Modeling the

Technology Mix

The Story in Brief

The electricity industry is now actively considering which combination of advanced technologies can best meet CO_2 emissions reduction targets. The fundamental challenge is to develop a portfolio of options that is technically feasible and can provide affordable electricity to customers. As the industry considers its investments in research, development, and demonstration projects, EPRI's PRISM and MERGE analyses address this challenge and point toward a solution that EPRI describes as "The Full Portfolio."

The EPRI Summer Seminar held in August 2007 produced a surprisingly strong consensus among its diverse participants: Development of a portfolio of advanced technologies is the most challenging but by far the most promising approach for the electricity sector to reduce its CO_2 emissions. In anticipation of future CO_2 emissions policies, EPRI has analyzed the technical potential for the U.S. electricity sector to reduce emissions over the next 25 years and has assessed the economic benefits of using advanced technologies to achieve required reductions. The result: If the U.S. electricity sector deploys a full portfolio of technologies rather than a more limited one, the overall cost of emissions reductions to the U.S. economy could be lowered by as much as one trillion dollars.

The anticipation of national regulation is already driving extensive efforts to develop technologies that can reduce emissions of CO_2 and other greenhouse gases. Major government and private industry research programs are focused on advanced nuclear power plants, carbon capture and storage for coal plants, a variety of renewable energy resources, and diverse technologies to increase end-use energy efficiency. What has largely been lacking, however, is a clear vision of how to create a portfolio of technologies optimally suited for reducing CO_2 emissions from the electricity sector, as well as an assessment of the economic advantages of widely deploying these technologies.

To clarify the range of features for such a portfolio, EPRI has considered two cases—one with a limited range of R&D investment and resulting technology deployments and another with a more comprehensive set of R&D targets and technology deployments. The latter has become known as the Full Portfolio. A comparison of the two approaches highlights differences of both degree and kind. The limited portfolio focuses primarily on evolutionary improvements in conventional coal- and gas-fired generation, further development of renewable technologies, and increases in end-use efficiency. While ongoing technical improvements would ensure that today's fleet of nuclear plants continue to operate effectively, nuclear capacity would remain at existing levels.

The Full Portfolio includes all of the developments of the limited portfolio but adds technology that will increase capabilities beyond evolutionary improvements. For example, the development of a "smart" electricity grid and commercialization of plug-in hybrid electric vehicles would greatly accelerate improvements in end-use efficiency; and the deployment of energy storage technologies would increase the cost-effectiveness of intermittent renewable generation. Even more important for the Full Portfolio are two large-scale developments that would not be available under a limited approach: U.S. deployment of advanced light water reactors, which would substantially increase the number of nuclear plants, and carbon capture and storage technology, which would drastically reduce CO_2 emissions from coal-fired plants.

Consideration of these portfolio options leads to two fundamental questions: Can the technologies being considered indeed reduce greenhouse gas emissions to desired levels, and what is their economic value? To help answer those questions, EPRI recently completed two related studies. The first, the so-called PRISM analysis, assessed the U.S. electricity sector's technical *potential* for reducing CO_2 emissions, assuming deployment of the Full Portfolio of advanced technologies. A separate analysis, MERGE, calculated the economic value of deploying these technologies and projected the least-cost combination of technologies needed to meet assumed CO_2 emissions reduction targets representative of potential policies. These results inform EPRI's ongoing efforts to identify the research, development, and demonstration (RD&D) pathways to successful and economical CO_2 emissions reductions (see "Pathways to the Full Portfolio," page 20).

Calculating Technical Potential

The PRISM analysis assumed that the industry could achieve "aggressive but feasible" targets for deploying seven advanced technology options:

