Evolving Energy Market Design Structures for Sustainable Development: Challenges and Solutions

Dr. Alex Papalexopoulos, Ph.D.
President & CEO, ECCO International, Inc.
San Francisco, CA
alexp@eccointl.com

July 4-7, 2017
Shandong University
Weihai, China

ECCO INTERNATIONAL
An Energy Consulting and Software Company

Outline

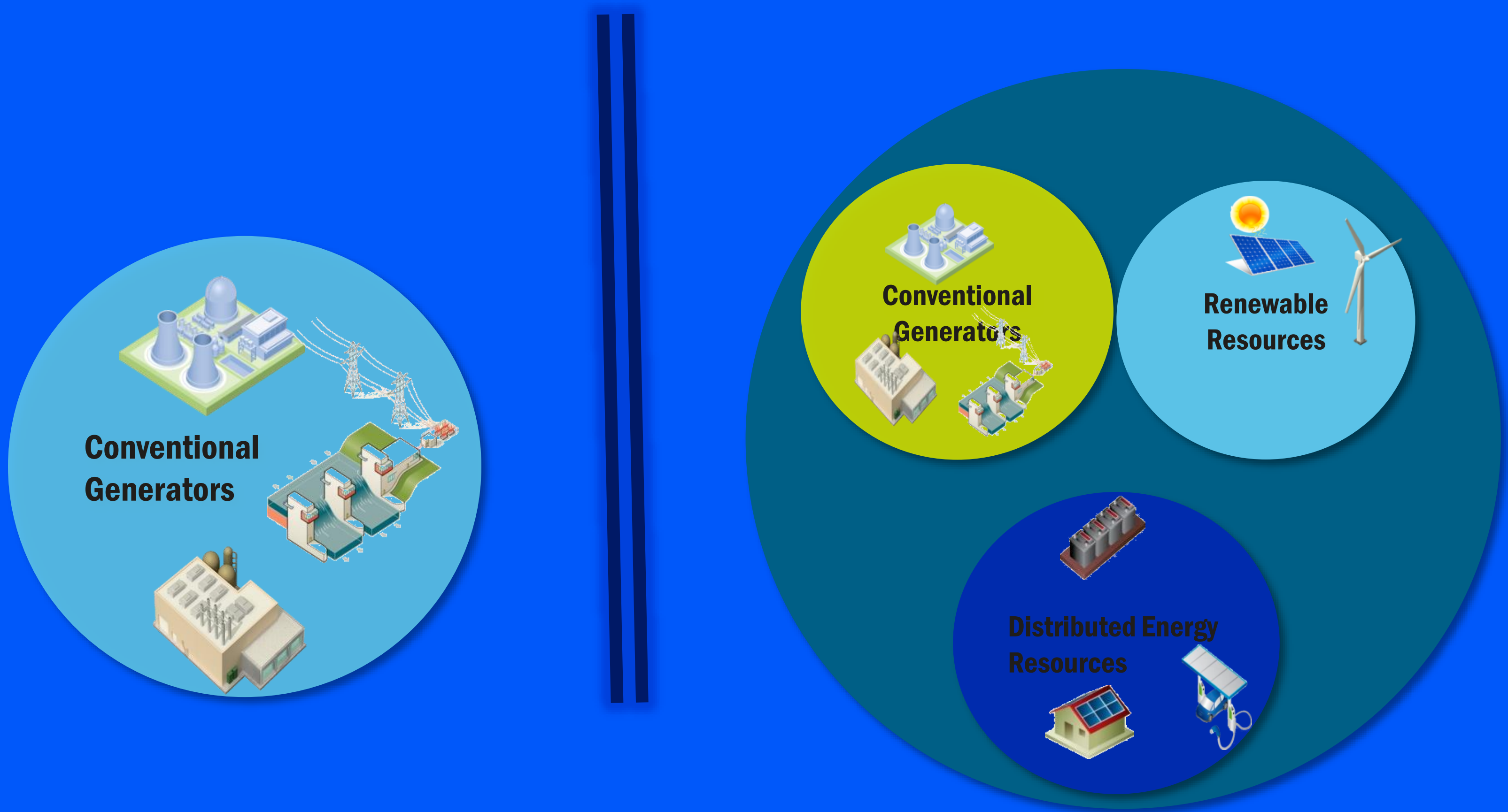
- Global Energy Trends and Predictions
- Next Generation Power Market Challenges & Solutions
- Next Generation Grid – Smart Grid Future
- The Evolution of a Centralized to a Distributed Energy System
- Distributed Energy Resources & Multi-Market Participation
- Local Distribution Power Market (DSO) Development
- Coordination of DSO Distribution and ISO Transmission
- Closing Remarks

Trends Transforming the Power Industry

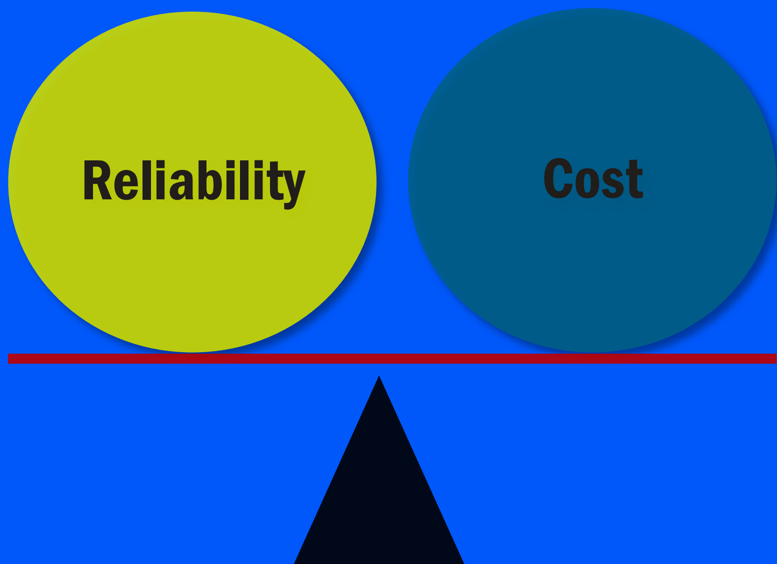
	Old	New
Load	Growing	Flat or falling
Paradigm	Centralized	Decentralized
Generation	Dispatchable	Intermittent
Gas/Coal	Coal	Gas (Shale gas)
Renewables	Expensive	Grid Parity
Grid Power flow	One-way	Bi-directional
Customers	*"Consumers"*	*"Prosumers"*
Tariffs	Volumetric	Transactive
Demand	Inflexible	Price-responsive
Data	Manageable	Explosive Growth
Electric Vehicles	Rare	Massive Penetration

ECCO INTERNATIONAL
An Energy Consulting and Software Company

The Power Market in Transition



Evolving Planning & Operating Principles



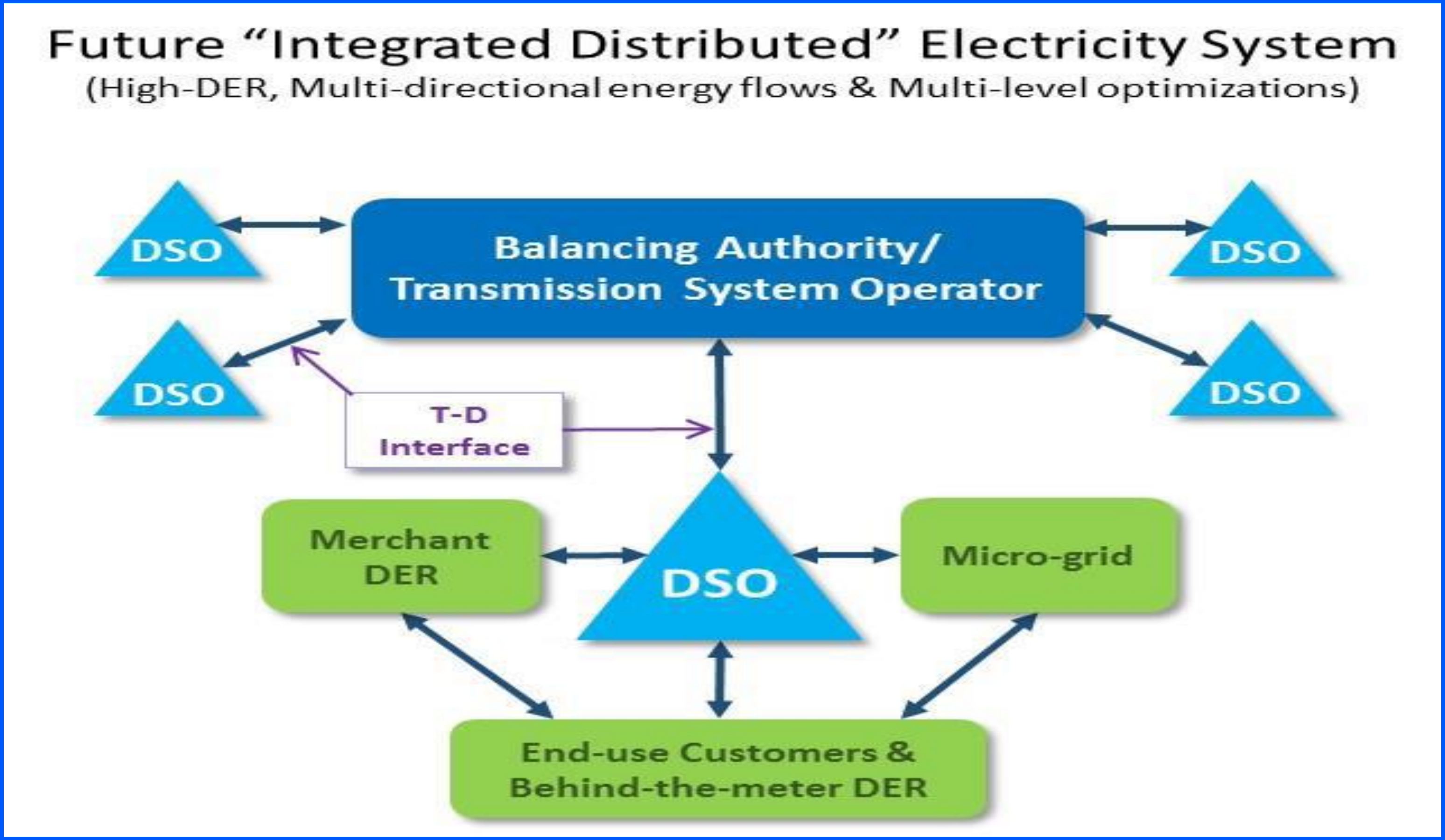
- Focus on reliability and cost
- Environmental considerations secondary

