Designing a Technology-Neutral, Benefit-Pricing Policy for the Electric Power Sector in Colorado

Prepared for the Colorado Governor's Energy Office by Colorado State University
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Dear Mr. Plant and Mr. Futch:

Attached please find our project report, "A Technology-Neutral, Benefit-Pricing Policy for the Electric Power Sector in Colorado." The purpose of the project is to develop a benefit-pricing model that reflects the private and social costs of energy generation. In our report we illustrate how benefit pricing could be used *either as an alternative to, or in conjunction with, legislative policies such as HB-10-1001 and HB-1365*. Accompanying our report is an Excel-based tool used to price environmental and performance electricity generation attributes.

A key objective of this project is to stimulate discussion about benefit- pricing, which reflects both private and social costs. It is our belief that benefit- pricing has the potential to ignite technological innovation and to assist in achieving environmental and technological goals. To jump-start this conversation, we create a comprehensive value-based pricing tool that integrates the major social costs of energy generation.

Our efforts represent an important first step to benefit pricing, which accounts for private and social costs; although we believe that further Colorado-specific research must be conducted before this type of policy can be implemented.

The benefit-pricing method is technology-neutral, and different than the traditional least cost pricing approach. Under our proposed plan, generators with low operating costs are still financially rewarded. However, financial incentives are also provided for generators to achieve environmental (e.g. low NO_x emissions) and performance (e.g. consistently available power) targets. Assigning marginal damage costs that are at least equal to targeted environmental and performance targets provides electricity generators incentive to innovate and achieve these targets. The ultimate goal is to reduce social costs to the citizens of Colorado.

The pricing tool uses default parameters (specified by technology) for private and environmental/technological targets. Users may also insert customized private costs in order to obtain customized information (both private and social) by generation source.

The first part of the report contains an Executive Summary that is targeted to the educated lay person. Following the Executive Summary is a detailed discussion of the project justification; experiences and lessons learned in other states; and a synthesis of these issues in the context of Colorado energy. There is also a detailed description of the pricing tool and how the marginal damage functions were calculated and applied to Colorado.

Many public entities were consulted for the creation of this report, including but not limited to Xcel Energy, the Colorado Department of Public Health and Environment (CDPHE), and the California Energy Commission. We also conducted invaluable interviews with think-tanks such as Resource for the Future and Western Resource Advocates, as well as energy companies (e.g. PG&E). We wish to thank all of those who have lent their experience and contributed to our knowledge base for this report. A complete list of references can be found in the text and in the reference section.

In summary, it is important to emphasize that this innovative approach is built upon experiences from other states and utilities, the gray literature, and the academic literature. What has been proposed is experimental in nature. We have not identified an entity with a track record for implementing what we propose. Furthermore, most of the data used to calculate marginal damage functions is based upon secondary data. When the data were not state specific, they were adapted as appropriately as possible for Colorado. It is our recommendation that further research be conducted to determine the specific value of some of these environmental attributes, such as the true value of water within the state of Colorado.

I speak on behalf of the entire project team when I say that we have appreciated the opportunity to work with you on this exciting, innovative project. We are happy to respond to questions or additional suggestions that you might have about gathering Colorado-specific primary data or about the pricing algorithm. Should you have any questions, please do not hesitate to contact me.

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1.0 List of Terms

CDPHE – Colorado Department of Public Health and the Environment

CO_2 – Carbon Dioxide

CPUC – Colorado Public Utilities Commission

C.R.S. – Colorado Revised Statutes

DSM – Demand-Side Management

EPA – U.S. Environmental Protection Agency

FIT – Feed-In Tariff

GB- Generator-Based

GEO – Colorado Governors Energy Office

H.B. – House Bill

IOU – Investor-Owned Utility

KWh – Kilowatt hour

LB – Load-Based

LCA – Life Cycle Assessment

LSE – Load Serving Entity

MeHg – Methylmercury

MWh – Megawatt hour

NAAQS – National Ambient Air Quality Standards

NO_x – Nitrogen Oxides (NO and NO_2)

NREL – National Renewable Energy Laboratory

NPS – National Park Service

O&M – Operations and Maintenance

PM – Particulate Matter

PSCo – Public Service Company of Colorado

PUC – Public Utilities Commission

RGGI – Regional Greenhouse Gas Initiative

RES – Renewable Portfolio Standard

SO_2 – Sulphur Dioxide

VOC – Volatile Organic Compound

2.0 Executive Summary

2.1 Project purpose and deliverables

The purpose of this project is to develop a benefit-pricing model that reflects the full social costs of electricity generation. The full technical report illustrates how benefit- pricing could be used *either as an alternative to, or in conjunction with, legislative policies such as Colorado HB-10-1001 and HB-1365*. The accompanying Excel tool implements the suggested approach using estimated values for environmental costs and performance costs. We believe that benefit- pricing could create important incentives for technological innovation and also assist in achieving key environmental and technological goals. Our efforts represent an important first step toward prescribing such a policy, though further research may be needed to work out the necessary implementation details; a key objective of the project at this stage is to stimulate discussion.

The benefit-pricing approach is technology neutral—it would link sourcing decisions to true social costs without favoring one technology platform over another. It is different from traditional, least-cost pricing. Under the proposed plan, generators would be financially rewarded for lowering the environmental costs that they pass on to society or for lowering the integration costs that they pass on to the bulk power provider—this would be on top of existing incentives to lower their own private generation costs. The mechanism would provide incentives for electricity generators to modify existing operations and to innovate. The ultimate goal is to maximize the net social benefits from electricity generation for the citizens of Colorado.

2.2 Basis for pricing tool and pricing algorithm

The value-based pricing rule developed in this report draws upon two key bodies of literature—one on environmental adders and another on value-based feed-in tariffs (FITs). It also draws on past experiences from other states. This background is summarized in an expanded literature review within the technical report. The detailed blueprint for the suggested policy is described in Section 5.0.

The pricing tool combines private generation costs incurred by firms, damages from environmental externalities, and utility performance costs to calculate the comprehensive cost of each contending generation source. This information is used to determine a suggested contract price for each source. The contract price is a function of the attributes of the provided electricity. Of the considered costs, private generation costs are the most straightforward. The accompanying pricing tool uses KEMA (Klein et al., 2009) values as default private costs. The pricing tool also allows users to ignore the default values and customize these inputs.

In addition, the report considers six environmental attributes—based on guidance from GEO. These are mercury, carbon dioxide, nitrogen oxide, sulfur dioxide, and particulate matter levels, as well as water consumption and quality. These were selected because federal and/or state regulation is pending for five of the six. With regulation pending, the value-based pricing rule would be a means for proactively managing the targets with a market based approach. In fact, federal EPA regulators are observing Colorado's current policies with the intention of potentially expanding similar energy policies elsewhere in the nation (Jaffe, 2010).

Mercury, carbon dioxide, nitrogen oxide, and sulfur dioxide are primary pollutants that can result from electricity generation. While not a pollutant, water is a scare resource in Colorado that can be consumptively used, disruptively diverted, thermally loaded, or otherwise impaired. Its external costs are difficult to measure comprehensively, yet the value of water is considered much higher than what has been reflected in water market prices.

Fine particulate matter, $PM_{2.5}$, is a secondary pollutant caused by complex chemical reactions combined with some of the primary pollutants already identified. $PM_{2.5}$ was disaggregated from the primary pollutants because specific additional damages can be attributed to $PM_{2.5}$. Furthermore, the EPA is in the process of reviewing the NAAQS for fine particulate matter and is considering a strengthening of federal standards.

To estimate marginal damage functions, this report uses published studies incorporating a range of different valuation methodologies. These include the statistical value of a human life, dose-response functions, regulatory risk (private costs incurred as a result of uncertainty over forthcoming regulatory action), and opportunity cost of resources relative to their "highest and best use". Whenever possible, data are cited or interpolated to be relevant to Colorado and conservative assumptions are chosen in incorporating them into the model.

Finally, firm or "dispatchable" power is a desirable performance target for electric power utilities: Production from more variable sources often cannot be relied upon during peak demand, thus requiring utilities to employ expensive, short run generation options as a stop gap (Milligan and Kirby, 2009). Our proposed social cost algorithm reflects the expected increases in marginal operational costs that are a function of integrating energy from intermittent sources.

Pricing tool instructions and a pricing simulation are provided in Sections 7.0 and 8.0, respectively. These provide a step-by-step approach for identifying the lowest cost technology when total social costs are considered.

2.3 Summary and future work

In summary, this innovative approach is built upon experiences from other states and utilities, the gray literature, and the academic literature. What has been proposed is experimental in nature. We have not identified an entity for implementing what we propose. Furthermore, most of the data used to calculate marginal damage functions is based upon secondary data. When the data were not state specific, they were adapted as appropriately as possible for Colorado. This report reaches two main conclusions, first, our judgment about which technology is "lowest cost" may differ when total social costs are considered, and, second, electricity prices can be constructed to account for these costs.

It is our recommendation that further research be conducted to determine the specific value of some of these environmental attributes, such as the true value of water within the state of Colorado. Such studies will be of great value to the energy industry and other sectors.

In considering needs for future work, it is also important to note that full life cycle analyses (LCA) of particular generation technologies were not conducted: and a future step of this work should be to conduct an LCA reflecting different steps in the energy extraction and supply process. That is, when scope of analysis is expanded—for instance exploration, drilling, and expansion are considered—the costs of the criteria pollutants may be greater. Which parameters to consider and how far to expand the scope are considerations and challenges in designing such a study.

During a time when Colorado is paving a path of progressive energy policies, this work seeks to begin a conversation about the total costs of energy generation in Colorado.

3.0 Project Justification in the Context of Colorado Energy Policy

Along with a handful of other states, Colorado has placed itself at the epicenter of energy reform. Legislation passed in 2010 reflects this momentum. Colorado House Bill 10-1365 ("Clean Air, Clean Jobs Act") allows the regulated utilities to develop plans that reduce nitrogen oxides by at least 70% below 2008 baseline levels by calendar year end 2017. The bill also covers a minimum retirement or control over 900MW of coal-fired generation or 50% of the utilities coal-fired generation. The other landmark energy bill is House Bill 10-10-1001 (the Renewable Portfolio Standard). H.B. 10-10-1001 mandates that by 2020, 30% of retail sales generated or purchased by the regulated utilities come from eligible renewable energy resources such as wind, solar and small hydro power, as defined by C.R.S. §7, 40-2-124(1) (d). There is also a carve-out for distributed generation, such as solar PV for 3% of the 30% threshold.

