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TECHNOLOGY OPPORTUNITIES TO REDUCE U.S. GREENHOUSE GAS EMISSIONS

Appendix B
Technology Pathways Characterization

(Working Document)

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Prepared by

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MASTER

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INTRODUCTION AND METHODOLOGY

Overview

A major objective of this study was to compile information on the potential of a wide range of energy-related technologies to reduce carbon dioxide emissions through additional RD&D. This was done by identifying a large team of individuals with relevant energy technology expertise, organizing them into 11 working groups to address 11 technology areas, and providing them with guidance for developing the desired information. The 11 technology areas included 9 categories of technology pathways, plus cross-cutting technologies and related areas of basic research.

Each working group was responsible for identifying the individual technology pathways appropriate to their technology, drafting the text for Chapter 2 of the main report, and preparing the two-pagers contained in this appendix. In order to complete all of these tasks, the working groups developed a large amount of information about the technologies in their area in the context of the 30-year timeframe that underlies this study. This information was critical in estimating which technologies provided the best opportunities for reducing GHG emissions in the U.S.

In addition to discussing the technical aspects of the best technological pathways for reducing GHGs, the working groups sought to develop general estimates of the potential costs and benefits of each technology pathway. It is important to note that the cost-benefit estimates are only approximate, relative indicators of what might be achievable if the technological goals are met.

The working groups relied upon Delphi Method principles to reach their conclusions about the technology pathways. Conditions and assumptions not defined in this Appendix were based on a consensus of the working group members.

An important part of the overall study methodology took the form of a "consistency scrubbing" exercise. A small group carefully reviewed all of the technology pathways for consistency and credibility, and then interviewed working group representatives to ensure that the technology pathway information had a firm technical basis and was developed through a sound analytic process. In addition, the small group reviewed how the carbon emission reduction estimates and the risk factor scores were developed to ensure that all the working groups followed the agreed upon guidelines.

Technology Pathway Two-Pagers

This appendix contains two-page descriptions of 47 climate change technology pathways. The appendix is not a comprehensive inventory of every possible technology that could reduce GHG emissions. Rather, it focuses on 47 pathways that were judged by the working groups to be sufficiently promising to warrant serious consideration. The attributes of the technologies comprising each pathway area were assessed independently by the working group responsible for that area. Thus further analysis would be required to prioritize all 47 technology pathways based on their likely costs and benefits.

Each two-page pathway provides a technology description (covering system concepts, representative technologies, and the technology's current status), describes current research, development, and demonstration (RD&D) activities (including RD&D goals and challenges), and presents one or more recent successes. Each pathway also discusses the prospects for commercialization and deployment of the technology and describes potential benefits and costs (including carbon reductions, market impacts, nonenergy benefits and costs, and RD&D expenditures). Finally, six types of risk factors are assessed, and study recommendations in the form of key federal actions are made.

The descriptive text and the numerical estimates presented in these pathways are based on the judgment of the working groups formed from the 11 national laboratories participating in this effort and in some cases, in collaboration with experts from other organizations across the country. Analysis supports some of the numerical estimates provided in the two-pagers. In other cases, the estimates were the best estimates of experts based on available information. Standardized protocols and assumptions were used by each working group to promote consistency in defining terms and in estimating values. As an additional mechanism for increasing overall consistency among the technology pathways, a small focus group discussed drafts of each pathway with the working group that drafted the two-pager. Although this was a lengthy and time-consuming process, it resulted in numerous clarifications and improvements to the pathways, including their numerical estimates. Finally, numerous DOE program managers reviewed preliminary versions of the report, as well as the technology pathways.

A discussion of the guidance provided to the teams and other relevant issues regarding assumptions and interpretation of the pathways is presented by topic.

Estimation of Carbon Emission Reductions

The estimated carbon emission reduction of each pathway is the portion of the cost-effective potential that could reasonably be expected to result from an enhanced RD&D effort, with no significant changes to government policies or deployment programs. These reductions are an estimate of reasonable expectations, not inherent capacity. Estimates of carbon reduction are provided in terms of millions of metric tons of carbon (MtC or 10^{12}gC) that could be displaced annually by the technology, above and beyond the reference case forecast, for each of the decades ending in the years 2010, 2020, and 2030.