- Integrating policy into market structures
- Valuing and monetizing externalities

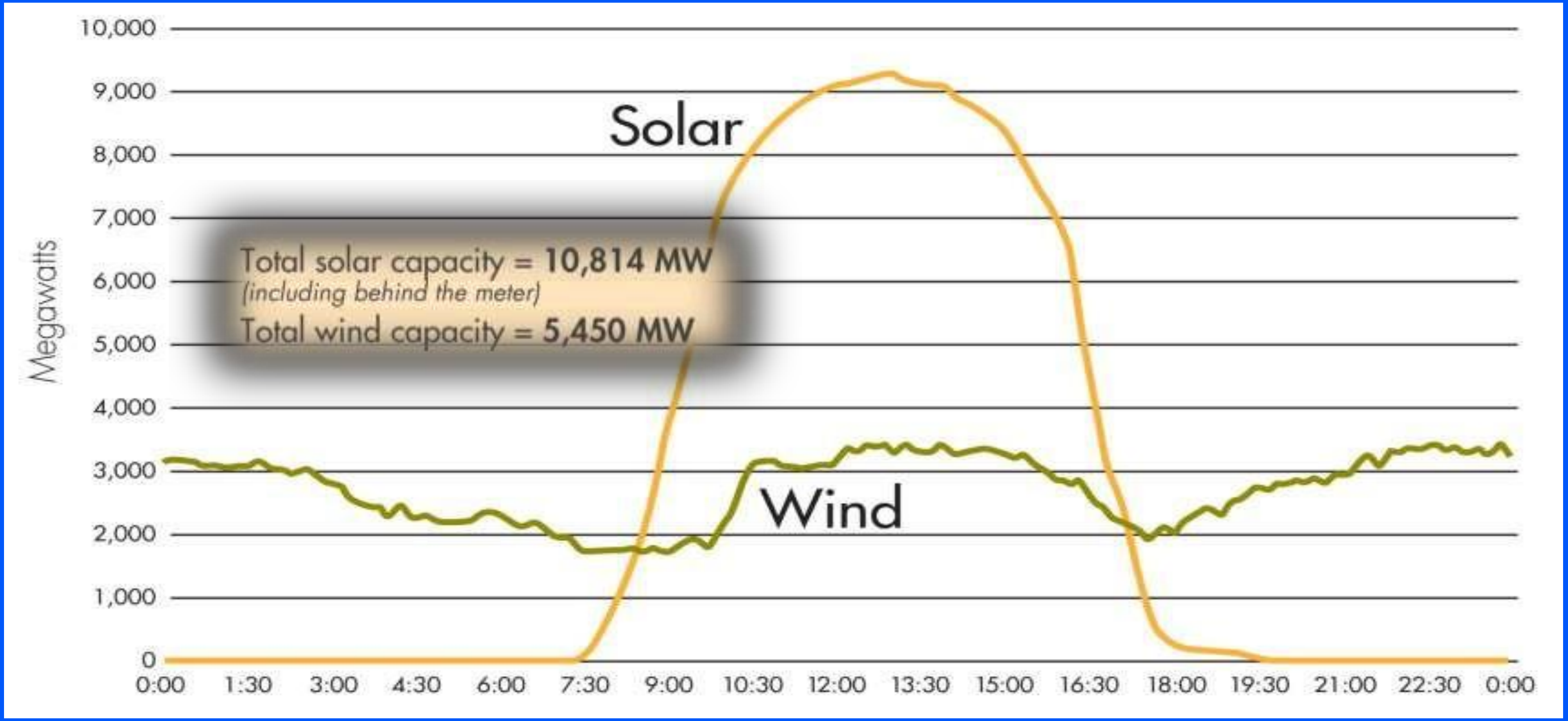
Distributed Energy Resources

- Distributed Energy Resources (DER)
  - *Solar Photovoltaic (PV) and wind*
  - *Small, gas-fueled generators*
  - *Energy storage systems*
  - *Combined Heat & Power*
  - *Microgrid systems*
  - *Demand Response*
  - *Electric Vehicles*

