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Renewable Integration Into Power Systems: Challenges and Solutions

8 February 2024 | Technical Topic Webinar

Presented by:

Professor Akhtar Kalam
EIT Academic Board Deputy Chairman

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Agenda

1	Welcome and Introduction
2	DER and market reform due to the presence of solar PV
3	Grid Trends and Drivers
4	Impact of Renewables
5	Systems Issues
6	Summary
7	Conclusion and Q&A

Introduction - Presenter

Professor Akhtar Kalam

BSc, BScEng, MS, PhD, FIET, CEng, FAIE, FIEAust, CPEng, NER, APEC Engineer, IntPE(Aus), PEV, MCIGRE, Life Senior Member of IEEE.

Professor Akhtar Kalam is currently working as an Academic Director at Texila College of Australia. He has been at Victoria University since 1984 and recently associated with the Institute for Sustainable Industries and Liveable Cities. He is the Editor in Chief of Australian Journal of Electrical & Electronics Engineering. Further, he has Distinguished Professorship position in many national and international institutions.

He has been recognized internationally and nationally for his research. He is regularly invited to deliver lectures, work on industrial projects, and examine external theses overseas. Professor Kalam is a registered Professional Engineer in the state of Victoria (PEV), Fellow of EA, IET, AIE, a life Senior Member of IEEE, NER, APEC Engineer, IntPE (Aus) and a member of CIGRE AP B5 Study Committee.

Customer Perspective

“I have the capacity and quality of electricity supply I need.”

“I can choose from a range of products including participating in energy management when it suits me.”

“We understand and have control of my electricity use to manage our costs.”

“We can choose the electricity supply mix that suits me including the use of renewable energy.”

“DNSP has visibility and control of our network.”

“DNSP uses an optimal mix of traditional and innovative network products to minimise the cost to operate our network and provide electricity to our customers.”

Distributed Energy

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Distributed Generation

- Enable **integration of renewables** to **maximise their benefit** for energy and **demand reduction**
- **Mitigate the barriers and issues** (voltage and power quality) to **enable customer connection** of **distributed energy**
- Enable **influence over policy** and standards.

LV StatCom

Grid Smart PV

Voltage Reg.

Energy Management

- Energy and **peak demand reduction**
- Facilitates renewables and **customer choice**, load knowledge and **control (energy use and cost)**
- **Extends the life** of aged and stressed networks
- Mitigates the barriers to **load control** including **customer acceptance**.

AutoDR

Res EMS / HAN

EV Charging

Distributed Storage

- Peak **demand reduction**
- **Reliability** and **power quality improvement**
- Facilitate renewables and **customer choice**
- **Extends the life** of aged and stressed networks.

Grid

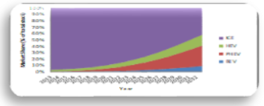
Centralised

Residential

Electric Transport

- Gain knowledge of **use and charging of EV** and its network impacts
- **Mitigate impacts and maximise opportunities**
- **Boost network energy use without peak demand**
- Influence community awareness, understanding and norms and **public policy and standards**

Customer Charging



EV Uptake and Impacts

Distributed Energy Resource Trends

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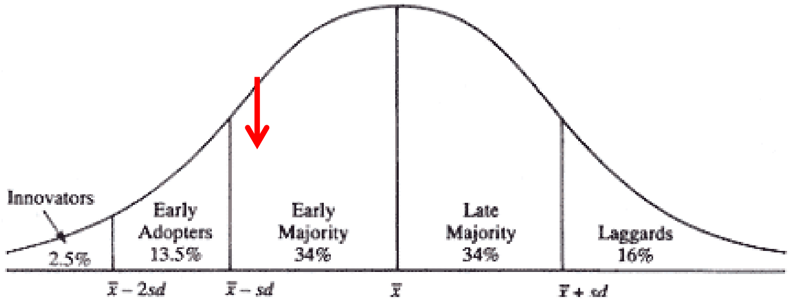
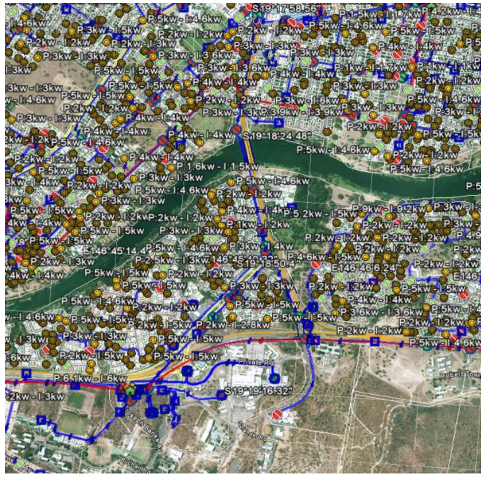
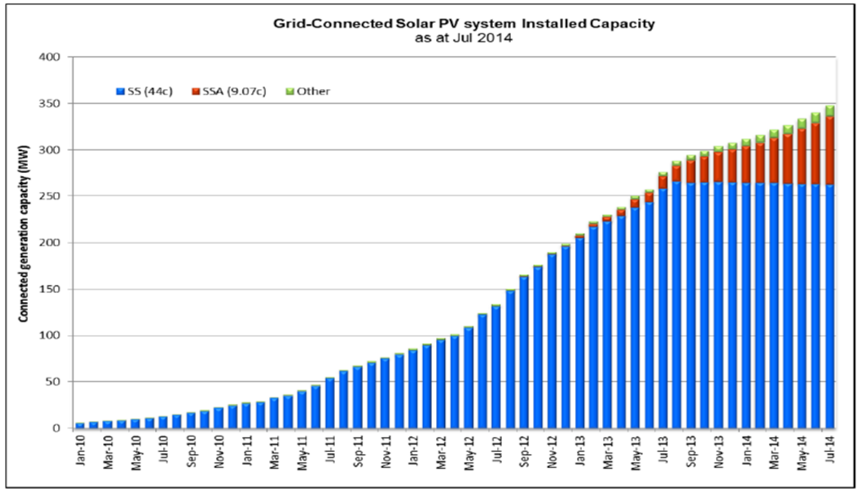
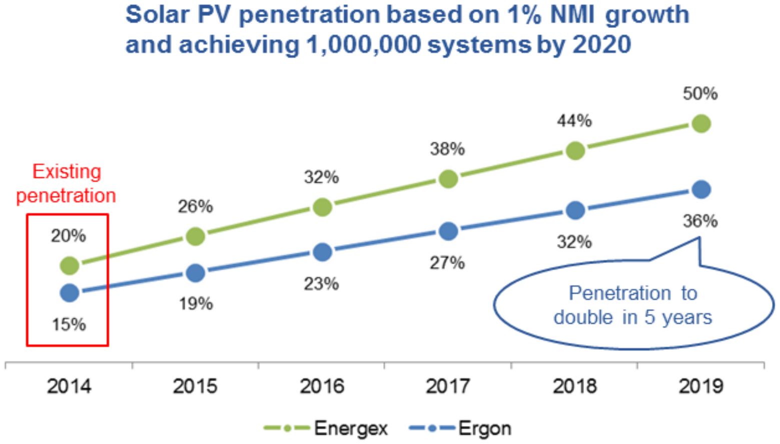
Many residential solar @ ~25% detached housing … past the tipping point

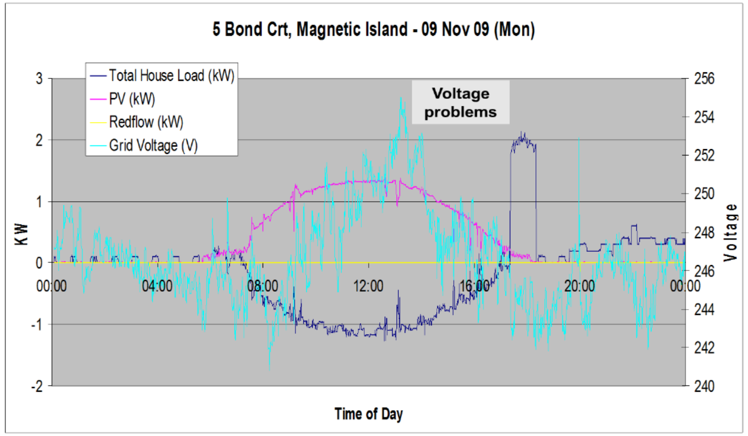


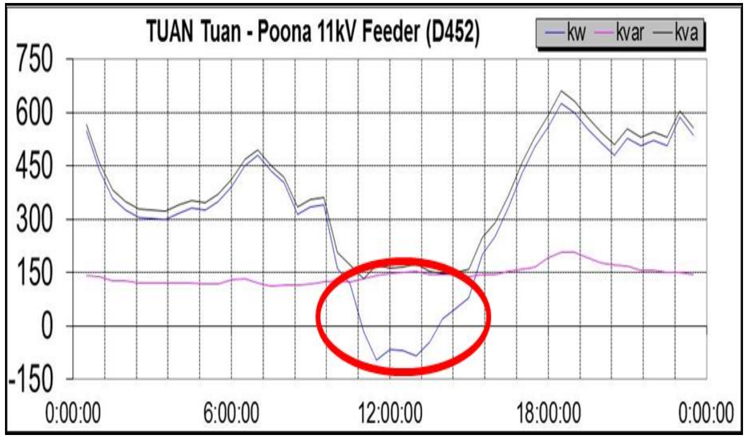


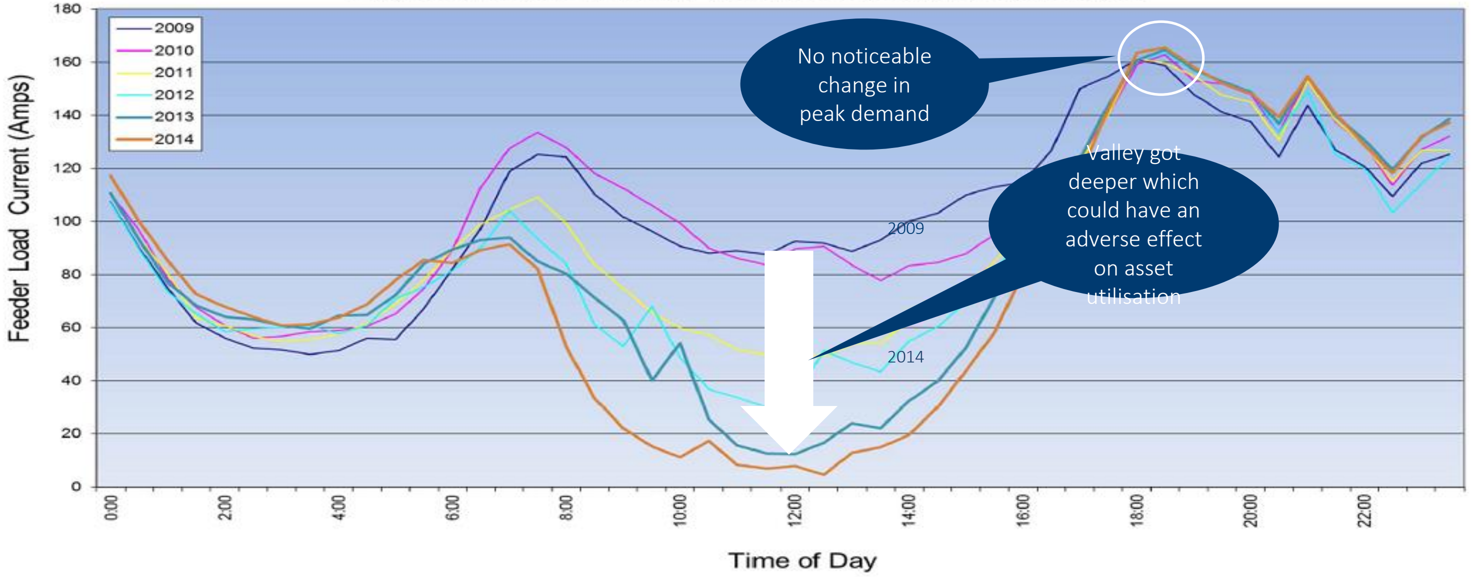




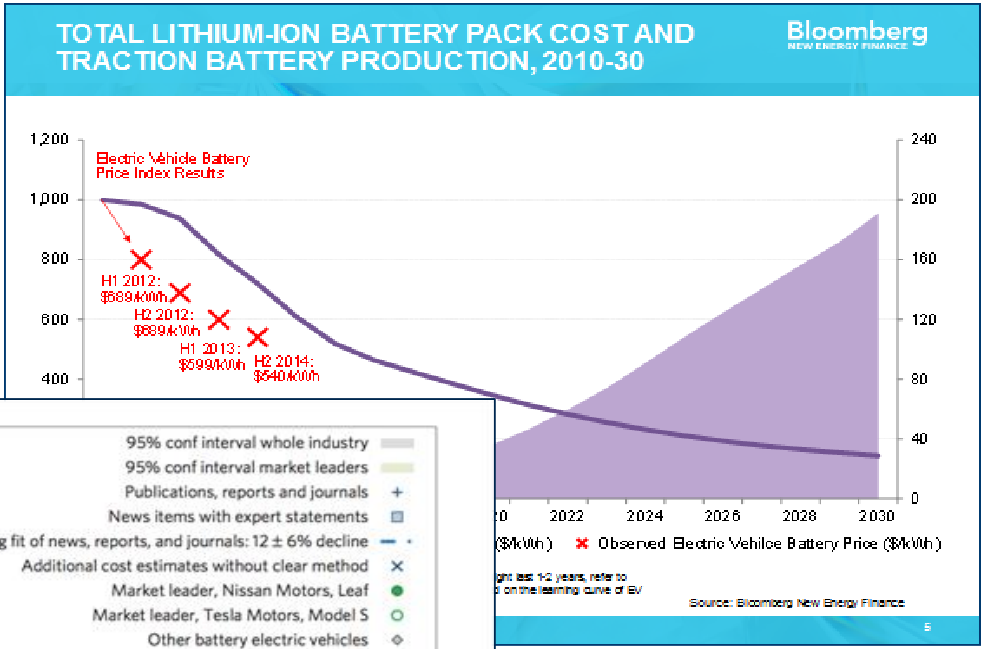
Solar - Impact of Solar PV on a Residential Feeder

