

# 21<sup>st</sup> Century Power Partnership

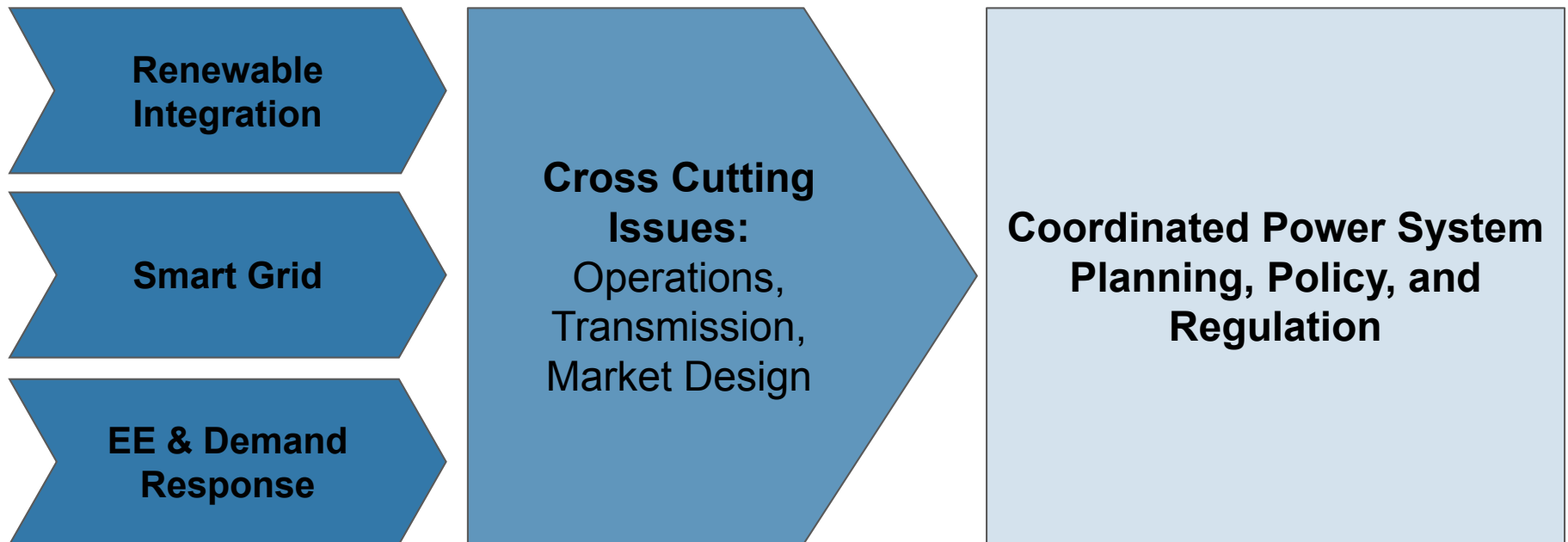
An Initiative of the Clean Energy Ministerial

Jeffrey Logan

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Operating Agent for the 21CPP

**Accelerating the transition to clean, efficient,  
reliable, and cost-effective power systems.**



**Elements of Power System Transformation**

## The Partnership aims to advance integrated policy development through four areas of activity:

### Faster Learning

**Developing and sharing knowledge** on key topics related to power system transformation.

### Better Tools

**Strengthening and disseminating technical tools** to accelerate policy and regulatory analysis.

### Capacity Building

**Bolstering the capacity of experts** to advance the needed policies, programs, and practices.

### Meaningful Partnerships

**Establishing applied multilateral partnership engagements** to leverage knowledge, tools, and capacity.

# 21st Century POWER PARTNERSHIP

Accelerating the transformation of power systems

# 21CPP THOUGHT-LEADERSHIP REPORTS

## Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience

Jacqueline Cochran, Lori Bell, Jenny Heeter, and Douglas J. Arent



ENREL JISEA SOLUTIONS CENTER CLEAN ENERGY

NREL/TP-6A50-0212  
April 2012

2012



## Market Evolution: Wholesale Electricity Market Design for 21st Century Power Systems

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International Copper Association  
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Global Green Growth Institute (GGGI)  
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China National Renewable Energy Center

