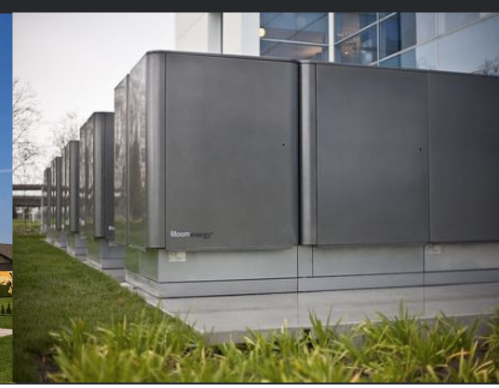
ENERGY STORAGE AND THE MIT UTILITY OF THE FUTURE STUDY

Jesse D. Jenkins

New England Restructuring Roundtable

December 9th, 2016 — Boston, MA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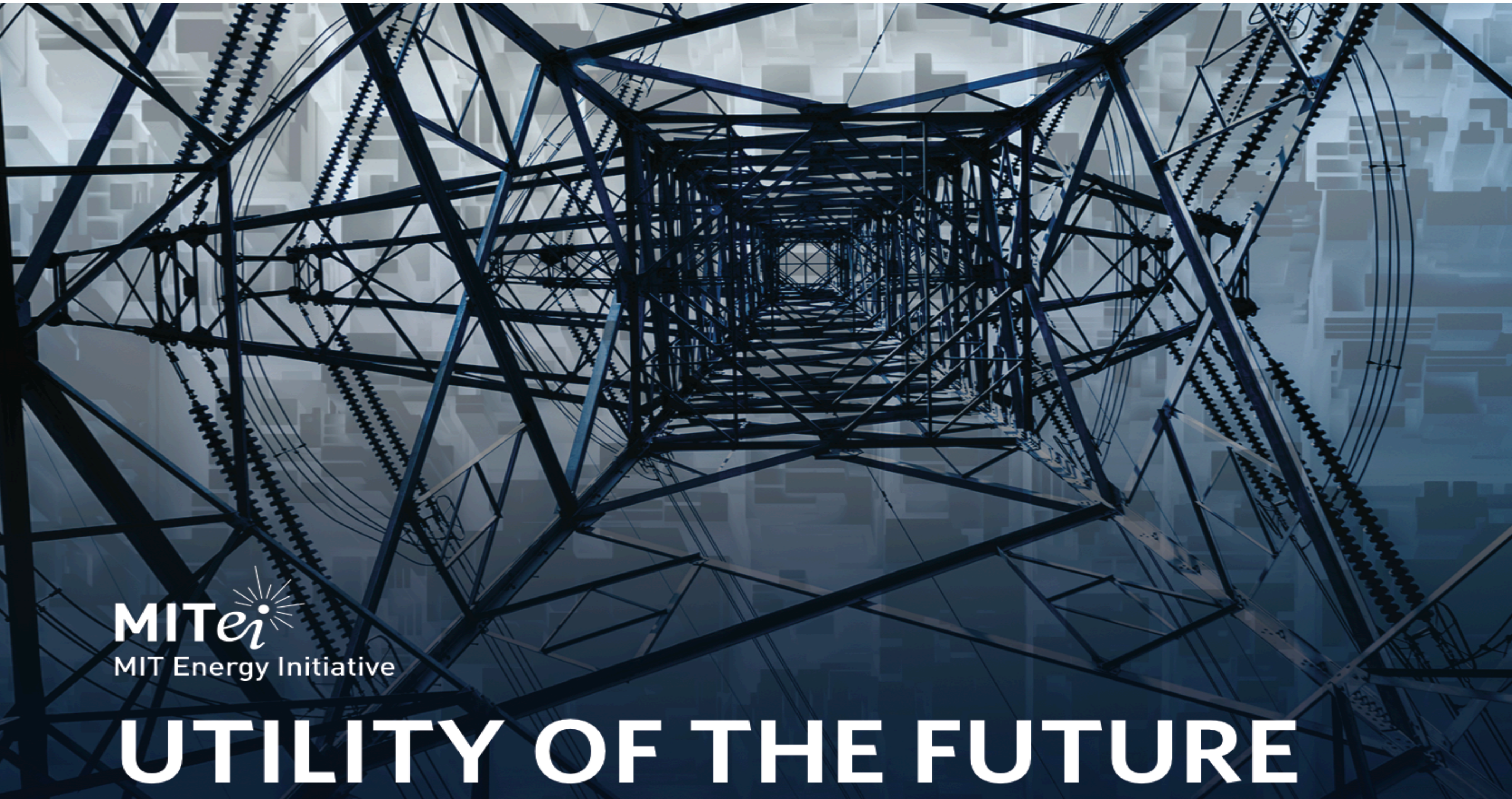

MIT*ei*
MIT Energy Initiative

UTILITY OF THE FUTURE

Understanding how distributed energy resources are changing the provision of electricity services

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"The MIT Energy Initiative's Utility of the Future study presents a framework for proactive regulatory, policy, and market reforms designed to enable the efficient evolution of power systems over the next decade and beyond."

1. A comprehensive and efficient system of market-determined prices and regulated charges for electricity services;
2. Improved incentives for distribution utilities that reward cost savings, performance improvements, and long-term innovation;
3. Reevaluation of the power sector's structure to minimize conflicts of interest; and
4. Recommendations for the improvement of wholesale electricity markets.

"This study also offers a set of insights about the roles of distributed energy resources, the value of the services these resources deliver, and the factors most likely to determine the portfolio of cost-effective resources, both centralized and distributed, in different power systems."

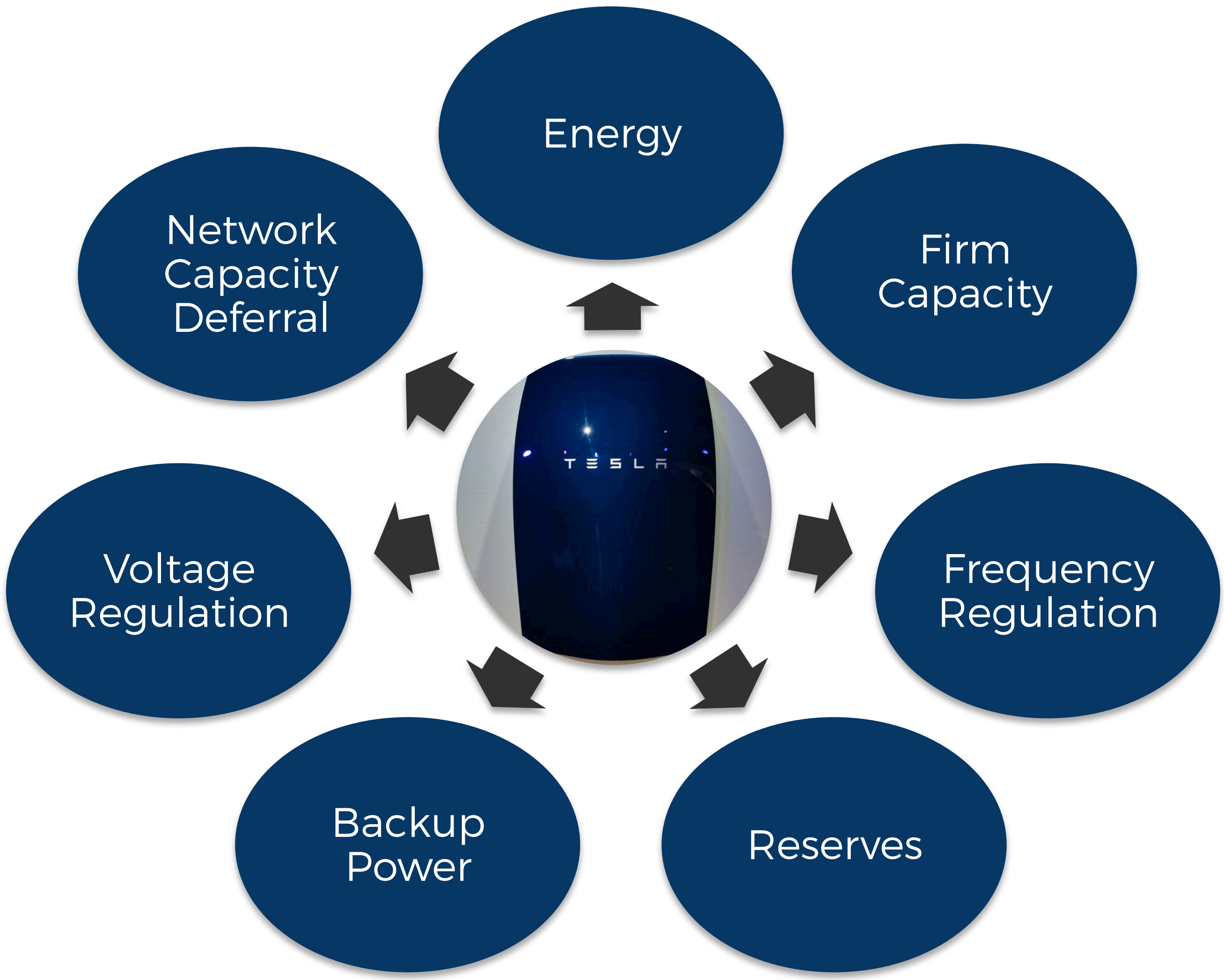
1. The value of some electricity services can differ substantially depending on where within the power system that service is provided or consumed.

2. This variation in "locational value" is key to understanding the value of distributed energy resources.

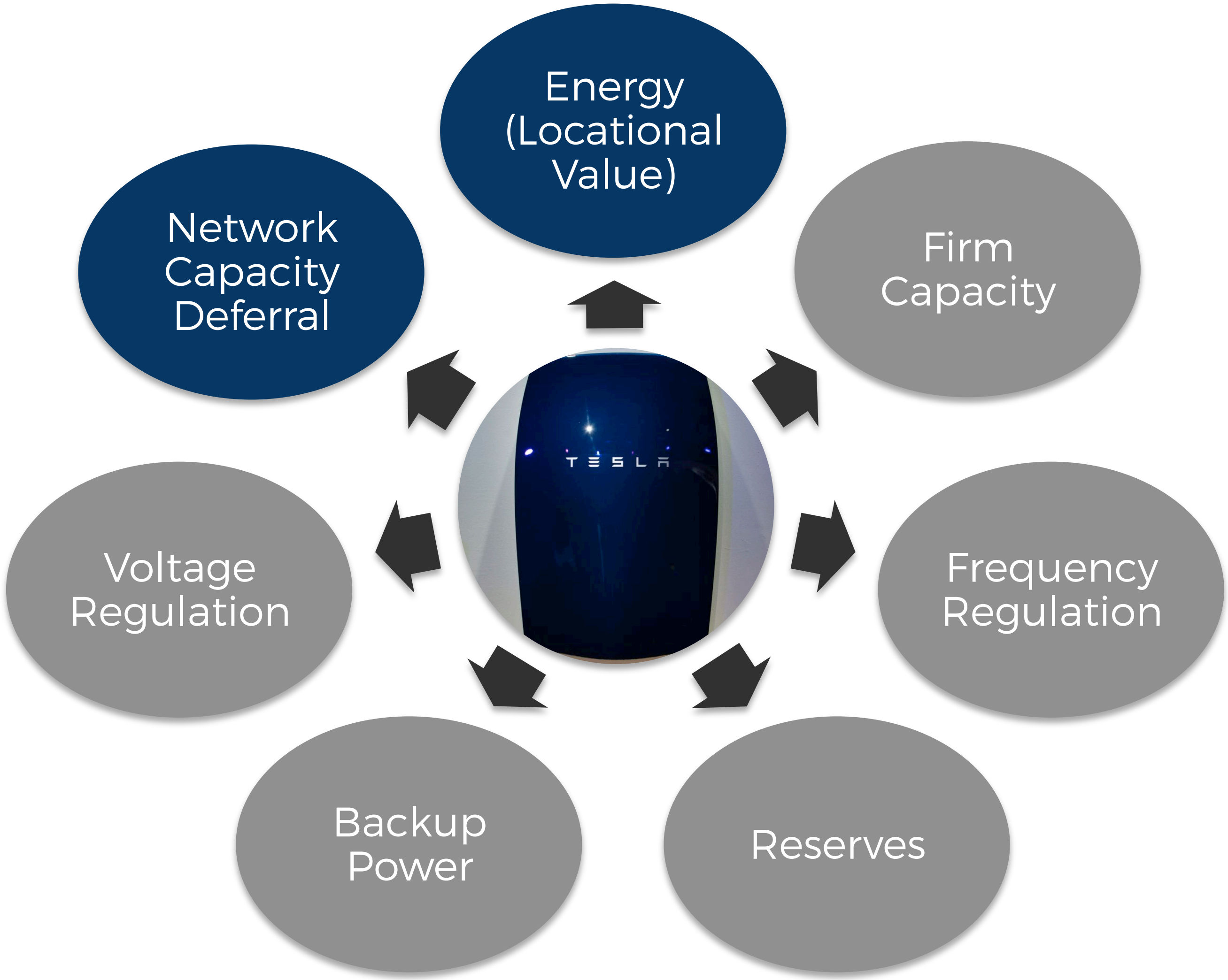
3. Unlocking existing resources such as flexible demand can be an efficient alternative to investments in generation, storage, or network capacity.

