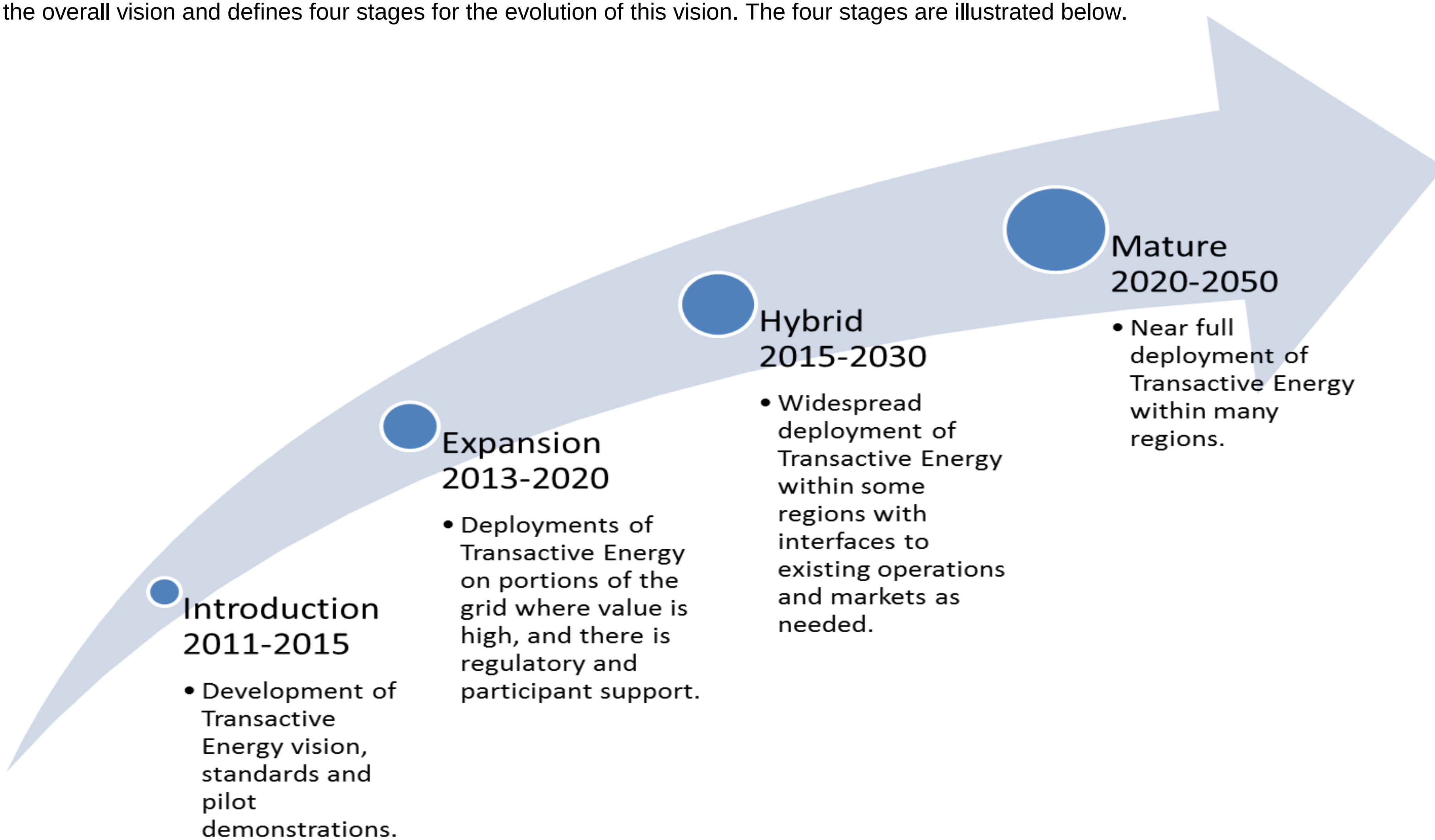
# Transactive Energy US Roadmap

## GridWise Architecture Council
## Transactive Energy Workshop

# SUMMARY

This roadmap outlines a vision and a sequence of stages to achieve a mature Transactive Energy grid starting from today's grid. The roadmap outlines the overall vision and defines four stages for the evolution of this vision. The four stages are illustrated below.