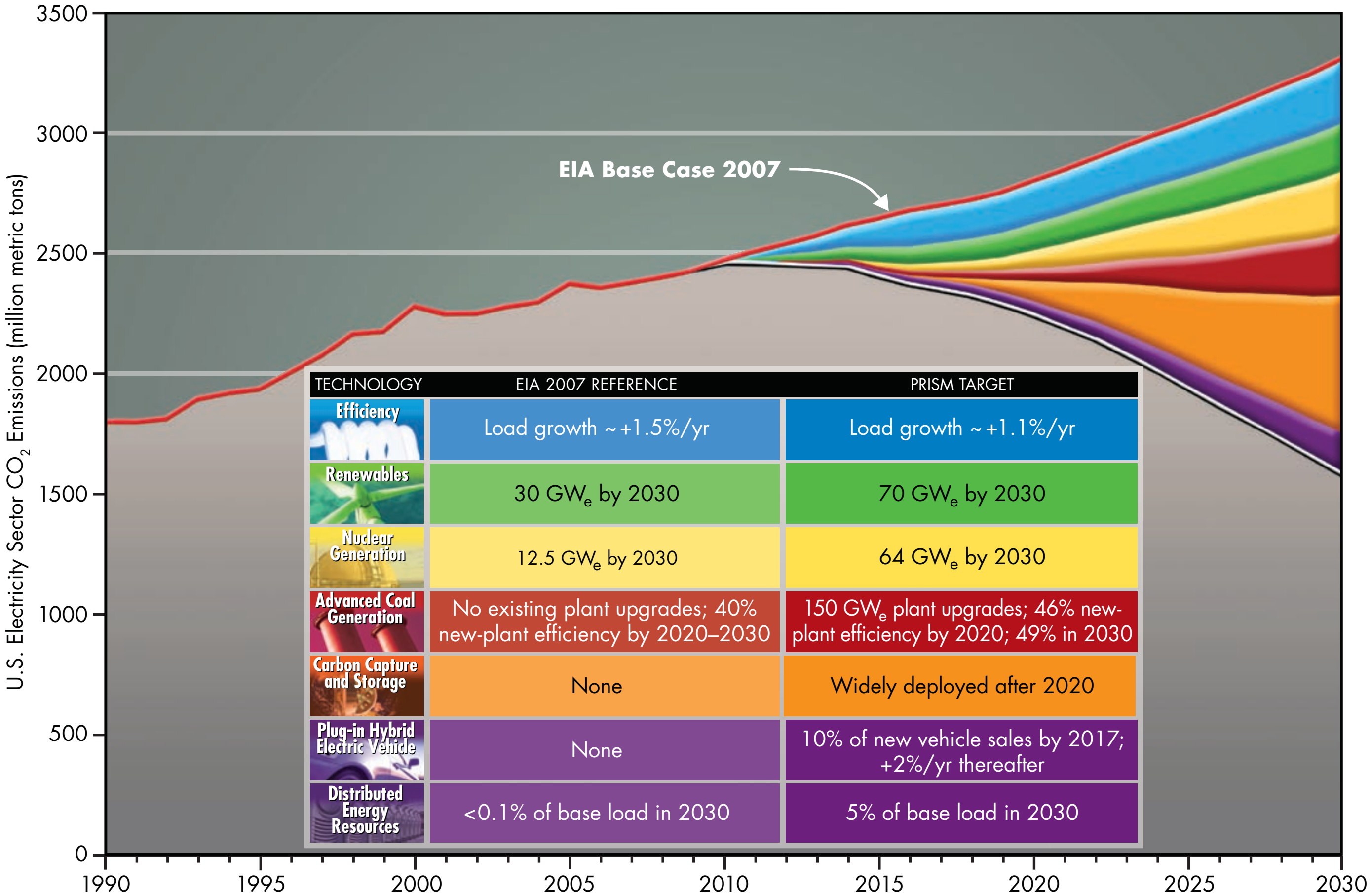
- end-use energy efficiency
- renewable energy
- advanced light water nuclear reactors (ALWRs) and life extension for existing reactors
- advanced coal power plants
- CO_2 capture and storage (CCS)
- plug-in hybrid electric vehicles (PHEVs)
- distributed energy resources (DER)

The calculated potential for CO_2 emissions reductions was based solely on the technical capabilities, assuming no economic or policy constraints.

The PRISM analysis gets its name from EPRI's graphic representation of the Full Portfolio's broad spectrum of emissions reduction technologies. In comparison with the base case projections of the Energy Information Administration (EIA) in its 2007 *Annual Energy Outlook,* the PRISM results show that aggressive deployment of the Full Portfolio of advanced technologies could reduce CO_2 emissions levels by about 45% in 2030. "The analysis also showed there is no 'silver bullet' for reducing emissions," says Revis James, director of the EPRI Energy Technology Assessment Center, which conducted the PRISM analysis. "Rather, the results show that a diverse combination of new and existing technologies will be required. By deploying a full portfolio of such technologies, the electricity sector can make a very substantial contribution to reducing U.S. CO_2 emissions."

Aggressive Assumptions: How Best to Anticipate the Future?

