Transforming America's Energy Economy

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This document was prepared by the Chief Research Officers of the U.S. Department of Energy national laboratories for the National Laboratory Directors Council.

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Introduction: A Call for Action

President Obama has called for a transformation of America's energy economy to ensure our energy security and to mitigate the environmental consequences associated with our current dependence on carbon-intensive energy sources. The need for this transformation—and the urgency with which it must take place—has been well established, and the general elements of a comprehensive strategy are being defined. The purpose of this white paper is to describe specific near-term opportunities and longer-term research challenges that will enable the required transformation. A key element will be the continuing role of basic science and technology.

The President has set a goal of reducing greenhouse gas emissions by 80 percent by 2050.[1] Toward this end, the nation must make our economy less carbon-intensive and less dependent on foreign oil.[2] This will require a comprehensive carbon management strategy that fundamentally transforms the U.S. and global energy system. This transformation necessitates an unprecedented pace and scale and will depend on progress in five broad areas:

1. Renewable and Low-Carbon Energy Sources for Electricity Production
2. Energy for Transportation
3. Carbon Capture, Sequestration, and Management
4. Electricity Transmission and Distribution
5. Energy Efficiency.

The following key points help to frame the near-term opportunities and longer-term research challenges:

- Transforming the nation's economy is neither a 3-to-5-year problem nor a 15-to-25-year problem; it is both. That is, there are near-term actions the nation can take while simultaneously laying the groundwork for long-term success.
- The ideas outlined in this white paper are driven by energy security and climate change concerns. Energy security requires us to wean ourselves off foreign oil. Climate change concerns drive us toward carbon-neutral energy sources—and to do so now.
- It is not sufficient to "simply" replace current fossil fuels with low-carbon alternatives; it also is necessary to meet the growing demand for energy.
- It is necessary to increase energy production from multiple sources, as well as to achieve greater energy efficiency (thereby reducing demand).
- Improved energy storage is needed at all scales, from improved batteries for transportation purposes (to enable electrification of the transportation sector) to improved grid storage (to facilitate the incorporation of intermittent renewables).

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[1] http://www.whitehouse.gov/agenda/energy_and_environment/.

[2] DOE Secretary Chu testimony before the House Science and Technology Committee, March 17; http://democrats.science.house.gov/Media/file/Commdocs/hearings/2009/Full/17mar/Chu_Testimony.pdf/.

Envisioning the Future of Energy

In the sections that follow, each of the five major areas is discussed. The near-term (circa 2015) desired outcomes and opportunities are described first, followed by the longer-term (2030) desired outcomes and associated research challenges.

B.1 – Renewable and Low-Carbon Energy Sources for Electricity Production

Central to transforming America's energy economy to reduce dependence on foreign oil and mitigating climate change is the development of renewable and low-carbon energy sources for electricity production. Such sources include solar, wind, geothermal, bio-power, tidal/marine, and nuclear power.

Desired Outcomes by 2015

- Between 10 and 15 percent of U.S. electricity comes from renewable sources: solar, wind, geothermal, bio-power, and tidal/marine.
- Nuclear power plants that will provide at least 30 percent of U.S. electricity needs (up from today's 20 percent) are under construction.
- Solar photovoltaic electricity cost is 8-10 cents/kWhr (for residential) and 5-7 cents/kWhr (utility scale).
- Concentrating solar power plants are cost-competitive in the southwestern United States' intermediate load markets.
- Monitoring, control, and reliability of wind systems are improved.
- Geothermal energy demonstrates first 5-MW_e (megawatt-electric) enhanced geothermal system plant.
- Advanced energy crops are developed for bio-power production.
- Advanced light water reactors are licensed and commercially implemented.
- Demonstration projects are established for tidal and ocean power.

Near-Term Research Opportunities

- Integrate renewable power using smart grid technologies into the nation's transmission system, including
  - assessing and implementing land-based and offshore renewable energy transmission corridors
  - researching, developing, and testing transmission planning expansion methods for constrained resources
  - developing enhanced forecasting capabilities and network of monitors.

