Clarification of Stabilization Costs in November 13, 2006 Draft of the CCSP Product 2.1a Report.

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This document provides draft material that clarifies the basis for differences in the total costs of stabilization between the three models participating in CCSP Product 2.1a. This material is put forward as a draft insert for incorporation into the CCSP Product 2.1a report.

The models employed in the CCSP Product 2.1a report shows substantial variation in Gross World Product (GWP) impacts for the four specified stabilization levels. For example, for the Level 1 scenarios, IGSM reports a 16% loss in Gross World Product in 2100 while MERGE and MiniCAM show losses less than 2%. The variation in cost estimates for stabilization at other, less stringent levels of radiative forcing is lower in absolute terms, but the ratio of costs among models are similar. Differences of this magnitude are observed in estimates of emissions mitigation costs seen in the open literature (IPCC, 2001).

This variation across the models highlights the normal role of scenarios. They are not predictions, but tools for understanding the forces that lead to emissions and potential climatic effects and that determine the cost and effectiveness of actions society might take to limit the human impact on the Earth system. In particular, the variation in costs illustrates the implications of unavoidable uncertainty about population and economic growth over a period of many decades; it highlights the critical role of advances in technology, especially in the second half of the century; and it contributes to understanding of the way that anticipated developments in the distant future can influence the desirability of actions in the short term. Naturally, with a longer the time horizon uncertainty increases.

The cost estimates yielded by the models applied in this study are the result of a complex interplay of differing structural characteristics and variation in key parameter values. Nonetheless major differences among them can be attributed to two influences: (1) the amount that emissions must be reduced to achieve an emissions path to stabilization, and (2) the technologies that are available to facilitate these changes in the economy.

On the first point, the three models require different levels of total CO_2 emissions reduction over the century, as shown in the table below. These differences come principally from three aspects of model behavior and assumptions: differences in economic growth and emissions in the reference case (Tables 3.2 and 3.3, and Figure 3.3), the behavior of the ocean and terrestrial systems in taking up carbon (Figures 4.5 and 4.16), and the ability to meet the radiative forcing targets by reductions in emissions of non-CO_2 greenhouse gases (Figures 4.7 and 4.8). For all stabilization levels, the IGSM scenarios require greater emissions reductions than MERGE or MiniCAM. For example, the Level 2 emissions reductions in IGSM are commensurate with those of MERGE and MiniCAM for Level 1. The Level 3 emissions reductions in IGSM are noticeably larger than those for MERGE and MiniCAM for Level 2. All other things being equal, the greater the required emissions reductions the larger will be the costs of meeting each target.

Table 1: Cumulative Emissions Reductions across Scenarios (GtC through 2100)

	IGSM	MERGE	MiniCAM
Level 4	472	112	97
Level 3	674	258	267
Level 2	932	520	541
Level 1	1172	899	934

The second factor, the modeling of technology, also contributes to the differences among cost results. The aggregate effect of differing technological assumptions is illustrated in Figure 4.19, which shows the relationship between the price of carbon and percentage reductions in 2050 and 2100. Roughly speaking, these figures represent the marginal abatement cost functions for these periods. Note that technological opportunities are similar among the models in 2050: the implication is that if in 2050 the three models were to report the carbon price for the same percentage emissions reduction it would be very similar.

It is in the second half of the century that substantial differences in the marginal abatement cost functions emerge, particularly when the required abatement pushes towards and beyond 80% below the reference level. There is no small set of technology options that determines these differences. Among the models, the representation of technology varies along a range of dimensions such as the rate of growth in labor productivity, the cost and performance of particular energy supply technologies, the productivity of agriculture and the associated costs of bioenergy, and the ability to substitute among various fuels and electricity in key demand sectors such as transportation. These assumptions are embodied not just in model parameters, but also, as discussed in Chapter 2, in the underlying mathematical structures of the models. As can be seen in Table 2.1, end-use technologies, are, in general, not represented explicitly. The models do not, for example, identify multiple steel production technologies or a wide range of vehicle options each with different energy using characteristics. Instead, energy demand responses are represented in relatively aggregate economic sectors (e.g., energy intensive industry). Other technologies, particularly in energy supply (e.g., CO_2 capture and storage) are more likely to be identified specifically. However, three general characteristics of technology bear note here: (1) the availability of low- or zero-carbon electricity production technologies, (2) the supply of non-electric energy substitutes such as biofuels and hydrogen, and (3) the availability of technologies to facilitate substitution toward the use of electricity.

In all three models, a variety of cost-effective technology options are available to limit CO_2 emissions from electric power generation. For example, in all three Level 1 scenarios, the electric sector is almost fully de-carbonized by the end of the century. That is, electricity is produced with non-fossil technologies (nuclear or renewables) or fossil-fired power plants with carbon capture technology.. Thus, although low carbon technologies in the electric power sector do influence the costs of abatement, it is forces outside of electric power production that drive costs at higher levels of abatement because options available to this sector can support its almost complete de-carbonization..

