EPRI | ELECTRIC POWER RESEARCH INSTITUTE

PRISM/MERGE ANALYSES
2009 UPDATE

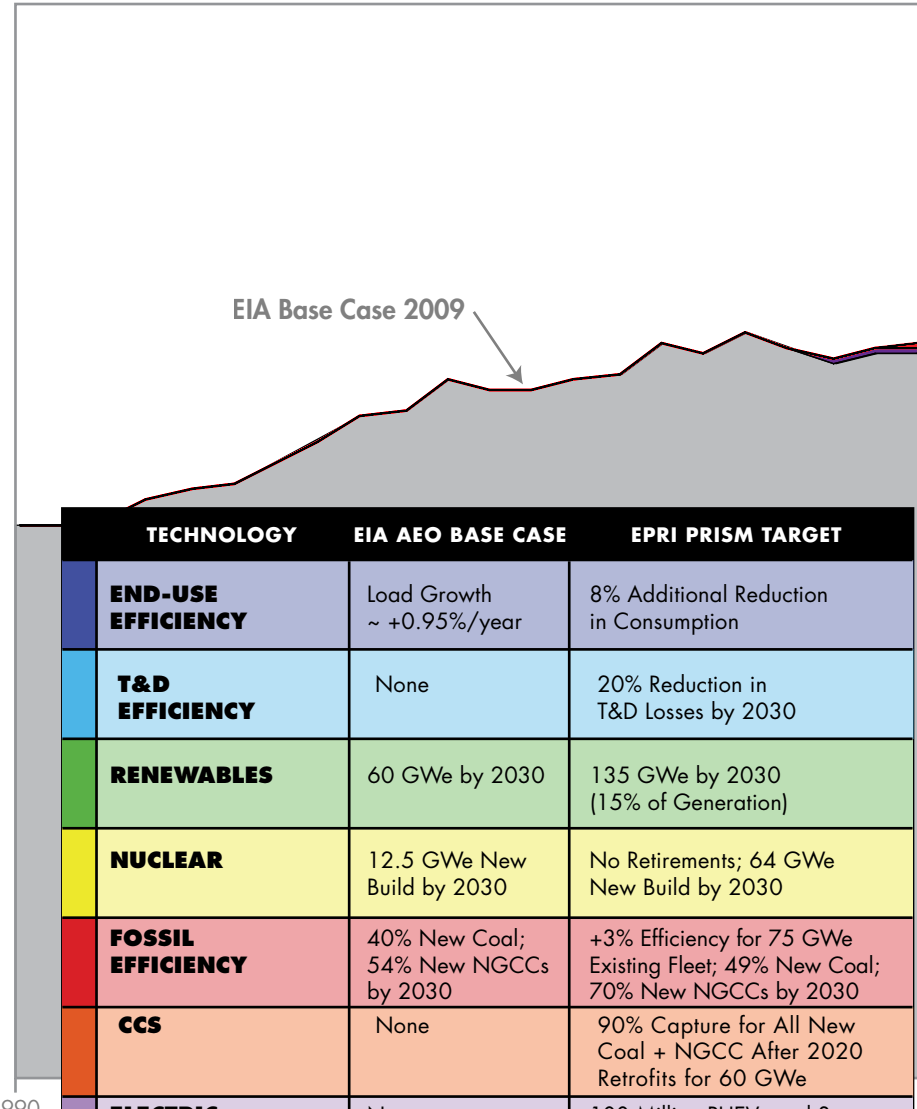
INTRODUCTION

In 2007 EPRI released its first Prism and MERGE analyses, providing a technically and economically feasible roadmap for the electricity sector as it seeks to reduce its greenhouse gas emissions over the next few decades. The Prism analysis provided a comprehensive assessment of potential CO_2 reductions in eight key technology areas of the electricity sector. The MERGE analysis identified the economically optimum technology portfolio in response to a given CO_2 emissions constraint.

