RENEWABLE AUCTIONS, GRID INTEGRATION & LEAST COST ZONE DEVELOPMENT

Allen Eisendrath, Power the Future program
Introduction to auctions & global auction trends
Recent record-winning bids & prices

Source: Bloomberg NEF. Note: Most tariffs will include adjustments for inflation and other factors that influence the final bid. For a full explanation on comparing nominal versus levelized bids, see pp6 in 1H 2017 EMEA LCOE Update.
Repeated auctions drive price declines: Drop in Indian solar tariffs at auctions in 2017

Repeated auctions drive price declines: Drop in Indian solar tariffs at auctions in 2017

Source: Solar Energy Corporation of India (SECI), Bloomberg New Energy Finance Note: The currency exchange rates used for conversion of rupees to $ are the closing rates of the date in which the auctions results were declared.
Low Bids in Indian Wind Auctions: Below India’s Current Levelized Cost of Energy

$/MWh

Source: Bloomberg New Energy Finance
Renewables are challenging existing plants on a cost-of-energy basis, just about everywhere

- India’s National Thermal Power Corporation’s average coal generation cost in 2018: $49.3/MWh.
  - 2019 Solar PV auction price: $36/MWh
  - 2018 Wind auction price: $36.1/MWh

- In China, best-in-class PV plants cost $34/MWh, below the national average regulated coal power price at 381 yuan ($56) per MWh.

- In US, recent on-shore wind farms have LCOEs of $35 to $50/MWh, close to the operating costs of both coal and gas plants.
In U.S., New Solar PV PPAs can be Cheaper than the Operating Cost of a Coal Plant

Example of US solar PPA compared to coal plant operating cost

Southeastern solar PPA prices, Most efficient Duke Carolina coal unit opex only

Source: Bloomberg New Energy Finance
In the U.S., new wind PPAs can be cheaper than the operating cost of old coal & gas plants

Comparison of US wind PPAs with coal and gas plant operating cost

SPS's Hale & Sagamore wind PPA
SPS's Bonita wind PPA
SPS's coal unit opex
SPS's gas unit opex

Source: Bloomberg New Energy Finance
Six Key Global Auction Design Trends

- Integration into wholesale markets
- Time based incentives & penalties
- Assigning balancing responsibilities
- Aggregation
- Hybrids
- Locational signals
Example: Integrating RE into Wholesale Markets, UK

- Bidders compete to deliver energy on basis of support level (£/MWh); lowest support level bid wins
- 2 auctions: “More established technologies” (wind, solar) and “Less established tech” (offshore wind, thermal, wave, etc)
Trend: Responsibility for forecast deviations

- RE is assigned penalties for forecast errors.
- Result: Increased contribution of RE to grid stability.
- But: Increased costs of compliance (communications & forecasting systems, penalties)
Trend: Time-based incentives & penalties

Time-based incentives and penalties

Design options that incentivize RE generation to more closely match the DISCOM demand curve (e.g. price adjustment factors, supply blocks).
Example: Time-based incentives & penalties

Country experience: Intraday and seasonal supply blocks in Chile

This policy enabled Chile to save on its daytime and nighttime supply – and both times RE & storage were cheaper than thermal power.

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Allowing intermittent technologies to optimize their feed-in potential and guarantee supply to distribution companies.</th>
</tr>
</thead>
</table>
| Design Solution | • Supply blocks: Intra-day hourly (12am-8am + 11pm-12am; 8am-6pm; 6pm-11pm) + four 3-month blocks.  
• Supply block translates generation risk to RE producer → Production deviation are settled at spot-market prices. |
| Results | • In technology-neutral auctions 2017, only RE projects won (2,200 GWh awarded).  
• Auction average price: 3.25 cents/kWh - lowest on record.  
• Lowest bids: 3.29 cents/kWh for wind & 2.15 cents/kWh for solar  
• Thermal price 7.54 cents/kWh |
Trend: Balancing responsibilities

• In the EU wind generators are responsible legally and financially for balancing. Responsibilities are usually the same as thermal generators.

• Balancing charges in the EU are generally Eur 2 to Eur 3/MWh.

• In some EU states, balancing costs are prohibitively high: Bulgaria: Eur 10 – 24/MWh; Romania: Eur 8 – 10 if not part of a large aggregator; Poland: Eur 6/MWh.