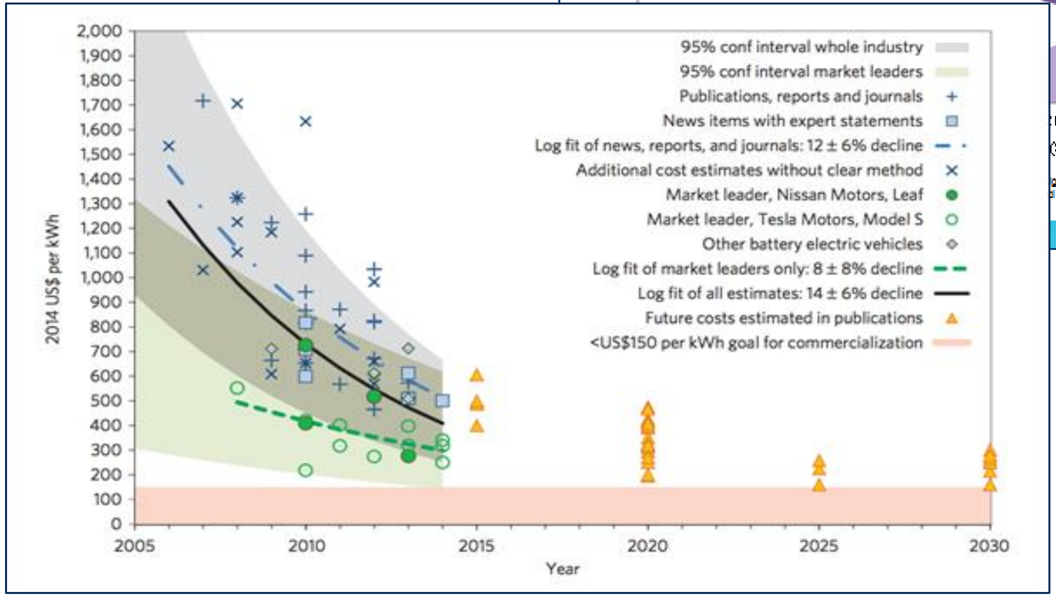






Distributed Energy Resource Trends

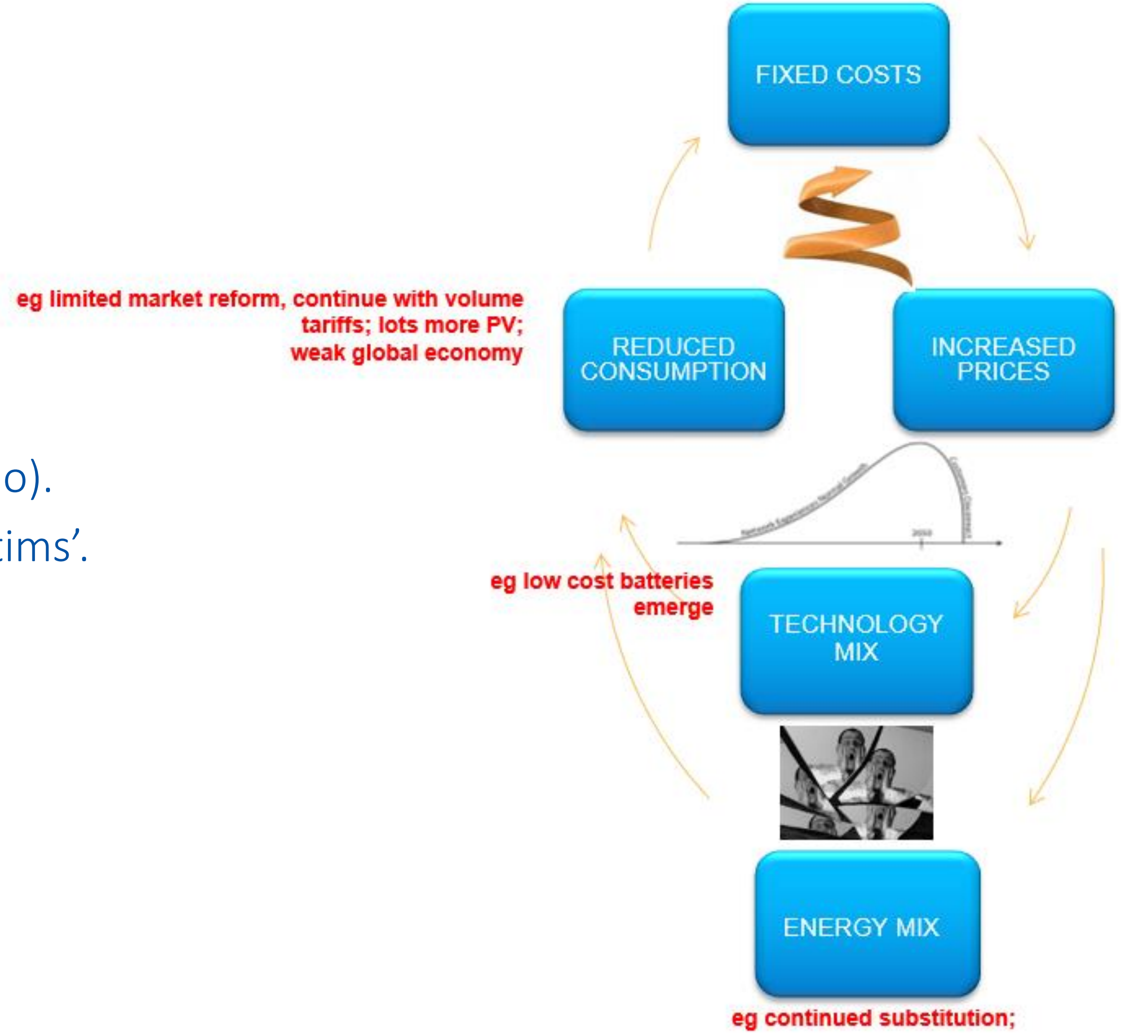




The Need for Market Reform

- New utility businesses emerge (regardless of what we do).
- The ‘great escape’ for some but others are ‘trapped victims’.
- We all pay …
  - Continued investment in the network
  - Limited development of new markets and economy
  - Significant customer / community (asset) value at-risk / loss

<u>**A LOT OF PAIN FOR EVERYONE**</u>



The Need for Market Reform

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- ‘New electricity utility’ businesses thrive (facilitated by ‘old’ utilities).
- Most/more ‘winners’.
- Optimal outcomes:
  - Invest in the customer.
  - Network enabled markets and economic development
  - Customer/community value preserved.

<u>**STILL A PAINFUL TRANSITION (BUT A VERY INTERESTING PROSPECT)**</u>

Implications for Distribution Utilities

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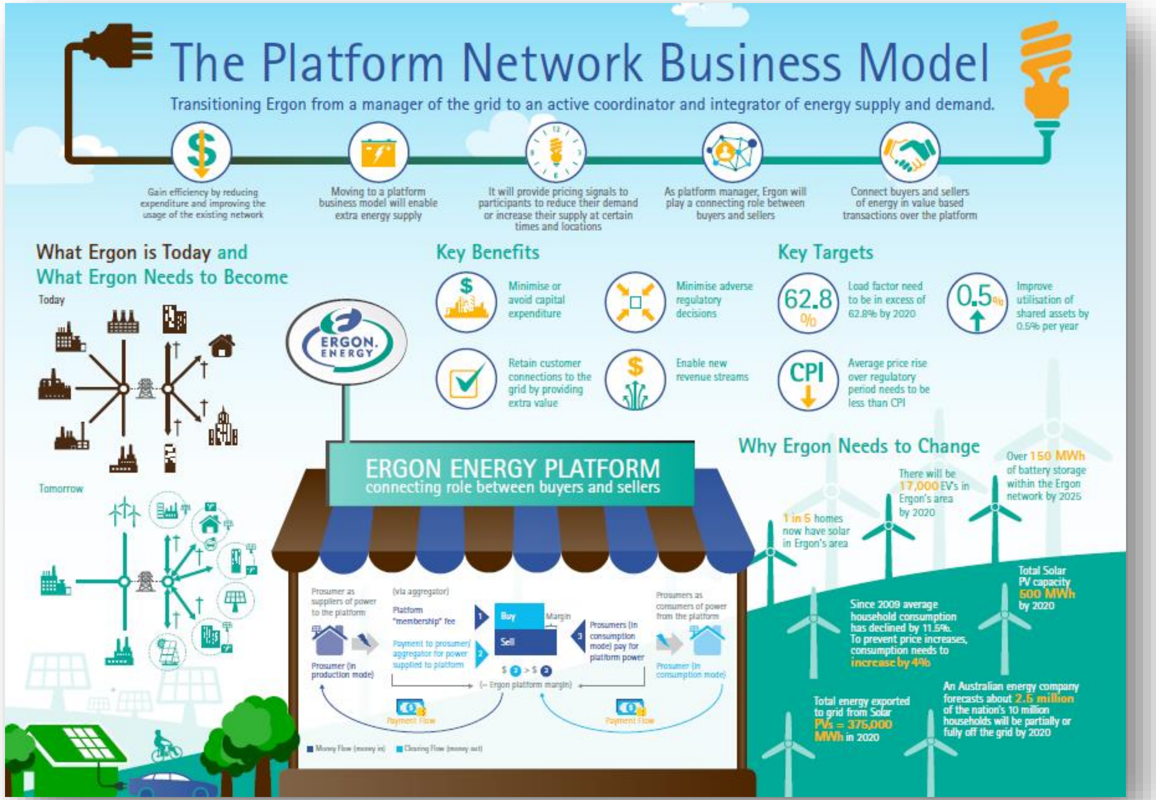
- Growth in DER primarily in MV/LV segments
- 2-way load flows challenges traditional capacity management/augmentation
- LV Control Room – Who manages the power flows?
- Changing investment model – focus on MV feeders and LV rather than ZS and sub-transmission
- Network Load Control – Unlikely to be DNSPs in the future
- Definition of a micro grid
  - Home
  - Street
  - LV Segment
  - MV Feeder



DNSP Energy Platform – Connecting Buyers and Sellers

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KEY GRID INTEGRATION ISSUES

What is Greening the Grid?

Greening the Grid provides technical assistance to energy system planners, regulators, and grid operators to overcome challenges associated with integrating variable renewable energy to the grid.