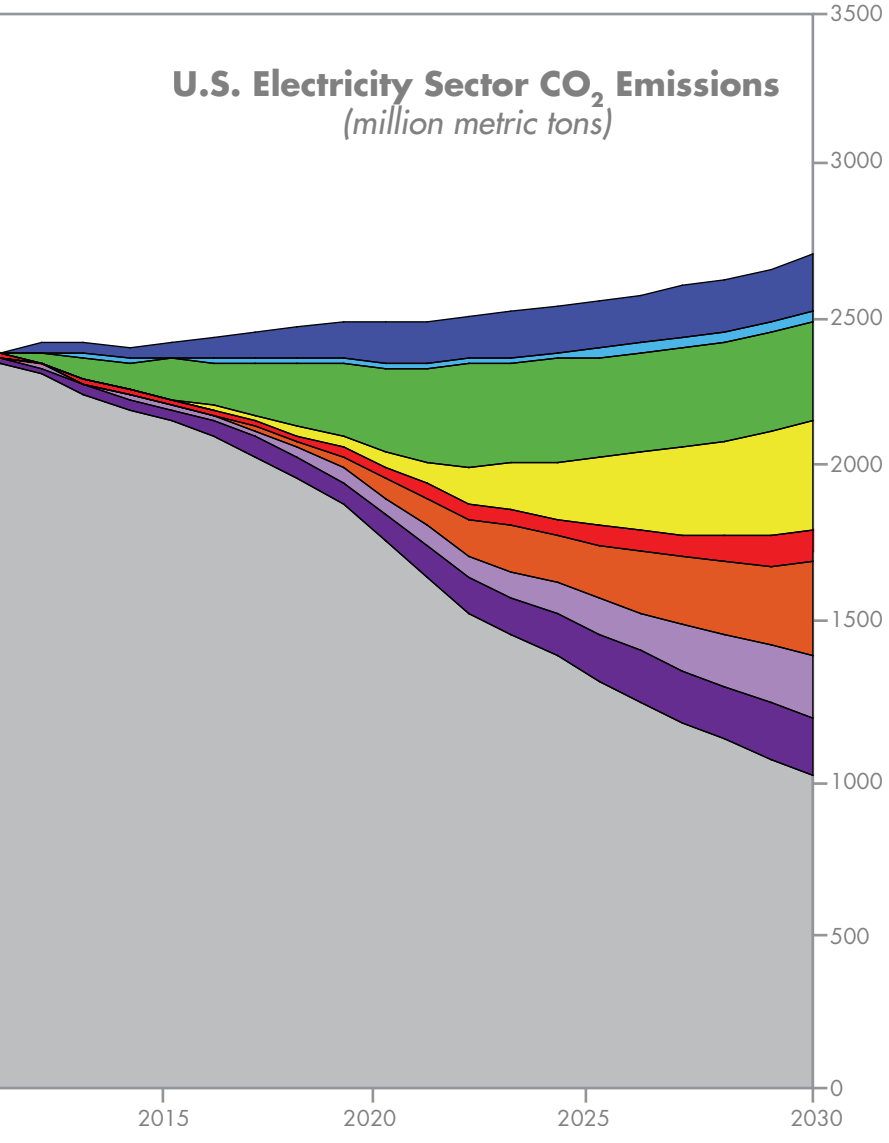
This 2009 update reflects economic and technological changes that have the potential to affect projected emissions and the technologies to address them. This update is also more comprehensive in that it includes new technologies and analysis features.

The Prism analysis determined that the sector can potentially meet the challenges that confront each technology option and deploy "The Full Portfolio" of technologies to achieve meaningful emissions reductions. The full Prism graphic builds from the top down. The top line of the graph represents the U.S. Energy Information Agency's (EIA) 2009 Annual Energy Outlook reference case estimate of CO_2 emissions from the U.S. electricity sector. Each color represents the incremental reduction in emissions projected as feasible for a given technology under a given set of assumptions. The Prism illustrates the overall reductions achievable using The Full Portfolio of technologies. This summary provides an overview of key factors, technical assumptions, and research, development, and demonstration (RD&D) priorities for each technology.

