Disruptive Technologies in Energy System and the Future Grid

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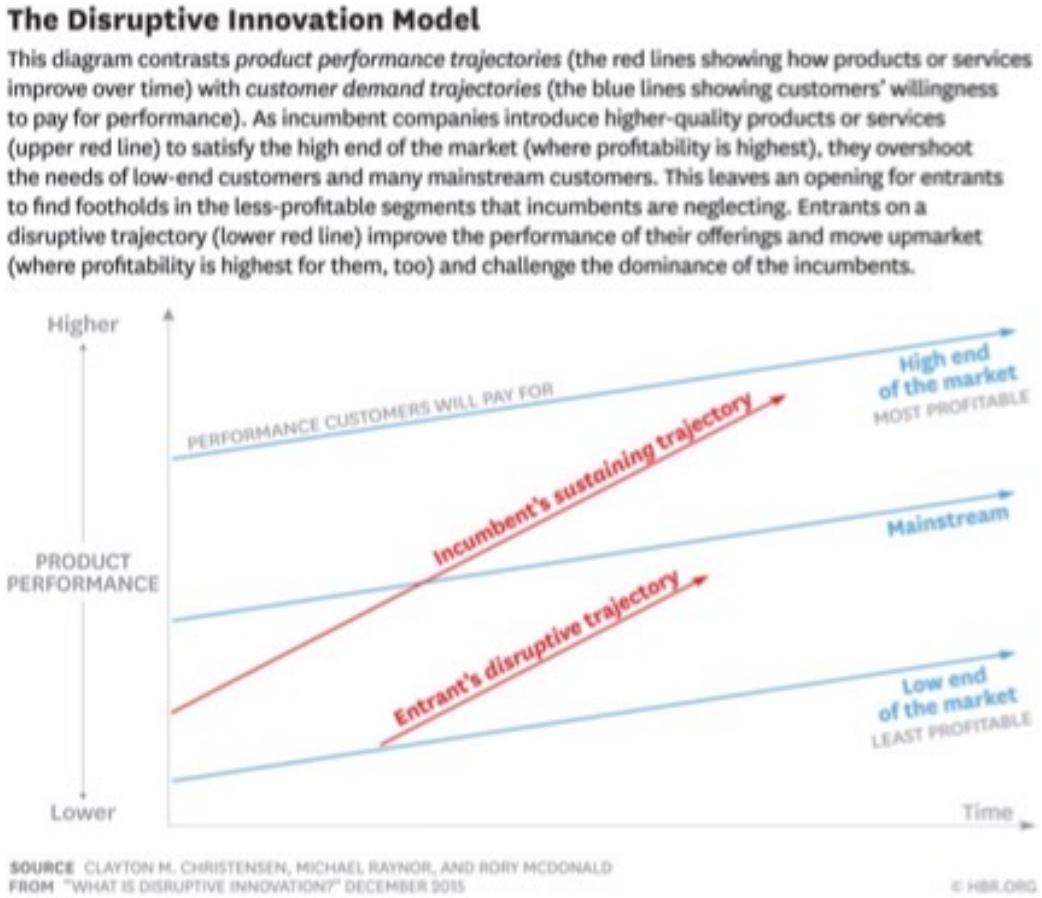
Energy Source Selection Factors

- Cheap
- Abundant
- Safe
- Generation technology available
- Clean

What is a Disruptive Technology?

- Disruptive technology is an innovation that significantly **alters the way** that consumers, industries, or businesses operate.
- A disruptive technology **sweeps away** the systems or habits it replaces because it has attributes that are **recognizably superior**.

The Definition of Disruptive Innovations



Clayton M. Christensen coined the term “disruptive innovation” in a 1995 paper for Harvard Business School.

- Disruption is a process in which a new market entrant, e.g. a startup, enters a market that is currently dominated by incumbents and successfully gains significant market shares, even though the new market entrant has far less resources than the incumbents.
- Even though incumbents had a market dominant position and were managed very well, they struggled to adapt to new products which eventually took away their customers and thereby their revenues.
- disruptive technologies do not take the incumbents’ market share by surprise, but that the incumbents face the upcoming threat but decide to ignore it, primarily, as the direct impact on the current revenue is not yet visible.

