



# Best Practices for Integrating Renewables: Power System Transformation Approaches

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# FOUNDATIONAL PUBLICATIONS: FLEXIBILITY IN POWER SYSTEM TRANSFORMATION



## Integrating Variable Renewable Energy in Electric Power Markets:

Best Practices from International Experience, Summary for Policymakers

Jaquelin Cochran, Lee Bird, Jenny Heeter, and Douglas J. Arent



## Flexibility in 21<sup>st</sup> Century Power Systems

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### 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 twenty-first century power systems, with higher levels of grid-connected variable renewable energy (primarily, wind and solar).



## Market Evolution: Wholesale Electricity Market Design for 21<sup>st</sup> Century Power Systems

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(co-lead)



China



India  
(co-lead)



Denmark



Finland



Mexico  
(co-lead)



South Africa



Spain



United States  
(co-lead, under review)

# Leading Transformation: A System-wide Approach

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India  
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Mexico  
 (co-lead)



South Africa



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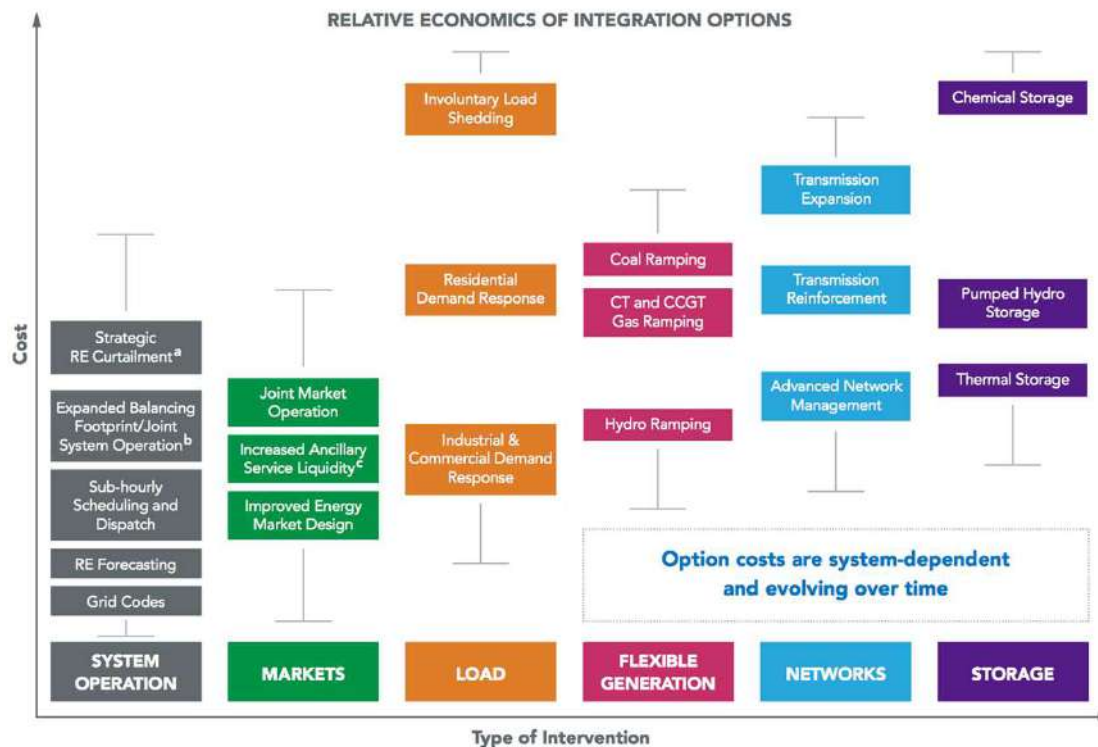


United States  
 (co-lead, under review)

