Net-zero power grid and electrification

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The Electricity Grid: An Engineering Marvel

United States Grid

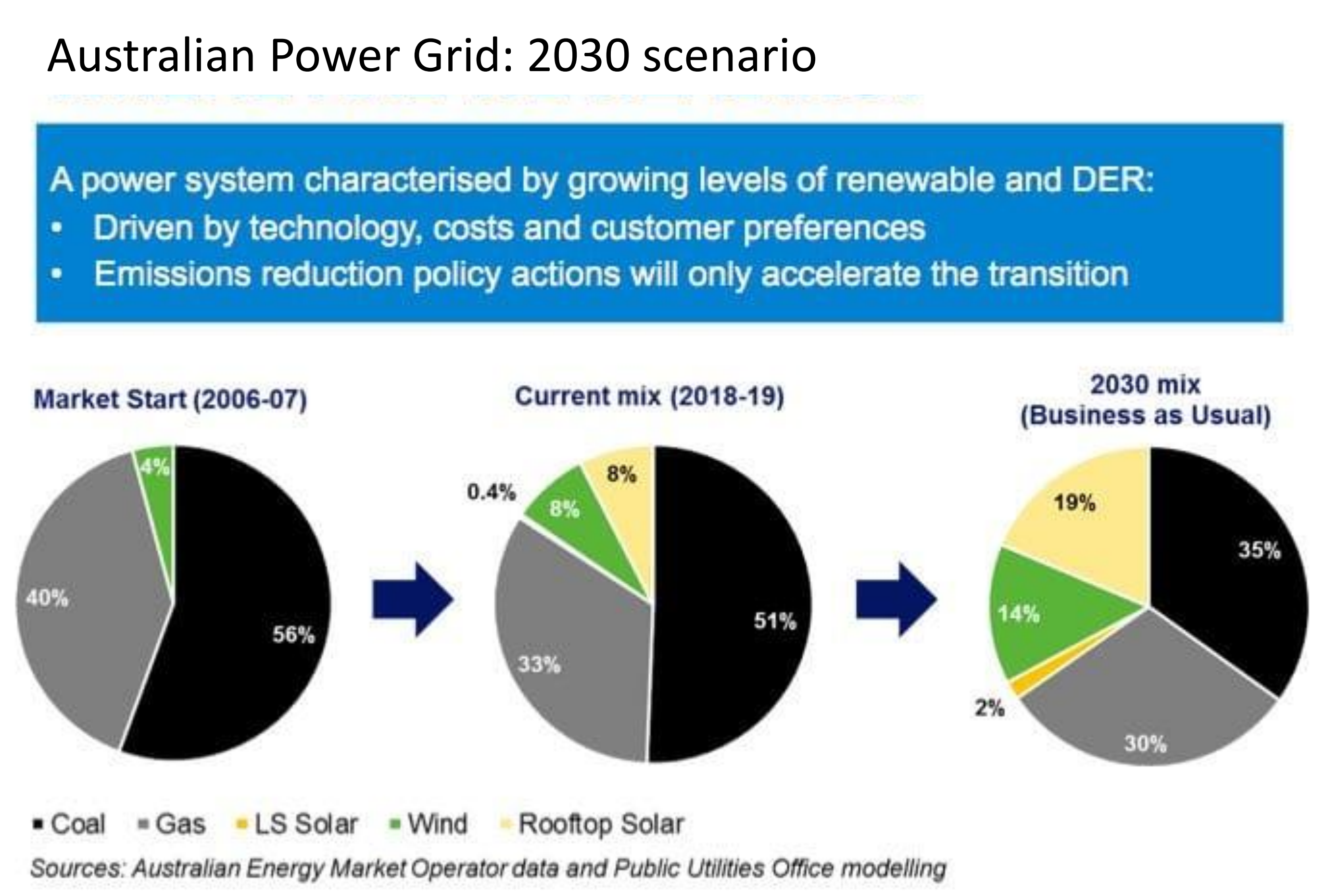
360,000 miles of transmission lines [1]
470 000 MW utility scale generation, 2019 [2]
20,000+ GW commercial generators, 2014 [1]

3 main interconnections
8 ISO/RTOs
10,000+ nodes in Western + ERCOT Interconnects [3]

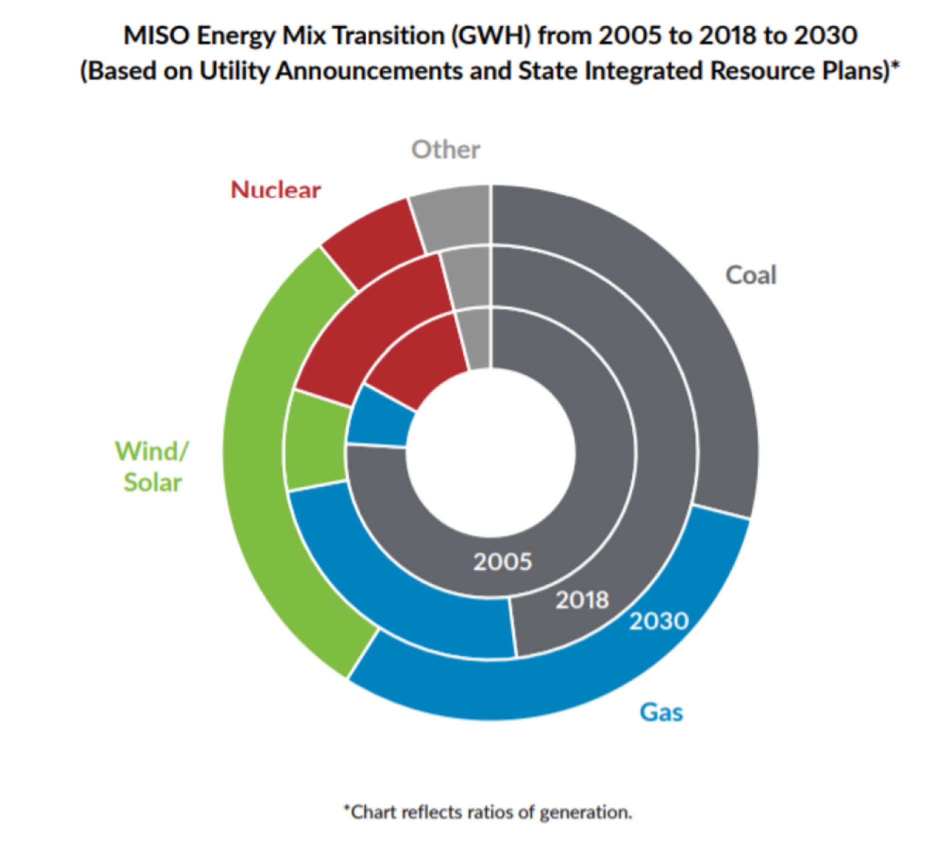
[1] https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php
[2] https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php
[3] https://arxiv.org/pdf/1204.0165.pdf
Image sourced: https://engineering.fb.com/connectivity/electrical-grid-mapping/

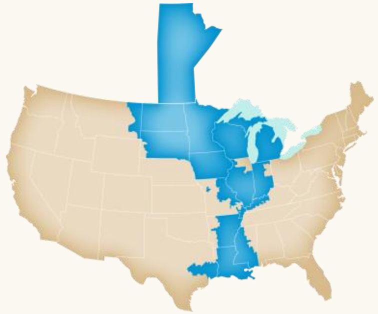
What’s changing? Push Towards Deep Decarbonization

Driver 1: Renewable Energy Penetration



Source: https://reneweconomy.com.au/wa-prepares-shift-from-coal-to-renewables-and-distributed-energy-18705/