For each technology considered, the PRISM analysis uses aggressive assumptions regarding technology performance and deployment and then calculates changes in electricity consumption and the generation mix resulting from a technology portfolio based on these assumptions. Finally, it determines CO_2 emissions reductions resulting from this transformation. A key underlying assumption is that



TECHNOLOGY	EIA 2007 REFERENCE	PRISM TARGET
Efficiency	Load growth ~+1.5%/yr	Load growth ~+1.1%/yr
Renewables	30 GW_e by 2030	70 GW_e by 2030
Nuclear Generation	12.5 GW_e by 2030	64 GW_e by 2030
Advanced Coal Generation	No existing plant upgrades; 40% new-plant efficiency by 2020–2030	150 GW_e plant upgrades; 46% new-plant efficiency by 2020; 49% in 2030
Carbon Capture and Storage	None	Widely deployed after 2020
Plug-in Hybrid Electric Vehicle	None	10% of new vehicle sales by 2017; +2%/yr thereafter
Distributed Energy Resources	<0.1% of base load in 2030	5% of base load in 2030

Potential CO_2 Reductions: *EPRI's PRISM analysis assessed the U.S. electricity sector's technical potential for reducing CO_2 emissions to 1990 levels by 2030—a goal considered critical for stabilizing atmospheric concentrations. Starting with the Energy Information Administration's* Annual Energy Outlook *2007 estimates as the base case, researchers calculated what additional reductions could result from accelerated development of a wide range of advanced technologies. While the EPRI targets are very aggressive, achieving the desired reductions is technically feasible.*

a specific sequence of RD&D activities could be identified that would achieve wide-scale deployment of the advanced technologies by 2030. In most cases, EPRI's deployment assumptions are considerably more ambitious than those used in the EIA base case analysis.

The PRISM assumption for nuclear power deployment, for example, is 64 GW of new capacity by 2030, compared with 12.5 GW in the EIA analysis. This larger assumption is supported by two particularly promising points: much of the new capacity could be added at existing nuclear sites, and the ALWR technology that would provide the basis for these new plants is well developed and is already being used in several countries.

Another major departure from the EIA base case involves CCS technology, which the EIA analysis did not include. The PRISM assumption—based on milestones established in a technology development roadmap jointly created by EPRI and the Coal Utilization Research Council—holds that CCS technology can be widely available and deployed after 2020, presuming that the large-scale CCS demonstration program sponsored by the U.S. Department of Energy is successful and is completed on schedule. The PRISM analysis also adopts in its estimates the development roadmap's targets for improving thermodynamic performance and heat rates at pulverized-coal plants and integrated gasification–combined-cycle coal plants.

With regard to end-use efficiency, the PRISM analysis assumes that the Energy Policy Act of 2005 mandate of a 20% energy intensity improvement for federal buildings will be extended to all consumption sectors. This would result in average annual electricity demand growth of only 1.1% between 2005 and 2030—about 30% less than the comparable EIA base case figure. An important technological component of meeting this target will be the development of a "smart" distribution system, incorporating distributed sensors and advanced metering, to enable greater automated control of electricity consumption.