- For key photovoltaic layers, develop cost-effective means to reduce the thickness of crystalline silicon and replace rare elements with more abundant elements.
- Develop new organic photovoltaic materials for commercial testing.
- Develop novel thermal storage materials.
- Improve understanding of wind characteristics to enhance efficiency and performance.
- Improve wind turbine technology and reliability by establishing
  - viable high-reliability, long-lifetime wind turbine drive trains
  - wind turbine drive train reliability testing facility
  - an offshore wind energy test facility and initiating a 5-year prototype program
  - an advanced manufacturing initiative to incentivize U.S. manufacturing
  - non-destructive evaluation techniques and prognostics for in-service turbine assessment.
- Enhanced geothermal systems are proven technically feasible.
- Enhance energy crops by creating new strains, including drought- and disease-tolerant grasses, trees that grow on marginal soils, and fast-growing algae with high lipid content.
- Develop reactor systems that integrate electricity production and hydrogen generation.
- Non-destructive evaluation techniques and prognostics for in-service reactor assessments.
- Develop an acceptable near-term approach for nuclear waste storage or waste transmutation.
- New materials for neutron environments for current and future fission and/or fusion reactors.
- Research, test, and validate marine energy design tools.

Desired Outcomes by 2030

- Greater than 40 percent of U.S. electricity comes from renewable sources, with a minimum of 20 percent (300 GWp) each from wind and solar energy.
- Wind energy displaces approximately 50 percent of electric utility natural gas consumption and approximately 18 percent of coal consumption, with the following effects:
  - CO_2 emissions from the electricity sector are reduced by 825 MMT (million metric tons).
  - Water consumption by the electric sector is reduced 17 percent annually from increased wind energy.
- Large electric load balancing areas are established in the United States to enable use of large-scale renewable and low-carbon generation sources.
- Geothermal energy (enhanced geothermal systems) provides at least 10 percent of electric power needs.
- Algae are introduced into commercial scale bio-power plants.
- The nuclear fuel cycle is closed.
- The current fleet of U.S. nuclear plants is certified and upgraded for 80-year operation.
- Nuclear energy produces emission-free hydrogen and oxygen and provides process heat for co-located bio-refineries.
- Marine energy supplies more than 2 percent of U.S. electricity demand.

Longer-Term Research Challenges

- Develop new photovoltaic materials (absorbers, transparent conductors) with breakthrough property improvements using materials–by-design (e.g., cheap materials with the performance of more expensive materials) to use the entire solar spectrum.
- Develop new solar energy conversion materials with a 50-to-1 decrease in cost-to-efficiency ratio for production of electricity.
- Develop gigawatt-hour scale, non-hydro (non-pumped storage) energy storage systems.

- Create subsurface hydrothermal systems at depths near 10,000 meters for enhanced geothermal systems.
- New high-temperature materials and manufacturing methods for advanced nuclear reactors.
- Demonstrate nuclear fuel recycling technologies that are economically competitive and proliferation-resistant.
- Materials for nuclear energy production that have longer lifetimes and improved reliability.
- Fission and/or fusion reactor technologies for commercial power production.
- Cost-effective tidal electricity generation systems that meet reliability demands.

B.2 – Energy for Transportation

The development of new technologies to meet America's transportation needs is a second major energy area. Here the goal is to power vehicles and to move people with minimal environmental impact and to use domestic energy sources for increased energy security. Research and development is needed in lightweight materials, engine efficiency, biofuels, hydrogen, fuel cells, and batteries.

Desired Outcomes by 2015

- 1 million plug-in hybrids on the road (DOE goal: http://www.whitehouse.gov/agenda/energy_and_environment/)
- The fuel efficiency of new conventional vehicles improves by 25 percent because of enhanced engine efficiency and vehicle lightweighting (U.S. auto industry goal).
- 5 percent of fuel used will be from biofeedstocks (doubling the current 2.5 percent biofuel use).
- Demonstration of next generation batteries for vehicles with an energy density of 600 W/L (USCAR/DOE goal).
- Prototype of hydrogen vehicle achieving a 60 percent peak energy-efficient, durable, direct hydrogen fuel cell power system that, including hydrogen storage, achieves a power density of 220 W/L and a specific power of 325 W/kg, at a cost of $30/kW, with a range of over 300 miles (USCAR/DOE goal).