Disruptive Innovation Markets

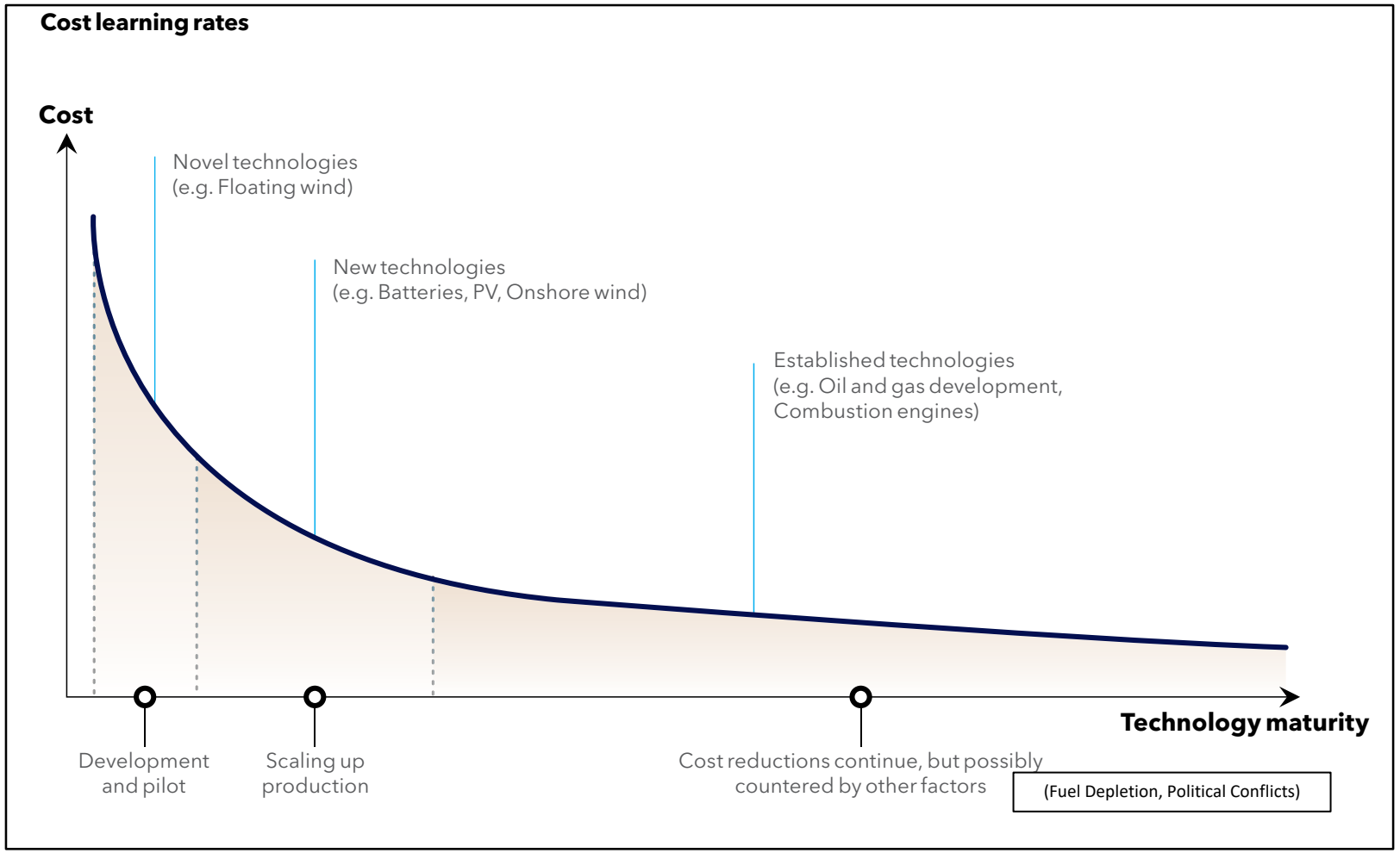
Disruptive innovations are made possible because they get started in two types of markets that incumbents overlook:

1. **Low-end** footholds exist because incumbents typically try to provide their most profitable and demanding customers with ever-improving products and services, and they pay less attention to less-demanding customers.
2. In the case of **new-market** footholds, disrupters create a market where **none existed**. They find a way to turn non consumers into consumers.

Renewables as a Disruptive Technology

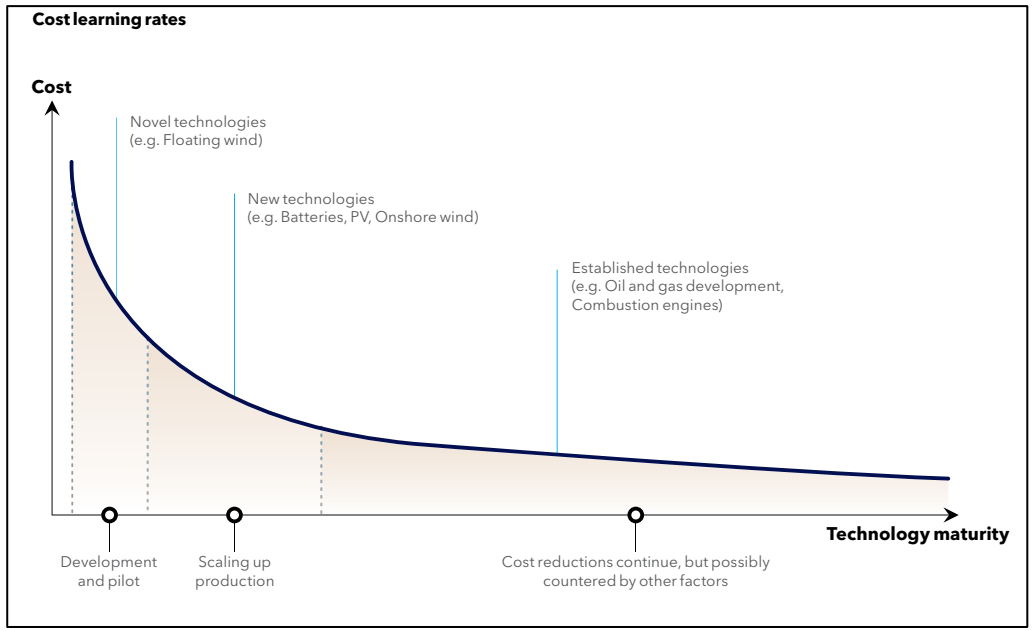
- Low-end/ new market & Return-on-investment
- From low-end and new market to mass-market based on a new feature
- Reduce revenue of premium products

Technology Maturity



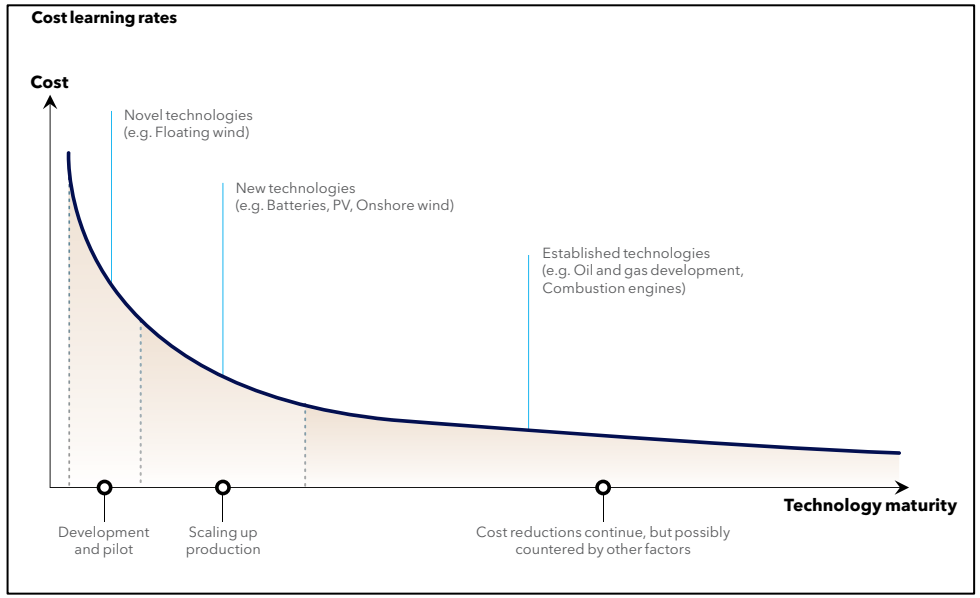
- Existing competitive technologies such as Solar and Wind Power – Take full advantage of cost decline caused by **growing number** of unit installations
- For less mature technology – scaling from prototype to worldwide commercialization.
- To predict green hydrogen growth – need to understand development of renewable resources of power.
- Understanding CCS (carbon Capture & Storage) is not complete without considering technology requirements for pipeline transporting enormous quantities of CO_2.

