both of these notions, the worthless and the exceptional projects, are ideal types and can only be thought about, not observed; nonetheless they represent crucial boundary points. First, let us consider the notion of the "worthless" project. This notion is best approached from the perspective of the "horrible" project.

Horrible is worse than worthless. By this we mean that DOE commercialization objectives for CCT could be set back by the existence of a "horrible" project. Such a project could give the whole effort a bad reputation, damaging the future prospects for CCT by labeling it a "lemon" technology. Horrible projects approximate total failure; i.e. capacity factors of zero or essentially zero. A worthless project, on the other hand, is one which neither advances nor retards the development of CCT. It is literally a project for which DOE would pay nothing. This is the meaning of worthless.

Translating this notion into a capacity factor estimate is difficult. We may assume by comparison with the Palo Verde performance standard cited above, that "worthless" means something below a 35% capacity factor. For discussion purposes, we will assume that a capacity factor of 20% constitutes a worthless project. This number represents an estimate of performance over a multi-year subsidy period, so 20% could consist of two years at zero and two years at 40%. In the discussion of market returns for CCT projects in section 4 we will introduce a related concept, the "minimum capacity factor." This concept is something like the 35% capacity factor used by the Arizona Corporation Commission to establish the minimum operation that could earn even a penalized rate of return on rate base. It is an annual minimum value rather than a multi-year average.

In summary we distinguish a hierarchy of performance types. At the bottom of this hierarchy is the horrible, the reputation destroying project that is essentially a complete failure. Next in line is the worthless project, which has no value to the CCT program. Another way to think about this performance level is that it represents a floor, above which DOE would be willing to pay for improved output. At this low level of output, incremental value would be small, but growing. Finally, there is the market minimum capacity factor which is just high enough to earn some capacity-related return.

At the opposite extreme, we have the exceptional project. Let us consider 85% capacity factor performance as representing the exceptional case. The value of such a project to DOE is bounded by the budget of the CCT program. The government can pay no more for the exceptional project than Congress has allocated. Nonetheless there are subtle issues of scale and replication. What size are the projects? How many of them are necessary to demonstrate the commercial nature of the technology? How many different clean coal technologies does DOE want to demonstrate? These questions must be answered to structure a performance based system for rounds four and five of the CCT program.

Let us consider a stylized example. Suppose DOE decided that out of a $600 million budget that it required four exceptional 100 MW projects to meet its commercialization

objectives. This means that each would be worth $150 million. A per-MWh performance subsidy maximum can be calculated using an estimate of the "worthless" capacity factor and the duration of the subsidy program. It is just the slope of the line between the value of an exceptional project and the value of the worthless project, where output is measured over the length of the whole period of DOE operating subsidies. Assuming that the zero value performance level is 20% capacity factor, and that the subsidy period is 5 years, then the maximum operating payment would be $52.70 per MWh ($150 million divided by 2847 gWh, which is 5 times 85% minus 20% times 100 MW times 8760 hours).

With estimates of the exceptional project's value and the worthless capacity factor, we have essentially drawn the maximum indifference curve for DOE's commercialization objective for CCTs. It should be noticed that our example assumes that the indifference curve is a straight line. This is a convenient form, but not strictly necessary. The only thing we know with reasonable certainty is that these indifference curves should all be monotonically increasing. This just means that DOE always prefers higher capacity factors to lower ones at the same cost. All other indifference curves are also assumed to be straight lines and to lie below the one indicating maximum value. The other significant property of all these curves is that they intersect the zero value point. The basic situation is illustrated in Figure 1. The competition among potential program participants will simply require them to bid an operating subsidy level that is at or below the maximum value specified by DOE ($52.70 per MWh in our stylized example above).

In section 5 we will discuss opportunities to structure the actual administration of the CCT program within this general framework that will address the financial requirements of bidders. These requirements typically amount to the need for non- contingent capital subsidies instead of the purely operating approach taken here. Some accommodation to these needs can be made with our general framework without compromising its incentive properties. Before turning to these questions, however, it is important to determine more precisely the nature of potential bidder behavior. A successful CCT program cannot be run without an understanding of the economic environment facing potential participants. In the next section we present a model of bidder behavior that can be used to help determine the crucial maximum value question. It will also be used to demonstrate the optimality of our approach to selecting program participants.

4. A Model of Participant Behavior

In this section we outline our approach to characterizing the individual participant, or project developer, and his response to different incentives. We assume that the developer's goal is simply profit-maximization subject to technology and financial constraints. This goal is influenced by the government incentives offered. We will first outline the structure of our model; i.e. the inputs and outputs. We then outline how this can be used to help design a performance oriented CCT program. The model includes a characterization of technology,

explicit treatment of financing constraints, which we call bankability, and profit maximization under government incentives.

In the discussion which follows we present a general modeling framework which identifies the relevant factors and their inter-relationships. This general framework must be distinguished from particular model realizations. A model realization involves specific functional forms for individual components of the over-all structure. In our research to date we have had occasion to alter particular model realizations, without changing the overall framework. We anticipate that this process would continue into the future. As more information is gained or the framework put to different uses, there will be occasions to alter individual components. The discussion below will invoke a particular realization of the general framework for concreteness of exposition. An explicit and detailed description of our current realization is contained in Appendix B. The examples discussed here depend on that realization.

4.1 Technology Characterization

Technology is represented in two distinct ways. First, there is a deterministic component which embodies the developer's trade-offs between investment and expected performance. New technologies typically experience operating problems. Firms are aware of this and plan their investment and operations to account for it. For recent discussion of these issues in the case of CFBs see the references in section 3.1 above. We use a two parameter function to embody the relation between capital and performance. One parameter represents the threshold level of investment necessary to achieve any operation. This can be thought of as the minimal equipment necessary for any production. The other parameter represents the incremental capital required for improved performance. The diversity of firms and technologies can be represented by different values for these parameters. In all cases we assume a fixed capacity.

Figure 2 illustrates this relationship for several different parameter values representing the incremental capital required to improve the expected operating rate. In all cases in this example, the values are normalized to a 100 MW project size. The figure says that $100 million (or $1000/kW) is the minimum required investment to achieve even an infinitesimally small output. As the shape parameter increases from zero, the incremental cost of output falls. In the examples to follow we work with shape parameter values of 10-12. Some use of this model will require engineering estimation of this parameter for different technologies.

There is also an uncertainty element in new technology. The capital/operating relation cannot be known with certainty. Moreover, there can be operating problems that are sufficiently severe as to require significant repair times and costs. We call these "major outages." These cannot be controlled by the project developer. Major outages have occurred with demonstration stage projects and during project start-up. We treat these major outages as involving both a loss of capital, i.e. a need for replacement equipment, and a delay in commercial operation. The cost and duration of major outages is modeled as exponentially distributed with a mean and standard deviation that must be estimated. There

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distributed with a mean and standard deviation that must be estimated. There is only one random variable that determines both the cost and the duration of the major outage, and these two outcomes a related by a proportionality factor that is a model input. The exponential distribution is commonly used in studies of equipment and system reliability (see Barlow and Proschan, 1975). One of its properties is that the mean and standard deviation are equal. The basic model of major outages is that they occur during start-up; they require replacement capital, and they result in delays that reduce earnings. The model does not include a permanent reduction in capacity factor in the representation as yet, although this feature can be added. Reductions in capacity factor due to operating problems have been documented in the engineering literature on CFBs (see Moll, et. al., 1989).

We distinguish between the deterministic and probabilistic aspects of performance. The relationships in Figure 2 are deterministic. We refer to performance of this kind as "capacity factor*." This terminology differentiates the performance measure from the more common use of the term capacity factor which typically is used to include the random element as well.

4.2 Financial Constraints

Projects must not only appear to be profitable under the best of circumstances, they must also demonstrate that under worst case conditions they have a high probability of at least returning the capital of investors. We refer to the adequacy of payback in the worst case as "bankability." To keep the model simple we do not explicitly model debt/equity ratios or other aspects of project finance in any detail. Rather we are trying to capture the threshold question of whether financial risks from projects are sufficiently managed so that firms could attract debt investors. This threshold question can be shown to boil down essentially to a very low probability of project default (see Appendix A, which is based on Stiglitz and Weiss, 1981).

We use our probability distribution of major outages as the link between the technology risk and the financial risk. The firm's profit is characterized as a probability distribution. The uncertainty is technology driven. Government cost-sharing improves expected profit. A project is deemed bankable if it will only generate negative profit 2% of the outcomes. The bankability criterion, i.e. the assumed maximum tolerable probability of zero profit, can also be varied. The model of CCT projects calculates a quantity called "Critical Capital Subsidy," which for a given configuration is the capital subsidy which will make a project bankable.

The bankability criterion defined here is a useful measure of the financial constraints facing developers. In the private wholesale power market under PURPA, financial constraints are often the limiting factor on the viability of projects. Tax benefits or other government incentives can strongly influence financial viability (see Kahn and Goldman, 1987). The trade press reports that increasing maturity of technology and the experience of individual firms is making it possible for a few private power projects to obtain for 100%

debt financing of capital requirements (see Independent Power Report, 1989). This is quite close to the financial characterization of our model.

4.3 The Profit Function

Firms earn profits from both market prices and government incentives. We represent return based on market prices flowing from either a regulated utility rate of return on capital investment or from private wholesale power contracts. Market returns accrue as fixed payments (rate-base rate of return or wholesale capacity payments) and operating profits (operating margin above variable production cost). Of the two elements, the fixed payments will typically be larger. We assume that projects must perform at some minimally acceptable operating rate to earn these fixed payments. In the examples discussed below, this minimum (called "fmin") is set at 40%. For simplicity we confine the analysis to a ten year operating horizon. This is defined as the loan period. In our examples, we assume that the period during which government subsidizes operations is five years, a period which should be sufficiently long to demonstrate commercial operability.

Firms make two choices that determine profit. First they choose a technology and second they choose a level of investment, i.e. capital. Technology choice amounts to the selection of a curve such as those shown in Figure 2; a major outage probability distribution accompanies each such curve. The level of investment is determined by picking a point on one of the technology curves. This choice is influenced by the structure of incentives available from the government. Capital cost sharing flows directly to profits and/or risk reduction by offsetting investment cost. It has no direct influence on performance, given a fixed level of investment. Performance based cost-sharing affects expected output by rewarding it. Depending on the magnitude of the reward and the shape of the capital/Capacity Factor[*] technology function, the performance of the bidder's project will be affected more or less. The profit function is given by the following expression.

Profit = Market Return + Government Subsidy - Investment - Capital Loss,

where Market Return = Capital Payment + Operating Margin * Output, and

Government Subsidy = Capital Subsidy + Operating Subsidy.

Developer's behavior is modeled by assuming profit- maximization given technology choice and government incentive structure. With these inputs fixed, the developer chooses the optimal level of capital. The model will then calculate the following outputs: (1) capacity factor*, (2) total government cost sharing, and (3) the capital cost subsidy necessary to achieve financial viability. The model is solved for a range of operating and capital subsidies. Results are plotted along with key input values on a graph such as Figure 3. These figures contain general input information on the bottom panel. The particular values of CS and

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PS correspond to one example which is characterized under "outputs." The graph includes the whole range of parameter values for CS and PS. All variables are defined precisely, equations are given and detailed examples are shown in Appendix B. The graph shows that capacity factor will increase above fmin as the level of price subsidy increases. Without these contingent subsidies, DOE would not attract participants in the CCT program who were highly confident that they could maintain high levels of performance.