Grid Trends and Drivers

Growing Dependency on Reliable Supply

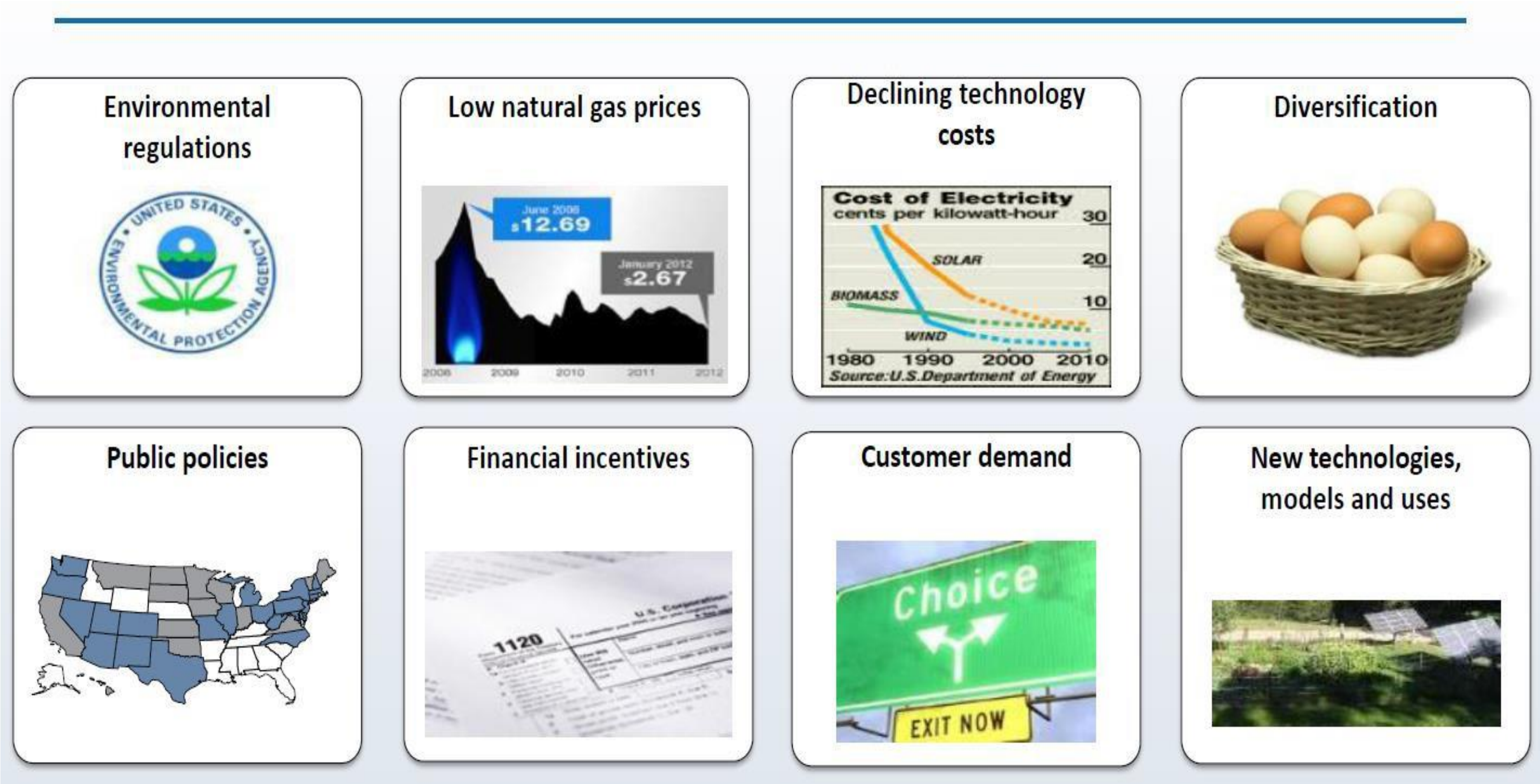
Infrastructure is more prone to failure

Increasing Environmental Requirements

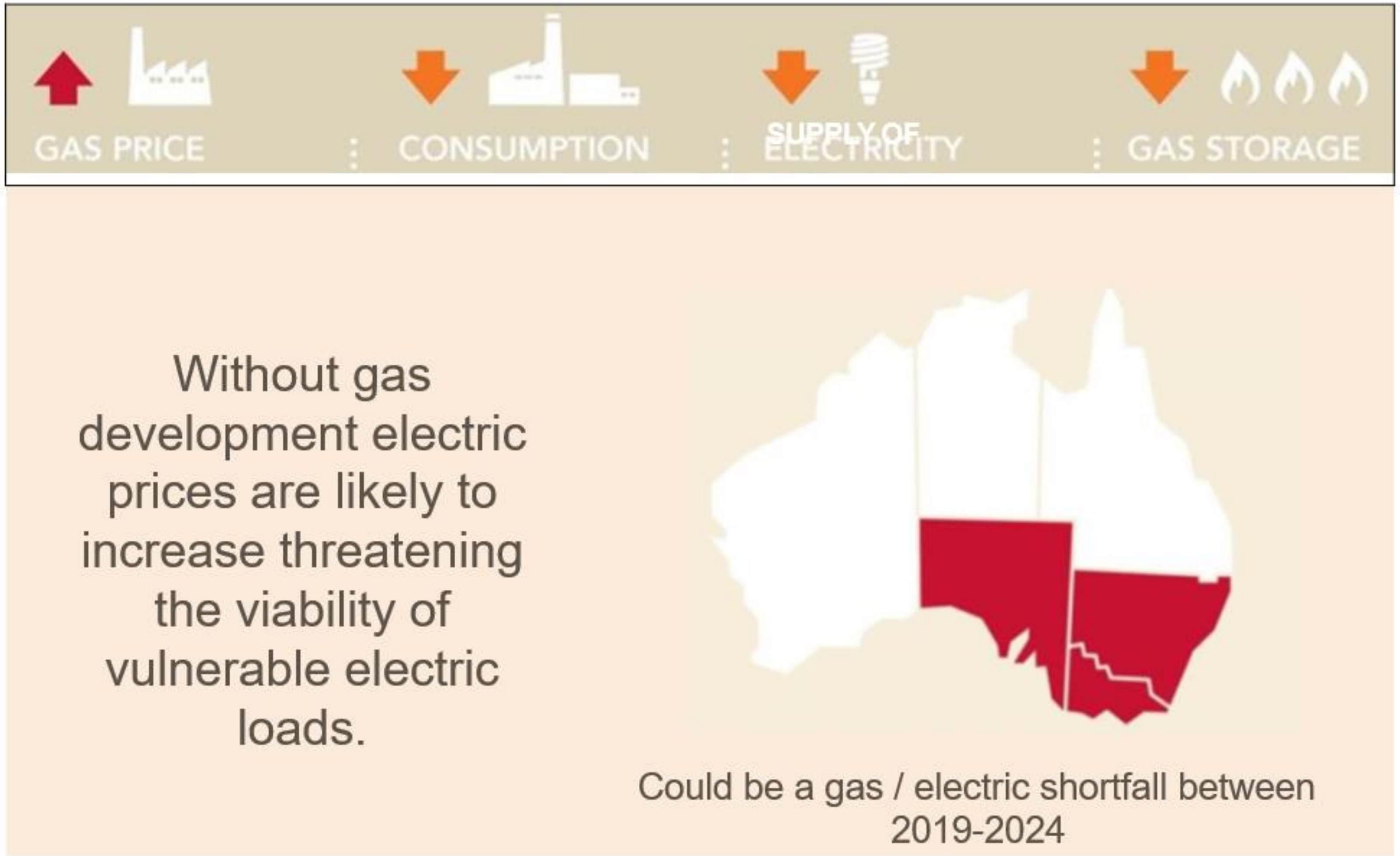
Escalating Security Concerns

Frequent Climatic Vulnerability

Factors Shaping The Clean Energy Transformation



Australia Projects Energy Shortfall



Hot Issue: Bushfires and Powerlines

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“The role of powerlines in bushfires is raising some pressing issues of climate change adaptation.”

The Conversation, September, 2012

Compelling Evidence of Rapid Climate Change

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Rising Sea Levels

Global sea level rose about 8 inches in the last century.

Ocean Acidification

Surface ocean acidity has increased ~30% from added CO_2 in the atmosphere: the upper layer absorbs ~2 billion more tons per year.

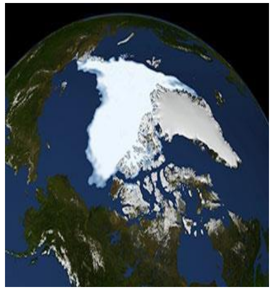
Rising Global Temp

Average surface temp has risen about 2°F (1.1° C) since the late 19th century, driven largely by increased CO_2 and other human-made emissions.

More Extreme Events

High temperature events in US has been increasing; low temperature events decreasing, since 1950.

Less Ice, Glaciers, Snow



The extent and thickness of Arctic sea ice has declined rapidly. Glaciers are retreating and the amount of snow in the Northern Hemisphere has decreased.

Warming Oceans

The top 700 meters (about 2,300 feet) of ocean showing warming of 0.302° F since 1969.

Why is grid integration an important topic?

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Introduction

Trends:

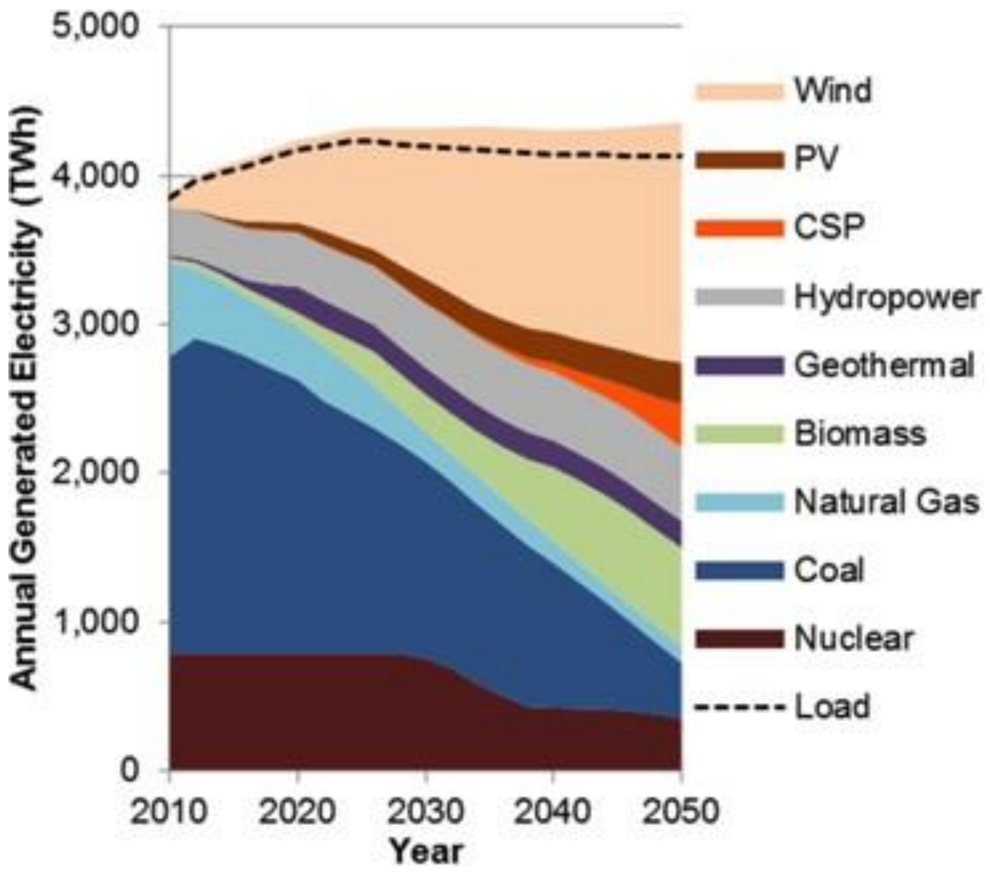
Increasing energy demand Urbanization

Climate change mitigation targets

Need for grid modernization

Every power system has characteristics that promote and inhibit integration of variable RE

Grid integration is the practice of developing efficient ways to deliver high penetration levels of variable RE to the grid



Source: Renewable Energy Futures" 2012

Integrating wind and solar energy resources requires an evolution in power system planning

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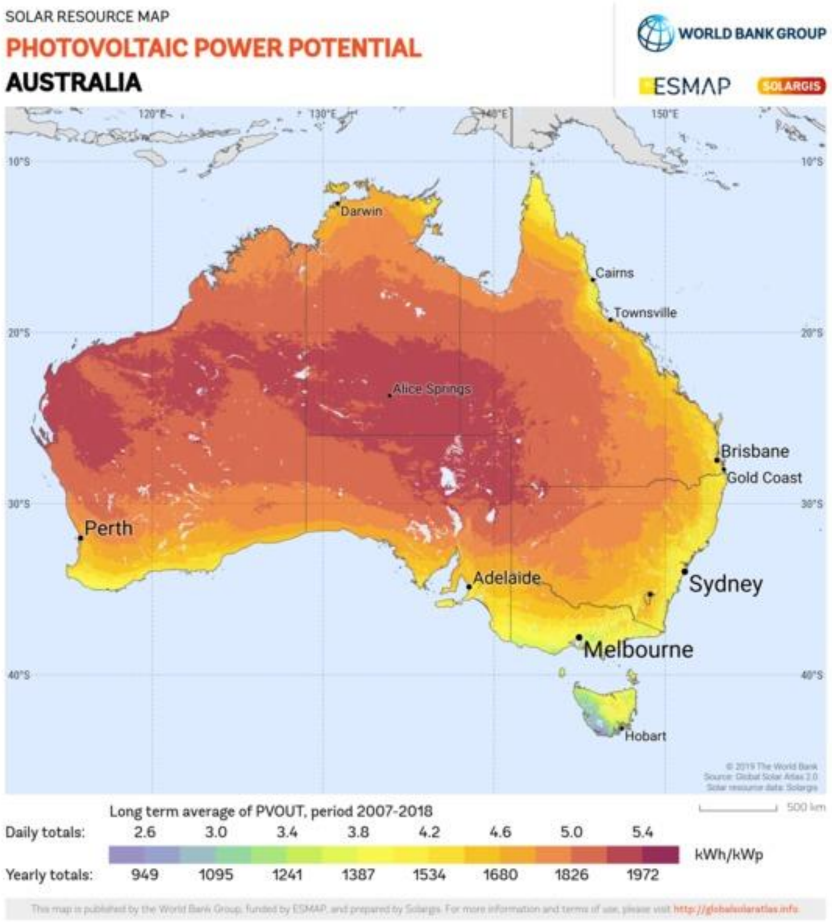
RE is variable, uncertain, and geographically dispersed



…raising new considerations for grid planning and operations

Balancing requires more flexibility

Existing thermal assets used less frequently, affecting cost recovery

More reserves

More transmission, better planning needed

Voltage control, inertia response come at added cost

Changes How We…

Make Energy:
- More distributed supply
- Accommodate growth

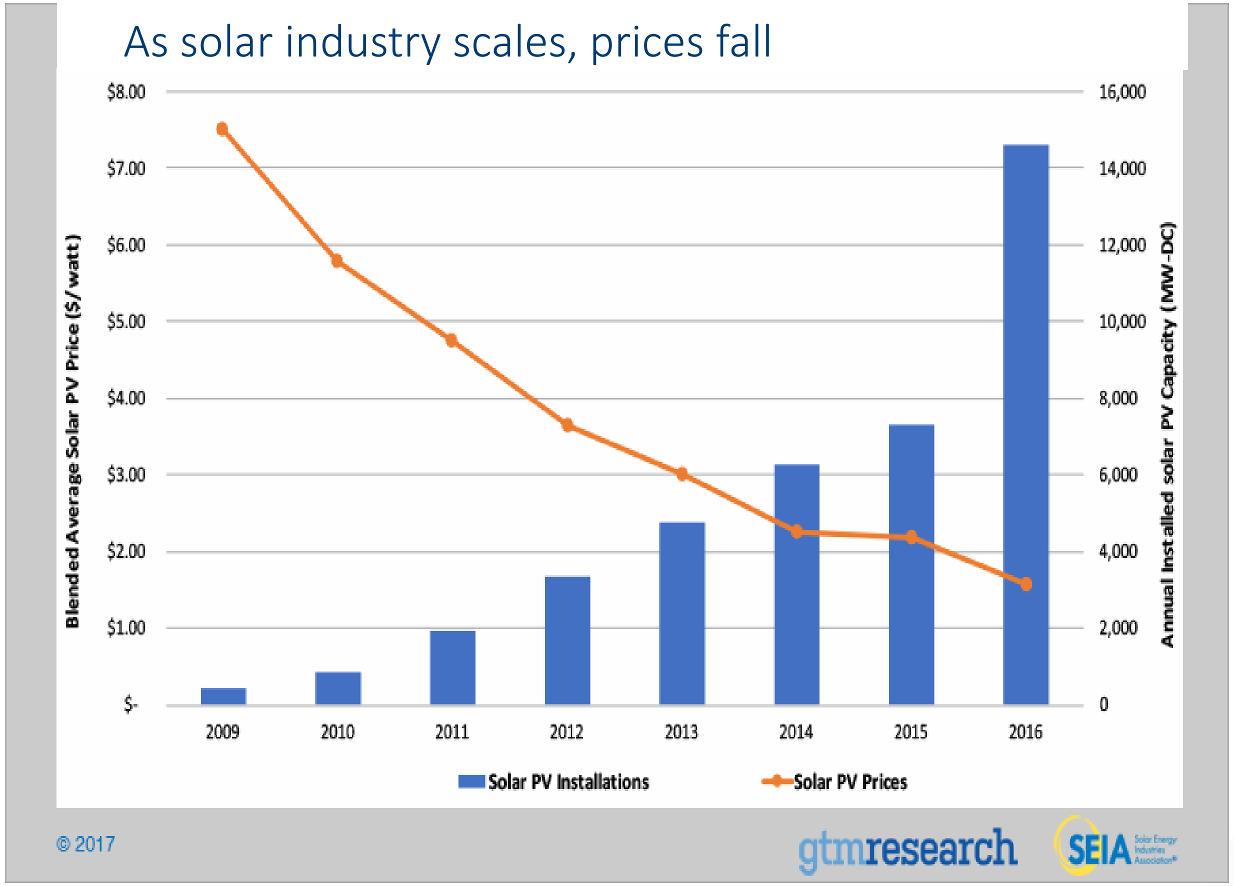
Move Energy:
- Flexible, reliable, resilient
- Increase visibility, controls

Use Energy:
- Integrate end-use activity
- Empower customers

Technologies:
- Energy storage
- Power electronics
- Distributed intelligence
- Adaptive protection
- Layered architecture
- Self-diagnostic, healing
- Data, cyber, analytics

Source: IEEE GridVision 2050

Technology Changing how we "Make It"