# ROADMAP TRACKS

The roadmap describes the vision and stages for Grid Services, Transactive Support Functions, Grid Participants, and the Environment.

## Grid Services

- Retail Service
- Distribution Service
- ISO/RTO, Other Transmission & Balancing Operator Services
- Wholesale Forward Energy and Transport Services
- Grid Custodian  Services

## Transactive Support Functions

- Adequacy and Reliability
- Ancillary Services
- Standards
- Uniform Transaction and Delivery Intervals
- Scheduling
- Uniform Settlement
- Clearing, Pricing and Coordination Algorithms
- Device and System Management Algorithms

## Grid Participants

- Distributed Generation
- Grid Generation
- Renewables
- Customers
- Plug-in Electric Vehicles
- Storage
- Micromarkets and Microgrids
- Intermediaries

## Environment

# Transactive Energy US Roadmap



| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | Overview | **Vision** | This roadmap envisions an evolutionary process from today's grid to a mature Transactive Energy grid. Different regions and elements of the grid within each region evolve at different paces, hence the overlapping ranges of dates for each stage in the roadmap. The roadmap is a living document to be updated as necessary.<br><br>In a mature transactive grid, optimization and control is largely decentralized and is associated with the parties, devices and systems that use and comprise the grid. Coordination is largely through forward tenders and transactions and automated processing of micro-tenders (buy or sell offers) and micro-transactions for both Energy and Transport (T&D) products when close to delivery. Energy products can be both Real Energy and Reactive Energy products. Energy products also include Reserve products that are contingency options that may be exercised for operating reliability. Transactions are generally asynchronous and mostly forward of delivery with ex-post transactions for differences between metered delivery and forward positions. Any party can transact with any other party including intermediaries. System operating reliability limits are honored by Transport (T&D) operators and balancing entities.<br><br>In a mature transactive grid, grid custodians such as today's federal, state and local regulatory agencies and grid operators enforce market rules, grid security, system operating limits, reliability and grid standards and collect, analyze and publish information on system operating limits and capabilities to all parties. Structural market changes evolve through more customer participation in the markets, more distributed generation, transitions to competitive markets, and reductions in any market power. Coordination of changes in retail, distribution, transmission and wholesale markets will be necessary. Public policy (1) sets standards, (2) implements environmental policy by constructing environmental commodities such as renewable and carbon certificates, and (3) influences the sharing of the cost and benefits among parties by explicit subsidies and taxes.<br><br>In a mature transactive grid, generation, storage and energy using devices and systems are self-managed in response to near continuously updated real-time and forward priced tenders (bids and offers) for energy and transport products among the parties. In a grid with increasing penetration of renewables, distributed generation, storage and smart devices, the balancing of supply and demand using Transactive Energy can efficiently accommodate high levels of renewables. Transactions can be designated as either financial or physical. Physical transactions are intended to schedule physical generation and load delivery within system operating limits. Financial transactions are forward hedges settled against physical delivery prices. Transactive Energy can be applied both in cost-of-service franchise markets and open or partially open competitive markets and markets that are transitioning to more open competitive markets. | | | |
| 2 | | **Benefits** | The benefits of Transactive Energy accrue to society at large. The benefits result from efficiency gains in investment, operation and consumption and innovation through markets. Consumers benefit from the lower costs and the use of automation to manage electricity usage and further reduce costs. Producers, wires owners and intermediaries benefit by transparent, stable long-term revenues and spot market revenues for their products to support investment recovery and profits. | | | |
| 3 | | | **Stage 1** | **Stage 2** | **Stage 3** | **Stage 4** |
| 4 | | **Dates** | **2011-2015** | **2013-2020** | **2015-2030** | **2020-2050** |
| 5 | | **Stages** | **Transactive Energy Introduction** | **Transactive Energy Expansion** | **Hybrid Transactive Energy Grid** | **Mature Transactive Energy Grid** |
| 6 | | **Scope** | Development of Transactive Energy vision, standards and pilot demonstrations of Its benefits and costs. | Deployments of Transactive Energy on portions of the grid where value is high, and there is regulatory and participant support. | Widespread deployment of Transactive Energy within some regions with interfaces to existing operations and markets as needed. | Near full deployment of Transactive Energy within many regions. |