This case is intended to represent a fluidized bed boiler financed under rate of return regulation. One particular configuration is listed under "Outputs." For this case, the capital cost ("In-place capital") of $178 million, or $1780/kW, is representative of this technology. We show a zero value for the operating margin, since regulated utilities typically do not earn profits from variable production. We limit the capital subsidy here to $50 million and the operating cost share to $24/MWh. The capital payment represents approximately 15% on investment. The cost of an "average" major outage is $10 million, and results in a one and a half month delay. Note that the upper panel shows "capacity factor*" for a range of operating subsidies; on the lower panel for this particular case the conventional capacity factor is calculated. In this example, the project earns an operating margin of $3/MWh. This can arise from economy energy sales to other utilities. The expected value of capacity factor is 60%, the worst case is 55%. Expected government subsidy is $113 million; worst case is $108 million. Expected profit represents the return above the rental rate on capital. It corresponds to the economic notion of excess profit. It is expressed as present-value dollars over the ten year operating horizon. Note that the project is "bankable" because even in the worst case there is still positive profit.

4.4 Further Examples Using the Model

The discussion so far has focussed primarily on the case of a single firm which has made its technology choice. It is important to understand the diversity of technology choices and developer configurations, so the basic model needs to be run a number of times over various technology and financial parameters. It is also important to show the influence of changes in government policy. Figure 3 shows, in the graphical portion, changes in capital investment and expected capacity factor as the level of operating subsidy is varied over the range from 0 to $40/MWh. This is with the fixed technology and market parameters listed under "Inputs."

In Figure 4 we show a variation on Figure 3 where the changes are in subsidy structure. We consider a case where the capital subsidy is $33 million and the operating subsidy is $30/MWh. All other parameters are fixed. The total government subsidy increases by $3 million in this example compared to the particular example highlighted in Figure 3. It is important to notice that by changing the incentive structure we have changed developer behavior and expected output. Figure 4 shows that the developer invests $3 million more and this increases expected capacity factor from 60% to 63% even though technical risk has not changed at all.

Next we illustrate a case involving higher technical risk, representing gasification/combined cycle technology. Compared to fluidized beds, this technology is less capital-intensive, but has higher technical uncertainties. Figure 5 shows a case where the capacity factor and government subsidy are roughly equivalent to the previous examples, but they arise out of very different underlying conditions. This case involves lower capital costs ($1160/kW), but more serious major outages (the delay factor is 2 vs. 1 in the previous cases, together with other parameter changes the result is an expected delay of 4.8 months). The expected cost of outages must be normalized to in-place capital to measure its financial impact. For the Figure 5 example this cost is 8.6% compared to about 5.5% for the Figure 3 and 4 cases. To compensate for this increased financial risk, expected returns are higher, particularly when normalized to investment. Notice that this is true despite a reduction in the capital payment which is nearly proportional to the differences in capital costs.

4.5 Using the Model for Program Design and Implementation

Models are useful to help organize our thinking in complex situations. This model brings together technology, financial and government policy variables in a context of private profit maximization. By estimating parameters for different technologies, DOE can determine a value for the exceptional project that is consistent with marketplace requirements and limits the government's contribution to reasonable levels. This estimation will not be a trivial task. Available information is limited and fragmented. DOE must get engineers and economists working together to assemble the required estimates. The process will be iterative. Some of the best data may come in the form of responses to the Program Opportunity Notice for rounds four and five. The model can serve as a reality check on the proposals of bidders and an organizing process for data in these solicitations. We will address some of the implementation issues associated with giving the CCT program a performance basis in Section 6. Before turning to those issues, however, we will argue that basing the selection of winners on the cheapest bids for operating subsidy per MWH is economically efficient.

5. Auction Format and Optimality

We would like to design a structure for the CCT program which links the performance of projects with government subsidies. Furthermore, it would be desirable to have participants bid for the level of performance subsidy they require, and select winners by choosing those who require least. These general design criteria can be implemented in a number of ways. In this section we outline the pre-conditions for running a CCT incentives auction based on performance and examine the efficiency of different approaches.

To insure that DOE does not accept frivolous bids, the CCT program should impose threshold requirements on bidders that provide assurances of capability and serious intent. These threshold requirement will probably resemble the kind of information currently collected from program applicants. It is an open question whether DOE should publicly

announce what these requirements are in advance. The argument in favor of such announcements is that it will clarify bidders expectations. The argument against is that it may be unduly constraining.

A similar issue concerning advance announcement of requirements concerns the maximum output subsidy that DOE will tolerate. Telling bidders in advance what this level is may create a tendency to reduce the level of price competition. They may all bid near the announced "reservation price" on the theory that no one else will respond. The difficulty with no announcement is just unnerving effect of no guidance on the ability of potential bidders to decipher DOE's intentions. On the other hand, if the CCT program pursues our scheme, intelligent bidders will simply read this report. We have no firm opinion on this point; it may require further study.

A basic concern that bidders will have with the performance based approach is the lack of non-contingent capital subsidies. They can be expected to argue that the pure performance approach is actually inefficient because it increases uncertainty and therefore raises the risk cost of doing a project.

Careful analysis reveals that these arguments have considerable merit. We demonstrate that the pure performance approach is only economically optimal if the risk tolerance of the capital market is high. Since this is not really the case, then capital subsidies can play an important role. The auction design problem becomes an exercise in constructing the appropriate mix of capital and performance based subsidies.

It is useful to recall that market incentives for performance are very strong for operating levels up to the rate we have been calling fmin. Because rate base return or capacity payments are such a large portion of the return to projects, there are very powerful incentives to achieve this level of performance. Beyond the fmin output level, there is much less profit incentive for additional production. This is the point at which DOE operating incentives can play a very constructive role. We can show with some relatively simple examples that a mixed system of capital and operating subsidies is less expensive to the government than a system based entirely on operating subsidies.

These arguments are illustrated in detail in Appendices C and D. The first issue involves the conditions under which a pure performance system is economically optimal. We show in Appendix C that in a world without capital constraints, then simply having bidders make operating subsidy offers along the DOE indifference curves will yield an optimal result. The bankability constraint, as represented in our model, means that this simple situation will not actually obtain. Only if the default probability which the bank uses to evaluate worst case outcomes is sufficiently high, will there be a convergence between the best bids from both the private and government points of view.

More light is shed on this situation by means of concrete examples in Appendix D. Here we compare two bidding systems using the examples illustrated in Figures 3-5. One system is based on the pure performance criterion. In this case we assume that the bidder will offer the operating subsidy that just meets the bankability constraint. This subsidy will

be paid over the operating range above the zero value point (i.e. f.null in Figure 1). The second system we examine is mixed. Bidders are offered a fixed capital subsidy of $50 million for a 100 MW project, and then offer an operating subsidy rate. We assume that the bidder in this case will be paid only on output above fmin, and again picks a subsidy rate that that just meets the bankability constraint. The examples show that the mixed system always costs DOE less money. Essentially, the extra cost is a risk premium that the banks extract from the government because returns in the pure performance case are more uncertain.

These examples do not predict the optimal auction format. Further research would be necessary to determine the precise parameters for bid evaluation that would yield the most efficient outcome. Nonetheless the results are instructive. The $50 million capital subsidy is somewhat less than half the total government cost share. By specifying the capital subsidy, we reduce the bid evaluation problem to the simple form suggested by the pure performance approach to CCT incentives. While more complicated rules are possible, we would have to investigate whether any efficiency gains obtained would be worth the additional complexity.

The simple mixed scheme we use is reasonably close in form to DOE's current procedures. The key difference is that the operating subsidies are made strictly contingent on performance. Further, these subsidies should only take effect for output above the level we call fmin. This gives the participant strong incentives to choose designs which are reliable and to use efficient operating procedures. By shifting toward a performance basis for operating subsidies, DOE would promote the commercialization objective.

6. Budgetary and Administrative Aspects

Performance based cost-sharing will involve some budgetary complexities. The principal issue surrounds the uncertain outlays in an environment where payments to participants are tied to performance that cannot be predicted very accurately in advance. To meet its budget constraint DOE must predict how much its program participants will produce and multiply this estimate by its cost per unit of output (i.e. the project-by-project weighted average of winning bidders prices) to determine its financial obligation. Even with the best output predictions the resulting estimate is unlikely to match the budget. This leaves room for negotiation with marginal bidders. We distinguish the budget problem at this stage from the problem of an actual implementation of a performance based system. It is the latter that requires our attention because of the potential for incentive effects under different administrative rules.

We focus on the situation where DOE has selected winners and negotiated agreements with them based on estimates of project performance. These estimated capacity factors presumably meet the CCT budget constraint. In practice, however, DOE cannot expect that its estimates will be realized. Some projects will perform better than expected, some will perform worse. DOE should not deviate from the announced structure of the performance basis for cost-sharing. It should pay on the basis of actual results. On the average it might be

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expected that the better performers will be exactly balanced by the poorer performers, so that budget outlays equal expected costs. What if this does not occur? We consider two cases: either the obligation falls short of the allocated funds (aggregate under-performance), or it exceeds allocated funds (aggregate over-performance).

The under-performance case leaves DOE with unobligated funds. In this situation there is likely to be political pressure from poor performers urging DOE to pay their expected subsidies instead of what they actually earned. It will be argued that "Acts of God" or other circumstances out of their control were responsible for the unsatisfactory outcome. In the extreme, these claims can relieve participants of all responsibility and reduce the program to paying non-contingent subsidies. If DOE wants to consider such reasoning at all, it would be best to clarify this at the very start, in the Program Opportunity Notice. This kind of situation, known as "force majeure," has been the source of much litigation in the private power industry.

A useful example of the anticipatory approach to limiting the impact of force majeure claims can be found in the New Jersey Board of Public Utilities Stipulation on Bidding Programs (1988). This document defines cases where force majeure claims will be allowed and where they will be rejected. The only situations where these claims are allowed involve either natural disasters or acts of government agencies (other than enforcement of known regulations). Losses resulting from economic circumstances such as strikes or fuel supply interruptions are excluded.

Assuming there are unobligated funds resulting from the under-performance case, DOE should allocate them to the superior performers. This makes the performance incentive much like a contest. "Prize money" could be allocated either by balancing the books at the end of every year, or over the entire duration of the program. There are benefits to each approach. The advantage to holding the unallocated funds across a number of years is that eventually DOE might have a year when all projects perform above expectations. In the over-performance case DOE will not have sufficient funds to pay all participants at their promised rate unless there has been a specific reserve allocated for this purpose back at the project selection stage. If no such reserve was allocated, or if it is insufficient, then holding over unallocated funds from under-performing years can help to make up the deficit.