Near-Term Research Opportunities

- Enable advanced and efficient combustion engines to become common in the market, which will involve
  - understanding the ignition chemistry controlling homogeneous charge, compression ignition engine designs
  - developing new theories of very high pressure (greater than 100 atm) chemistry and fluid dynamics for next generation, high-efficiency engines
  - demonstrating a predictive, science-based design tool for internal combustion engine design with fully coupled chemistry and fluid dynamics with moving pistons and valves.
- Enable plug-in hybrids to enter the market for the first time through development of reliable, high-power-density batteries, which will involve
  - understanding the transport of lithium ions in battery environments
  - developing an understanding of lithium ion battery failure mechanisms and chemistry and develop mitigation strategies.
- Demonstrate economically sustainable cellulosic ethanol production at pilot scale, which will involve commercial research in feedstocks, deconstruction, and fuel synthesis.

Desired Outcomes by 2030

- 50 million plug-in hybrids will be on the road. (This represents a logical extension of 1 million vehicles in 2015, based on production increases, and corresponds to 20 percent of the predicted fleet.)
- Batteries that are 10 times cheaper and feature improved density, cycling time, and reliability will be developed.
- Total vehicle fleet fuel use will decrease by 10 percent compared to 2000, and compared to a projected increase of 50 percent with no action (MIT "On the Road in 2035" study).
- 30 percent of fuel from is biofeedstocks (Industry "Biofuels Deployment Model").

- 10 percent of new vehicle sales are zero-emission vehicles—either hydrogen fuel cell or electric vehicles (CARB goal).
- There will be an 80 percent reduction in carbon dioxide produced from transportation by 2050 (CARB goal).

Longer-Term Research Challenges

- Research is needed from a heterogeneous mix of solutions, including
  - biofuels: cellulosic ethanol and second-generation fuels, algal biodiesel, thermochemical processing of biofeedstocks
  - more than 35 percent engine efficiency gains from 2000
  - achieving 20 percent or more improvement over 2000 levels in vehicle lightweighting
  - more than 50 percent of vehicles on the road are hybrids or plug-in hybrids
  - zero-emission solutions: hydrogen, fully electric vehicles.
- Predictive, 3D, time-dependent, science-based commercial modeling tools for design and optimization of energy storage, use, and structures for transportation, involving
  - combustion—fully coupled chemistry and fluid dynamics computed in real geometries at operating conditions
  - batteries—full battery modeling including chemistry and transport as well as heterogeneous failure mechanisms
  - hydrogen storage—discovery of optimal storage materials from first principles predictions.
  - fuel cells—full device modeling including off-normal behavior
  - lightweight, high-strength materials—discovery of novel structures and chemistries for the creation of affordable, lightweight, high-strength materials.

B.3 – Carbon Capture, Sequestration, and Management

Given a global abundance of affordable fossil fuels and an existing multi-trillion dollar infrastructure, fossil fuels are widely expected to remain the backbone of the global energy system through mid-century. The development and widespread deployment of carbon capture and sequestration (CCS) technologies are essential to a carbon management strategy that can deliver on the climate change goals without destabilizing the global economy. To move forward on an aggressive strategy to capture the greatest amount of greenhouse gas emissions possible, CCS efforts in the near term must focus on capture and storage of CO_2 in deep geologic formations. These technologies must include capture from a range of sources, including power plant retrofits, next-generation integrated gasification combined cycle and oxyfuel power plants, gas plants, biofuel facilities, and industrial sources. To the extent that captured CO_2 remains permanently sequestered, the U.S. Department of Energy (DOE) should also explore conversion of captured CO_2 to beneficial uses, such as products and fuels. This would include both biological and chemical approaches that are carbon neutral and cost effective.