4. Economies of scale still matter: tradeoffs between incremental unit costs and locational value must be considered.

ENERGY STORAGE CAN PROVIDE MULTIPLE SERVICES



FOCUS TODAY: LOCATIONAL VALUE OF DISTRIBUTED STORAGE



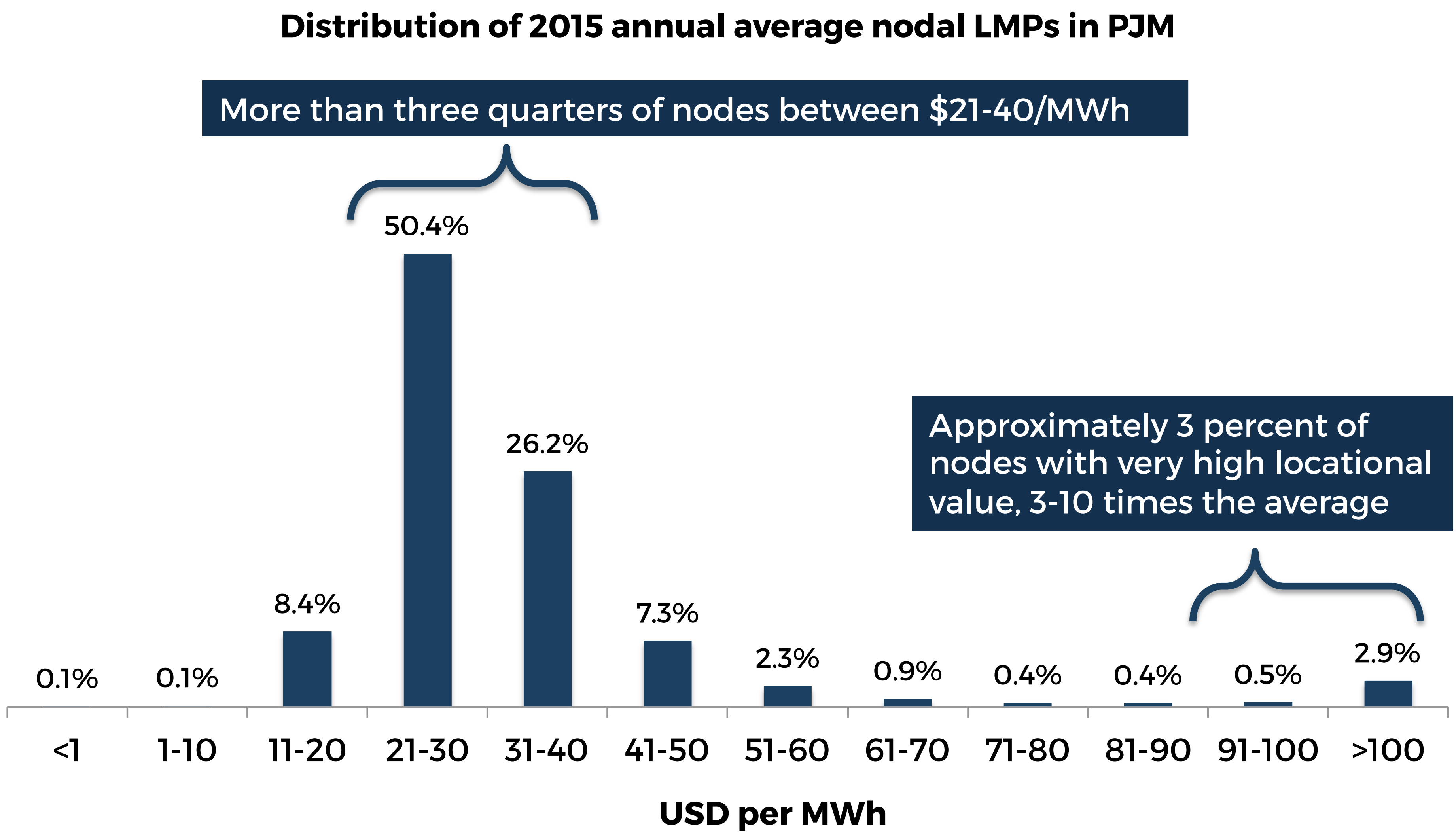
LOCATIONAL AND NON-LOCATIONAL VALUES

	Locational	Non-locational
Power system values	• Energy • Network capacity margin • Power quality • Reliability and resiliency • Black-start	• Firm generation capacity^ • Operating reserves^ • Price hedging
Other values	• Land value/impacts • Employment • Premium values*	• CO_2 emissions mitigation • Energy security

^ The value of firm capacity and operating reserves may vary by zone when frequent network constraints segment electricity networks and prevent delivery of capacity or reserves to constrained locations.

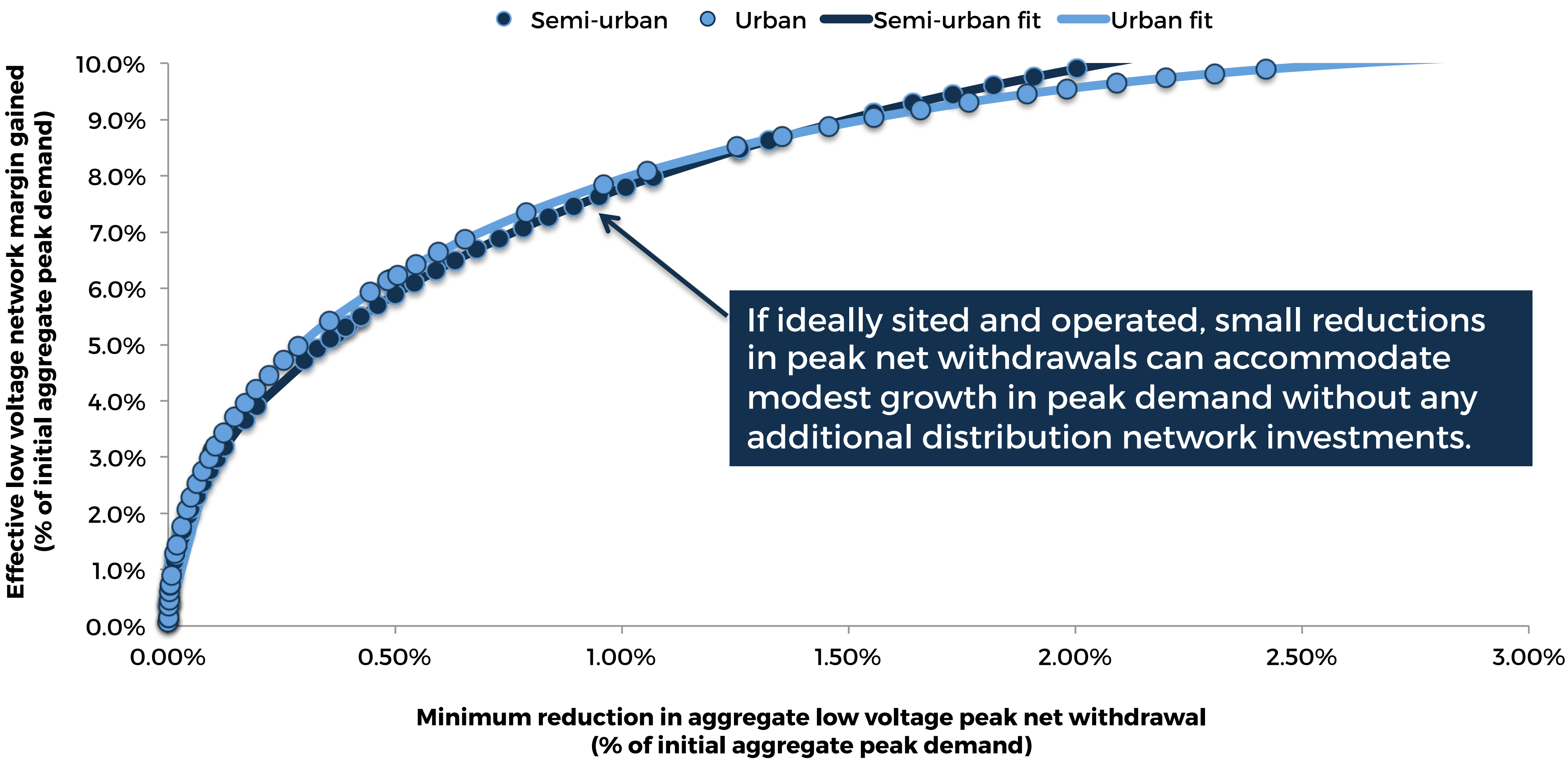
* Private values; do not need to be reflected in prices and charges.

LOCATIONAL VALUE VARIES DRAMATICALLY



NETWORK CAPACITY DEFERRAL

Potential for DERs to substitute for distribution network upgrades in representative European distribution networks - low voltage distribution example

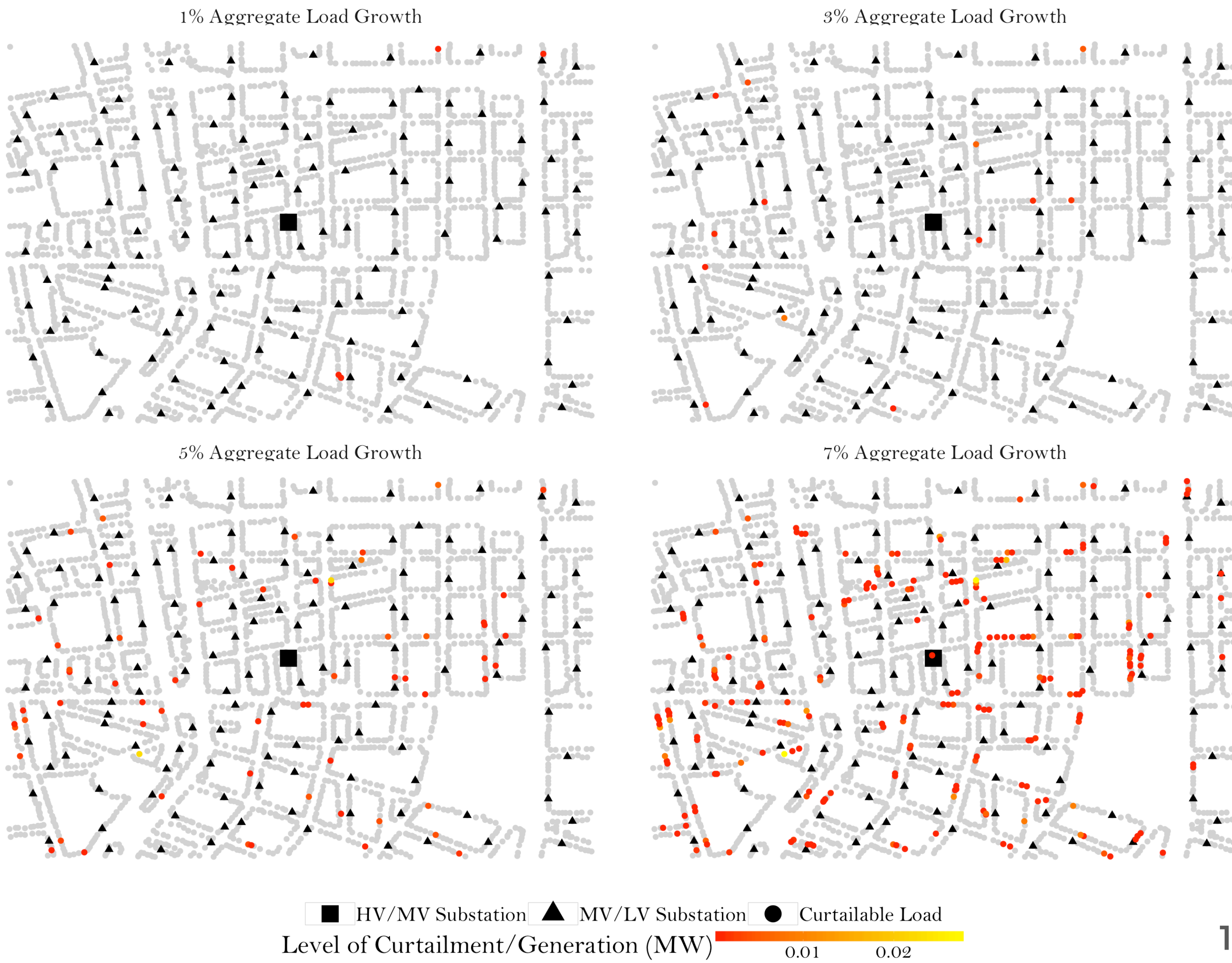


Source: Jenkins, Luke & Vargara, forthcoming (part of MIT Utility of the Future Study)