Alternatively, DOE may decide not to hold over funds and not to allocate an initial funding reserve for the over-performance case. This will transfer some of the overall randomness of outcomes to program participants. For the successful projects, there may be a larger gain in this case than under a more conservative approach because there will not be any delays in compensation for superior performance. In this case, however, DOE would be obligated to inform potential bidders that under some circumstances the full operating subsidy might not be paid. Some more careful analysis will be required to determine the best policy to account for forecasting uncertainty in allocating the CCT budget under a performance based system.

7. Unresolved Implementation Issues

This report has presented a simple analysis of a performance based cost-sharing approach for the CCT program. While the general framework we present is plausible, it is not a blueprint for program design. This has only been a conceptual development effort, not an implementation plan. To the degree that the arguments presented here are reasonable, however, they suggest a variety of tasks that would be required to make the transition from a conceptual approach to a plan for implementation. In the interest of clarity we conclude by enumerating unresolved issues and making some suggestions about how to approach them. We focus these concluding comments around two basic sets of issues: (1) technological diversity, and (2) uncertainty analysis.

Our discussion of technological particulars has been highly limited. We have only treated re-powering technologies, and even those at a very high level of generality. Since the CCT program includes more than these technologies, there is a threshold question concerning whether our approach can be extended to alternative fuel forms or retrofit technologies. We are not prepared to give an unambiguous answer to this question now. Even within the domain of re-powering we have largely suppressed question of alternative scale in different projects. Does DOE want one big project or two equivalent smaller ones? We have not distinguished between these alternatives so long as both gave the same output. Perhaps there is a value to replication in two small projects. Alternatively, the scale economies of one large project might be more attractive.

Uncertainty is ubiquitous in technology development and commercialization. It has received surprisingly little explicit attention in the analysis tools used by the CCT program. While our model of bidder behavior incorporates uncertainty in several ways, it still leaves the user with difficult parameters to estimate. We re-iterate these here. The relation between investment cost and output is currently specified in our model with a two-parameter function. Perhaps this particular function is not the best representation of the capital/output relation, but some such function must be estimated. While this does not necessarily involve probabilities explicitly, it is certainly not something that is known with certainty. The model also has a component that allows for "major outages" and their cost. This also involves parameters that must be estimated, but are difficult to grasp. Perhaps the creative use of engineering contingency methods would help with these questions.

Finally our discussion of budget issues in Section 6 highlights the need for DOE to make output estimates for the projects it selects in order to decide how many projects can be supported. These estimates cannot be expected to be very accurate. Budget allowances will be required to deal with inaccuracies. Without proper attention to this issue the program may end up blunting performance incentives instead of encouraging them.

This report may leave the reader with the impression that more questions have been raised than answers given. At bottom our approach is simple. The electricity marketplace rewards performance. For clean coal technologies to compete successfully they must demonstrate performance that meets marketplace standards. The best way for the CCT

program to achieve this is to reward performance by program participants. Achieving this orientation within the budgetary, institutional, and political constraints facing the CCT program is the challenge we have tried to delineate.

Figure 1 - DOE Indifference Curves
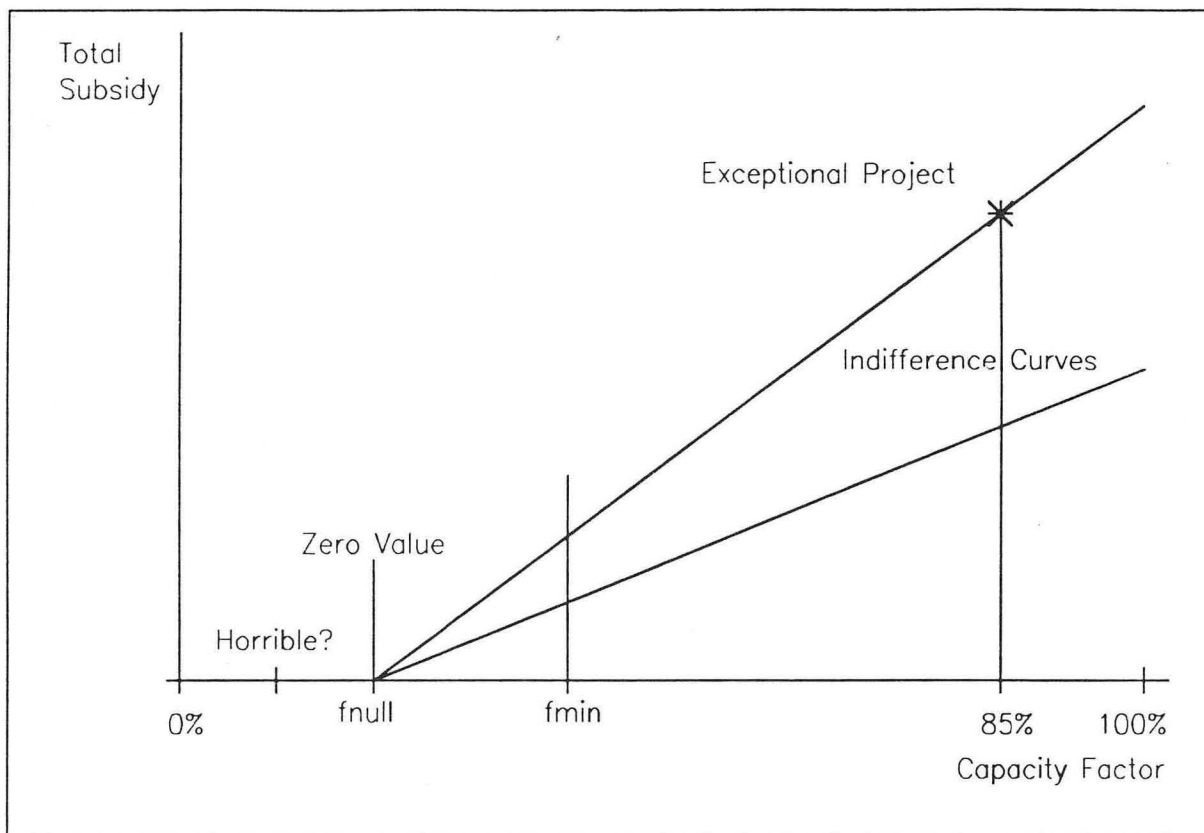
The Family of Capacity Factor* Functions
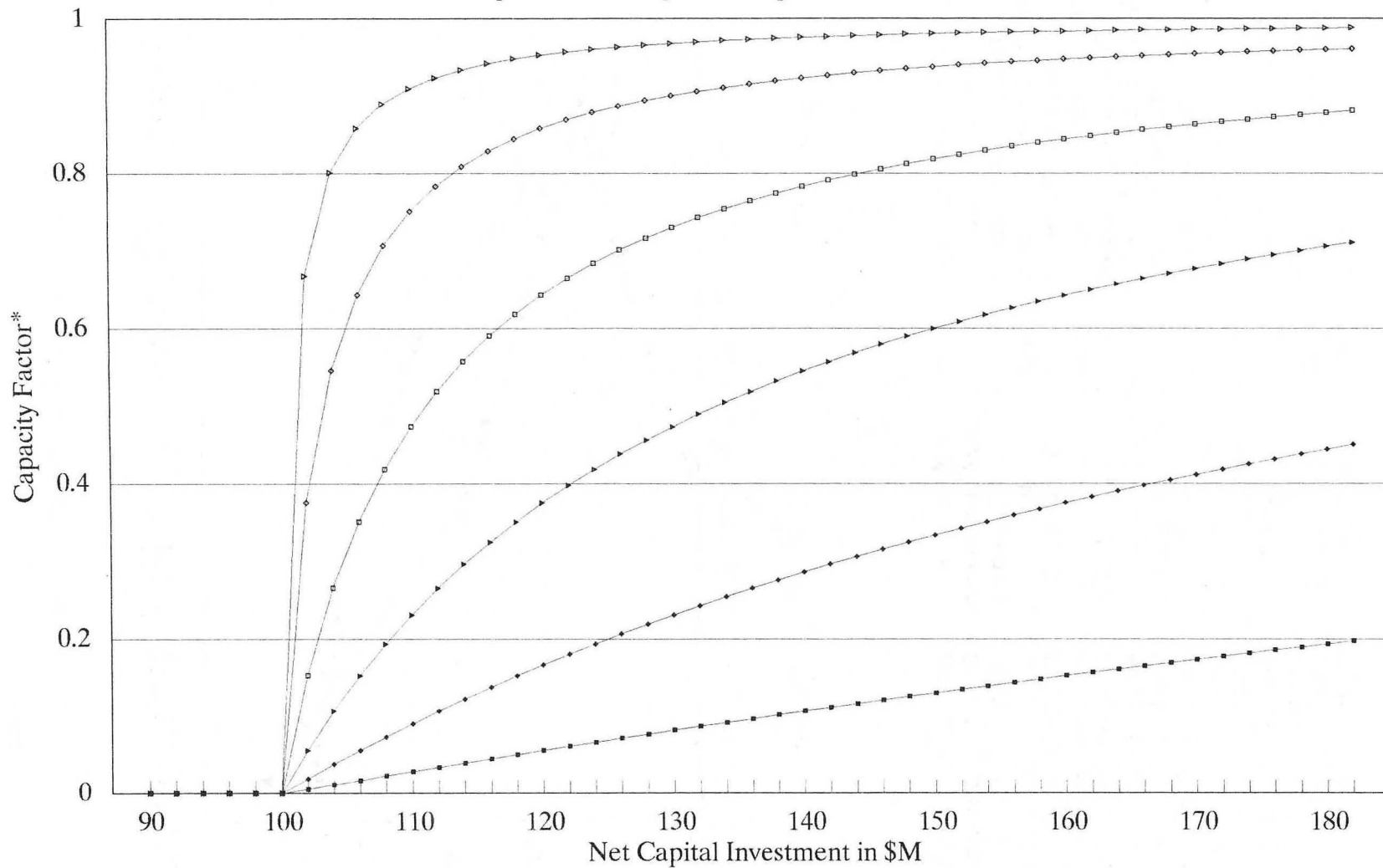
Figure 3 - Fluidized Bed Example: Regulated Case