The MERGE analysis determined the most economic combination of technologies over time to meet a specified CO_2 emissions constraint. Based on current and projected technology costs, consideration of fuel costs and reserves, and competition for resources with other parts of the economy, MERGE projects electricity generation from different technologies, electricity costs, CO_2 prices, and the overall cost of implementing CO_2 emissions reductions.



TECHNOLOGY	EIA AEO BASE CASE	EPRI PRISM TARGET
END-USE EFFICIENCY	Load Growth ~ +0.95%/year	8% Additional Reduction in Consumption
T&D EFFICIENCY	None	20% Reduction in T&D Losses by 2030
RENEWABLES	60 GWe by 2030	135 GWe by 2030 (15% of Generation)
NUCLEAR	12.5 GWe New Build by 2030	No Retirements; 64 GWe New Build by 2030
FOSSIL EFFICIENCY	40% New Coal; 54% New NGCCs by 2030	+3% Efficiency for 75 GWe Existing Fleet; 49% New Coal; 70% New NGCCs by 2030
CCS	None	90% Capture for All New Coal + NGCC After 2020 Retrofits for 60 GWe
ELECTRIC TRANSPORTATION	None	100 Million PHEVs and 3x Increase in Non-Road Use by 2030
ELECTRO-TECHNOLOGIES	None	Replace ~4.5% Direct Fossil Use by 2030

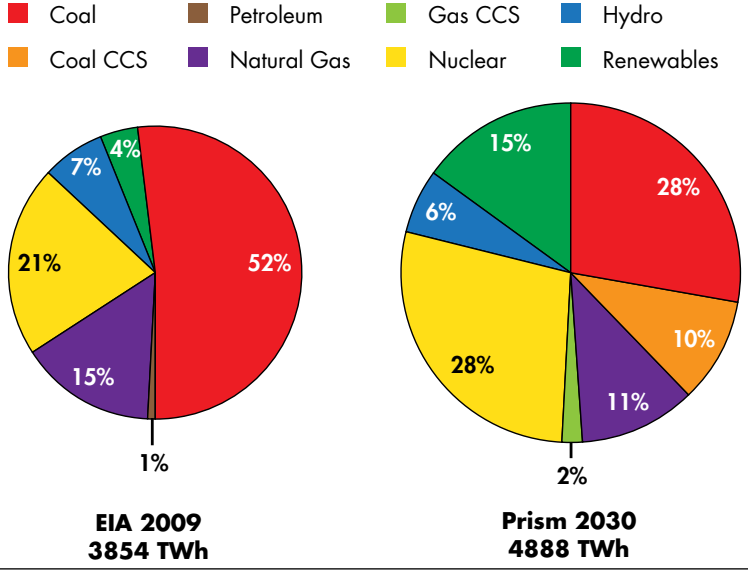

U.S. Electricity Sector CO_2 Emissions
(million metric tons)
3500
3000
2500
2000
1500
1000
500
0
2015
2020
2025
2030

2009 Prism Analysis

The 2009 Prism analysis estimates that the technical potential exists for the U.S. electricity sector to reduce annual CO_2 emissions in 2030 by:

- 41% relative to 2005 emissions, based on improvements to electric sector technologies;
- 58% relative to 2005 emissions, if reductions due to electro-technologies and electric transportation are included; and
- 62% relative to the 2030 reference case projection in the Energy Information Administration's 2009 Annual Energy Outlook[1]. ***(Emissions reduction potential for each technology area is also expressed as a percent reduction relative to this reference case.)***

The Prism analysis projects that by 2030, 60% of the total U.S. generation mix would consist of low- or non-CO_2 emitting generation—provided that the required research, development, and technology demonstrations can be carried out and the technical assumptions can be met.



1. U.S. DOE Energy Information Administration (EIA), *An Updated Annual Energy Outlook 2009 Reference Case Reflecting Provisions of the American Recovery and Reinvestment Act and Recent Changes in the Economic Outlook, April 2009, SR/OIAF/2009-03,* www.eia.doe.gov

The 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 6.5% as a result of gains in energy efficiency.