The time frame of this study did not allow analysis of all of the various factors that could affect the performance and market penetration of a new technology. However, the study has compiled a considerable amount of information on a wide range of factors and has taken this information into account in estimating carbon reductions. The factors that the teams considered include the following:

- size of domestic and international markets for the technology
- turnover rate of capital stock
- technical risks associated with the RD&D
- size of the federal RD&D resources required
- magnitude of the technology's capital and operating costs
- extent of changes in infrastructure required for commercialization
- size of the resource base available to support the technology
- environmental and health risks associated with the technology
- public perception and acceptance risks
- characteristics of competing technologies

Reference Case. U.S. CO_2 emissions are projected by the U.S. DOE Energy Information Administration (EIA) to increase at a rate of 1.2% per year under a "business-as-usual" scenario. This scenario assumes that some efficiency and process improvements will offset what would otherwise be a larger rate of CO_2 increases. The rise in emissions is driven by a forecasted GDP growth rate of 1.9%. (Underlying this growth rate is the assumption of sustained economic growth and an increasing population.) Without a major intervention, CO_2 emissions will increase by almost 50% from the current annual level of approximately 1.4 billion MtC to about 2.1 billion MtC in 2030. The data shown in Table B.1 for the period 2015 to 2030 are based on extrapolations of the EIA reference case for 2015. Thus they do not take into account the significant reduction in nuclear power that could occur after 2015 if nuclear power plants are retired according to their current license expiration dates.

Table B.1. U.S. carbon dioxide emissions by end-use sector
(in MtC per year)

	Emissions				Change from 1990		
	1995	3020	2020	2030	2010	2020	2030
Buildings							
Fossil	159	170	178	185	22	30	37
Electricity	335	406	463	515	94	151	203
Subtotal	494	576	641	700	116	181	240
Industry							
Fossil	293	335	357	380	49	71	94
Electricity	171	213	241	269	47	75	103
Subtotal	464	548	598	649	96	146	197
Transportation							
Fossil	464	591	655	727	160	224	296
Electricity	1	7	10	14	6	9	13
Subtotal	465	598	665	741	166	233	309
Total							
Fossil	918	1096	1189	1291	231	324	426
Electricity[a]	506	626	714	798	147	235	319
Total	1424	1722	1904	2089	378	560	745

[a]The extrapolation beyond 2015 does not take into account the significant reduction in nuclear power that could occur as nuclear power plants are retired according to their current license expirations. Recent results of a new forecast by the Energy Information Administration suggest that carbon emissions will grow at a slightly faster pace through the year 2015. This new forecast is not yet published and is therefore not used in this report. In any event, using the new forecast would not substantially change the results of this report.

Sources: The carbon estimates for 1995 and the forecast for 2010 are taken directly from the Reference Case of EIA 1996a. Carbon emissions for 2020 and 2030 are forecasted using the same growth rates as for 2010. Electric utility emissions are distributed across sectors. GHGs other than CO_2 are not included.

Federal RD&D Efforts. The federal government has a substantial program in energy RD&D, designed to support the broad national goals of energy security and environmental quality. Although the existing energy RD&D programs were not designed specifically to reduce carbon emissions, they also will have significant benefits for mitigating climate change. The carbon emission reduction estimates presented in Appendix B and the main report are based on the assumption of an enhanced federal RD&D program. Because the current federal RD&D effort is taken into account in the reference case, the pathway estimates of carbon reductions are incremental to the reductions that would result from a continuation of current levels of federal RD&D funding. The estimated RD&D support needed to achieve these incremental carbon reductions is based on the judgment of the working groups from the 11 participating national laboratories (and in some cases in collaboration with experts from other organizations across the country).

The RD&D budget estimates are expressed in 1997 dollars. R&D priorities and any budget decisions should be based on more detailed planning and analysis than was possible during development of this report. Initiation of that analysis and planning is one of this report's primary recommendations.

Private-sector Efforts. Federally funded RD&D is certainly not the only effort that will be needed to develop and demonstrate the technologies described in these pathways. Private-sector collaboration is a major element of many federal RD&D programs and will need to continue and expand along with the federal commitment to enable the nation to achieve the advances described in this report. Private-sector expenditures are not included in the estimates of the required federal RD&D expenditures.

Federal Policies. The technology pathways—and the main report—assume a continuation of existing federal programs and policies. The estimates do not presume the creation of any new incentives such as investment tax credits, a carbon charge, or a domestic or international CO_2 trading system.

Non-additivity. The effects of the market success of one technology pathway on the market success of another technology pathway were generally considered within one particular technology area, such as within nuclear energy or within buildings efficiency. The effects of competition among technology areas could not be fully evaluated; therefore, carbon reduction estimates from different technology areas (such as nuclear and buildings efficiency) cannot simply be summed. The problem is that the technology areas compete and interact with each other. For instance, if enhanced natural gas production should cause electricity generation to shift from coal to gas, new coal technologies would generate fewer carbon savings. If carbon emissions from the generation of electricity were reduced, the carbon reduction potential from saving electricity in the buildings and industrial sectors would also decline.