Desired Outcomes by 2015

- Develop and deploy clean coal technology,[3] including a portfolio of cost-effective emissions capture technologies for both gasification and pulverized coal-based power plants.
- Identify 20 large-scale CCS demonstration projects globally by 2010 to enable broad deployment of CCS by 2020.[4]
- Launch five "first-of-a-kind" commercial-scale coal plants with CCS domestically,[5] injecting 10,000 to 20,000 tonnes/day of gas.[6]

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[3] http://www.whitehouse.gov/agenda/energy_and_environment/.

[4] Joint Statement by G8 Energy Ministers, Aomori, Japan on 8 June, 2008.

[5] Obama-Biden: New Energy for America.

[6] U.S. Climate Action Partnership, http://www.US-CAP.org/.

Near-Term Research Opportunities

Establish strong public-private and international partnerships to rapidly advance CCS research, development and demonstration (RD&D). Place a special focus on China, India, and their energy trading partners, such as Australia. The RD&D programs should emphasize

- Rapid discovery, synthesis, and engineering of new materials and approaches to capture CO_2 at low cost,[7] high efficiency and with a low overall energy penalty, including
  - materials/solvents to capture and release CO_2 with subsequent regeneration of the sorbent
  - classes of material that rapidly translate into integrated CCS processes that scale.
- Advances in the underlying science and engineered systems required for safe, large-scale, long-term geologic sequestration that
  - provide a fundamental understanding of the fluid-mineral interactions of both supercritical and brine-saturated CO_2
  - develop a computational platform that enables rapid incorporation of science into repository simulators and supports a community framework for subsurface modeling
  - develop science-based and field-validated models, algorithms, tools, and databases in order to predict the fate and transport of supercritical CO_2 in geologic systems at regional scales and thousand-year timeframes
  - provide high-fidelity simulation of carbon sequestration with full coupling of geochemistry, hydrology, and geomechanics.
- Safe, cost-effective approaches for capturing and sequestering CO_2 with other emissions (co-sequestration)[8] which rely upon
  - rapid discovery, synthesis, and engineering to enable capture of CO_2 simultaneously with other emissions at very high efficiency
  - advances in science to understand the impact of mixed gas streams on deep geologic reservoirs and caprocks under the high pressures and elevated temperatures experienced during sequestration.
- The development of monitoring, mitigation, and verification capabilities to measure the amount of CO_2 stored at a specific sequestration site, monitor the site for leaks or other deterioration of storage integrity over time, and verify that the CO_2 is stored or isolated as intended and will not adversely affect the host ecosystem.

Desired Outcomes by 2030

- Broad deployment of CCS globally beginning in 2020[9]
- Deployment of cost-neutral technologies for re-use of captured CO_2

Longer-Term Research Challenges

Long-term research should reduce the cost, increase the effectiveness and expand deployment of CCS systems in an aggressive drive towards 2050 carbon reduction goals and the possibility that we must meet negative greenhouse gas emission targets to avoid significant climate change impacts. This research should include

- Capture of CO_2 by phototrophic microbes and production of high-value products. These will be beneficial to total carbon emission reductions only if their deployment is coupled with CCS systems at the tail end, which will be dependent upon

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[7] Capture currently accounts for approximately 75 percent of the cost of CCS in typical applications.

[8] Particularly important to enable developing countries to participate in global GHG emissions reduction without repeating the historical and expensive unit-by-unit approach to emissions capture in the United States.

[9] Joint Statement by G8 Energy Ministers, Aomori, Japan on 8 June, 2008.

– optimization of CO_2-concentrating and -assimilating biochemical pathways by elucidation of catalytic mechanisms and regulatory controls

– metabolic engineering of high-value organic end products (lipids, polymeric alkanoates, solvents) and hydrogen in phototrophic bacteria and algae. This requires development of phototrophs that are molecularly tractable and robust under large-scale cultivation.

– mass-cultivation systems that remain stable and functionally productive as complex microbial communities and are cost-effective to harvest and process into biofuels.

- Chemical conversion of CO_2
- Improvements in climate modeling and impact assessment to represent full carbon cycle, global water systems, energy infrastructure, technology adoption, and regional effects that will provide a basis for meaningful greenhouse gas emission reduction targets and next-generation CCS systems.