Integrated Distributed Electricity System

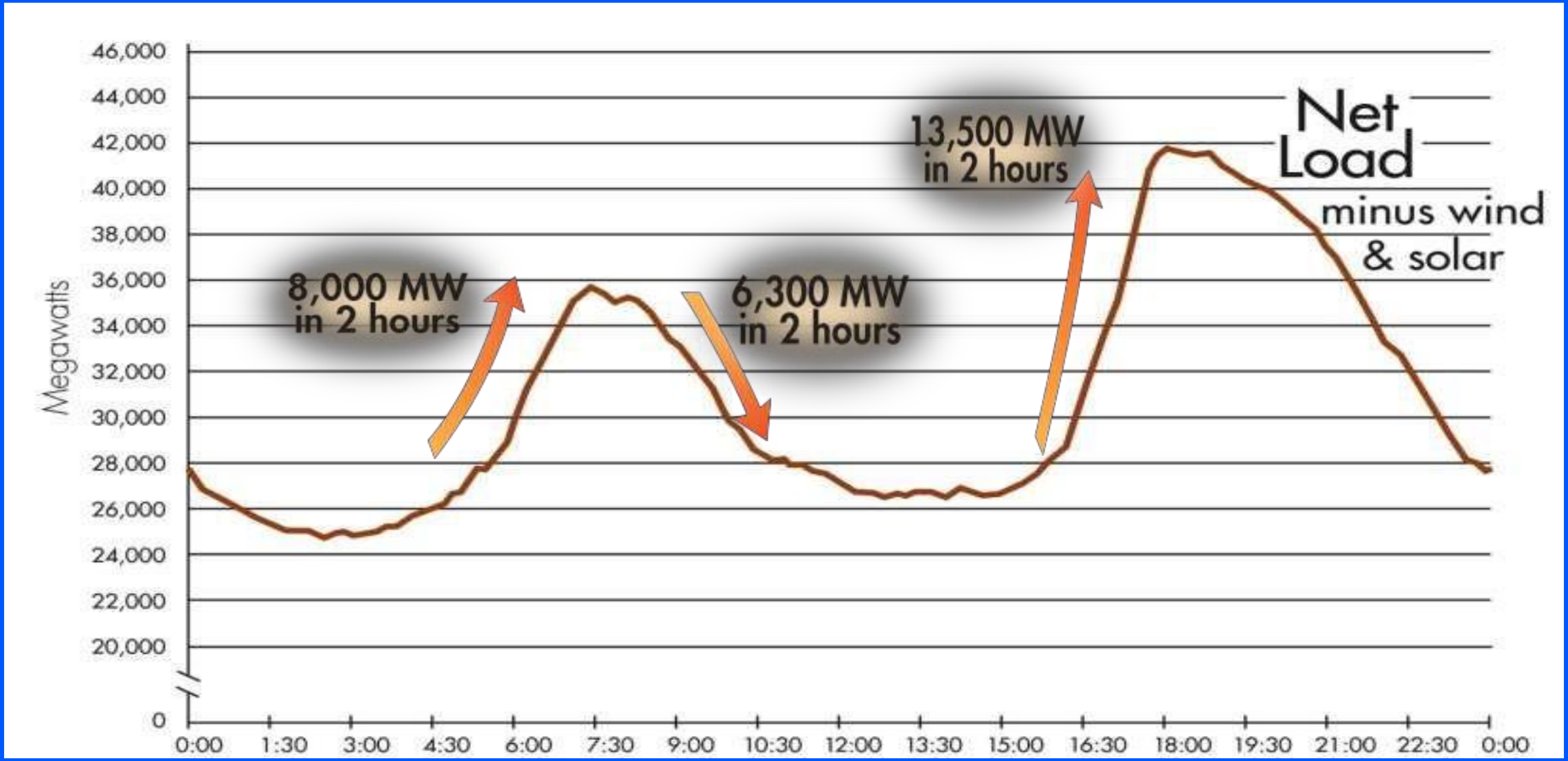


Solar and Wind Profiles: Sample Winter day in 2020



*Source: CAISO

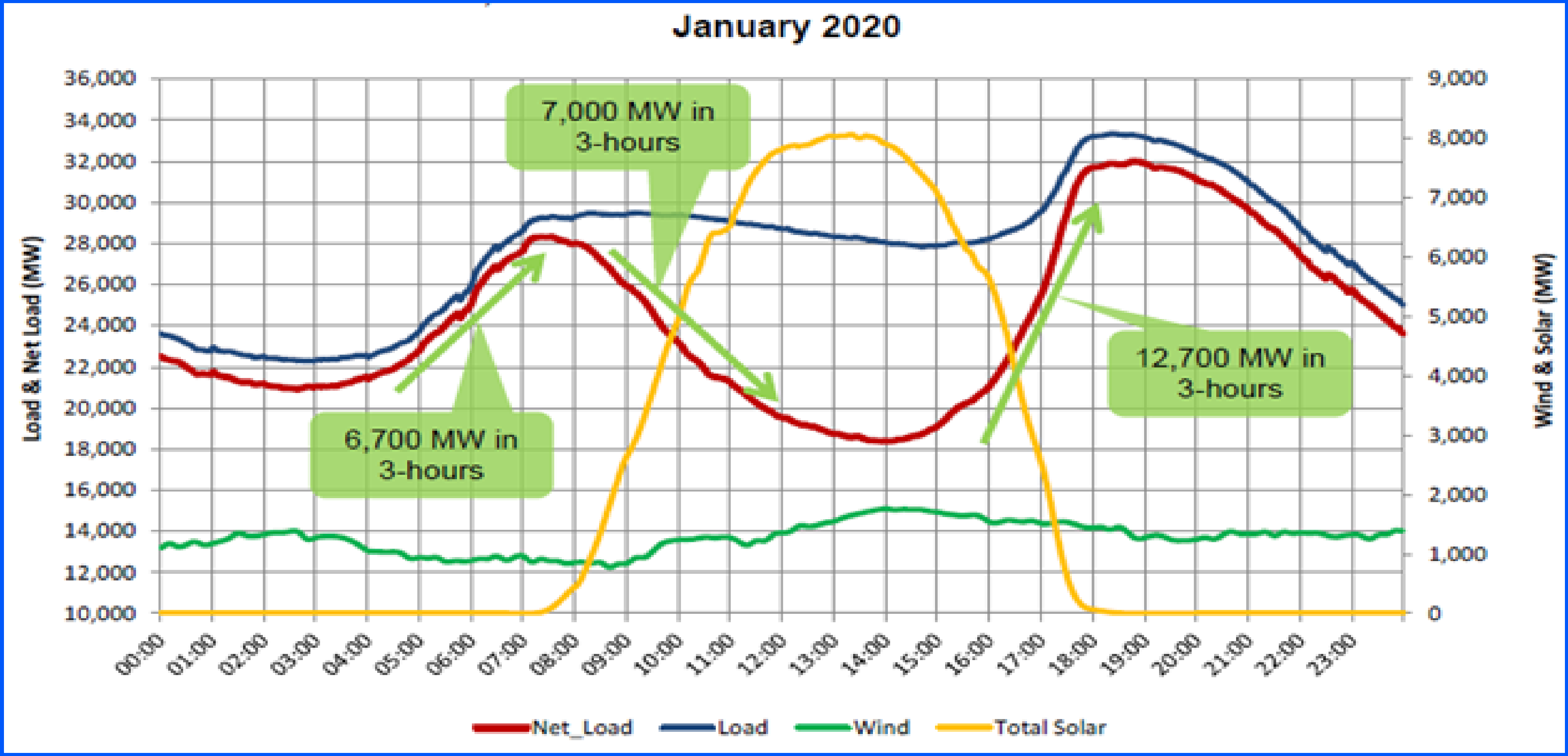
Net Load Demand Curve: Sample Winter day in 2020



*Source: CAISO

Load, Wind and Solar Profile

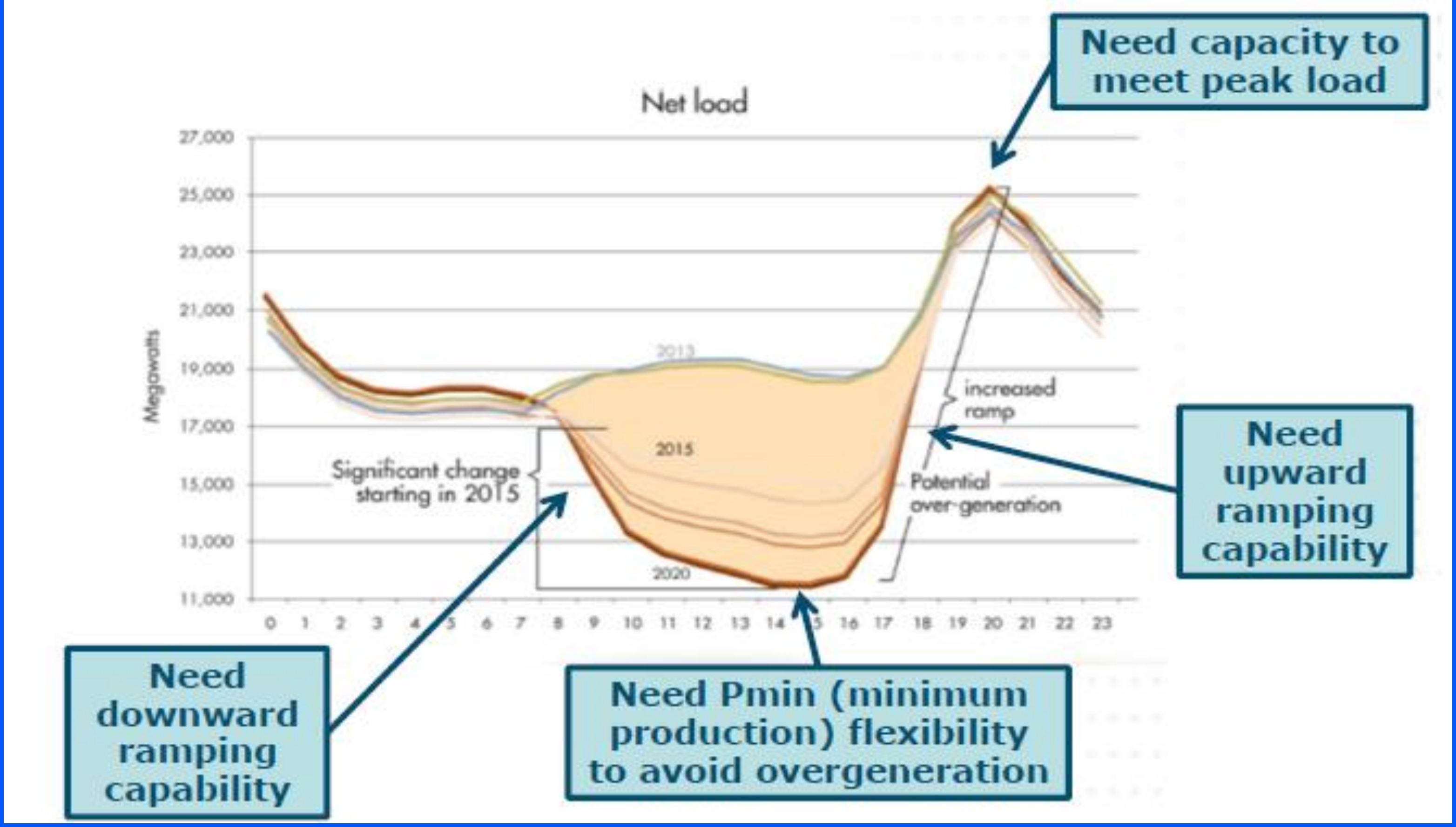
California will need 13 GW ramping in 3 Hrs by 2020