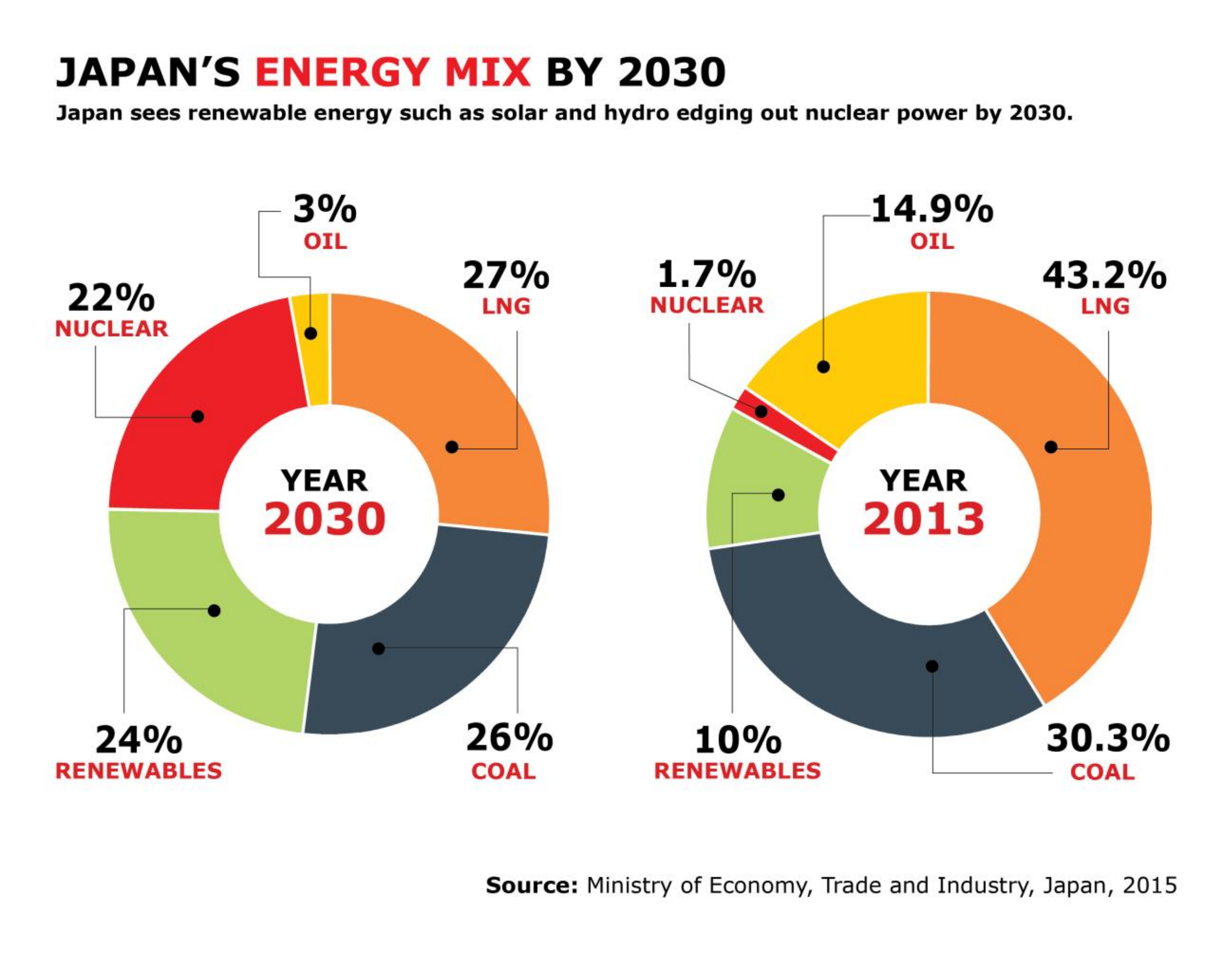




Size: 1.2 million **square miles** (15 US states + Manitoba in Canada)

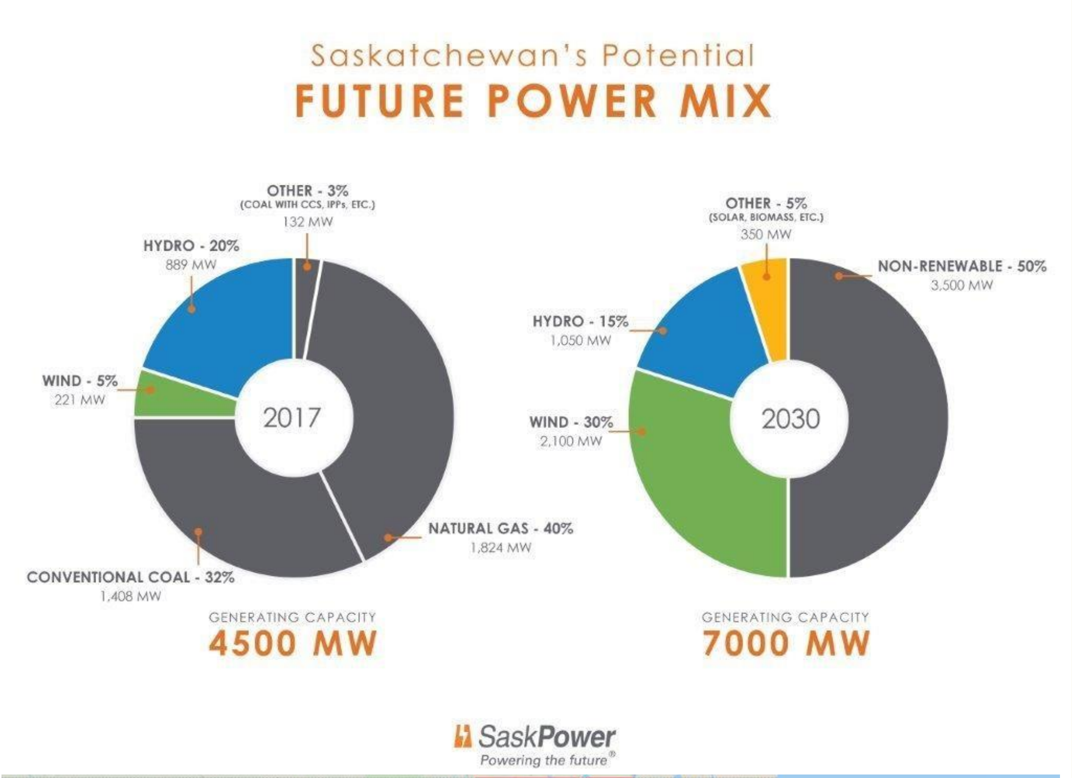
Source: https://cdn.misoenergy.org/MISO%20FORWARD324749.pdf, Wikipedia

Push Towards Deep Decarbonization - Across the Globe



Size: 145,914 square miles; Population: 126.5 million

Source: http://recap.asia/Data-Hub-Detail.php?dataid=29



Canadian province –
Size: 651,900 square kilometers
Population: 1.174 million

Source: https://energi.media/news/saskatchewan-commits-50-renewables-2030-mainly-driven-wind/

Biden administration shoots for the sun with goal of 45 percent solar power by 2050

"Achieving this bright future requires a massive and equitable deployment of renewable energy and strong decarbonization policies," the secretary of energy said.