Colorado's elected officials acknowledge the necessary balance between environmental and economic targets, and that these need not be mutually exclusive. In the words of Governor-Elect John Hickenlooper during his acceptance speech, Colorado is the "center of the Clean Energy Economy". The eyes of the nation are on Colorado to see how this unfolds (Jaffe, 2010).

Moreover, increasingly stringent national standards loom for EPA criteria pollutants tied to the electricity sector, such as carbon dioxide and nitrogen oxide. Recent legislation may be viewed as a proactive measure to coordinate state energy policy changes before federal requirements are imposed. While Colorado is at the forefront of energy policy, it is not alone. Other states have attempted progressive and market-based energy policies, and parallel efforts such as cap and trade systems with free allocation to utilities are also underway (Burtraw, 2010).

House Bills 10-10-1001 and 10-1365 exemplify an energy policy paradigm shift, but they are only a starting place. The complex interaction of these policies with future federal and state efforts creates environmental uncertainty. Uncertainty and financial risk to shareholders may prevent utilities from expanding their energy efficiency efforts, despite H.B. 07-1037, an efficiency mandate. As a result, it is critical to develop effective ratemaking and policies that create less uncertainty and that are incentive-compatible with utilities (National Action Plan for Energy Efficiency/NAPEE, 2007).   It is with this intention that the Colorado Governor's Energy Office asked to create a pricing algorithm that considers social costs and rewards technological innovation.

This report describes a conceptual energy blueprint and a comprehensive value-based pricing rule that reduce the social cost of energy generation. This blueprint does not include details about how it would be implemented in Colorado, but may be considered as a supplement to electric resource planning, pricing methodologies, or as a substitution for certain aspects of current policies in the future.   The approach outlined below is technology-neutral, meaning it does not give preferential treatment to any particular generation technology, yet it is a departure from the traditional least cost pricing regulatory approach. Under this plan, generators with low operating costs are still financially rewarded. However, financial incentives are also provided for generators to achieve environmental (e.g. low nitrogen oxide emissions) and performance (e.g. consistently available power) targets. Assigning marginal damage costs above targeted environmental and performance thresholds provides electricity generators incentive to innovate and achieve these targets, thus reducing total social costs of electricity provided to the citizens of Colorado.

Costs imposed by pollutants are easier to conceptualize than many other social costs, because they can be associated with costs to human and environmental health and their presence can be measured. Other social costs that are more difficult to measure include risk and inefficiency. For example, ensuring uninterrupted energy dispatch when it's most in demand during peak times of the day may require back-up generation facilities/technologies beyond what the private sector is willing to provide. Under preparing for risk can impose costs on utility users as well as society.

One of the key attributes of the pricing policy outlined in this report is that it rewards innovation. The three broad dimensions along which electricity generators can compete are private costs, environmental attributes, and performance attributes relative to the portfolio of current generation technologies. Depending upon how it is implemented, this pricing mechanism can create incentives to continually improve upon the environmental and performance characteristics of electricity generation, integration, and even conservation technologies. This is an important advantage over both traditional PUC cost-minimization policies and other renewable energy policies currently being advanced in Colorado and other states.

This energy pricing blueprint demonstrates how social cost pricing might work in the regulated utility framework. We have evaluated the experiences of other states and countries and acknowledge that there is an extraordinary amount of complexity with currently existing policies. Likewise, while we have adapted our results to best reflect conditions in Colorado, we have been limited to the use of secondary data to exemplify how the pricing rule would work. Thus, the implementation of this pricing rule would require primary data collection, frequent updating of this data, and more in-depth modeling if implemented. The pricing rule that we are describing is a novel one that has never been fully implemented at the state regulatory level. It is susceptible to many of the same criticisms that have been leveled against past policies. Nonetheless, much of the purpose of this blueprint is to show how a value-based model might work and to have the regulator and other stakeholders consider how it might be used to inform future rate making and resource planning in Colorado's regulated market.

The report is structured as follows. Section 4.0 provides a literature review of previous state policies. This is followed by a theoretical description of our energy pricing blue print in Section 5.0. Section 6.0 then applies studies and secondary data to Colorado in order to develop marginal damage functions for environmental and performance attributes. Section 7.0 provides instructions for using the pricing tool.

Accompanying this report is an Excel-based pricing tool (Appendix A) that is programmed to reflect base level technology. The user has the option of using default parameters, or the user may customize entries with private cost data, or select from a low, medium, or high range of marginal damage estimates.

For brevity, we do not describe every possible scenario. Appendix B provides an overview of the interaction of pricing policies with regulation, which provides the reader with insight into the complexities of energy policy. Although it is impossible to anticipate the complex interaction with all policies, we can anticipate possible scenarios and provide further elaboration, if needed. In summary, this value-based blueprint demonstrates a methodology for social cost pricing and how it is possible to keep both environmental and economic goals in mind when creating energy policy.

4.0 Literature Review

The value-based pricing rule developed in this report draws upon two key bodies of literature (environmental adders and value-based feed-in tariffs), as well as experiences from other states that have implemented some of these policies. As follows is an abbreviated literature review of environmental adders and feed-in tariffs (FITs). This literature is synthesized to formulate an energy pricing blueprint, which is further described in Section 5.0. Appendix B describes the application of adders policies in the context of other policies.

4.1 Environmental adders

Adders-type policies incorporate environmental costs by "adding" or "subtracting" external costs to utility prices. Interest in adders policies began in the late 1980's, and by the mid 1990's, over half of all states had either implemented an adders policy or were considering doing so. Many economists were critical of the concept (see Joskow 1992) though a respectable minority of policy-oriented economists (Freeman et al. 1992; Burtraw et al. 1995) saw a constructive role for adders' policies. However, with energy deregulation in the late 1990's and beginning of the new century, the majority of adders policies were never implemented.

Electricity arguably faces a quasi-public good market failure (Dahl, 2005) accompanied by many externalities, but, like other firms, the majority of electricity utilities strive to maximize profits. Externalities are formed when the real costs to society (often times environmental costs) are not incorporated into the profit maximizing calculus of the utilities. The standard economic prescription for addressing environmental externalities is to introduce a tax on emissions equal to the incremental cost to society generated by the polluting activity (otherwise known as a Pigouvian tax).

In contrast to emissions taxes, adders policies do not directly impose costs upon already established energy generation sources. Instead, the adder is applied to new generation sources or power generation expansions, thereby forcing utilities to account for what would otherwise be external costs when considering new sources of energy. By imposing "shadow prices" (i.e. marginal costs) upon the new sourcing emissions that exceed certain targets, the utilities are required to evaluate alternatives on the basis of total social cost, equal to the bid price plus the appropriate adder.

A major appeal of an adders policy is that it applies to all technologies neutrally. Utilities are required to rank decision options on the basis of total social cost, but they are free to choose the best technology to accomplish this. By not favoring one technology over another, utilities may develop new technologies in line with stated public interests, including improvements to traditional coal and gas generation technologies. Since utilities are not actually charged the adders, the baseline level is flexible and can be set according to policy targets. For example, the adder could be a sum of the marginal damages plus the private costs (i.e. the bid price) for each energy source. Alternatively, the adder could be set to zero for the cleanest energy source, and adders could reflect differences in marginal damages between the cleanest source and the respective alternatives.

Implementing an adders policy assumes that the regulator faces a "second-best" problem. The assumed objective is to set policy to minimize total social costs in the context of existing pollution control policies. Therefore, the adder must reflect a policy that interacts with pre-existing state and federal regulations. If not properly understood or designed, or if the regulatory environmental is simply too complex, an adder could do more harm than good. Examples how other regulations may render an adders policy successful (or unsuccessful) are provided in Appendix B.

There are draw-backs to adders policies such as the following:

- Interactions with other policies complicate the adders program and may reduce the effectiveness. For example, cap-and-trade programs (such as SO_2) push externalities to other regions of the nation involved in the trading program, creating market distortion. Adders policies are limited by the precision of the social cost estimates, or the marginal damage estimates.

- So long as adders charges are not actually charged, it is in the utility's private interest to manipulate the decision process to favor generation sources with low private costs.

- Applying adders policy to sourcing (rather than dispatch) decisions induces utilities to run older plants for a longer period of time, thus causing or exacerbating regulatory bias against new sources relative to existing ones.

- An adders policy that increases electricity prices at regulated utilities may induce "bypass" or "fuel switching" for large commercial customers to contract directly with outside generators, thus bypassing the grid, or to generate electricity in-house using unregulated fuel sources. By doing so, the unregulated sources may potentially generate more pollution than through the regulated sources. Alternatively, customers may also obtain energy through another state.

In principle, adders policies could be applied to dispatch decisions (so-called "environmental dispatch") as well as to new source investment decisions. Indeed, an important conclusion in the economics literature on adders policies is that a policy that excludes dispatch would likely exacerbate the new source bias associated with existing environmental regulations. The policy would lead to new sources with a different cost structure from the existing sources (tending toward higher private operational costs offset by lower environmental costs). Economic dispatch would consequently tend to favor the operation of older (dirtier but cheaper) sources, running these sources more frequently than would be efficient.

Despite the recognized importance of including dispatch in a well-designed adders policy, almost all legislative examples have restricted attention to new source investments only (including evaluation of DSM projects). Several states explored environmental dispatch in the nineties, but all such policy experiments were eventually abandoned. The main stated concern was that environmental dispatch would require detailed regulatory control—including, for example, daily oversight of the order in which different sources are dispatched and the factors and considerations that led to those decisions—and that these regulations would be more costly than was politically palatable at the time. The issue of environmental dispatch is an important one, which is discussed in detail later in the report.

In contrast, policies such as Renewable Energy Standard (RES), which sets target percentages for sourcing from specified technologies), or FITs (which specify contract bid prices for certain technologies) may not provide incentives for utilities to improve environmental performance within specified categories of renewable energy sources.

