Pathways to the Utility of the Future

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Discussion Agenda

- **Long-term vision for electricity industry: the Grid of Grids (GoG)**
- **The big gap between future and present, and pathway(s) during the transition**

Electricity Industry 2050?

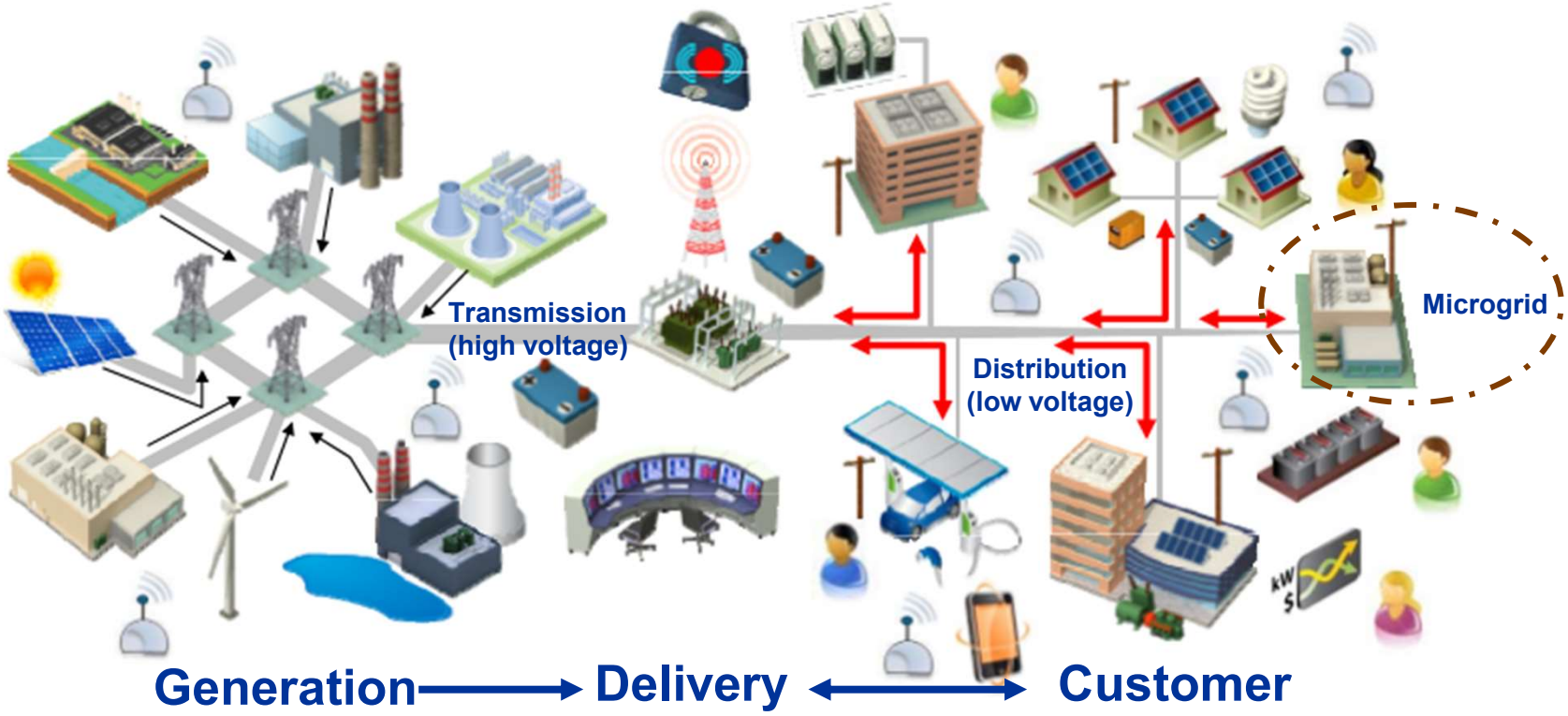
Desired outcomes

- Zero carbon emissions from power generation
- Full electrification of vehicles and space heating
- Increased resilience to sources of disruption

"Grid-of-grids"

- 100% supplied by renewables plus energy storage
- Customer-sited resources (DER) and islandable microgrids
- Intercustomer balancing via local distribution utility
- Interregional balancing via transmission (increasingly DC)
- Cloud services and blockchain for transactability between all parties

The GoG: A "Grid-of-Grids"



An Interconnected Power System Balancing Forecasted Resources with Dispatchable Loads

Source: "The Future of the Electric Grid and the Role of Energy Storage" Electric Power Research Institute, May 24, 2016

Characteristics of the GoG

ENABLING TECHNOLOGIES	INFRASTRUCTURE	END-USER DEVICES	APPS AND SERVICES
Connectivity	Distribution System Upgrades	Smart Meters	Billing
Cybersecurity	Transmission System Upgrades	Smart Thermostats	Web
Data Storage and Management	Supergrids	Smart Appliances	Outage Solutions
	Drones and Robotics	EV Chargers	Call Center
	Solar	Home Energy Storage	IT Systems
	Wind	Smart Solar Inverters	Analytics
	Microgrids		
	Utility-Scale Storage		