By Jenna Romaine | Sept. 8, 2021

September 8, 2021

September 17, 2020

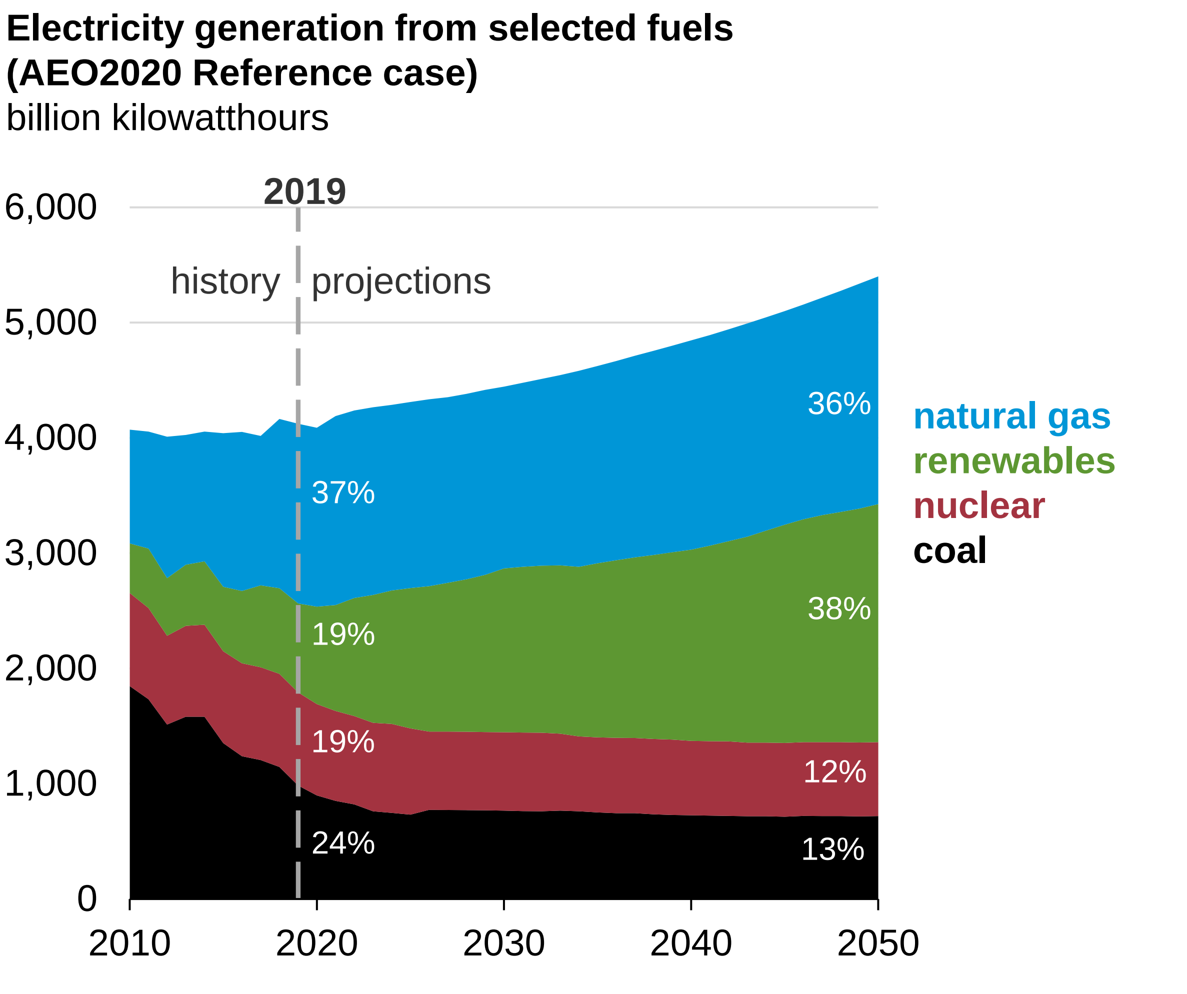
FEDERAL ENERGY REGULATORY COMMISSION

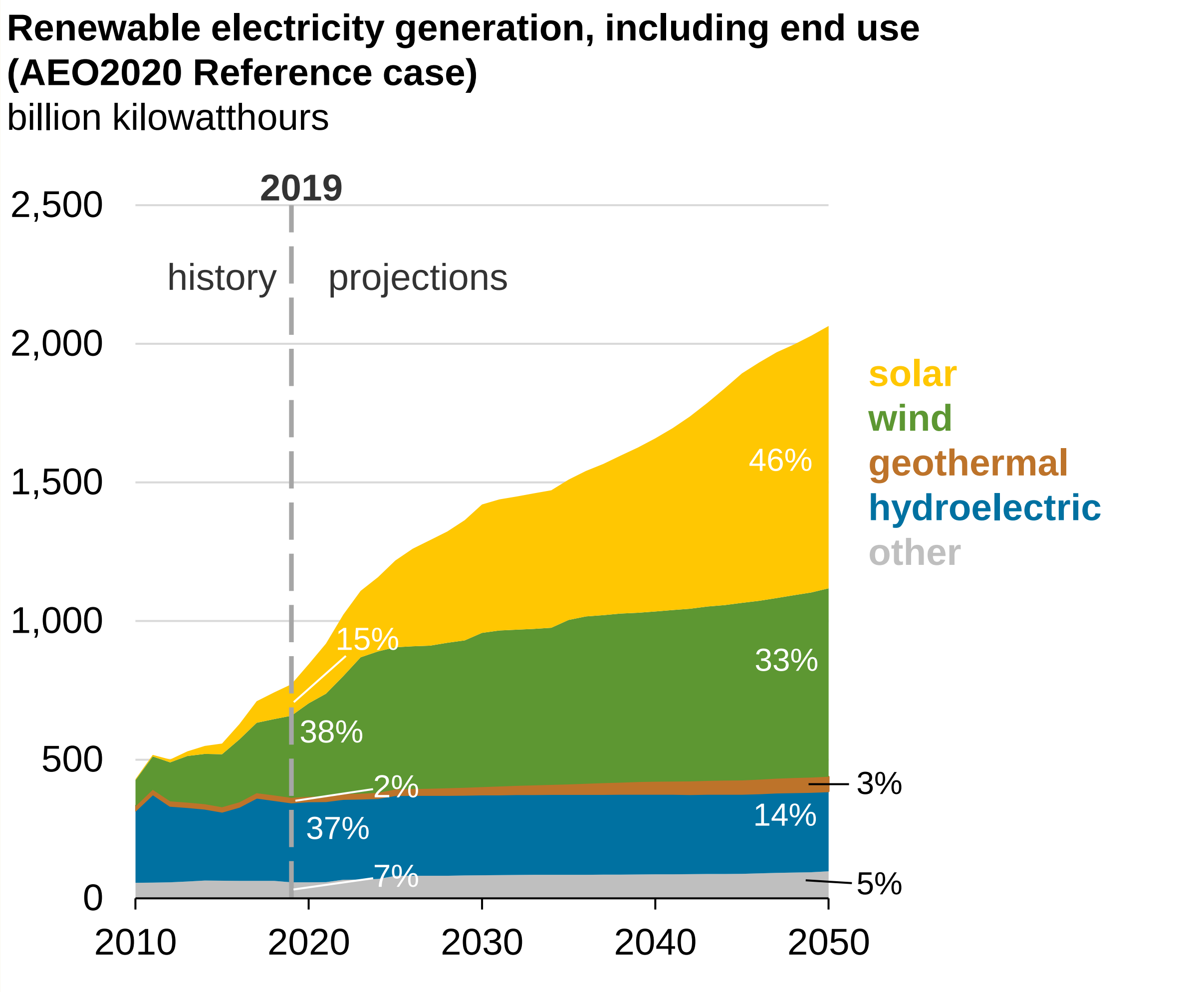
Fact Sheet

FERC Order No. 2222: A New Day for Distributed Energy Resources

FERC Opens Wholesale Markets to Distributed Resources: Landmark Action Breaks Down Barriers to Emerging Technologies, Boosts Competition

US Energy Mix: 2020 and beyond





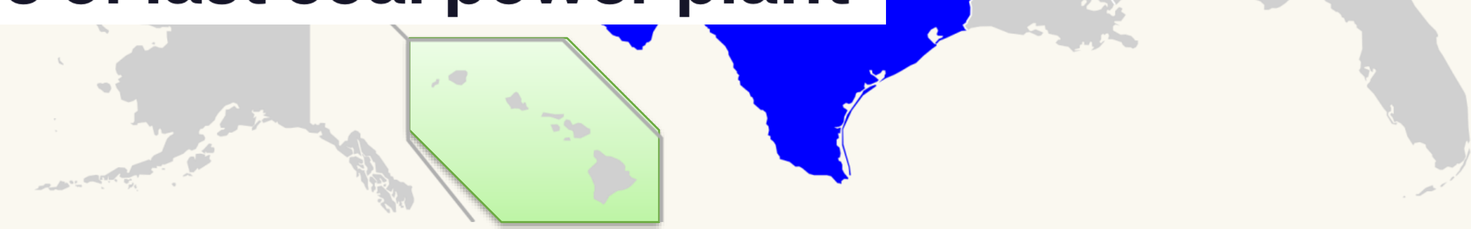
U.S. Energy Information Administration's (EIA) *Annual Energy Outlook 2020* (AEO2020)

100% Renewable: It is Becoming Real

LA100: The Los Angeles 100% Renewable Energy Study

NREL provided rigorous, integrated engineering-economic analysis to the Los Angeles Department of Water and Power (LADWP) through the Los Angeles 100% Renewable Energy Study (LA100).

Results show that meeting LA's goal of reliable, 100% renewable electricity by 2045—or even 2035—is achievable and will entail rapid deployment of wind, solar, and storage technologies this decade.