Bidder's Response to Price Subsidy

Legend:
- ■ Capacity Factor*
- ◆ Critical Capital Subsidy
- ▲ Total Subsidy

X-axis: Price Subsidy ($0 to $80)
Left Y-axis: $ Millions (0 to 300)
Right Y-axis: Capacity Factor* (30% to 90%)
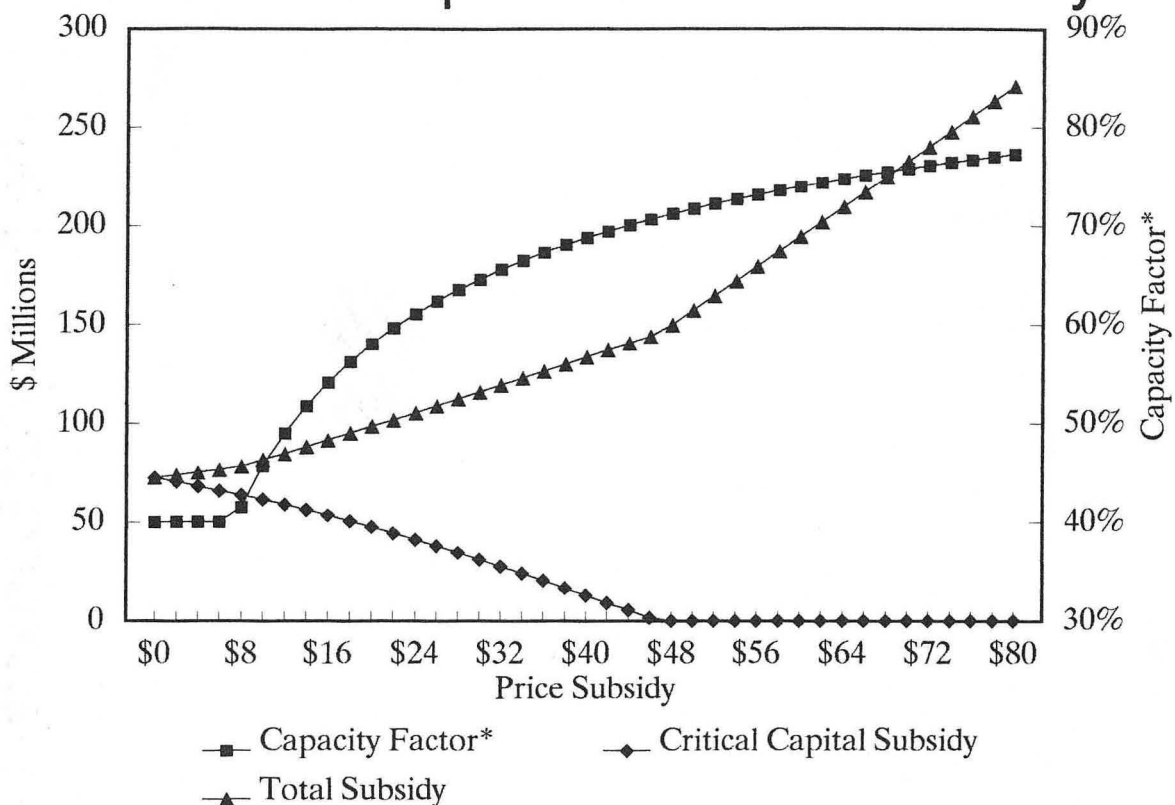
INPUTS:					OUTPUTS:	
Capital Subsidy	CS	$50 M	DOE		Expected	Worst
Price Subsidy	PS	$24.0 /MWhr	DOE		Expected	Worst
Subsidy Duration	S.yrs	5 years	DOE		========	=====
f of Zero-Value Project	f.null	20%	DOE		In-Place	Capital
Capital Payment	CP	$250 k/MWyr	Market		$181	$181
Min f() to receive CS & CP	fmin	40%	Market		--------	-----
Operating Margin	M	$3 /MWhr	Market		Capacity	Factor
Loan Interest Rate	LR	12.0%	Market		60%	55%
Term of Loan	L.yrs	10 years	Market		--------	-----
Max Loan Default Rate	DR	2%	Market		Total Subsidy	
X-intercept of f()	b	$160 M	Tech.		$113	$108
Shape of f()	shape	12.0	Tech.		--------	-----
Mean and SD of Capital Loss	s	$10 M	Tech.		Profit	
Delay Factor	DF	1.0	Tech.		$51.07	$8.85
Construction time	C.yrs	2.0 years	Tech.		--------	-----
Capacity	Cap	100 MW	Tech.		Bankable?	Yes

Figure 4 - Fluidized Bed Example: Alternate Subsidy Structure

Bidder's Response to Price Subsidy
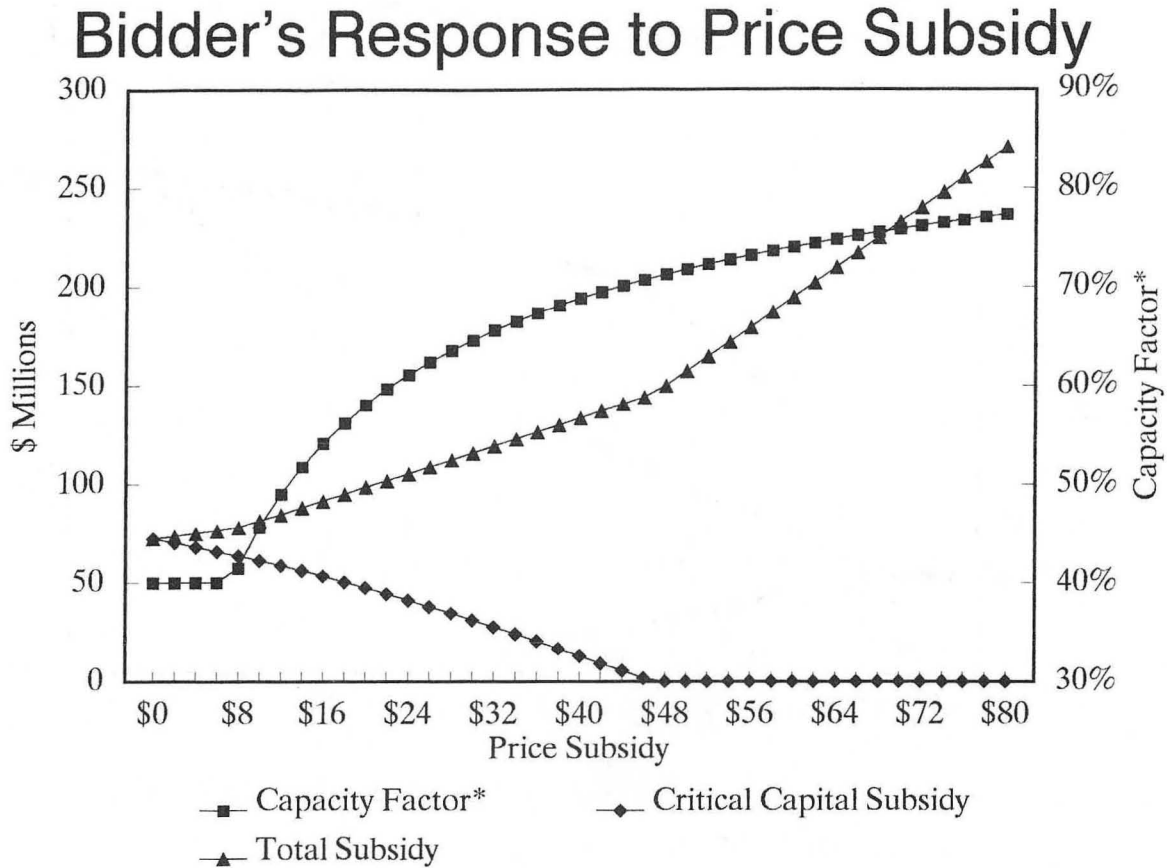
INPUTS:

						OUTPUTS:	
Capital Subsidy	CS	$33 M	DOE		Expected	Worst
Price Subsidy	PS	$30.0 /MWhr	DOE		========	=====
Subsidy Duration	S.yrs	5 years	DOE		In-Place	Capital
f of Zero-Value Project	f.null	20%	DOE		$184	$184
Capital Payment	CP	$250 k/MWyr	Market		--------	-----
Min f() to receive CS & CP	fmin	40%	Market		Capacity	Factor
Operating Margin	M	$3 /MWhr	Market		63%	58%
Loan Interest Rate	LR	12.0%	Market		--------	-----
Term of Loan	L.yrs	10 years	Market		Total Subsidy	
Max Loan Default Rate	DR	2%	Market		$116	$110
X-intercept of f()	b	$160 M	Tech.		--------	-----
Shape of f()	shape	12.0	Tech.		Profit	
Mean and SD of Capital Loss	s	$10 M	Tech.		$45.59	$1.98
Delay Factor	DF	1.0	Tech.		--------	-----
Construction time	C.yrs	2.0 years	Tech.		Bankable? Yes	
Capacity	Cap	100 MW	Tech.			

Figure 5 - Gasification Case

Bidder's Response to Price Subsidy

Legend:
- ■ Capacity Factor*
- ◆ Critical Capital Subsidy
- ▲ Total Subsidy

INPUTS:					OUTPUTS:	
Capital Subsidy	CS	$50 M	DOE			
Price Subsidy	PS	$24.0 /MWhr	DOE		Expected	Worst
Subsidy Duration	S.yrs	5 years	DOE		========	=====
f of Zero-Value Project	f.null	20%	DOE		In-Place	Capital
Capital Payment	CP	$180 k/MWyr	Market		$116	$116
Min f() to receive CS & CP	fmin	40%	Market		--------	-----
Operating Margin	M	$0 /MWhr	Market		Capacity	Factor
Loan Interest Rate	LR	12.0%	Market		57%	42%
Term of Loan	L.yrs	10 years	Market		--------	-----
Max Loan Default Rate	DR	2%	Market		Total Subsidy	
X-intercept of f()	b	$100 M	Tech.		$110	$95
Shape of f()	shape	10.0	Tech.		--------	-----
Mean and SD of Capital Loss	s	$10 M	Tech.		Profit	
Delay Factor	DF	2.0	Tech.		$60.92	$1.30
Construction time	C.yrs	2.0 years	Tech.		--------	-----
Capacity	Cap	100 MW	Tech.		Bankable?	Yes

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Credit Rationing for Multi-Period Risky Projects

Motivation

Some projects pose operating risks that are so large they cannot attract capital. If the government were to underwrite the start-up risk in these cases, then credit might become available for such projects. This scenario is the motivation for start-up insurance subsidies that have been discussed by DOE. In this Appendix we set up a model of bank lending in the situation where the borrower gets a loan in period 1 ("construction"), but may need additional capital in period 2 ("start-up"). Lenders are aware of the problem that borrowers may need to come back for additional capital infusions if there has been insufficient initial investment. In the model described below the bank has an incentive to fund the initial investment adequately so that subsequent back-up lending is less likely. We will use this framework to define a condition on the ultimate probability of project success which determines whether the initial loan will be made at all.

Relation to Maximum Loan Default Rate

In our analysis of bankability, we model banks as requiring the loan default probability to be less than some threshhold, DR. So unlike the developer, they are not interested in the expected value of a project, but rather in the probability that it will realize a negative profit. This we believe is a good representation of the rule of thumb actually used by the banks. What should be noted here is that this rule of thumb is designed to maximize the bank's own expected profit, which is not at all the same as the project's expected profit. In the present appendix we assume that banks will not lend unless they expect a profit greater than zero. This is in keeping with the economists definition of profit which includes all costs including the cost of capital. If the bank is risk averse then it will require a risk premium, which amounts to increasing the expected profit threshhold to a positive value.

It would be desirable to explain the banker's rule of thumb on loan default rates by considering the bank's expected profits, and the constraints on credit described by Stiglitz and Weiss, but that task is well beyond the scope of this paper.

Model

The framework described here derives from Stiglitz and Weiss, "Credit Rationing in Markets with Imperfect Information," American Economic Review, v.71, no.3 (June, 1981), 393-410.