## ACTIONS REFLECT MARKET STATUS

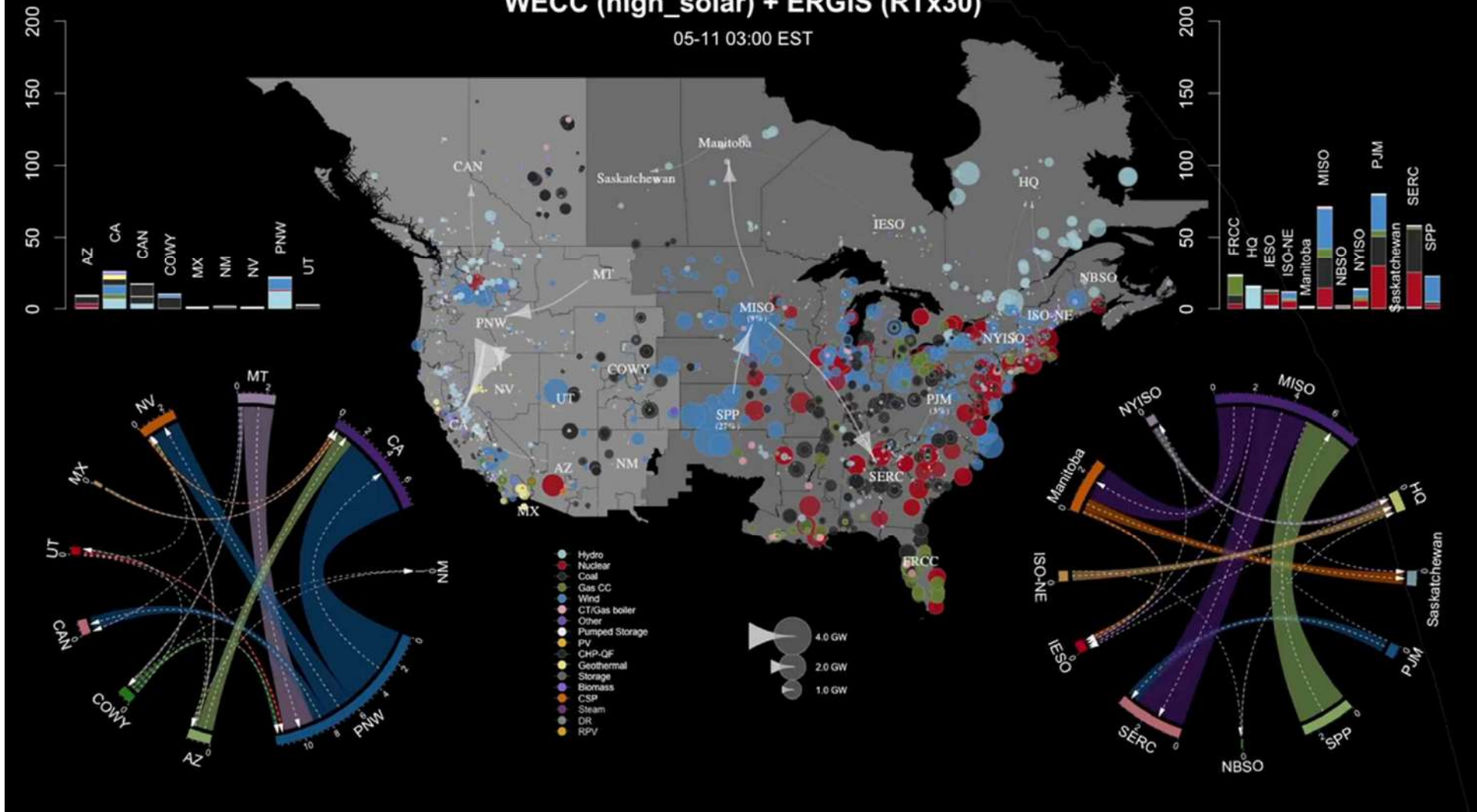
	Public Outreach	Planning	Market Rules	Expanded Access	System Operations
At LOW RE Penetrations	Involve public stakeholders in planning	Evaluate system flexibility, penetration scenarios, transmission needs, and future flexibility needs	Evaluate market design and implications for higher penetrations of RE	Assess renewable energy resources and options for encouraging geographic diversity	Build capacity of grid operator staff; review regulatory changes needed to require advanced forecasting
At MEDIUM RE Penetrations	Communicate to public why new transmission is essential	Regulatory and legislative changes needed to accommodate revised scenario planning, such as laws to support renewable energy zones (REZs)	Ensure that market design and pricing environment aligns with technical needs, such as accessing flexibility, minimizing uncertainty, and managing risk	Make necessary regulatory, market, or institutional changes	Implement grid codes to accommodate high penetrations of variable RE
At HIGH RE Penetrations		Monitor and review effectiveness of actions; revise	Make additional changes to market rules to meet technical needs, such as accessing flexibility, minimizing uncertainty, and managing risk	Ensure broad systems solutions are sought, including smart grid/demand response, storage, and complementary flexible generators	

# INTEGRATION OPTIONS



# WECC (high\_solar) + ERGIS (RTx30)

05-11 03:00 EST



A laboratory setting with several large glass vessels on a dark surface. The vessels contain liquids that glow with vibrant colors: one is bright green, another is red, and others are illuminated with blue and purple light. In the background, three people wearing safety glasses are looking intently at the equipment. The overall atmosphere is one of scientific research and discovery.

# Transforming Energy through Science

NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.