A 2009 EPRI study[1] assessed the potential to reduce demand growth and electricity consumption based on different levels of success and penetration of energy efficiency technologies and programs. The study compared effects of different efficiency assumptions relative to the 2008 EIA Annual Energy Outlook[2] reference case (the most current assessment at that time.)

2009 Prism analysis assumption:

- Achieve "maximum achievable potential" as calculated in the 2009 EPRI efficiency study, resulting in a 2030 net consumption reduction of 8%.

Required research and development to realize this assumption:

- Standardized communications
- Advanced, mobile metering
- Interoperability
- Distributed computing

1. *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010–2030)*, Technical Report 1016987, January 2009
2. U.S. DOE Energy Information Administration (EIA), *Annual Energy Outlook 2008*, June 2008, DOE/EIA-0383(2008), www.eia.doe.gov

TRANSMISSION & DISTRIBUTION

The 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 0.9% as a result of efficiency gains in the U.S. transmission and distribution system.

A key aspect of the "smart grid" will be a more efficient transmission system. Research in line engineering, advanced conductors, preventing corona and insulation losses, and optimizing voltage will increase transmission capacity, optimizing the use of existing generation capacity.

Efficiency gains also may be realized through more effective system planning and operation, including voltage control and optimal network designs.

2009 Prism analysis assumption:

- 20% reduction in transmission & distribution losses by 2030

Required research and development to realize this assumption:

- Advanced grid management technologies, such as real-time simulation and grid security assessment tools
- Wide-area monitoring

RENEWABLE ENERGY RESOURCES

The 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 13% as a result of substantially increased deployment of renewable generation.

The 2009 Prism assumes the penetration of a diverse set of renewable generation resources, based on consideration of existing and potential state and federal programs, cost and performance improvement opportunities, and grid integration challenges.

2009 Prism analysis assumption:

- 135 gigawatts by 2030, consisting of ~100 GW new wind; ~20 GW new biomass; ~15 GW other technologies, including solar

Required research and development to realize this assumption:

- Improved reliability for wind turbines with reduced O&M costs
- Cost reduction and variability management for solar PV
- Augmentation of existing fossil assets with concentrated solar or geothermal resources
- Pre-processing of bio-based materials for use in thermal power generation
- Bulk and distributed energy storage
- Integration and grid control technologies

NUCLEAR POWER

The 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 11% as a result of substantially increased deployment of advanced nuclear power plants.

The fundamental components of the 2009 Prism assumption regarding nuclear power's expected contribution to emissions reductions is based on several factors:

- Existing fleet continues to operate safely at high capacity factors;
- Ongoing efforts to extend the service of existing plants beyond 60 years;
- Approximately 30 applications for new nuclear plant construction licenses; and
- Siting of nearly all new capacity expected by 2030 at existing nuclear plant locations.

2009 Prism analysis assumption:

- Construction of 10 gigawatts of advanced reactors by 2020, and ultimately 64 GW by 2030

Required research and development to realize this assumption:

- Tools and methodologies ensuring consistent and efficient construction times
- Integrated spent fuel management strategy
- Material and equipment life cycle management to ensure reliable operation through 60 years and beyond

FOSSIL EFFICIENCY

The 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 3.7% as a result of increasing the efficiency of new and existing fossil-fueled generation.

Economic analysis indicates that a subset of existing 300- to 500-megawatt coal units could remain competitive as baseload during the transition to new plant designs – and contribute to an overall carbon reduction strategy.

The EPRI/Coal Utilization Research Council Technology Roadmap[1] establishes aggressive but achievable technological advances that could result in new levels of efficiency in key fossil technologies. The 2009 Prism assumptions for new fossil plant performance are based on assumption of achieving these milestones.