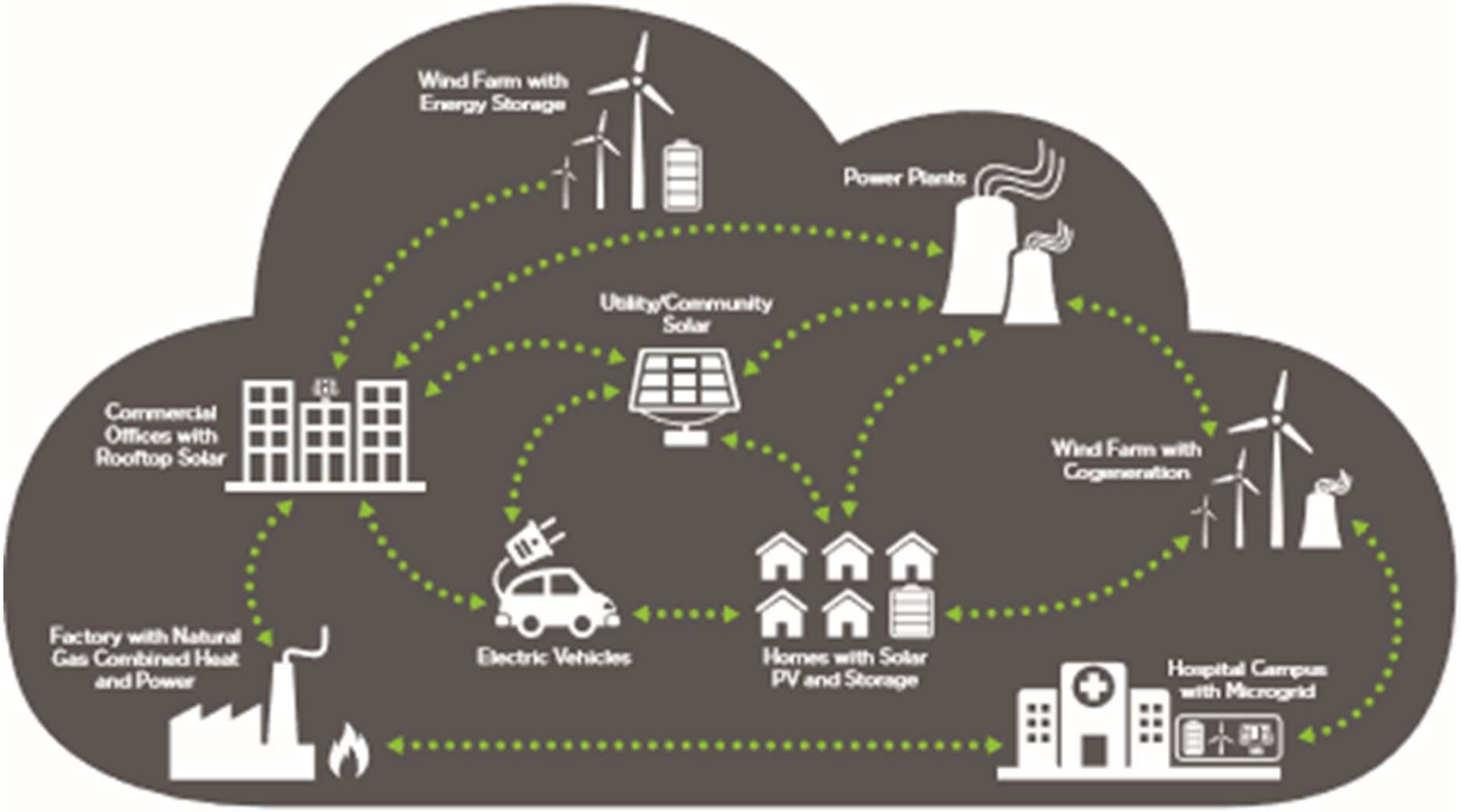
Source: Navigant "From Smart Grid to Neural Grid", 1Q 2018

GoG Technology Advancements

Grid Component/Opportunity	Description
AC/DC power flow controllers/converters	Technologies that adjust power flow at a more detailed and granular level than simple switching.
Advanced multi-mode optimizing controls	Controls capable of integrating multiple objectives and operating over longer time horizons, to replace simple manual and tuning controls, or controls that operate based only on conditions at single points in time.
Bilaterally fast storage	Energy storage in which charge and discharge rates are equally fast and thus more flexible.
Control frameworks	New hybrid centralized/distributed control elements and approaches.
Management of meta-data, including network models	New tools for obtaining, managing, and distributing grid meta-data, including electric network models.
Synchronized distribution sensing	Synchronization of measurements in order to provide more accurate snapshots of what is happening on the grid.
Transactive buildings	Buildings with controls and interfaces that connect and coordinate with grid operations in whole-grid coordination frameworks.
"X"-to-grid interface and integration	Interface technologies, tools, and standards for the general connection of energy devices to power grids; includes integrated mechanisms for coordinating those devices with grid operations in whole-grid coordination frameworks.