B.4 – Electricity Transmission and Distribution

America must re-invent its electricity transmission infrastructure. The "smart grid" must become a reality—and this reality will require the development of grid monitoring and management technologies including phasors and real-time data analysis for grid management. It also will be essential to advance the state-of-the-art in large-scale energy storage devices to facilitate the integration of intermittent renewable energy sources.

Desired Outcomes by 2015

- Ensure 10 percent of our electricity comes from renewable sources by 2012, and 25 percent by 2025.[10]
- Develop and deploy large-scale energy storage systems so that variable renewable energy sources such as wind or solar power can become base-load power generators.[11]
- Build a more efficient electric grid based on clean and renewable generation.[12]

Near-Term Research Opportunities

- Establish a real-time, nationwide grid monitoring system to achieve transparency of grid performance, including phasor measurement unit build-out (needed by 2012) which involves

  – developing network systems for near real-time data collection, clearing, and secure, subscribed transfer, including specialized network protocols to ensure rapid, dynamic and selective data transfer; software architectures for merging legacy and new codes; and novel mathematical algorithms to dynamically identify data relevant to current situation

  – developing near real-time grid performance (state estimator) models and analytics, including algorithms and methods for solving large nonlinear optimization problems; and verification that computations have been completed to specification within time frame.

- Develop wide-area grid simulations to enable national grid performance near-term prediction (on-line tools) and longer-term planning (off-line tools) including

  – algorithms and data processing systems to dramatically increase the complexity and speed of grid performance models

  – the incorporation of renewable input, demand response, plug-in hybrid electric vehicles, and energy storage functions into grid models for off-line, long-term planning.

- Develop cyber security methods to secure sensors, data, analysis, and transfer in near real-time (standard encryption approaches may not work).

[10] http://www.whitehouse.gov/agenda/energy_and_environment/

[11] DOE Secretary Chu testimony before the House Science and Technology Committee, March 17; http://democrats.science.house.gov/Media/file/Commdocs/hearings/2009/Full/17mar/Chu_Testimony.pdf/.

[12] White House Press Release, February 19, 2009 http://www.whitehouse.gov/the_press_office/President-Obama-and-Prime-Minister-Harper-vow-joint-effort-on-North-American-economic-recovery/.

- Establish capacity to reliably integrate more than 20 percent renewables and electric vehicles onto the electricity grid by
  - developing electrochemical energy storage and power management systems, including multi-scale synthesis and multi-component assembly of materials and fundamental understanding of ion and electron transport
  - developing enhanced renewable generation forecasting and monitoring
  - planning and testing transmission expansion, and implement land-based and offshore renewable energy transmission corridors
  - developing communication standards to enable load management strategies.

Desired Outcomes by 2030

- Create technology and market conditions for increased functionality of the electricity infrastructure (smart grid) to enable broad and diverse national energy objectives, including:
  - greater penetration of renewables
  - large electric load balancing or energy accumulation areas allowing regions to use a variety of renewable and low-carbon generation sources
  - two-way communication built into electricity infrastructure to enable end-use efficiency through precise knowledge of pricing, demand, and carbon offset signals
  - real-time matching of dispatchable capacity to demand.
- Improve overall grid reliability, security, flexibility, and efficiency.

Longer-Term Research Challenges

- Improved (faster, better) grid performance management, including
  - grid simulation and analytic improvements to anticipate, understand, and respond to multi-component anomalies and improve operating contingency management (faster, better grid performance management)
  - intrinsic cyber security methods to predict and adapt to threats and operating anomalies in near-real time
  - integrated sensor analytics (smart power management units) to improve accuracy and speed of data collection and transfer.
- Increase capacity and decrease cost of energy storage systems, including
  - gigawatt-hour scale storage capabilities (non-hydro/non-pumped)
  - integrated storage systems (e.g., large-scale stationary batteries, above and below ground, compressed air storage, hydrogen generation as storage option).
- Develop market structures that will incentivize intelligent load customers (smart buildings, smart appliances) to collaborate with smart grid.