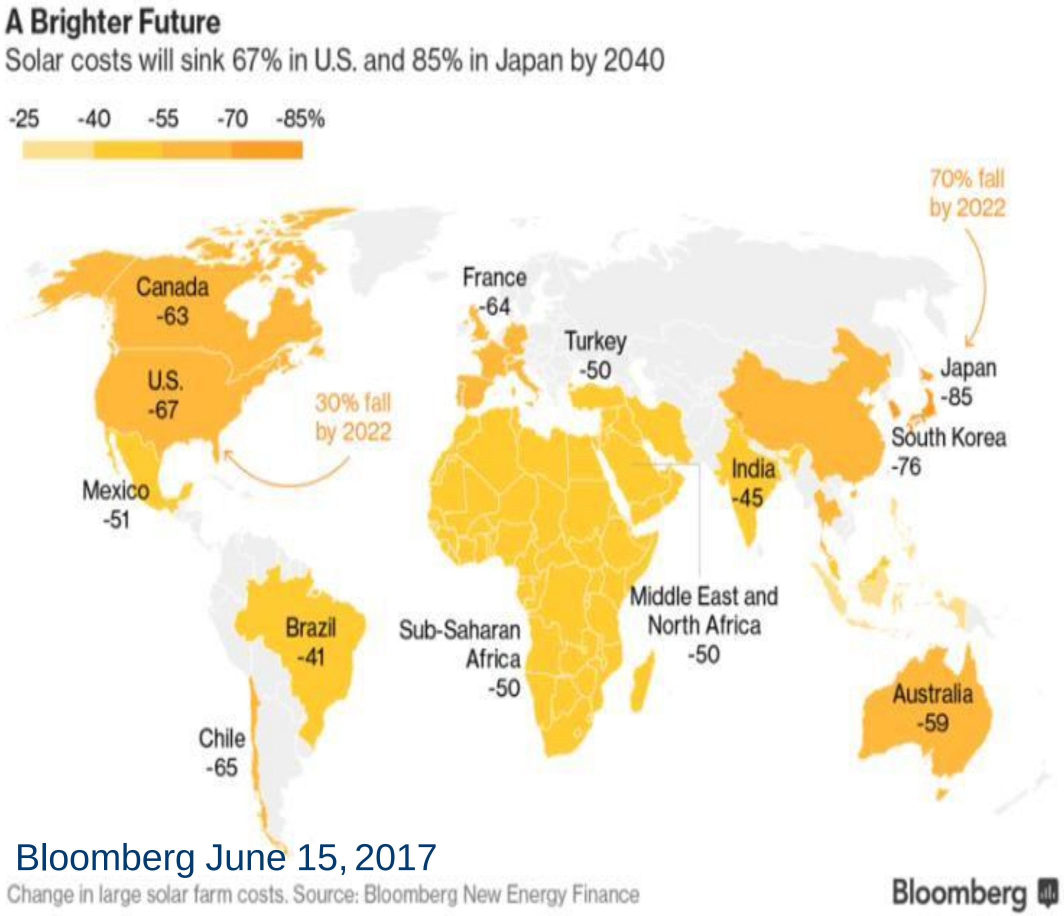


More Electric Vehicles are Coming

Incremental capacity is coming from edge-of-grid

“Make It”: Solar is at Parity and Dropping

Deutsche Bank: March 10, 2015

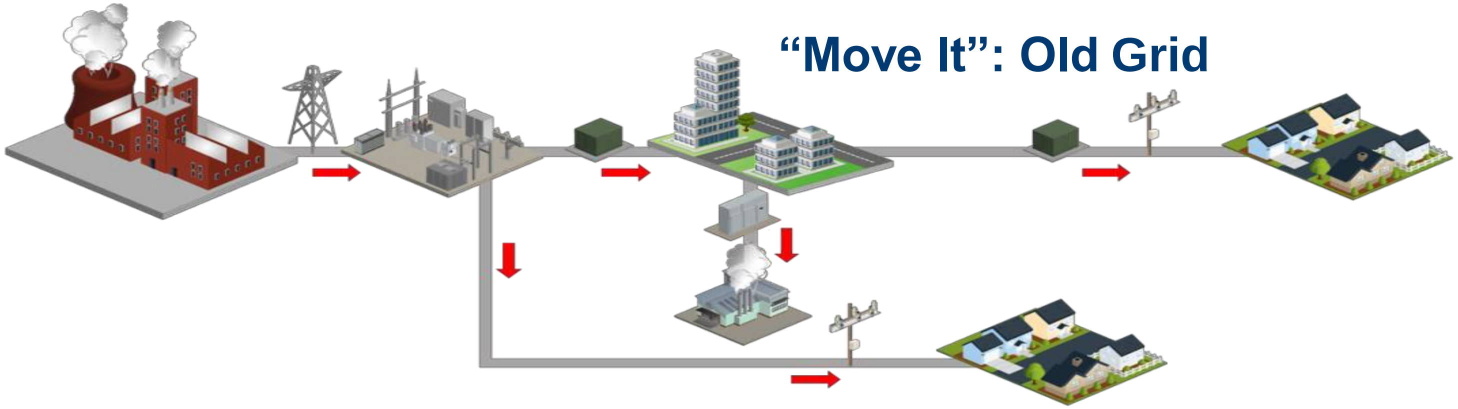


Bloomberg June 15, 2017

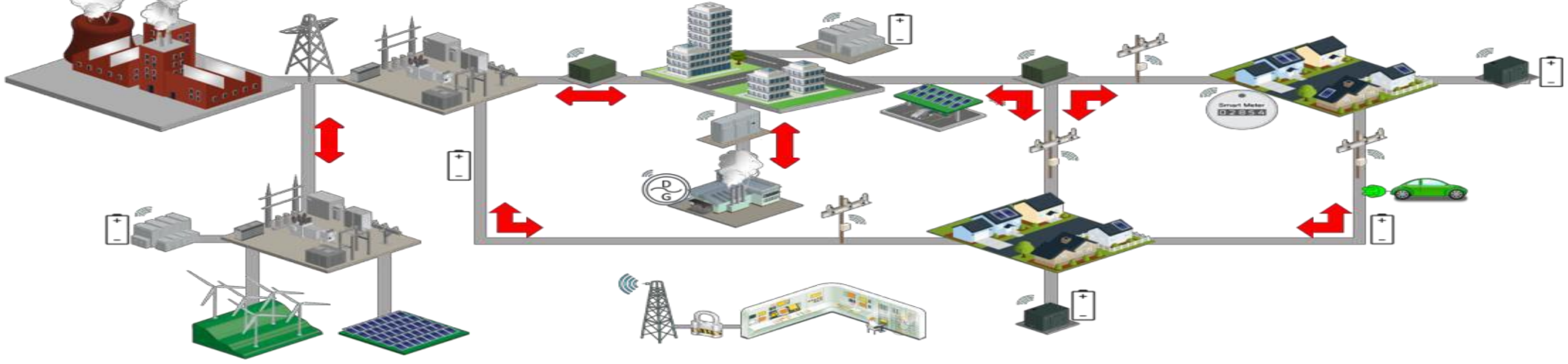
As renewables reach parity, what changes?

Grid Trends and Drivers

“Move It”: Old Grid



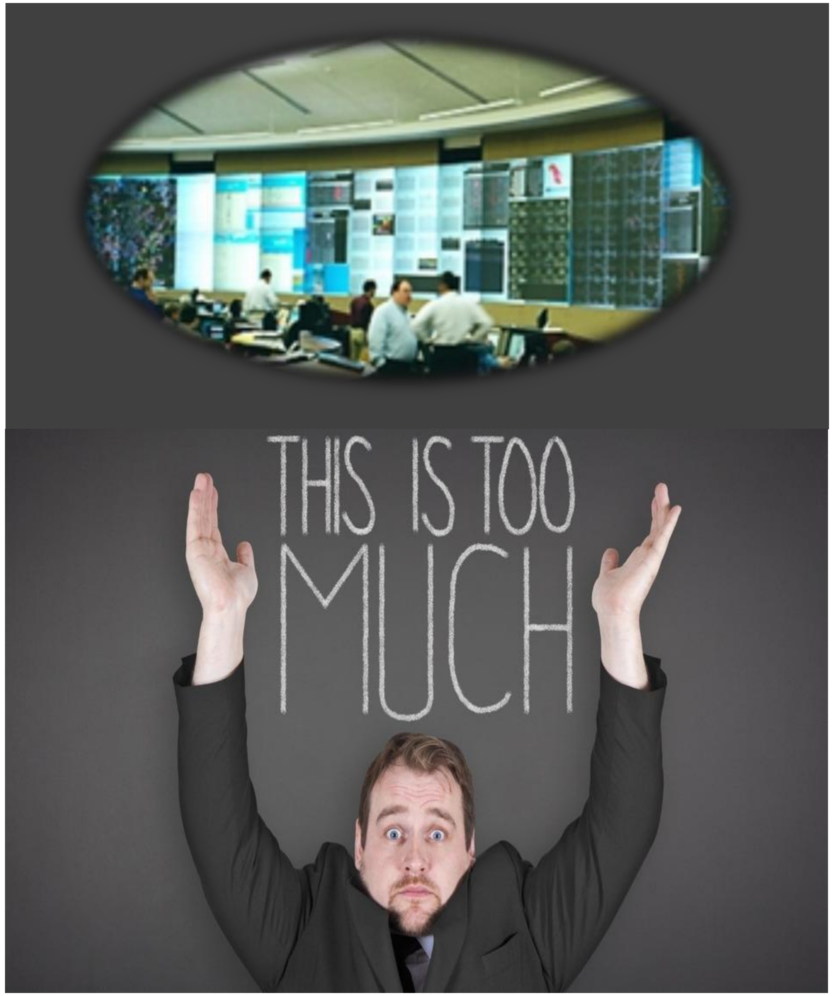
“Move It”: Modern Grid



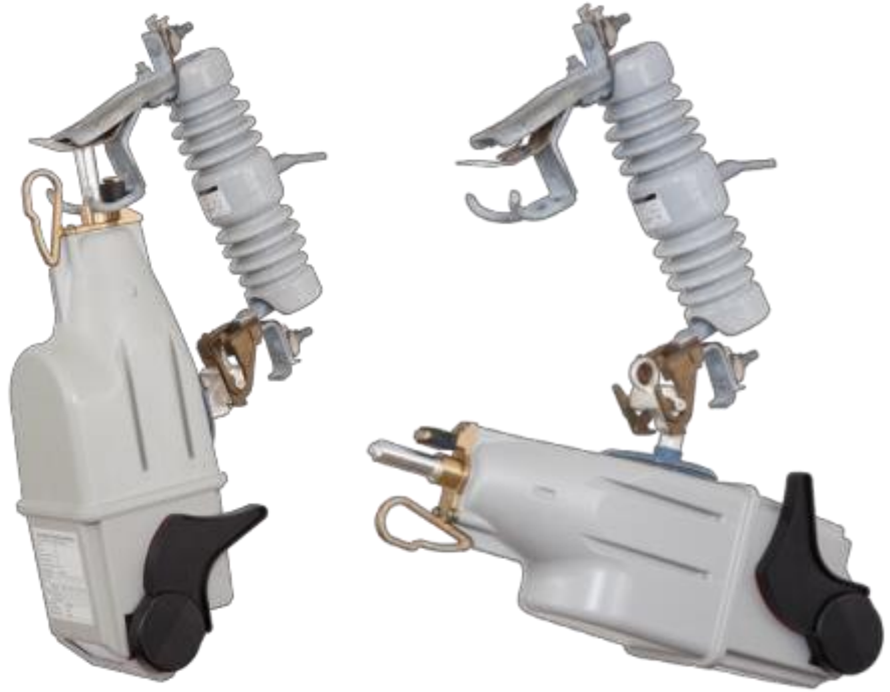
Bi-directional power flows is driving circuit design changes, new grid components and control systems

Challenges to "Move It" With Central Control

- Too much to manage centrally:
  - Multi-directional power flow
  - DER inter-connections
  - Dynamic operations
  - System balancing
  - Microgrids
  - Wild voltage swings



Distributed Intelligence is Key



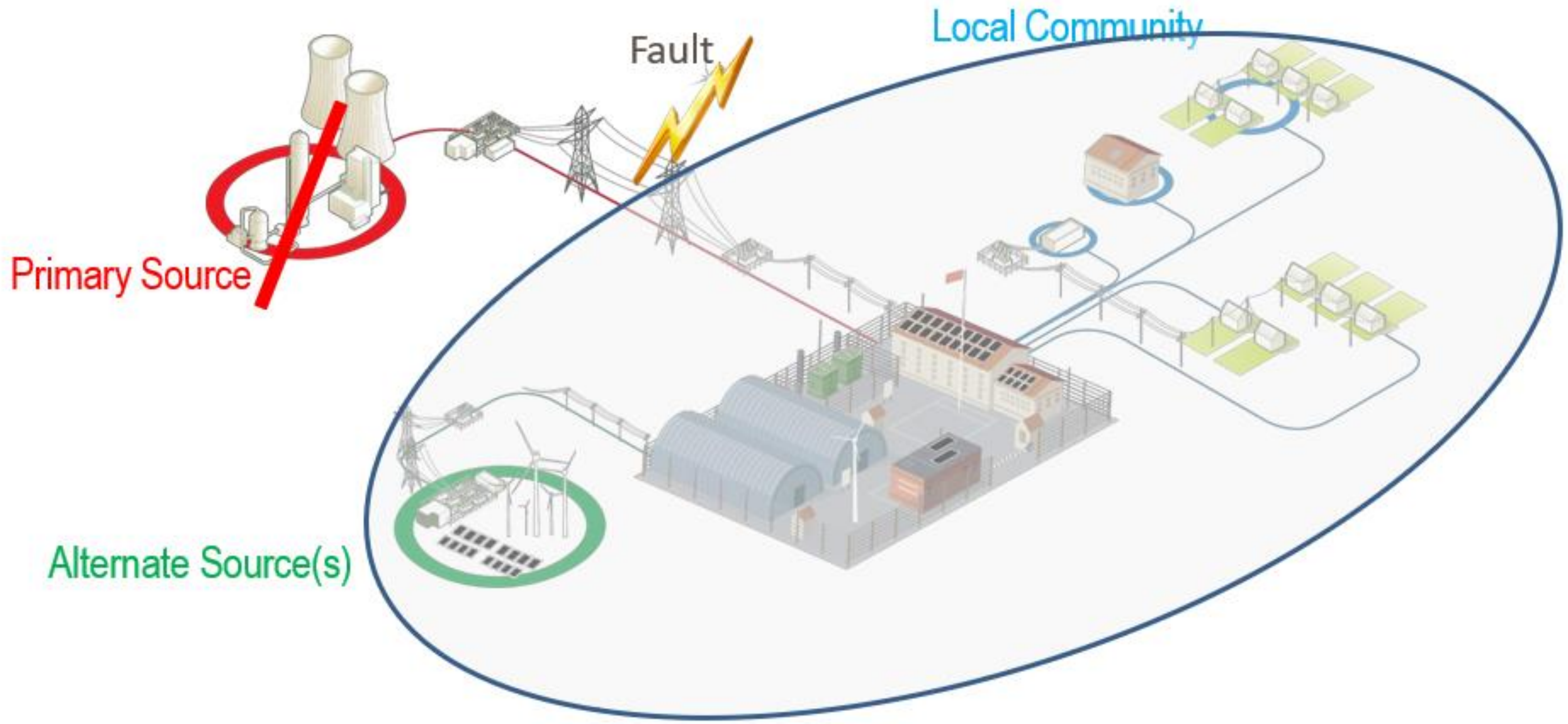
TripSaver® II Cutout Mounted Recloser

- Single phase
- Avoid truck rolls
- Minimizes momentaries

IntelliRupter® PulseCloser

- Interrupt fault current
- Segments load
- Two-way sensing
- Adaptive protection
- Detects power quality events