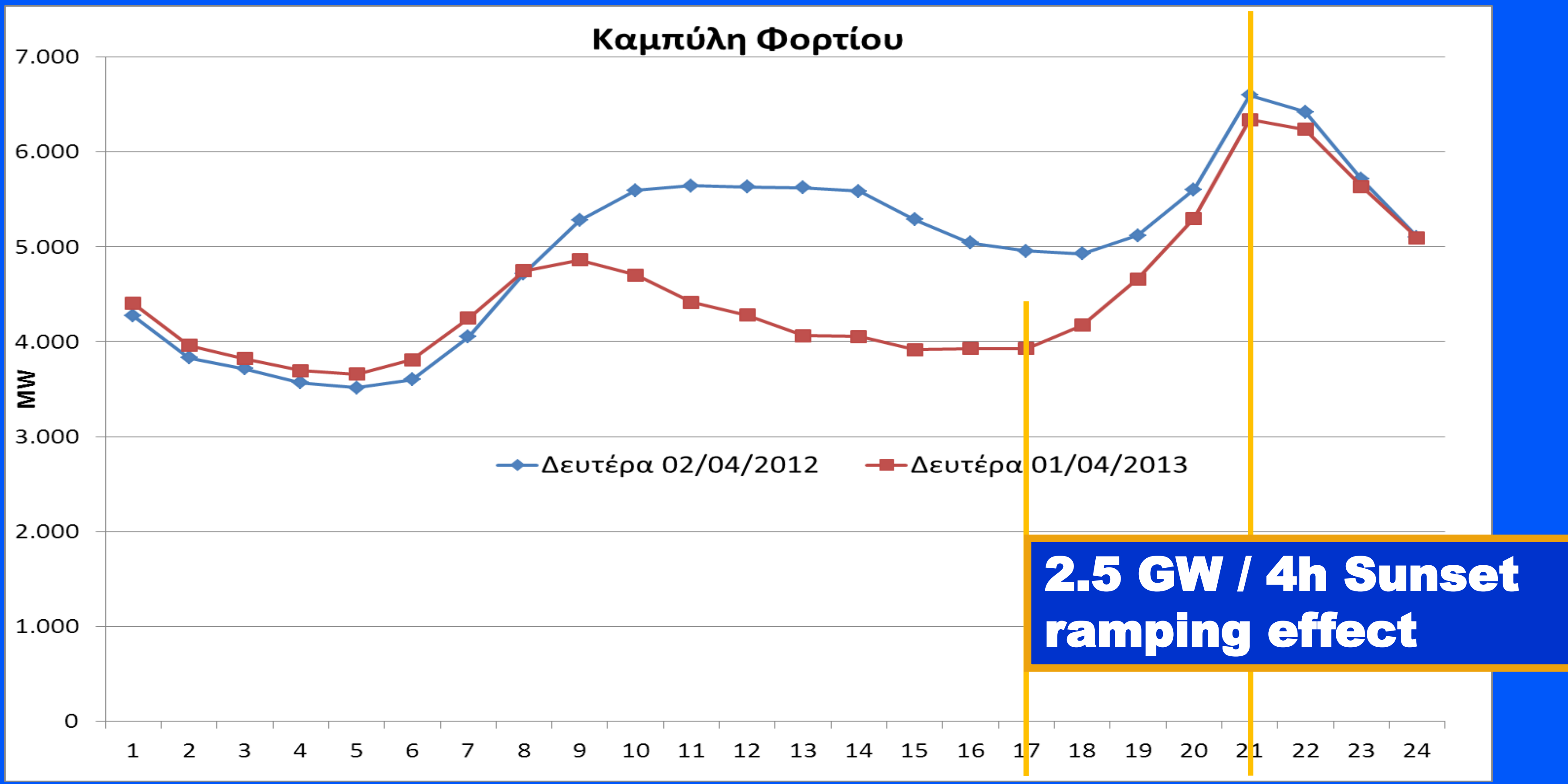
*Source: CAISO

ECCO INTERNATIONAL
An Energy Consulting and Software Company

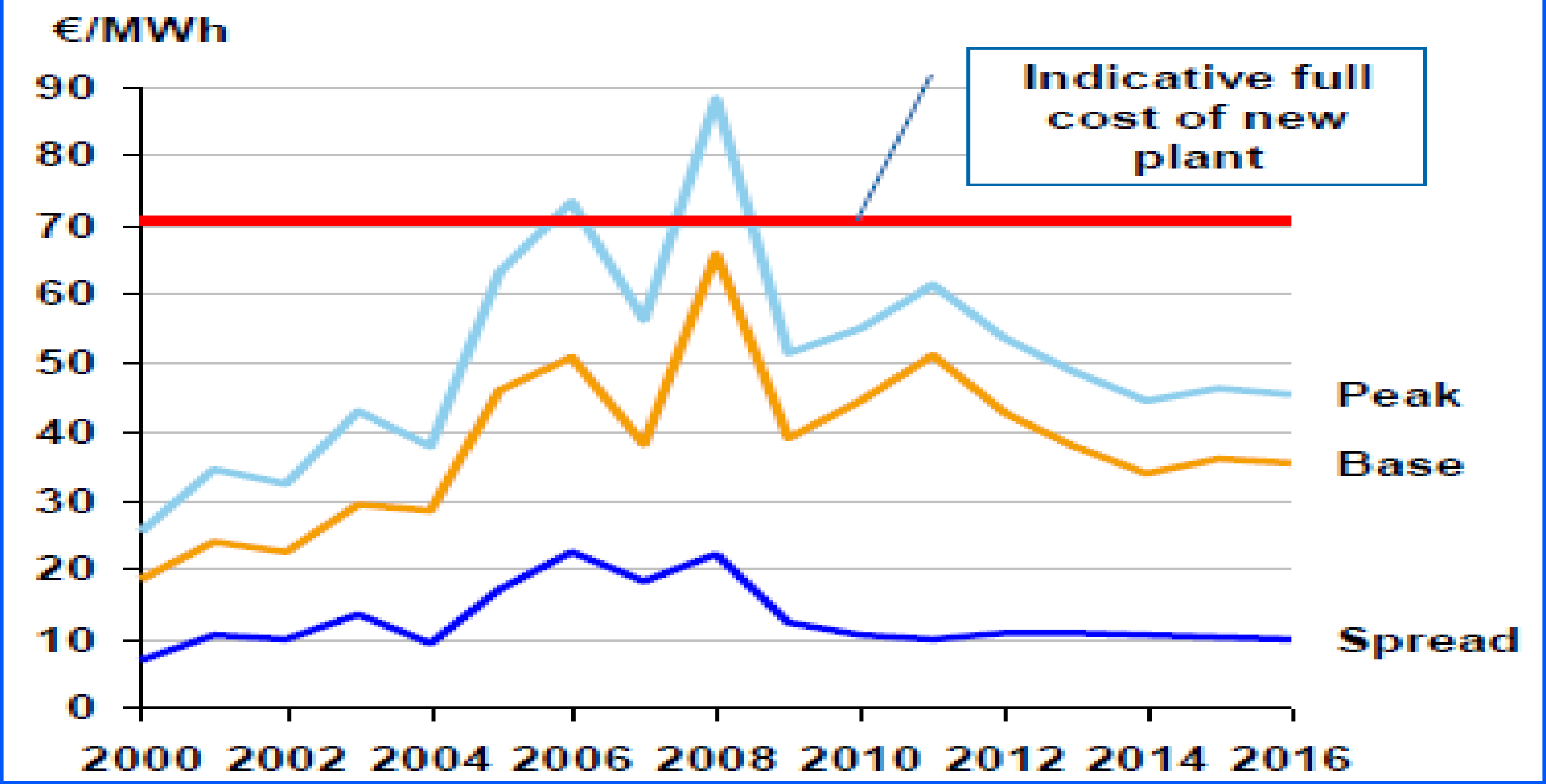
Potential Flexibility Challenges: Anatomy of a 'Duck'



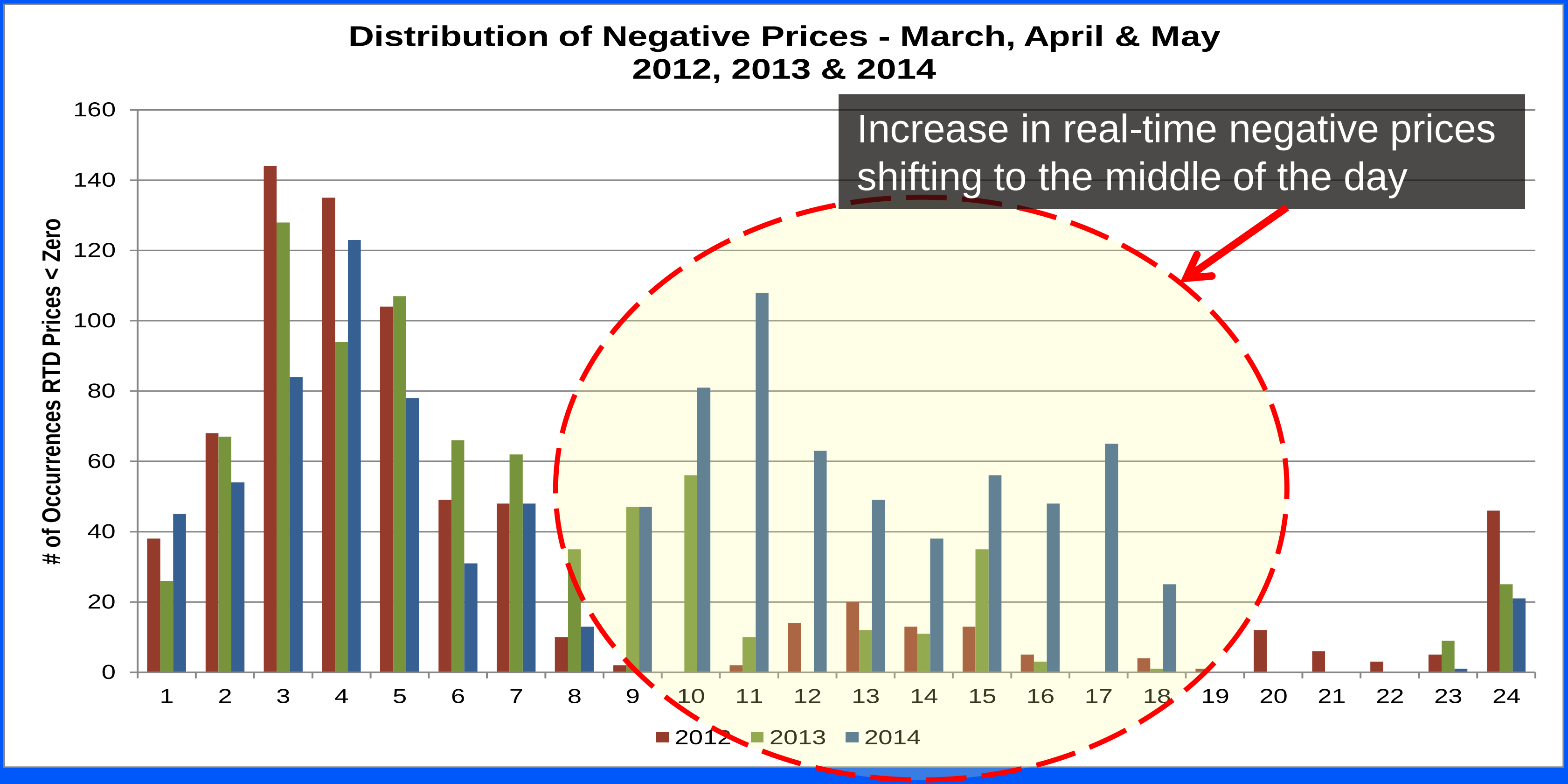
The Duck Curve in a EU market



German Wholesale Prices Down 50%



Negative Energy Prices Indicating Over-Generation Risk Start to Appear in the Middle of the Day



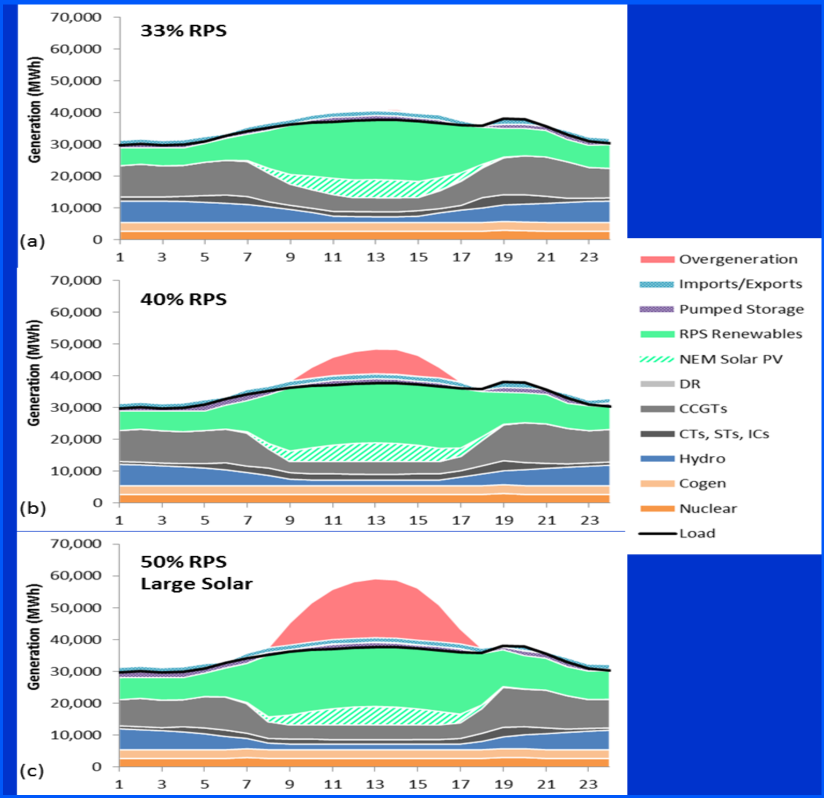
*Source: CAISO

ECCO INTERNATIONAL
An Energy Consulting and Software Company

Over-generation is the Most Significant Integration Challenge

- **Chart shows increasing overgeneration above 33% in CA**
  - Overgeneration is very high on some days under the 50% Large Solar case
  - Fossil generation is reduced to minimum levels needed for reliability
- **Renewable curtailment is a critical strategy to maintain reliability**
  - Reduces overgeneration
  - Mitigates ramping events