The second of these technology factors is the modeled options to substitute alternative, non-electric fuels for fossil energy in end-use sectors, most importantly in transportation. All three models include biofuels as a substitute for fossil fuels in non-electric applications. As discussed in Section 2 and 3 of the report, in IGSM and MiniCAM, production of bioenergy crops must compete with other uses of agricultural lands, which constrains total production. MERGE uses an aggregate parameterization to represent these same constraints. Even with these differing approaches, bioenergy production is similar across the stabilization scenarios. However, because if its higher oil prices (Figure 3.7), IGSM brings in substantial biofuels in the reference case (Figure 4.10) so that expansion of this source under stabilization targets is more limited.

In addition to biofuels, MiniCAM and MERGE include other non-electric alternatives, and these become important for more stringent emissions reductions. MERGE includes a generic alternative fuel generated from renewable sources; which could be, for example, hydrogen from solar or wind power. In the MERGE Level 1 scenario, this alternative fuel provides roughly 80% as much non-electric energy as biofuels by 2100. MiniCAM includes hydrogen production using electricity, nuclear thermal dissociation, and fossil fuels with and without carbon capture and storage. Though smaller than biofuels, the contribution of hydrogen rises to a little over 15% of global non-electric energy consumption in the Level 1 scenario. Without these hydrogen technologies in the IGSM the marginal cost of emissions reduction is higher, and more of the abatement is met through reductions in energy use.

Another factor influencing abatement costs at higher levels of abatement is the ability to substitute to electricity in end-use sectors, through technologies such as heat pumps, electrically-generated process heat, or electric cars. Were all end uses to easily switch to electricity, then the availability of nearly carbon-free power generation options would allow complete CO_2 emissions reduction at no more than the cost of these generation options. However, the options for electrification differ substantially among the models. MERGE and MiniCAM assume greater opportunities for substitution to electricity than does IGSM in the second half of the 21st century. As a result the electricity fraction of energy consumption is higher in MERGE and MiniCAM for both the reference and stabilization scenarios. This means that low- or zero-carbon electricity supply technologies can serve more effectively as a low-cost option for emissions reduction, reducing its costs. In the IGSM, fuel demand for transportation, where electricity is not an option and for which biofuels supply is insufficient, continues to be a substantial source of emissions.

Although the main technological influences discussed above do not emerge for many decades they influence emissions prices and economic costs from the outset because of the way the models allocate emissions abatement over time. Across the models the approach to “when” flexibility results in carbon price paths that rise at an essentially constant exponential rate over time.[1] This approach tends to minimize the present discounted cost of emissions mitigation over the whole century, but it also links future carbon prices to near-term carbon prices in a predicable way. Thus, when there are differences in technology assumptions that mostly appear in the second half of the century or in reference emissions that occur mostly in the first half of the century, the assumption imposed on the price path means that the abatement burden is spread over the entire century. In this way, forces that do not emerge until the second half of the century, such as anticipated technology availability, cast a shadow onto the present. This dynamic view of the mitigation challenge reinforces the fact that climate change is long-term challenge; actions taken today must take into account the possible ways that the world might evolve in the future.

Finally, there are other structural differences among the models that likely play a role in the economic costs of stabilization. For example, MERGE and IGSM explicitly track investment, which directly affects Gross World Product, reducing savings for the next period, with the effect on Gross World Product cumulating over time, whereas the MiniCAM does not include the impacts of abatement on capital accumulation. This difference would tend to lead to higher economic costs in MERGE and IGSM relative to MiniCAM. Similarly, MERGE is a forward-looking model and that behavior allows it to more fully optimize investment over time, whereas in the MiniCAM and IGSM investments may be made in one period that would be regretted in later periods. This difference would tend to lead to lower costs in MERGE relative to the other two models. Finally, MiniCAM includes carbon capture in cement production which allows for cement emissions to be reduced almost to zero at higher stabilization levels. IGSM and

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[1] While this approach is true in general, there are some important exceptions to the generalization. These exceptions do not negate the overall effect of the assumed carbon price paths employed in the three models.

MERGE include cement production within an aggregate sector so that mitigation options that may be specific to this industry are not explicitly modeled. This omission puts more pressure on emissions reductions elsewhere and raises costs.

Expressed throughout the report is the view that the development of independent sets of scenarios using three different models helps to inform our understanding of the forces that shape opportunities to stabilize greenhouse gas concentrations. The differences discussed here demonstrate the fundamental importance of technology in facilitating stabilization—particularly the importance of *future* technology, even developments more than half a century in the future. The results also suggest the particular importance of options that facilitate the production of alternative non-electric fuels and demand-side technologies that will allow the substitution of electricity for current applications of fossil fuels.