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| 7 | **Grid Services** | **Residential Interval Meter Adoption** | Time-based measurement using of physical electricity usage and production using interval meters is critical to implementation of Transactive Energy. Larger generators and most industrial and larger commercial customers have interval metering. As indicated below, residential customers increasingly have interval meters. So called "Smart Meters" combine interval metering with two-way communication channels with the distribution operator and some on-board intelligence. Transactive Energy may employ but not require such smart meter communications as other wired and wireless communication, both one-way and two way and broadcast may also be employed using multiple interfaces, communications and device and cloud-based intelligence. | | | |
| 8 | | | (End 2012: 16 states at 100%) 33% | 50% | 75% | 95% |
| 9 | | **Retail Services** | The increasing adoption of (1) residential and commercial interval meters, (2) the internet, and (3) device automation lays the foundation for transactive retail service. Transactive Energy may apply to both regulated cost-of-service retailers and competitive retailers where local regulatory policy allows. Transactive Energy can apply to bundled or unbundled energy, transport and other services. Retail transactions must recover both variable and fixed costs which in some regions are much larger than variable costs. Transactive Energy provides actionable forward buy and sell tenders by the retailer for blocks of energy (subscriptions) at tendered fixed prices . Based on the tenders and automation a forward portfolio of energy purchases and sales is acquired that specifies the net subscribed energy in each metered time interval. Based on the meter readings the customer sells at a tendered spot price any subscribed energy not used and buys for any excess energy used at a tendered spot price. Transactive Energy service thus provides price responsiveness with a contracted baseline that provides forward hedging and bill protection. And retail transactions can be better aligned with wholesale forward and spot transactions to minimize retailer risk exposure. With automation and simple customer interfaces the customer experience and be enhanced while saving money and improving quality of service. | | | |
| 10 | | | Transactive Energy service is currently used for larger retail customers in some markets (i.e. Block and Index Contracts).<br>Demonstrate transactive retail rates for residential and commercial customers.<br>Co-existence of transactive rates with full-requirements rates, real-time pricing with indicative price forecasts and event-based demand response. | Implementation of opt-out or opt-in retail transactive service in jurisdictions with high penetrations of renewables. Demonstration of transactive retail electricity exchanges. | Transactive service common in both competitive and cost of service markets. Development of transactive retail electricity exchanges. | Competitive transactive retail energy markets, micro markets and microgrids. Further evolution of transactive retail electricity exchanges. |

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| 11 | **Grid Services** | **Distribution Services** | The roadmap envisions a transition to a distribution grid with highly variable two-way flows and increasing complexity from distributed renewables and other generation, storage, PEV, power electronics, micro grids and net-zero energy buildings. And as customers become more self-sufficient the net usage of the distribution grid declines and the volatility of flows on the distribution grid increases. This roadmap also envisions a transition to transactive distribution tariffs that provide for forward reservations and options to use distribution capability and dynamic price tenders for distribution usage in both directions that encourage efficient investment and operation. | | | |
| 12 | | | Distribution grids with high penetration of renewables and self-generation begin to investigate Transactive Energy distribution service. | Distribution grids with high penetration of renewables and self-generation implement transactive distribution rates. | Wide spread use of transactive distribution rates for distribution grids with high penetration of renewables and self-generation. | Wide spread use of transactive distribution rates. |
| 13 | | **ISO/RTO, Other Transmission and Balancing Operator Services** | Today's transmission and balancing operators comprise both vertically integrated utilities and independent operators (ISO/RTOs). The roadmap envisions continued important roles for central operators such as ISO/RTOs and integrated private and municipal utilities including custodian roles and increasing balancing roles for microgrids as outlined below. For ISO/RTOs conducting LMP auctions with multi-part bids, the roadmap envisions transition to transactive price responsive loads first with ex-post real-time prices and indicative forward prices and then to single part bid, near continuously clearing markets that continue to employ grid models that characterize the complex grid flows, constraints, and contingencies. For other operators the roadmap envisions a transition to transactive interactions with other grid participants to facilitate balancing and enforcement of grid constraints using transactive tenders, transactions and clearing and settlement methods as described below. Some RTOs and ISOs may use demand response providers and aggregators acting as virtual power plants as counterparties rather than two-way transactive interactions with other participants as a transitional technology while their retail markets are still largely based on fixed price, full-requirements tariffs but such techniques should be unnecessary in a mature transactive grid. | | | |
| 14 | | | RTO/ISOs begin to publish indicative forward prices for 5-min and hourly Intervals based on existing software. Other balancing entities begin to offer forward actionable and indicative 5-min tenders for energy and transport. | Move toward single part tenders to balancing operators by participants and actionable forward small tenders to participants by balancing operators. | More frequent clearing of single part single part tenders and publication of actionable forward tenders. | Near continuously transacted forward single part tenders for transmission and energy passed to customers and generators. |