Cost Learning Rate (CLR)



- For each technology cost tends to decline at constant rate with each doubling of accumulated capacity.
- Each doubling of the installed capacity of a technology takes longer, progressively slowing the annual rate at which costs will decline
- CLR comes from core technology improvement based on Research and Innovation (for example: material choices, shift from combustion engine to electric)
- CLR is also driven by more **effective production**, **learning-by-doing**, and as **experience** from increased deployment **improves** over time.

Cost Learning Rate (CLR)



- CLR is self-reinforcing: Cost reduction both causes and caused by the growing number of unit installations.
- Economics of scale: where cost of producing the initial unit compared with the $n^{th.}$ unit falls over time also plays a role.
- Labor and Installation Costs: Technology costs tend to fall at constant rate while other cost such as labor costs don't.

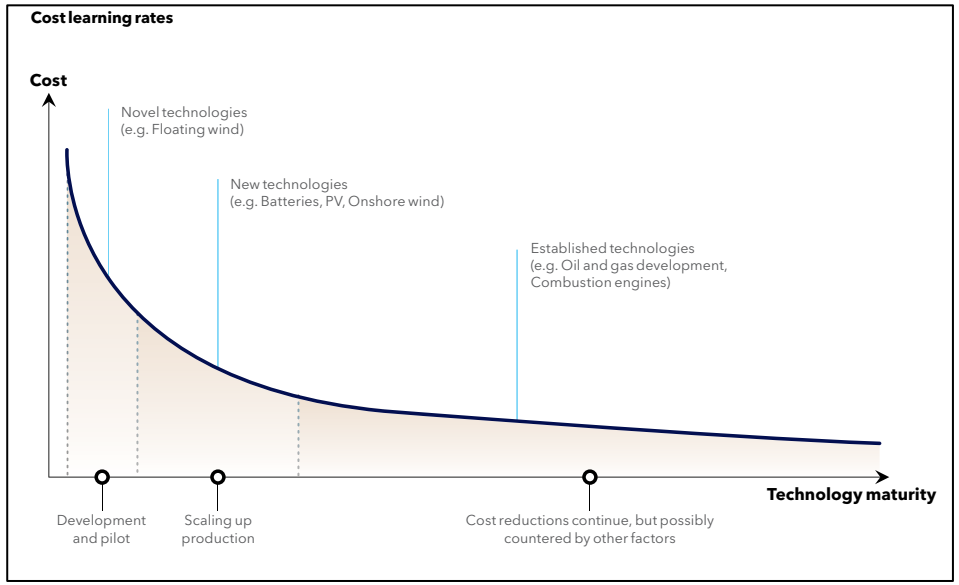
CLR associated with "**core" technologies** tend to be higher than that of supporting technologies.

Therefore, technologies that mainly comprise "core" technology such as batteries tend to have higher learning rates.

How China Came to Dominate the World in Solar Energy

- China installed more solar panels in 2023 than the United States has in its history.
- It cut the wholesale price of panels it sells by nearly half. And its exports of fully assembled solar panels climbed 38 per cent, while its exports of key components almost doubled.
- While the US and Europe are trying to revive renewable energy production and help companies fend off bankruptcy, China is racing far ahead.
- With China's economy stumbling, the ramped-up spending on renewable energy, mainly solar, is a cornerstone of a big bet on emerging technologies.
- China's leaders say that a "new trio" of industries – solar panels, electric cars and lithium batteries – has replaced an "old trio" of clothing, furniture and appliances.