Weekly data: Hawaii continues push for 100% renewables with closure of last coal power plant

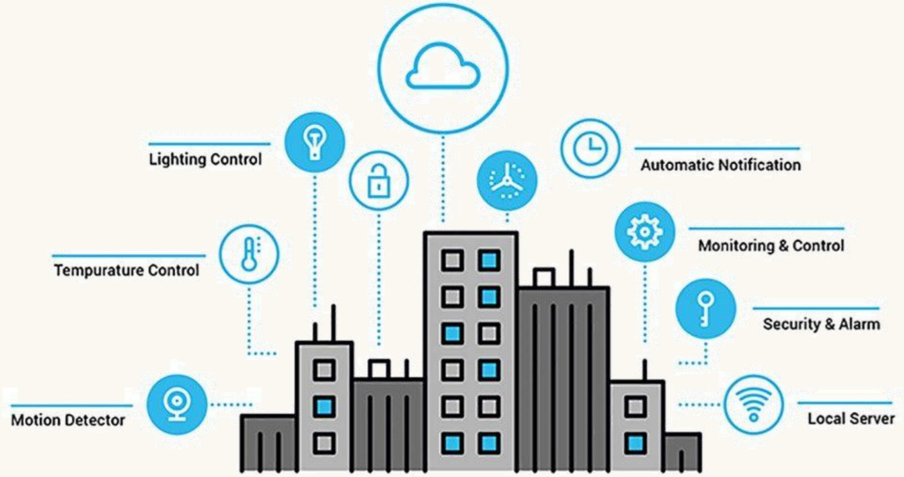
What’s changing? Push Towards Deep Decarbonization

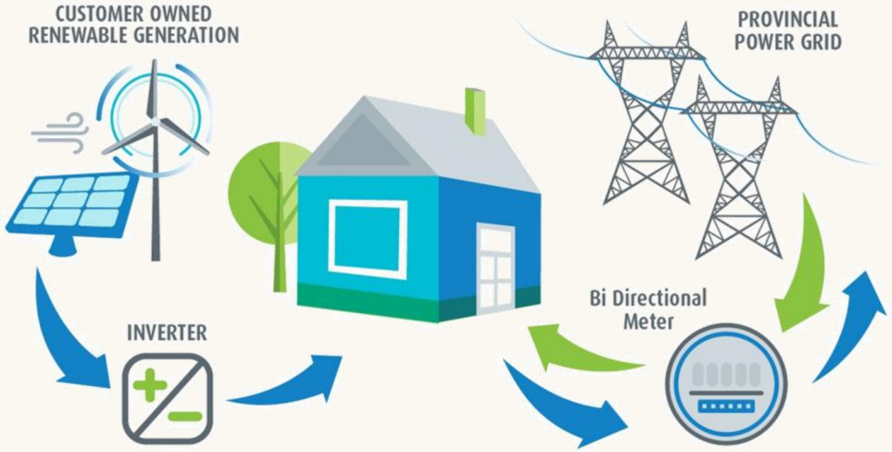
Driver 2: Electrify Everything

- Electric Vehicles
- Smart buildings and increased electrification
- Net-energy homes: small-scale solar

Challenges

- Increased load
- Forecasting load is difficult, historical data less relevant





Power Grid: 20th Century

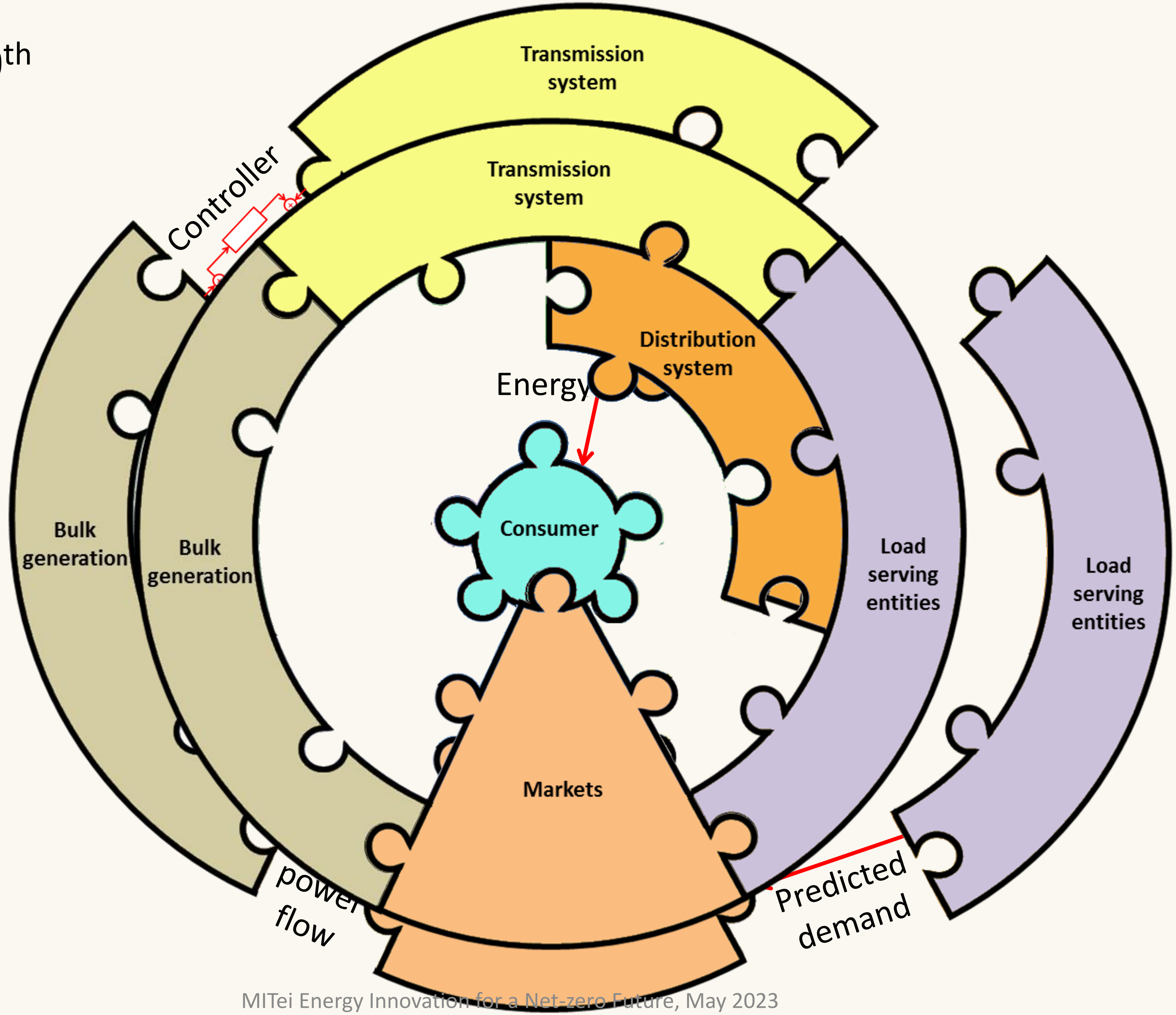
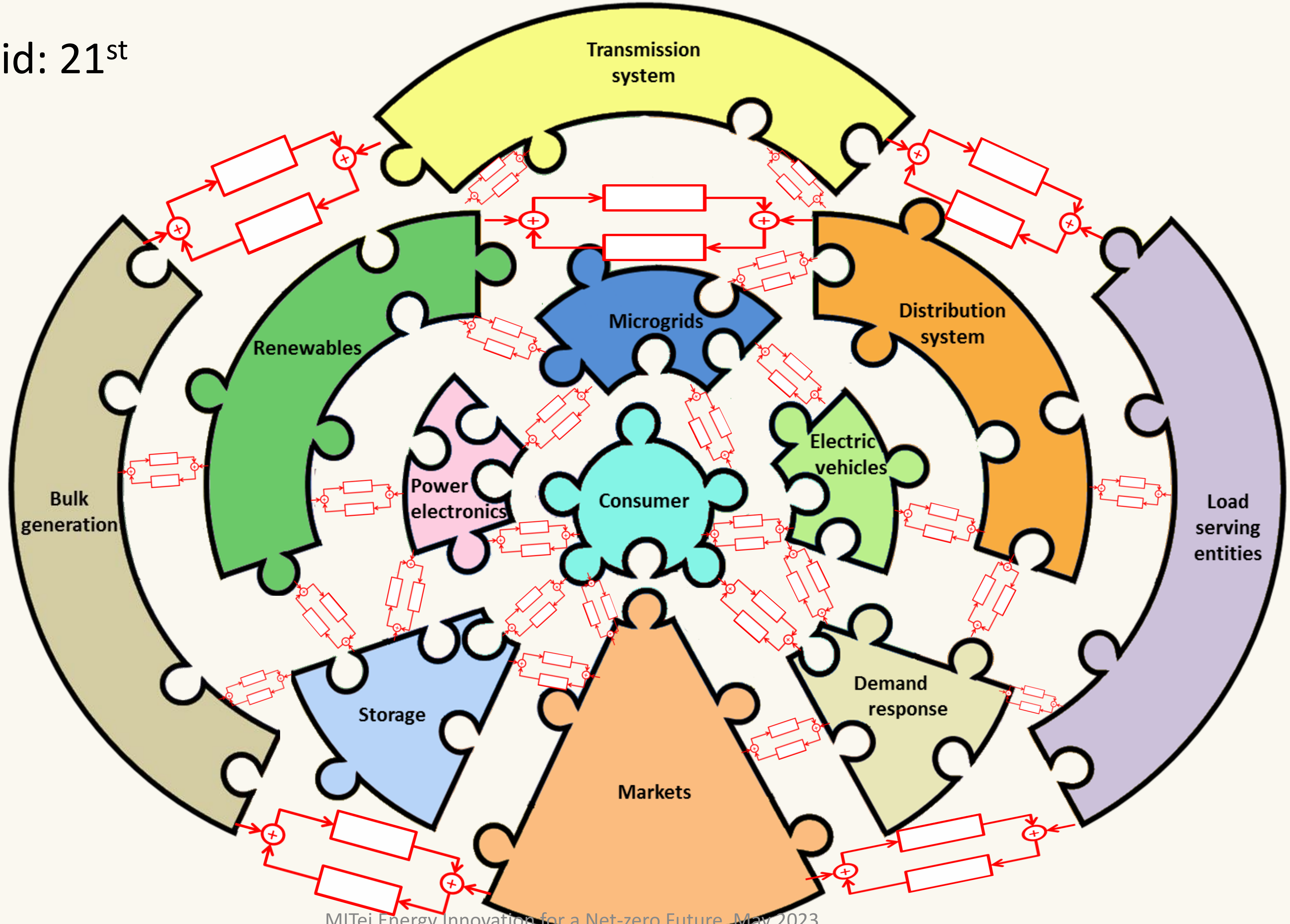