21stCenturyPower.org

Technical Report  
NREL/TP-6A50-0217  
October 2013  
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2013



## Flexibility in 21st Century Power Systems

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National Renewable Energy Laboratory, Aquila Cochran, Mackay Miller, Owen Zeman, Michael Milgen, Douglas Arent, Bryan Borer  
University College London, York University, International Energy Agency, Green Markets 2014, Green Markets 2014, 2014  
Northwest Power and Conservation Council, Jon Lyle, The Gridplus Alliance, National Renewable Energy Laboratory, Technical Research Center of Finland, Helsinki  
Hydro, John Kolarik, Power System Operation Corporation, U.S. DoE

### Introduction

Flexibility of operation—the ability of a power system to respond to change in demand and supply—is a characteristic of all power systems. Flexibility is especially prized in heavily first century power systems, with higher levels of grid-connected variable renewable energy (primarily, wind and solar).

All power systems have some inherent level of flexibility—designed to balance supply and demand at all times. Variability and uncertainty are not new to power systems because loads change over time and in sometimes unpredictable ways, and conventional resources fail unexpectedly. Variable renewable energy supply, however, can make this balance harder to achieve. Both wind and solar generation output vary significantly over the course of hours to days, sometimes in a predictable fashion, but often, unpredictably.

It must be supplied by the remaining generation, assuming no curtailment of total energy. The graph shows that the output level of the remaining generation must change more quickly and be turned to a lower level with wind energy in the system. Solar energy will cause quarterly similar impacts on the power system.

To illustrate how variable renewable energy can increase the need for flexibility, Figure 1 demonstrates how variable wind output impacts power system operation. The figure introduces the concept of “net load” which represents the demand that must be supplied by the conventional generation fleet if all of the renewable energy is to be utilized. The yellow area in the graph represents demand, and shows the daily variability of demand and an hourly load for one week. The green shows wind energy, and the orange represents the demand-based net load that

must be supplied by the remaining generation, assuming no curtailment of total energy. The graph shows that the output level of the remaining generation must change more quickly and be turned to a lower level with wind energy in the system. Solar energy will cause quarterly similar impacts on the power system.

Because it can take several years to design and build new generators and transmission lines, the planning process to the full capacity to ensure that the power system of the future possesses sufficient flexibility to accommodate the growth of variable renewable generation. In regulated markets, this function may resemble a merit-ordering model in which some combination of industry and government jointly assesses potential flexibilities. In areas with competitive markets, there must be sufficient investment signals regarding the potential need for flexibility to the absence of other sufficient planning or investment, clarity the resulting power system may not have sufficient flexibility to operate reliably.



## Status of Power System Transformation 2017

System integration and local grids



## Power Systems of the Future

### A 21st Century Power Partnership Thought Leadership Report

Owen Zeman, Mackay Miller, Ali Aali, Douglas Arent, Jacqueline Cochran, and Ron Yora  
National Renewable Energy Laboratory

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Columbia University, Sustainable Engineering Lab  
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Iciba, Shell-GDF Forum

Technical Report  
NREL/TP-6A50-021511  
February 2015

2015



## Clean Restructuring: Design Elements for Low-Carbon Wholesale Markets and Beyond

### A 21st Century Power Partnership Thought Leadership Report

Mona Shah, José María Valenzuela, Hector Alejandro Barrios, Manoj, Kim Walker, Peter, Anders Henningsen, Sandra Frid-Jensen, Maria Vignani, Fabian Vignani, Shruva Tedemansi, Lori Bell, Owen Zeman, and Jeffrey Logan

1. National Renewable Energy Laboratory
2. World Wildlife Fund - Mexico
3. Energy Regulatory Commission of Mexico
4. Danish Energy Agency
5. E.ON

Technical Report  
NREL/TP-6A50-06105  
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2016

2017



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