Notation

L = initial loan in period 1, repaid at end of period 2

M = additional capital required at start of period 2 if
      project does not succeed in period 1

P_1 = probability of success in period 1

P_2 = probability of success in period 2 (independent of
      outcome in period 1)

r_1 = interest rate on L, $\quad R_1 = 1 + r_1$

r_2 = interest rate on M, $\quad R_2 = 1 + r_2$

c = bank cost of funds, $\quad C = 1 + c$

The loans are repaid at the end of period 2 unless there is failure in both period 1 and period, in which case they are never repaid. We now develop a formula for the bank's expected profit by considering the three possible outcomes and their probabilities. The first outcome to consider is success in period 1. That happens with probability P_1, and in that case

$$Income = R_1^2 \cdot L$$

$$Cost = C^2 \cdot L$$

With probability $(1-P_1) \cdot P_2$ there will be failure in period 1 but success in period 2. In that case

$$Income = R_1^2 \cdot L + R_2 \cdot M$$

$$Cost = C^2 \cdot L + C \cdot M$$

The third case is failure in both periods in which case there is no income but cost is the same as in the previous case. By taking an average of these three cases weighed by their probabilities we can find expected profit as follows:

$$E(\pi) = P_1 \cdot R_1^2 L + (1-P_1) \cdot P_2 \cdot (R_1^2 \cdot L + R_2 \cdot M) - [C^2 \cdot L + (1-P_1) \cdot C \cdot M]$$

It is useful to reorganize this equation, grouping together the terms that include L and those that include M.

$$E(\pi) = [(P_1 + (1-P_1) \cdot P_2) \cdot R_1^2 - C^2] \cdot L + (1-P_1)[P_2 \cdot R_2 - C] \cdot M$$

The contents of the two pairs of square brackets we now denote by A and B respectively.

$$E(\pi) = A \cdot L + (1-P_1) \cdot B \cdot M$$

We can now see that $E(\pi)$ will be positive for all combinations of postive M and L if and only if $A > 0$ and $B > 0$. These conditions give us two constraints on the probabilities P_1 and P_2, namely:

$$B > 0 \quad \rightarrow \quad P_2 > \frac{C}{R_2} \qquad (1)$$

$$A > 0 \quad \rightarrow \quad P_1 + (1 - P_1) \cdot P_2 > \frac{C^2}{R_1^2}$$

We do not mean to imply that both conditions must be satisfied, only that these would have to be satisfied for the bank to be unconcerned about the size of M and L. Generally the initial loan, L, is more likely to be profitable than the follow-up loan M. This is because, while the chance of default on M is $(1 - P_2)$, on L it is only $(1 - P_1)(1 - P_2)$, which is generally considerably smaller. This means that equation (1) is the constraint most likely to be violated.

If $A \cdot L > 0$ then the bank would be willing to finance the project even if constraint (1) is violated provided it has some assurance that its losses on M will be limited. This means that M itself must be limited. This is a potential role for DOE. To find what limit DOE must put on M in order to induce the banks interest, we assume $A > 0$ and $B < 0$, and then compute the largest acceptable M/L.

$$E(\pi) > 0 \quad \rightarrow \quad A \cdot L > (1 - P_1) \cdot (-B) \cdot M$$

$$\frac{M}{L} < \frac{A}{(1 - P_1) \cdot (-B)}$$

This put an upper limit on M/L and then on M for any particular L. In order to get a sense for the effect of this limit we make a small numeric calculation. Assume $c = 8\%, r_1 = 10\%$, $r_2 = 15\%, P_1 = .7$, and $P_2 = .9$. In this case, without the backing of DOE, the bank would find condition (1) violated because

$$P_2 = .9 < \frac{C}{R_2} = .94.$$

Therefore the bank would not finance the project unless DOE assured it that

$$\frac{M}{L} < .54$$

This means that DOE would have to assure the bank would not have to lend more that .54 times as much as its initial loan.

In the case where the bank will loan for any combination of M and L, then it is constraint (1) which is binding. This simply means that the ultimate probability of project success must be high for banks to lend since C will be close to R_2.
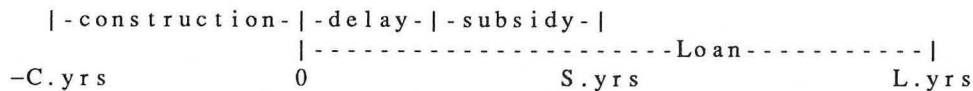
Appendix B
Description of the Model

Description of the CCTIM Model

The Inputs

The model describes a sequence of events that represent a typical Clean Coal demonstration project. That sequence begins with construction, and is followed by a delay of random length caused by technical difficulties. The operating subsidy does not begin until actual effective operation which comes at the end of the delay. As a simplification, the loan is modeled as if it started at time 0. Technically this means the loan value has the interest payments for the construction years capitalized into its value. The figure below serves to define the model variables (delay, C.yrs, S.yrs, and L.yrs) that measure time, and to illustrate the described sequence.

```
   |-construction-|-delay-|-subsidy-|
                  |---------------------Loan-----------|
-C.yrs            0                 S.yrs              L.yrs
```

The top of the first page of the CCTIM model displays its inputs and some of its most crucial outputs. A description of these will provide an introduction to the model.

Policy Inputs:

CS: Capital Subsidy is all paid at time zero. And depends on performance only to the extent that a certain minimal operating rate is required.

PS: Price Subsidy is paid strictly in proportion to production during the Subsidy period. This period starts at a date certain, so any construction delays cause a loss of subsidy.

S.yrs: The Duration of the price Subsidy period. This period starts at the target date for the end of construction, whether or not construction is complete.

f.null: This is the capacity factor of what DOE considers to be a "worthless" project. Such a project neither encourages nor discourages the adoption of clean coal technology by the market.

CS.Bid: In figures D-3, D-4, and D-5, two auction strategies are compared. One auction uses CS.Bid1 in place of CS, and the other uses CS.BID2.

f.Bid: This is the second auction parameter and specifies the capacity factor above which the operating subsidy will be paid.

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V.xcep: This is the value of an "exceptional" project; that is, one that operates at an average capacity factor of f.xcep By value we mean the most that DOE would be willing to pay if the choice was between this project and no project.

f.xcep: This is the capacity factor of the "exceptional" project.

Market Inputs:

CP: Capital Payment is the return on the amount of capital that the PUC allows in the rate base, or the private producer receives as a capacity payment, provided the operating factor is above fmin.

fmin: Fmin is the minimum capacity factor* that must be achieved in order to satisfy the PUC. Note that the model does not quite enforce this rule (and neither may the PUC) but instead only requires that the project put in place enough capital, and keep it repaired, so that after an average size major outage the capacity factor* will still average f(), (this function is defined in the technology input section). Note that capacity factor* is defined as the average excluding the time during which the major outage is being repaired.

M: Operating Margin is the revenue, net of operating costs, that the project will receive from market sources per MW hour of generated energy.

LR: This is the "loan rate", or nominal interest rate on the project's bank loan.

L.yrs: The term of the Loan. For simplicity this is modeled as starting on the same date as the subsidy period, i.e. at the target date for completion of construction. Before this time a short-term bridge loan is used and it's cost is counted as part of the cost of construction.

DR: DR is the maximum loan Default Rate that the lender will tolerate. For example if the lender will not make a loan if it believes that the probability that it will not be repaid on schedule is less than 98%, then DR is set to 2%.

Technology Inputs

f(): The capacity factor* function is not an input, but is determined by the next two input parameters, *b* and *shape*. It computes the average capacity factor* over the life of the subsidy period from the capital invested, under the assumption that major outages do not cause delays or do not occur.

b: f() has two parameters, **b** (base capital) and "**shape**". The x-intercept of f() is given by **b**. The function is zero to the left of the x-intercept, at which point sufficient capital has been invested to complete the project in a minimal way.

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shape: The steepness of f() is given by **"shape"**.

Ex,Wx: The cost to fix a major outage is a exponentially distributed random variable, which we call the capital loss, x. Because it is random it is generated by the model, using "s" as it's mean and standard deviation (always the same for an exponential distribution), and thus is not directly input by the user. Ex is the expected capital loss and Wx is the worst case capital loss.

s: The mean and standard deviation of the actual capital loss, x. X has a exponential distribution whose density is given by $\frac{1}{s}e^{-x/s}$. If the probability of finding a value of x greater than "Wx" is p, then $Wx = -ln(p) \cdot s$

DF: The Delay Factor which governs the severity of the delay caused by a capital loss, x. This delay will cause a loss of price subsidy (PS), capital payment (CP), and operating margin (M). The delay is calculated as $DF \cdot C.yrs \cdot (x/b)$, where c.yrs is the expected time for construction, and b is the base capital cost. This means that if half of the base capital is destroyed and the delay factor is 2, the repair will take the full construction time.

C.yrs: The expected construction time in years.

Cap: Capacity in MWs is the rated capacity of the project.

Model Inputs:

maxPS: This is the maximum Price Subsidy that will appear on a graph or table. It represents the larges Price Subsidy that DOE wishes to consider in this analysis.

The core of the model is contained in the first two pages of the spreadsheet. These are reproduced at the end of this section. Following them is a list of all the equations hidden within the cells of these two pages. The rest of the model consists of calculations that are equivalent to those presented here, but which are used to construct tables of values on which the model's graphic output it based. The model also contains several pages of programming that make it convenient to display graphs, print output, and save and recall scenarios.

The first model page displays all of the inputs described above plus eight of the most important outputs. The input values can be changed in this panel and new outputs are immediately displayed. The input values for CS and PS are those used to produce the displayed outputs. Most graphs, on the other hand, do not use these values but instead use a whole range of values for *PS*, from zero to *maxPS*.

Calculations

Preliminary calculations are carried out at the bottom of page one. These include factors for taking present values, and for changing units. These calculations are not essential for understanding the model and will not be discussed here. However the equations for these calculations are all displayed in the list of equations at the end of this section.

On the second page of the model two parallel calculations are carried out, one for the expected case and one for the worst cast. Turning first to the Expected Case, we begin with optK, the optimal level of capital if CS and CP were not conditional on the capacity factor*, f, exceeding fmin. This is computed by maximizing profit, π. In the following derivation, *PVmP* and *PVmM* are the present value multipliers for the price subsidy, and for market income (M plus CP). APF and ACF are used to convert units and are defined in the table of equations near the bottom of the first model page.

$$\pi = (PVmP \cdot PS + PVmM \cdot M) \cdot APF \cdot f(K)$$
$$+ PVmM \cdot CP \cdot ACF$$
$$- (K + Ex - CS)$$

The first term accounts for payments that depend on the capacity factor*, f. The second term is the capital payment (CP) made by the utility that buys the power. This is made only if $f > fmin$, but the developer will inevitably choose to invest to at least this level just because CP is contingent on f. The third term measures capital expenditure net of capital subsidy.

$$f(K) = \frac{(K-b)}{(K-c)} \qquad f'(K) = \frac{(b-c)}{(K-c)^2} \qquad c = b - \frac{b}{shape}$$

These equations define the capacity factor* function and its derivative. Now re-write the profit equation emphasizing its dependence on K.

$$\pi(K) = A \cdot f(K) - K - constant, \qquad \text{where}$$
$$A = (PVmP \cdot PS + PVmM \cdot M) \cdot APF$$

Now differentiate profit with respect to K.

$$\pi' = A \cdot f' - 1 = 0$$

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Setting the derivative of π with respect to the firm's single control variable, K, equal to zero provides the first order condition for optimization.

$$A \cdot (b-c) = (K-c)^2$$

We now have a quadratic first order condition, which we solve to find the value of *optK* given below.

$$optK = \sqrt{A \cdot (b-c)} + c$$

This concludes the derivation of the first variable in the calculations panel of the model. At this point we have already determined how the firm will behave and all that is left to find the consequences of that behavior.