Figure adapted from *Vision for smart grid control: 2030 and beyond. Eds: A.M. Annaswamy, M. Amin, T. Samad, and C. DeMarco*. IEEE Standards Publication, 2013.

Power Grid: 21st Century



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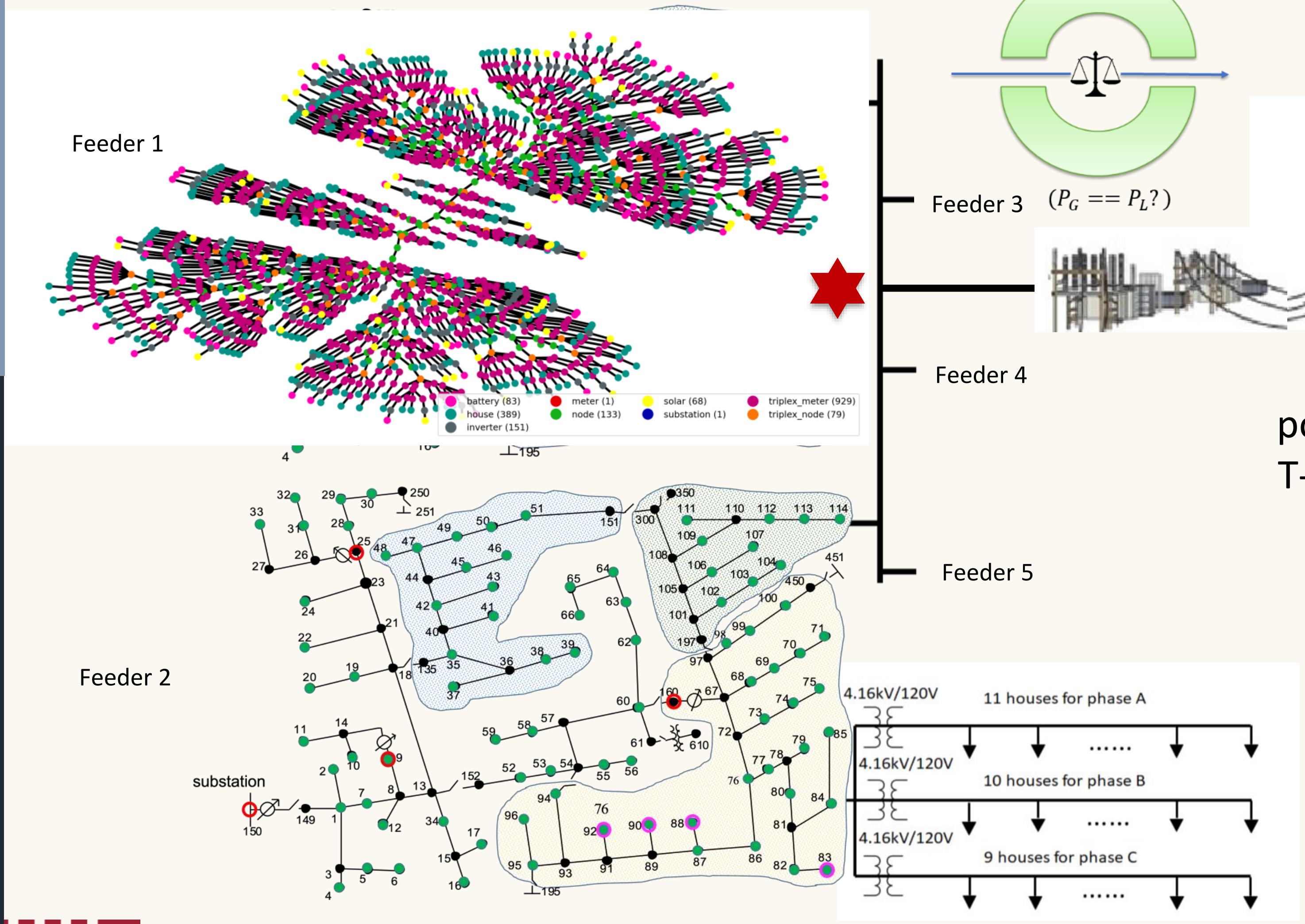
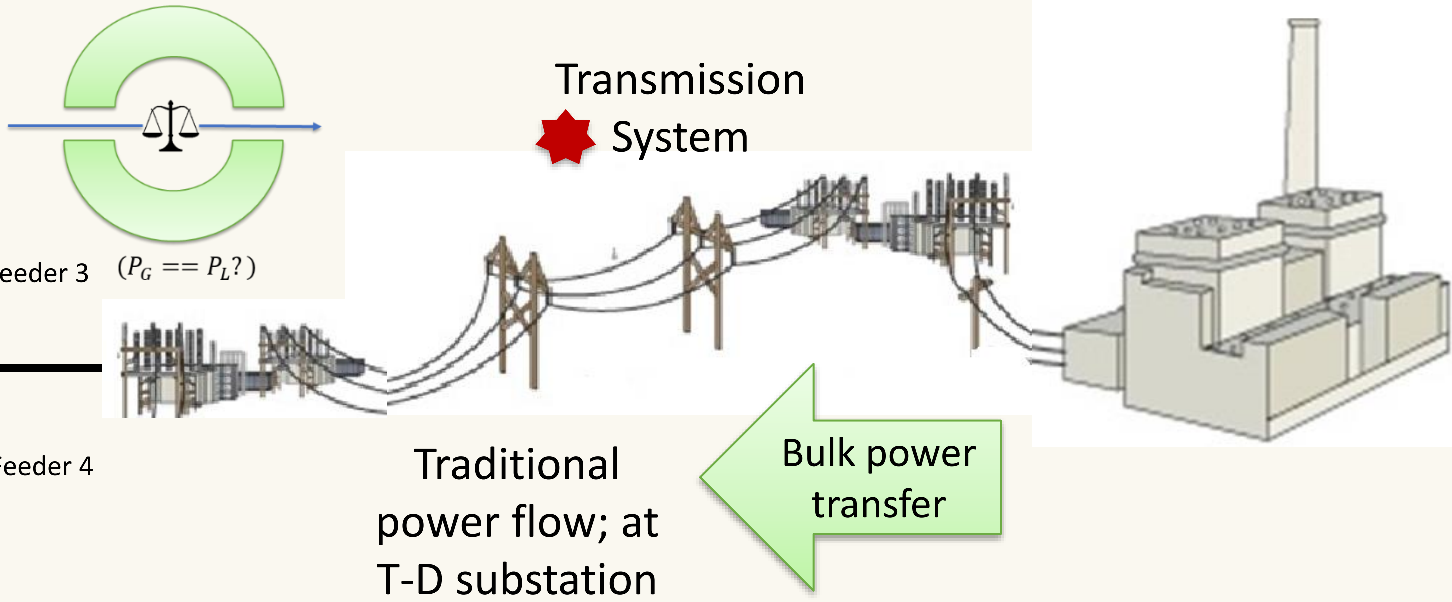
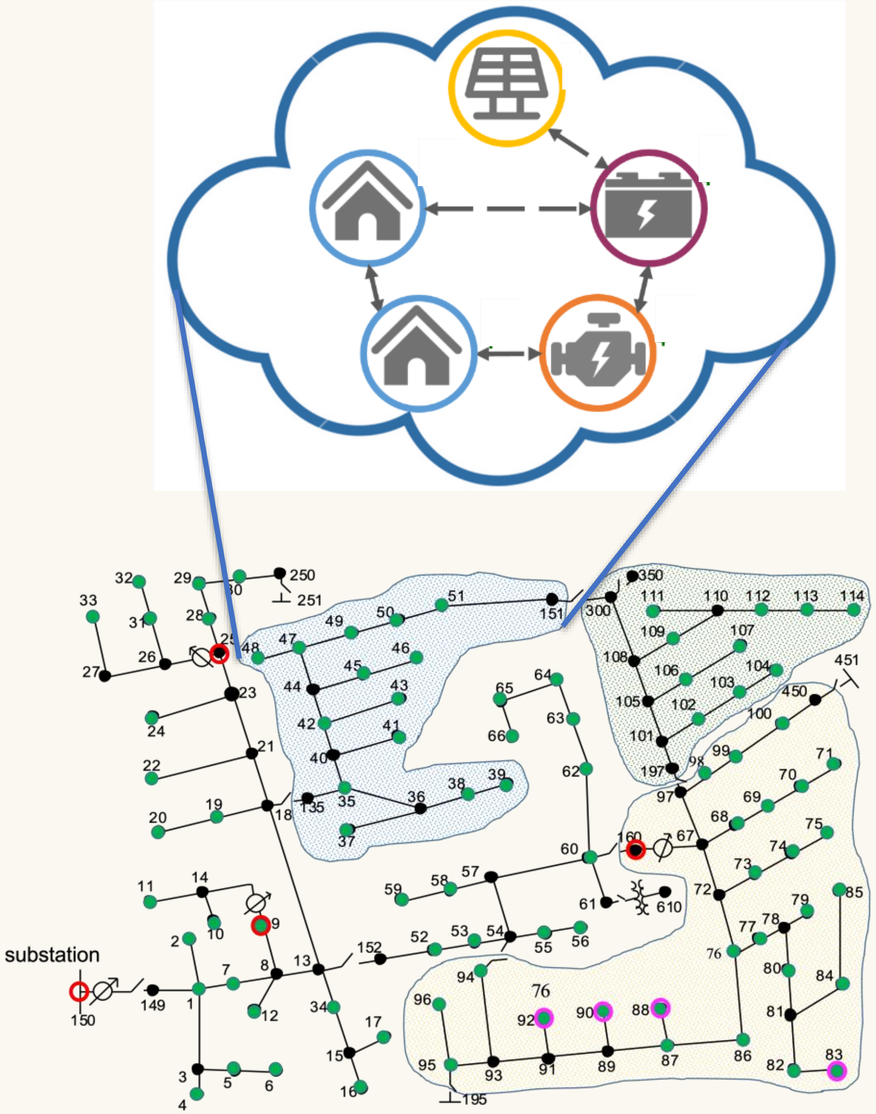
Power balance becomes challenging