How China Came to Dominate the World in Solar Energy

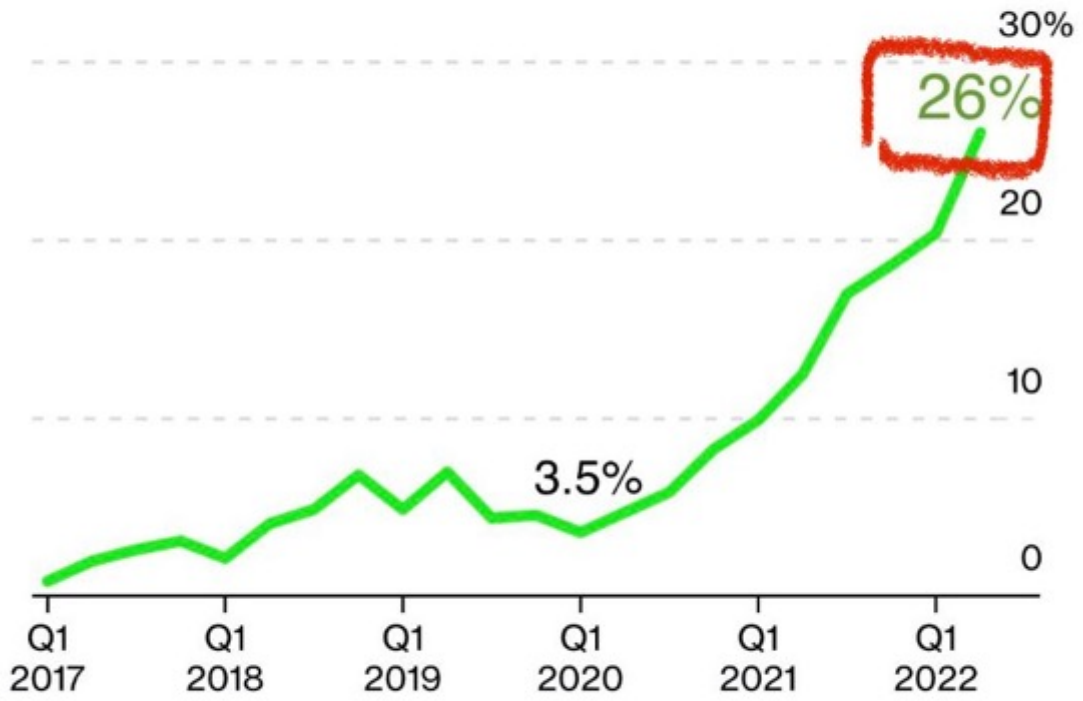


- A research unit of the European Commission calculated in a report in January that Chinese companies could make solar panels for 16 to 18.9 US cents per watt of generating capacity.
- By contrast, it cost European companies 24.3 to 30 US cents per watt, and US companies about 28 US cents.
- The difference partly reflects lower wages in China.
- Chinese cities have also provided land for solar panel factories at a fraction of market prices.
- State-owned banks have lent heavily at low interest rates, even though solar companies have lost money, and some went bankrupt.
- Chinese companies have figured out how to build and equip factories inexpensively.
- Manufacturing the main raw material for solar panels, polysilicon, requires huge amounts of energy. Low electricity prices in China make a big difference.
- Solar panels typically must generate electricity for at least seven months to recoup the electricity that was needed to make them.

The Paradigm Shift and Games Changers

Electric Vehicles on the Rise

Plug-in share of total passenger vehicle sales in China



Source: BloombergNEF
Note: Includes battery-electric and plug-in hybrid passenger vehicle sales

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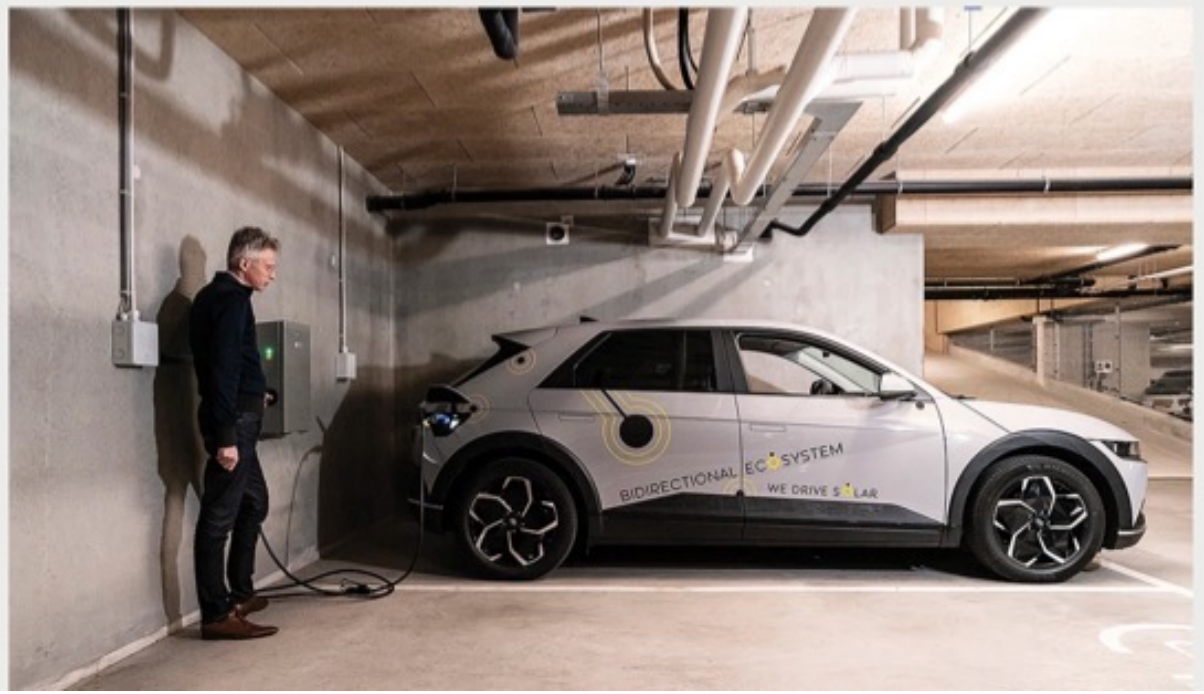
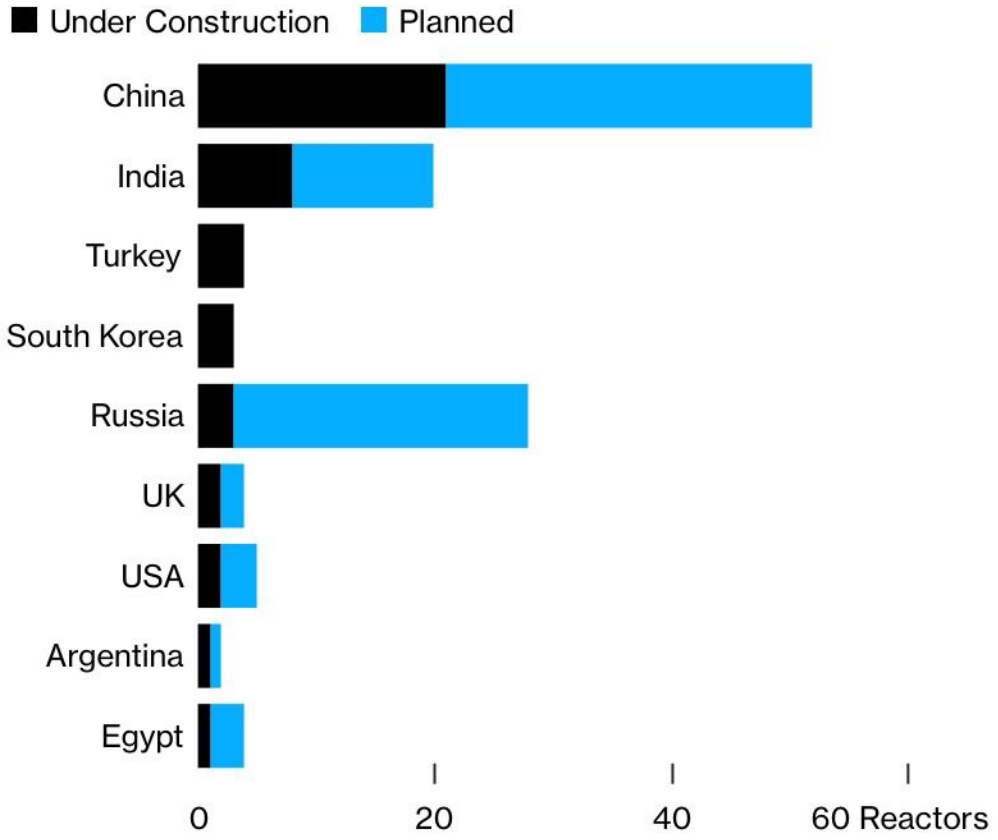
BY HARRY GOLDSTEIN | 01 AUG 2022 | 3 MIN READ



