Distributed Generation & Storage to Improve Grid Resiliency

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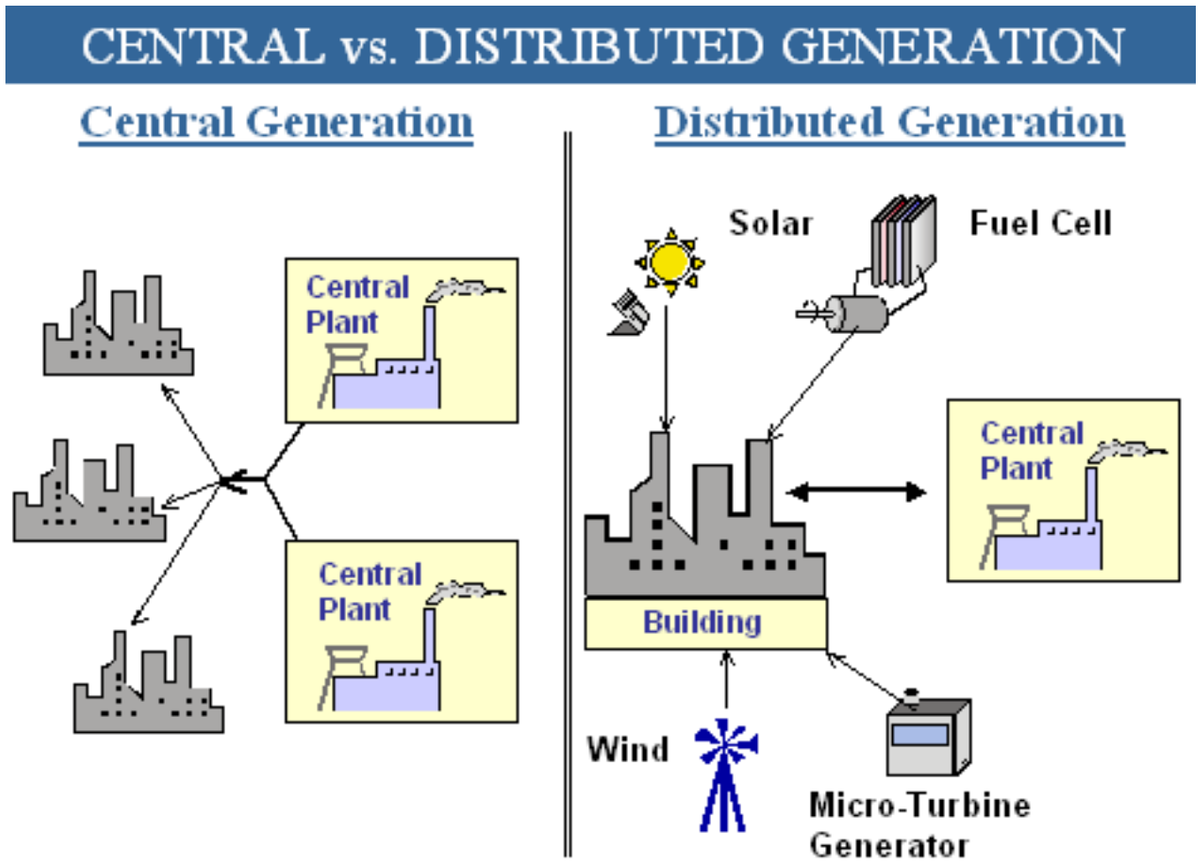
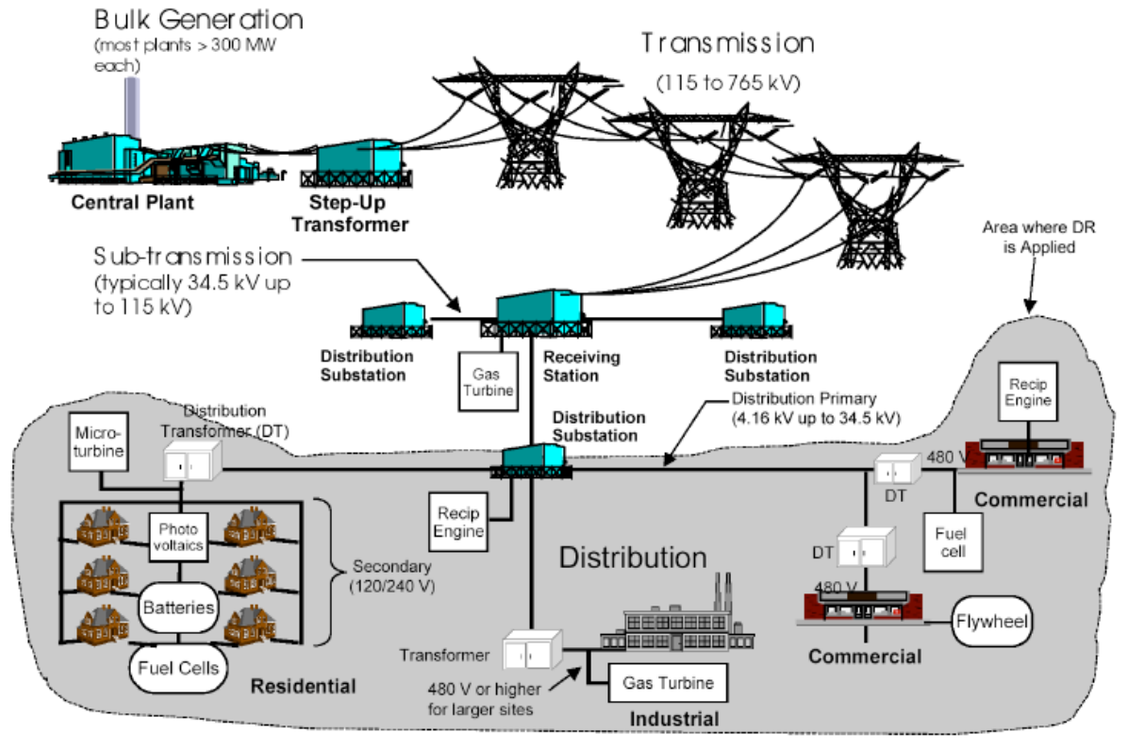
Distributed vs. Centralized Generation