DECLINING MARGINAL VALUE: MORE LOCATIONS

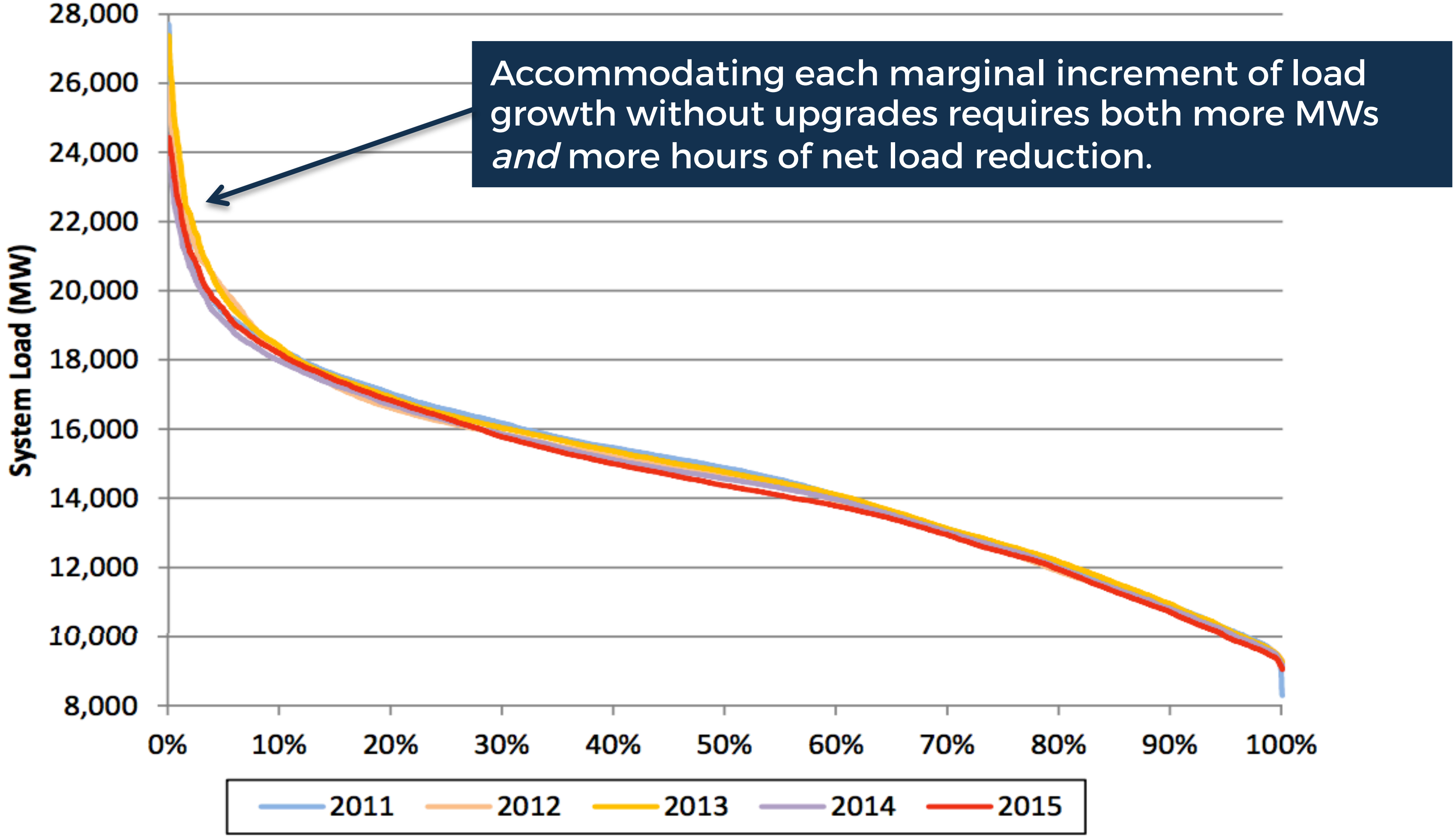
Location and magnitude of load curtailment or DER generation necessary to accommodate peak demand growth without network reinforcement – European urban network case

(Jenkins, Luke & Vargara, forthcoming, part of MIT Utility of the Future Study)



DECLINING MARGINAL VALUE: MORE HOURS

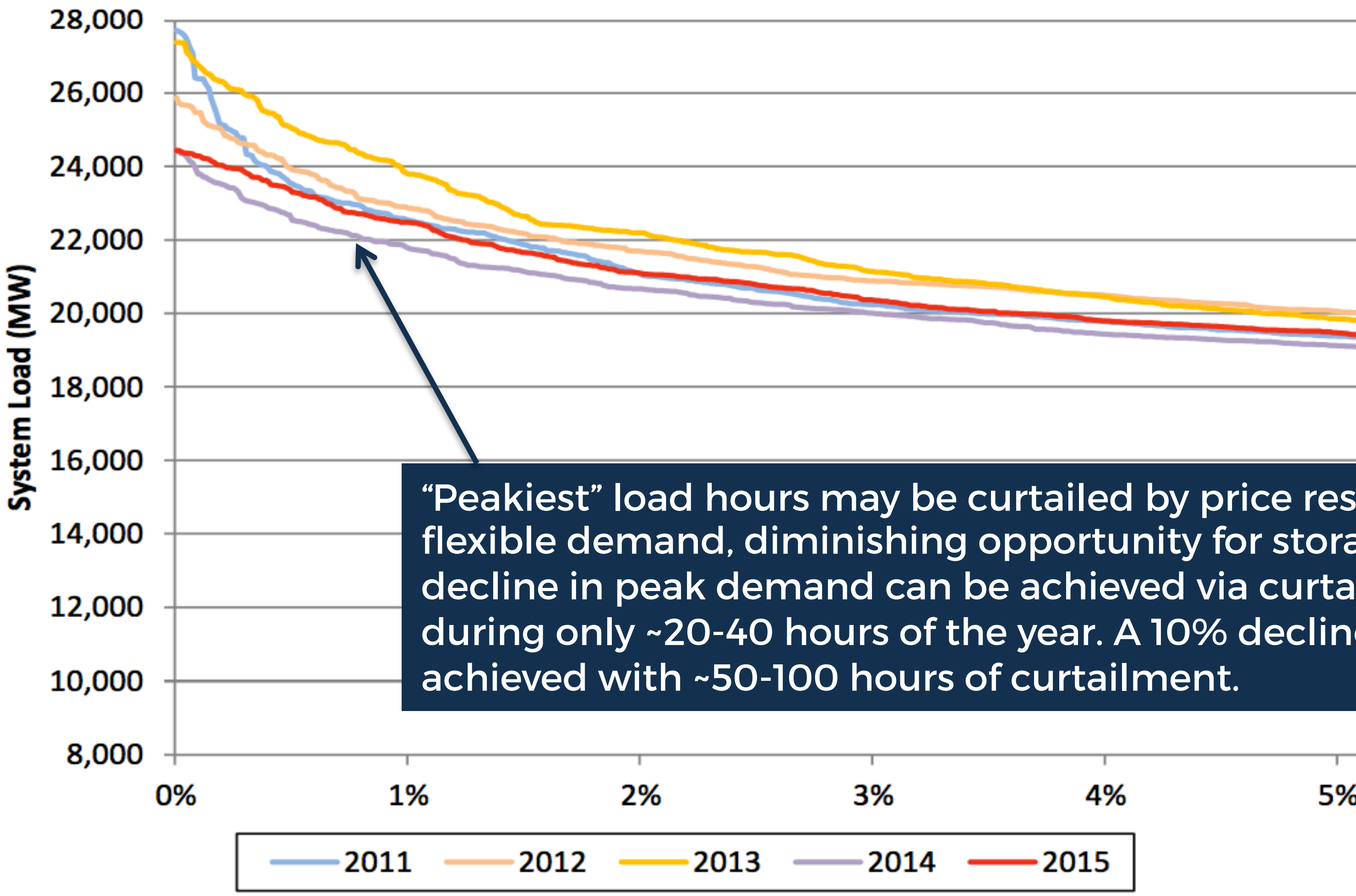
Load duration curve for ISO New England, 2011-2015, all hours.



Source: ISO New England (2015), "ISO New England's Internal Market Monitor 2015 Annual Markets Report."

COMPETITION WITH FLEXIBLE DEMAND

Load duration curve for ISO New England, 2011-2015, top 5% hours



"Peakiest" load hours may be curtailed by price responsive or flexible demand, diminishing opportunity for storage: a 5% decline in peak demand can be achieved via curtailment during only ~20-40 hours of the year. A 10% decline can be achieved with ~50-100 hours of curtailment.

Source: ISO New England (2015), "ISO New England's Internal Market Monitor 2015 Annual Markets Report."

ECONOMIES OF SCALE STILL MATTER

Economies of unit scale vs locational value

Utility Scale

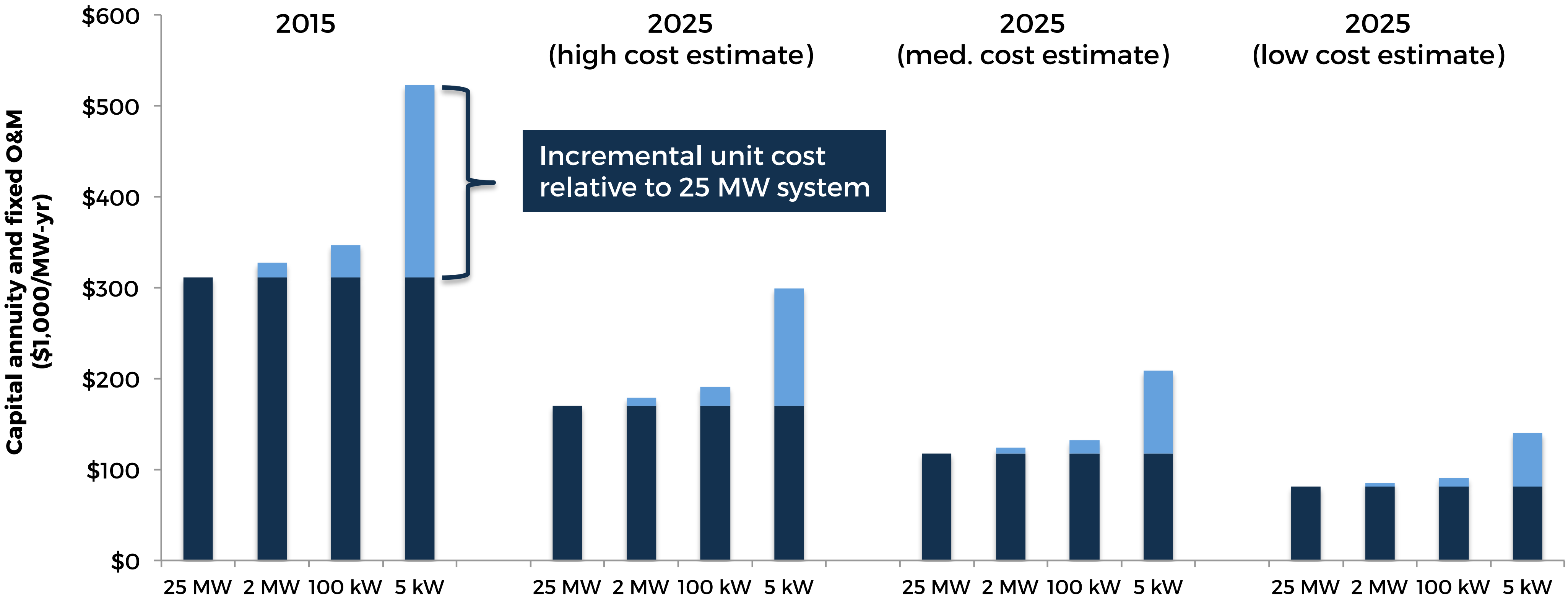
C&I Scale

Residential Scale

INCREMENTAL UNIT COSTS

Storage systems exhibit economies of unit scale. Locational value must be compared to incremental unit costs for each application.