In summary, the effectiveness of adders policies hinges on detailed regulatory oversight. An adders policy will accomplish what it is intended to, which is to encourage utilities to consider total social costs in their decision alternatives. In contrast, when charges are real, there is no need for detailed oversight of utility decisions because it is in the utility's private interest to make decisions in the way that minimizes costs, and respond in a manner that satisfies regulators. However, elements from adders policies may be effectively integrated into a hybrid model, which is described in our energy pricing rule.

4.2 Value-based feed-in tariffs (FITs)

Feed-in tariffs (FITs) are a policy mechanism for rapidly deploying renewable energy technologies. While popular in Europe, FITs are gaining attention of U.S. policy-makers and regulators as a potential alternative or complement to renewable portfolio standards and tradable renewable credit programs. FIT design varies considerably across regions; however, the policies have common features. First, FITs mandate that utilities purchase the renewable energy from eligible sources. Second, FITs establish a pricing mechanism that applies to all generators developing a given technology. For a comprehensive review of the FIT literature see Klein et al, 2008; Burgie and Crandall, 2009; and Couture et al, 2010.

Two FIT design options have been explored in detail and implemented in various global jurisdictions. The most widely implemented is the *project-cost* approach. In this approach, the governing institution (usually a national government) agrees to pay a set price for a given technology based on the project's costs plus a reasonable rate of return. This attracts investors by minimizing price uncertainty over multi-year contracts. The project-cost approach has proven successful in a number of European countries in developing renewable capacity. However, the project-cost approach is not technology neutral, thus violating a key objective of our policy design exercise. In light of this, it is more helpful to focus on an alternative FIT pricing mechanism known as the *value-based* approach.

Under the value-based FIT methodology, prices are set to reflect the value to society provided by electricity generation. This approach has not been adopted as extensively as the project-cost approach, but it has the potential to achieve technological neutrality. Value-based FITs are set according to a selected baseline technology and the avoided costs of generation from a traditional energy source by working with that selected technology. Avoided costs can include (but are not required or limited to) direct project costs, environmental damages, and performance attributes.

Avoided direct project costs consist of construction and operating costs that would have been incurred had the clean energy alternative not been adopted. While the avoided costs will obviously differ according to the baseline generating facility, they should reflect avoided variable (e.g. fuel costs) and fixed (e.g. up-front capital costs) costs. When assigning values to variable costs that may fluctuate over time (e.g. fuel costs), the calculations should be adjusted to reflect risk and uncertainty. This may be done by assigning a range of values and assigning a probability density function to the range of values. The concept of avoided direct project costs is commonly understood, as avoided direct costs are typically required when a regulatory authority is considering the approval of a new generation source. The difference is that in a FIT design, the avoided cost is in reference to a chosen baseline technology.

Calculations should also include avoided environmental damages, which could be applied either as a "carrot" or a "stick". Like the previously outlined adders method, the value-based FIT could penalize generators for their emissions by imposing costs reflective of environmental damages. Alternatively, firms may be rewarded for producing electricity that decreases emissions relative to a predetermined baseline. Like the adders approach, the calculated damages are highly dependent upon accurate marginal damage estimates, as well as the choice of baseline technology.

Avoided costs should also reflect performance attributes such as avoidance of variable power. When compared to tradition coal-burning power plants, technologies such as wind and solar provide energy intermittently. Some technologies (such as hydro and biomass) have high capacity factors (the ratio of actual energy production to potential nameplate capacity) and can be used as baseload substitutes for coal. These sorts of characteristics impact the integrity of the entire electricity system, and therefore careful consideration of these costs (and in some cases, benefits) is appropriate.

In comparison, energy cap and trade programs provide financial incentives for reducing environmental emissions. A regulatory committee first sets a total cap of permitted emissions, and then allocates the credits either by auction or by allocated allowances. There are three main approaches for an electricity sector cap-and-trade: generator-based, load-based and first seller. Electricity sector cap-and-trade programs have been developed recently in California, Oregon, and New Mexico, as well as in the regional organization Regional Green House Gas Initiative (RGGI). While cap-and-trade may present a viable policy option, an in-depth discussion of these policies is beyond the scope of this report.

However, because the topic is highly relevant to current policy making, a summary of the interaction of cap-and-trade with regulatory policies has been provided in Appendix B. In general, it is important to note that national cap-and-trade policies in the context of adders or FIT policies may yield potential complications.

5.0 Energy Pricing Blueprint and Theoretical Basis for Pricing Algorithm

This section proposes a value-based algorithm that could be appropriate for Colorado's electricity generation based upon lessons learned from the environmental adders, the value-based FIT literature and other state pricing policies. Like the value-based FIT, this algorithm positively rewards social cost savings from reductions in private costs, environmental damages, and distributional performance measures. Environmental and performance adders may also be included. The pricing formula could be incorporated into a FIT policy with an explicit purchase obligation, or it could simply be used as a pricing rule to guide PUC oversight of new source generation contracts. In summary, we have combined elements of prior adders policies with underlying principles of the value-based FIT in order to design a pricing blueprint. We have also made these concepts relevant in the context of other policies such as the state-renewable energy standard [as codified in C.R.S. 40-2-124 (1) (d)], and national cap-and-trade systems that have come under future consideration at the federal level.

The design of the value-based pricing rule reflects two guiding principles. First, as described in the literature review, the pricing structure creates incentives for electricity generation from sources that minimize total social costs. Social costs include private costs, such as facility and fuel expenses, as well as external costs, such as damage from environmental pollution. Second, it seeks to be technology neutral—it does not favor one technology platform over another.

5.1 Comprehensive cost algorithm

We combine private generation costs incurred by firms, damages from environmental externalities, and utility performance costs to create a comprehensive cost algorithm to minimize total social costs. Of these, private generation costs are the most straightforward. In a purely regulated environment, private costs would be comprised of the investment and operating costs to build, run, and maintain a given facility, along with an appropriate rate of return for investors. In a competitive situation, private costs could simply reflect the winning price from a competitive bid process. The accompanying pricing tool uses KEMA (Klein et al., 2009) values as the default private costs. It is important to note that the pricing tool also allows users to ignore the default values and impute customized private costs in accordance to their own source data set.

Environmental damage costs are difficult to precisely measure, because the values must be inferred from secondary data or information that may not precisely reflect Colorado-specific values. Environmental damages and externalities fall outside the firms generating them, though the implied costs are as real from the perspective of society as the cost of facilities or fuel. For the purposes of this blueprint, the environmental damages are estimated as the marginal damage for environmental attributes in the state of Colorado. The marginal damage estimates are presented in Section 6.0.

Utility performance costs (or integration costs) capture the increment in bulk power system operating costs that would result from adding a particular generation technology—typically an intermittent source or "variable power source"—to the existing portfolio. For example, Milligan and Kirby (2009) note in a recent NREL Technical Report that wind's variable power availability increases overall system operation costs, due to the need for increased cycling of intermediate and peaking units and an increase in flexible reserves. Integration costs could also include transmission and distribution losses that result from locating a facility in a particular location. Integration costs fall on the utility and thus on customers, so, while they constitute private costs, they indeed contribute to social costs.

Due to the complexity of the existing bulk power system, integration costs are also difficult to estimate. Precise calculations require detailed system modeling that is beyond the scope of this paper, although we do include recent variable power estimates to illustrate how variable power availability may affect total social costs. Implementation of the pricing rule suggested in this report would require careful assessment of integration costs for a variety of potential generation sources in Colorado, and these studies would need to be updated on a regular basis (perhaps annually).

Since social cost for each potential source serves as an essential input to the pricing algorithm, formalized notation will be used. For a particular source *j* (this could reflect any technology), SC^j denotes the total social cost (per kWh) due to generation from that source. PC^j is the associated private costs of generation. INT^j denotes integration costs. Again, all of these costs reference source "j".

The notation "*i*" serves as an index for different environmental externalities–SOx emissions, for example. The marginal damage estimate per unit of emission (or externality "*i*") is written as "MD_i". If *i* were SOx emissions measured in tons per kWh, then MD_i would be the damage associated with an incremental unit of SOx measured in dollars per ton. In addition, for a specific source j, the emission or externality *i* is denoted E^j_i. It follows that the total damages (in dollars) associated with externality *i* from source *j* are given by the product $MD_i \times E^j_i$, and the total damages associated with source *j* from the included externalities is given by the sum:

$$\sum_i MD_i \cdot E_i^j$$

Combining environmental costs with private generation and integration costs, total social costs for source *j* are given by

$$SC^j = PC^j + \sum_i MD_i \cdot E_i^j + INT^j.$$

This formula will be used in the pricing algorithm below.

5.2 How the pricing algorithm minimizes social costs

Once the regulator determines the total social cost per kWh of electricity for every possible source, the optimal source (or sources) from a social cost perspective can be determined. We index the optimal source by "o"; this means that, among all possible sources *j*, $SC^o \leq SC^{j,}$ *where* $j \neq$ o.

The suggested contract price (or social-cost-minimizing price) for any source *j* will be denoted p^j. Since we never want to pay more for a source then its private cost and because it is socially optimal to provide an adequate price to encourage generation from the socially optimal source, it must be that the contract price for the socially optimal source is its private cost, expressed as: $p^j = PC^0$

The private cost for the social-cost-minimizing source provides the baseline against which other technologies are gauged. In particular, the algorithm sets the contract price for an arbitrary source j equal to PC^0 plus or minus the value of offsetting compensation that would result from generating electricity from source j instead of source "o". This implies the following pricing formula:

$$p_j = PC^0 + \sum_i MD_i \cdot (E_i^0 - E_i^j) + (INT^0 - INT^j)$$

To understand the formula, it is easiest to consider the case in which there are no integration costs and only one externality—say, SOx emissions. In that case, total social costs for source j would simply be:

$$SC^j = PC^j + MD_{SOx} \bullet E^j_{SOx}$$

Suppose, for the sake of argument, that coal was identified as the social-cost-minimizing source. Then the contract price for source j (another technology) would be

$$P_j = PC^{coal} + MD_{SOx} (E^{coal}_{SOx} - E^j_{SOx})$$

This means that the pricing algorithm would only pay source j a higher price than coal to the extent that the alternative source reduces environmental damages from SOx emissions. If the analysis had identified wind as the socially optimal source, then the private costs and SOx emissions levels for wind would be substituted for coal in the formula above. The pricing algorithm builds upon this simplified example and takes into account multiple externalities, while also allowing for compensation due to integration cost differences.