2009 Prism analysis assumptions:

- An increase of 3% in thermodynamic efficiency for 75 gigawatts of the existing coal generation fleet
- Higher efficiencies for new ultra-supercritical coal and integrated gasification combined cycle (IGCC) plants: 42% efficiency by 2020, 49% by 2030
- Combined-cycle plants achieve 60% efficiency by 2020 and 70% by 2030; combustion turbine achieve 45% by 2030

Required research and development to realize this assumption:

- Technologies, operations and maintenance for existing units to operate at higher temperatures/pressures
- Increases in pulverized coal main steam and reheat process conditions (1050° – 1300°F), and ultimately to 1400°F with double reheat
- Improved performance in IGCC plants, including advanced combustion turbine and better oxygen separation

1. *The Coal Utilization Research Council/EPRI Clean Coal Technology Roadmap,* 2008, www.coal.org

CARBON CAPTURE & STORAGE

The 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 11% as a result of bringing into service technologies that (1) capture CO_2 emissions from fossil-fueled generation, (2) transport the CO_2 and (3) securely sequester it.

The 2009 analysis bases these estimates on assumptions that new coal and gas units coming online post-2020 will be equipped with CCS, and that 60 gigawatts of the existing fleet could be retrofitted with CCS. It assumes that existing coal units of >500 MW capacity and <12,000 Btu/kWh heat rate, with all installed environmental controls, and placed in service after 1970, are viable candidates for CCS retrofit.

2009 Prism analysis assumptions:

- 90% CO_2 capture for all new coal and natural gas combined-cycle plants built after 2020
- CCS retrofit for 60 gigawatts of existing coal generation at 90% capture efficiency

Required research and development to realize this assumption:

- High-efficiency, cost-effective CO_2 capture
- Commercial, large-scale CO_2 storage
- Completed pilot and demonstration projects for post-combustion capture, IGCC capture, oxygen separation, and oxy-firing

The 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 9.3% as a result of electricity displacing gasoline and diesel to fuel a substantial portion of the vehicle fleet.

The 2009 Prism bases this estimate on the assumption that plug-in hybrid electric vehicles (PHEVs) are introduced to the market in 2010, consistent with product plans of many automakers, and the subsequent rapid growth of market share to almost half of new vehicle sales within 15 years.

Net emissions reduction estimates from the increasing market share of PHEVs are based on research by EPRI[1] and others, factoring vehicle miles traveled, carbon savings from gasoline not burned, and the trend for the electric system to become "cleaner" – i.e., for an increasing share of power generation to emit less or no CO_2.

2009 Prism analysis assumptions:

- 100 million PHEVs in the fleet by 2030
- Electric vehicles represent three times the current share of non-road applications by 2030

Required research and development to realize this assumption:

- Standard smart grid capabilities to enable widespread PHEV deployment
- Completed pilot and demonstration PHEV projects

1. *Environmental Assessment of Plug-In Hybrid Electric Vehicles*, EPRI Report 1015325, July 2007, jointly with the National Resources Defense Council

ELECTRO-TECHNOLOGIES

The 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 6.5% as a result of electric technologies displacing traditional use of primary energy consumption for certain commercial and industrial applications.

Electro-technology research[1] indicates there are applications through which net reductions in CO_2 emissions can be achieved. This projection is based on replacing significant use of direct fossil-fueled primary energy with relatively de-carbonized electricity for selected applications: heat pumps, water heaters, ovens, induction melting, and arc furnaces.

2009 Prism analysis assumptions:

- 4.5% of primary energy supplied by fossil fuels is replaced by electricity by 2030

Required research and development to realize this assumption:

- Development and demonstration of key end-use electro-technologies for the above applications

1. *The Potential to Reduce CO_2 Emissions by Expanding the End-use Applications of Electricity,* EPRI Report 1018871, March 2009