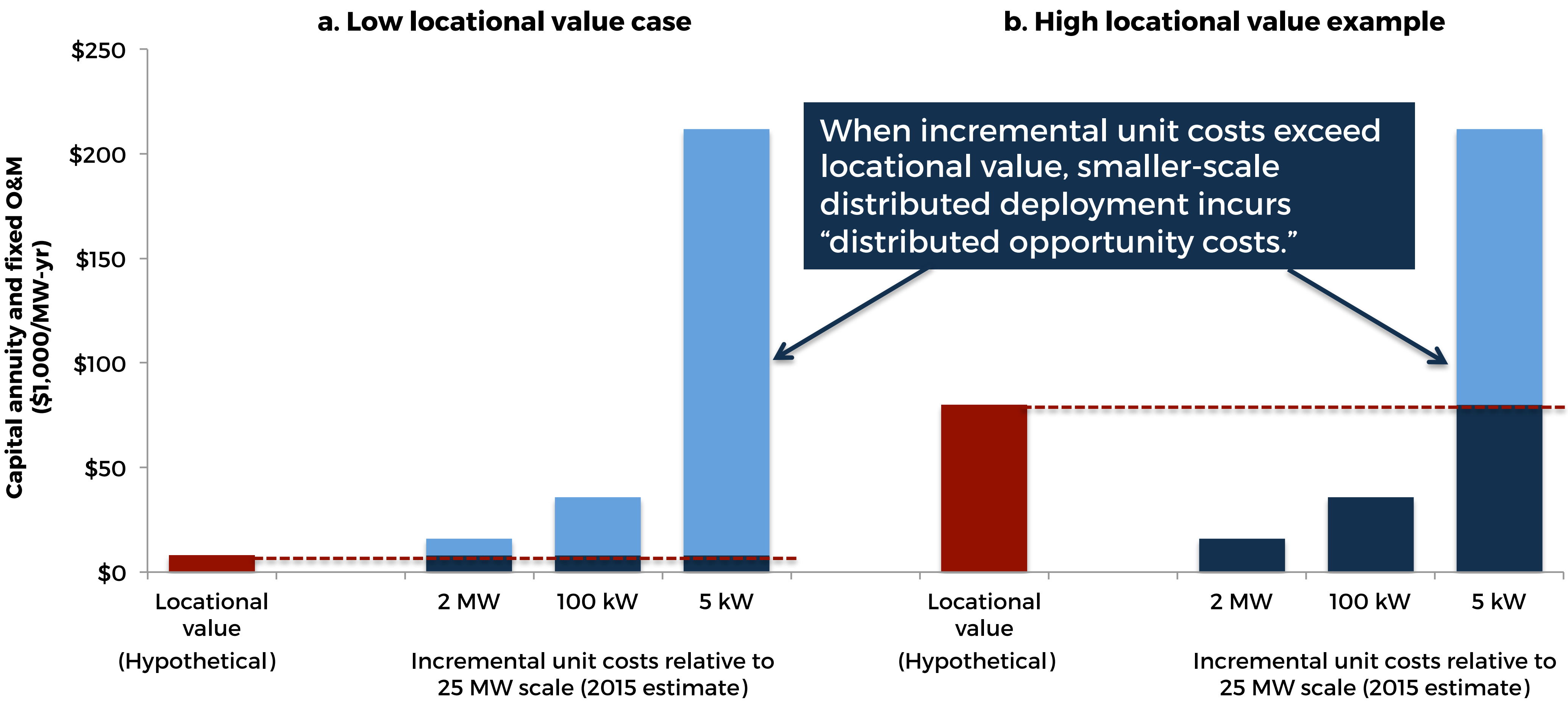
Economies of unit scale for Li-ion energy storage systems (1:2 power:energy ratio): 2015 and projected 2025 annual costs



Source: Author's estimates, forthcoming (part of MIT Utility of the Future Study)

DISTRIBUTED OPPORTUNITY COSTS

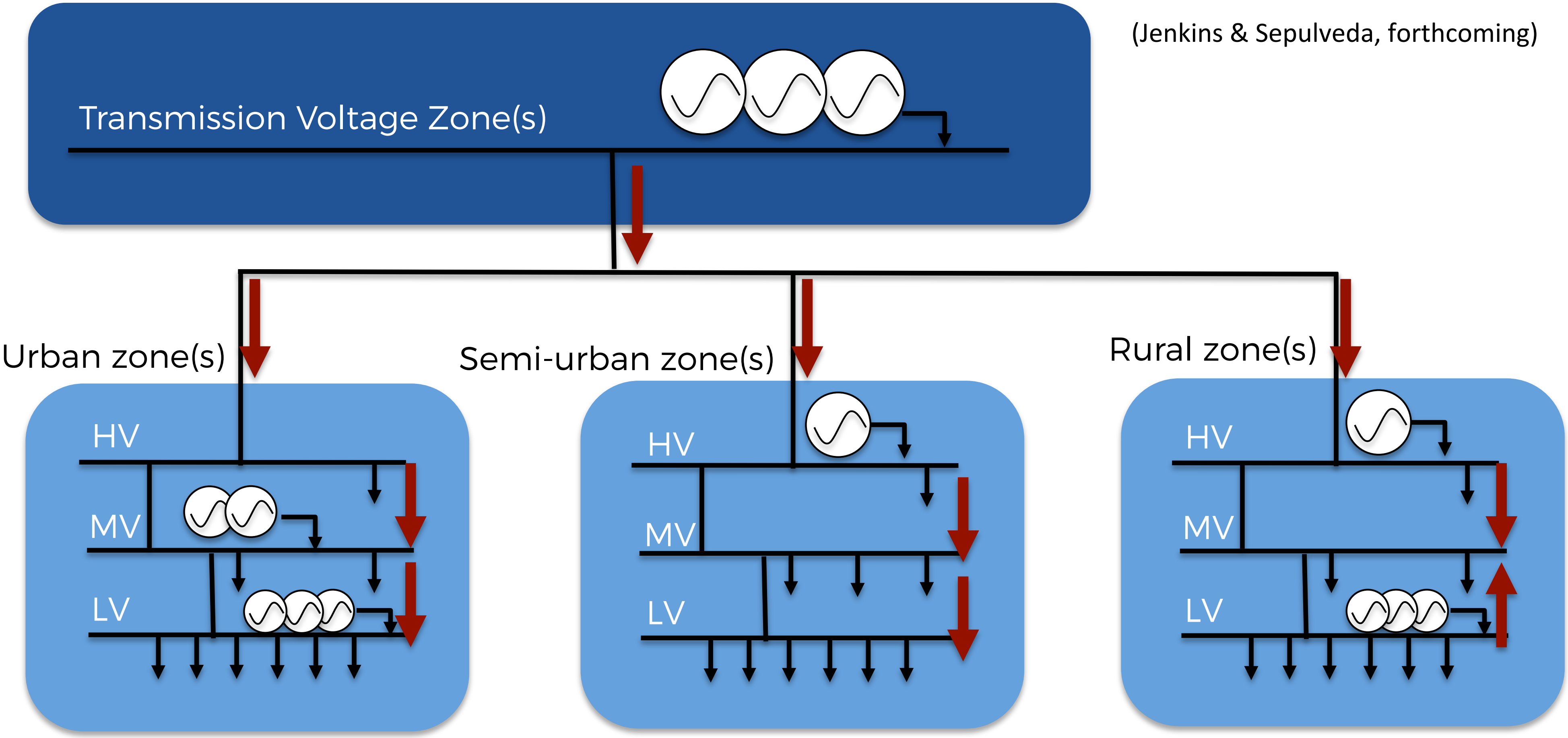
Comparison of 2015 estimated incremental unit costs for Li-ion energy storage systems (1:2 power:energy ratio) vs. *hypothetical* locational values.



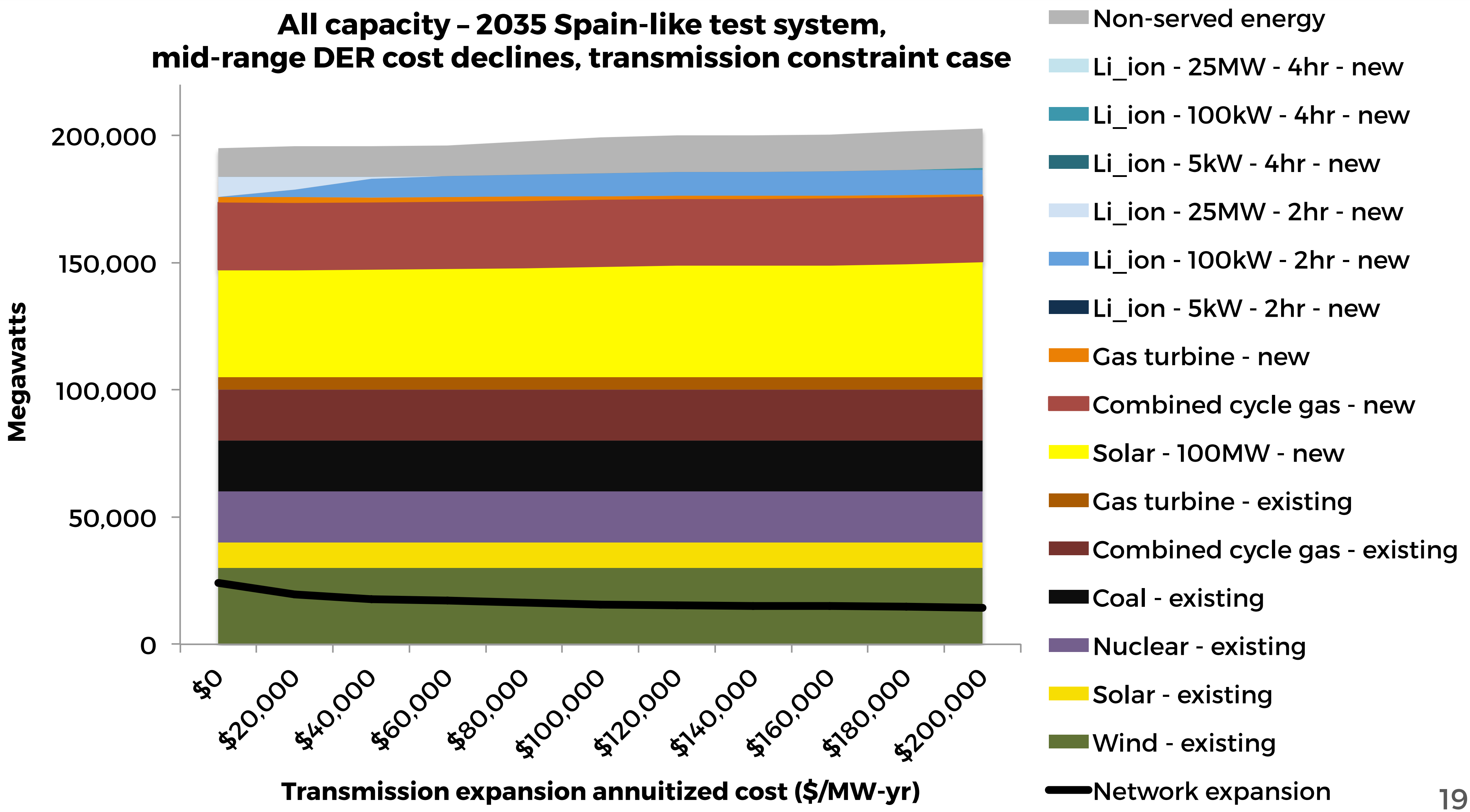
A NEW MODEL FOR NEW OPPORTUNITIES & TRADEOFFS

GEN-X: a new electricity resource capacity expansion planning model that captures key tradeoffs between locational value and economies of unit scale

(Jenkins & Sepulveda, forthcoming)



TRANSMISSION EXPANSION AND STORAGE CASE STUDY



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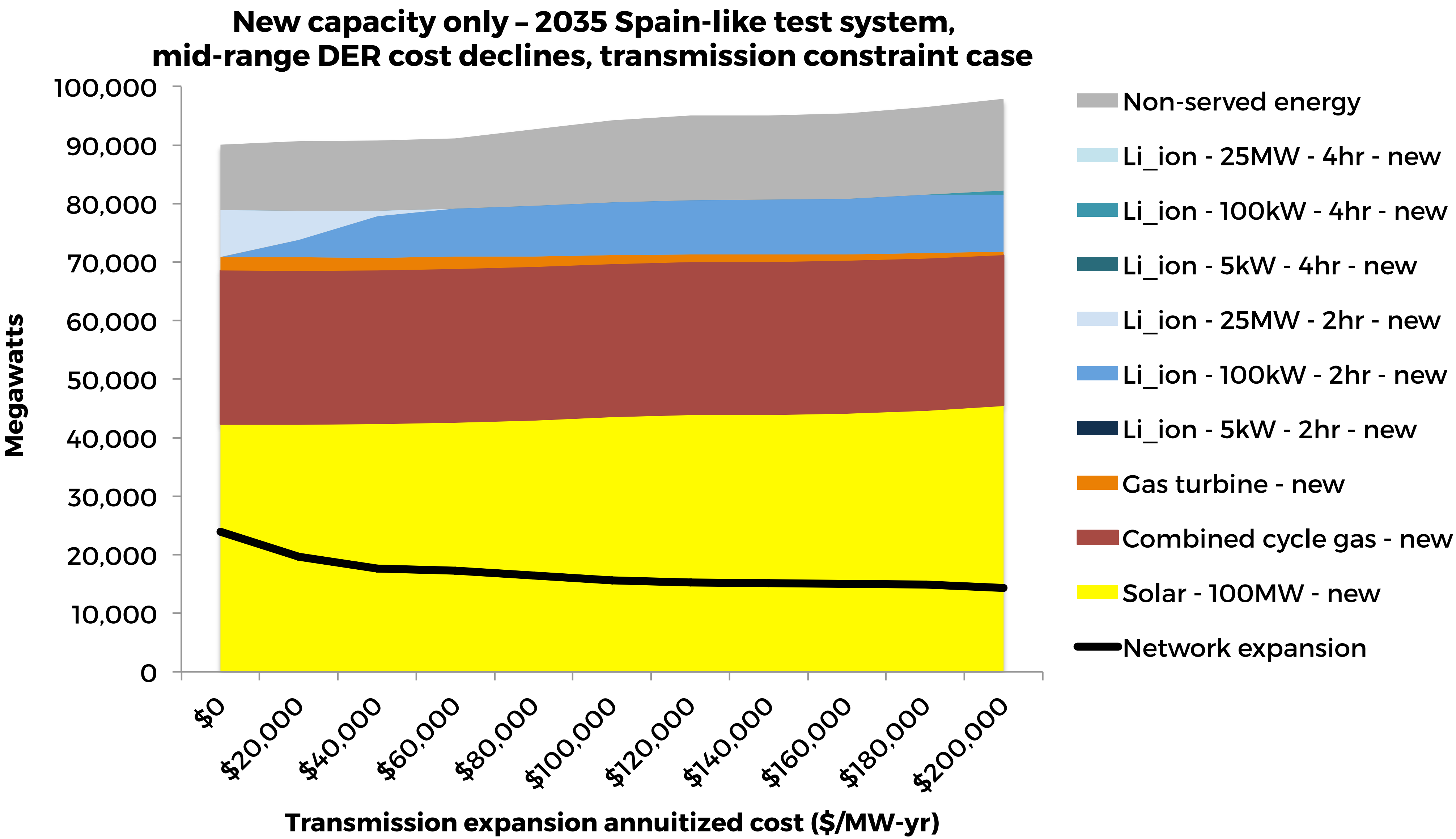