• Actual integration costs in EU and US generally between Eur 1 and Eur 4.50 /MWh.1

• Wind generators can participate in balancing markets

**Trend: Procurement of (physical) hybrids**

**Procurement of (physical) hybrid solutions**

Competitive procurement of RE electricity from technologies such as wind, solar, storage or thermal to get complementary generation profiles.
Example: Procurement of (physical) hybrids

**Country experience:**
Hybrid procurement for firm energy in Thailand

**This policy enabled Thailand to purchase dispatchable RE with guaranteed evening generation.**

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Ensure continuous supply even during peak hours, reduce intermittency of RE generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Solution</td>
<td>• Peak: 100% contracted capacity, ± 2% tolerance range (Mon.-Fri., 9:00am-11pm)</td>
</tr>
<tr>
<td></td>
<td>• Off-peak: 65% of contracted capacity, ± 2% tolerance range (at all other times)</td>
</tr>
<tr>
<td></td>
<td>• Penalty: 20% of fixed tariff (FIT&lt;sub&gt;f&lt;/sub&gt;) component (FIT = FIT&lt;sub&gt;f&lt;/sub&gt; + FIT&lt;sub&gt;v&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Results</td>
<td>• Volume offered: 755 MW, against 300 MW ceiling</td>
</tr>
<tr>
<td></td>
<td>• Average bid price: 7.39 cents/kWh against a ceiling price of 11.09 cents/kWh</td>
</tr>
<tr>
<td></td>
<td>• Technology: predominantly biomass with 258.7 MW, biomass-solar with 29.31 MW solar + storage with 12 MW</td>
</tr>
</tbody>
</table>
Trend & Example: RE Hybrid Auctions

Indian auctions: Solar in 2019: $36/MWh; Wind in 2018: $36/MWh; Hybrid in 2019: $38.7/MWh

Lower grid connection costs
- RE projects with a high Capacity Factor (CF) such as hybrids may have lower grid connection costs.

Generation that better matches the demand curve
- Time-based tariffs or supply blocks provide a better demand-generation match.
- Hybrid plants with storage align generation with peak demand.

Balancing out intermittency
- Co-location of technologies can result in more balanced generation curves.
- Hybrid plants incorporating storage (e.g., pumped hydro or batteries) can provide balancing energy to the grid.
Trend: Storage is Now Economically Viable

• BNEF’s global LCOE benchmark for battery storage is now $186/MWh. US has the cheapest at $177/MWh.

• Most utility-scale battery storage provides capacity.

• Short-duration battery systems are the cheapest way to meet peak load. Capacity cost of one-hour battery in Australia is $114/kW/yr, including charging cost. This is cheaper than capacity cost of a peaking gas plant operating at a 4% capacity factor.

• Utility-scale uses include:
  – Ancillary services
  – Peaking capacity
  – Energy shifting
  – Investment deferral in dense grid areas

Source: Bloomberg NEF 2nd Half 2019 Energy Storage Market Outlook
<table>
<thead>
<tr>
<th>Developer</th>
<th>PV capacity (MW AC)</th>
<th>Storage capacity (MW)</th>
<th>Storage duration (hours)</th>
<th>AC based capacity factor (%)</th>
<th>PPA $/MWh</th>
<th>Capacity payment ($/MW/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NextEra</td>
<td>200</td>
<td>50</td>
<td>4</td>
<td>32.8</td>
<td>27.51</td>
<td>$73,320</td>
</tr>
<tr>
<td>NextEra</td>
<td>100</td>
<td>25</td>
<td>4</td>
<td>30.9</td>
<td>29.96</td>
<td>$74,400</td>
</tr>
<tr>
<td>Cypress Creek</td>
<td>101</td>
<td>25</td>
<td>4</td>
<td>33.5</td>
<td>26.5</td>
<td>$93,060</td>
</tr>
<tr>
<td>8minuteenergy</td>
<td>300</td>
<td>0</td>
<td></td>
<td>35.1</td>
<td>23.76</td>
<td>$0</td>
</tr>
<tr>
<td>Sempra</td>
<td>250</td>
<td>0</td>
<td></td>
<td>32.9</td>
<td>21.55</td>
<td>$0</td>
</tr>
<tr>
<td>Hanwha</td>
<td>50</td>
<td>0</td>
<td></td>
<td>32.1</td>
<td>29.89</td>
<td>$0</td>
</tr>
</tbody>
</table>

*Source: Bloomberg New Energy Finance*
**Trend: Locational Signals**

Locational signals steer projects to specific areas/grid connection points to **avoid concentration of projects in resource-rich but costly-to-connect areas.**

**Substation I** (20 MW)
- 3 cents /kWh - Awarded
- 4 cents /kWh - Not awarded

**Substation 2** (40 MW)
- 2 cents /kWh - Awarded
- 5 cents /kWh - Awarded

**Awarded projects**
- With capacity quotas
  - Ø auction price: 3.33 cents/kWh

**Projects**
- 20 MW
  - 20 MW
  - 20 MW
  - 20 MW

**Bid prices**
- 2 cents /kWh
- 3 cents /kWh
- 4 cents /kWh
- 5 cents /kWh
**Trend: Locational signals**

Incorporating locational steering in procurement design:

<table>
<thead>
<tr>
<th>No location signals</th>
<th>Bid bonus/penalty</th>
<th>RE Zones</th>
<th>Maximum capacity quota</th>
<th>Site-specific auction</th>
</tr>
</thead>
<tbody>
<tr>
<td>RE projects are built everywhere (i.e. best resources sites)</td>
<td>Bonus applied to bids in places with available grid capacity or power capacity needs</td>
<td>Zones with simpler environmental/grid connection approval process</td>
<td>Capacity limits (quotas) are defined in certain areas</td>
<td>Authorities select a site according to grid and land availability</td>
</tr>
</tbody>
</table>

- **Most RE auctions**: Germany, Mexico
- **South Africa India**: Kazakhstan, Germany
- **Zambia, Turkey, Germany Kazakhstan**

*Hard locational signals*
Example: Locational signals

Country experience: Capacity Quotas in Kazakhstan

This policy enables Kazakhstan to limit grid expansion needs to the minimum by using existing substations for its RE.

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Limiting new transmission costs from auctioned installations and ensure that the system can absorb generation capacity.</th>
</tr>
</thead>
</table>
| Design Solution | • Set capacity limits at multiple grid nodes. Maximum capacity and number of grid connection points are set before the auction.  
• If bids for a node exceed capacity limit, bids will be excluded in descending order of bid price. |
| Results | • 857.9 MW of RE projects at nodes with sufficient grid capacities contracted.  
• Awarded technologies: wind (500.9 MW), solar (270 MW), hydro (82.1 MW), biogas (5 MW). Lowest awarded bids: hydro (3.5 cents), wind (4.7 cents), and solar (4.9 cents). |
Auction Design & Process
Auction Design Components

- **Capacity**: most countries set capacity limits and auction MW.

- Brazil, Poland and Chile auctioned energy (MWh). Some countries set a budget limit instead of a capacity limit (Netherlands, Italy & UK)

- **Technology**: most countries had technology-specific auctions. California grouped technologies by generation profile. Chile and Mexico held technology neutral auctions. Dutch SDE+ has a technology-neutral tranche. Poland held baskets by various criteria: load hours, biomass, CO2, micro- and macro-clusters

- **Project size restrictions**: most EU countries have had capacity size limits for individual projects

- **Schedule**: most countries scheduled one or more auctions per year
Auction Design Components

- **Market integration**: Most EU countries – Denmark, Italy, Netherlands, UK – used a form of Feed In Premium, with RE bidding into the wholesale market.

- **Bidding rules**: Most auctions are sealed bid. Netherlands uses a dynamic ascending auction, with prices stacked as they are bid. Brazil uses two phases: phase 1 = descending clock; phase 2: pay as bid final round.

- **Payment**: 9 of 12 countries used pay as bid. UK and Netherlands used pay as cleared prices. China has used an average price rule.

- **Ceilings**: Most countries except China and France had price ceilings.

- **Evaluation of bids**: Majority of EU countries held price-only auctions. Other countries had multi criteria evaluations, including features like local content or labor, location.
Auction Design Components

• **Stage of project development**: Many countries set conditions for late stage auctions: bidders need to have permits and interconnection agreements prior to the auction.

• **Foreign exchange**: out of 12 emerging markets surveyed, 6 had full fx indexation, 3 split indexation, and 3 no fx indexation.

• **Balancing**: usually separately regulated, but the trend is to include it as a charge in the PPA. Poland charges Eur 4/MWh for balancing. In Brazil, chose: RE generators must deliver fixed monthly volumes of energy or cover the shortfall by purchasing on the balancing market; or they must deliver a fixed annual amount of energy.

• **PPA duration**: 12 years (Finland), 15 years (Poland, Turkey and multiple countries), 20 years (still the norm).
# Bid and Performance Bonds

<table>
<thead>
<tr>
<th>Country (Year)</th>
<th>Bond Requirement</th>
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</table>
| India (2016-17) | Bid bond: Earnest Money Deposit INR 1 million/MW (approx. $15,000/MW)  
Completion bond: Performance bank guarantee INR 2 m/MW (approx.. $30,000/MW)                                                                 |
| Germany (2015) | Bid bond: €4 / kW (reduced by half if building permit is in place)  
Completion bond: $57 /kW ($28 / kWh if building permit is in place)                                                                                      |
| Brazil (2015)  | Bid bond: 1% of estimated investment (Round 1); 5% of estimated investment (Round 2)  
Completion bond: 5% of estimated investment cost of awarded project                                                                                           |
| Portugal       | Bid bond: $500,000 Euros  
Completion bond: 10% of the investment value                                                                                                           |
|                | Source: Aures Wp4 Synthesis Report                                                                                                                                                                               |
| California IOUs  | Performance bond: $20/kW                                                                                                                                                                                        |
| Kazakhstan 1st & 2nd auctions | Performance bond: $30/kW  
| Brazil         | Performance bond: 5% of investment  
Source: https://d2oc0ihd6a5bt.cloudfront.net/wp-content/uploads/sites/837/2017/06/4_Auctions_Renewables_Brazilian_Approach.pdf |
General comments on auction design trends