The algorithm is technology neutral because it prices the attributes of electricity without distinguishing the technology directly—though the result of the algorithm will favor some technologies indirectly, but only to the extent that they generate low social costs. In some instances, the results can be surprising: the pricing algorithm may not "chose" the generation technology that one might be predisposed to think of as the optimal alternative. This unbiased assessment creates incentive to develop new technologies in line with stated public interests. In contrast, RES polices or project-cost FITs are one-dimensional and reward a single identified technology.

The same incentives could play out in a constructive way also within a given, fixed generation contract. In particular, generation firms could be rewarded for future process or facility modifications that reduce social costs; by lowering its environmental imprint or its associated integration costs, the generator could become eligible for a higher contract price as governed by the pricing algorithm.

An important implication of the pricing rule is that it only rewards social-cost-minimizing power sources. In particular, the offer price for an optimal source is its private cost, which by definition includes enough of a profit margin to attract capital to the project. In contrast, the offer price for a sub-optimal source is always less than its private cost: $p^j < PC^j$.

To show this, we revisit the one-externality, no-integration-cost example above. Let source j be suboptimal and suppose wind is optimal. This means that

$$PC^{wind} + MD_{SOx} * E^{wind}_{SOx} < PC^j + MD_{SOx} * E^j_{SOx}$$

Using algebra, we can rearrange this inequality to read:

$$PC^{wind} + MD_{SOx} \cdot (E^{wind}_{SOx} - E^{j}_{SOx}) < PC^j$$

The left-hand side of this equation is just the offer price p^j, for the *sub*-optimal source, j, so the inequality says that the offer price for source j will be less than source j's private generation costs. In general, the offer price for an arbitrary, suboptimal source will be too low to attract capital to the project. This result will continue to hold when more externalities and integration costs are included.

5.3 Algorithm adjustments to support early-stage technologies

The feed-in tariff literature discusses a host of situations in which pricing rule modifications may be desirable. One example might be to attract funding to generation projects from suboptimal sources identified by policymakers as warranting early stage subsidies. As previously discussed, the algorithm would not provide an adequate price to attract capital investments to suboptimal sources. Instead, it would typically only support the source identified as minimizing social costs. It may then be necessary to include some flexibility to allow regulators to modify the algorithm price.

The simplest approach would be a staged pricing schedule. This is illustrated in Figure 1. Under this pricing schedule, the price would first start at the source-specific private cost, PC^j, and then fall over time, eventually dropping to the social-cost-minimizing algorithm price. Such a contract would ensure generator profitability for some initial phase, but also send a clear signal that the subsidy is only temporary and that the source must eventually be able to compete on social cost grounds. The length of the subsidy would have to be determined by policymakers and it would naturally depend on the expected rate of technological development for the subsidized source, along with its perceived future value.

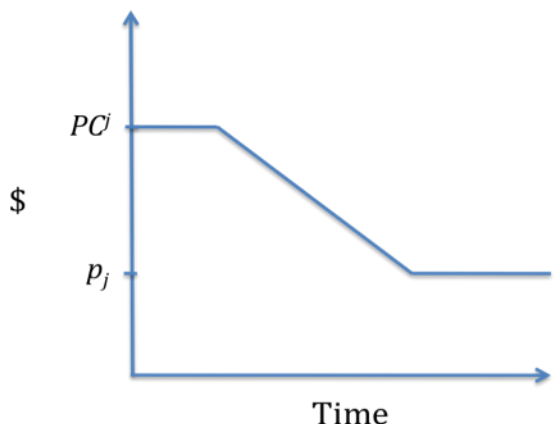


Figure 1.0 Illustration of Staged Pricing Schedule. A staged pricing schedule with a temporary subsidy at PC^j can support generation from technologies with identified long term potential p^j.

5.4 Policy considerations in the context of H.B. 10-1001 and H.B. 1365

It is important to note that this proposed pricing rule represents a starting point for calculating the comprehensive avoided costs of energy production. Successful implementation of the pricing rule requires selection of the baseline technology and careful consideration of other energy regulations at the state level (e.g. H.B. 10-1001 and 1365), as well as the incorporation of any default values stemming from federal air quality regulations. The efficacy of the algorithm depends upon the accuracy of the private cost information and marginal damage functions. These values will require periodic updating.

Existing state and federal policies also affect the effectiveness of the pricing algorithm. For example, the SO_2 allowance trading system established under the 1990 Clean Air Act, SO_2 emissions in Colorado would likely be redistributed to other places across the nation as a result of the permit system. Hence, there would be a national net improvement of zero. In addition, the adders on other pollutants should be set flexibly, with an eye toward future federal regulation. An appropriate adders-like policy in Colorado should recognize the need to adjust policy in the future should a pollutant become subject to a federal allowance trading program sometime in the future.

It is also important to view the proposed pricing rule in the context of current Colorado regulatory policies. Colorado House Bills 10-1001 and 1365 will dramatically change the generation portfolio in Colorado's regulated electricity sector. The main thrust of H.B. 10-1001 requires that 30% of the Colorado's investor owned utility (IOU) retail electricity sales in Colorado by year 2020 come from Sec. 124 eligible renewable energy sources. H.B. 1365 mandates the retirement a minimum of 900 MW (or 50%) of the PUC's coal-fired electric generating units in Colorado, by 2017 (whichever is smaller). In essence, somewhere in the 2018-2020 timeframe, the largest regulated load will shift from a high percentage coal and gas baseload profile to a gas baseload/renewables resource stack.

These regulations have two major consequences for designing a forward-looking value-based policy. First, by significantly reducing the amount of residual pollution, H.B. 10-1001 and H.B. 1365 will eventually reduce the appropriate baseline from which the marginal damages from an incremental unit of pollution should be measured. Second, as the penetration of renewables increases under the RES, it becomes increasingly costly to take on yet more intermittent sources. On the other hand, there is also incentive for wind generators (for example) to innovate and reduce variability in power.

In the context of H.B. 10-1001 and 1365, the main effect of this proposed pricing rule would either tweak the composition of renewable sources used to meet the RES or alter the composition of traditional sources adopted in future sourcing agreements. Because the RES would supersede our proposed pricing rule, the composition of renewables taken on under the RES is first determined by both the total MWh retail sales requirement and the technology-specific carve out for renewable distributed generation. Once legislated carve outs have been met, the composition of the remaining fraction of electric generation resources would be determined in a way that minimizes total social costs. Differences in the calculated social cost under the pricing rule would be most affected by differences in private costs to the generator (reflected by the bid price) and differences in the variable power pricing rule.

In summary, a renewable energy standard (e.g. H.B. 10-1001) or a technology standard (e.g. House Bill 1365) can influence the design and effects of a value-based pricing rule by changing the relevant baseline of residual emissions at which marginal damages should be measured. Implementation of H.B. 1365 and H.B. 10-1001 will substantially decrease the relevant marginal damage estimate and thus decrease the price difference computed by this pricing rule. At the same time, the higher penetration of renewables under the RES would increase the baseline level of renewable sources from which the variable power costs would be assessed.

6.0 Colorado-Specific Marginal Costs for Desired Environmental and Performance Attributes of Electricity Generation

Section 5.0 describes a value-based cost algorithm that positively rewards social cost savings. Social cost savings arise when a cleaner or more reliable generation source is chosen, thus avoiding costs of a dirtier or more variable source which could otherwise have been used. The avoided costs may include private costs, environmental damages, or costs from variable power/intermittency. Externalities can be measured through marginal damage functions—the damage from each unit above a technology baseline. Section 6.0 identifies these environmental and performance attributes and the respective marginal damage estimates for minimum, "typical" (either mean or median), or maximum levels of damage. A description of how the pricing algorithm operates is provided in Section 7.0. As follows is a brief description of the environmental attributes and how the marginal damage estimates were determined.

6.1 Selection of Environmental Attributes

GEO identified six environmental attributes for inclusion in the social cost algorithm: mercury, carbon dioxide, nitrogen oxide, sulfur dioxide, and particulate matter levels, as well as water consumption and quality. These were selected because federal and/or state regulation is pending for five of the six. With regulation pending, the value-based pricing rule would be a means for proactively managing the targets with a market based approach. In fact, federal EPA regulators are observing Colorado's current policies with the intention of potentially expanding similar energy policies elsewhere in the nation (Jaffe, 2010).

Mercury, carbon dioxide, nitrogen oxide, and sulfur dioxide are primary pollutants that can result from electricity generation. While not a pollutant, water is a scare resource in Colorado that can be consumptively used, disruptively diverted, thermally loaded, or otherwise impaired. Its external costs are difficult to measure comprehensively, yet the value of water is considered much higher than what has been reflected in water market prices (Western Resource Advocates, 2010). This has led Xcel Energy to consider water use when locating its recent plants (B. Chacon, Personal Communication, October 6, 2010).

Fine particulate matter, $PM_{2.5}$, is a secondary pollutant caused by complex chemical reactions in addition to the identified primary pollutants. $PM_{2.5}$ was disaggregated from the primary pollutants because specific damages can be separated from other pollutants and attributed to $PM_{2.5}$. Furthermore, the EPA is in the process of reviewing the NAAQS for fine particulate matter, and is considering a strengthening of that federal standard in "Policy Assessment for the Review of the Particulate Matter National Ambient Air Quality Standards, Second External Review Draft," dated June 2010.

Similarly to $PM_{2.5}$, ammonia is a secondary pollutant created by a complex chemical reaction of primary pollutants from electricity generation. However, we have not created a marginal damage function for ammonia. The fate and transport of related primary pollutants (e.g. nitrogen) is complex and at this point cannot be attributed to a single source (Baum and Ham, 2009). Furthermore, a standardized EPA test method for measuring and monitoring ammonia emissions directly from stationary sources is currently not in place (C. Welch, Personal Communication November 5, 2010), which adds to the complexity. In the future, marginal damage functions should also be provided for ammonia. A brief summary of pending regulation for the other environmental attributes is provided in the respective sections.

6.2 Modeling and estimating marginal damage functions

Marginal damage estimates have been adapted from secondary data to reflect the energy sector within the state of Colorado.