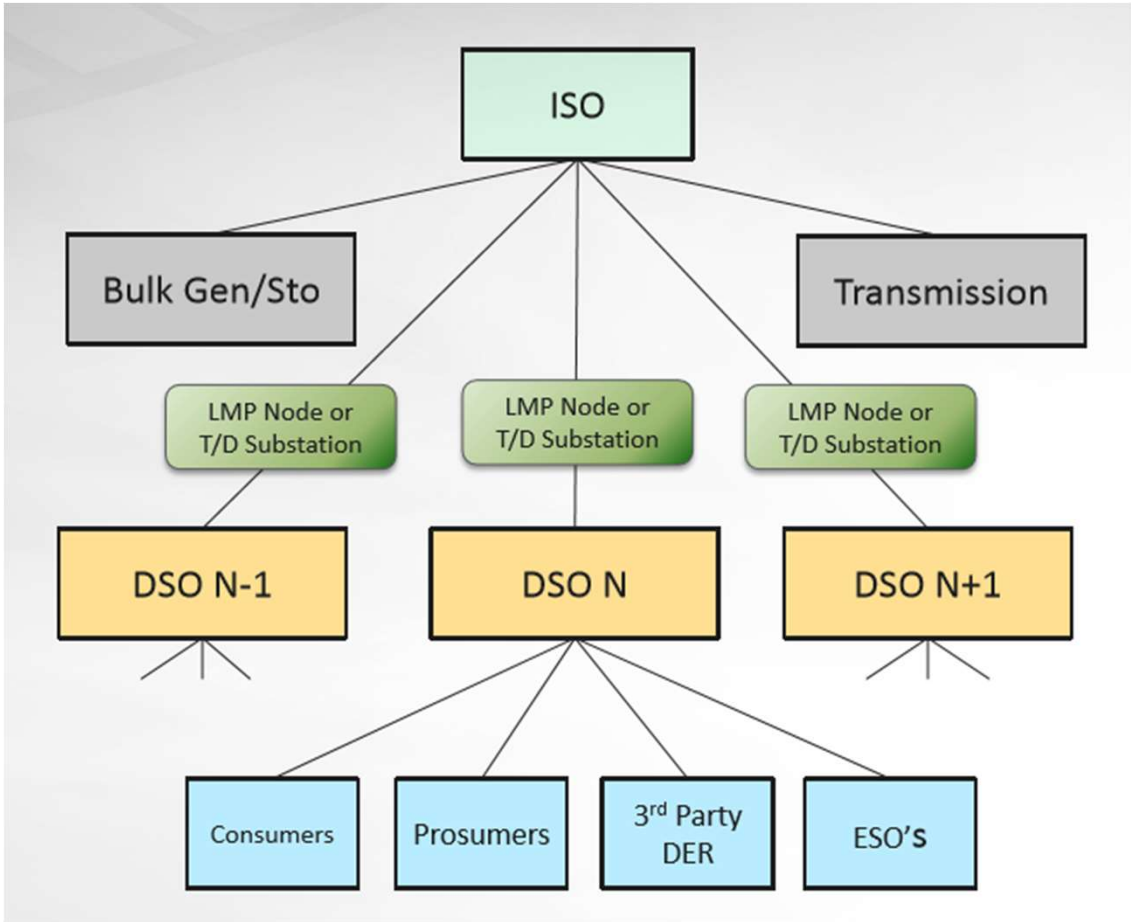
Source: DOE Quadrennial Energy Review, January 2017

Transacting on the GoG Via the Cloud



Source: Navigant "From Smart Grid to Neural Grid", 1Q 2018

Industry Structure in the GoG



Bulk power grid dispatcher and wholesale market administrator

Participants in wholesale markets: bulk power asset owners and operators

Distribution system operator (local utility grid assets) and DER market administrator

Buyers and sellers of energy in DER markets

Source: PNNL "Grid Architecture and the Interactions of Power Systems, Markets and Grid Control Systems" July 2015

Key Gaps Between Today and the GoG

The GoG

- 100% renewables
- Plentiful storage
- Lots of long-distance point-to-point HVDC
- Microgrids
- Cloud and blockchain transactability
- Digitally-controlled
- Operations based on predictive analytics

Today

- <10% renewables
- Minimal storage
- Mostly latticed AC network
- Common distribution
- Closed SCADA-based systems
- Mostly analog
- Rules-based grid operations