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| 15 | **Grid Services** | **Wholesale Forward Energy and Transport Services** | Today's bilateral forward physical and futures markets generally are Transactive Energy markets. Forward generation investment and forward physical energy and capacity markets provide retailers and customers with the opportunity enter into transactions for energy and transport to meet their forecasted demand. These physical transactions may be supplemented by financial contracts settled against price indices for spot energy. | | | |
| 16 | | | No change. | Wholesale and retail markets better align products with needs of both markets. | Wholesale market better align products to meet retail exchange product needs and standards. | Transactive Energy wholesale products and standards fully aligned with Transactive Energy retail products and standards. |
| 17 | | **Grid Custodian Services** | This roadmap envisions a continuing and evolving role for today's grid custodians including FERC, NERC, Regional Reliability Coordinators, Balancing Authorities, Public Utility Commissions and Municipal Boards. We use the generic term Grid Custodian because the reliability and regulatory institutions may evolve over time and because microgrids, for example, may have their own Grid Custodians for some functions. | | | |
| 18 | | | Study of transactive methods by grid custodians and planning for pilots and early deployments. | Custodians facilitate the roadmap. | Custodians actively support the roadmap. | Custodians are fully supportive of the transactive grid. |

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| 19 | **Transactive Support Functions** | **Adequacy and Reliability** | The roadmap does not envision significant changes to existing reliability standards to accommodate Transactive Energy. The roadmap does envision a transition to more customer self-determination of supply / demand adequacy with the customer bearing the consequences of inadequacy and the costs of adequacy. NERC definitions of reliability and adequacy for the bulk power system have been evolving to the concept of an "Adequate Level of Reliability. (www.nerc.com/docs/pc/Definition-of-ALR-approved-at-Dec-07-OC-PC-mtgs.pdf). This concept appears to permit customers through self-management and price responsiveness to determine how much adequacy to purchase. | | | |
| 20 | | | Most current grid custodians establish adequacy standards such as planning reserve margins or loss of load probability. Some regions use forward capacity markets and some use procurement by vertically integrated utilities procurement to implement adequacy. ERCOT with an energy-only market relies on price to support some self-determination of adequacy. In many states renewable portfolio standards, loading orders impact adequacy. And integrated utilities, munis and coops may employ integrated resource planning. | Increasing deployment of customer site solar, CHP, and fuel cells and deployment of smart thermostats and appliances and building management systems make centralized adequacy planning more difficult and risky because of potential over or under procurement. Implementation of transactive price responsive retail rates spreads to support more self-determination of adequacy. | Widespread deployment of transactive customer rates where the prices of forward tenders guide forward purchases and investments and potentially volatile near-real-time tender prices assure real-time supply demand balance. | Adequacy is largely a matter of customer choice assured by forward transactions and spot prices allowed to reflect market surpluses and shortages. Reliability, grid protection and security remains under the control of Grid Custodians such as reliability coordinators. Customers with self-generation, microgrids, and smart devices and smart buildings have more direct control over their own adequacy. |
| 21 | | **Ancillary Services** | This roadmap envisions an evolution of some of today's ancillary services such as secondary frequency regulation and load following to transactive services. Such ancillary transactive services would be carried out using transactive options and tenders and transactions on 5-minute and 4- to 6-second intervals. Transactive call and put options with various notification lead times, strike prices and reservation premiums will evolve to provide contingency reserves from generation, storage, and end use automated response. And tenders and transactions for reactive energy (VAR) alongside real energy (W) to parties with 4-quadrant power conversion devices will monetize investment in such devices and support local voltage. | | | |
| 22 | | | Almost all ancillary services purchased and dispatched by central operators and charged to loads. | Transactive price responsive demand begin to provide 5-minute load following services | Transactive call and put options to customers and devices begin to provide contingency reserves. | Several ancillary services embedded in transactive real and reactive energy option transactions and paid for by those who use the services. |