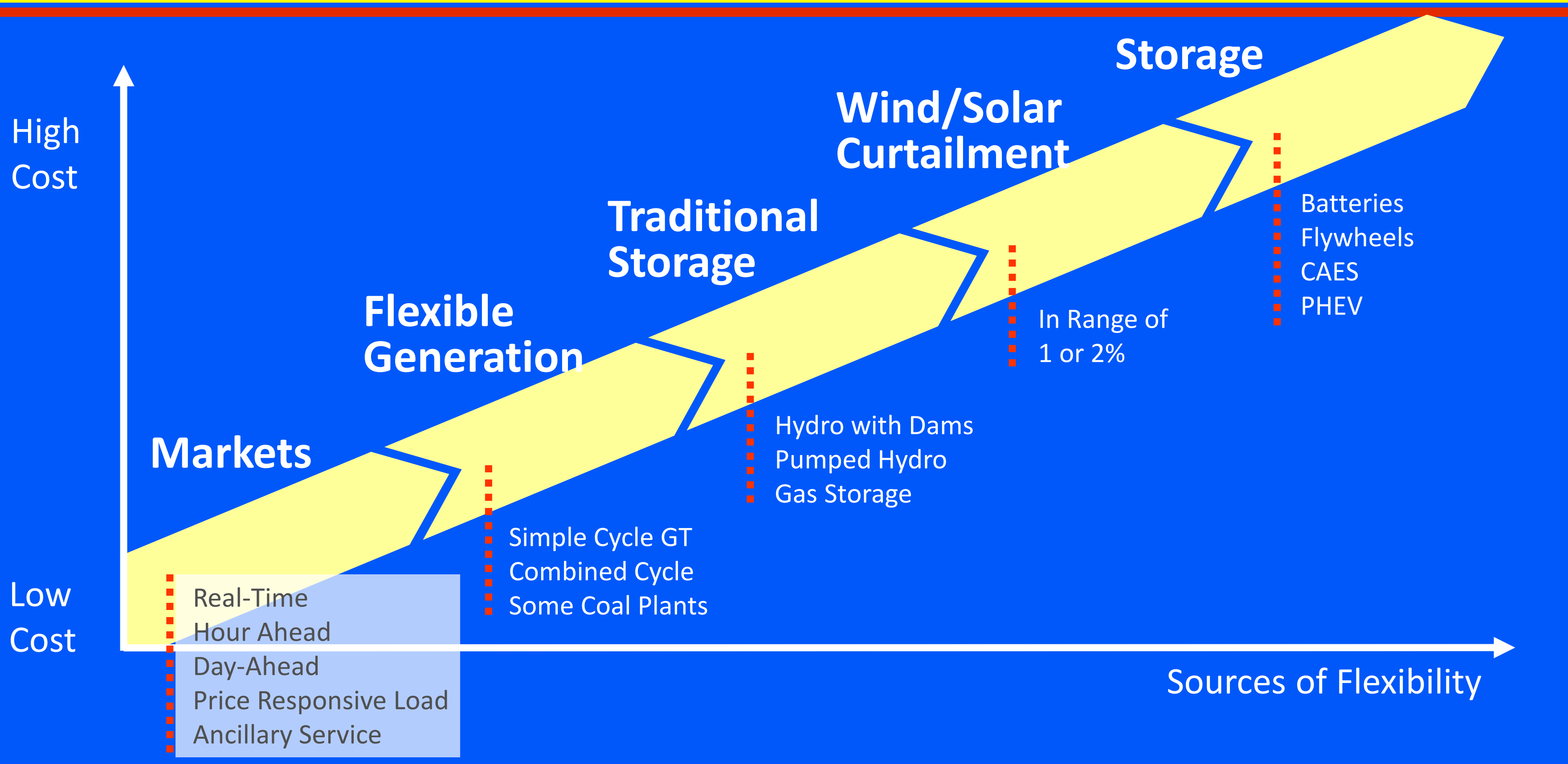
Example April Day



ECCO INTERNATIONAL
An Energy Consulting and Software Company

Flexibility Supply Curve

Study needed to determine shape of Flexibility Supply Curve and Quantify Costs

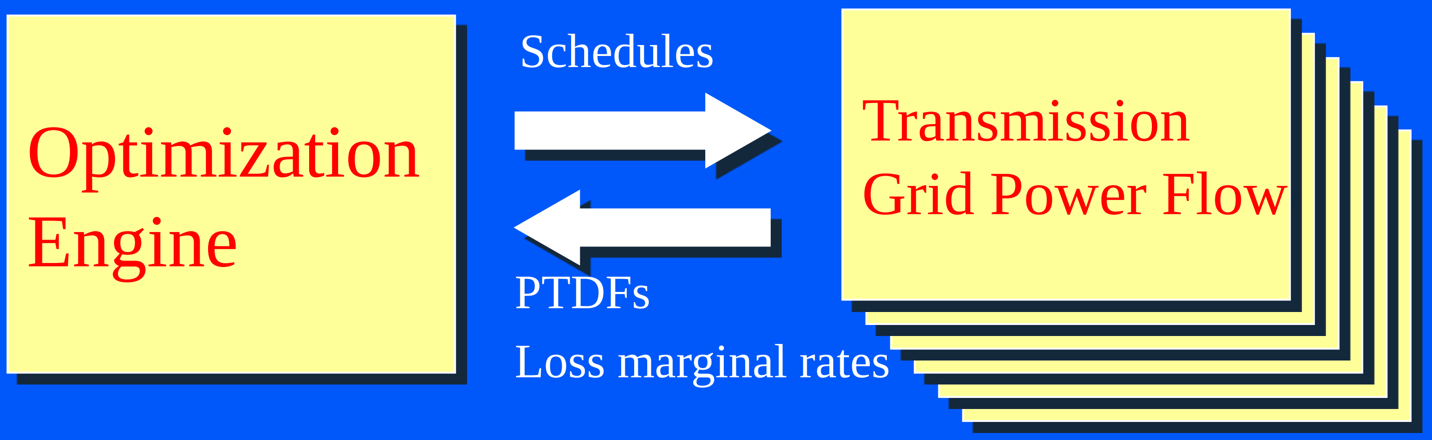


Power Market Design Elements

- Forward Market, Mitigation and Reliability Process
- Transmission & Ancillary Services Markets
- Real-Time Markets
- Financial Transmission Rights (FTRs)
- Capacity Markets
- Virtual Trading Markets

Solution Method

- Mixed Integer Linear Programming (MILP)
  - Separate power flows for each time interval
  - Iterate with optimization engine that has a single power balance constraint and the active inequality constraints for each time interval



Problem Size: Breakthroughs achieved over the Last 10 Years

- Time Horizon: 1 day, 24 increments
- Network model: 4,000 buses, 7,000 lines
- Number of Generators: 1,000
- Number of Constraints: 1,000,000
- Number of Controls: 100,000
- Performance: 10 minutes!!

Next Power Markets: Major Challenges

- <u>**Climate Change: Move to a low Carbon Economy**</u>
- Investment Issues
- Lack on proper market price signals to drive investments in new technologies – CCS is problematic (only 14 CCS projects globally)
- Renewable Integration (Short Term & Long Term)
- Demand Response products & Regulatory Incentives Alignment
- Distributed Energy Resources such as Storage

Next Power Markets: Major Challenges

- Need for Flexible Capacity Markets, Security of Supply
- Changes in Electricity Demand (Increasing ratios of peak loads to average loads, Electric Vehicles, dynamic rates, shifting loads)
- Innovative technologies for increased reliability and efficiency (EVs, sensors, communications infrastructure, control equipment, intelligent management systems, etc.)
- Data Communications, Cyber security and Information Privacy Challenges (hacking of the IoTs, the cloud and the smartphones and other devices)

Next Generation Grid Potential Solutions

- Increase the footprint of the market
- Change the Power Market architecture – design a market that properly values flexibility and capacity
- Clear power markets taking into account that we are moving into a ZERO marginal cost system
- Develop a price for Carbon – the current EU ETS system is not working
- Develop new Power Market products (Ancillary Services)
- Invest on flexible generation, like gas power plants
- Develop organized Local Energy Markets at the Distribution Level for Distributed Energy Resources
- Implement smart grid technologies and invest on the Internet of Things (IoT) in the power sector

A Price for Carbon

- Mechanisms that put a price on carbon will change the environmental footprint of economic dispatch
  - Carbon Tax – This is the most direct means of solving this problem. The tax becomes part of the marginal cost for carbon emitting plants. This leads to a seamless integration with short-run economic dispatch
  - Cap and Trade – This is an indirect approach of solving this problem. If the cap and trade system allows for banking and borrowing over any reasonably extended period, the current price of permits operates like a carbon tax. This also leads to a seamless integration with economic dispatch

A Price for Carbon

- The possible implementation details range from those consistent with efficient electricity markets to those that would destroy the necessary market fundamentals
- Good Solutions
  - Carbon Tax and Cap-and-Trade
- Bad Solutions
  - Self-Scheduling
  - Deemed Cost-Adders
  - Proliferating Subsidies

Will Market Design Survive the Implementation of Environmental Goals?

- Important Observation: It is much more effective to penalize carbon emissions than to subsidize everything else, e.g., Electric Vehicles
- Why subsidize Electric Vehicles (which we do) and not biking (which we do not)? Is the answer to subsidize all low carbon activities?
- It would prove astronomically expensive if we subsidize all low carbon activities
- Another problem is that subsidies are so uneven in their impact
- A study by the US National Academy of Sciences has shown that the net effect of all the subsidies taken together was effectively zero!
- Monetizing carbon is the key to meshing environmental goals and electricity market design

Tesla: Battery on Wheels
Storage Not Just Batteries

- ✓ The electrification of the transportation sector poses a great opportunity and a major challenge for the evolving grid
- ✓ DOE expects 400% growth in annual sales of EVs by 2023; more than 2.3 million EV cars will be in the streets in the US by 2023
- ✓ Demand on the grid will double by the end of the century
- ✓ How this demand can be aggregated for demand response?