Gaps

- Massive investment requirements
  - Generation
  - Storage
  - Transmission
  - Distribution
  - Communications
  - Control systems
- Major shifts in institutions
  - Regulatory compact
  - Market structures
  - Role of operators

Closing the Gaps

Massive investment requirements

- Generation
- Storage
- Transmission
- Distribution
- Communications
- Control systems

…easier to incur as technologies improve and costs fall, but will only happen with/when…

Major shifts in institutions

- Regulatory compact
- Market structures
- Role of operators

Institutional Shifts to Enable the GoG

What needs changing	Changes required
Regulatory compact	• Full retail competition, encompassing commodity supply and DER services (including microgrids) • Distribution service redefined as wires ownership/operation and peer-to-peer transaction facilitation under fixed (rather than variable) price tariffs
Market structures	Wholesale energy markets restructured to • Adequately compensate investments in renewables and storage with near-zero variable costs and • Manage bulk power grid operations to maintain reliability
Role of operators	• Distribution grid operated by local monopoly utility as a platform (DSO) supporting peer-to-peer transactions • Transmission grid operated by ISO to facilitate balancing between DSOs • Both with significantly enhanced commitment to cybersecurity and privacy to protect cloud-based transactions and operational signals

Economic Misalignments to Solve

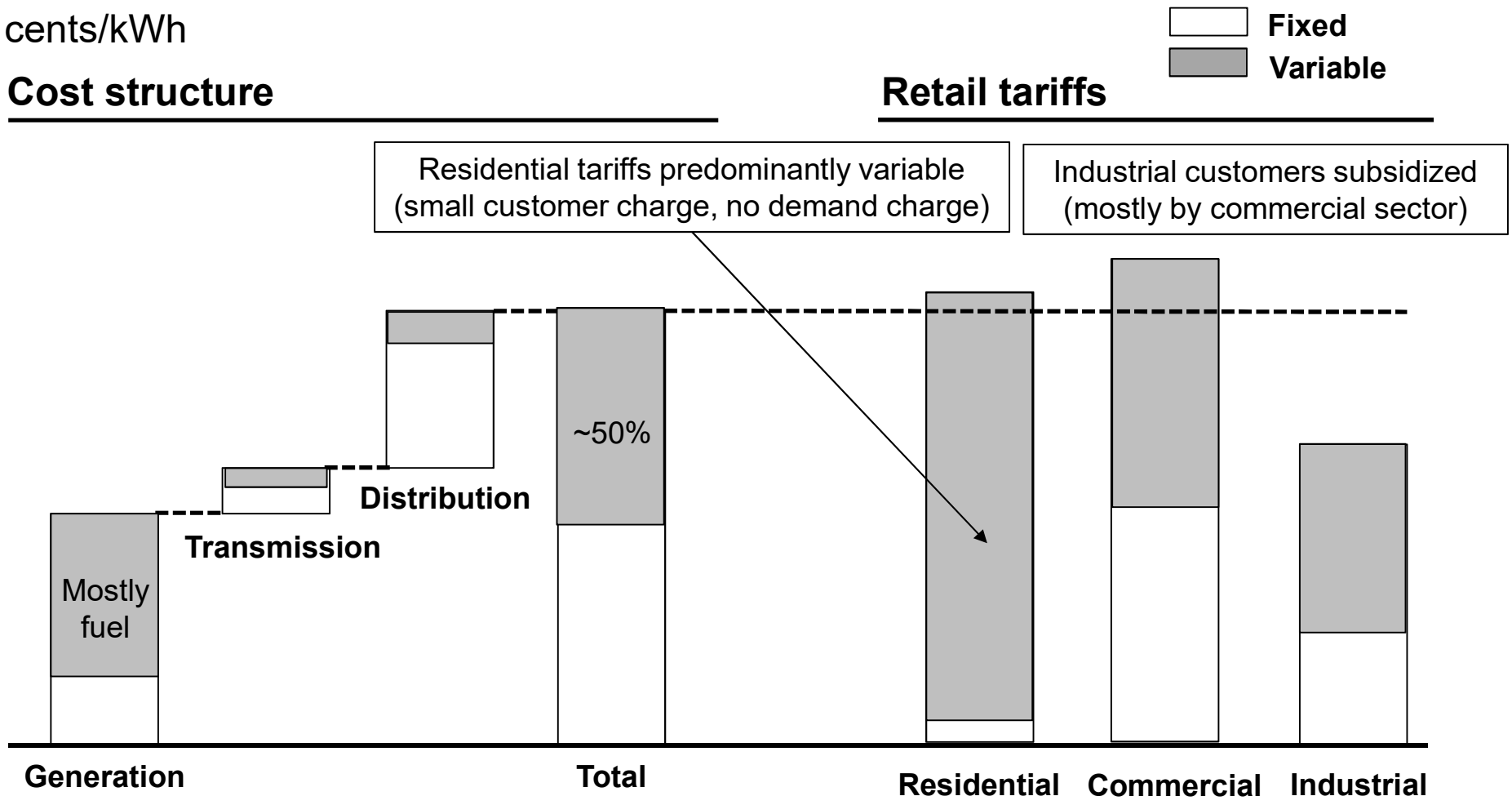
Major shifts in institutions

- Regulatory compact
- Market structures
- Role of operators

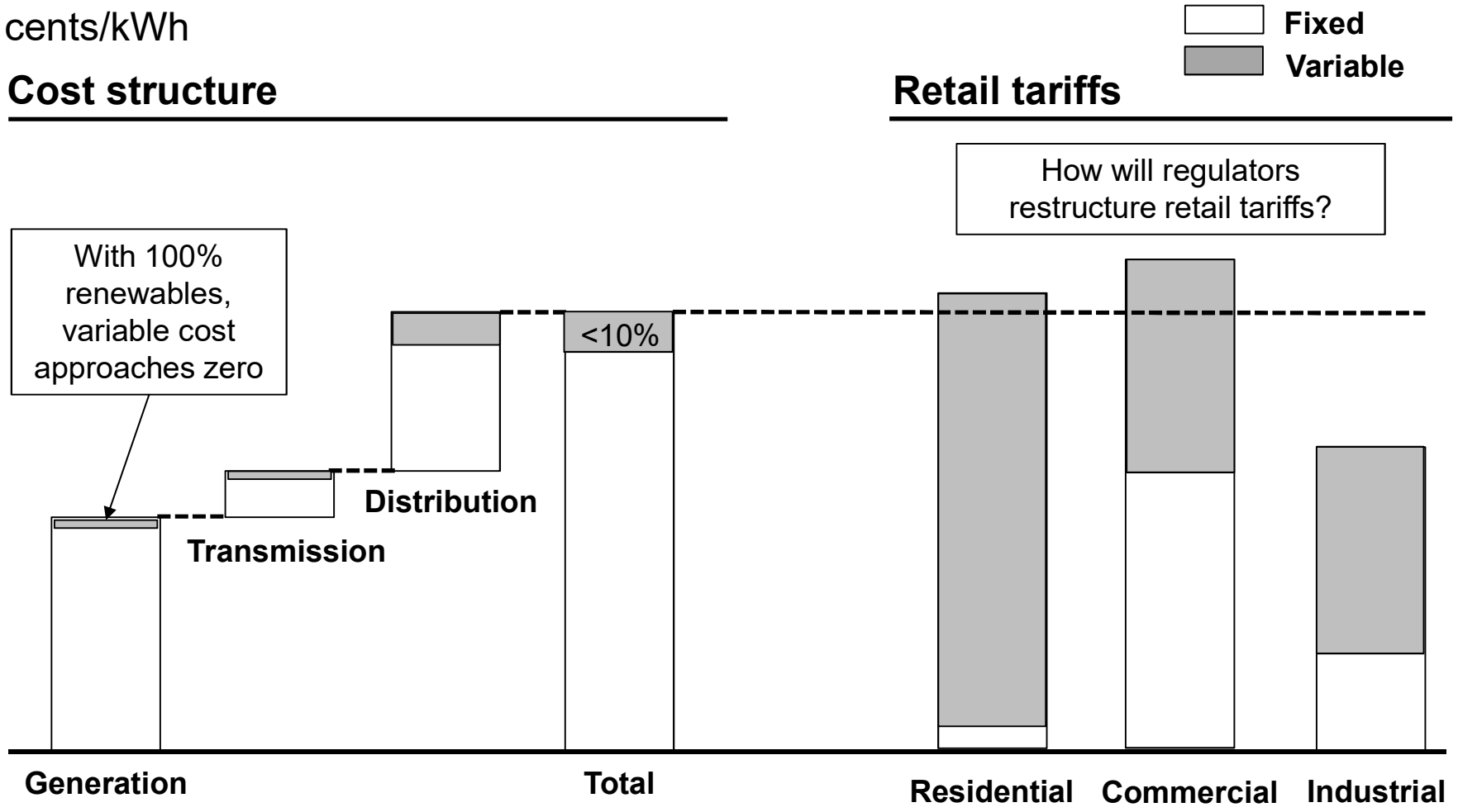
…likely to be driven by pressures to resolve economic misalignments

- Cost structure for supplying electricity with renewables + storage becoming less variable, more fixed
- Electricity pricing (both at wholesale and retail) remains heavily oriented towards variable element