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| 23 | **Transactive Support Functions** | **Standards** | Transactive Energy standards address the informational and policy standards in the GWAC stack. Transactive Energy builds on the technical standards in the GWAC stack. | | | |
| 24 | | | OASIS eMIX/Energy Interop TeMix Profile entered into SGIP Catalog of Standards. Tenders, Transactions are based on fixed rate of delivery over intervals. | Develop new use cases for Transactive Energy operational requirements within IEC and IEEE standards | US and international Transactive Energy standards begin to converge. | Global Transactive Energy standards aligned with other global power industry standards. |
| 25 | | **Uniform Transaction and Delivery Intervals** | Adoption of uniform time intervals for tenders, transactions and delivery is essential to efficient transactive interactions. Transactive uniform intervals must (1) have a start time and a duration such as a year, month, day, hour, 5-minutes: (2) must be nested so that shorter duration intervals nest within longer duration intervals such as twelve 5-minute intervals within an hour and account for summer time rules, leap years, and leap seconds. All intervals must begin at the start of the year, month, day, hour etc. Metering for delivery and settlement must be on uniform intervals such as an hour, 5-minutes, or 4-seconds. Transactive Energy should use at least hourly metering, and ideally 5-minute or 4-second metering. Smaller retail customers may be metered and settled on longer uniform intervals. | | | |
| 26 | | | Generally there are already standard intervals for wholesale transactions. | Continue to align retail intervals with wholesale intervals. | Extend retail to shorter intervals where needed. | Standardization of intervals is widely accepted. |
| 27 | | **Scheduling** | Generation scheduling in ISOs and RTOs is determined in day-head and real-time dispatches. No transmission scheduling is necessary in ISOs and RTOs and financial transmission rights can be purchased and sold to hedge congestion costs. Outside of and between RTOs, generation, load, and interchange schedules are submitted to transmission operators and ownership or purchase of transmission rights is necessary to support the generation and load schedules. Transactive Energy schedules are determined by physical transactions among parties at points of injection and takeout. Transactive Energy uses point-to-point Transport (T&D) products or services (obligations or options) that satisfy grid security constraints and are made available by Transport service providers for purchase and repurchase. On the distribution grid, point-to-point transport products provide both real-time management of congestion and long-term recovery of investment and hedging of real-time congestion costs. | | | |
| 28 | | | Transactive Energy scheduling piloted on distribution and transmission grids. Increasing granularity of scheduling outside of ISO/RTOS. | Path based scheduling entities begin to adopt Transactive Energy scheduling and point-to-point transport products. | Some regions implement Transactive Energy scheduling | Widespread use of Transactive Energy scheduling. |