• Need to be flexible
• Focus on national power sector objectives
• Allow designs to evolve
• Auctions sometimes fail
• Results depend heavily on grid integration & location
Grid Integration
The general solution for the grid

Bigger

The Grid

Faster

Smarter
## Five Solutions for Flexibility

<table>
<thead>
<tr>
<th>Solution</th>
<th>Description</th>
<th>Planning for Extremes</th>
<th>Continuous Balancing</th>
<th>Controlling Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlocking flexibility of existing power system</td>
<td>The more the market reflects physical realities of the grid, the fewer the corrective actions to balance the grid</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Power market reform</td>
<td>The more the market reflects physical realities of the grid, the fewer the corrective actions to balance the grid</td>
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<tr>
<td>Power exchange</td>
<td>Power trading allows access to flexibility services</td>
<td></td>
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<tr>
<td>Increasing the balancing role of wind and solar</td>
<td>Forecasting enables the system operator to react more accurately to variability of RE generation</td>
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</tr>
<tr>
<td>Better renewables forecasting</td>
<td>Forecasting enables the system operator to react more accurately to variability of RE generation</td>
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</tr>
<tr>
<td>Balancing obligation for renewables</td>
<td>Ensuring solar and wind operators match sales with delivered output increases predictability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System services by renewables</td>
<td>As the thermal generation share declines, RE can provide system services</td>
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</tr>
</tbody>
</table>

Source: Bloomberg NEF Flexibility Series
Flexibility Options (Flexibility Supply Curve)

Option costs are system-dependent and evolving over time.
Impact of Variable Renewable Energy on Grid Stability

**Frequency stability** (supply-demand balance) is an issue at high penetration levels.

- **Solution:** Wind turbines need to provide active power controls (synthetic inertia, governor response).
- **Example:** ERCOT mandates governor response on wind turbines.

**Voltage stability:** issue in weak systems, such as those with long, radial lines.

A single turbine tracking a step change in the de-rating command followed by primary frequency control response to an under-frequency event.
Faster Dispatch to Reduce Expensive Reserves

Hourly dispatch and interchanges

Sub-hourly dispatch

Dispatch decisions closer to real-time (e.g., intraday scheduling adjustments; short gate closure) reduce uncertainty.
Broader balancing areas and geographic diversity can reduce variability and need for reserves.
Increase Balancing Area Coordination

Consolidated Operation

Captures benefits of geographic diversity in demand, wind, solar, and provides more accurate dispatch.
Flexible Load: Demand Response

- **Energy Efficiency** programs can reduce peak demand

- **Price Response** programs move consumption from day to night (real time pricing or time of use)

- **Peak Shaving** programs require more response during peak hours and focus on reducing peaks every high-load day

- **Reliability Response** (contingency response) requires the fastest, shortest duration response. Response is only required during power system “events” – *this is new and slowly developing*

- **Regulation Response** continuously follows power system minute-to-minute commands to balance the system

Flexible Generation: Thermal Cycling

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)*
India studied 436 coal generating units with aggregate capacity of 165 GW.

One-third of thermal units can deliver the mandated ramp rate of at least 1% per minute.

Due to increased RE penetration, net load ramp will peak at 32 GW per hour. Generation that serves net load must be more flexible.

International experience: coal-fired plants are transitioning from baseload obligations. Many units can provide 2% - 5% per minute ramping.

A regulatory framework is needed for ramping capability metrics, testing procedures and payment/incentive mechanisms.
Incentives for Thermal Ramping in India

Table 3: CEA’s projected thermal ramping capacity in 2021-22

<table>
<thead>
<tr>
<th>Unit size (MW)</th>
<th>Capacity utilisation (%)</th>
<th>Capacity on bar (MW)</th>
<th>Assumed ramp (%)</th>
<th>Ramp rate (MW per minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;150</td>
<td>40</td>
<td>4,073</td>
<td>1</td>
<td>41</td>
</tr>
<tr>
<td>200-210</td>
<td>80</td>
<td>25,824</td>
<td>1</td>
<td>258</td>
</tr>
<tr>
<td>250-360</td>
<td>80</td>
<td>30,885</td>
<td>1</td>
<td>309</td>
</tr>
<tr>
<td>500</td>
<td>80</td>
<td>37,276</td>
<td>1</td>
<td>373</td>
</tr>
<tr>
<td>600-800</td>
<td>82</td>
<td>86,043</td>
<td>1</td>
<td>860</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>184,100</strong></td>
<td></td>
<td><strong>1,841</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: POSOCO report on “Analysis of Ramping Capability of Coal-fired Generation in India”