Continuing down the calculations page, *Kmin* is the amount of capital expenditure needed to produce an capacity factor* of *fmin*. "In-Place Capital", K, is simply the maximum of optK and Kmin. Capacity factor*, f, is then computed using f(K), which is defined above. Expected capital loss, Ex, is exactly the input parameter s, because we are assuming an exponential distribution. The lost capital will have to be replaced, so the expected capital expenditure will be $CE = K + Ex$.

The value of the loan is simply the CE minus the capital subsidy. We use the loan interest rate as the projects discount rate, therefore when the loan payments are discounted to the present they have a present value exactly equal to the principal of the loan. The PV of the price subsidy stream takes into account that the subsidy does not start until after any delay. This is also the case for capital and operating payments.

Total price subsidy is not a discounted value. DOE has a nominally fixed budget and so we compute the simple sum of the price subsidy payments.

The worst case differs from the expected case because after the contract is accepted and the loan is secured a greater than expected "major outage" occurs. Thus the first variable in the worst-case table that differs from the its twin in the expected-case table is the capital loss. This leads to an increase in the "Worst-Case Capital Expenditure". Because a bigger major outage causes a longer "delay", the present values of the price subsidy, the capacity payments, and the the operating payments are all reduced. This of course reduces profit, and may cause the project to be unbankable even though expected profit is high. DOE's operating subsidy is of course also reduced.

```
INPUTS:        Capital Subsidy            CS      $50 M          DOE    |    OUTPUTS:
                 Price Subsidy            PS      $24.0  /MWhr   DOE    |Expected   Worst
              Subsidy Duration          S.yrs      5 years      DOE    |========  =====
         f of Zero-Value Project        f.null     20%          DOE    |In-Place Capital
               Capital Payment           CP      $250 k/MWyr    Market |  $178     $178
Min f() to receive CS & CP              fmin       40%          Market |--------  -----
              Operating Margin            M        $0  /MWhr    Market |Capacity Factor
           Loan Interest Rate            LR       12.0%         Market |   56%      52%
                Term of Loan           L.yrs      10 years      Market |--------  -----
         Max Loan Default Rate           DR        2%           Market |Total Subsidy
            X-intercept of f()            b       $160 M        Tech.  |  $110     $104
                 Shape of f()          shape      12.0          Tech.  |--------  -----
      Mean and SD of Capital Loss         s       $10 M         Tech.  |Profit
                 Delay Factor            DF        1.0          Tech.  | $42.45   $1.02
             Construction time         C.yrs       2.0 years    Tech.  |--------  -----
                     Capacity            Cap      100 MW        Tech.  |Bankable? Yes
      Capital Subisidy of Bid 1       CS.Bid1      $50 M        DOE    |
      Capital Subisidy of Bid 2       CS.Bid2      $0 M         DOE    |
      f Threshhold for PS, Bid 1      f.Bid1       40%          DOE    |
      f Threshhold for PS, Bid 2      f.Bid2       20%          DOE    |
      Max Graphed Price Subsidy        maxPS       $80          Model  |
Value(Exceptional Project)            V.xcep      $300 M        DOE    |
      f of Exceptional Project         f.xcep      0.9          DOE    |
```

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Preliminary Calculations:

```
      E( Capital-Loss Delay )         delay     0.1 years        1.5   months
        PV multipier for Loan          PVmL     1.00
          PV multipier for PS          PVmP     3.49
      PV multipier for M & CP          PVmM     5.53
         Worst-Case Delay            delay.w    0.5 years
      Worst-Case PVm for PS            PVwP     3.16
Worst-Case PVm for M & CP             PVwM     5.20

Intermediate f() parameter              c      $147
       Annual Price Factor            APF      0.88    $/MWhr --> $M/plant-year
          Annual CP Factor            ACF      0.10    $k/MWyr --> $M/plant-year

                                   Bank.f      57%
                                   Bank.PI     $42
                                   Bank.TS     $110
```

Calculations:		==Expected Case==
Optimal In-Place Capital	optK	$178 M
Min K to receive CPay	Kmin	$169 M
In-Place Capital	K	$178 M
Expected f(IPK)	f	57%
Epected Captal Loss	Ex	$10 M
E(Capital Expenditure)	CE	$188 M
PV of Loan	PV.L	($138)M
PV of Price Subsidy	PV.PS	$42 M
PV of Capital Payments	PV.CP	$138 M
PV of Opperating payments	PV.OP	$0 M
PV of Expected Profit	PI	$42 M
Total Price Subsidy	TPS	$60 M
Total DOE Subsidy	TS	$110 M

Calculations:		===Worst Case===	Expected Value Comparison
Optimal In-Place Capital		$178	=
Min K to receive CPay		$169	=
In-Place Capital		$178	=
Worst-Case f(IPK)		57%	=
Worst-Case Capital Loss	WX	$39	$10
Worst-Case Cap. Exp.	WCE	$217	$188
PV of Loan		($138)	=
PV of W-Case Price Subsidy	WPV.PS	$38.05	$42.06
PV of W-Case Cap. Payments	WPV.CP	$130.02	$138.33
PV of W-Case Op. payments	WPV.OP	$0.00	$0.00
PV of W-Case Profit	WPI	$1.02	$42.45
Bankability	Bank	1	n.a.
Total Price Subsidy	WTPS	$54	$60
Total DOE Subsidy	WTS	$104	$110

Equations from Bottom of input page:

```
delay    = +DF*C.YRS*(EX/B)
PVmL     = 1
PVmP     = @MAX(0,@PV(1,LR,S.YRS)-@PV(1,LR,DELAY))
PVmM     = @MAX(0,@PV(1,LR,L.YRS)-@PV(1,LR,DELAY))
delay.w= +DF*C.YRS*(WX/B)
PVwP     = @MAX(0,@PV(1,LR,S.YRS)-@PV(1,LR,DELAY.W))
PVwM     = @MAX(0,@PV(1,LR,L.YRS)-@PV(1,LR,DELAY.W))


c        = +B-B/SHAPE
APF      = 8760*CAP/1000000
ACF      = +CAP/1000


Bank.f  = +BANK*F
Bank.PI= +BANK*PI
Bank.TS= +BANK*TS
```

Equations from Top of Calculation page:

```
optK     = @SQRT((PVMP*PS+PVMM*M)*APF*(B-C)/PVML)+C
Kmin     = (B-C*FMIN)/(1-FMIN)
K        = @MAX(KMIN,OPTK)
f        = @IF(K>B,(K-B)/(K-C),0)
Ex       = +S
CE       = +K+EX


PV.L     = -PVML*(CE-CS)
PV.PS    = +PVMP*APF*PS*F
PV.CP    = +PVMM*ACF*CP
PV.OP    = +PVMM*APF*M*F
PI       = +PV.L+PV.PS+PV.CP+PV.OP


TPS      = +APF*PS*F*(S.YRS-DELAY)
TS       = +CS+TPS
```

Equations from Bottom of Calculation page:

```
WX       = -@LN(DR)*S
WCE      = +K+WX


WPV.PS  = +PVWP*APF*PS*F
WPV.CP  = +PVWM*ACF*CP
WPV.OP  = +PVWM*APF*M*F
WPI      = +PV.L+WPV.PS+WPV.CP+WPV.OP-(WX-EX)
Bank     = +WPI>0


WTPS    = +APF*PS*F*(S.YRS-DELAY.W)
WTS     = +CS+WTPS
```

Appendix C
Discussion of Bid Evaluation Strategies

Overview

The problem under analysis can be described as that of conducting an auction where bidders can name both a price and a quality but in which quality is not freely observable until after the auction. This problem is easily solved by standard economic theory. In fact the optimal bid evaluation procedure for such an auction, in a rational and perfectly informed system, has undoubtedly been discovered many times. As we will show in this appendix, that solution is to evaluate bids according to the auctioner's preferences. This straight-forward solution is guaranteed to be optimal under certain conditions. Unfortunately, as we will see, those conditions are not satisfied in the present case.

In order to show why the standard result is inappropriate we first state and prove that standard result, and then take a careful look at the necessary assumptions to discover where they are violated by the present real-world case. Appendix D then examines our proposal for an alternative form of bid evaluation which proves to be superior, given the imperfections of the present situation.

Statement of the Standard Result

Assume that DOE's Valuation of a project depends on total subsidy, S, and on capacity factor, f. Formally we write $V(S, f)$. It is impossible for DOE simply to let bidders specify a pair (S, f) because the bidder may not be able to achieve f, and in this case DOE will not wish to pay S. Consequently the best DOE can do is to allow bids of the form $T(f)$; which means that the bidder is providing a table or function that specifies the level of subsidy paid for each level of capacity factor achieved. Of course the bid could also specify the bidder's target for S and f, but since he cannot be held to this target, except in as much as the function $T(f)$ tends to encourage this, such a target could not be trusted and would provide no additional information on which to judge the bid.

DOE could constrain the relationship between S and f in the way prescribed by the standard result, or it could allow the bidder to specify any possible relationship. A bid submitted in accordance with the constraint on T(f) that is imposed by the standard result will be referred to as a constrained bid, while if T(f) is freely chosen by the bidder the bid will be call unconstrained. What we wish to show is that for any given level of profit, π_o, the bidder will choose a constrained bid that is at least as valuable to DOE as the bid s/he would have chosen if unconstrained.

Now the standard result specifies that bids must take a form such that whatever quality level (f) is chosen by the bidder after the auction, DOE will derive the same utility from the bidder. In other words DOE would be indifferent between all outcomes of the project: if it performed well DOE would incur a high total subsidy cost, while if it performed poorly the subsidy would be commensurately reduced. We now see that the standard constraint

specifies a family of functions from which the bidder chooses one as his bid. We will denote this family (parameterized with b) by $S(b; f)$. The parameter b will be used to measure how good a bid is. Because it is based on DOE's utility function, this family can be designed to have the following properties, which hold for all $f, f' > 0$.

P1. $S(0; f) = 0$, and $S(\infty; f) = \infty$.

P2. $S(b; f)$ is monotonically increasing in b for any f.

P3. $V(S(b; f), f) \geq V(S(b'; f'), f')$ if and only if $b \geq b'$.

The first two properties say that DOE's total subsidy increases monotonically from 0 to ∞ as b increases from 0 to ∞. The third property says that no matter what capacity factors are realized, a bid with a larger b will always be preferred to a bid with a smaller b. This is accomplished my making b an indicator of which indifference curve DOE is on, and making $S(b, f)$ lie along the indifference curve indicated by b.