"Use It": Emerging Microgrids



"A group of interconnected **loads** and **distributed energy resources** with clearly defined electrical boundaries that acts as a **single controllable entity** with respect to the grid and can connect and disconnect from the grid to enable it to **operate in both grid-connected or island mode."**

Microgrid Advantages

1. Greater reliability and resiliency
2. Greener power
3. Modernized infrastructure
4. Increased security
5. Cost savings
6. Bushfire Mitigation

The traditional utility model is changing to include stand- alone power systems

Distributed Energy Resource (DER) Considerations

- Inverter based (harmonics)
- Intermittent, uncertain output
- Grid interconnection codes
- Capable of being observed, dispatched
- Provide reliability services
  - Voltage support
  - Frequency response
  - Ramping
  - Inertia for bulk power operations
- Safeguard against cyber attacks

Distributed Energy Resources (DER)

Storage

Storage technologies – general considerations

- Electrical storage
  - Electrolyte type batteries – Lead Acid, Lithium Ion, etc
  - Flow batteries – Vanadium Redox, Zinc Bromide, etc
  - Capacitors and supercapacitors
- Magnetic storage
  - Superconducting magnetic energy storage (SMES)
- Mechanical storage
  - Flywheels
  - Compressed air
  - Pumped hydro storage

Prof Geza Joos McGill University Canada Role of Storage CIGRE Paris 2008

Storage

Background and justification

- The new electricity generation context
  - Increasing the penetration of renewable energy resources, mainly wind and solar, as well as hydro power and biomass
- The issues
  - Managing the intermittency of wind and solar energy, so that these resources can be incorporated into to the base load generation
  - Managing large load fluctuations – supplying peak consumption
- The solution
  - Storing energy from renewable sources and from the grid in a form recoverable as electrical energy when required
- The constraints
  - Technologies – equipment availability and life cycle
  - Capital and operating costs (losses, maintenance and others)

Prof Geza Joos McGill University Canada Role of Storage CIGRE Paris 2008

Storage

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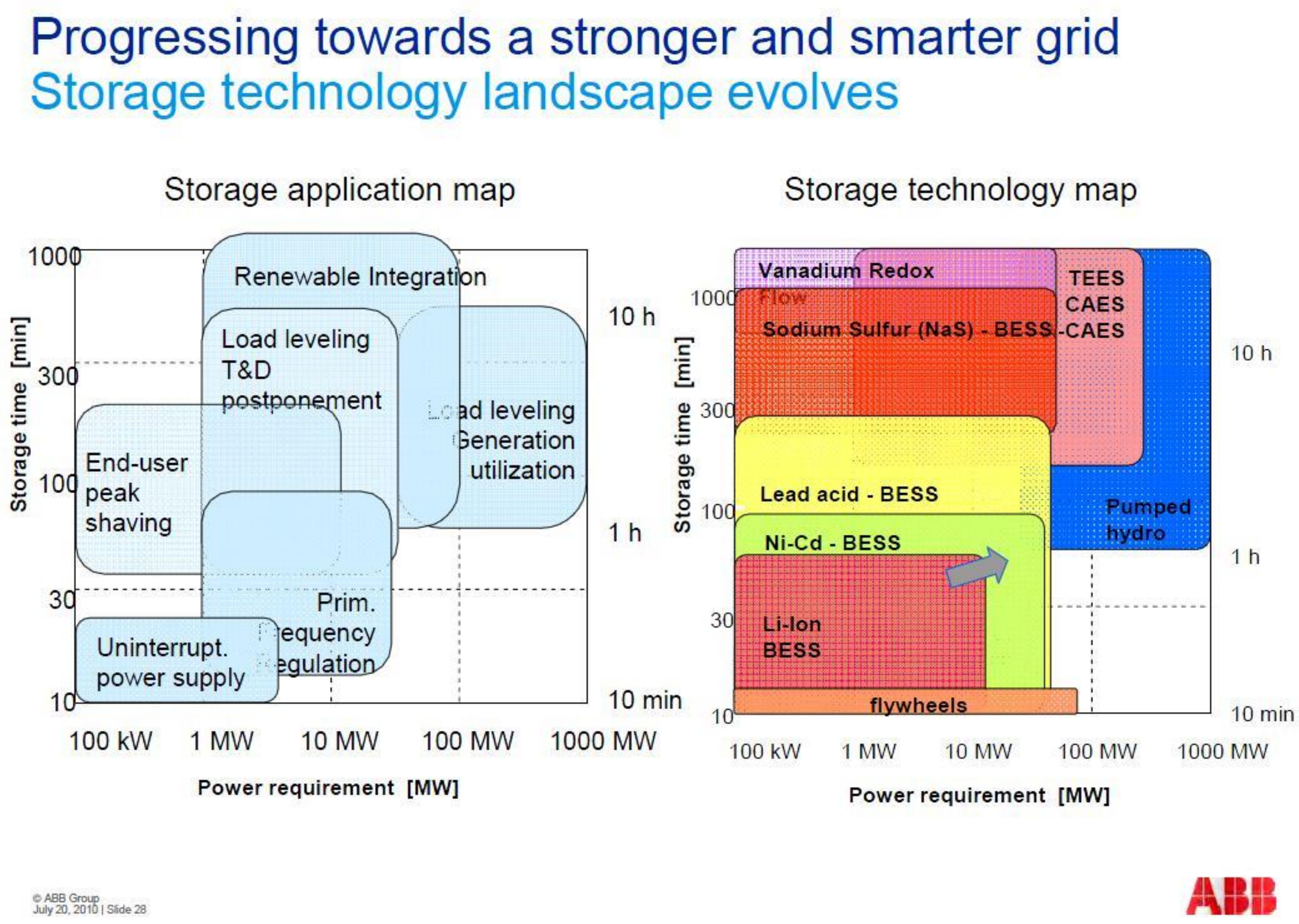
Benefits of storage

- Accommodating intermittent generation - allows it to operate at peak power and efficiency by storing surpluses
- Ability to dispatch energy during times of peak demand – peak load management
- Ability to supply peak demand locally and reduce transmission line demand (avoid transmission line congestion)
- Ability to provide voltage support, voltage regulation (voltage sag compensation, flicker) and power factor correction
- Ability to provide other ancillary services – frequency regulation, black start, reactive power
- Possibility of islanded operation
- Ability to perform arbitrage on electricity prices – electricity markets

Prof Geza Joos McGill University Canada Role of Storage CIGRE Paris 2008

Storage



Source:
CIGRE Paris Session 2010
Terwiesch ABB Keynote Session

Storage is Important

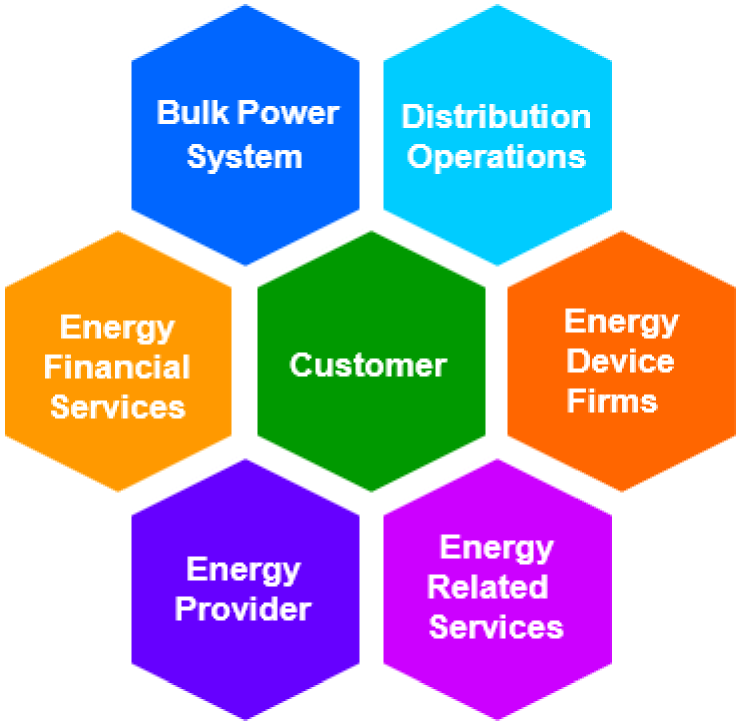
- Synchronize sources
- Smooth transition to/from utility source
- Manage intermittency
- Minimize reverse power flow, maintain voltage
- Store output and release coincidental with local load

Energy Storage - Solar Hybrid Project

Energy Storage – Wind Hybrid Project

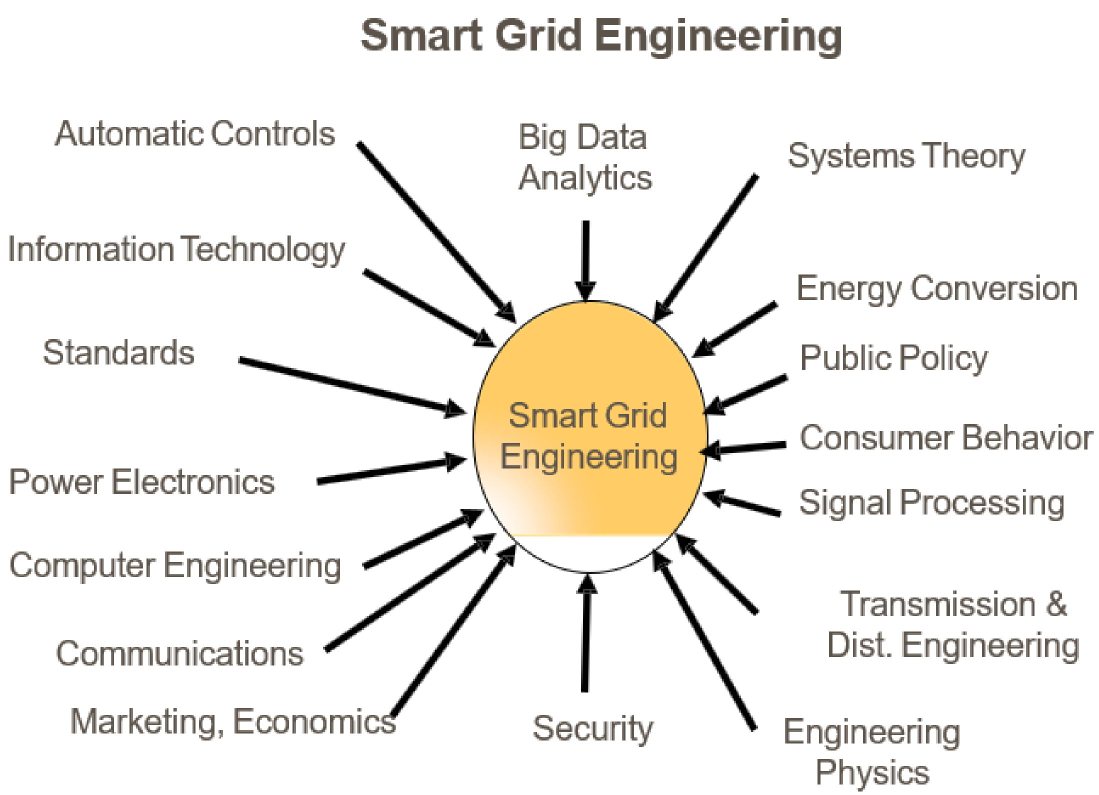
Opportunities Remain

- Regulatory, ownership, price issues
- Re-defining the roles
- Advancing interoperability of everything
- Capability for dynamic operations
- Utilize lots of data with varying time domains
- Develop workforce competencies



Processes and coordination needed across multiple entities

Changing Workforce Needs

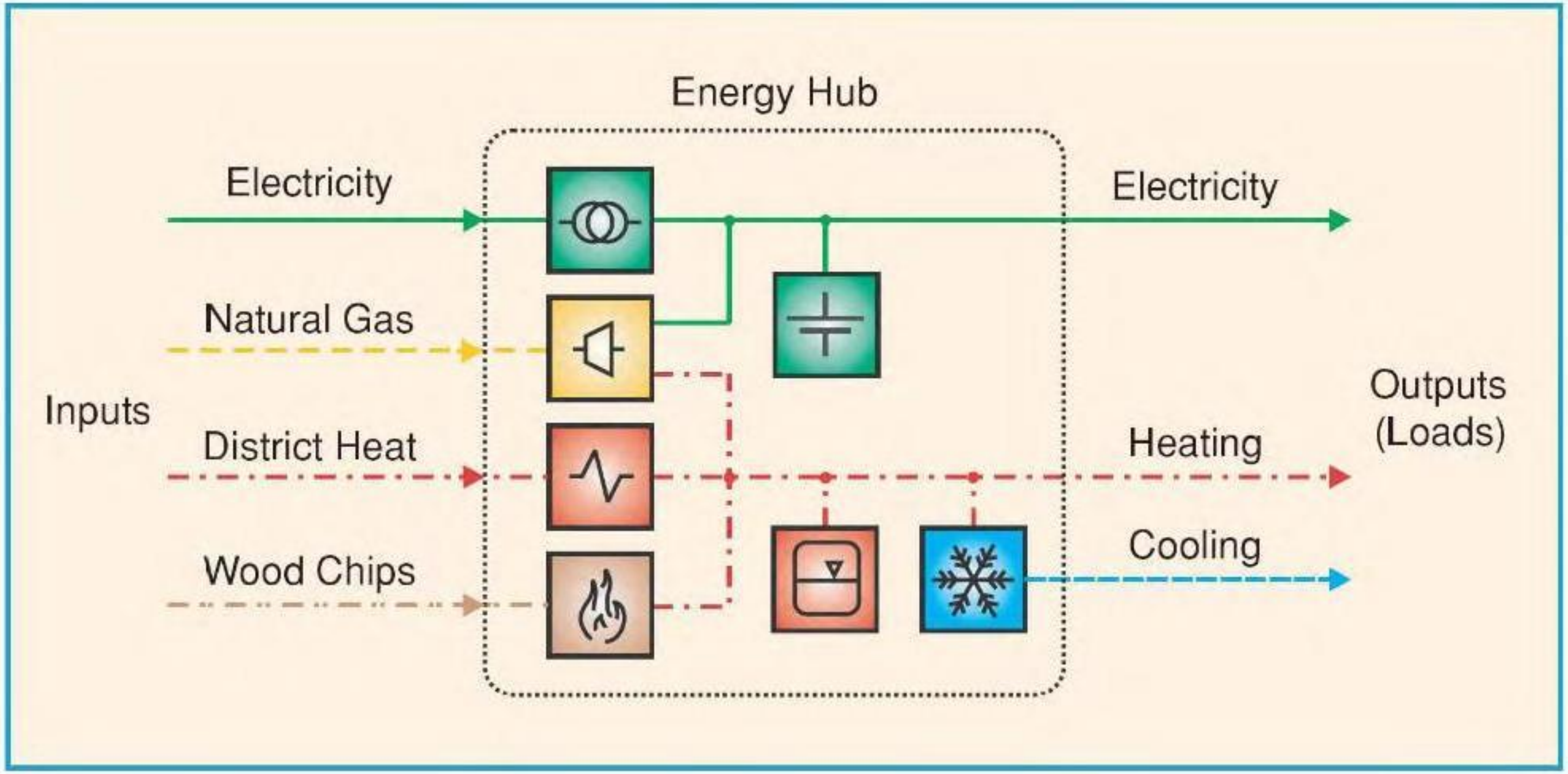


Adopted from Source: Professional Resources to Implement the "Smart Grid"; Gerald T. Heydt and others. 2009 IEEE Power & Energy Society General Meeting