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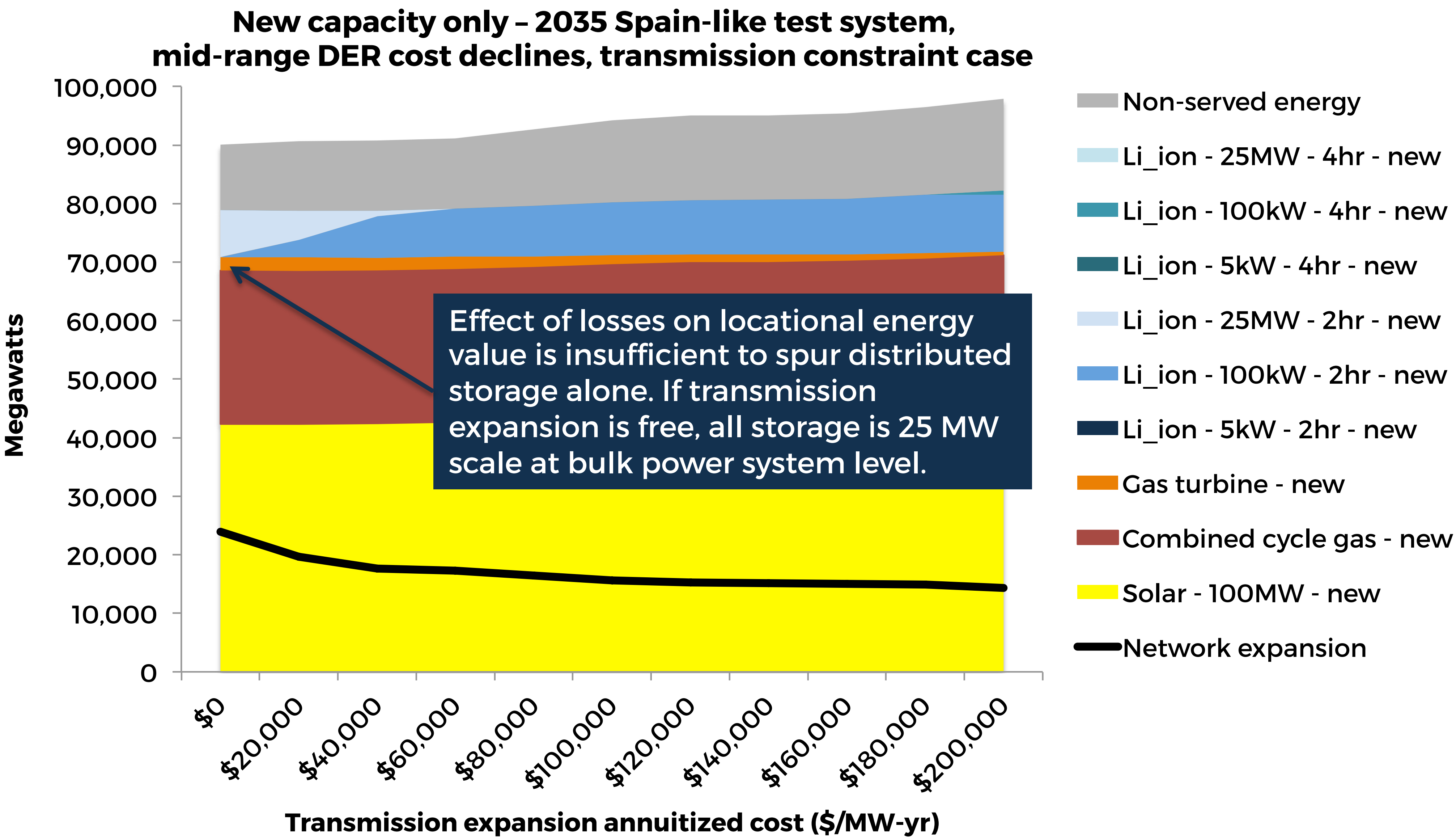

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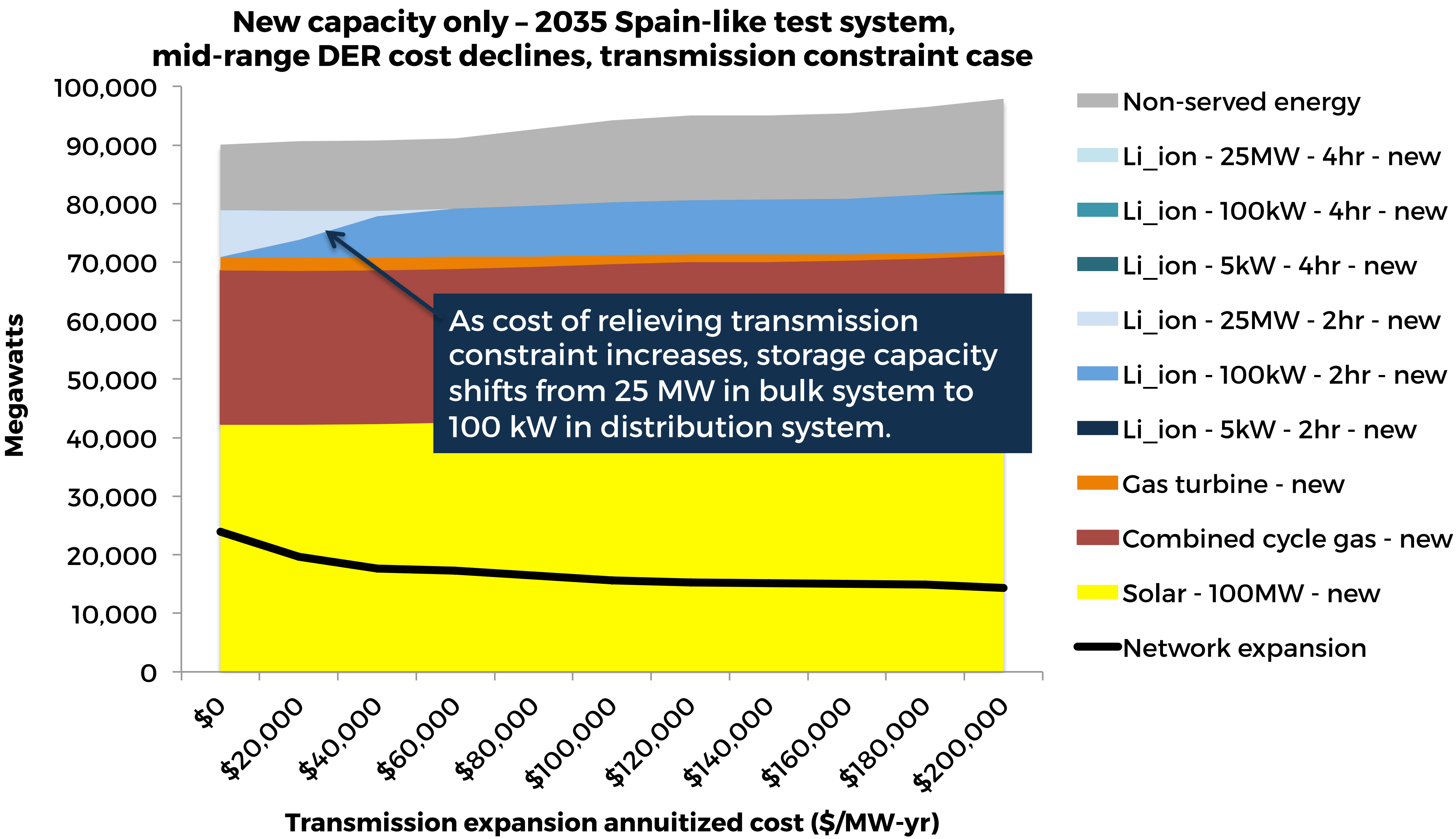

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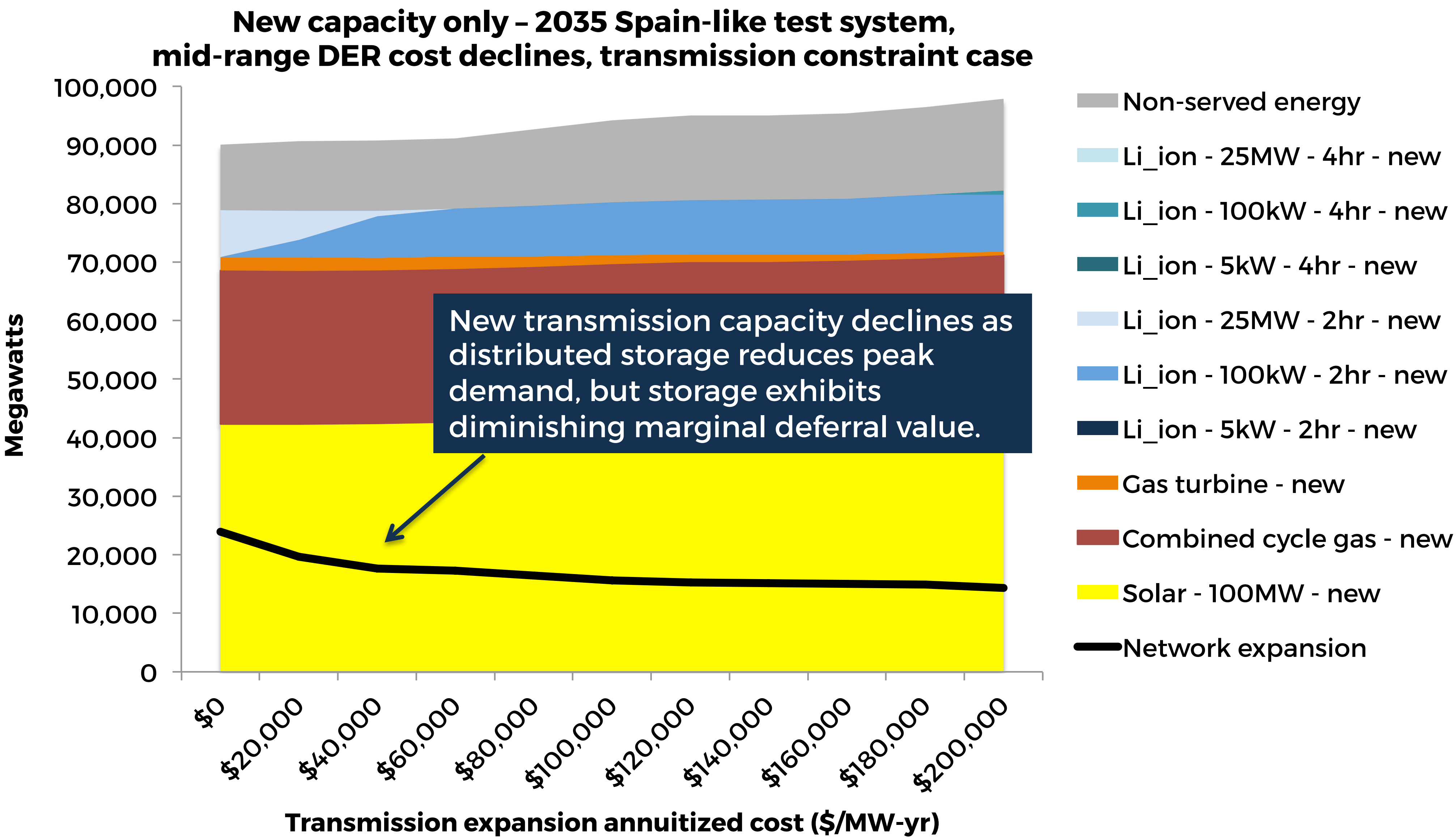