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| 29 | **Transactive Support Functions** | **Uniform Settlement** | The roadmap envisions uniform settlement systems across the entire grid. For physical transactions, settlement is based on a sequence of forward transactions on uniform nested intervals that specifies the total rate of delivery in each metered settlement interval. The difference between the forward total rate of delivery, positive or negative is settled by a transaction at a tendered price for the metered settlement interval. For financial transactions, settlement is based on a sequence of futures transactions that are financially settled using a delivery price or index of delivery prices. The roadmap envisions near immediate settlement publication and frequent payments. Credit, collateral, or pre-payment would typically be required by counterparties and exchanges and facilitated by uniform settlement systems and rules. | | | |
| 30 | | | Uniform settlement proposals. | Uniform settlement partial implementations. | Some regions implements uniform settlements. | Wide spread use of uniform settlement rules. |
| 31 | | **Clearing, Pricing and Coordination Algorithms** | This roadmap envisions the development and deployment of automated algorithms initiating forward and real-time tenders to coordinate the decentralized optimization of devices and systems on the grid. These algorithms are used by the parties to assure that the operations on the grid observe all grid energy, voltage and other constraints. The details of such algorithms are beyond the scope of this roadmap. However, one issue in algorithm development is stability which is in part addressed by the use of forward transactions and micro transactions. | | | |
| 32 | | | No deployed Transactive Energy clearing systems.<br>Pilot single price clearing at wholesale and indicative forward prices. | Publication of forward indicative clearing prices. Early publications of forward actionable tenders to retailers. | Single price clearing at wholesale; Bid/ask clearing at retail. | Transaction clearing algorithms with proven stability, convergence and efficiency. |
| 33 | | **Device and System Management Algorithms** | This roadmap envisions devices and systems, such as HVAC, electric water heating, refrigeration, pumps, thermal storage, electricity storage and CHP that are optimally operated based on forward tenders, device constraints, other forecasts and owner preferences. The devices may also post forward tenders based on current planned operation. Forward tenders and transactions can be both long-term for investment recovery and short-term for efficient operation. | | | |
| 34 | | | Virtually no deployed Transactive Energy devices. Co-existence with existing voluntary, price-based, and direct load control methods | Increasing local and cloud based self-dispatch based on optimization and heuristic algorithms. | Self-dispatch becomes common. | Devices self-dispatched based on local optimization and forecasting algorithms. |

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| 35 | Grid Participants | Distributed Generation | The roadmap envisions that distributed generation(DG) is operated using the same tenders and type of algorithms as for generic devices above. Forward tenders and transactions can be both long-term for investment recovery and short-term for efficient operation. | | | |
| 36 | | | Low penetration of distributed generation. Begin to plan distributed generation operation based on forward indicative prices. | Higher penetration of distributed generation (20%). Local and cloud based self-dispatch based on optimization and heuristics. | High penetration of distributed generation (50%). Self-dispatch becomes common. | Self-dispatch of distributed generation in response to forward tenders. Distributed generators also originators of forward tenders. |
| 37 | | Grid Generation | The roadmap envisions that grid generation is operated using the same tenders and type of algorithms as for generic devices above. | | | |
| 38 | | | Largely centralized generation dispatch. | Centralized generation dispatch in some ISO/RTOs begins to change to single part tenders and more frequent forward dispatch. | Centralized generation and decentralized generation compete based on single part forward tenders and more frequent forward self-dispatch. | Increasingly distributed mix of generation and low load factors on many centralized generators. Self-dispatch of almost all generation in response to forward tenders. Generators also may be originators of forward tenders. |
| 39 | | Renewables | This roadmap envisions the use of automated processing of micro-tenders and transactions on short-time intervals when close to delivery to support the increasing deep penetration of variable renewables such as wind and solar on the distribution and transmission grid and within microgrids. | | | |
| 40 | | | About 20% RPS in some states. Sub hourly transmission scheduling to be required in non-ISO areas. | Higher RPS % (~33%) in some states ; sub hourly transmission scheduling and deployment of transactive methods in those states | Deployment of Transactive Energy methods in many regions enables greater penetration of variable renewables. | Automated processing of micro-transactions on short-time intervals support deep penetration of variable renewables. |
| 41 | | Customers | This roadmap envisions a transition by end-use customers (residential, commercial, industrial, etc.) towards more use of smart devices, appliances, lighting, buildings, HVAC, machines, and controllers. Smart device controllers may be hosted at the device, on-site, or by cloud service providers in response to retail tenders. The roadmap also envisions a transition to more on-site generation using PV, CHP, fuel cells and the use of on-site electricity and thermal storage and in some cases the use of customer microgrids. The roadmap further envisions a transition to transactive retail tariffs and rates as described in the Retail Services roadmap track above. | | | |
| 42 | | | Customers primarily on flat or TOU full requirements rates combined with event-based demand response programs settled against estimated base lines. Low customer participation and low automation of responses. | Customers begin to use automated communicating thermostats and building management systems to respond to price, weather, and occupancy. | Customers move to retail transactive services and further automation of response. Customers with on-site PV and other generation are high penetration adopters of transactive services.. | Customers buy and sell energy both forward and in real-time based on actionable priced tenders. Automation of device and system response and customer risk management. |