China is in the Midst of a Massive Nuclear Power Buildout

Enormous energy demand is underpinning China's nuclear push



Source: World Nuclear Association

Japan turns back to nuclear power in significant policy shift as fuel prices soar

By Rhea Mogul, Junko Ogura and Tetsu Sukegawa, CNN
Updated 1002 GMT (1802 HKT) August 24, 2022

Japan's Prime Minister Fumio Kishida at his official residence in Tokyo, Japan, on July 14.

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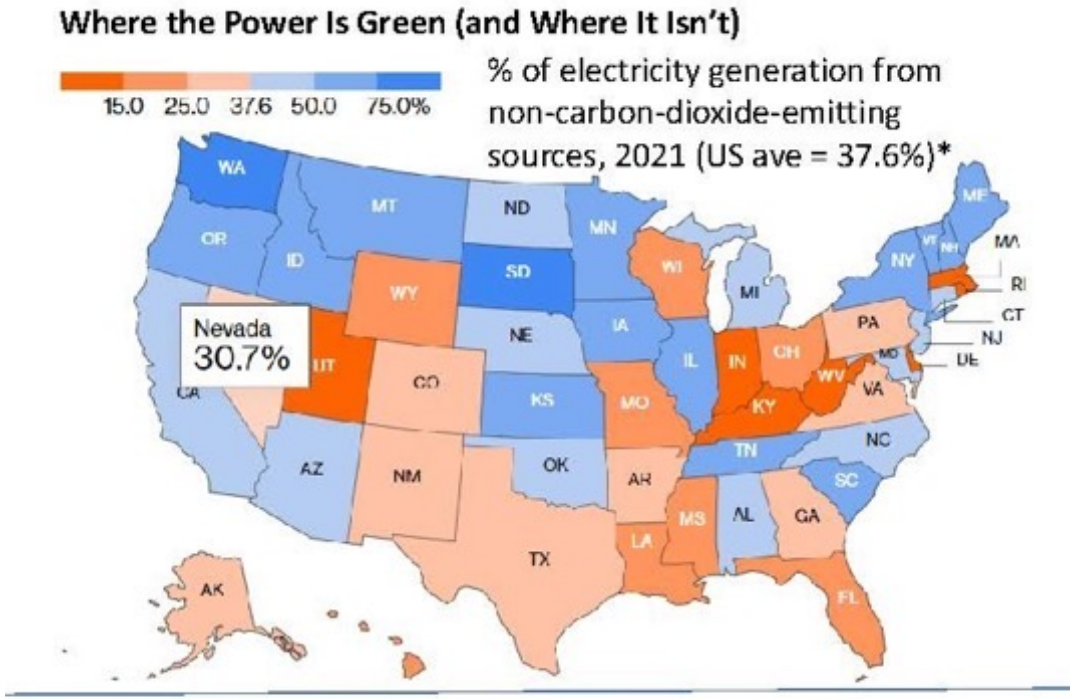
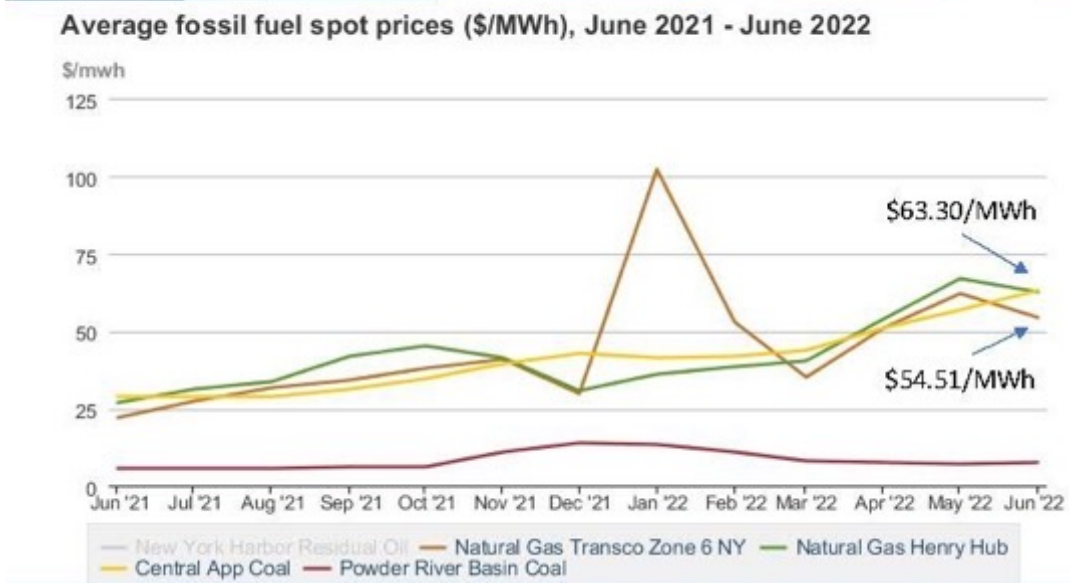