- ex. WECC, 1553 buses reduced order model
- ex. Urban city scale distribution network ~2 million nodes *

Technological Challenges



❑ Integration challenges:

- Real-time balance of supply and demand
  - coordination of DG, storage and flexible DER
- Imbalance across three-phase AC – introduces two-way flows that can affect grid losses, protection equipment, and may lead to outages – better visibility to operators
- Loss of synchronous generators – that provide rotating inertia – due to shift to renewables that are small and distributed.

❑ Increased complexities:

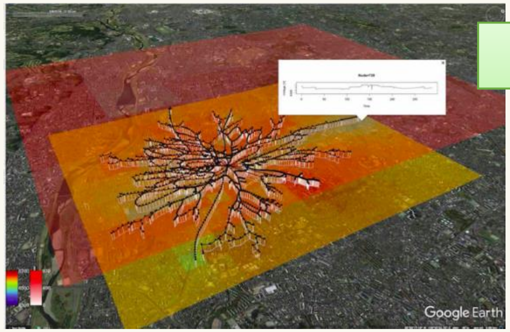
- Customer demand becomes uncertain – load varies in an unknown manner
- Typical top-down approach of planning and operations is fundamentally challenged
- Operators cannot forecast load – essential for quantifying risk and for efficient planning and operation
- Security and privacy considerations become more urgent

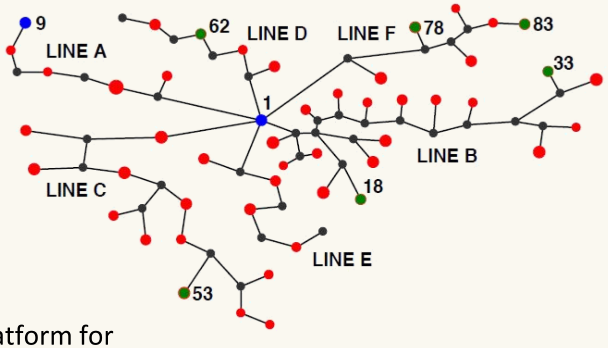
❑ Emerging technologies in power electronics, control, and communication can be leveraged

Haider, R., D'Achiardi, D., Venkataramanan, V., Srivastava, A., Bose, A. and Annaswamy, A.M. Reinventing the utility for distributed energy resources: A proposal for retail electricity markets. *Advances in Applied Energy, 2021*

Results: Example 1 – A democratized grid with a retail market

Komae-city, Tokyo, Japan





Source: Hayashi et al. “Versatile modeling platform for cooperative energy management systems in smart cities." *Proceedings of the IEEE* 106.4 (2018): 594-612.

Increase in Revenue for DSO with Energy Market:

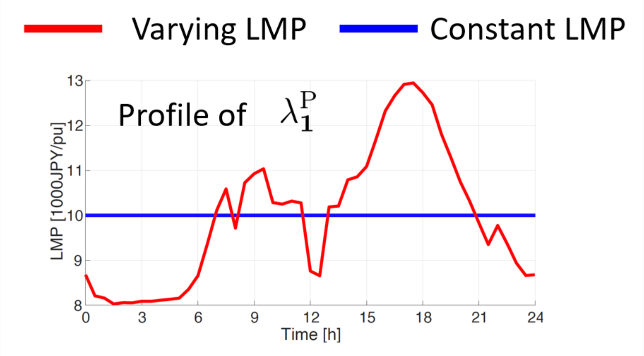
$$\mathcal{P}_{\text{DSO-increase}} = \mathcal{P}_{\text{DSO}} - \mathcal{P}_{\text{no-DSO}}$$

Where: $$\mathcal{P}_{\text{DSO}} = \underbrace{\mathcal{R}^{\text{L}}_{\text{DSO}}}_{\text{Revenue from Loads}} - \underbrace{\mathcal{C}^{\text{flex}}_{\text{DSO}}}_{\text{Payments to DRs}} - \underbrace{\mathcal{C}^{\text{DG}}_{\text{DSO}}}_{\text{Payments to DGs}} - \underbrace{\mathcal{C}^{\text{WEM}}_{\text{DSO}}}_{\text{Payments to WEM}}$$