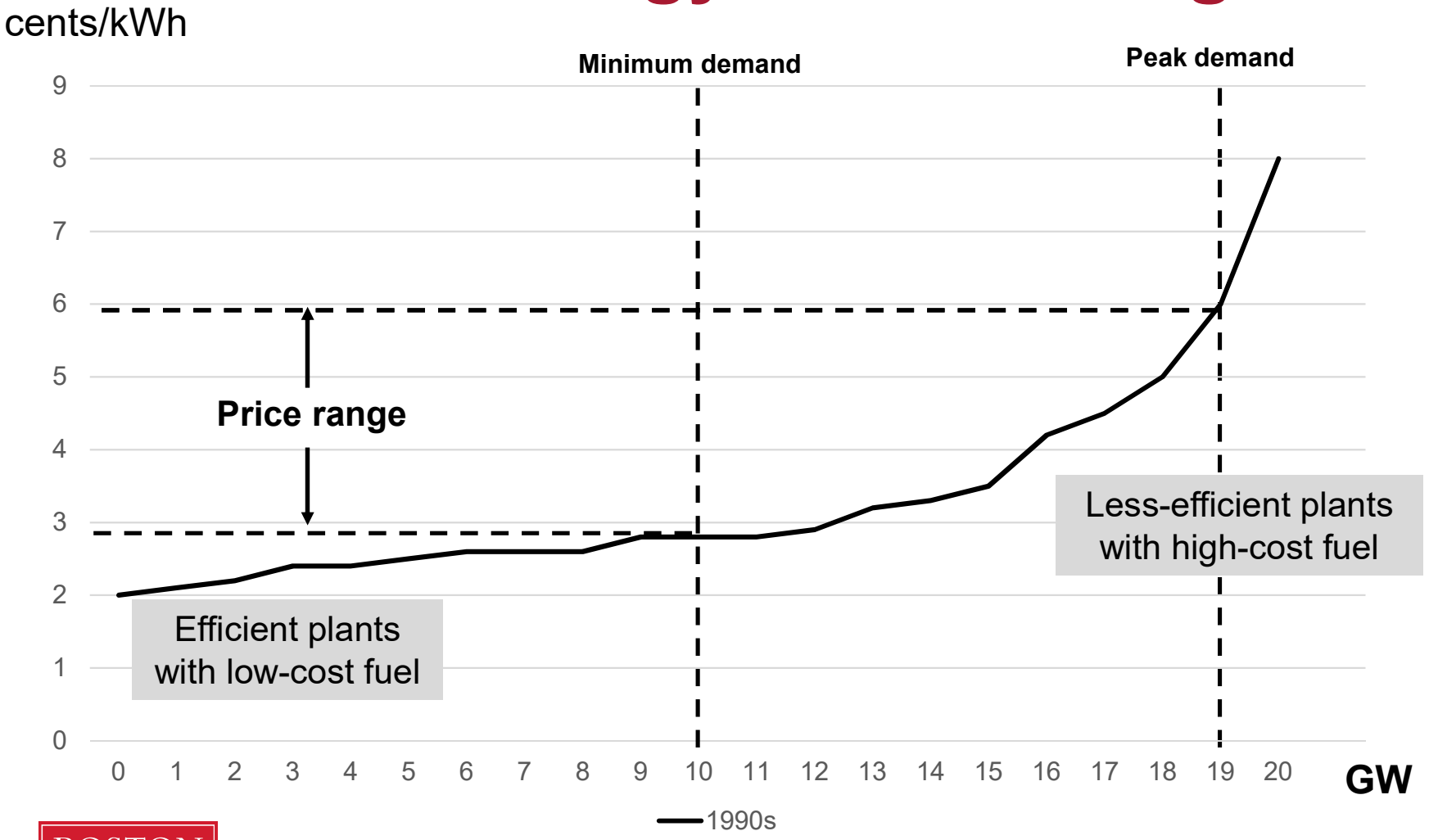
Historical Economics of Electricity



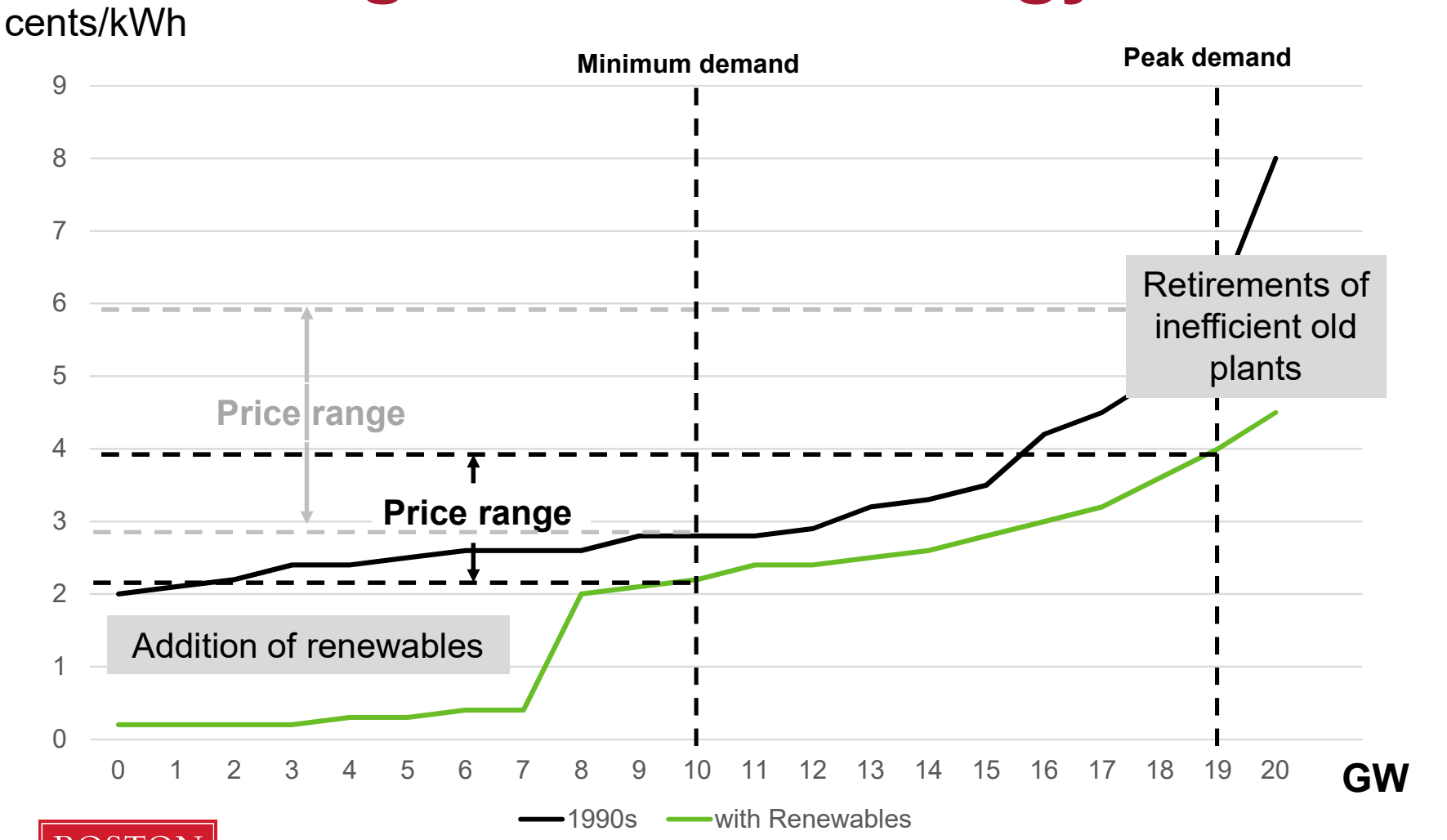
Increasing Retail Price Mismatch



Wholesale Energy Price Setting

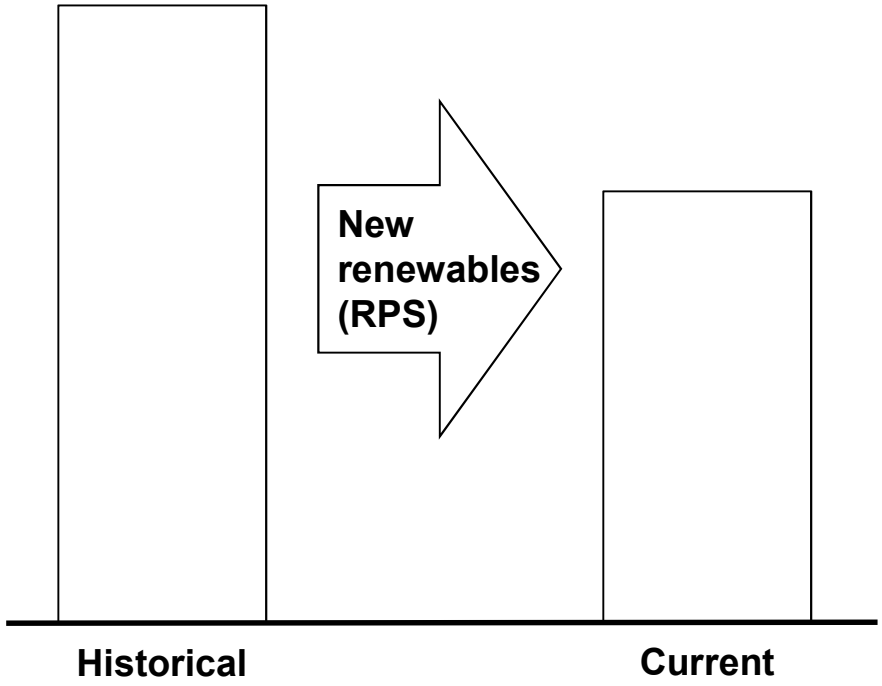


Declining Wholesale Energy Prices



Wholesale Markets Under Stress

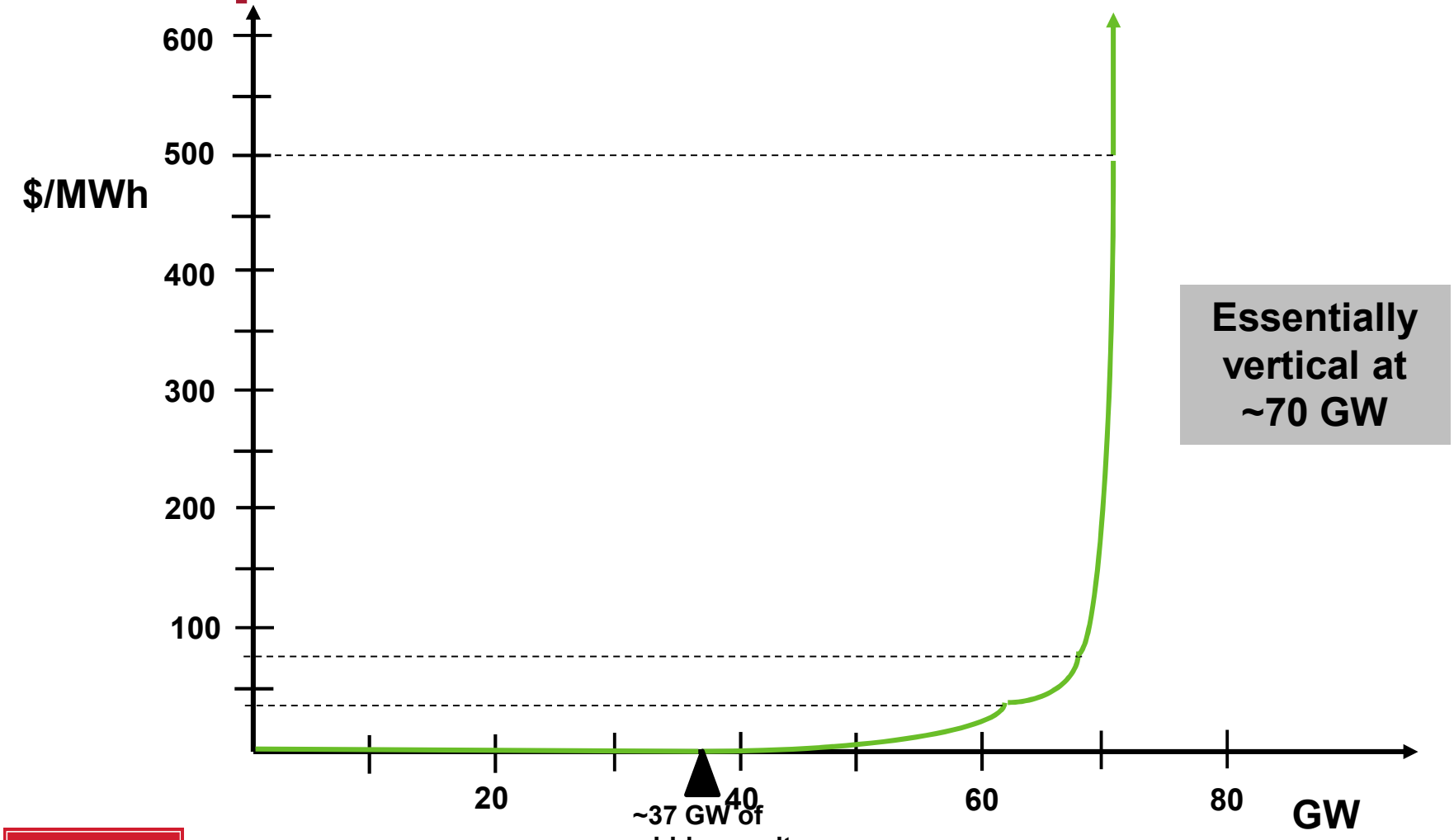
Declining average energy prices



"Lose-lose"

- Fossil generators not making enough profits to keep plants operating → retirements
- Insufficient profit opportunity to encourage investment in further renewable additions

Example: ERCOT Offer Stack 2017



Source: Future Energy Advisors analysis (based on Potomac Economics 2017 State of ERCOT Market Report, May 2018)

Required Changes in Pricing

	Change required	Objection
Wholesale markets	Shift most cost recovery for generation to capacity markets (rather than energy markets)	Will financially harm fossil power plants
Retail tariffs	Restructure tariffs away from variable energy charges	Will discourage energy efficiency

Summary Perspective

- The Grid of Grids (GoG) can provide a zero-carbon and resilient energy future
- Massive investments required to achieve the GoG won't happen until institutions are significantly changed
- Institutional changes will be driven by growing pressures to resolve economic misalignments