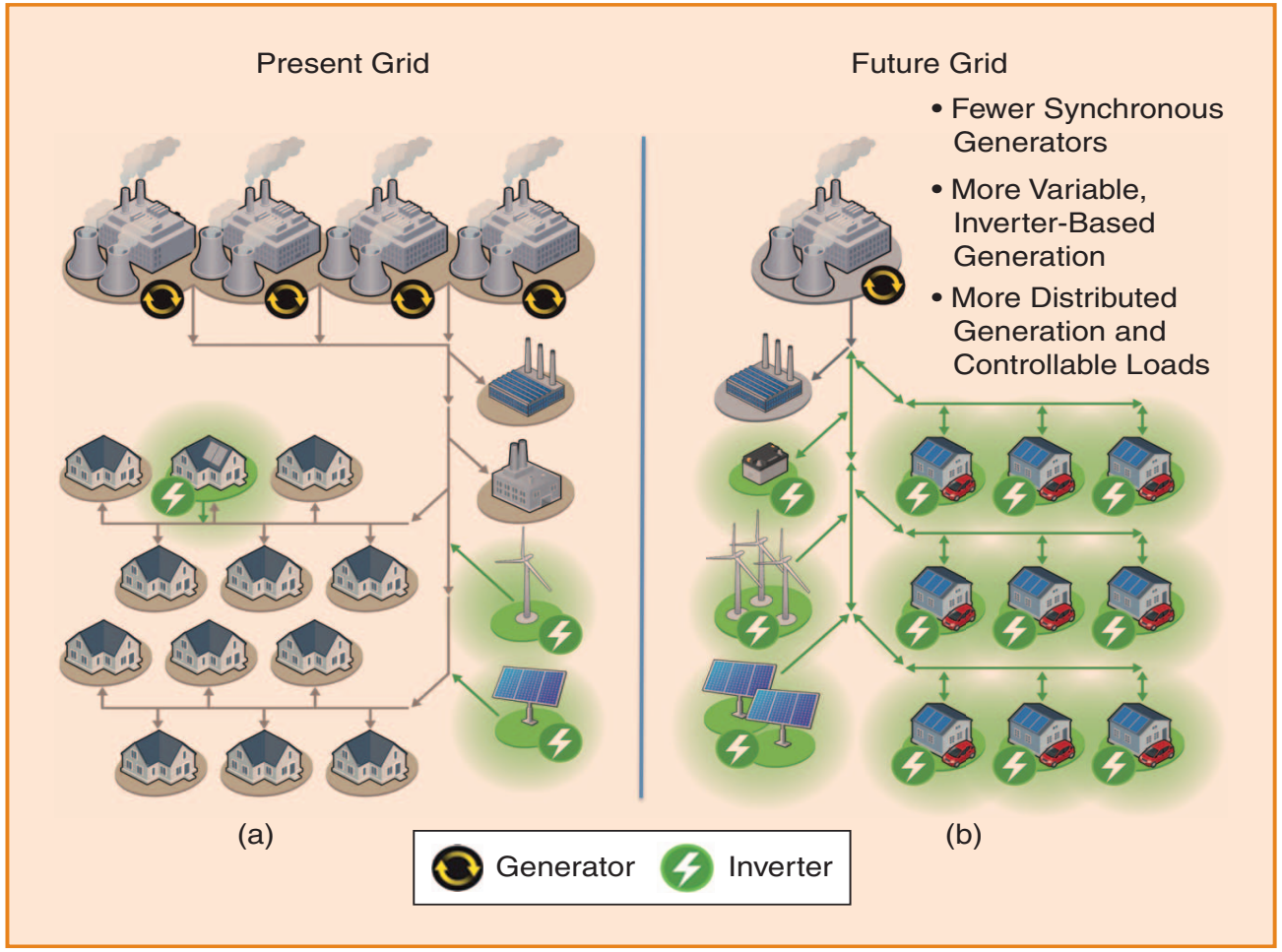
Need to decouple gas price from electricity prices.

Demand side response, or consumption flexibility, or consumption elasticity

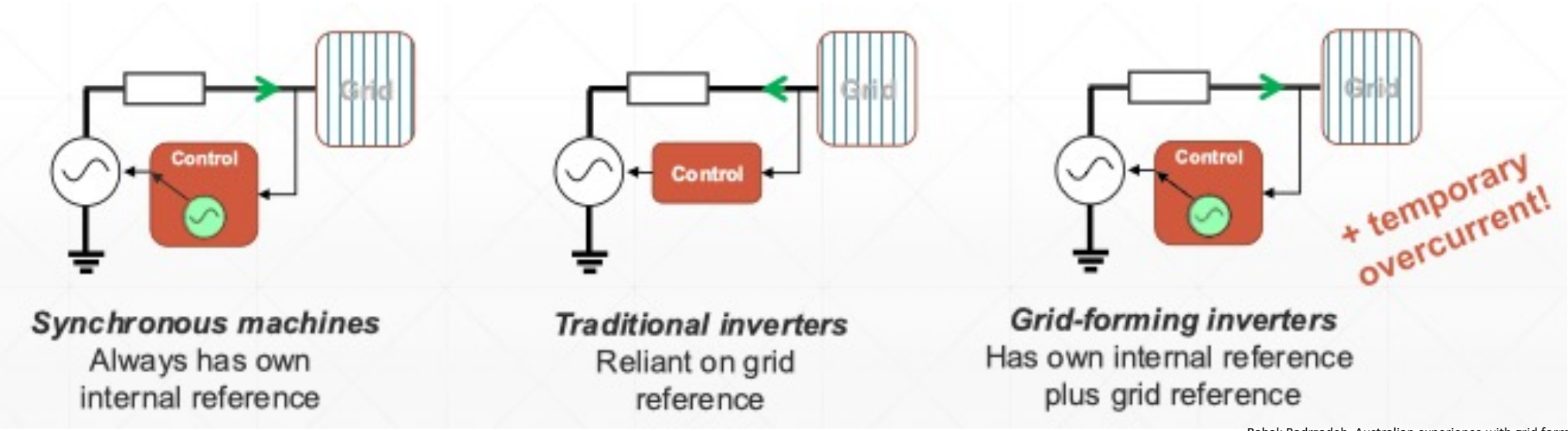
References:
•Bloomberg: https://www.bloomberg.com/opinion/articles/2022-08-28/new-york-risks-falling-behind-texas-in-carbon-free-power#xi4v7vzkg
•NYT: https://www.nytimes.com/2022/05/03/business/energy-environment/high-electric-bills-summer.html
•EIA: https://www.eia.gov/electricity/monthly/update/resource-use.php
•Berkeley Labs: https://emp.lbl.gov/hybrid