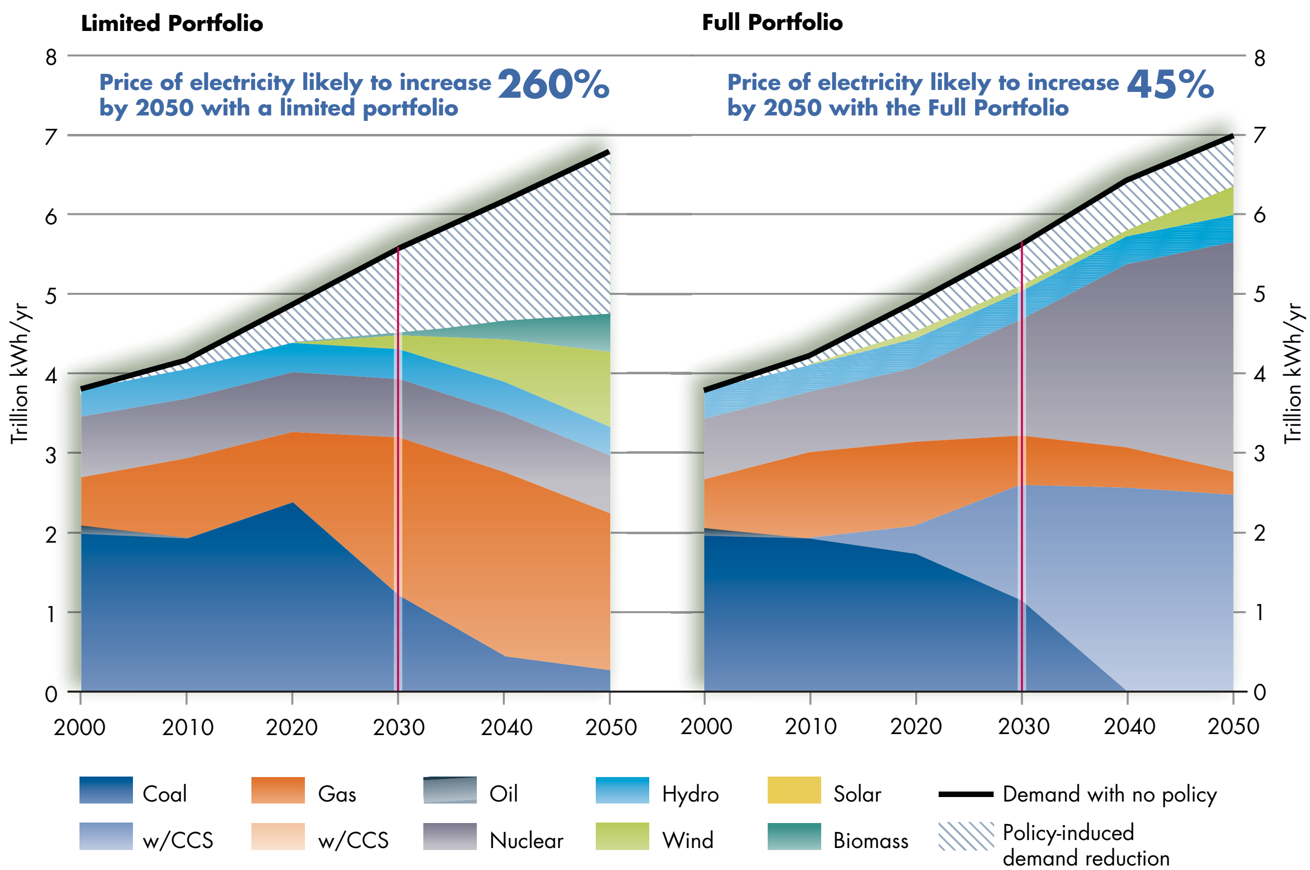
The PRISM analysis assumes that non-hydro renewable energy capacity will continue to grow at a rate of 2 GW/year from 2020 to 2030, resulting in a total capacity of 70 GW by 2030—more than twice the EIA base case projection. This increased capacity is assumed to include widespread deployment of intermittent resources, such as wind and solar, facilitated by ongoing changes in utility transmission and distribution systems. EPRI's renewables deployment assumption matches the combined requirements of existing state-mandated renewable portfolio standards.

The study also established assumptions for two technologies not owned or controlled by utilities—PHEVs and DER. In the case of PHEVs, an aggressive assumption is made: 16% market penetration for new light-duty vehicles by 2020 and 30% by 2030, compared with no consideration of this technology in the EIA base case. Similarly, PRISM assumes that DER will represent 5% of baseload generation by 2030, compared with the EIA assumption of less than 0.1%.

"PRISM's aggressive targets really push the envelope, and its projected generation mix for 2030 is very different from that envisioned by the EIA base case," observes Bryan Hannigan, vice president of EPRI's Environment sector and a major force in the model's creation. "In particular, the PRISM results show much greater use of nuclear power, renewable energy, and coal with CCS, and a sharply lower contribution from natural gas and coal without CCS."

The MERGE Analysis and the Full Portfolio

What are the potential economic impacts of deploying the Full Portfolio versus a limited technology portfolio? In a general equilibrium economic model called MERGE (model for estimating the regional and global effects of greenhouse gas reductions), EPRI researchers modeled outcomes based on projected capital and operating costs of these technologies, together with assumed generic CO_2 emissions constraints in line with potential policies. MERGE has been used by climate scientists for more than a decade to analyze the lowest-cost technology mix that is able to achieve a specified CO_2 emissions constraint as a function of tech-



__Generation Mix:__ Under a limited portfolio scenario, natural gas becomes the dominant generation fuel by 2030, and CO_2 reduction policies can only be met through large reductions in electricity demand, placing severe constraints on economic growth. With the Full Portfolio, nuclear power and advanced coal generation with carbon capture and storage reduce emissions to the point where a much lower demand reduction is needed. By 2050, the Full Portfolio will have essentially de-carbonized the electricity sector and reduced the impact on electricity prices to less than a fifth that of the limited portfolio.

nology cost, availability, and performance.