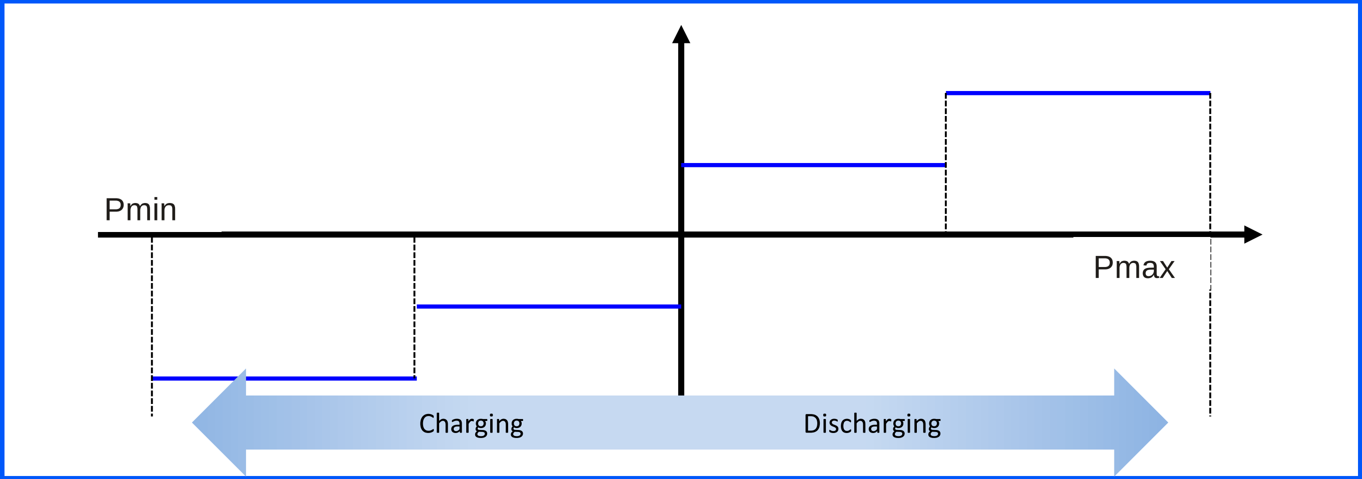
ECCO INTERNATIONAL
An Energy Consulting and Software Company

Energy Storage: The Game Changer

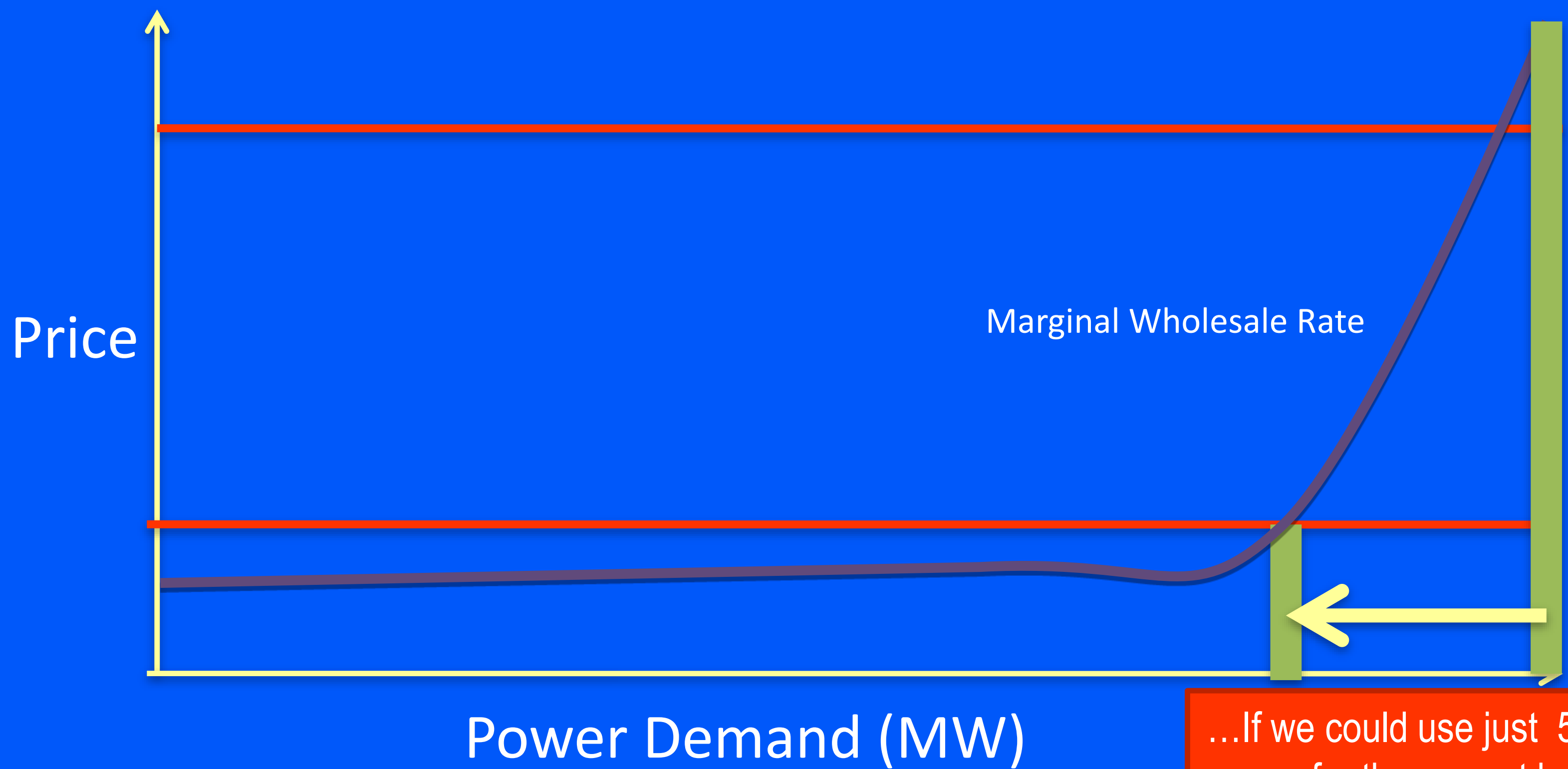
- Storage may provide multiple value streams
- Market opportunities include energy, capacity, ancillary services and transmission / distribution service to end-use consumers
- Multiple uses in distribution and behind the meter, but avoided T&D cost is likely driver in near to mid term
- Good complement for RES capacity if economics develop
- Storage capital cost may reach parity with combustion turbines in 2020 – 2023 (to about 1,000 $/KW)

Storage Modeling

- Improve model to include transition limits, opportunity costs, operating characteristics, etc.
- Stochastic problem in multiple dimensions
- The resource owner should manage limitations related to charge and discharge, depth and frequency of cycling, etc.



Electricity Markets in Pain



…If we could use just 5% less power for the current hour….

No Price-Sensitive Demand -> Inefficiency Everyone Pays For

Demand Response: Evolving Energy Trends

- Demand Response is about to make a comeback; new technologies are emerging that are not coercive and top-down; they are bottom-up, accurate, non-intrusive, precise and fast
- The approach we advocate is based on distributed-computing based stochastic control
- It identifies flexible demand on a device level, aggregates on a system level and re-distributes along with the demand target
- Aggregators will aggregate this flexible demand and using priority service concepts will bid this demand into the wholesale energy market to compete with physical generators and set the price

Key Requirements of a New Approach

- The proposed methodology departs from prior DR approaches in three key ways:
- Customers are not directly involved in auction markets
- Customers control DR availability in terms of tiers of services provided by individual appliances
- The coordination problem of determining which devices should consume power at what times is solved through distributed aggregation and stochastic control

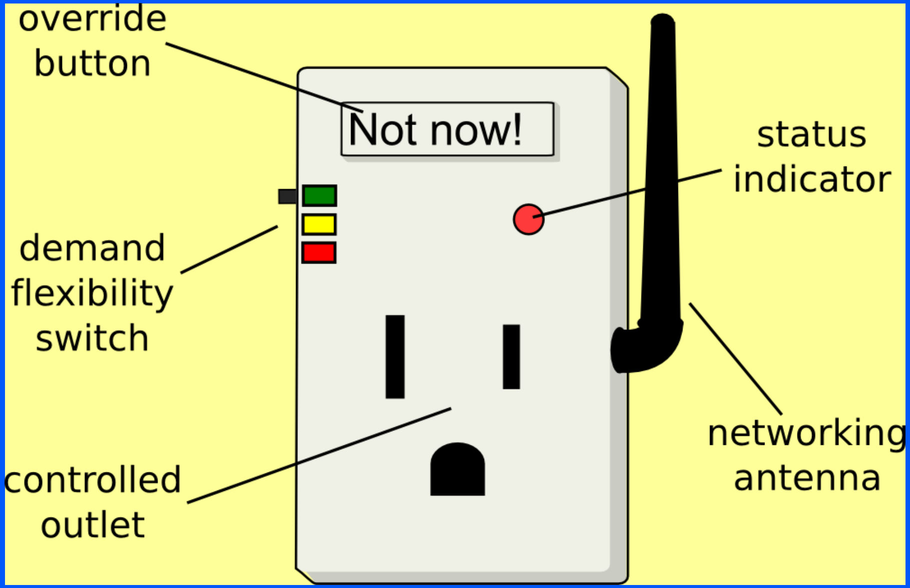
Capturing User Requirements
(colors organize devices into priority tiers)