Non-Synchronous Generation
Inverter-Based Distributed Grid

Grid of the future will have many more **inverter-based** generators and be much more **distributed** than the current power system, which is dominated by central-station synchronous generators.



Generation Technologies and Inverters



Babak Badrzadeh, Australian experience with grid forming inverters, March 2021

- **Traditional** inverters require sufficient number of synchronous machines for their stable steady-state and transient operation. (Grid-following Inverters)
- **Grid-forming** inverters don't rely on synchronous generators for their stable operation. They require sufficient storage and fault current capability when used as a black starter in addition to default features of grid-forming inverters.

10 technologies setting the pace of the energy transition over the next five years.

DNV is an international accredited registrar and classification society headquartered in Norway. It provides services for oil & gas, renewable energy, electrification.

1. Floating wind
2. Developments in solar PV
3. Waste to fuel and feedstock
4. Pipelines for low-carbon gases
   - Energy infrastructure and nano materials
5. Meshed HVDC grids
6. New battery technology
7. Novel shipping technologies
   - Marine Fuel cells
   - Nuclear-powered ships
8. EVs and grid integration
9. Green hydrogen production
10. Carbon Capture and Storage

Energy production	Energy transport, storage, and distribution	Energy use and conversion
Floating Wind	Pipelines for low-carbon gases	Novel shipping technologies
Developments in solar PV	Meshed HVDC grids	EVs and grid integration
Waste to fuel and feedstock	New battery technology	Green hydrogen production
		Carbon capture and storage

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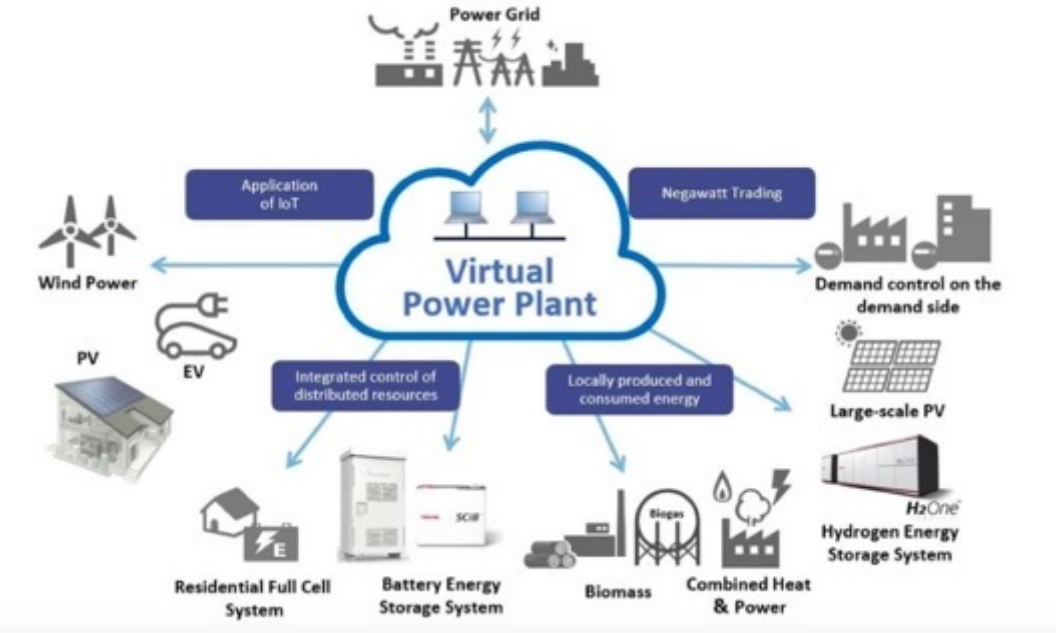
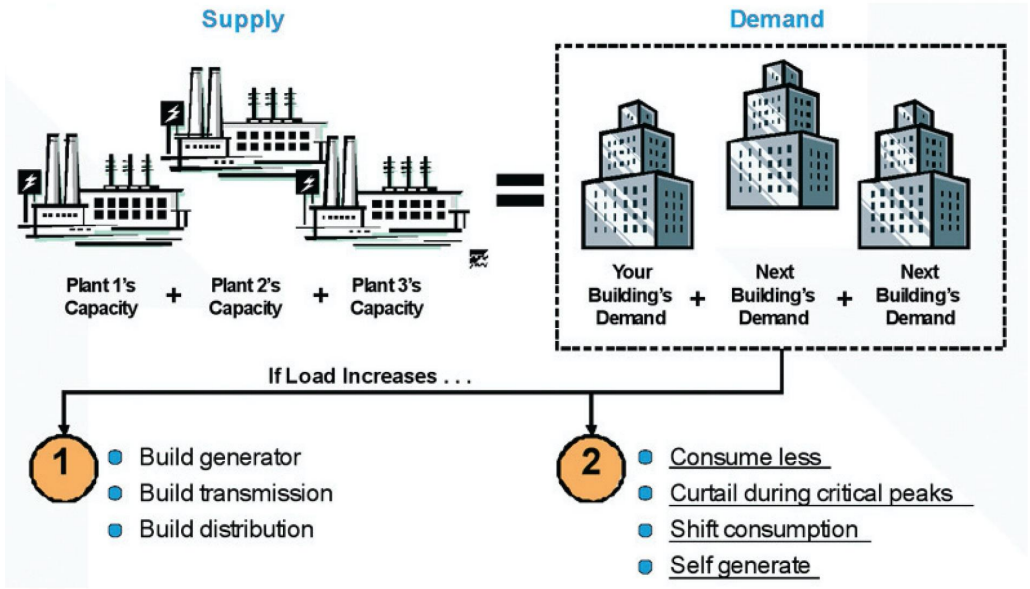
Virtual Grid and Demand Response