Incentives for ramping coal plants:

- -0.25% Return on Equity for plants that fail to achieve the 1% per minute ramp rate

- +0.25% Return on Equity for every increased in ramp rate of 1% per minute achieved above the prescribed level, with a rate ceiling of 1% additional Return on Equity
Storage

ENERGY STORAGE can support: Load Leveling/Arbitrage; Provide Firm Capacity and Operating Reserves; Ramping/Load Following; T&D Replacement and Deferral; and Black-Start. Storage must compete with other sources of flexibility.

Two main applications:

Operating reserves – seconds to minutes and provide regulating and contingency reserves.

Energy management – continuous discharge to provide operating reserves as well as firm and system capacity.

Storage is always useful but may not be economic.

Simulations of power system operation find no need for storage up to 30% wind penetration (WWSIS, CAISO, PJM, EWITS).
Incorporate Forecasting in Unit Commitment & Dispatch

• Reduces uncertainty
• Improves scheduling of other resources to reduce reserves, fuel consumption, and O&M costs
• More accurate closer to operating hour
• Forecasting of extreme events is more important than mean error reduction
• Access to renewable energy plant data is critical

At 24% (annual) wind penetration levels, improving forecasting by 10%–20% provides significant savings in annual operating costs in U.S. west.

How Does Large Balancing Size Help?

Reduce the need for ramping by combined BAs (real or virtual):
- Ramping *capability* adds linearly;
- Ramping *need* adds less than linearly.

Operating separate balancing areas causes extra ramping compared to combined operations.

Blue: up-ramp
Green: down-ramp
Yellow: combined ramp

Some areas are ramping up nearly 1000 MW/hr while other areas are ramping down nearly 500 MW/hr

Ramping that could be eliminated by combining operations

Faster Energy Markets to Reduce Cost

Average Total Regulation for 6 Dispatch/Lead Schedules by Aggregation (Dispatch interval - Forecast lead time)

Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. October
Change Energy Market Designs

• **Ramp products**
  - May provide cheaper flexibility

• **Larger, faster, more frequent markets**

• **Negative pricing**
  - Economically efficient way to reduce output during excess generation
  - Allows curtailment to proceed through scheduling software rather than manual intervention

• **Forecast integration and allowing variable RE to participate as dispatchable generators**

Source: Milligan et al. (2012) NREL/CP-5500-56212
Flexible Demand

Demand response (DR)

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

Policy and Regulatory Options

• Allow DR to compete
• Introduce ratemaking practices—such as time-varying electricity pricing—that encourage demand response
• Consider enabling DR when evaluating advanced metering

Studies 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.
Flexible Generation

• New or retrofitted conventional power plants can improve system flexibility by incorporating capabilities to:
  – Rapidly ramp-up and down output to follow net load
  – Quickly shut-down and start-up
  – Operate efficiently at a lower minimum level during high renewable energy output periods

NREL PIX 06392
Dealing with Project Location
Importance of Location for RE Programs

• A key factor in the long-term cost of an RE program
• Basic principle: concentrate RE capacity in locations with the best RE resources, adjusted for transmission cost and land

• Three main options:
  – Award to the lowest price regardless of location. Bidder is responsible for grid interconnection costs and risks.
  – Develop transmission system nodes located in areas with the best RE resources.
  – Develop new RE zones.
What is a Renewable Energy Zone?

- Transmission planning and approval process customized for renewables
- A zone has a high concentration of high quality, easily developed renewable energy potential
- Aims for full use of highest-voltage transmission
Transmission and RE Project Development Take Place Along Different Timescales

<table>
<thead>
<tr>
<th>Technology</th>
<th>Construction Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>~10-20 years</td>
</tr>
<tr>
<td>Conventional Generation</td>
<td>~5-10 years</td>
</tr>
<tr>
<td>Renewable Generation</td>
<td>~2-3 years</td>
</tr>
</tbody>
</table>

Challenges:

a) Limited transmission capacity may discourage wind and solar in areas with good RE resources

b) If wind and solar overwhelms transmission capacity at certain nodes, the operator may order curtailments
The REZ Approach: Use the Most Productive Resources

• Direct high-voltage transmission development to the best RE resources areas

• High capacity factors mean high utilization of transmission assets

• VRE projects with high capacity factors have lower cost per MWh

• Most MWh for the amount of capital invested, for both generation and transmission
Build a Few High-Capacity Lines