B.5 – Energy Efficiency

Efficient use of energy (both supply- and demand-side efficiency) is essential to lowering energy consumption and achieving greenhouse gas emission targets. Significant energy savings and greenhouse gas reduction can be achieved through extensive deployment of near-term technologies. Invention and commercialization of advanced energy-efficiency technologies, such as improved insulation materials and smart building control systems, integrated with an advanced smart grid that includes time-of-day metering and bi-directional power flows, offer great potential for additional energy savings and emissions reductions. Efficiencies also require the implementation of new building codes and incentives that will accelerate the construction of net-zero energy homes and buildings.

Desired Outcomes by 2015

- New residential buildings use half the energy of those built in 2005 with zero or less net cash flow.
- New commercial buildings use 50 percent less energy than those built in 2005.
- Solid state lighting devices are commercially available with performance equal or exceeding 125 lumens/watt.
- Windows are developed with 50 percent reduction in overall effective conductance and the ability to control visible transmittance and transmitted heat gains.
- More efficient and cost-effective residential and commercial heating, ventilation, and air conditioning is developed.
- Energy intensity of U.S industry is lowered by 20 to 25 percent compared with 2008 levels.

Near-Term Research Opportunities

- Develop thin-section superinsulation capable of providing R-30 walls and R-60 roofs, along with cost-effective R-10 to R-15 windows with dynamic shading capability.
- Create heating and cooling systems that use enhanced heat transfer technologies such as micro-channels and nano-scale surface treatments or replace traditional vapor compression cycles with alternatives such as thermo-chemical systems.
- Develop new technologies or systems to improve indoor air quality in "tight" energy efficient buildings.
- Create "smart" networked lighting control systems and develop systems and protocols for integration of all building systems.
- Integrate architecture and information technology for system and subsystem integration, building simulation, and data mining.
- Develop advanced building analysis/modeling programs using high-performance computing.
- Develop advanced technology to reduce energy use in existing buildings.

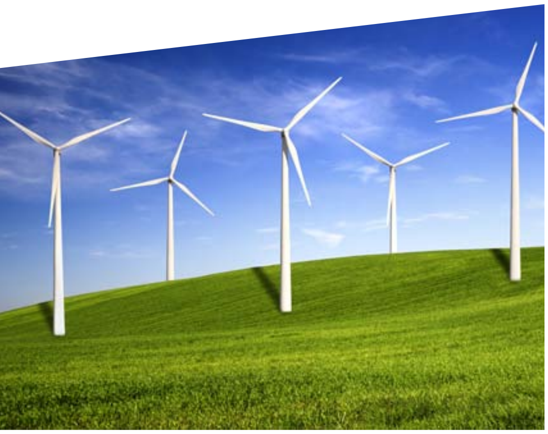
Desired Outcomes by 2030

- New commercial buildings use 70 percent less energy than those built in 2008 and existing commercial buildings are modified to use 50 percent less energy than in 2008.
- Homes and commercial buildings are fully integrated with the "smart" electricity distribution system and distributed energy storage systems.

Longer-Term Research Challenges

- "Self-tuning" buildings enable continuous visualization, monitoring, reporting, diagnostics, and demand response to signals from service providers.
- Achieve reliable building operation, peak demand reduction, and electric grid stabilization using "smart" interaction of building systems with the utility, onsite renewable and distributed energy resources, and storage systems to allow for research into fully integrating autonomously controlled smart buildings with the smart grid.
- Scalable energy modeling software that monitors and controls the relevant parameters from an individual building scale to community and regional scales in order to optimize cost and energy savings.
- Improved dynamic models of components and systems through use in whole building models.