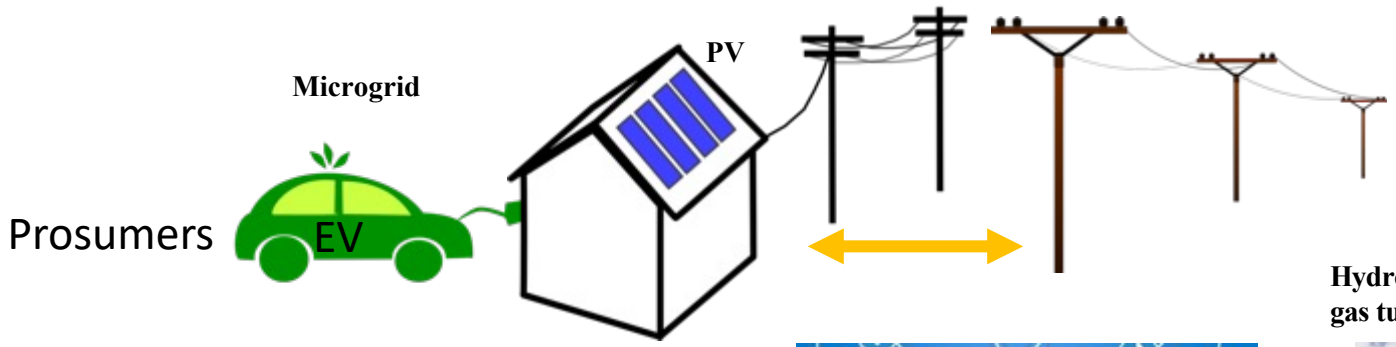
- Grid operators meet peak demand reliably with all available resources.
- Enabling the demand side of the equation optimizes resources.

DER + IoT + DERMS

Distributed Energy Resource + High Speed, broadband digital communication + Real-Time Monitoring & Control

- Inverter-Based Resources – Opportunities and Challenges
- The demand rise
- Offshore wind
- Demand Response and Energy Storage
- G2V
- Prosumers
- Nuclear – Again?
- Hydrogen
- Grid-Forming inverter
- The role of Transmission, Energy Storage, and GFM

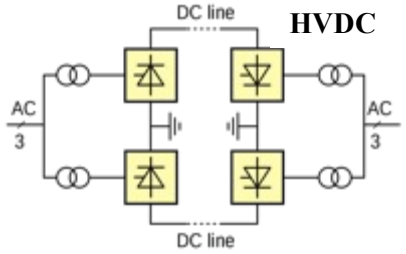
Future Smart Grid



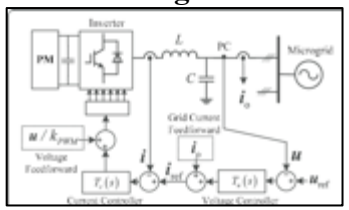
Black Start

Offshore Wind

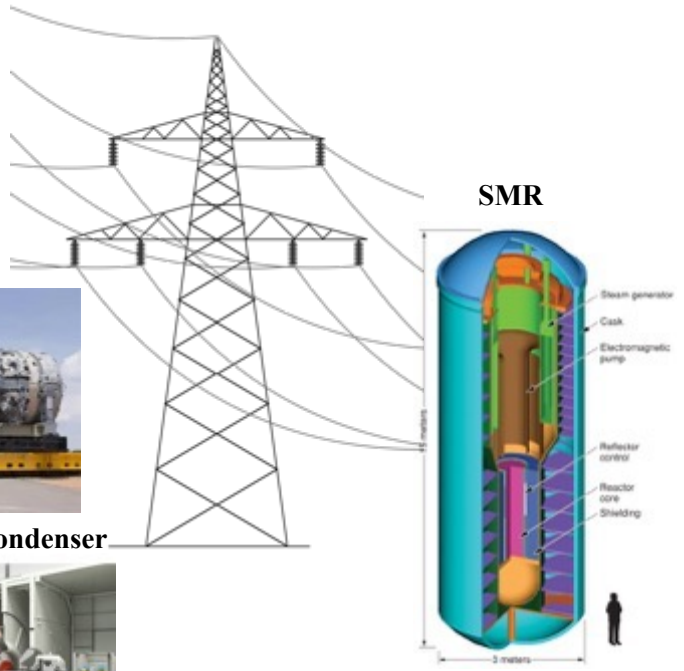
IoT and AI and Deep Learning for Demand Response



Grid-Forming Inverter



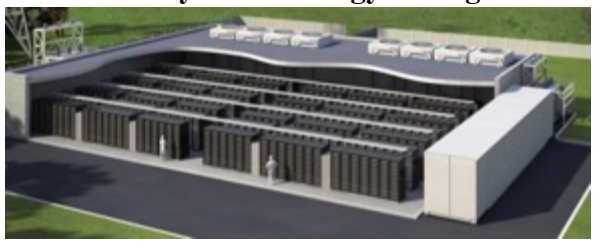
Hydrogen-fueled gas turbines



Synchronous Condenser

SMR

Utility Scale Energy Storage



Continuous Innovation is key to Competitive Advantage