- Distributed generation can range from an individual building to a community



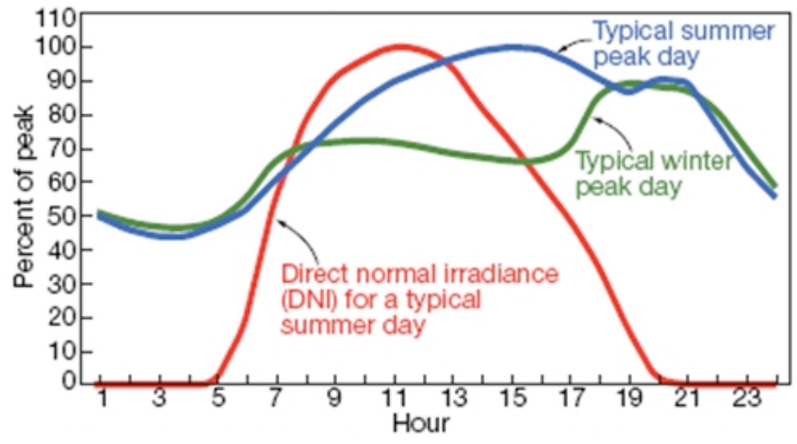
- Distributed generation enables:
  - greater efficiency through CHP and reduced transmission line losses
  - greater deployment of renewables
  - greater resiliency at the source

- Microgrids employing distributed generation can be integrated to improve overall grid resilience

Distributed Generation & Storage

Solar & Wind

- Only works when sun shines or wind blows
  - Low capacity factor and energy produced (kWh) per rated power (kW)
- Does not provide backup/emergency power
  - Interconnect shuts system down when grid goes down

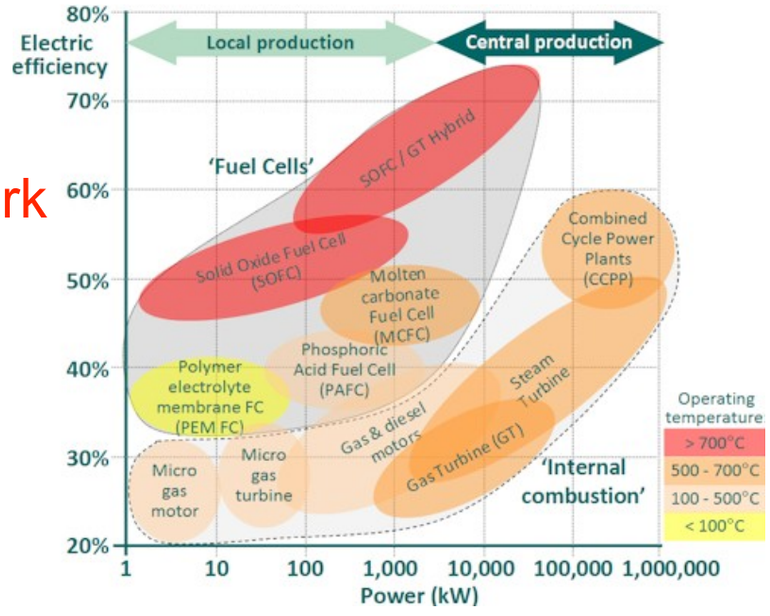


Storage

- Battery storage solves these issues but doubles system cost without generating any more power
- Can also be used to level loads and help with demand side regulation
  - This arbitrage can help offset battery cost
- Stationary storage batteries have different performance metrics than portable/automotive batteries allowing for a greater variety of chemistries
  - Cost is coming down
- Storage will play a major role in near future