Managing Cyber Security and Resiliency

- Create a cyber framework with accountability
- Create procedural path that parallels IT
- It's a mindset: a series of layered precautions is better than a super firewall

Integration of sources energy hub



Source:
CIGRE Paris Session 2010
Anderssen ETH Zurich Keynote Session

Integration

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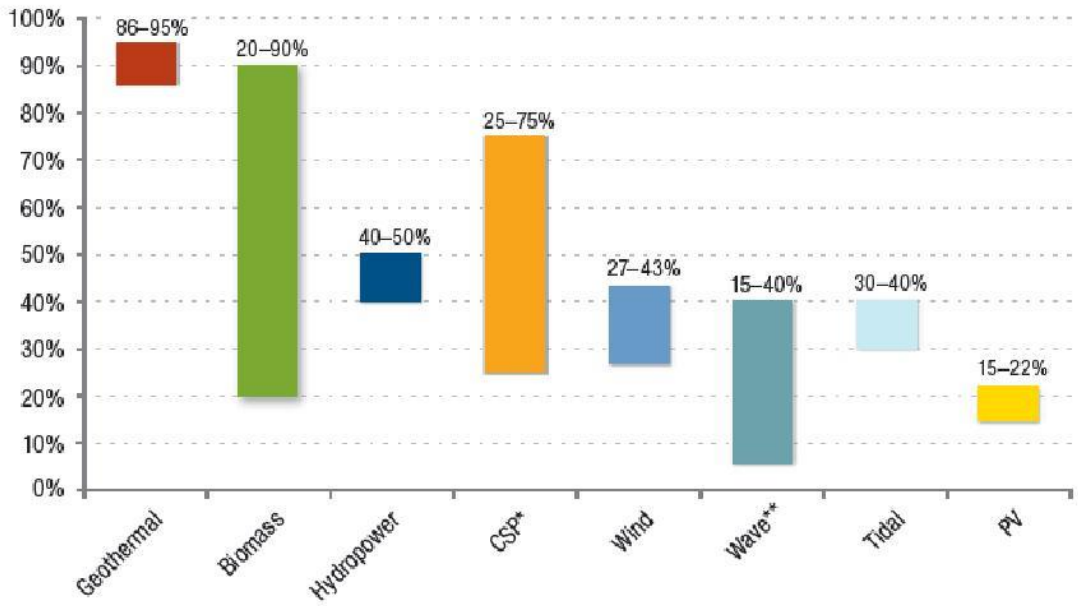
The case for more technology and intelligence
Capacity factors of renewables require stronger transmission



Source: US DoE, Renewable Energy Data Book, 7/2009.

ABB

Source:
CIGRE Paris Session 2010
Terwiesch ABB Keynote Session

Technical issues for renewables

- Maturity of technology
- Network Design
- Network Operation
- Electrical Protection
- Variety of technologies
- Connection costs
- Role of Information Communication Telecoms

Technical issues (cont'd)

- Network Capacity
- Power Quality
- Reactive Power and Voltage Control
  - Impact of weak systems
- Reliability
- Impact/ benefit to security
- Islanding
- Safety

Maturity of technology

- Technology still developing
- “New” and improved technologies
- Power electronics key to most technologies
- Still searching for “magic bullet”
- Many applications still looking for storage
- Super capacitor provides new dimension

Role of ICT

- Research now underway in many countries
- Optimum voltage control based on integral control of all the voltage controllable equipment in the grid
- Technology to utilize EG as a reliable source via centralized control
- Research on the configuration of distribution systems to utilize EG

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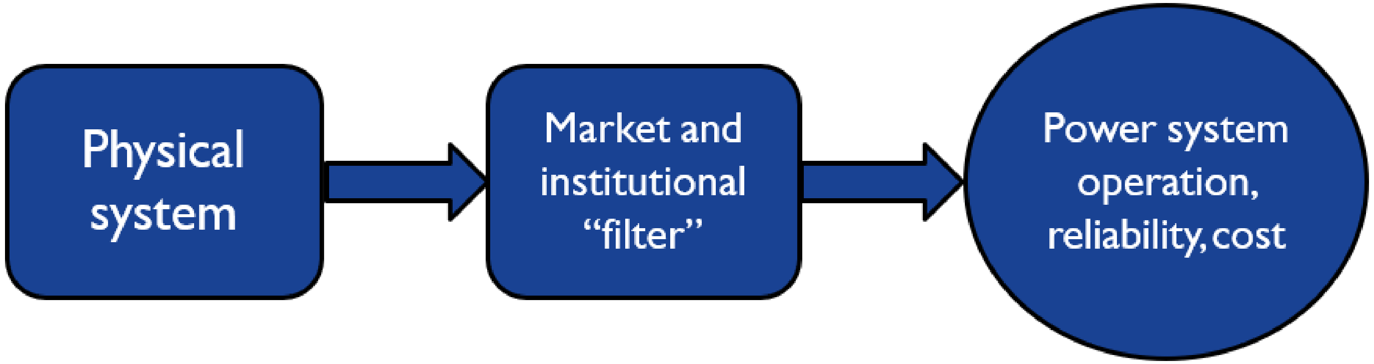
Flexible Power Systems

Flexibility reflects not just physical system, but institutional framework

- Flexibility can come from two sources
  - Physical power system: generators, transmission, storage, interconnection
  - Institutional system: making dispatch decisions closer to real time, better use of forecasting, better collaboration with neighbors

- Power system operation must carefully consider both



Smarter grids require smarter frameworks and markets

"Flexibility" can help address the grid integration challenges

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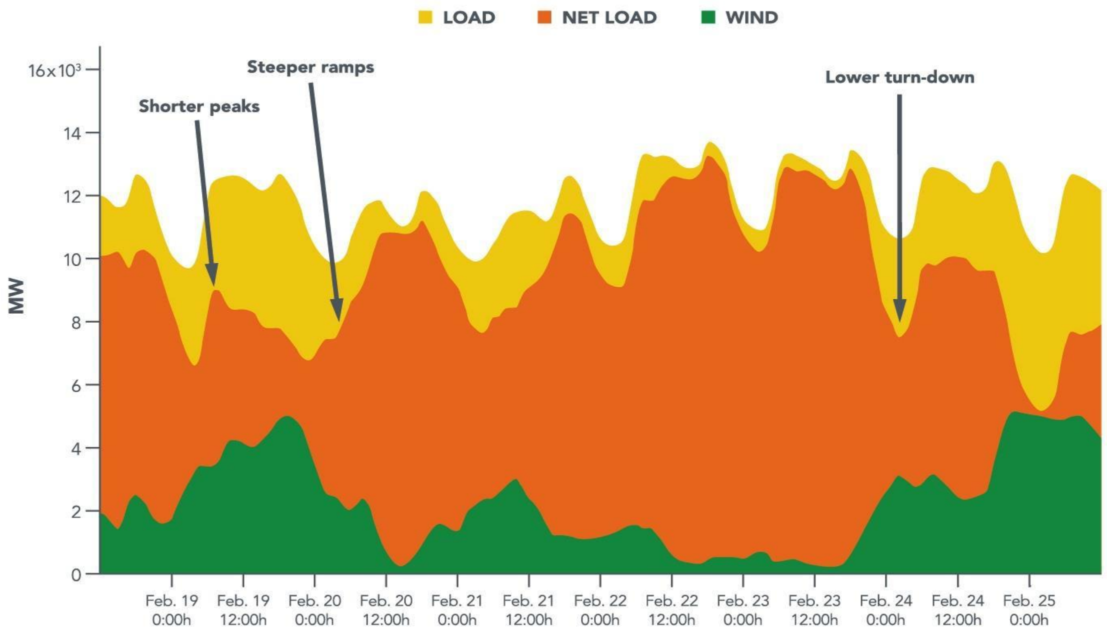
***Flexibility**: The ability of a power system to respond to change in demand and supply*



- Increases in variable generation on a system increase the variability of the 'net load'
  - 'Net load' is the demand that must be supplied by conventional generation unless RE is deployed to provide flexibility
- High flexibility implies the system can respond quickly to changes in net load.

Frequently used options to increase flexibility

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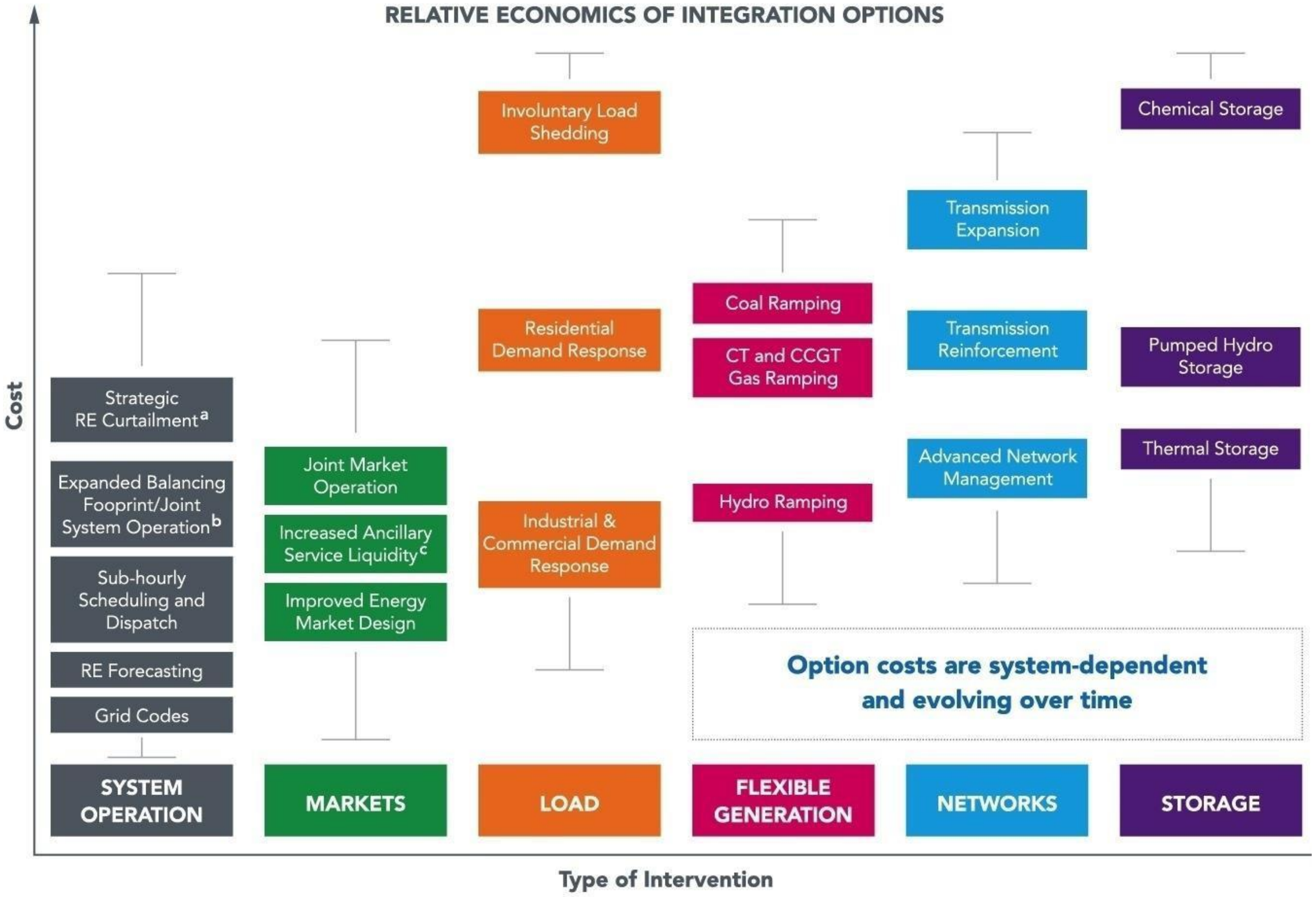
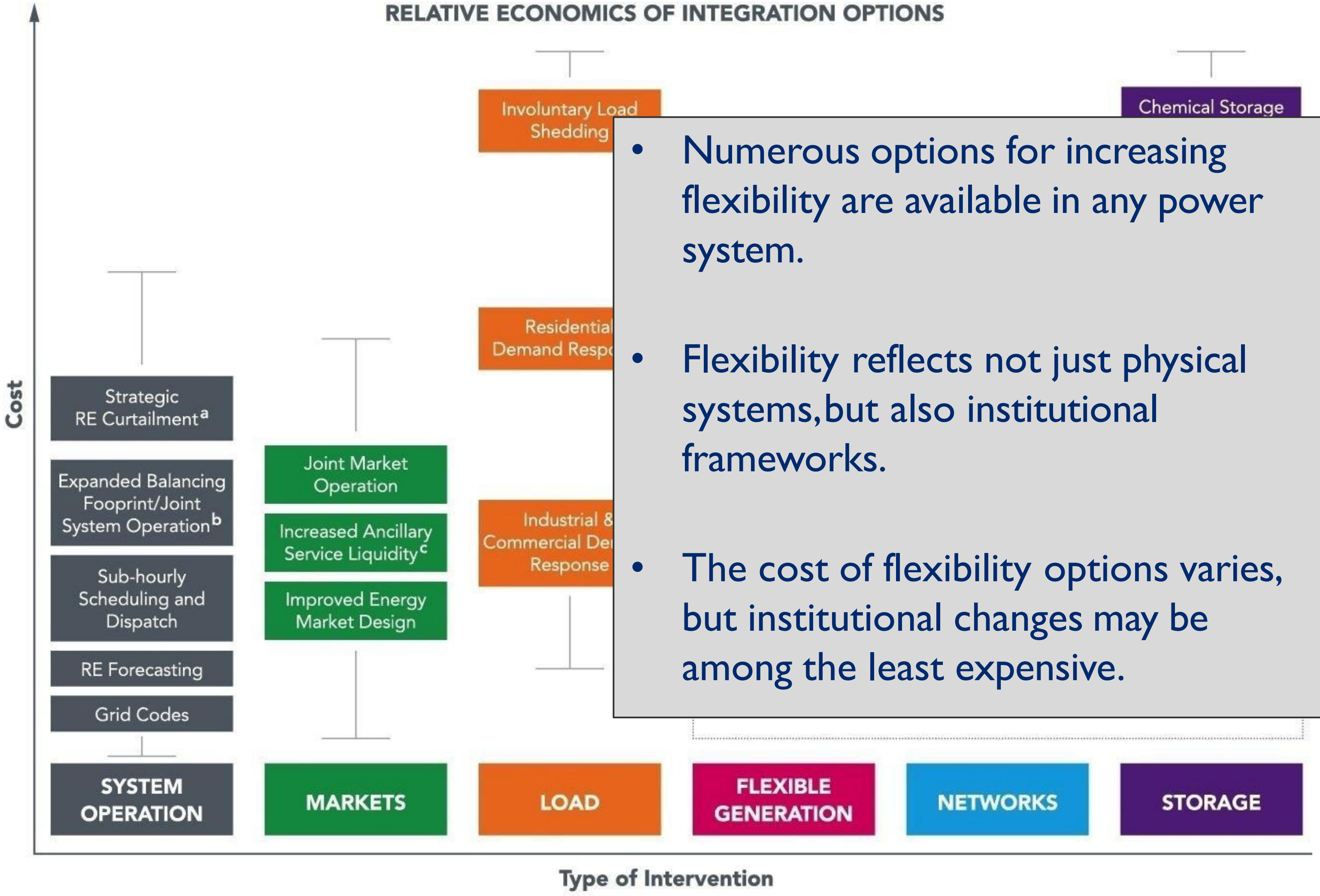