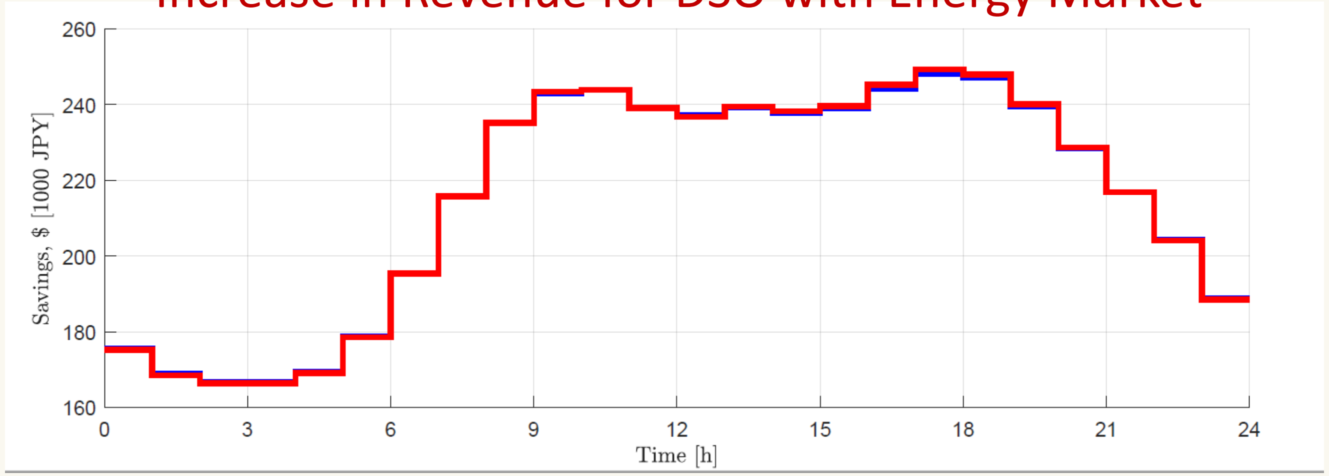
At d-LMP

$$\mathcal{P}_{\text{no-DSO}} = \underbrace{\mathcal{R}^{\text{L}}_{\text{no-DSO}}}_{\text{Revenue from Loads}} - \underbrace{\mathcal{C}^{\text{WEM}}_{\text{no-DSO}}}_{\text{Payments to WEM}}$$

At utility retail price

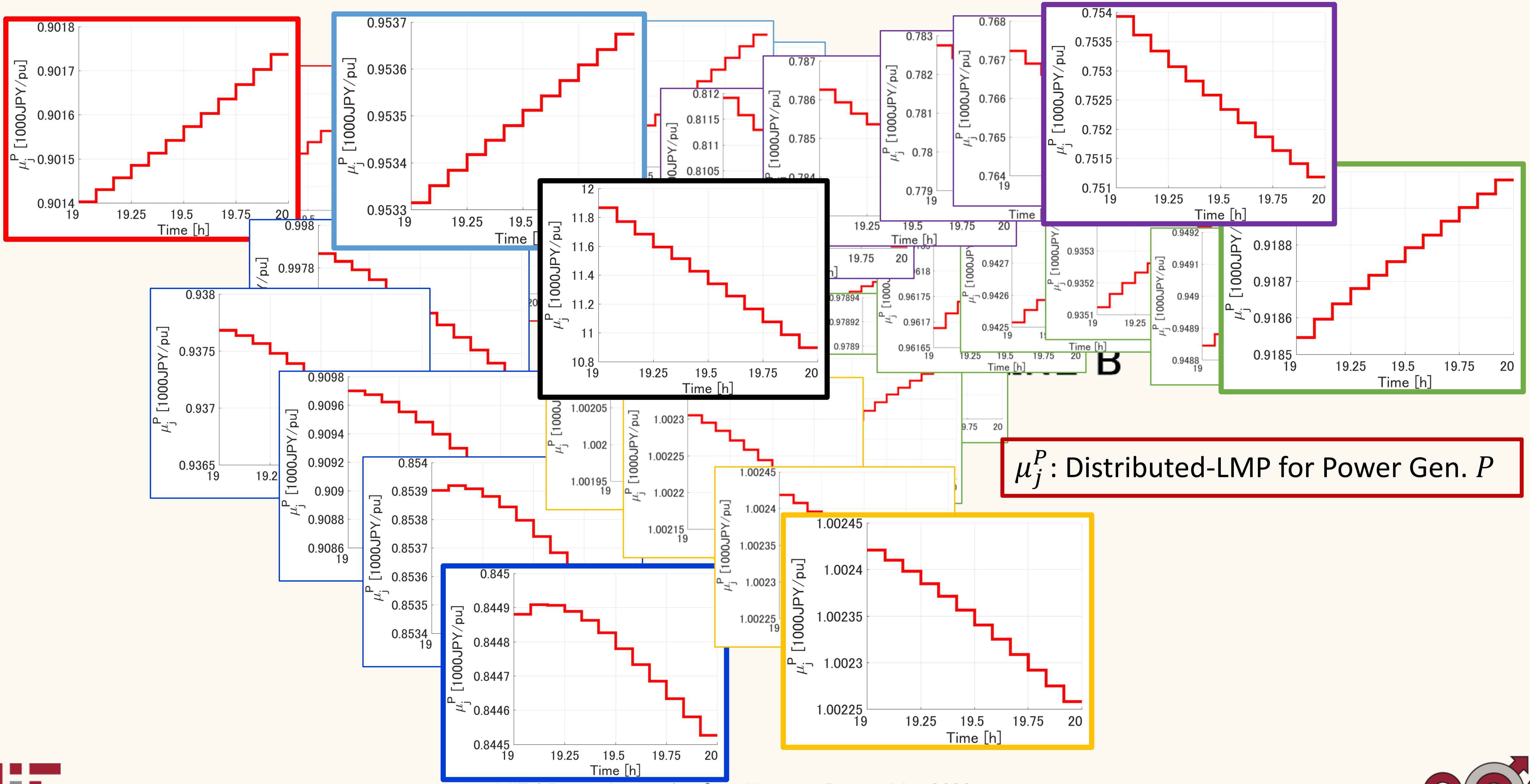


Increase in Revenue for DSO with Energy Market



* R. Haider, S. Baros, Y. Wasa, J. Romvary, K. Uchida and A. M. Annaswamy, *IEEE Transactions on Smart Grid*, doi: 10.1109/TSG.2020.2996565.

Results: Example 1

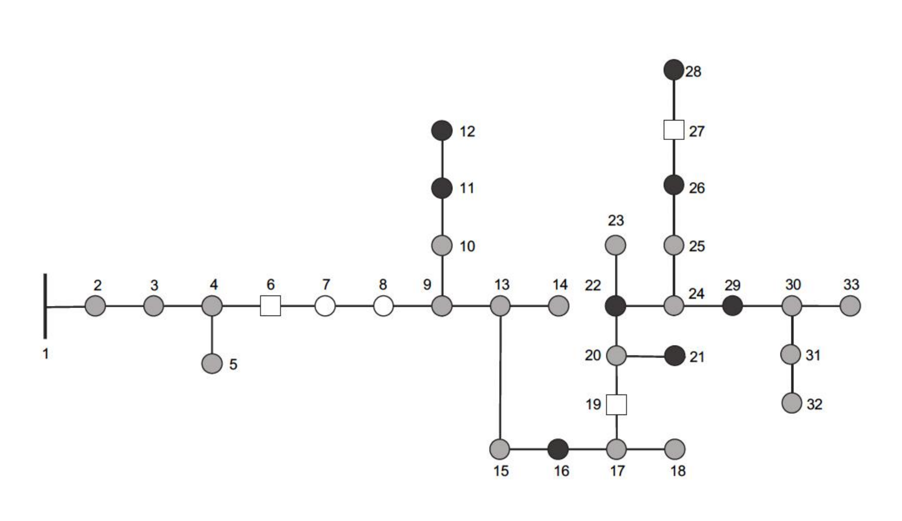


μ_j^P: Distributed-LMP for Power Gen. P

* R. Haider, S. Baros, Y. Wasa, J. Romvary, K. Uchida and A. M. Annaswamy, *IEEE Transactions on Smart Grid*, doi: 10.1109/TSG.2020.2996565.