2009 MERGE ANALYSIS

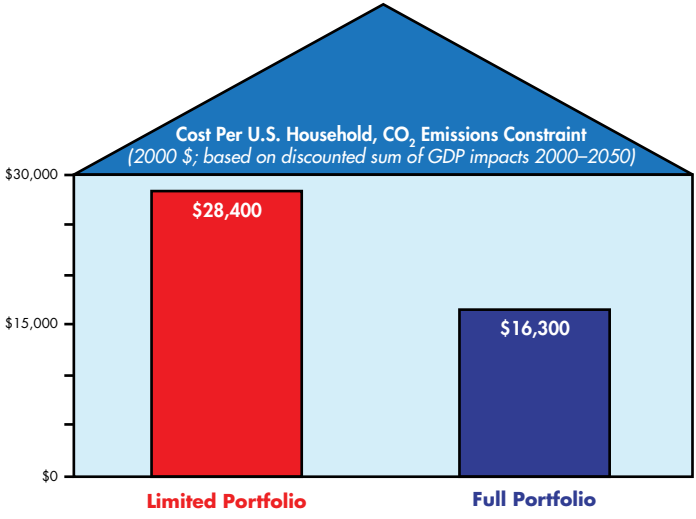
The 2009 MERGE analysis estimates the economically optimum portfolio of electricity sector technologies that will meet a CO_2 emissions constraint comparable to those suggested in current policy proposals. MERGE (Model for Estimating the Regional and Global Effects of Greenhouse Gas Reductions) analyzes the economywide impacts of climate policy in a global context. Under assumptions regarding CO_2 emissions constraints and technology costs and availability, MERGE compares economic consequences of different technology scenarios.

The 2009 MERGE analysis compares two technology scenarios: "limited portfolio" and "full portfolio." These two contrasting scenarios allow an assessment of the value of investing in RD&D. The limited portfolio assumes that CCS is not successfully deployed, and no expansion of the nuclear fleet. The full portfolio assumes availability of CCS, advanced nuclear, significant improvement in costs of renewables, availability of plug-in hybrid electric vehicles (PHEVs), and accelerated improvements in end-use efficiency. The 2009 analysis adds several features to previous EPRI analyses:

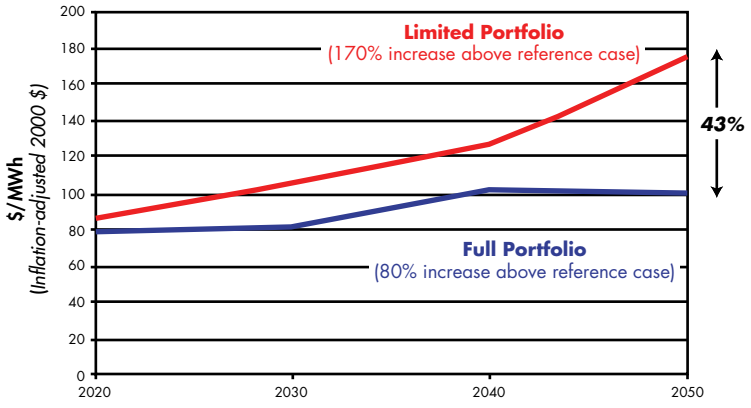
- Emissions constraints indicative of current U.S. and international policy proposals (80% below 2005 levels for developed countries);
- Updated technology costs based on EPRI's Technical Assessment Guide;
- Unconventional resources such as shale gas factored into natural gas supply;
- CCS retrofit for up to 60 GW of existing coal plants;
- Grid integration costs considered for high levels of variable output generation from renewables; and
- Higher biomass feedstock costs for large-scale biofuels and/or biomass electricity production.

MERGE Economic Results

The analysis confirms that while the cost of implementing major CO_2 emissions reductions is significant, development and deployment of a full portfolio of technologies will reduce the cost to the U.S. economy by more than $1 trillion. Less than half of these savings would be achievable if the future electricity sector generation portfolio does not include advanced coal with CO_2 capture and storage or advanced light water nuclear reactors.