Frequently used options to increase flexibility

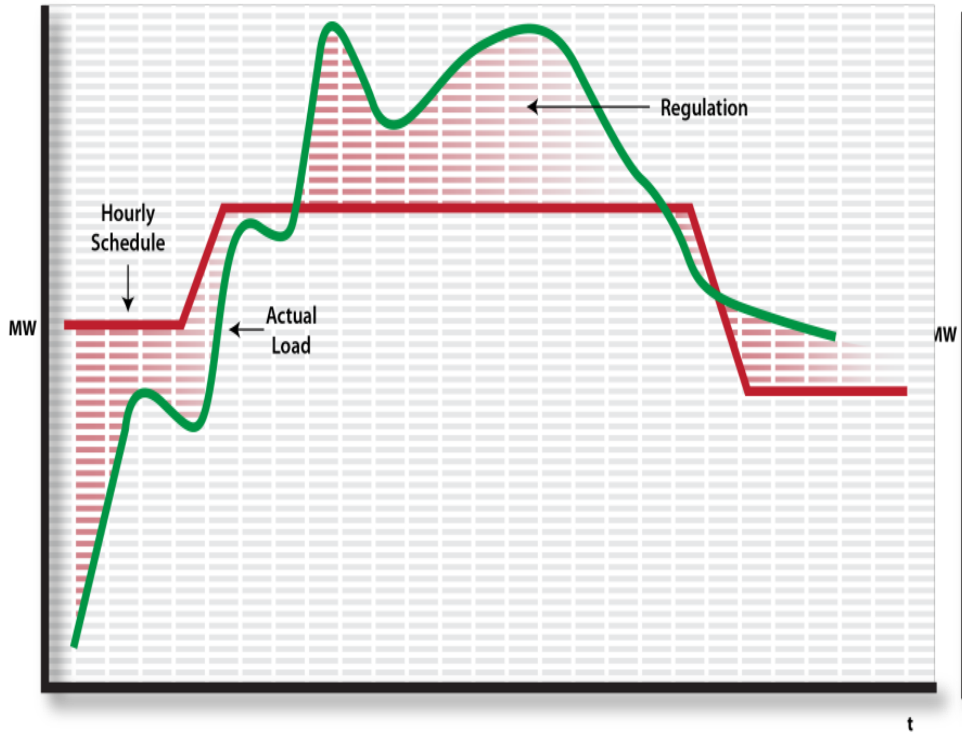


- Numerous options for increasing flexibility are available in any power system.
- Flexibility reflects not just physical systems,but also institutional frameworks.
- The cost of flexibility options varies, but institutional changes may be among the least expensive.

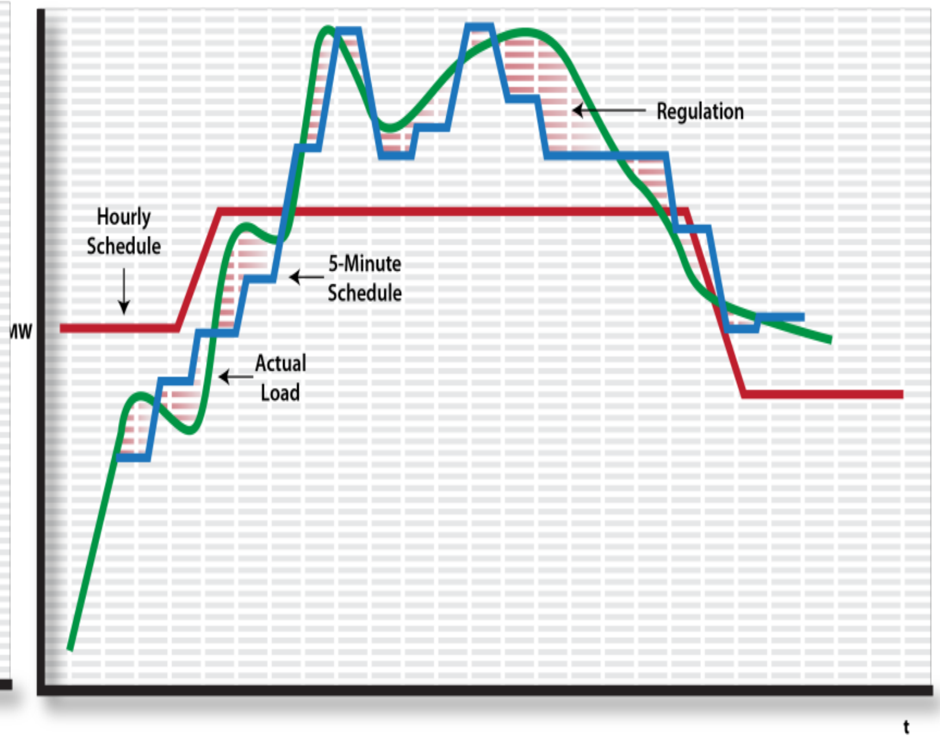
Faster dispatch to reduce expensive reserves

System Operation

Hourly dispatch and interchanges



Sub-hourly dispatch



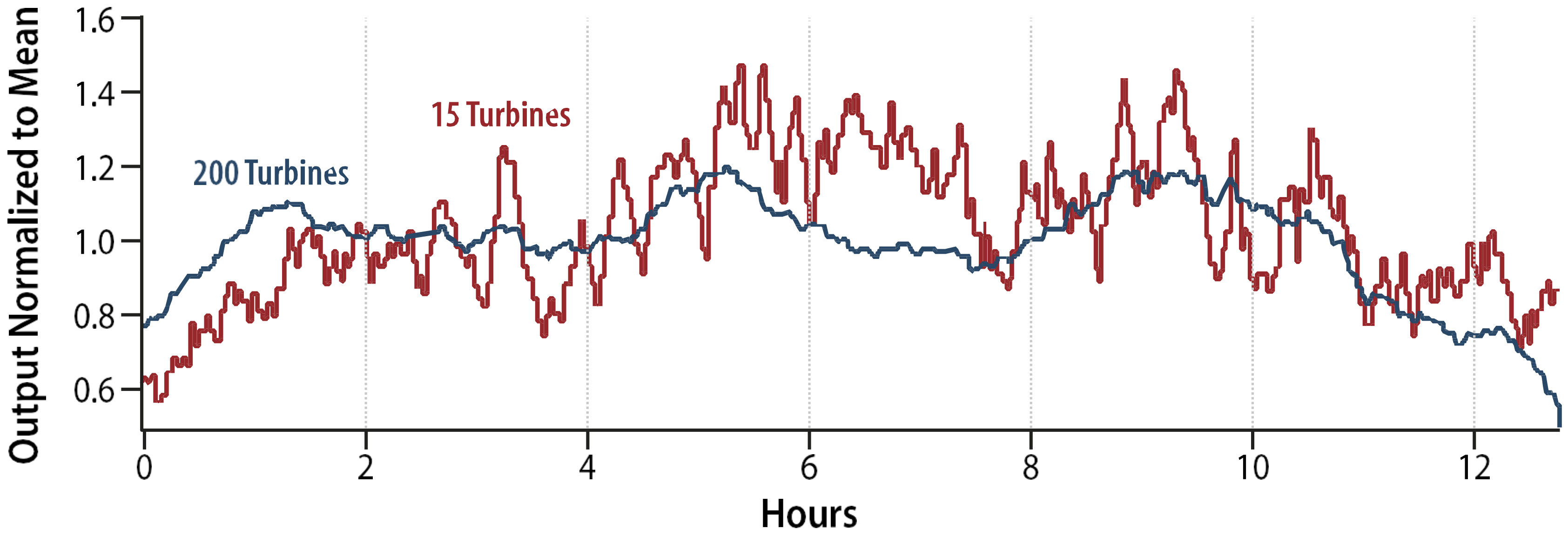
Source: NREL

Dispatch decisions closer to real-time (e.g., intraday scheduling adjustments; short gate closure) reduce uncertainty.

Expand balancing footprint

System Operation

Broader balancing areas and geographic diversity can reduce variability and need for reserves.



Source: NREL/FS-6A20-63037

Increase balancing area coordination

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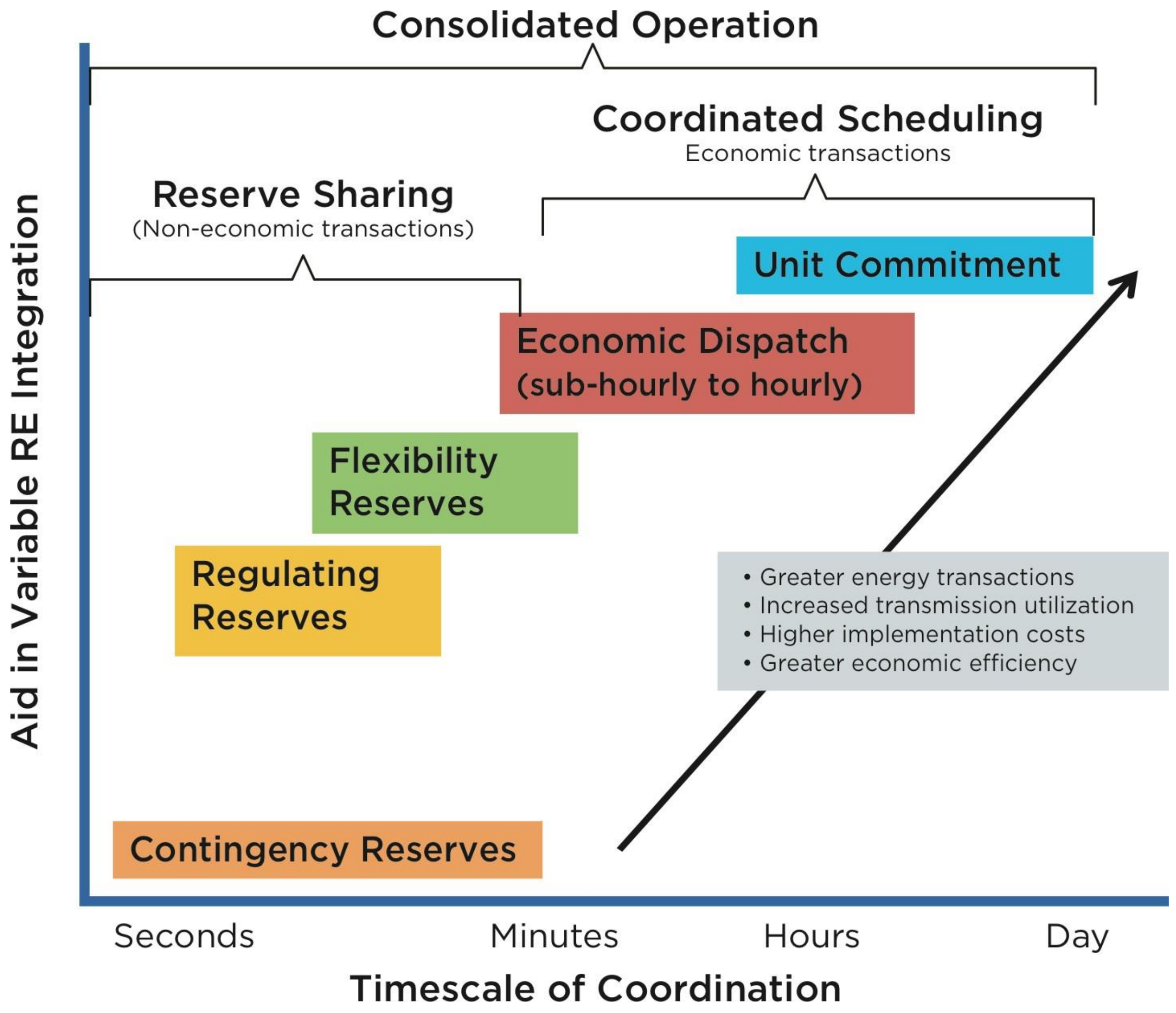
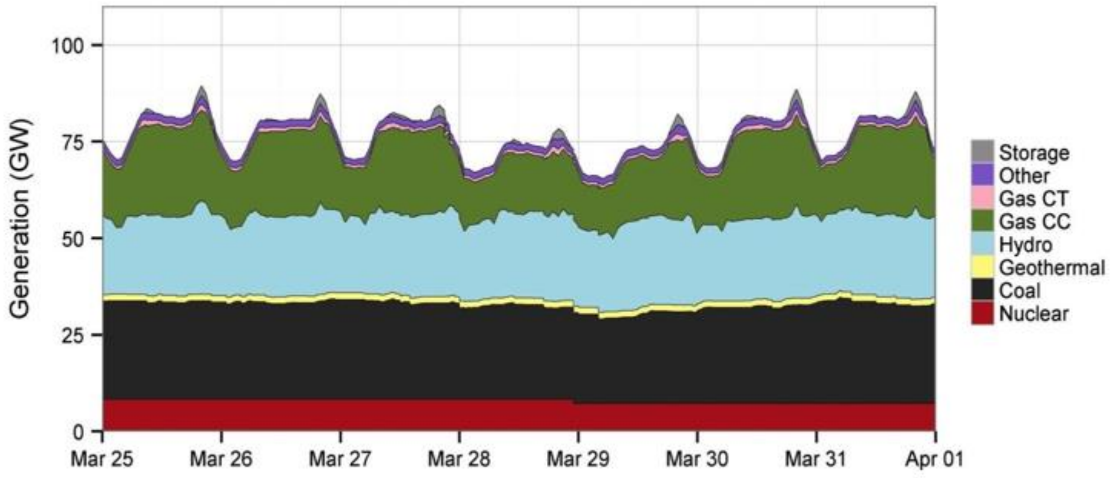
System Operation