• Higher voltages have smaller losses and are more economically efficient per MW of capability

• Minimize transmission corridors to cause less environmental damage than a large number of small lines

• Fewer proceedings for siting and permitting
Implementing a REZ

1. Conduct renewable energy resource assessment
2. Screen resource areas for quality, development potential, and general social and environmental impacts
3. Conduct a formalized input process for developers to indicate interest
4. Conduct economic analyses of zones with high interest
5. Designate REZs
6. Develop and approve transmission plan to connect REZs to the grid
Example RE Resource Screening

Geospatial screening to identify areas favorable to construction of large-scale concentrating solar power (CSP) systems

1. Start with direct normal solar resource estimates derived from 10 km satellite data.

2. Eliminate locations with less than 6.75 kWh/m²/day.

3. Exclude environmentally sensitive lands, major urban areas, and water features.

4. Remove land areas with greater than 1% (and 3%) average land slope.

5. Eliminate areas with a minimum contiguous area of less than 5 square kilometers.
Opportunities for Large CSP: Unfiltered Resource
Opportunities for Large CSP: Transmission Overlay
Opportunities for Large CSP: > 6.75 kWh/m²/day
Opportunities for Large CSP: Environmental and Land Use Exclusions

Direct Normal Solar Radiation
kW/m²/day

- 8.00 - 8.25
- 7.75 - 8.00
- 7.50 - 7.75
- 7.25 - 7.50
- 7.00 - 7.25
- 6.75 - 7.00

Transmission Lines by Voltage
- 500 - 750
- 345 - 499
- 230 - 344
- 115 - 230
- DC Lines

Potentially sensitive environmental lands, major urban areas, and water features have been excluded.
The direct normal solar resource estimates shown are derived from 10 km Perez data, with modifications by NREL.

February 2005
Opportunities for Large CSP: Slope < 3%
Opportunities for Large CSP: Slope < 1%

Map represents areas that have no primary use today, exclude land with slope > 1%, and do not count sensitive lands.

Direct Normal Solar Radiation
KWh/m^2/day
- 8.00 - 8.26
- 7.75 - 8.00
- 7.50 - 7.75
- 7.25 - 7.50
- 7.00 - 7.25
- 6.75 - 7.00

Transmission Lines
by Voltage
- 500 - 750
- 400 - 499
- 350 - 344
- 300 - 339
- 250 - 229
- DC Lines

February 2005

Potentially sensitive environmental lands, major urban areas, and water features have been excluded. Areas with slope > 1% and minimum contours area <= 5 km^2 were also excluded to identify those areas with the greatest potential for development.

The direct normal solar resource estimates shown are derived from 10 km Perez data, with modifications by NREL.
Conduct a Formalized Input Process for Developers to Show Interest

• Necessary input on areas for commercial consideration

• Objective: developers prioritize areas with development potential
  – Eliminate areas with no developer interest

• Result: zone designation by authority in charge of REZ
Economic Analyses of REZ Scenarios

• Production cost modeling
  – Model dispatch on the entire network to determine how the variable cost of production changes under different REZ scenarios
  – Outcomes include total production costs over a test year, congestion costs, local marginal cost of power

Other technical studies:
• Ancillary services needs
• Dynamic stability studies
• Power flow studies
Example: Texas Competitive REZ (CREZ) for Wind Energy

Zones designated by regulators as REZs based on developer input

Transmission upgrades approved to interconnect REZs

2,400 line miles constructed
$7 billion (costs rolled into rate base)
>18 GW wind interconnected
Competitive REZ (CREZ): Harness the Power of Competition

- Pioneered by the Texas power system
- Let the competitive market decide who builds wind projects
- Transmission plan directs developers to the largest concentrations of highest quality resources
- Raw potential should be more than the capacity of new lines
  - Rule-of-thumb: if the line can handle 1,000 MW, developable potential should be 4,000 MW
Texas: REZs and transmission approved in 2008

2,400 line-miles
$5 billion (estimated)
$7 billion (actual)

Last element completed in 2013

345 kV double-circuit upgrades identified in CREZ transmission plan
Did it work?