Anytime Flexible

Peak Power

Emergencies Only

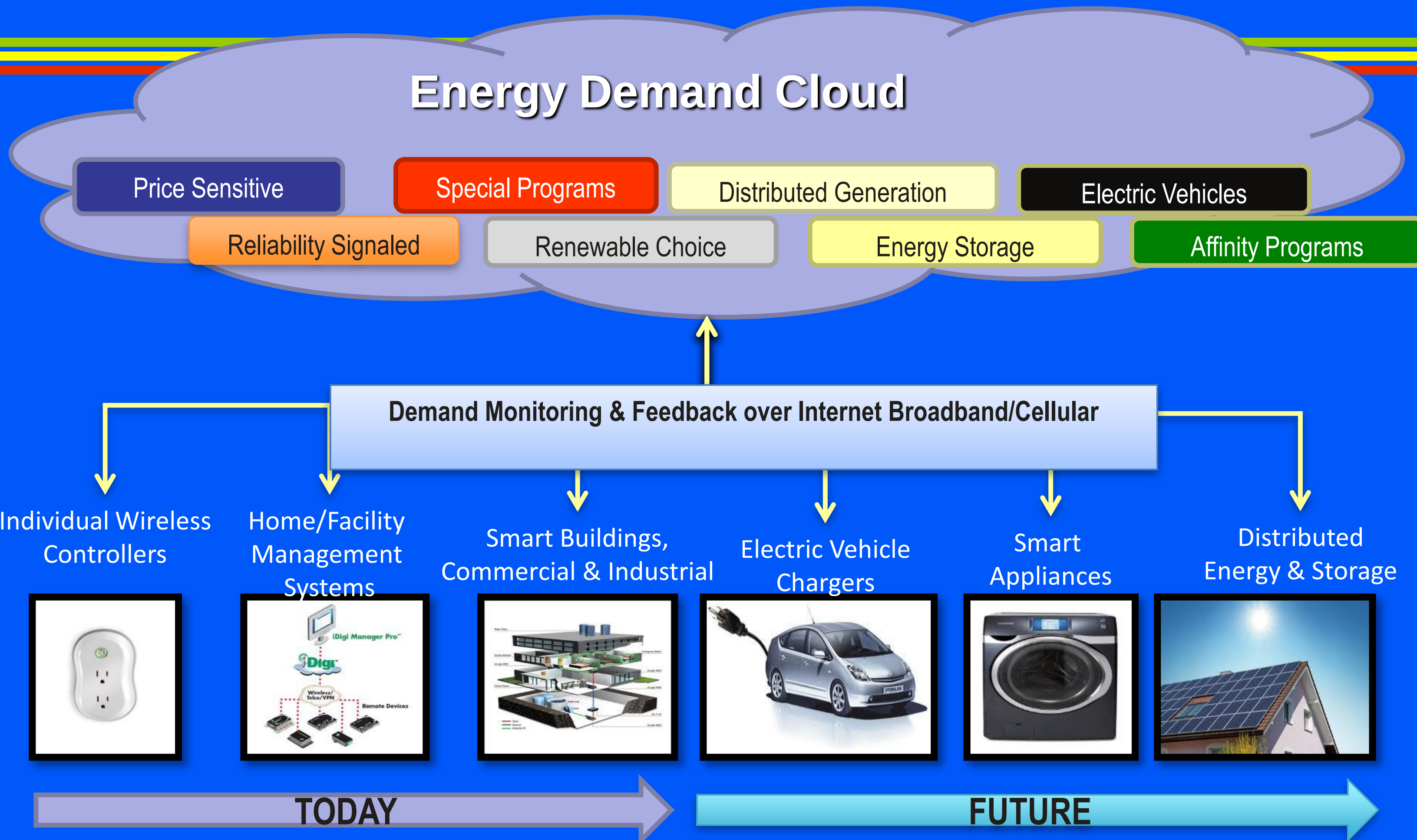
Uncontrolled



Qualitative
Energy Flexibility

Smart plugs, new appliances, home automation, …

Energy Demand Cloud



DR client is ~10kb—virtually any embedded device can run it

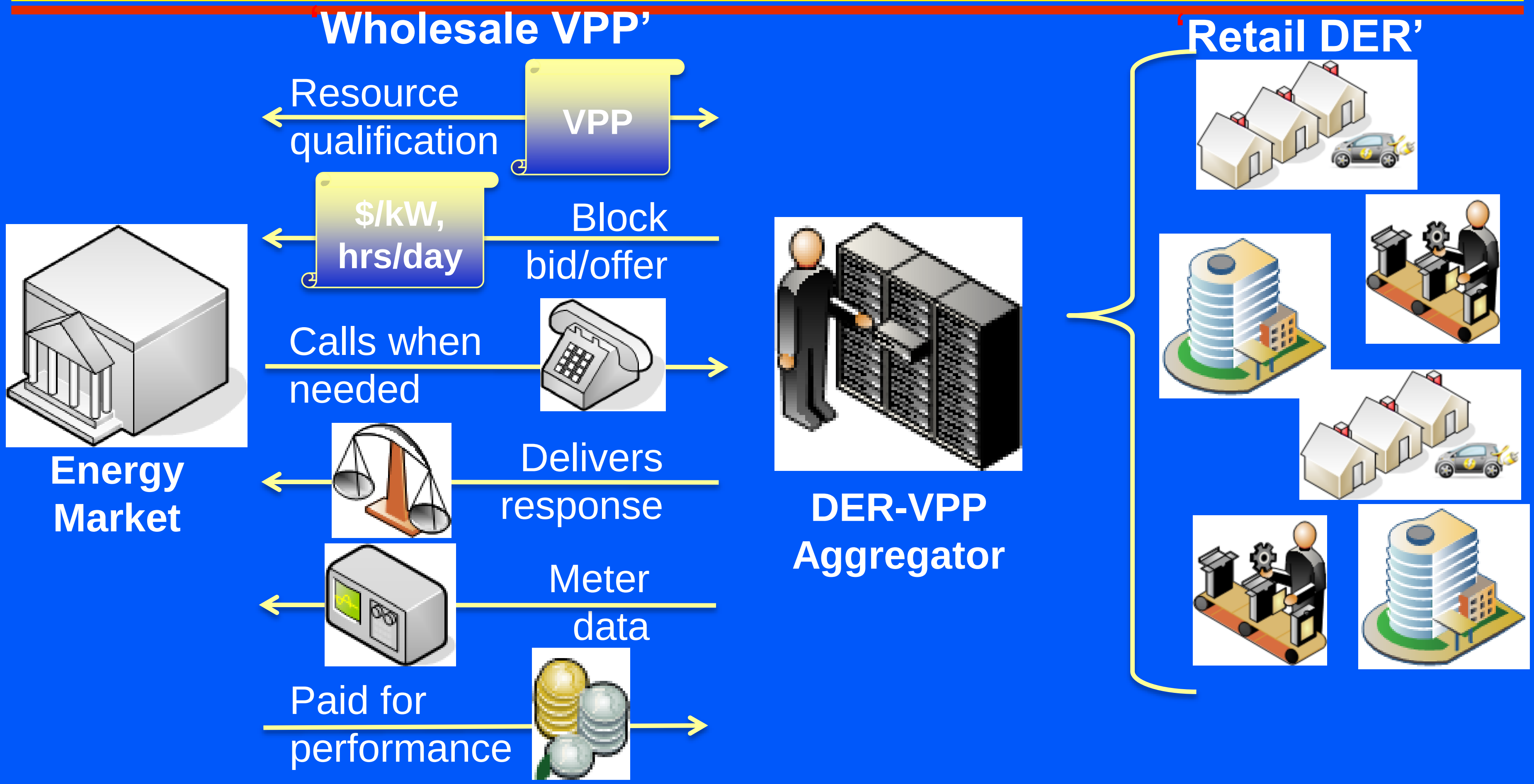
Home Energy Management

Will Google/Nest be able to monetize HEM?

- ✓ The IoTs has breathed new life in this industry
- ✓ The HEM will reach an annual value of $2.2 Billion in the US by 2022
- ✓ Advancements in mobile technologies, such as more responsive apps will allow customers to control their home devices from anywhere

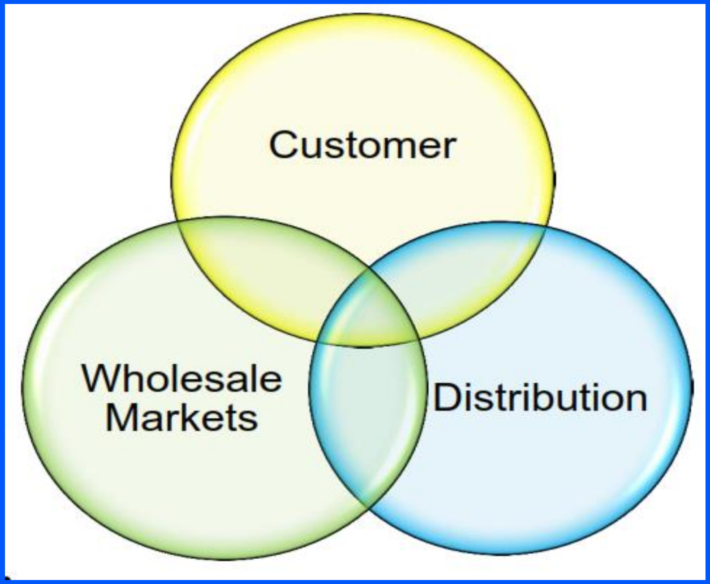
DER Aggregators and Virtual Power Plants