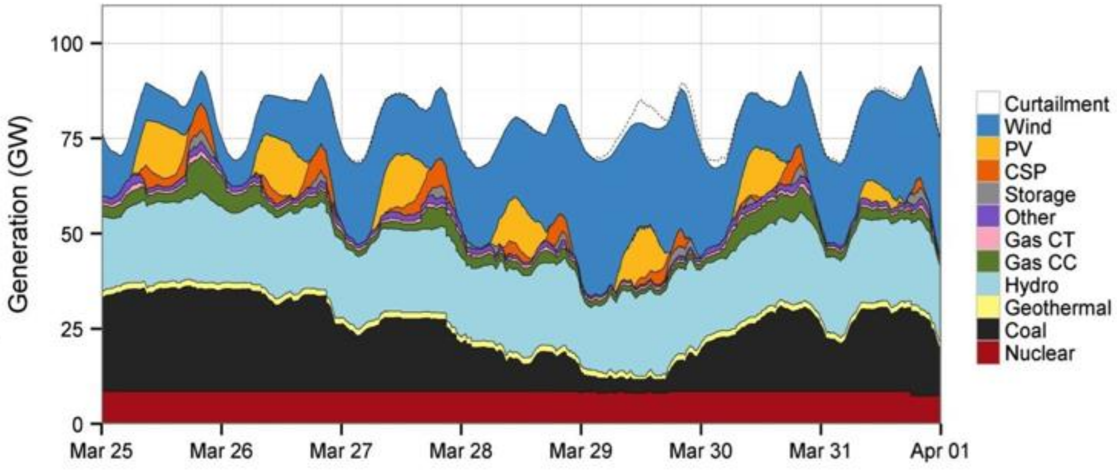
Increase thermal plant cycling

Flexible Generation

0% wind and solar



33% annual wind and solar energy penetration



Generation dispatch for challenging spring week in the U.S. portion of WECC

Source: WWSIS Phase 2 (2013)

Flexible generation from wind

Flexible Generation

- Wind can provide synthetic inertial control and primary and secondary frequency response
- Wind can follow economic dispatch signals, and can be incorporated into economic dispatch or market operations
- This example shows how Public Service Company of Colorado improved its Area Control Error using controllable wind energy during a period of very high wind and low demand

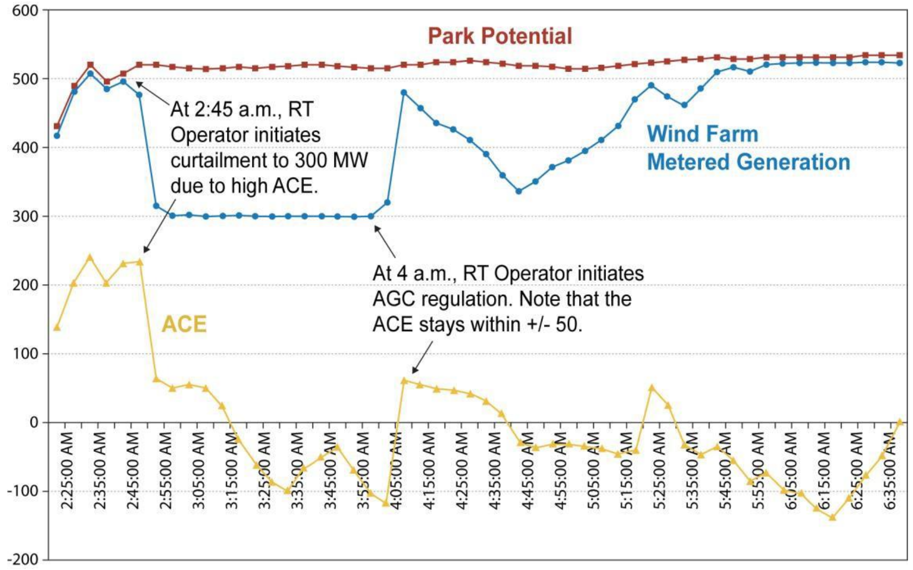


Figure: Impact of wind power controls regulation, dispatch, and area control error

Public Service Company of Colorado

Flexible demand

Load

Demand response (DR)

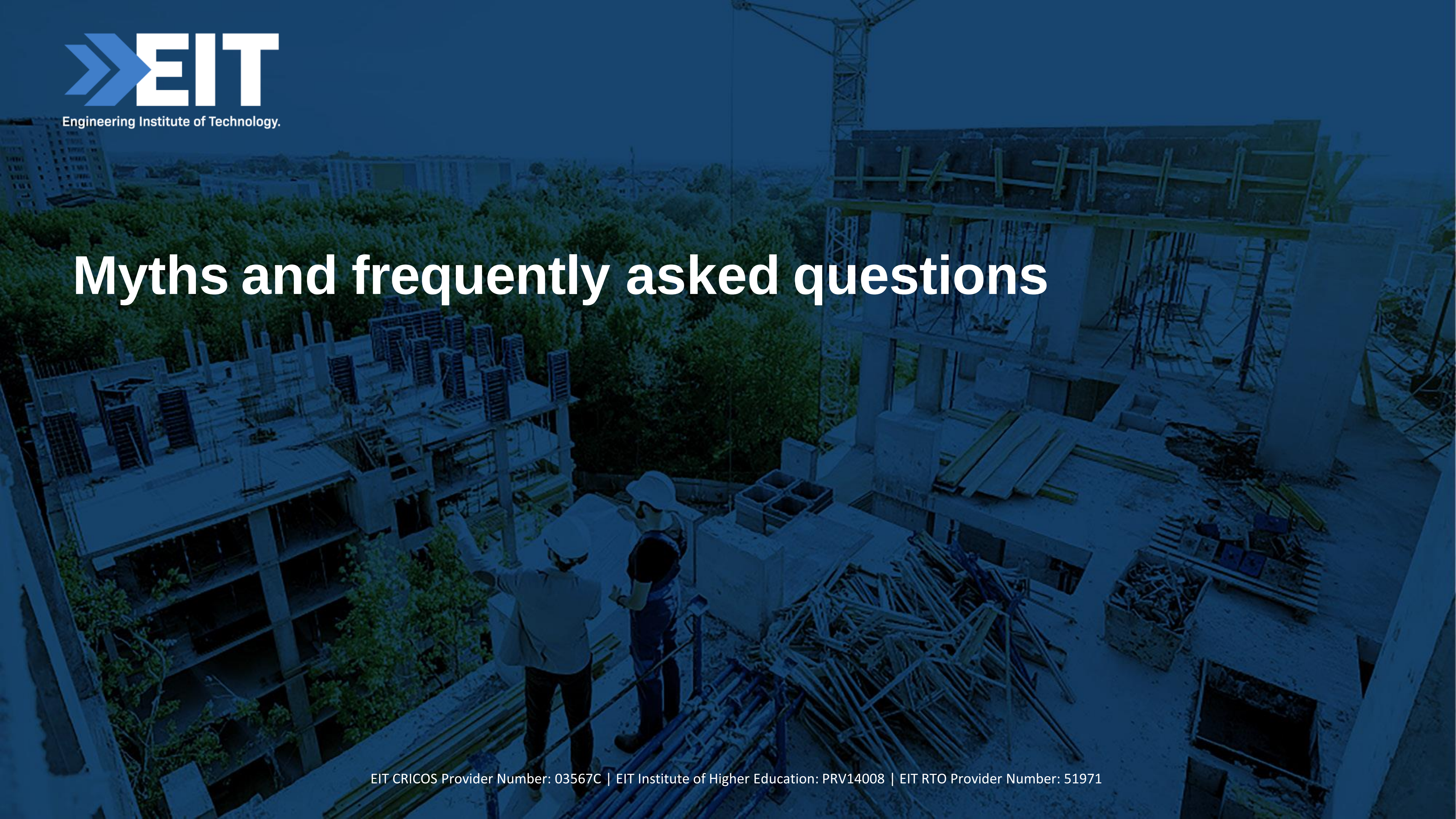
- Examples: direct load control, real- time pricing
- Cost effective for extreme events and for reserves

Policy and Regulatory Options

- Allow DR to compete on a par with supply-side alternatives in utility resource planning and acquisition
- Introduce ratemaking practices—such as time-varying electricity pricing—that encourage cost-effective demand response, even in communities without significant deployment of smart meters.
- Consider potential value of enabling DR when evaluating advanced metering

Photo credit: Susan Bilo

Studies have found that it is cheaper to pay load to turn off (demand response) for the 89 problem hours (1%) than to increase spinning reserves for 8760 hours/year.



Myths and frequently asked questions

Can grids support high levels (>5-10% annually) of variable RE?

Country	% Electricity from Wind	Balancing
Denmark	**39% in 2014**	Interconnection, flexible generation (including CHP), and good markets
Portugal	**25% in 2013**	Interconnection to Spain, gas, hydro, and good market
Spain	**21% in 2013**	Gas, hydro, and good market
Ireland	**18% in 2013**	Gas and good market

Many grids are operating with 20%–30% variable renewables.

Their experiences demonstrate that actions taken to integrate wind and solar are unique to each system but do follow broad principles.

Do individual renewable energy plants require backup by conventional plants?

- Reserves are already a part of every system
- Individual plants do not require backup
  - Reserves are optimized at system level.
- Wind and solar could increase need for operating reserves.
  - But this reserve can usually be provided from other generation that has turned down to accommodate wind/solar
  - This reserve is not a constant amount (depends on what wind/solar are doing)
  - Many techniques are available to reduce needed reserves.
- Wind can also provide reserves; in both directions when curtailed, but it may not be economic do obtain up-reserve from wind or solar.

Photo from iStock 72283000

Does variable renewable energy generation require storage?

- Storage is always useful but may not be economic.
- Detailed simulations of power system operation find no need for electric storage up to 30% wind penetration (WWSIS, CAISO, PJM, EWITS).
- 50% wind/solar penetration study in Minnesota found no need for storage (MRITS, 2014)

Source: Adrian Pingstone (Wikimedia Commons)

- At higher penetration levels, storage could be of value.
  - Recent integration study for 40% penetration in California: storage is one of many options.

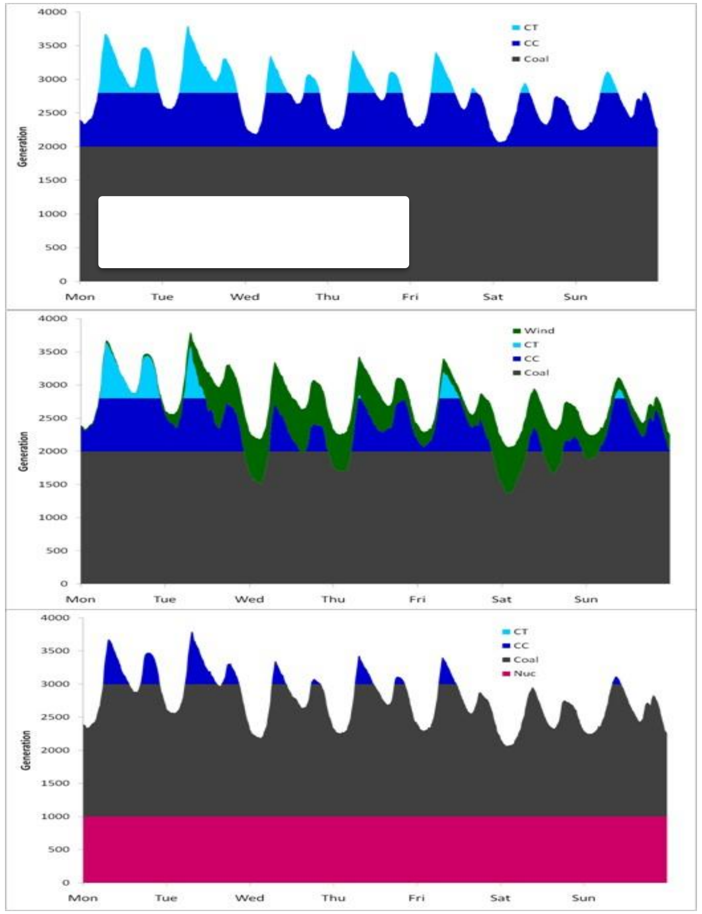
How expensive is integrating variable renewable energy generation to the grid?

All generation (and load) has an integration cost:

- Any generator can increase cycling for remaining generation
  - E.g., Baseload nuclear can increase coal cycling, as shown in lower figure

- Conventional plants can impose variability and uncertainty costs
  - Contingency reserves sized for largest plant, often thermal
  - Operating reserves needed for plants that cannot follow dispatch signals precisely

- Conventional plants can create conditions that increase need for system flexibility
  - Must-run hydropower, must-run IPP contracts, thermal plants that



http://www.nrel.gov/docs/fy11osti/51860.pdf

Key Takeaways

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- Wind and solar generation increase variability and uncertainty
- Actual operating experiences from around the world have shown up to 39% annual penetrations are possible
- Often most the cost-effective changes to the power system are institutional (changes to system operations and market designs)
- Specific back-up generation is not required, but additional reserves may be necessary
- Specific detailed analyses will help identify the most cost-effective measures to integrate RE in each power system

NREL/PIX 10926

Thank You!

What courses cover this topic?

- Professional Certificate of Competency in Renewable Energy Systems
- Professional Certificate of Competency in Smart Grids
- 52894WA Advanced Diploma of Applied Electrical Engineering (Renewable Energy)
- 52859WA Graduate Certificate in Renewable Energy Technologies
- Online – Bachelor of Science (Electrical Engineering)
- Online – Master of Engineering (Electrical Systems)

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52888WA Advanced Diploma of Applied Electrical Engineering (Power Industry)	5 March 2024
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Q&A

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