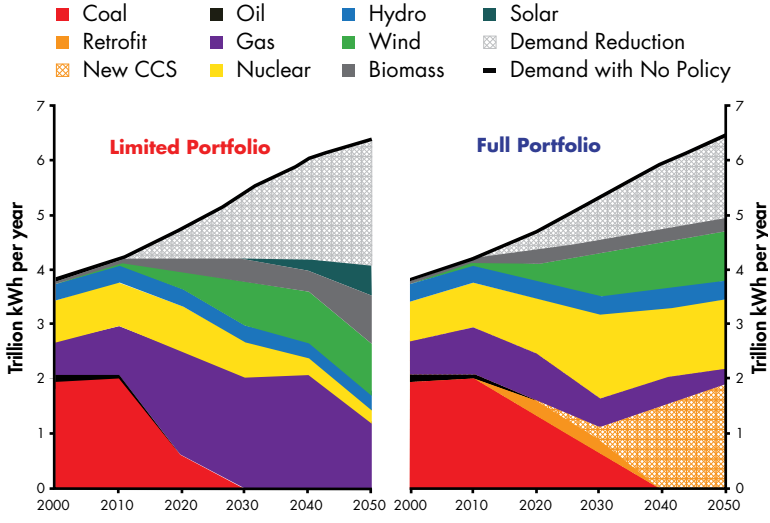


The benefits of investing in technology are also evident when comparing MERGE's projections of the wholesale electricity costs for the limited or full portfolio of technologies. By 2050, the wholesale electricity price in the full technology portfolio is 43% less than in the limited portfolio.

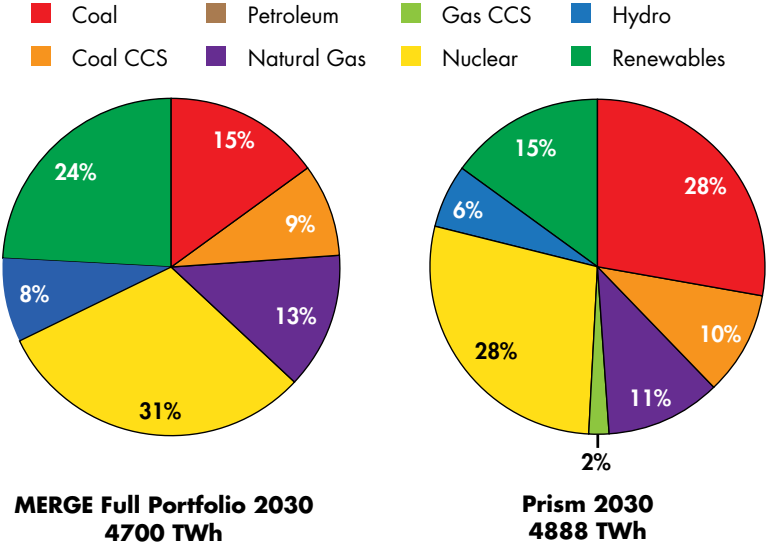


MERGE Technology Results

Under CO_2 emissions constraints representative of current proposals, MERGE projects that the economically optimal full technology portfolio consists of substantial amounts of renewable electricity generation, significant electricity production from coal and nuclear, as well as large reductions in electricity consumption. Retrofit of CO_2 capture and storage for existing coal plants plays an important transitional role between 2010 and 2030. The sharp growth of new coal with CCS after 2030 will be driven by the continually tightening emissions constraints, retirement of coal units with CCS retrofits, the need to reduce emissions from natural gas, and anticipation of more limited uranium supplies for nuclear plants based on the once-through fuel cycle.



MERGE results indicate that the Prism technology assumptions are reasonable; comparison of the MERGE and Prism technology mixes in 2030 validates this. The generation shares of the different technologies in MERGE are generally consistent with those in the Prism. This suggests that the Prism technology portfolio may also be economically optimal.



MERGE Full Portfolio 2030
4700 TWh

Prism 2030
4888 TWh

Conclusion

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The 2009 Prism and MERGE analyses underscore the importance of research, development, and demonstration leading to a full portfolio of electricity sector technologies. No one technology can do the job; the full portfolio of technologies is required.

The full portfolio comprises both supply- and demand-side technologies: end-use efficiency and plug-in hybrid electric vehicles supported by a smart grid; wind, biomass, solar, advanced nuclear, and coal with CO_2 capture and storage.

The MERGE analysis indicates that a technology portfolio similar to that outlined by the Prism can achieve CO_2 emissions reductions at a considerably lower economic cost—as much as $1 trillion in some scenarios. Much of the required technology is not yet available, and substantial, sustained research, development and demonstration is required. Low-carbon electricity technologies drive growth in electricity demand even as CO_2 emissions are reduced.

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Together...Shaping the Future of Electricity

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