According to these properties the higher is b, the higher is V. Thus when DOE selects winning bids, it need only select those with the highest b. Note that although V depends on both S and f, a bid consists simply of a specification of T(f) and does not include a value for either S or f. Thus a "constrained bid" is completely defined by a choice of b.

Since the firm wishes to maximize its chance of winning the auction it will pick the highest value of b that allows it to realize π; this we call the best constrained bid yielding π_o. This gives DOE the most value, V, and the bidder the best chance of winning while guaranteeing the firm a profit of π_o. We will call this bid b_o, but mean that the subsidy function $S(b_o, f)$ is specified by the bid. Note that the firm must choose the correct f, which we will call f_o, in order to realize π_o under this bid.

We now define the function $\pi(S, f)$ to be the maximum profit that a firm can make if receives total subsidy S and builds for a capacity factor of f. We also make the following definitions for the constrained bid:

C1. b_o is the greatest b such that $\pi(S(b_o, f_o), f_o) = \pi_o$ for some f_o.

C2. $S_o = S(b_o; f_o)$

C3. $V_o = V(S_o, f_o)$

Now define an unconstrained bid for π_o. This is a bid, $T(f)$, that can produce at most π_o for the correct choice of f, called f^*. Now make the following definitions for the unconstrained bid:

U1. $T^* = T(f^*)$

U2. $V^* = V(T^*, f^*)$

U3. f^* maximizes $\pi(T(f), f)$ and $\pi(T^*, f^*) = \pi_o$

We can now state our optimality result formally. It assures us that in an ideal world, DOE cannot do worse by using the standard constraint. In an ideal world, this would imply that DOE would, in fact, do better than if the wrong constraint were imposed, and better than if no constraint were imposed and the bidders guessed incorrectly what the optimal constraint was.

$$\text{Optimality Result:} \quad V_0 \geq V*$$

Proof:

1. From P1 and P2, $S(b;f*)$ increases from 0 to ∞ as b goes from 0 to ∞. Thus there exists a $b*$ such that $S(b*;f*) = T*$.

2. From step 1, $\pi(S(b*,f*),f*) = \pi(T*,f*)$.

3. From U3, $\pi(T*,f*) = \pi_0$.

4. From steps 2 and 3, $\pi(S(b*,f*),f*) = \pi_0$.

5. From step 4 and C1, $b_o \geq b*$

6. From property P3, $V(S(b_o,f_o),f_o) \geq V(S(b*,f*),f*)$

7. From C2 and C3, $V(S(b_o,f_o),f_o) = V(S_o,f_o) = V_o.$

8. From step 1 and U2, $V(S(b*,f*),f*) = V(T*,f*) = V*.$

9. From steps 6, 7, and 8, $V_o \geq V*.$

This proof can be informally summarized as follows. There is some constrained bid, $b*$, that is just as valuable to DOE as the unconstrained bid, $T()$, and which can (with $f*$) produce the reference profit level π_o. Although $b*$ is not the constrained bid that would be submitted, the one that would be submitted, b_o, would be at least as valuable to DOE as $b*$, and thus as valuable as $T()$. Note that we have tacitly assumed that if a firm could submit an unconstrained bid, $T()$, nothing would prevent it from submitting an equally profitable constrained bid. Note also that we have tacitly assumed that there is a single definition of subsidy such that if $S_1 = S_2$ then both $\pi(S_1,f) = \pi(S_2,f)$ and $V(S_1,f) = V(S_2,f)$.

Real-World Implications for the Standard Result

There are two aspects of the Clean Coal Technology Incentive Model (CCTIM) which violate the conditions under which the standard result holds. This means that the standard constraint on bidding is sub-optimal in practice.

First Violation of the Standard Assumptions

The first violation of an assumption arises because the bidder and the bank (the joint investors in this project) will in general disagree on what is the optimal investment strategy. In particular it may turn out that the bidder wants to invest more than the bank considers

optimal because it maximizes expected profit. The bank is not concerned with expected profit, but with the probability that profit will be great enough to assure repayment of the loan. Increasing the investment beyond a certain level increases the chance of failure, and if this level is far enough below the profit maximizing level, the bank may find the project too risky to engage in if the bidder pursues a profit maximizing strategy. This is because, from the banks point of view, optimal investment may risk too much capital. This occurrence presents a serious dilemma because the bidder has no way to assure the bank that he will not optimize profit after receiving the loan. Consequently an external constraint that prevents the bidder from doing what is most profitable, may have the unexpected effect of making the project bankable. The ramifications for the standard result of this effect are detailed below.

Step 1 finds a constrained bid (b^*) that would generate the same subsidy as the unconstrained bid ($T()$) if the bidder provided the same f as as is optimal under the unconstrained bid. This b^* provides the same value to DOE as the unconstrained bid. The proof then goes on to show that b_o, the actual constrained bid, provides at least as much value as b^*. The difficulty is that while b_o is just as profitable as b^* or $T()$ (all three give π_o), neither b_o nor b^* may be bankable, even though $T()$ is bankable.

Thus while the proof tacitly assumes that a bid (b_o) is feasible, just because an equally profitable bid ($T()$) is feasible, when bankability is considered this might not be the case. This is because both bids, b_o and b^*, if accepted, might induce the bidder to do something even more profitable than f^*, and it is only the pair (b_o, f^*) that is known to be bankable. The "more profitable" f's might be too risky for the bank to accept. Because the bidder has no way to assure the bank that it will not pursue such a profitable strategy after it receives the loan, the bid becomes unbankable and cannot be made.

Thus if unconstrained, a firm might come up with a bankable bid that was less valuable to DOE than the "best" (ignoring bankability) constrained bid. However, it is still possible that the best unconstrained bid is more valuable than *any bankable* constrained bid. In fact we have produced examples of such situations using CCTIM.

Second Violation of the Standard Assumptions

The second violation of the standard assumptions arises because the bidder and DOE value the total subsidy (S) differently. The bidder considers the present value of S at some non-zero discount rate, while DOE's budget constraint is for undiscounted dollars; i.e., DOE uses a zero discount rate.

In the first step of the proof, we find an f^* that generates a subsidy $S(b^*; f^*)$ which is equal to $T(f^*)$, also called T^*. Let us assume that this means equal from the bidder's point of view. In this case step 2 is valid, but the first equality in step 8 does not necessarily hold because DOE may well not consider $S(b^*; f^*)$ equal to T^*. This will almost surely be the case if the constrained and unconstrained bids have different mixtures of capital to operating subsidy and thus different time profiles.

What Model Parameters Would Restore the Standard Assumptions?

Even though we have seen that in principle the standard assumptions are violated by the real-world conditions of the present situation, it could be that the discrepancies involved are small. What parameters would have to change in our model in order to restore the standard assumptions? This question is easiest to answer for the second violation. In this case it is clear that the discount rates need to be equal.

The first violation would vanish if the bank evaluated capital investment in the project in accordance with the bidder's evaluation. The bank looks at the profitability of the project for the case where a certain "worst-case" capital loss occurs, while the bidder consider the average profitability over all capital losses. Since the expected capital loss is s, the two will see the same profitability if the bank considers the worst-case loss also to be s. Since "worst-case" loss is given by $-s \cdot ln(DR)$, this will only be true if $ln(DR) = -1$, or $DR = 1/e = 37\%$. Recall that DR is the "maximum loan default rate"; in other words, it is the maximum probability of default that the bank is willing to tolerate. Because 37% is far beyond the default rate that banks find tolerable, we must suspect that this violation of the standard assumptions is indeed significant.

Appendix D
A Preferred Bid Evaluation Scheme

Overview

In Appendix C we showed that the standard solution to the bid evaluation problem, which assumes an idealized world, is likely to be quite sub-optimal in the present situation. This appendix suggests a bid evaluation scheme that would provide DOE with projects of significantly greater value. To demonstrate this we consider the three examples used in figures 3, 4 and 5 of the text. The figures in this section are numbered D3, D4, and D5 to indicate the correspondence with the earlier figures. (There are no figures D1 or D2.)

The standard bid evaluation procedure, represented by the "Pure Bid" (labeled Bid 2), restrict bids to zero capital subsidy and requires them to choose an operating subsidy that will take effect above a capacity factor of $f.null$, which is currently approximated as 20%. $F.null$, it should be recalled, is the capacity factor of the "worthless" project. The preferred bid evaluation scheme, represented by the "Mixed Bid" (labeled Bid 1) will allocate a capacity subsidy (CS.Bid1) of $50 million to every project, and require bidders to choose an operating subsidy which takes effect above fmin, the cutoff for private sector capital payments. Note that in Figures 3-5 the price subsidy is paid over the entire operating range.

On the last three pages of this section can be found graphs that show the cost and value to DOE of all relevant bids of both types. By cost we simply mean the un-discounted total subsidy.

"Value", as shown in figures D-1 through D-3 measures how valuable a project is relative to a project for which DOE has paid the absolute maximum that it would ever pay for a project. The absolute maximum that DOE would pay for a "worthless" project is zero, and the absolute maximum that DOE would pay for an exceptional project is called $V.xcep$ and is taken to be $300M.

Given these endpoints, we linearly project the total subsidy it would have required to push the project to the exceptional level. Value is then defined as the difference between $V.xcep$ and the projected total subsidy, TS, if the project were pushed to the exceptional level. The exact formula is given below:

$$f.null = 20\%$$

$$V.xcep = \$300M$$

$$f.xcep = 85\%$$

$$Value = V.xcep - \frac{f.xcep - f.null}{f - f.null} \cdot TS$$

In summary, the "value" of a project is the value of an exceptional project minus the total subsidy it would have required to push it to the exceptional capacity factor. Here is a sample calculation for the highest value point on the Mixed Bid in figure D-3.

$$\$150M \ = \ \$300M \ - \ \frac{85\% - 20\%}{72\% - 20\%} \cdot \$120M$$

The value of total subsidy, TS, can read off of figure D-3, above the $49 price subisdy corresponding to the highest value point. The capacity factor must be read off of figure 3 at the same price subsidy level.

As seen in the formula, the value of *V.xcep* is not crucial since changing it by x merely changes all values by x. We have just chosen it high enough to be plausible and to give positive values for graphing convenience.

"Value", as we define it, has a simple interpretation. It is just a version of the price-performance ratio with sensible units and the right sign. The price-performance ratio for the "demonstration effect" is simply:

$$\text{price-performance ratio} \ = \ \frac{TS}{f - f.null}$$

This quantity has rather incomprehensible units so to standardize it we multiply by $(f.xcep - f.null)$. This converts the units to dollars, and these dollars project the cost of the project if its performance were adjusted to the exceptional level. Since we are looking for a measure of value and the price-performance ratio decreases with increasing value, we subtract it from the value of the exceptional project. We now have a dollar value that increases with value, but which always ranks projects in the same order as the price-performance ratio.