Before REZ: wind in 2003

After REZ: wind in 2014

Panhandle (new wind development area)

McCamey (first wind development area)

CREZ lines in red
CREZ Results

- Almost 18 Gigawatts of wind generation built in the CREZ
- Texas’ wind generation cost is among the lowest in the world at $26/MWh
- CREZ lines are already at maximum capacity

Source: Generation capacity – NREL 2017 CREZ description. Generation price – Bloomberg NEF 2nd Half 2019 LCOE Report, price is without Production Tax Credit. With PTC, the wind price in Texas is as low as $12/MWh. CREZ capacity: MIT Technology Review, August 6, 2016
Ancillary Services Markets
Types of Ancillary Services

- **Primary Control Reserve**
- **Secondary Control Reserve**
- **Tertiary Control Reserve**

**Union for the Co-ordination of Transmission of Electricity (UCTE)**

**North American Reliability Corporation (NERC)**

- **Frequency Response Reserve**
- **Regulating Reserve**
- **Spinning Reserve**
- **Non Spinning Reserve**
- **Supplemental Reserve**

Source: Eric Ela, NREL
Frequency control ensures that the BPS is synchronized & stabilized for normal & contingency conditions. Frequency is controlled in stages that range from seconds (inertia) to hours (spinning reserves). AGC & operational flexibility of generation resources are critical to maintaining frequency control.

Short run regulation ensures supply meets demand every minute while load following ensures plants follow the trend in demand all day.

Reserves are staggered by response time so there is backup generation for the grid at various response times (seconds, minutes, tens of minutes).

Voltage control is needed all day. It is location-specific & requires reactive power control from reactive sources.

Source: Analysis Group, Advancing Past “Baseload” to a Flexible Grid, June 2017
NYISO’s Ancillary Services

- **NYISO-Wide Uplift Charge** covers cost of dispatching economic units to provide NYISO reliability.
- **Local Reliability Uplift Charge** covers cost of dispatching uneconomic units to provide locational reliability. Pricing varies largely based on sub zone.
- **Reserve Charges** deliver operating reserve by providing spot-market support, ensuring pool-scheduled generation, and ensuring demand resources are guaranteed to recover daily offer amounts.
- **Regulation & Frequency Response Service** pays generators for balancing support of the transmission grid and maintaining acceptable frequency limits at interconnection sites.
- **Black Start Service** ensures reliable grid restoration following a shutdown of the NYISO transmission system.
- **Scheduling, System Control & Dispatch Service** is a fee paid to the grid operator for running the transmission system, including dispatch, control, and scheduling.
- **Voltage Support Service** pays generators to deliver voltage support to the transmission grid.
- **Phase Angle Regulator Charges** recover the costs for NYISO’s monthly payment.
- **New York Power Authority (NYPA) Transmission Access Charge** is an embedded cost to recover the NYPA transmission revenue requirement not recovered through the transmission service charge.
- **Residual Adjustment** is a cost associated with the operation of the transmission system and administration of the tariff by the grid operator.
- **Unaccounted for Energy** is a settlement mechanism for line losses. This variable carries a hybrid of market-based and non-market-based risk that can be hedged or mitigated through risk premiums.
Example of Cycling Costs

Warm Start Cost Lower Bounds-Includes Outliers (Maintenance and capital cost per MW capacity)
UNIT/PLANT SALE CHOICES

Capacity Allocation
reserved for real-time balancing market
spinning reserve
hour-ahead market
day-ahead market

Energy Payments
balancing market energy (including AGC)
hour-ahead energy market
day-ahead energy market

AGC downward capability
THE RESERVES AUCTION

uniform price paid for reserve capacity

the winning bidders

the losing bidders

required reserves

$/MW
REAL TIME MARKET ENERGY SOURCES

CA ISO estimates

- Supplemental energy: 81%
- Spinning reserves: 12%
- Non-spinning reserves: 3%
- Replacement reserves: 4%
Ancillary services are not expensive

<table>
<thead>
<tr>
<th>Historical Cost of Ancillary Services in PJM per MWh of Load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Regulation</td>
</tr>
<tr>
<td>Scheduling, Dispatch &amp; System Control</td>
</tr>
<tr>
<td>Reactive</td>
</tr>
<tr>
<td>Synchronous Reserve</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Source: Quarterly PJM State of the Market Report, 2018
The impact of variable renewables on ancillary services

- Hourly shape by weather year
  - Developed by third party consultant by site
  - Aggregated to CDR values for study year

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RE is driving Innovation in Ancillary Services

Increased Flexibility through Innovative Ancillary Service Markets

New Ancillary Services

New market participants providing ancillary services

- Ramping products
- Fast frequency response by batteries
- Wind turbines providing inertial response
- Solar PV and utility scale storage providing voltage support
- Distributed energy resources (DERs) providing frequency and voltage control

Source: IRENA, Innovative Ancillary Services, 2019
Examples of ancillary service innovations