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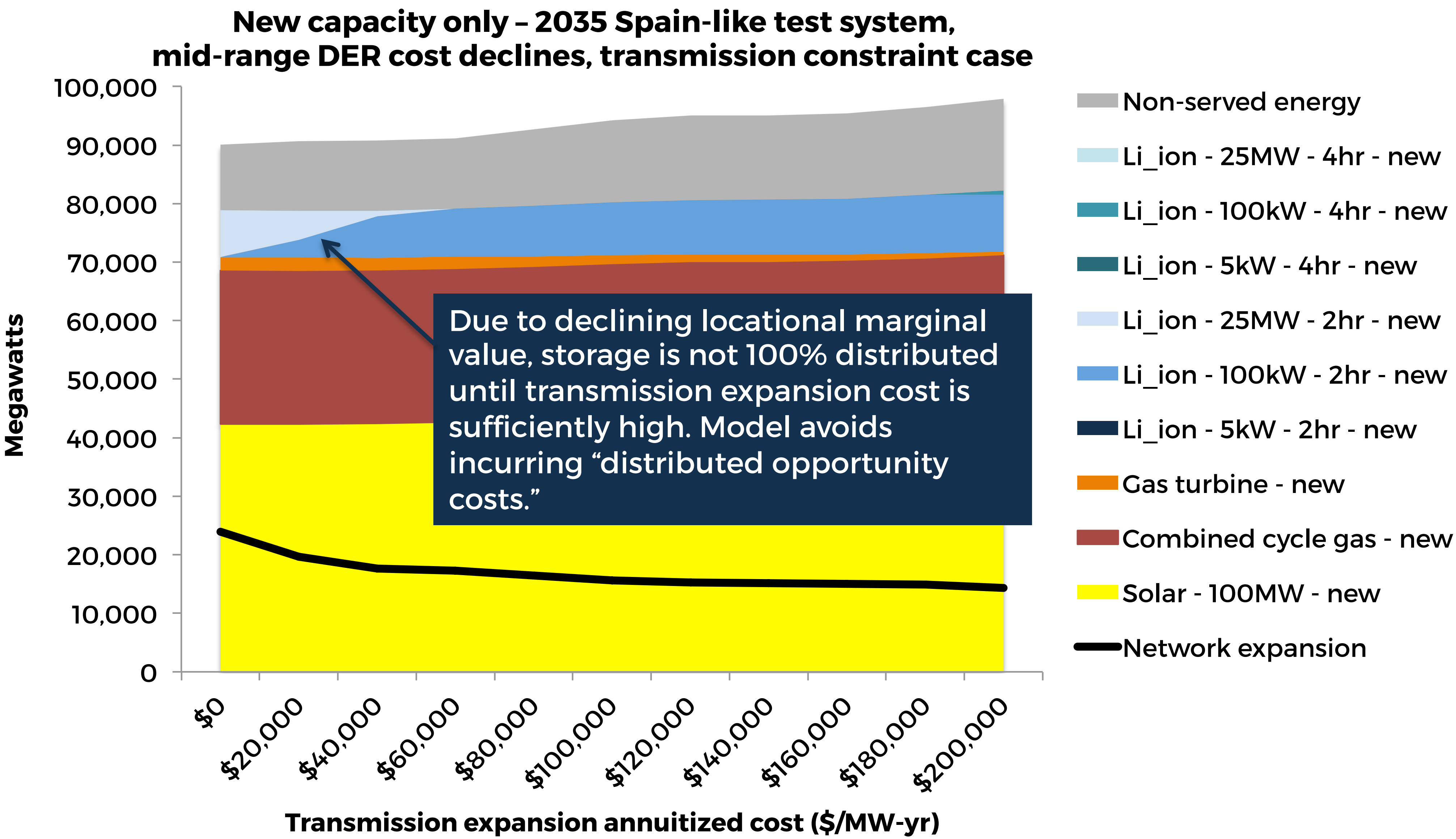

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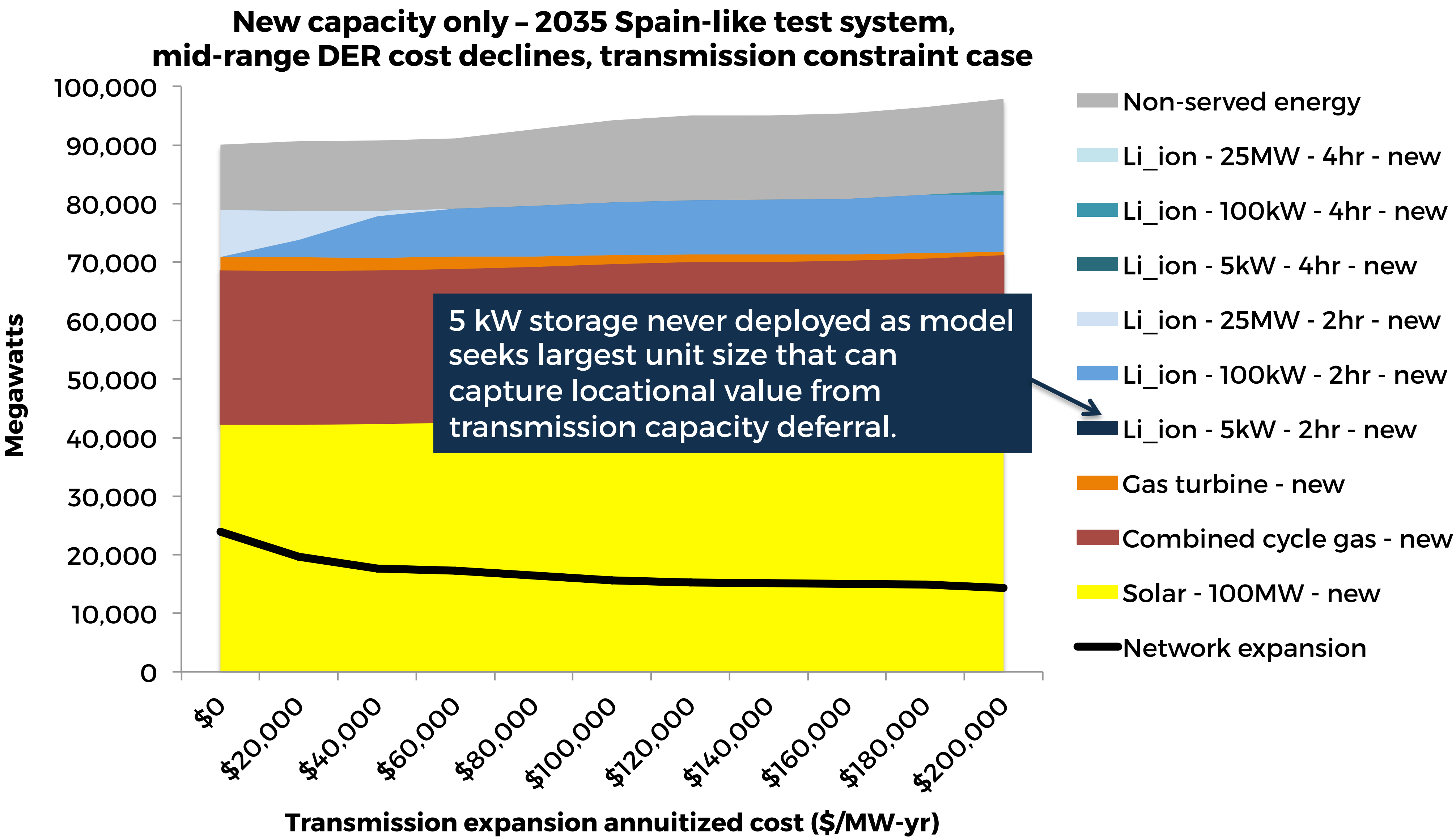

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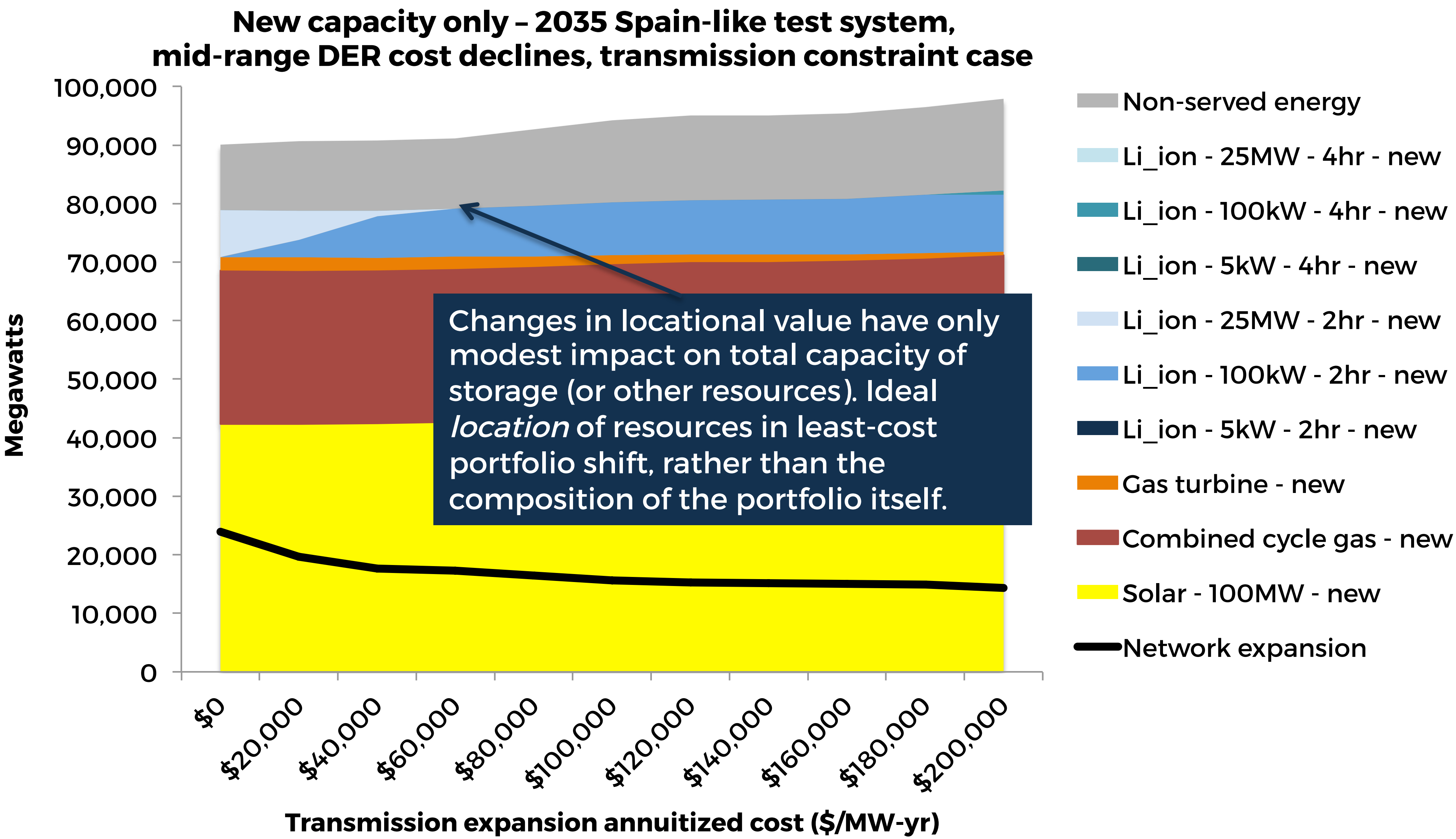
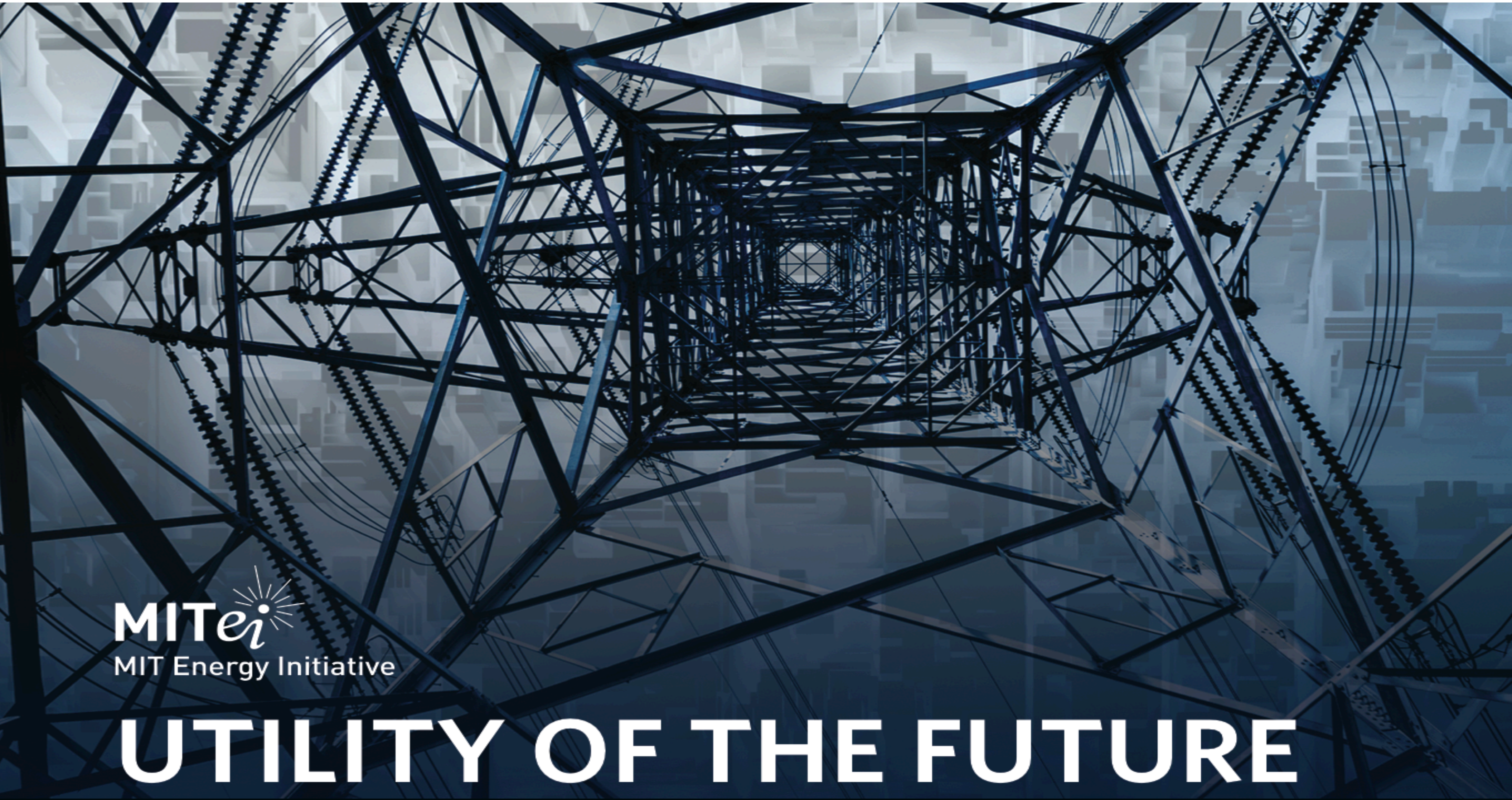