A marginal damage cost model was chosen to measure the external costs of these environmental attributes, rather than a marginal abatement cost model. In a meta-analysis of external energy costs, Sundqvist (2004) concludes that marginal abatement costs (costs associated with avoiding damages) yield higher estimates compared to marginal damage functions, which empirically measures the net costs of externalities. Along with Joskow (1992), Sundqvist concludes that the marginal abatement cost and marginal damage cost estimates are not interchangeable, and that differences in site specificity contribute to large variances in estimates. The high variance in damage costs between states is also noted by Fang (1994). In other words, location matters when determining costs. Although we have been limited to the use of secondary data, others have shown that use of secondary data and benefit transfer studies may still present a cost-effective means to estimate external environmental damages in Colorado (Hoag, Boone, and Keske, 2010; Keske and Loomis, 2008).

To estimate marginal damage functions, studies are cited that incorporate a range of valuation methodologies. Methodologies may include the statistical value of a life, a dose-response function, damages that may be incurred by regulatory action, and opportunity cost of a resource relative to highest and best use. Whenever possible, data are cited or interpolated to be relevant to Colorado. Details relevant to the calculations are provided under the respective environmental targets described below. Readers desiring a more in-depth description behind the respective methodologies can review Lesser, Dodds, and Zerbe (1997) and Fang (1994). The calculations in this report do not reflect the social value of energy security or global climate change, although a case can be made to include these respective measures (Hohmeyer, 1992; Kammen and Pacca, 2004). In summary, a more conservative model has been chosen, and efforts have been made to adapt the marginal damages to Colorado wherever possible.

6.3 Marginal damage estimates for environmental pollutants

6.3.1 Mercury

Mercury occurs naturally in soil and rock. It does not environmentally degrade, and its presence is bio-accumulative and long term. Coal fired electric plants, zinc/copper mining, and medical products have been identified as leading sources of mercury pollution (Lissianski et al., 2009; USGS, 2010). When mercury drifts into water it is transformed into methylmercury (MeHg), a highly toxic substance that accumulates in aquatic species and animals that consume them (EPA 2010), including humans. Mercury toxicity can cause organ and immune system damage to people of any age. MeHg has been most highly correlated with fetal nervous system damage and IQ loss stemming from maternal ingestion of contaminated fish. States may issue warnings against fish consumption from lakes and streams that are known to be contaminated; however, far-reaching international fish trade can yield contamination beyond regional boundaries.

Due to atmospheric transport, chemical transformations, and deposition into lakes, rivers and aquifers, the effects from mercury fate and transport are far-reaching (Pirrone and Mason, 2009). At this writing, the EPA is developing mercury emissions standards for power plants under §112 of the Clean Air Act. Several states, including Colorado have already enacted state legislation to reduce Mercury emissions (Colorado Mercury Reduction Regulation for EGUs 2012, 2014, 2018). As much as 40% of mercury in the U.S. actually originates from outside the country (Rossler, 2002). Accumulation of mercury in U.S. water ways from international sources will likely continue to be a source of concern and require international cooperation (United Nations Global Partnership for Mercury Transport and Fate Research, 2010). In the meantime, Colorado marginal damage estimates must account for world-wide damages.

Marginal damage function estimates are based on work of Spadaro and Rabl (2008). MeHg is estimated by applying damage from a dose response model to the statistical value of human life in the United States. The authors cite literature that U.S. ingestion of MeHg is statistically similar to the world average. Using the EPA damage dose threshold of 6.7 μg/day, the authors estimate damages as the sum of the impact per person exceeding the threshold (as measured by social costs resulting from loss of IQ) averaged over the entire population. Loss of IQ has been used in modeling damages from pollutants (including lead) that cause a decrease in cognitive skills and whose affects are cumulative over a lifetime (Pizzol et al., 2010). This model has been used in estimating the social costs of MeHg, as well (Tresande et al, 2006; Lesser, Dodds, and Zerbe, 1997).

Through meta-analysis of prior studies, a value of $18,000 per loss of IQ point for a U.S. resident is assigned, as a baseline. Because the effects of MeMg contamination are cumulative and damages are often not realized for years, the authors apply a time lag of 15 years. Using a 3% discount rate over 15 years yields a discount factor of .64. With an average per person IQ point loss of 0.02, accounting for the population that is above the threshold on a given day, the mercury marginal damage estimate equates to an average of $1,663/kg. A Monte Carlo simulation to calculate 68% confidence intervals in cost/kg yields low and high estimates of $141/kg and $2,494/kg respectively. The authors also vary the interest rate in the uncertainty analysis.

6.3.2 Carbon

GEO's 2009 Renewable Energy Development Infrastructure (REDI) Report promulgates clear carbon dioxide (CO_2) emission reduction targets. This includes the "20x20" goal of reducing annual CO_2 emissions by 20% in the electricity generation sector from 2005 levels by year 2020. Implementation of GEO's "20x20 goal" was modeled in the REDI addendum (2010). This progressive stance places Colorado ahead of other states in carbon reduction policies, particularly in the context of emissions from energy generation. While CO_2 emissions have been linked to global climate change (IPCC, 2007; Bruce et al., 1999; Denning, 2003), the financial impact and social costs of carbon emissions have been the source of diverse opinions and spirited debate (Goulder and Mathai, 1998; Nakata and Lamont, 2001; Tol, 2005). Nonetheless, Colorado's carbon reduction policy goals are clear, as national carbon reduction policies are under consideration by legislatures and regulators.

Because the social costs of carbon are highly uncertain and the effects may be geographically diffuse, proposed carbon social costs vary widely. For purposes of this project, marginal damage estimates have been derived from the 2010 Interagency Workgroup on Social Cost of Carbon (SCC). The Interagency Workgroup consists of 12 agencies, including Department of Energy, Department of Agriculture, and the Office of Management and Budgeting. The estimates reflect annual monetized damages associated with an incremental increase in carbon emissions in a given year. The values include changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change. Uncertainties are present with the estimation and it is important to periodically update the values.

The Interagency Workgroup values are based upon different climate scenarios of three scientifically accepted integrated assessment models: FUND (Nordhaus and Boyer, 2000; Nordhaus, 2008); DICE (Hope 2006; Hope, 2008); and PAGE (Tol, 2002a; Tol, 2002b; Anthoff et al., 2009; Tol, 2009). These respective models reflect the median, lower bound, and higher bound estimates of $22.12, $5.27, and $8.48 per metric tonne, respectively, when adjusted for inflation. The median and lower bound estimate are based upon the climate change damage estimates at the 3 and 5 percent discount rates, respectively. The max value ($68.48) represents higher than expected impacts from temperature change for the 95th percentile at a 3 percent discount rate.

6.3.3 Nitrogen oxide, sulfur dioxide, fine particulate matter

6.3.3.1 Nitrogen oxide

Nitrogen oxides (NO_2 and NO_3, or collectively, NO_x) are major pollutants contributing to elevated tropospheric ozone (O_3) levels and regional haze (known colloquially as the "brown cloud over Denver"). Burning fossil fuels like gasoline, oil or coal comprises approximately 7% of NOx emissions in the state (Middleton, 2010; Mauzerall et al., 2005). NO_x damages are associated with respiratory and cardiovascular morbidity, particularly in asthmatics, children, and older adults (Miller, 2010). NO_x has also been linked with poor visibility and long term O_3 concentration in national parks such as Rocky Mountain and Mesa Verde, as well as wilderness and natural areas (Middleton, 2010; Loomis, 2002; Tong et al., 2006).

Reducing Nitrogen Oxide emissions is a national and state environmental priority. According to sworn testimony in response to PSCo's "Clean Air-Clean Jobs Act Emissions Reduction Plan" filed on August 13, 2010, one of GEO's top three goals is to "meet and exceed existing and foreseeable Clean Air act Regulations through an specified annual reduction of NO_x" (Futch, 2010).

The costs may be high if Colorado does file a Regional Haze State Implementation Plan (SIP) by January 2011. Based on levels recorded in 2007-2009, nine counties along Colorado's Front Range consistently fail to achieve 2008 National Ambient Air Quality Standards (NAAQS) for ozone of 75 parts per billion (ppb), averaged over three years. The EPA's Regional Haze Rule also requires reductions in visibility-impairing pollutants like NO_x to improve visibility in pristine air sheds in Colorado and nearby states. If Colorado's SIP is not submitted to EPA by January 2011, the EPA will regulate utilities and other large sources of NOx in the state through an EPA-promulgated Federal Implementation Plan, likely leading to a piecemeal, expensive, and relatively inefficient approach to air quality management. PSCo's role in the SIP is also required.

Several authors have estimated marginal damage functions from NO_x emissions (Farrell et al., 1998; Burtraw et al., 2003; Mauzerall et al., 2005; Kumar and Manangi, 2010; Deck, 2010). However, many of these studies combine impacts from NO_x, Sulfur Dioxide (SO_2), O_3 and $PM_{2.5}$ into a single marginal damage estimate. Although SO_2 has also been identified as a pollutant contributing to Regional Haze and ozone, the case can be made for disaggregating NOx, SO_2, and $PM_{2.5}$ damage estimates. The chief rationale is that the complex chemical reactions cause health and environmental impacts to vary across time and space. Furthermore, damages that result from these pollutants vary in intensity and origin (Mauzerall et al., 2005). Muller and Mendelsohn (2010) reiterate the importance of assigning damage values to the primary pollutant from which pollution is formed. Compared to SO_2, NO_x has been shown to have a disproportionately large effect on agriculture, forestry, and recreation (Muller and Mendelson, 2007). Separating the impacts of the individual pollutants may yield a more precise marginal damage value (Muller, Tong, and Mendelsohn, 2009). Furthermore, the effect of NO_x emissions on generating secondary pollutants such as O_3 and $PM_{2.5}$ varies depending on relative concentrations of NOx, volatile organic compounds (VOCs,) sunlight, temperature, and other factors (Mauzerall et al., 2005). Due to atmospheric chemistry, NO_x and SO_2 emissions in urbanized areas leads to higher exposures and damages from both compared to rural areas (Muller, Tong, and

Mendelsohn, 2009; Muller and Mendelson, 2007). This implies that damage estimates from these emissions should be weighted higher for urbanized areas.