In order to interpret the graphs it is necessary to decide which of the many possible bids would actually be submitted. Because both schemes prefer bids with lower operating subsidies, we assume that under both the lowest bankable bid would be submitted. Bids with too low an operating subsidy are not bankable and this fact is shown by a zero "value" on the graph. The total subsidy lines on the graph are show to the left of the bankability cuttoff even though these points cannot be realized. Note that any bid that is bankable has quite a healthy expected profit.

The first thing to note from the three graphs is that in each case the value if the Mixed (preferred) Bid is greater than that of the Pure (standard) Bid. In fact this difference in value is quite large, varying between about $34M in figure D3. and about $77M in figure D5. Remember that value dollars are adjusted to the standard "exceptional project" which operates at 85% efficiency, so they cannot be compared directly with subsidy costs. Nonetheless, they do provide a fair means of comparison, and for projects with reasonably high capacity factors (as in the present case) they provide a rough sense of magnitude.

It is also informative to read off the Total Subsidy for the lowest bankable (submitted) bid. From this we see that the Pure (standard) Bid is always more expensive. The extra cost varies from about $34M in figure D3 to about $80M in figure D5. This extra cost is partly compensated for by an increased capacity factor, which is why "value" should remain the
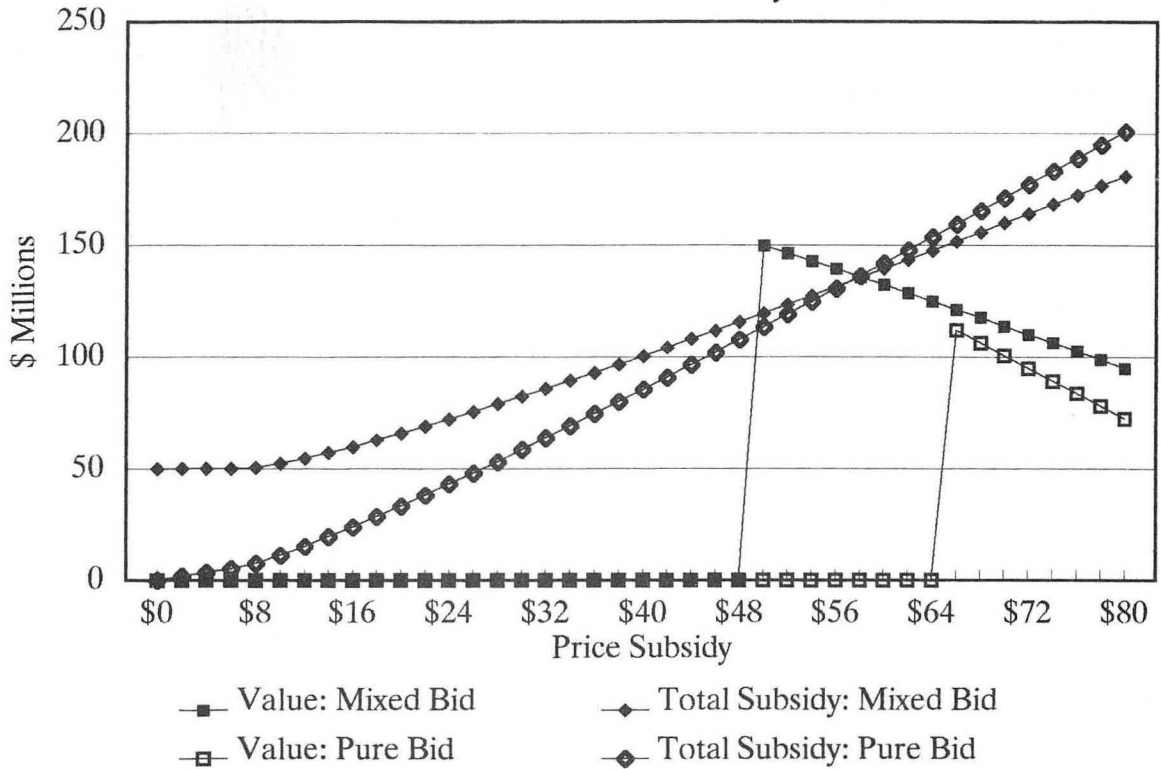
main mode of comparison. Nonetheless, DOE may have some constraints on how much they spend per project whether or not they are getting a good deal.

We are not claiming that the Mixed Bid scheme analyzed here is optimal, only that it is better than the pure scheme and that it is quite good. Some experimentation conducted with the model indicates that for these examples it is impossible to do very much better. However, if DOE were to proceed with these recommendations some further optimization of bidding parameters would be desirable.

Cost and Value
of Pure– and Mixed–Subsidy Auctions

Legend:
- Value: Mixed Bid
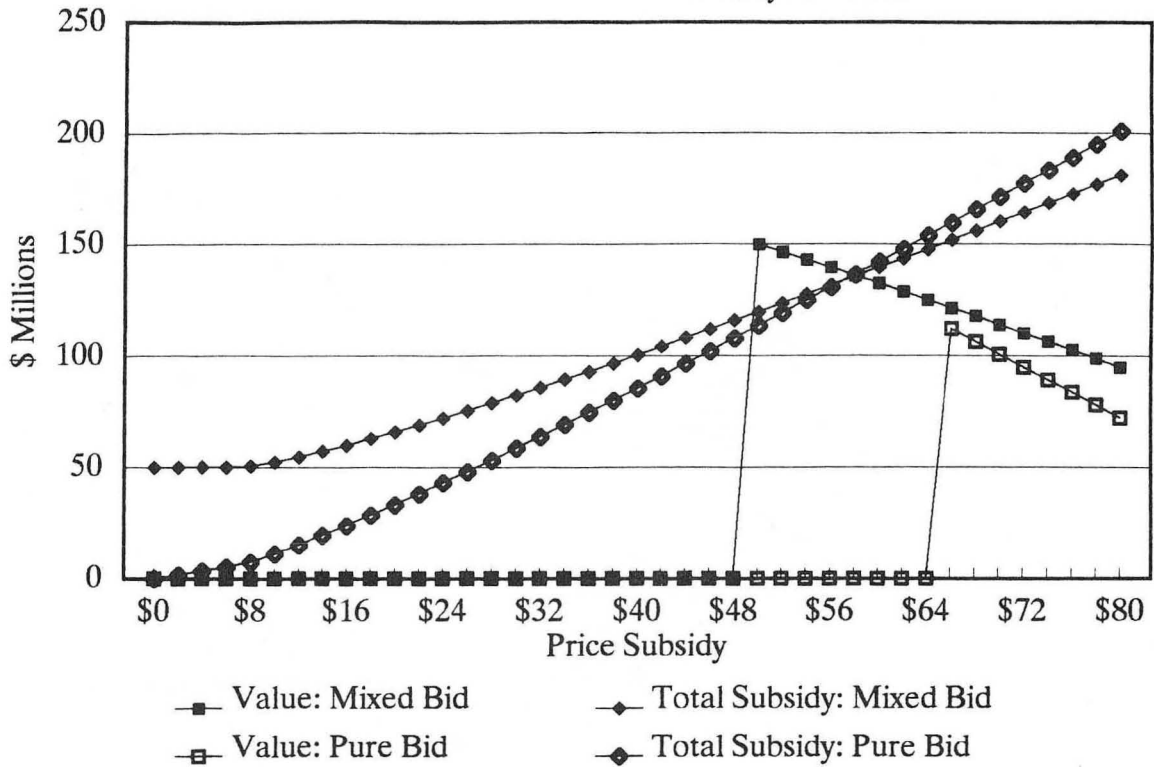- Value: Pure Bid
- Total Subsidy: Mixed Bid
- Total Subsidy: Pure Bid

Subsidy Duration	S.yrs	5 years	DOE
f of Zero-Value Project	f.null	20%	DOE
Capital Payment	CP	$250 k/MWyr	Market
Min f() to receive CS & CP	fmin	40%	Market
Operating Margin	M	$3 /MWhr	Market
Loan Interest Rate	LR	12.0%	Market
Term of Loan	L.yrs	10 years	Market
Max Loan Default Rate	DR	2%	Market
X-intercept of f()	b	$160 M	Tech.
Shape of f()	shape	12.0	Tech.
Mean and SD of Capital Loss	s	$10 M	Tech.
Delay Factor	DF	1.0	Tech.
Construction time	C.yrs	2.0 years	Tech.
Capacity	Cap	100 MW	Tech.
Capital Subisidy of Bid 1	CS.Bid1	$50 M	DOE
Capital Subisidy of Bid 2	CS.Bid2	$0 M	DOE
f Threshhold for PS, Bid 1	f.Bid1	40%	DOE
f Threshhold for PS, Bid 2	f.Bid2	20%	DOE

Cost and Value
of Pure− and Mixed−Subsidy Auctions

| Value: Mixed Bid | Total Subsidy: Mixed Bid |
| Value: Pure Bid | Total Subsidy: Pure Bid |

Subsidy Duration	S.yrs	5 years	DOE
f of Zero-Value Project	f.null	20%	DOE
Capital Payment	CP	$250 k/MWyr	Market
Min f() to receive CS & CP	fmin	40%	Market
Operating Margin	M	$3 /MWhr	Market
Loan Interest Rate	LR	12.0%	Market
Term of Loan	L.yrs	10 years	Market
Max Loan Default Rate	DR	2%	Market
X-intercept of f()	b	$160 M	Tech.
Shape of f()	shape	12.0	Tech.
Mean and SD of Capital Loss	s	$10 M	Tech.
Delay Factor	DF	1.0	Tech.
Construction time	C.yrs	2.0 years	Tech.
Capacity	Cap	100 MW	Tech.
Capital Subisidy of Bid 1	CS.Bid1	$50 M	DOE
Capital Subisidy of Bid 2	CS.Bid2	$0 M	DOE
f Threshhold for PS, Bid 1	f.Bid1	40%	DOE
f Threshhold for PS, Bid 2	f.Bid2	20%	DOE

Cost and Value
of Pure− and Mixed−Subsidy Auctions

Legend:
- Value: Mixed Bid
- Value: Pure Bid
- Total Subsidy: Mixed Bid
- Total Subsidy: Pure Bid

X-axis: Price Subsidy ($0 to $100)
Y-axis: $ Millions (0 to 300)

Subsidy Duration	S.yrs	5 years	DOE
f of Zero-Value Project	f.null	20%	DOE
Capital Payment	CP	$180 k/MWyr	Market
Min f() to receive CS & CP	fmin	40%	Market
Operating Margin	M	$0 /MWhr	Market
Loan Interest Rate	LR	12.0%	Market
Term of Loan	L.yrs	10 years	Market
Max Loan Default Rate	DR	2%	Market
X-intercept of f()	b	$100 M	Tech.
Shape of f()	shape	10.0	Tech.
Mean and SD of Capital Loss	s	$10 M	Tech.
Delay Factor	DF	2.0	Tech.
Construction time	C.yrs	2.0 years	Tech.
Capacity	Cap	100 MW	Tech.
Capital Subisidy of Bid 1	CS.Bid1	$50 M	DOE
Capital Subisidy of Bid 2	CS.Bid2	$0 M	DOE
f Threshhold for PS, Bid 1	f.Bid1	40%	DOE
f Threshhold for PS, Bid 2	f.Bid2	20%	DOE

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