Secondary Demand Effects. The estimates of carbon reduction potential do not reflect possible changes in demand for energy services resulting from the introduction of the technology. Improved energy efficiency and more competitive low-carbon energy sources suggest lower energy prices and costs of energy services. These would likely increase demand for energy services and "take back" some portion of the reported savings. Should the demand for energy services and the energy cost of these services change, so would the competitiveness of the technologies explored. These secondary demand effects are not incorporated in the carbon reduction potentials.

Restructuring. The carbon reduction estimates do not take into account any long-term impacts that might be precipitated by restructuring of the electric utility industry. If restructuring produces lower electricity rates, energy use will increase and investments in conservation technologies might decrease, with a concomitant rise in GHG emissions. On the other hand, future utility restructuring legislation calling for renewable portfolio standards and public benefits programs could significantly promote clean power, thereby reducing GHG production.

Description of Risk Factors

The technology pathways consider six risk factors that are labeled: "technical," "commercial," "ecological," "human health," "economic," and "regulatory." These risk factors are defined as follows.

Technical Risk: Refers to the risk that the federal R&D dollars will not result in the commercialization of the technology for cost or performance reasons. Technologies that require only incremental innovation generally have lower technical risk than technologies that require a major breakthrough. Technical risk also generally increases as the number and complexity of associated technologies increase. Thus a technology that is a stand-alone product tends to have lower risk than a technology with many components that need to be developed. In addition, technical risk is negatively correlated with the availability of necessary resources. Therefore, a technology that can be developed with readily available resources (i.e., equipment and/or skills) involves less technical risk than a technology that requires more demanding types of resources. This risk factor takes into account the probability of achieving the cost reductions necessary for a technology to be cost-competitive.

Commercial Risk: Reflects the magnitude and likelihood of commercial vulnerabilities that could hinder successful deployment. Examples of high commercial risk include the need to make massive infrastructure investments or the need to establish a new system of operations and maintenance support for a product. Thus the more changes that are needed in the infrastructure and the more training that will be required by the operations and maintenance providers, the higher the commercial risk. Commercial risk also depends upon the size of the resource base relative to the technology's requirements: limited resources will constrain commercial deployment, and risks are especially high when a technology is strongly dependent on foreign sources.

Ecological Risk: Refers to the probability that a technology could cause significant effects on nonhuman species and aquatic and terrestrial ecosystems. Ecological risk is calibrated in comparison with the new technology's competitors and is generally positively correlated with the severity of the possible effects and their spatial and temporal extent. Examples of high severity include the release of highly toxic byproducts from a technology or the severe modification of habitats as a result of land conversion or water depletion. Spatial extent includes land area or aquatic system length or volume, normalized to the importance of the ecological resource. The temporal extent includes both the time for which the ecological resources would be affected and the time to recovery given the persistence of contaminants and the rate of recovery and adaptation of the affected ecosystem.

Human Health Risk: Refers to the probability of adverse human health consequences as a result of the commercialization and deployment of the technology. As in the case for estimating ecological risk, human health risk is calibrated in comparison to the new technology's competitors. Thus the human health risk of high-efficiency coal-based power generation is considered relative to alternative sources of electricity, including conventional coal generation, natural gas systems, nuclear power, and electricity from renewable resources. Occupational hazards associated with the manufacture of a technology are included in this risk factor.

Economic Risk: Refers to the probability that a technology could be rejected because competing technologies are preferred by consumers. Economic risk is lower when consumers do not have to change their behavior when using, purchasing, or servicing the product. In addition, economic risk is reduced when the new technology's costs compare favorably with the costs of the product that would be displaced, so that the economic decision makers don't need to change their investment behavior. Public preferences can be strongly supportive (as with energy-efficient industrial technologies that also reduce pollution), or they may impede implementation of a technology, leading to economic penalties.

Regulatory Risk: Refers to the probability that current or future U.S. regulations will prevent the technology from meeting its commercialization and deployment targets. For existing technologies, onerous regulations would increase regulatory risk. For technologies that have not yet been commercialized, the absence of regulations such as codes and standards may suggest a high regulatory risk.

The study teams assessed the risk factors for each pathway using a 10-point scale. Values on this scale should be interpreted as follows:

- Scores of 9–10 are considered to be so high as to render a technology infeasible over the next half century. All of the pathways in this report are considered feasible during this time frame, so none have been rated with risk scores above 8.

- A score of 1 is considered to be very close to no risk at all. Since some uncertainty is inherent in all research, few of the pathways received this score in any risk category.

- Scores of 2–3 are considered low risk; scores of 4–6 are considered moderate risk; and scores of 7–8 are considered high risk.

The scores apply to the pathways over the 30-year range of the study, reflecting the results of strongly supported RD&D but assuming today's policies (consistent with the rest of the report). The scores represent the best judgments of the national laboratory participants. "N/A" or "not available" was assigned in cases where it was not possible to anticipate what the risk levels might be in the future.

APPENDIX B CONTENTS