Separating the damaging effects of primary pollutants such as NO_x from secondary pollutants (O3 and $PM_{2.5}$) can be challenging, as the link between the primary and secondary pollutants can be difficult to distinguish. However, in order to remain consistent with GEO's prioritization of NOx reduction as well as economic marginal damage function methodology, separate marginal damage estimates are provided for NO_x, SO_2, and $PM_{2.5}$. Marginal damage estimates for these separate pollutants are based upon work by Muller and Mendelsohn (2007; 2010), whose values are based on marginal damages resulting from increased morbidities and mortalities. The authors' computations are based upon changes in emissions as a result of the 1990 amended Clean Air Act, and apply U.S. EPA standards reflecting the statistical value of a life and dose–response functions.

Muller and Mendelsohn calculate the typical damage estimates for NOx emissions at $381/ton/year for urban regions and $254/ton/year for rural areas, adjusted for inflation to 2010 levels. Hence, weighting the damages to areas within the 9-county Denver-Metro non-attainment areas is not unreasonable. When the authors provide a specific estimate for rural and urban values, those values are used. After reviewing a series of comparisons between urban and rural regions, the typical difference between urban and rural regions yields NOx emissions at a level of .75 lower than urban regions. Hence, when the authors do not provide a specific estimate, a difference of .75 is used as a proxy.

Using the proxy, the lower bound threshold for rural regions is $191. The lower threshold for urban areas is $254, which reflects an un-weighted average estimate conducted by the authors that does not differentiate between damages to urban and rural areas. Muller and Mendelsohn's upper bound estimate for urban areas is $2,261 per ton/year. Applying the proxy, $2,261 *.25, or $1,696, reflects the upper estimate for rural areas.

Marginal damage functions do not appear to have been adequately calculated for NO_x as damage estimates in the literature have been limited to health effects. Thus, a "true" estimate of marginal damage from NO_x should be skewed towards the higher range. Although gross annual damages of NOx emissions on agriculture, recreation and forestry have been proposed by Muller and Mendelsohn (2007) and Tong et al. (2006), these damages were not included in Muller and Mendelsohn's (2007, 2010) marginal damage functions. In summary, it appears that the economic effect of NO_x on the environment and recreation presents a gap in the literature and under-represents the level of economic damages.

Poor visibility in natural areas including Rocky Mountain National Park and Mesa Verde has the potential to diminish both cultural and economic value of the region (Loomis, 2002). Adverse impacts of NO_x in natural areas are echoed in the Rocky Mountain National Park Nitrogen Deposition Reduction Plan, a joint effort between the CDPHE, the NPS, and the EPA (2007). Readers interested in better understanding the science behind nitrogen cycling and deposition process along Colorado's Front Range are encouraged to review IMPROVE (Interagency Monitoring of Protected Visual Environments) educational materials (2009). Damage effects are particularly noteworthy because mountain ecosystems are vulnerable to ecosystem damage (Lohman, 2010), and recreators at high mountain summits such as Long's Peak in Rocky Mountain National Park attach a much higher economic value to their experience compared to typical hiking or recreational experience (Keske, 2010; Keske and Loomis, 2007; Loomis and Keske, 2009). It is therefore conceivable that the upper bound estimate for NO_x emissions could be higher, with the inclusion of recreational damages.

6.3.3.2 Sulfur Dioxide

As previously outlined, individual marginal damage estimates have been created for SO_2, as recent studies suggest that policies should not treat NO_x and SO_2 emissions as though they are alike (Muller, Tong, and Mendelsohn, 2009). SO_2 has been more highly correlated with high morbidity and mortality, and thus the marginal damages in the context of the statistical value of a life are higher. Muller and Mendelsohn's Colorado-specific median value is $1,232 per ton, with the upper and low and high estimates at $635-$1,270 per ton, statewide (2010). Estimates are skewed towards the high end of the distribution, and all values have been adjusted for inflation.

Most recently, the EPA NAAQS for SO_2 were updated in 75 Fed. Reg. 35519 on June 22, 2010. SO_2 has a national cap and trade market. As discussed throughout the document as well as in Appendix B, the co-existence of these policies may cause interactions with the proposed pricing algorithm. For example, it could be argued that the proposed adder for SO_2 should be changed in the pricing algorithm to complement changes in national policies and create proper incentives for SO_2 emissions in Colorado in the context of national efforts.

While health damages from SO_2 are clear (CAFE, 2005; Middleton, 2010), the relative impact of SO_2 on Colorado and the rural western United States is less than the eastern United States. For example, Muller and Mendelsohn (2010) project that emissions of sulfur dioxide in large eastern cities cause damages that are 50 times larger than equivalent emissions produced in rural western locations. Hence, it is our opinion that their higher bound marginal damage function estimate of $10,860 is not appropriate for Colorado. Deck (2010) makes a similar case for applying lower marginal damage function estimates to the Denver-Ft. Collins metro area in his estimates. It should also be noted that Deck uses a similar dataset, but combines the pollutants to calculate marginal abatement costs.

6.3.3.3 $PM_{2.5}$

Fine Particulate Matter ($PM_{2.5}$) refers to particles that are less than 2.5 micrometers in aerodynamic diameter. $PM_{2.5}$ is a secondary pollutant that is formed by a convergence of anthropogenic pollutants, as well as naturally occurring elements from dust and vegetation. Anthropogenic sources include gasoline, open burning, and coal-based power production. The effect of SO_2 and NOx on ambient concentrations of $PM_{2.5}$ has led many scientists to aggregate the damage functions for SO_2 and NOx on $PM_{2.5}$ (Deck, 2010; Kumar and Manangi, 2010). However, the complexity of this multi-source pollutant, as well as linkages $PM_{2.5}$ between high adult mortality rates levels (Pope et al., 2002) necessitates further delineation.

Of course, the challenge is to avoid double-counting the marginal damages from primary pollutants such as nitrogen oxide. For this reason, we rely on county-level marginal damage estimates from Muller and Mendelsohn (2010) that only reflect the damages of $PM_{2.5}$ on human health. $PM_{2.5}$ concentrations and subsequent damage functions vary considerably across the state. Marginal damage estimates for Denver and Jefferson Counties are $12,701-$25,402 per ton, placing the estimates in the second highest category of severity. Three nearby counties also reach the damage threshold of $12,701. Probably due to their low population densities, the far northwest and southeast corners of the state present $0-$635 per ton of damages, the lowest category of damages.

Putting this into perspective and remaining consistent with the prior regional marginal damage estimates, different marginal damage estimates should be applied to the Front Range compared to other regions in the state. Front Range min, mean, and maximum values should reflect $12,701, $19,051, and $25,402, respectively. Facilities outside of the nine-state out of compliance area present values between $635-$953, yielding min, mean, and max values of $635, $794, and $953, respectively.

6.3.4 Water Use

"Whiskey is for drinking, water is for fighting over." The symbolism of Mark Twain's quote is as relevant today in Colorado as it was 100 years ago. Adequate water quality and quantity are critical to most dimensions of health and economic prosperity. Without water, life would cease to exist.

Thermoelectric utilities use a considerable amount of water for use thermally driven water-cooled energy conversion cycles (Torcellini, Long, and Judkoff, 2003). According to a recent report by Western Resource Advocates (2010), thermoelectric power plants in five western states (including Colorado) consumed 292 million gallons of water a day in 2005, a value estimated as approximately equal to the combined water consumption by the cities of Denver, Phoenix, and Albuquerque each year.

Although water historically has been scarce in the West, many view future water availability as a sleeping giant (Interlandi, 2010). Balancing water demand with projected water quality standards, agricultural production, population increases, and climate change—while achieving incrementally more rigorous environmental water quality standards—presents a formidable challenge. For reasons stated above, water consumption has been included as an environmental target. Water used in energy production is water that could otherwise be used for other purposes.

Concerns about the future availability of water, and the associated social benefits of water have arguably resulted in a sub-optimal price for water in Colorado. That is, water is not fully priced in the market. Theoretically speaking, the adder should reflect the difference between the marginal social cost and the price paid for water. Ultimately, further study of the social cost of water in Colorado is necessary in order to quantify these differences. However, since the social cost is unknown, the highest measured market price (municipal use) is used as a proxy for the difference between the social cost of water and the price paid, since municipal prices represent a lower bound on social cost.

Furthermore, competing water uses and externalities make estimation of marginal damages tricky, particularly in the context of energy generation. Based upon the best scientific information presently available, this report generates a range of marginal damage estimates that are based upon the opportunity cost from loss of highest and best use of one acre foot of water in Colorado, which is municipal use. This choice does not imply that water should be converted to municipal use, but rather represents the opportunity cost of water used for power generation. Values generated do not include annualized treatment O&M costs, tap fees, new project costs, or externalities.

Water markets reveal preference and provide price data not available through stated preference studies that include externalities and other non-market attributes. Furthermore, the type of water traded Water Strategist (2009) data from years 1987 through 2009 show Colorado with the most transactions (approximately 2,150) of the twelve western states tracked. Although not all water transactions have been recorded in this database (Howe and Goemens, 2003) and the database shows some bundled transactions, more than one half of Water Strategist observations are from Colorado. Likewise, Colorado has more than three times the recorded market transactions of any other state. There is considerable variability in transaction prices between water use categories, and within the same category of use. This may be due in part to lack of price information, high transactions costs and few buyers and sellers on either side of the market (Carey, Sunding, and Zilberman, 2002). Overall, Colorado demonstrates higher water prices compared to other states, particularly along the Front Range. The higher prices are an indication of the scarcity driven by high demand for municipal, agricultural, and environmental uses.

Lower, median and upper bound estimates of municipal prices have been compiled using the Water Strategist database, based upon 1210 observations for which sales price data were available from 1987 through February 2009. The inflation adjusted min, median, and max values are $78, $284, and $853, which represent the 10th, 50th, and 90th percentiles, respectively. The values used reflect the inflation adjusted annual price per acre foot, for water transfers only, and adjusted by using infinite discount rate of 8%, which reflects the interest rate of private capital. Leases were not used because they reflect a short time period (typically one year), and may be influenced by a number of exogenous market variables and weather. The typical lease rate, not surprisingly, is considerably lower (roughly $25 per acre foot/year), according to Northern Colorado Water Conservation District, 2010 (A. Berryman, Personal Communication September 10, 2010). Water transfers typically take place from agriculture to municipalities, and there is a much higher premium to water rights transfers.