SUMMARY

- If optimally sited, value of storage for distribution network capacity deferral is initially quite high, but marginal value declines rapidly.
- Transmission deferral also exhibits diminishing marginal value.
- If price responsive or flexible demand can reduce peak load hours, value and market opportunity for storage significantly diminished.
- Network deferral presents higher value opportunity for storage, but unlikely to justify storage on its own. Storage must provide value to overall resource portfolio as well (e.g. firm capacity, flexibility, reserves).
- If storage makes sense in resource portfolio, then ideal location depends on tradeoffs between locational value and incremental costs due to economies of unit scale.
- Goal: maximize net value and avoid distributed opportunity costs: e.g. largest unit size that can accomplish network deferral benefit.



Stay tuned, December 15th

http://energy.mit.edu/research/utility-future-study/

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Questions



Massachusetts Institute of Technology

BACKUP SLIDES

Topics:

1. Frequency Regulation
2. Energy and Capacity Value Under a CO_2 Limit

1. FREQUENCY REGULATION

What is “regulation”?

- Electricity supply & demand must be balanced in (nearly) real-time.
- Limited automatic inertial response in spinning mass of synchronous generators and loads (e.g. electric motors).
- Regulation “reserves” track control signals to make small/ fast changes to rebalance supply/demand and maintain frequency within narrow band (60 hz +/- 0.036 hz)

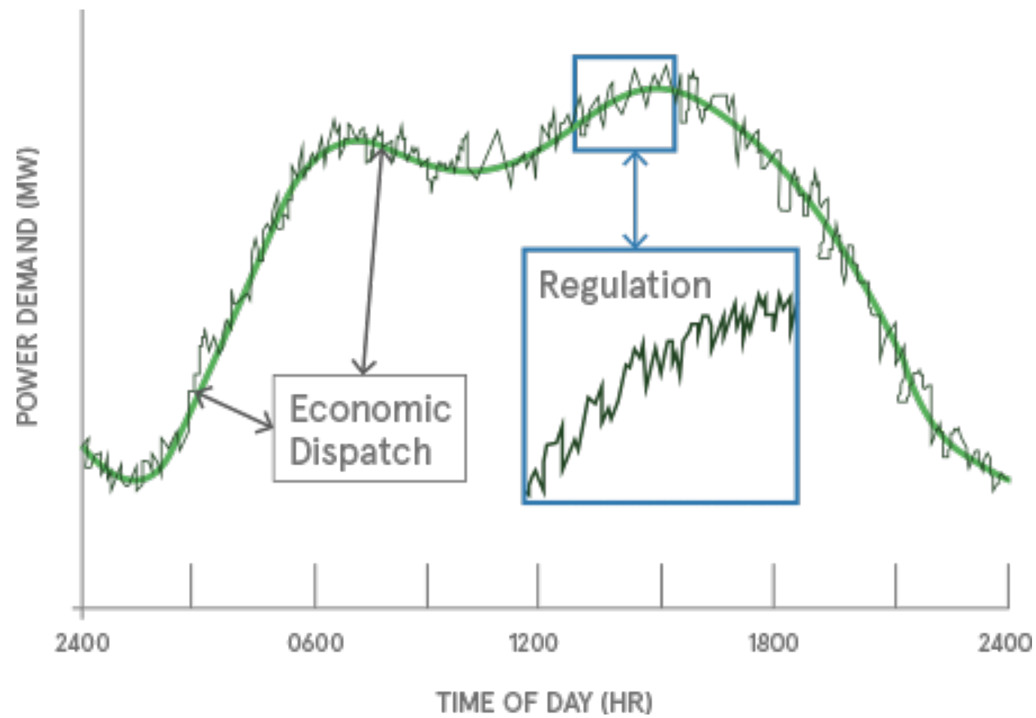


Image source: Solar City

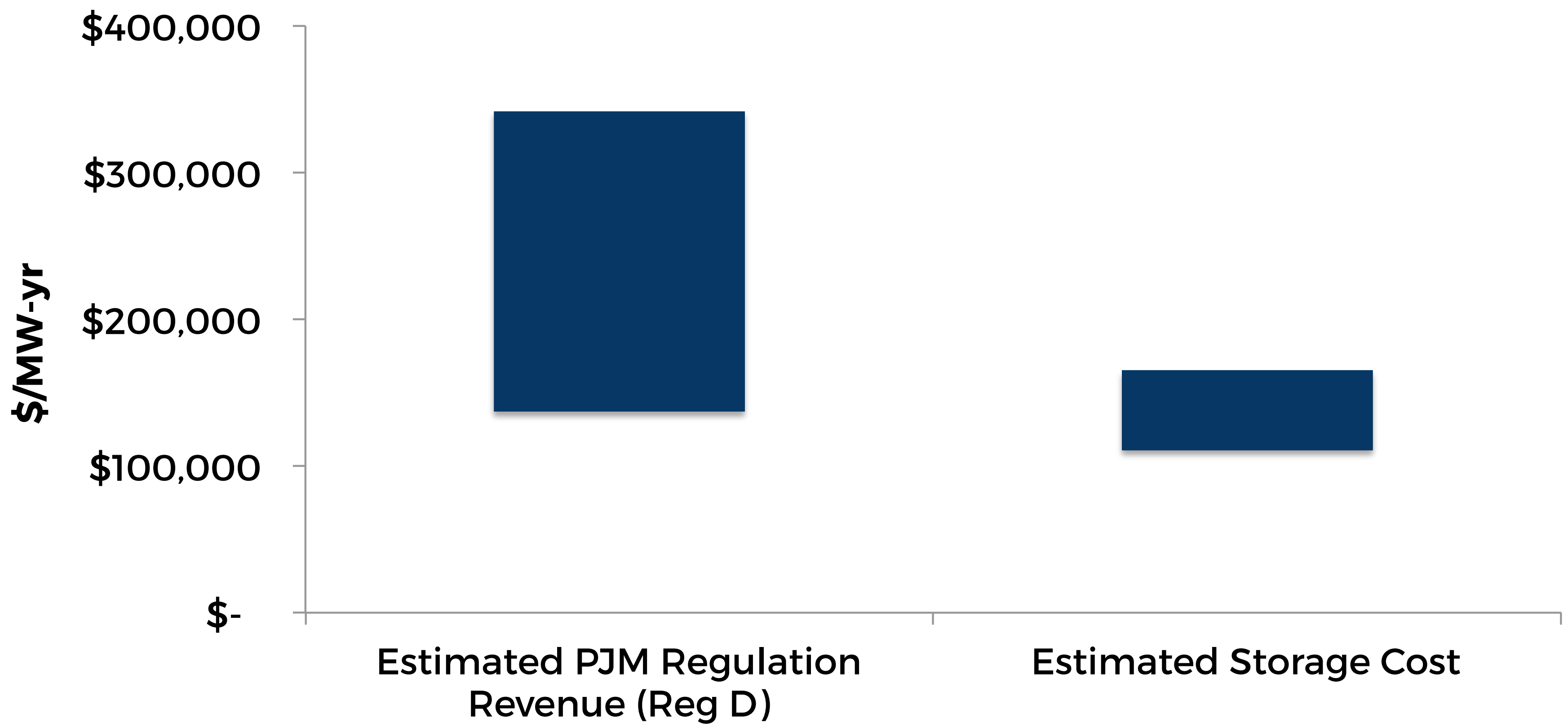
1. FREQUENCY REGULATION

Storage as “fast response” regulation resource

- FERC Order 755 (2011): “pay for performance” for frequency regulation services.
  - Rewards resources that accurately track regulation signals (including storage).
- Storage has fast response and accurately tracks regulation signal.
  - Storage has best accuracy of any regulation resource.
- Regulation services can be close to “energy-neutral,” so does not require large energy (MWh) capacity.
  - Typical power:energy ratio for storage systems used in fast-response frequency regulation is 4:1 (e.g. 15 mins of energy storage at full power).
  - For conventional regulation products, storage typically sized to 2:1 or 1:1 ratio (e.g. 30-60 mins of storage).

1. FREQUENCY REGULATION

Regulation is valuable



Sources: Jan-Aug 2015 market clearing prices, mileage ratio and performance scores from Eric Hsia "Regulation Market Performance Overview, January 1, 2015 – August 24, 2015" PJM, September 8, 2015. Low range revenues 60% below 2015 levels as per PJM Market Monitor "State of the Market 2016: Ancillary Services." Storage costs from Lazard, "Levelized Cost of Storage, Analysis, Version 1.0" November 2015, for Li-ion storage w/2:1 power:energy ratio and with capital costs annuitized at 7.68% WACC, 10 year asset life.

1. FREQUENCY REGULATION

Regulation markets are small and quickly saturated.

- Regulation markets total only a few hundred MW per ISO
- Perhaps ~3,000 MW nationwide (~0.3% of total US generating capacity).

ISO/ RTO	PJM	ISO-NE	MISO	ERCOT	SPP	CAISO	NYISO
Reserve market size	Fixed at 525 MW off-peak / 700 MW on-peak	Varies, averages ~60 MW	Varies, averages ~400 MW	Varies, Reg-up, average 459 MW; (297-847 MW). Reg-down, average 456 MW (297-956 MW)	Varies, Reg-up and Reg-down, average 350 MW	Varies, averages 350 MW	Varies, averages 220 MW (175-300 MW)

Source: Danielle Martini, "ISO/RTO Regulation Market Comparison," PJM, January 13, 2016.

1. FREQUENCY REGULATION

SUMMARY

Regulation markets are valuable.

- Regulation revenues for storage in PJM range from ~$150,000 to $350,000/MW-yr, generally quite profitable at current storage prices.

And small

- Only a few hundred MW in each ISO, approximately 3,000 MW nationwide or 0.3% of total US installed capacity.