Charting the Path Forward



Achieving the energy solutions mentioned in this white paper will require sustained research, development, demonstration, and deployment efforts that span the range from fundamental research for discovering breakthroughs to technology transfer and commercialization for bringing results to market. The effort must be framed under the following tenets:

- "Science to Solutions" – The solutions should be based on best-in-class science and engineering, rely on openness and collaborations, and encompass a suite of alternatives eventually made available and from which the marketplace can choose. The approach involves:
  - including researchers from academia, national laboratories and elsewhere, and partnering with companies to incorporate the customer perspective and entrepreneurial drive
  - supporting a broad spectrum of fundamental research sustained over a long period of time to form the basis for future technology development
  - ensuring a sustained commitment to large-scale, multidisciplinary research and development that leverages the capabilities of the entire science and technology enterprise (national laboratories, academia, and industry)
  - streamlining the translation of scientific breakthroughs to technology solutions through mechanisms including Advanced Research Projects Agency-Energy and improvements to technology transfer processes so that the path toward commercialization is largely dictated by the technology development and only minimally impacted by process
  - pursuing U.S. leadership in science and technolgy but recognizing that the problems and solutions must be pursued on a worldwide stage; and when experiments, facilities and activities are conducted internationally, the United States must be a reliable partner in the international research arena.
- "Best and the Brightest" – The problems must be pursued by the very best people that are available both now for the short-term needs and in the long run to sustain the effort and develop solutions that will be needed going forward. This includes:
  - providing open competitions for funding of centers of excellence, as was done for the Bioenergy Centers and the Energy Frontier Research Centers, and with block funding to enable them to attract and support outstanding leaders with superb scientific talents, and the flexibility to move quickly toward a new solution or to tackle a slightly different problem as the situation arises
  - requiring such block funding activities and centers to undergo regular, rigorous reviews by respected leaders in the field, and ensuring an effective mechanism for dropping poor performers

- granting early career researchers an opportunity to tackle interesting and challenging problems outlined above by providing awards of, say, 5 years of known and steady funding predicated on periodic reviews
- supporting broad education and training efforts to ensure that the pipeline of researchers, engineers and other professionals that work in the energy field is maintained at the level necessary and with the access to the nation's leading edge facilities and tools to sustain technological development and progress.

• Role of the National Laboratories – DOE National Laboratory system is an integral part of the research fabric of this nation. It has the ability to provide best-in-class scientific and engineering expertise and to apply leading edge experimental and computational facilities, advanced tools, and creative methods to address the activities outlined in this paper. The laboratories have the flexibility to redirect efforts within a reasonable scope as the task and results dictate and the capability for the sustained effort needed. Addressing the energy needs requires

- opening the laboratories more broadly as focal points for public-private partnerships with industry and universities to accelerate technology development on key market sectors. The laboratories work best when such partnerships are in place. Partnering with the private sector allows a logical conduit to the researchers to understand the market needs and constraints, and for the U.S. industry to fully use the existing science and engineering investments made by the government at the laboratories
- considering the national laboratories broadly as "user facilities" to enable collaborative use of the unique facilities and capabilities by all researchers (academia, industry and other laboratories), provide unique equipment and techniques that can be applied to testing and developing ideas, pursue research in transformational engineering so that the latest tools and techniques are available for future manufacturing needs, and offer technology assistance for companies and governments to help determine appropriate solutions for a given application
- using the buildings and land comprising the national laboratories as test beds for demonstration of both "shovel ready" and next-generation technologies for energy efficient buildings, infrastructure, vehicles and other applications
- engaging laboratory personnel as an extension of the government, where appropriate, to take advantage of the special relationship that exists under the government-owned, contractor-operated model. This could include using the laboratories to build bridges between different federal agencies to coordinate resources toward solving national problems.

The concepts noted in this white paper should be further developed through a broadly based national road-mapping activity, conducted collaboratively with DOE, industry, academia and the national laboratories. The model that was followed by DOE in the Office of Science that resulted in the series of Basic Research Needs reports could serve as a suitable model for this road-mapping exercise.

It is important to note that this white paper focuses on (1) identifying energy technology research and development needs and (2) discussing mechanisms for discovering and developing solutions to meet these needs. There are certainly economic, policy, and political considerations that may dictate the success of one technological path over another. Ideally, the options outlined here can inform ongoing policy discussions. At the very least, policy mechanisms (e.g., cap-and-trade) must be identified and considered when determining which technological options to pursue. The road-mapping exercise noted above could help in this regard.

For additional information, please contact:

Steven Ashby
Deputy Director for Science and Technology
Pacific Northwest National Laboratory
sfashby@pnl.gov

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