It is important to emphasize the substantial body of research suggesting that Colorado water prices do not appropriately reflect the "true" value of water. Several authors have argued that water prices should increase to reflect "social values" such as ecosystem services (Brauman, Daily, Duarte, Mooney, 2007); agricultural production/food security (Rosegrant, Ringler, and Zhu, 2009); and risk/uncertainty of future population growth (Watson and Davies, 2009). In the context of energy, PSCo states that the social value of water and uncertainty of future water availability affects PSCo's decisions, even when financial payback indicate otherwise (B. Chacon, Personal Communication October 6, 2010). Likewise, in PSCo's response to Clean Jobs Act Emissions Reduction Plan (CPUC Docket No. 10M-245E) the company commits to reporting water consumption for existing and proposed facilities and the water intensity (in gal/MWh) of resource portfolios. Many argue that municipal rates do not appropriately reflect social costs, but the municipal price estimate is higher than typical agricultural or environmental market prices (Stednick, 2010; Western Resource Advocates, 2010; Loomis et al., 2003; Loomis, 1992).

Social valuation of water also involves water quality issues. Non-point source pollution and the confluence of emissions, nutrients, and pollutants from multiple sources have profound environmental effects that can be difficult to isolate (Stednick, 1996). In the case of electricity generation, the effect on water quality from different technologies is also complex and heterogeneous. For example, a 2003 NREL study, eighty-nine percent of thermoelectric utilities use thermally driven water-cooled energy conversion cycles (Torcellini, Long, and Judkoff, 2003). This requires a considerable amount of water, but much of the water is reused in this closed loop system, keeping evaporation rates much lower than hydro-electric so the amount that escapes through the evaporation process is significantly less. In contrast, disruption of the natural cycling paths caused by hydo-power may also yield further damages to ecosystem services such as riparian areas, wildlife, and societal cultural values (Corson, 2002; Loomis, 2002). Inclusion of water's social costs could increase prices considerably, particularly for plants using traditional water-cooled energy conversion cycling (Younos, Hill, and Poole, 2009; U.S. General Accounting Office, 2009), which would have a windfall effect and subsequently increase the social cost per kWh of electricity.

In summary, marginal damage estimates currently reflect the current opportunity cost of highest and best use in the market. However, a valuation study measuring the impact of energy on water availability and quality is a worthwhile area for future research, given the projected scarcity and important role of water to Colorado.

6.4 Performance Attributes

6.4.1 Variable Power

Firm or "dispatchable" power is a desirable performance target for the electric power utilities. Production from variable power sources often cannot be relied upon during peak demand, thus requiring utilities to employ expensive, short run generation options as a stop gap (Milligan and Kirby, 2009). Our proposed social cost algorithm reflects the expected marginal increases in operational costs that are a consequence of producing energy from intermittent sources.

Wind and solar generation technologies have been specifically identified as variable energy resources, while coal, natural gas, and hydro powered plants are considered baseload technologies that are available upon demand (Wan and Parson, 1993). Geothermal is also being increasingly considered as a base load technology (U.S. Department of Energy, 2008). Original experiments with adders policies did not address variable power in any meaningful way. A possible explanation stems from the fact that variable power sources entailed a small fraction of the overall generation portfolio in the 1990's, which imposed lower displacement of non-variable power sources, and likely negligible costs. In contrast, adding a variable resource to a generation portfolio of 15%, 20%, or even 30% penetration would add considerable expense (NREL WWSIS, 2008; Zavadil, 2008).

Costs of building new sources of wind energy are declining (CalISO KEMA, 2010), and technologies that forecast wind availability have continued to improve (Zavadil, 2008; Milligan and Kirby, 2009; EIA, 2010).

Nonetheless, at this writing, in order to achieve large variable energy penetration rates, the back-up resources that are necessary to ensure lack of energy disruption are considerable. Hence, proposed renewable penetration rates of 10%, 20%, or 30% will impose costs for every MWh of variable energy produced. We note there is an element of market uncertainty about the capacity and economic feasibility of utility scale energy storage such as pumped hydro, CAES, and batteries to effectively reduce the cost of integration by retaining the off-peak generation from renewables and dispatching the value added energy during peak usage. It is possible that the commodification of these technologies will begin to place downward price pressure on renewables and lower the integration cost of variable power over time. At this juncture, we are being conservative as utility scale storage is not widely deployed in Colorado and therefore we are not "counting" on this technology to lower integration costs.

A recent, Colorado-specific study (Zavadil, 2008) modeled the additional cost of wind integration between $3.51 to $5.13 MWh, depending upon the penetration rate of wind integration (10% through 30%, respectively). This assumes a geographically diverse location of wind generation facilities (i.e. beyond where wind is currently concentrated, primarily in the northeastern corner of the state), and accurate forecasting technology. This range uses the assumption that variable energy production displaces electricity produced by natural gas, running at $5 MMBTU. The authors adjust their assumptions to allow for less geographical diversity, different gas prices, smoothing adjustments to accommodate differences in wind speeds, and forecasting. Most of the values for the $5 MMBTU model hover around $5 per MWh ind integration cost. Not surprisingly, higher natural gas prices yield higher integration cost prices (roughly around $8 MWh). Given the complexity of the modeling process, we apply an adder of $5 MWh for variable power technologies. In a manner similar to the environmental targets, the performance adder should be reevaluated frequently to reflect technological advancements within the field, and within the state.

6.4.2 Time of Delivery Benefits

It is well established that energy demand varies throughout the day and peaks during early evening. There are also peaks in demand associated with seasonal changes. Ensuring energy availability when it is most in demand is a desirable and important performance attribute. Benefits arising from a system that delivers energy during peak times of day without interruption are called "time of delivery benefits".

At this writing, considerable infrastructure exists for the sole purpose of generating power during times of peak demand. In Colorado, the majority of these marginal sources are coal-fired energy plants, although Texas and other states have demonstrated that other energy sources (including wind) can provide time of delivery benefits (P. Pasrich, Personal Communication November 24, 2010).

Calculating the value of time of delivery benefits—or associated external costs of disruption—is not an easy task. The time of delivery values that are most readily available reflect energy demand, or the prices that consumers pay for energy during different times of the day or season. A fair amount of research has been conducted on the demand side, including a PSCo's 2010 pilot rate structure test as part of the Smart Grid Task Force.

However, for a value-based pricing algorithm, calculation of time of delivery benefits should reflect supply side costs of an additional unit of energy generation. As with intermittency, another performance attribute, under preparing for risk can impose costs on utility users. Ensuring uninterrupted energy dispatch when it's most in demand during peak times of the day may require back-up generation facilities/technologies beyond what the private sector is willing to provide.

A starting point for calculating social costs could be the prices that generators receive from the utilities (such as the PSCo), in order to determine the marginal cost of providing another unit of energy during peak time periods. Not unexpectedly, this information is difficult to obtain because contract prices are subject to change, and there is incentive for both the generator and the utility to not disclose this information.

There are examples available that illustrate supply side time of delivery calculations. For example, a summary of time delivery benefits calculations by California Investor Owned Utilities (IOUs) was presented to the California Energy Commission in 2006 (Price and Cutter, 2006). In summary, each IOU uses futures market data to calculate monthly trading blocks (e.g. base, peak, and critical peak) and to forecast hourly prices. The utilities then calculate average prices for each trading block and estimate capacity values which they allocate to certain time of delivery periods. The IOUs then calculate time of delivery "factors", to reflect the value that time of delivery benefits present at a particular time of day.

In summary, the current pricing algorithm does not explicitly contain adjustments for time of delivery benefits. Future research and iterations of the pricing tool should account for time of delivery benefits and diurnal energy supply that are specific to Colorado.

7.0 Social Benefit Pricing Tool

The Excel-based social benefit pricing tool presented in Appendix A is an applied, simplified illustration of the social benefit pricing model. The pricing tool parameterizes the benefit-pricing algorithm outlined in Sections 3.0 through 6.0 by applying secondary data to the context of Colorado. The tool estimates total social costs for up to seven selected technologies. The algorithm rank orders the lowest social cost technology, based upon the parameters and energy technologies selected for comparison. As previously outlined, total social costs are comprised of private generation costs, environmental costs, and variable power costs. Default cost estimates are provided for all three cost categories, based upon the most currently available scientific literature. However, the pricing tool enables users to impute customized cost data, to reflect information and cost updates. In other words, the pricing tool is both customizable, as well as technology neutral.

In summary, the model calculates total social cost, a ranked list of technologies according to total social cost, and the social price of each technology.

As follows are basic instructions on how to use the social benefit pricing tool, which can be customized in several different ways. Information about how to use the pricing tool is also written in the "Overview" worksheet tab of the pricing tool. A description of the parameter assumptions are provided in 7.2.

7.1 Pricing Tool Instructions

7.1.1 Option One: Calculating Socially Optimal Technology Using Default Parameters

Step 1. Click on "Pricing Algorithm" tab.

Step 2. Click the "Default Technologies" button. Private, environmental, and variable power costs are displayed for the respective technologies

Step 3. Click the "Calculate Optimal" button.

- The source with the lowest social cost (ie. "Optimal Source") is displayed at the top of the Optimal Source matrix.

The Optimal Source matrix displays social costs for all seven energy sources in $/MWh and cents/kWh.

In addition to the total social cost, the Optimal Source matrix presents private, environmental, and variable power costs for each technology, separately.

7.1.2 Option Two: Calculating Socially Optimal Technology Using Semi-Customized Parameters

Step 1. Click on "Pricing Algorithm" tab.

Step 2. Select the technologies for comparison using the drop down menu for each energy source.

Step 3. Private Costs: Default private costs (in $/MWh) will appear. For customized values, click on the "private costs" cell and enter the values.

Step 4. Default environmental damage costs default "typical" or mid-line levels. For customized data, click on the respective button to adjust for low, typical, or high environmental cost estimates.

- To exclude consideration of an environmental factor, select "none" under the appropriate externality. Emissions factors appear in the respective cells. If desired, click on the appropriate cell to customize emission factor estimate into the environmental cost cells.