MERGE can project energy production for each technology, wholesale electricity prices, CO_2 emissions allowance prices, and the costs to the overall U.S. economy of the specified emissions reduction constraint. All MERGE monetary outputs are in constant 2000 dollars.

The analysis showed that the economic impacts of pursuing the Full Portfolio versus the limited portfolio are significant. Several CO_2 reduction profiles—reflecting the requirements of different future emissions policies—were examined using MERGE; for each combination of technology scenario and policy constraint, the MERGE model calculated the economic cost to the U.S. gross domestic product over the analysis period. The policy assumption considered here is the one that most closely resembles the PRISM emissions profile—an intermediate case widely discussed by policymakers that stabilizes emissions from 2010 to 2020 and then reduces them by 3% per year. For this case, the economic cost to GDP associated with the limited portfolio scenario was calculated to be $1.5 trillion. This could be reduced to roughly $0.5 trillion through availability of the advanced technologies in the Full Portfolio scenario. The MERGE analysis showed that reliance on any single technology would not come near to achieving the reduction in policy cost that could be achieved by using them all together.

Even when an economically efficient path for CO_2 emissions reduction is pursued, the wholesale price of electricity is likely to rise substantially as emissions are restricted. However, the MERGE analysis makes it clear that the increase will be much lower and will stabilize if advanced technologies are deployed. Assuming an intermediate emissions policy, the real price of electricity is projected to increase about 45% by 2050 with the Full Portfolio, compared with a 260% increase in the limited portfolio scenario. In addition, implementation of the Full Portfolio would lead to nearly full de-carbonization of the electricity sector by 2050.

The MERGE analysis shows how this change will occur by tracing the impact of technology availability on the U.S. generation mix. Under the emissions constraint discussed here, the model points to a drastically different deployment of generation technologies under the limited portfolio scenario after about 2020. Assuming that CCS would not be available to help meet the emissions constraint, the use of coal would fall off sharply and coal would be largely replaced by natural gas. Moreover, there would be a profound reduction in the demand for electricity, driven by very high prices. With the Full Portfolio, however, the availability of CCS would allow coal to be maintained, taking on a new role as a non-emitting generation option. At the same time, aggressive technology deployment would enable nuclear power to expand greatly, while natural gas would essentially maintain its current position as a fuel of choice for peaking units.

Wider Implications

By illustrating the critical interactions among various sectors of the economy, EPRI's MERGE analysis identifies wider implications of carbon constraints on electricity technology evolution. For example, if the electricity sector must replace coal with natural gas in the limited portfolio scenario, sharp increases in natural gas prices could result. In terms of constant 2000 dollars, the wellhead price of natural gas could rise from the current level of about $6/thousand cubic feet (MCF) to around $13/MCF by 2050. With the Full Portfolio, the price is likely to rise to only about $10/MCF. The contrast between the two scenarios is even greater in terms of natural gas consumption, which would be more than two-and-a-half times greater in 2050 for the limited portfolio. With the Full Portfolio deployed, the economy could reduce both its overall consumption of natural gas and the share used for electricity generation between now and 2050.

MERGE projects a similarly dramatic contrast in the projected price of CO_2 emissions. With limited technology development, the economy-wide cost of enforcing emissions constraints would grow very rapidly, driving up the real price (in year 2000 dollars) of CO_2 to more than $300/ton by 2050 in the intermediate policy case. The Full Portfolio would enable electricity sector emissions to fall, so the price of CO_2 would rise more slowly, reaching about $150/ton by 2050. At this point the electricity sector would be essentially decarbonized, and any further CO_2 reductions would have to come from industry, transportation, and other non-electric segments of the economy.

Such price differences provide a strong incentive to develop and deploy advanced electricity-related technologies. They also support the conclusion of other analyses that electric power will increasingly be used to provide low-carbon energy throughout the economy. The Full Portfolio scenario leads to accelerated electrification of other sectors of the economy, as consumption of electricity relative to non-electric energy use more than doubles by 2050, with an even greater increase under an emissions constraint.

"It's important to remember that these figures are not chiseled in stone," concludes Richard Richels, senior technical executive for EPRI's global climate change research. "What we have tried to analyze in MERGE are the economic advantages that could be realized by using advanced technologies to limit CO_2 emissions. To get realistic estimates, we have restricted ourselves to technological advances that can be foreseen with some level of confidence. However, history has taught us to expect significant —though unpredictable—breakthroughs as well, and policy incentives may also accelerate the process."

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