<table>
<thead>
<tr>
<th>New Developments</th>
<th>Examples</th>
</tr>
</thead>
</table>
| VREs are able to participate in the existing ancillary services markets | • Wind power generators can provide balancing services in Belgium, Denmark, Estonia, Finland, the Netherlands, Poland, Spain, Sweden and the UK  
• In Chile, the first pilot was implemented to enable a PV power plant to provide ancillary service to the utility grid and ensure grid stability |
| New ancillary service products have been designed for VRE integration | • In the UK, a new product was introduced for battery storage: enhanced frequency response  
• Ramping products introduced in the US  
• EirGrid, the Irish TSO, defined several additional system service products to cope with wind energy fluctuations  
• PJM Interconnection, a system operator in the US, has developed different frequency regulation products for slower conventional resources and for faster battery storage ones |
| Battery storage can participate in ancillary services markets | • Australia, Belgium, Germany, the Netherlands, the UK and the US allow batteries to participate in AS markets |
| Reforms are made to ongoing ancillary services market or balancing market | • The EU-wide implementation of network codes for balancing markets and system operation, including the procurement of ancillary services by TSOs (applicable in all EU member states)  
• In Denmark, wind turbine operators now face charges for incorrect forecasts, just like conventional generators  
• In the UK, recent reforms have increased charges in general for incorrect forecasts and rewarded generators and suppliers that can plug these gaps |

Source: IRENA, Innovative Ancillary Services, 2019
The need for shorter intervals to trade power

- Shorter lead times: reduce the time between end of trading & physical power delivery
- Shorter trading intervals: move from 30 to 15 or even 5 minute trading intervals
- Review single price zones: breaking up zones with transmission constraints reduces cost of redispatch and loop flows
- Balancing market reform: Balancing should ensure adequate incentives to inject and withdraw power in line with traded positions

Day ahead power is traded in 1 hour intervals…

…but demand, solar and wind output change constantly, driving intra-hour imbalances
<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation – Up</td>
<td>Must immediately increase output in response to automated signals.</td>
</tr>
<tr>
<td>Regulation – Down</td>
<td>Must immediately decrease output in response to automated signals.</td>
</tr>
<tr>
<td>Responsive Reserves</td>
<td>Must respond within “the first few minutes of an event that causes a significant deviation from the standard frequency”</td>
</tr>
<tr>
<td>Non-spinning Reserves</td>
<td>• Must respond within 30 minutes.</td>
</tr>
<tr>
<td></td>
<td>• Must run for at least one hour.</td>
</tr>
<tr>
<td>Product</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>--------------------------------------------------------------</td>
</tr>
<tr>
<td>Regulation</td>
<td>Must immediately increase or decrease output in response to automated signals</td>
</tr>
<tr>
<td>Ten-minute Synchronized Reserves (TMSR)</td>
<td>Synchronized to the grid</td>
</tr>
<tr>
<td></td>
<td>Must respond within 10 minutes</td>
</tr>
<tr>
<td>Ten-minute Non-synchronized Reserves (TMNSR)</td>
<td>Must respond within 10 minutes</td>
</tr>
<tr>
<td>Thirty minute operating reserves</td>
<td>Must respond within 30 minutes</td>
</tr>
<tr>
<td>Product</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Regulation</strong></td>
<td>Must immediately increase or decrease output in response to automated signals</td>
</tr>
<tr>
<td><strong>Ten minute spinning reserves</strong></td>
<td>Synchronized to the grid. Must respond within 10 minutes.</td>
</tr>
<tr>
<td><strong>Ten minute non-synchronized reserves</strong></td>
<td>Must respond within 10 minutes</td>
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<tr>
<td><strong>Thirty minute spinning reserves</strong></td>
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<td><strong>Thirty minute non-synchronized reserves</strong></td>
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<td>--------------------</td>
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<tr>
<td>Regulation</td>
<td>Must respond fully within five minutes. Online and synchronized with the grid. Able to respond to automated signals.</td>
</tr>
<tr>
<td>Spinning Reserve</td>
<td>Synchronized to the grid. Must respond within 10 minutes</td>
</tr>
<tr>
<td>Supplemental Reserve</td>
<td>Not necessarily synchronized to the grid. Must respond within 10 minutes</td>
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<tr>
<td>Regulation – Down</td>
<td>Must immediately decrease output in response to automated signals.</td>
</tr>
<tr>
<td>Regulation Mileage</td>
<td>The absolute change in output between four-second set points.</td>
</tr>
<tr>
<td>Up/Down</td>
<td></td>
</tr>
<tr>
<td>Spinning Reserves</td>
<td>• Synchronized to the grid.</td>
</tr>
<tr>
<td></td>
<td>• Must respond within 10 minutes.</td>
</tr>
<tr>
<td></td>
<td>• Must run for at least two hours.</td>
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<td>• Must respond within 10 minutes.</td>
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<tr>
<td>Synchronized Reserves</td>
<td>Synchronized to the grid. Must respond within 10 minutes.</td>
</tr>
<tr>
<td>Primary Reserves</td>
<td>Must respond within 10 minutes. Includes Synchronized Reserves.</td>
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