1. What are the session key findings? What are the new Lesson(s) learned / Scientific progress (since AR5 release, if relevant)?

• Successful transformation of our energy system will require game-changing technological innovations. Some of these innovations are here today – for example, photovoltaics, wind turbines and natural gas. Some are likely to be coming soon but require additional time and effort to decrease costs and scale them up to the enormous size of our energy system. Examples include battery storage, modernization of the electrical grid and electric cars. Looking to the future, additional game-changing technologies are needed and on the horizon: carbon capture and storage, renewal fuels made without plants, radiative cooling, just to name a few.

• Carbon capture and storage is a critical technology for accelerating the pace of and reducing the costs of decarbonizing the energy system. Technologies are here today for each of the steps required for carbon capture and storage. Integrating these into the electric power generation system faces challenges, not the least of which is the increased costs. The first-of-a-kind power plants with CO2 capture and storage are now operational and will provide valuable information on cost and performance. Other hurdles include gaining public enthusiasm for this solution and regulatory issues associated with permanent retention of CO2 in deep underground formations.

• Increased deployment of intermittent and variable renewable energy generation into the electrical grid will place new demands on energy systems integration. Additional flexibility on both the supply and demand side is needed. Approaches for accomplishing this are being developed. Critical technologies include fast-start natural gas turbines, batteries for grid storage, information technology to enable real-time electricity markets, and customer information to enable real-time demand side management. No single technology or approach will suffice. The coordinated management of these and other approaches will be needed to assure the reliability and quality of the electrical grid while introducing more low-carbon power generation into the grid.
2. What are the major knowledge Gaps and Research Needs identified in the session?

The following critical challenges were identified:

* Cost effective approaches for very high penetration of renewable energy into the electrical grid.
* Cost effective approaches for capturing carbon dioxide from power plants and other large stationary emission sources of CO₂.
* Approaches for increasing confidence in the safety and security of CO₂ storage.
* Alternative uses of capture CO₂.
* Carbon neutral transportation fuels for heavy-duty transportation and aviation.
* Alternative and more efficient approaches for heating and cooling buildings.

3. Did the session discuss/identify promising approaches in the fields of Adaptation and Mitigation, or both?

Mitigation.

4. Are there take-home messages from the session?

* Tremendous progress has been made over the past decade for providing cost-effective low carbon electricity. Examples include wind turbines, solar PV, and shale gas.
* There are a spate of new technologies that coming soon, including electric cars, a more capable electrical grid, and grid-scale energy storage.
* More work is needed to sustain decarbonization over the coming decades, but there are many exciting technologies on the horizon. To name just a few, carbon capture and storage, renewal fuels made from carbon dioxide and water, and passive radiative cooling.
* Sustained support for energy R&D is crucial, from discovery through pilot projects. The dramatic progress over the past decade is testament to the fact that the energy R&D ecosystem can deliver the needed innovations for a transition to a low carbon energy system.

5. Are there Important Quotes from the session?

* “There are no technical limits to the amount of renewable energy that can be integrated into the electrical grid, it’s just a matter of money.” Mark O’Malley, University College, Dublin, Ireland.
* “All of the technology needed for Carbon Capture and Storage is available today. The challenge is integrating all the pieces and doing it cost effectively.” Gardiner Hill, BP, UK.

6. Please include any other remark that you might have.