Gas Turbines

- Combined Cycle Power Plants (CCPP) are benchmark for baseload (24/7) grid scale high efficiency power generation
  - They do not scale down for small DG applications
- Microturbines (≤100kW) have much lower efficiency



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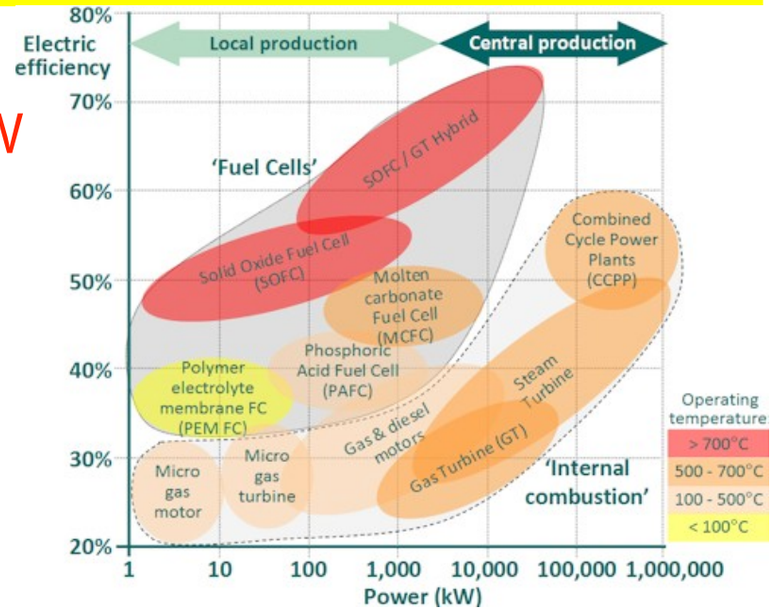
Distributed Generation & Storage

Fuel Cells

- Have the efficiency of combined cycle gas turbines *and* scale to ≤100kW
- Electrochemically convert fuel and air to electricity with high efficiency
  - Solid Oxide Fuel Cell (SOFC) efficiency is comparable to CCPP
  - SOFC efficiency can be ~90% for combined heat and power (CHP)
- Issue has been higher capital cost of fuel cells relative to CCPP (~$1000/kW)



Fuel Cell Energy

2.8 MW MCFC

<50% efficiency

~$2500/kW

Bloom Energy

200 kW SOFC

~55% efficiency

~$8000/kW

Redox Power Systems

25 kW SOFC

~55% efficiency

Planned to be competitive with CCPP

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Fuel Cells for Resilient Generation

- Impact of major storms on grid can last days to weeks
- Accompanied by storm surge

- Fuel cells are quiet, vibration free, with negligible emissions :
  - can be sited on roof or inside building
  - operate on continuous pipeline gas

- Generators are noisy, vibrating, with harmful emission issues:
  - sited in basement or ground floor subject to flooding
  - subject to fuel supply disruption

- During Superstorm Sandy 80 regional fuel cell systems provided backup power for communications and critical infrastructure with **100% reliability** and no failures
- While numerous diesel, propane generators and battery backups had problems.

Fuel Cells for Resilient Generation

Comparison of features/costs for residential and distributed generation systems

	Residential 5 kW System			1.5MW DG
	Photovoltaic	Generator	Fuel Cell	Fuel Cell
Fuel consumption	0	High	Low	Low
CO_2 emissions	0	High	Low	Low
CO/NO_x emissions	0	High	Negligible	Negligible
Noise	None	Loud	Quiet	Quiet
Maintenance	Negligible	High	Negligible	Negligible
Lifetime for 24hr/day operation	~20yrs	<1yr[1]	>10yrs	~20yrs
Installed system cost[2]	$20K	~$10K	~$50K	~$3.6M
Peak power availability/day	<2hr	24hr	24hr	24hr
Annual power production	~5,200kWh[3]	43,800kWh	43,800kWh	13,140MWh
Capital cost over lifetime	~$0.19/kWh	>$0.23/kWh	<$0.11/kWh	~$0.01/kWh
Fuel cost at retail NG cost[4]	0	~$0.09/kWh	~$0.04/kWh	~$0.04/kWh
Levelized cost of electricity[5]	~$0.19/kWh	>$0.32/kWh	<$0.15/kWh	~$0.05/kWh

[1]Typical air- and water-cooled gensets run for ~500 hrs and ~8000 hrs, respectively, between rebuilds. They are not designed to run continuously and are for emergency backup power only.

[2]With no rebates or tax credits.

[3]Based on annual average solar insolation for Baltimore.

[4]Current retail natural gas cost is $0.55/therm. Assumes fuel cell and genset efficiencies of 50% and 20%, respectively. Does not take into consideration higher efficiency fuel cell CHP systems.

[5]LCOE does not include financing charges.