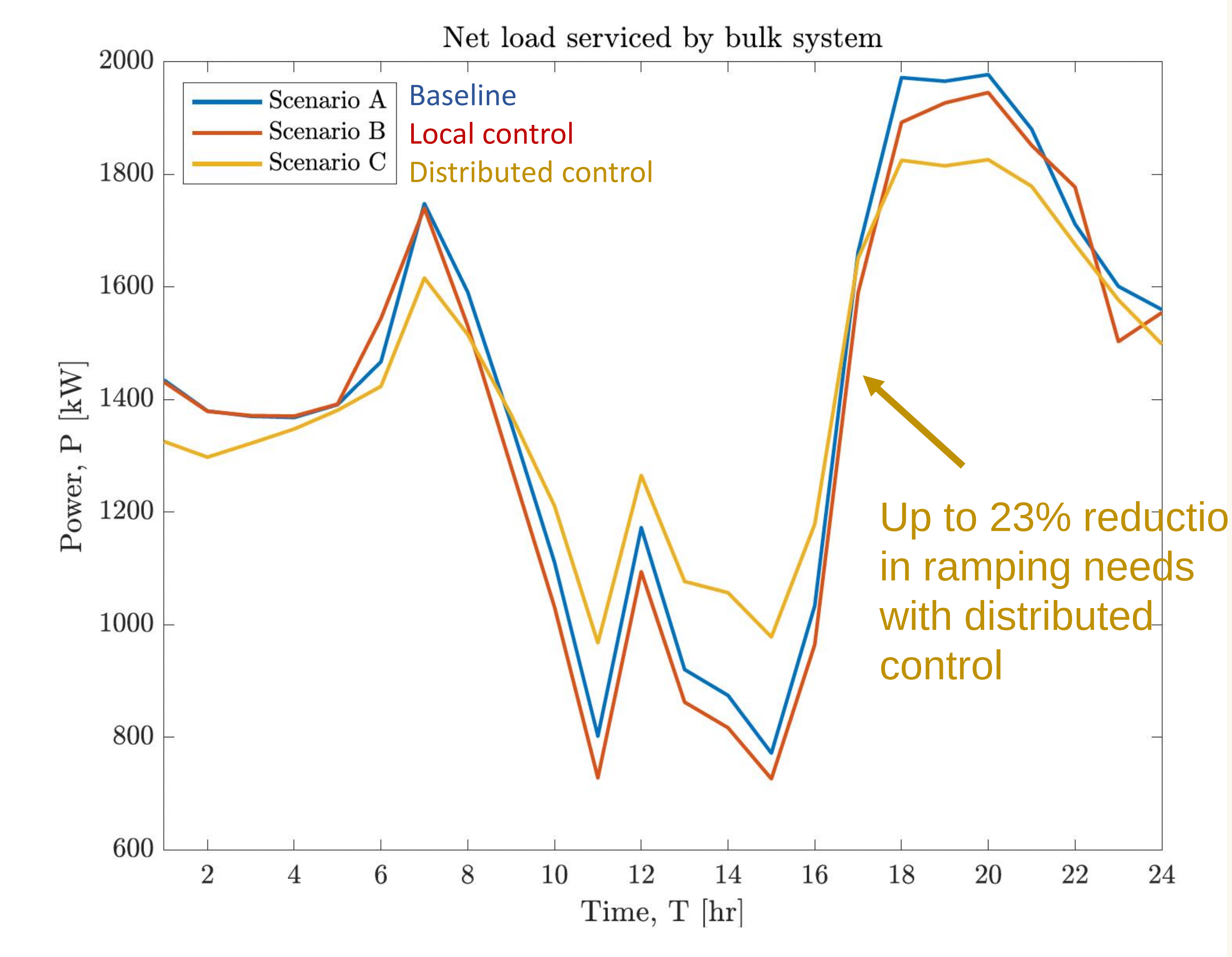
Results: Example 2 - Flattening the "Duck Curve"

Modified IEEE-34 node network with:
- 38% renewables
- Flexible cooling loads
- Batteries



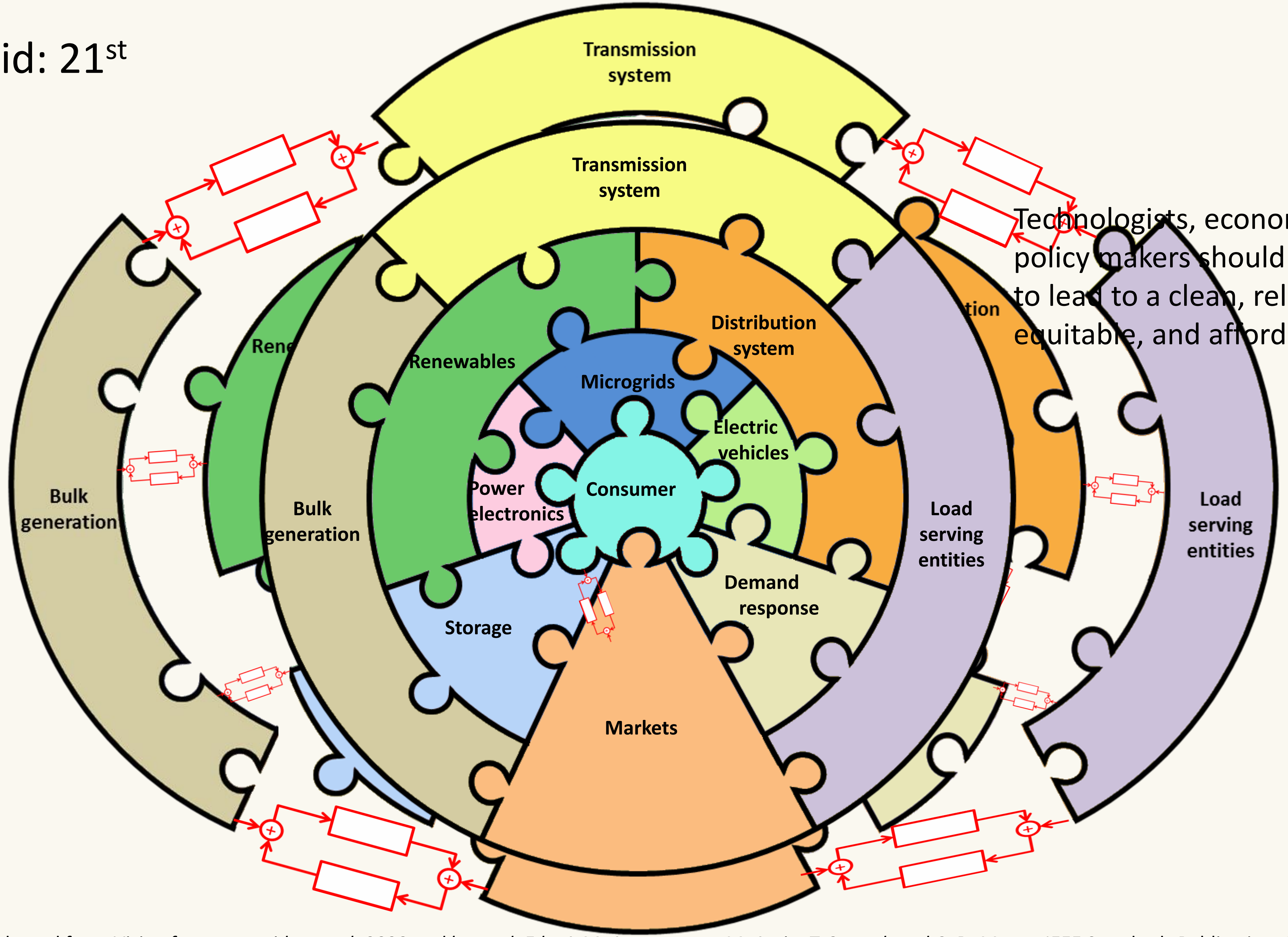
Residential Loads
Commercial Loads
Batteries
No load

DERs (PV and flex load) present throughout network



R. Haider, G. Ferro, M. Robba, A.M. Annaswamy, PESGM 2022

Power Grid: 21st Century



Technologists, economists, and policy makers should come together to lead to a clean, reliable, resilient, equitable, and affordable grid.

Figure adapted from *Vision for smart grid control: 2030 and beyond. Eds: A.M. Annaswamy, M. Amin, T. Samad, and C. DeMarco*. IEEE Standards Publication, 2013.

Thank you!

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