2. CAPACITY AND ENERGY VALUE UNDER CO2 LIMIT

Applied Energy 175 (2016) 368–379

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journal homepage: www.elsevier.com/locate/apenergy

The value of energy storage in decarbonizing the electricity sector

CrossMark

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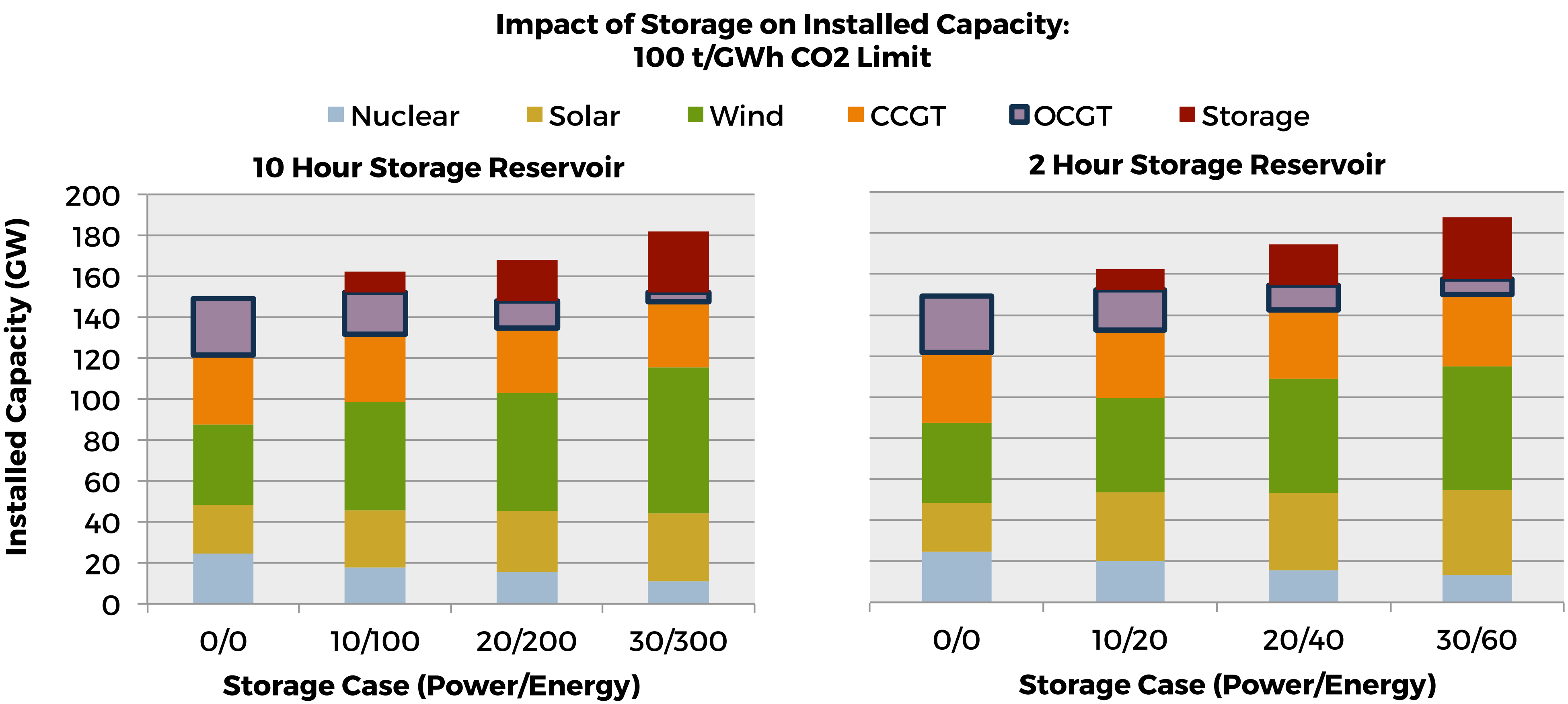
HIGHLIGHTS

- Energy storage value increases with tighter carbon dioxide (CO_2) emissions limits.
- The marginal value of storage declines as storage penetration increases.
- Large-scale deployment of available battery technologies requires cost reductions.
- Energy storage increases utilization of the cheapest low-CO_2 resources.
- Longer-duration storage increases the share of wind more than solar photovoltaics.

2. CAPACITY AND ENERGY VALUE UNDER CO2 LIMIT

Storage is a strong substitute for "peaking" power plants.

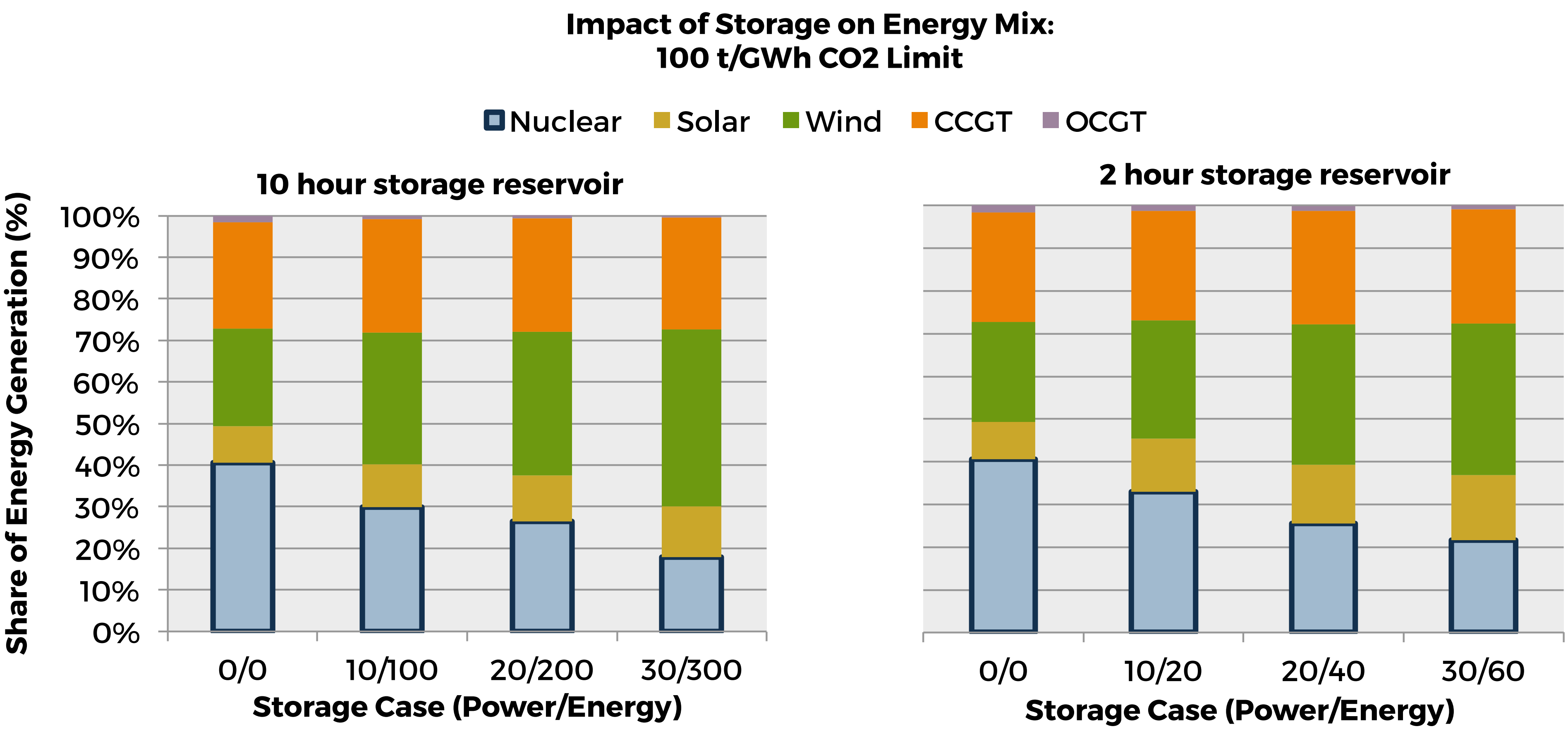
Total market opportunity as capacity resource: ~10-20% of total capacity



Source: de Sisternes, Jenkins & Botterud (2016), "The value of energy storage in decarbonizing the electricity sector," Applied Energy 175: 368-379,

2. CAPACITY AND ENERGY VALUE UNDER CO2 LIMIT

Variable renewables + storage are weak substitutes for flexible base resources (e.g. gas combined cycle, nuclear).

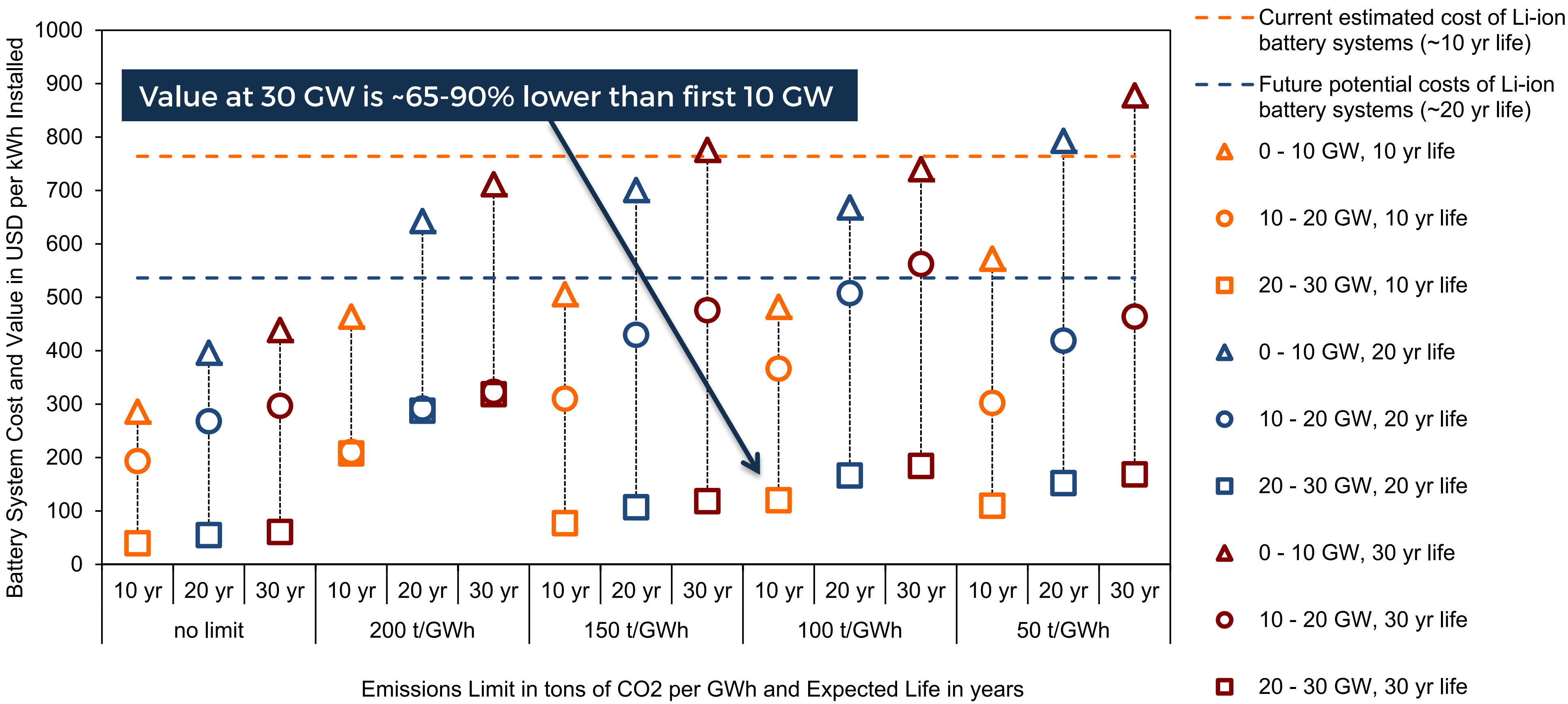


Source: de Sisternes, Jenkins & Botterud (2016), "The value of energy storage in decarbonizing the electricity sector," Applied Energy 175: 368-379,

2. CAPACITY AND ENERGY VALUE UNDER CO2 LIMIT

Marginal value of storage declines (rapidly):

Cost-benefit of energy storage: system value of 2-hour energy storage capacity for different carbon emissions goals and current and potential future cost for Li-ion battery systems for comparison.



Source: de Sisternes, Jenkins & Botterud (2016), "The value of energy storage in decarbonizing the electricity sector," Applied Energy 175: 368-379,

3. CAPACITY AND ENERGY VALUE UNDER CO2 LIMIT

SUMMARY

Storage is a strong substitute for peaking plants.

- Total market as capacity resource may be 5-20% of total capacity (50-200 GW nationwide). Note: storage competes here against demand response as well.

Storage enables wind/solar to act as weak substitute for “flexible base” resources such as nuclear or gas combined cycle.

- Larger market opportunity if wind/solar become very cheap.

Marginal value of storage as substitute for capacity resources or a complement for renewable energy resources both decline.

- ~65-90% decline in marginal value as storage goes from 6-20% of total system capacity