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| 43 | **Grid Participants** | **Storage** | This roadmap envisions the deployment of many types of storage at many locations on the grid in buildings, communities, substations, storage farms and at solar and wind farms. Coordinated dispatch of storage is achieved using transactive micro-tenders and transactions and self-optimization of storage dispatch that reflects the specific storage device state of charge, charge and discharge limits, storage capacity and costs. | | | |
| 44 | | | Low penetration of storage except pumped hydro. | Storage MW at about 1% of peak usage. Distributed Energy Storage deployment begins at locations with high penetration of PV. | Storage MW at about 5% of peak usage. Customers with on-site storage are high adopters of Transactive Energy services. | Storage MW at about 10% of peak usage. Transactive Energy forward tenders and transactions enable efficient dispatch of grid scale and distributed storage. |
| 45 | | **Plug-in Electric Vehicles (PEV}** | This roadmap envisions increasing deployments of PEV, first charge only and then charge and discharge capable. Using transactive forward tenders, the PEV storage is optimally charged and discharged based on customer preferences and requirements, battery capability, and warranty in response to forward tenders that reflect conditions on the local circuits, the distribution and transmission grid and energy supply and demand. Services provided by the PEV can include ancillary services such as regulation and contingency options (reserves) using transactive methods. | | | |
| 46 | | | Early deployments of charge only PEVs. | Increasing deployments of PEV and charging stations including fast charging stations. | Charge and discharge PEVs emerge. | PEV owners may both charge and discharge optimally to minimize cost and make forward reservations. |
| 47 | | **Micromarkets and Microgrids** | This roadmap envisions a transition to a grid with micromarkets within micromarkets and a multi-level structure of transactive markets. Parties may transact with other parties in their local market or in other markets where transport is available and regulations permit. Some micromarkets may be aligned with microgrids that provide local balancing and other services and that can be operated independently of other connected grids, if necessary. One important developing technology is distribution micromarkets and microgrids that coordinate local distribution services, generation and load while allowing operation independently of the main grid when necessary. Such microgrids and micromarkets provide resiliency while still supporting efficient transactions among participants within the micromarket and with other markets. | | | |
| 48 | | | Demonstration micro markets and microgrids. | More customers install self-generation, storage and controls that can support microgrids. Microgrids become common. | Expanding role of micro markets to decentralize generation operation and investment. Microgrids continue to develop. | Many microgrids operating transactive micromarkets interacting with other microgrids and micromarkets |
| 49 | | **Intermediaries** | This roadmap envisions a continuing and expanding role for intermediaries such as power marketers that provide transaction liquidity, credit, and risk management to support efficient transactions. | | | |
| 50 | | | Intermediaries provide forward market liquidity and risk management services. | Increasing role of intermediaries to provide transactive wholesale and retail liquidity extending to short duration close to delivery intervals. | Continued increase role of power marketers and other intermediaries as liquidity and risk providers. | Power marketer and other intermediaries expanded role as liquidity, credit and risk management providers. |

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| 51 | | **Environment** | This roadmap envisions both (1) transactions for shares of the actual output of specific generation sources such as wind and solar and (2) transactions for environmental certificates such as renewable energy credits (RECs), carbon credits, SOX credits and NOX credits. Generally, environmental certificates or commodities are defined by government policy and employ registries to issue and retire credits. | | | |
| 52 | | | Environmental registries for RECs, carbon etc. deployed in most US States. | Increased transactions for environmental commodities. | Transactions for environmental commodities are common. | Transactions for environmental commodity rights widely required. |

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