Aggregators hide some of this complexity via VPP abstraction



DER Multi-Market Participation

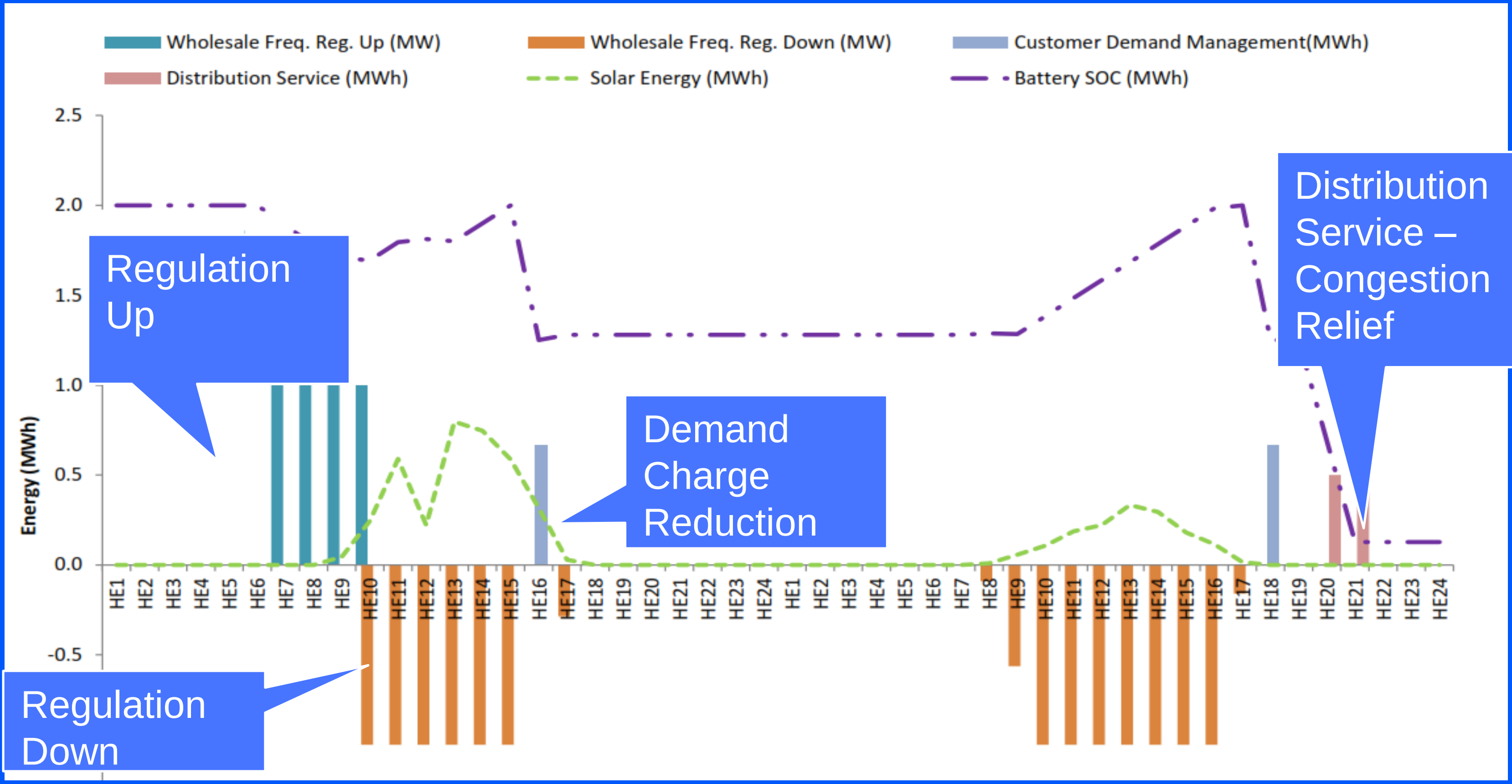
Time of Use Bill Management
Demand Charge Reduction
Back-up Power
Increased solar self-consumption
Located Behind the Retail Meter (BTM)



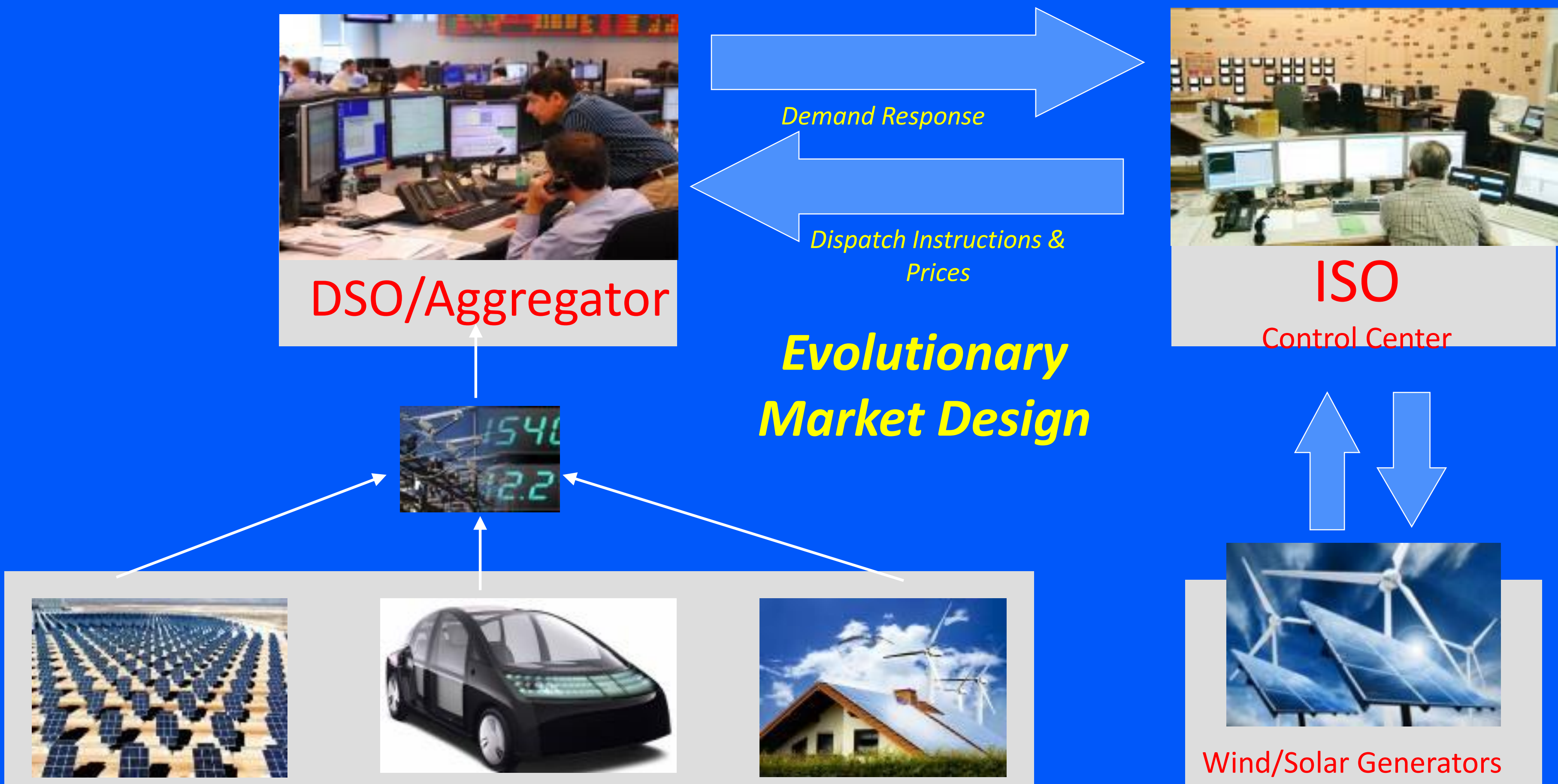
Energy
Regulation
Spin/Non-Spin Reserve
Resource Adequacy
Flexible Capacity
Flexible Ramping
Located IFOM or BTM

Distribution Asset Deferral
Reactive Supply
Voltage Control
Frequency Response
Islanding
Located BTM or IFOM

Multi-Use Application
Customer + Distribution Service + Wholesale AS



Markets & Power System Operations DR, PV, PEV aggregation and Wind/Solar integration

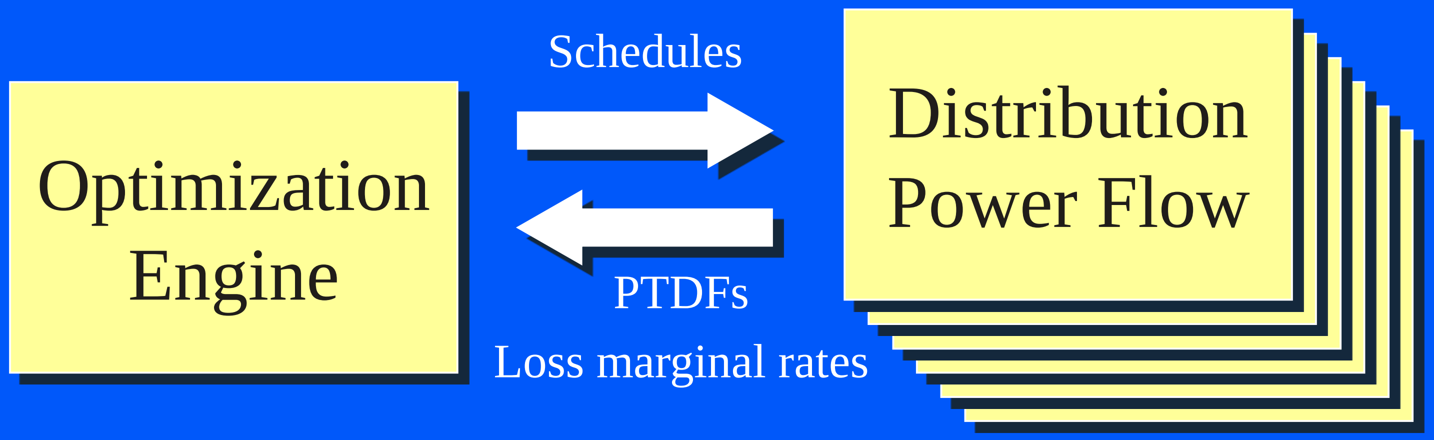


DSO Local Market Development Principles

- ECCO is in the process of developing the first DSO market of its kind in England
- We plan to follow the same principles we adopted in implementing wholesale markets
- We'll overlay the economic model (probably MIP where offers and bids are housed) on a distribution power flow
- Offers and bids will be submitted by DER aggregators and the market will clear through an iteration process between the economic model and the distribution power flow
- Distribution DLMPs (one DLMP per phase) will be produced along the feeder – these reference prices will be deployed to allow trading for transactive energy, DSO and ISO markets
- ISO LMP prices will also be used as an input to the market clearing

DSO Local Market Solution Method

- Mixed Integer Linear Programming (MILP)
  - Separate distribution power flows for each time interval
  - Iterate with optimization engine that has a single power balance constraint and the active inequality constraints for each time interval



Major Conclusions

- The market impact on transitioning to a low carbon economy has not been substantial; the transition will require trillion of dollars, not billions
- Putting a price on carbon is fundamental to maintaining energy markets (the price should be about 100 $/ton); anything lower cannot work
- Gas is the transition fuel; we need to support market structure that values flexibility
- Policy and technology are contributing to transition the grid from a centralized system to a distributed system
- Intelligence is moving to the edge of the grid – smart grid
- The development of organized Local Energy markets (DSOs) is essential
- Coordination of transmission and distributions systems and markets is essential

In the Past Utilities Sold Energy, in the Future will sell Energy Insurance
New Electric Company: Your Home