Step 5. Default variable power cost estimates appear. If desired, impute a customized variable cost estimate.

Step 6. Click the "Calculate Optimal" button.

- The source with the lowest social cost (ie. "Optimal Source") is displayed at the top of the Optimal Source matrix. This also reflects customized data, as selected or entered.
- Note that the user has the option to provide their technology data. Under each source select "custom" from the drop down menu and input the relevant data.
- The Optimal Source matrix displays social costs for up to seven energy sources in $/MWh and cents/kWh.

7.2 Parameter Assumptions

The **private costs of generation** are assumed to be the levelized costs of electricity (LCOE) for a given technology. While other measures of private costs may also be appropriate, LCOE allows for comparisons across a range of technologies. Most public utility commissions require utilities to conduct LCOE analysis for any new projects and thus, these figures can be inserted directly into the pricing tool. The default LCOE parameters used are based upon recent estimates provided to the California Energy Commission for specific facilities (Klein et al, 2009). As stated above, customized LCOE information may be incorporated into the algorithm to reflect updated information.

To reiterate, two features of the **environmental cost** component can be customized. The user can determine which environmental costs are considered in the model, as well as the marginal damage level. For an included pollutant, the user must choose either the lower, middle, or upper marginal damage estimates, (or none) which reflect secondary data applied to Colorado. By default, marginal damage estimates are set to mid-range values.

Second, for each technology the user must input the relevant emissions factor for each pollutant. This is a measure of effluent per unit of electricity produced. For SO_2, NO_X, CO_2, PM, and MeHg, the units must be provided in tons per megawatt hour of electricity produced. For water the unit is acre-feet consumed per megawatt hour of electricity produced. The emissions factors for the seven default technologies have been calculated based on various sources. Table 1 documents these sources:

Table 1: Sources for Default Emission Factors

<table>
<tr><th>Technology</th><th>NO_x</th><th>SO_2</th><th>CO_2</th><th>PM_{10}</th><th>Hg</th><th>H_2O</th></tr>
<tr><td>Conventional Combined Cycle</td><td colspan="4" rowspan="2">Klein et al, 2009</td><td rowspan="2">No Emissions</td><td rowspan="3">Macknick, 2010</td></tr>
<tr><td>Advanced Simple Cycle</td></tr>
<tr><td>IGCC-Coal</td><td colspan="5">NETL, 2007</td></tr>
<tr><td>Hydro-Existing Site Upgrade</td><td colspan="5" rowspan="4">No Emissions</td><td>Torcellini et al, 2003</td></tr>
<tr><td>Onshore Wind- Class 5</td><td>No Emissions</td></tr>
<tr><td>Solar-Parabolic Trough</td><td rowspan="2">Macknick, 2010</td></tr>
<tr><td>Geothermal-Binary</td></tr>
</table>

All monetary values are normalized to 2010 dollars using the U.S. Bureau of Labor Statistics' inflation calculator.[1]

The "marginal damages" and "LCOE" worksheets contain background data needed for the model to run (and set default scenarios). It is not necessary for the user to interact with these worksheets. They have been made visible to the user for transparency and to understand how the module operates.

[1] Available at: http://data.bls.gov/cgi-bin/cpicalc.pl

8.0 Simulation Results

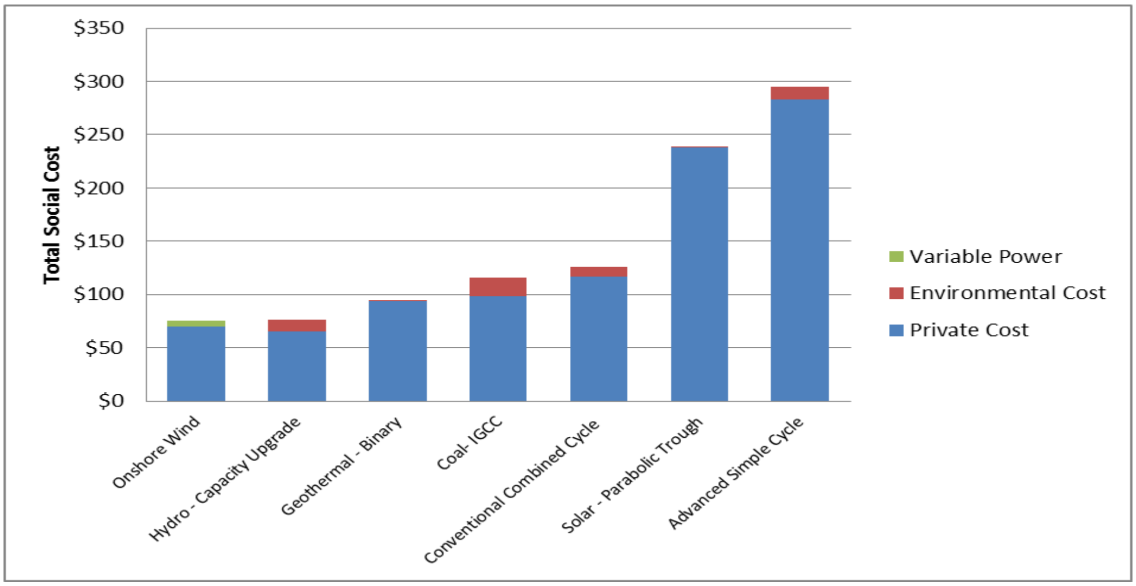
To demonstrate the benefit-pricing tool, seven technologies have been chosen for comparison. Table 2 shows the input assumptions for each technology. In the Excel workbook, this scenario can be run by clicking the "default scenario" button in the pricing algorithm worksheet. Private generation costs, emissions factors, consumption water use rates, and variables power costs for wind have been compiled from a variety of sources. While care has been taken to choose values that appropriately reflect the current state of technology, users should note that there is a lot of variation in these estimates based on factors such as plant size and technological design.

Table 2: Default Technology Values

Source	**Capacity (MW)**	**Private Costs (LCOE) $/MWh**	**Environmental Costs (Emissions Factors)**						**Variable Power Costs ($/MWh)**
			SO_2 (tons/MWh)	NO_x (tons/MWh)	CO_2 (tons/MWh)	HeMg (tons/MWh)	PM (tons/MWh)	Water (acre ft/MWh)	
Conventional Combined Cycle	500	116.32	.000002	.00003	.4195	0	.00001	.000675	0
Advance Simple Cycle	200	282.92	.000004	.00004	.507	0	.00003	.000675	0
IGCC (Coal)	300	98.32	.000047	.00020	.7295	2.1E-9	.00002	.001196	0
Wind	100	70.19	0	0	0	0	0	0	5
Hydro-Capacity Upgrade	80	65.39	0	0	0	0	0	.038054	0
Solar-Parabolic Trough	250	238.27	0	0	0	0	0	.001074	0
Geothermal-Binary	15	93.52	0	0	0	0	0	.000644	0

For each technology, Figure 2 displays total social costs decomposed into private cost, environmental costs, and variable power costs. Environmental damage values have been set to reflect median estimates. For the simplified context shown here, onshore wind turns out to be optimal. Environmental costs represent only a small fraction of total social costs, and they do not substantially influence the ranking of sources; a notable exception is the ranking between wind and hydro when consumptive water use is considered.

Figure 2: Diagram of Total Social Costs



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Appendix A.

Excel-Based, Technology Neutral Pricing Tool

Appendix B. Summary: The Interaction of Pricing Policies and Regulation

Command and Control Policies: When firms are required to keep the amount of pollution per unit of output below a specified level, the correct adder equals the marginal damage associated with residual emissions after existing regulations have been met. Since residual emissions are not priced, the firm has no incentive to reduce emissions beyond the necessary steps to meet the standard. Thus the "correct" adder amid pre-existing command and control policies is essentially the same as without other regulations (Freeman et al. 1992, Burtraw et al. 1995)

Emission taxes: The simplest situation arises when the existing regulation is an emission tax. If the tax appropriately equals the marginal damage associated with an incremental unit of pollution, then the correct adder is zero because external environmental costs have already been internalized. In contrast, if the existing tax is not equal to marginal damages, then the goal of the adders policy is to make up the difference. The correct adder then equals the marginal damage estimate minus the amount of the tax (Freeman et al. 1992, Burtraw et al. 1995). This number could be positive or negative depending on whether the existing tax is greater than or less than the optimal tax (which is equal to marginal damages).

Allowance Trading Programs ("cap and trade"): Adders policies that coincide with an allowance trading program ("cap and trade") could net a zero reduction in emissions. Cap and trade policies limit pollutant emissions within a particular region, and permits are allocated to exactly cover the amount of pollution allowed under the cap. Polluting firms must hold permits to cover the amount they pollute, but permits can be traded, providing firms incentive to reduce emissions up the point at which the cost of further abatement equals the market price of a permit. Using the case of SO_2, for which there is an active market, by emitting less pollution, Colorado utilities would need fewer permits to cover their own pollution. This would free up permits in the national permit market; however, permits are quite valuable, they will not go unused and the total amount of SO_2 pollution in the country will still equal the cap. Thus, the SO_2 reductions induced by Colorado's adder will be exactly offset by emission increases elsewhere. The net environmental impact nationally then is zero, while distortions are created in Colorado.

Implementation of adders is difficult in practice. As a result, the academic literature (for example, Hobbs 1992, Joskow 1992) has typically argued against positive adders for pollutants covered by a national allowance trading program.

From the literature it appears the there is no clear-cut ranking of d approaches, as each boasts its own benefits in different contexts. It can be agreed that a cap-and-trade approach may be a viable option for reducing emissions, but the exact approach depends on the scope, context and expectations of future regulations, especially at the federal level. RGGI and California have proven to be leaders in emissions regulation, so their interest in different variants of cap-and-trade policies indicates promising potential for other states and regions.

Portfolio and Technology Standards: A renewable portfolio standard (e.g. House Bill 1365) or a technology standard (e.g. House Bill 10-1001) can influence the design and effects of a policy by changing the relevant baseline of residual emissions at which marginal damages should be measured. Implementation of an aggressive version of either policy would substantially decrease the relevant marginal damage estimate and thus decrease the adder. At the same time, the higher penetration of renewables under the RES would increase the baseline level of renewable sources from which the intermittency adder should be measured.