Electrical Generation

APPA
LEADERSHIP IN EDUCATIONAL FACILITIES

Generation Topics to Cover

- Forms of Generation
  - Turbine Generators
  - Solar
  - Combined Heat and Power

HOW?

- The Case for Self-Generation

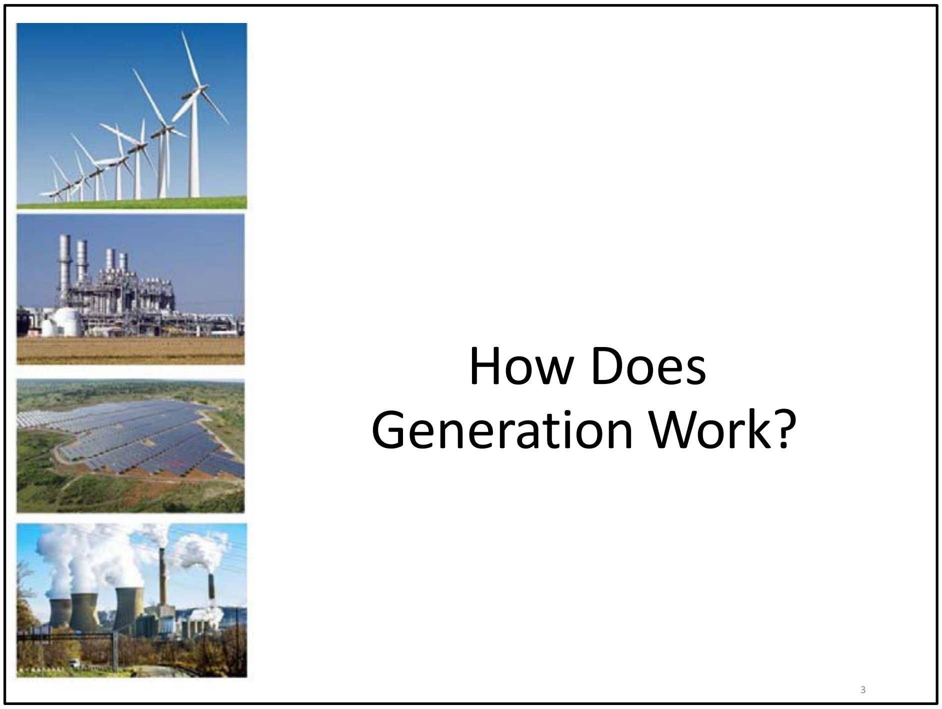
WHY?

- Cost Considerations
  - Understand Energy Use vs Demand
  - What's your Generation Strategy?

HOW MUCH?

- Technology Selection
  - Renewable Energy Generation

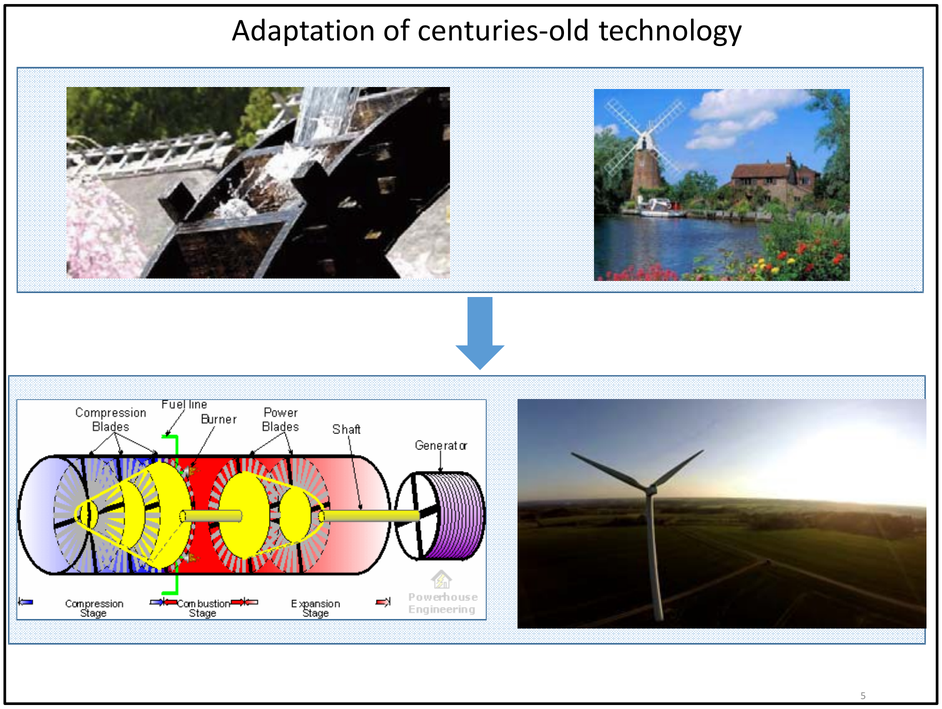
WHICH KIND?



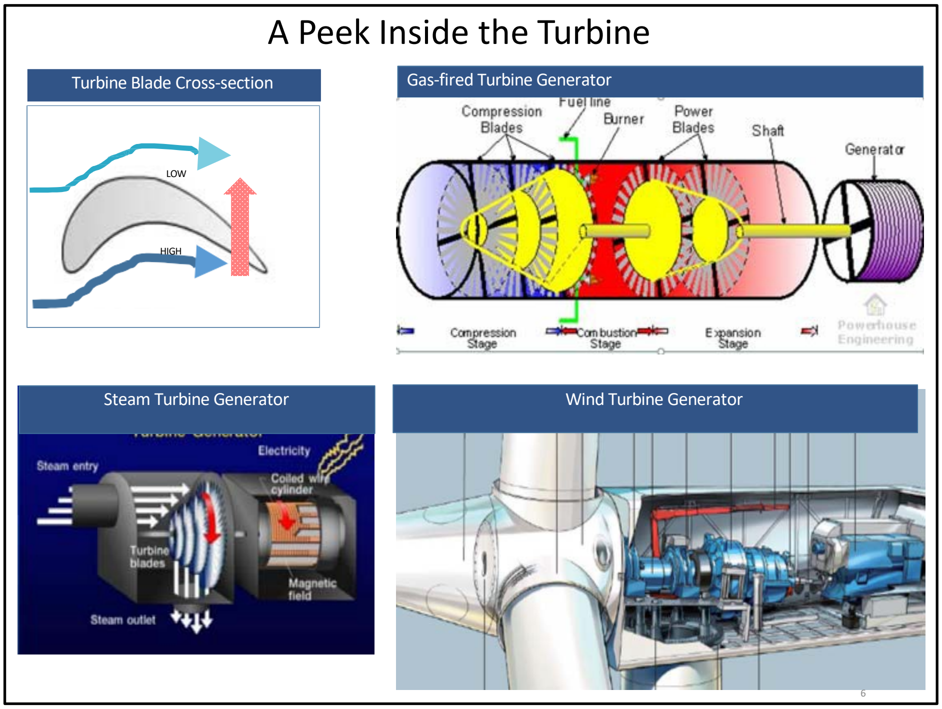
How Does Generation Work?

Turbine Generators

- 80% of world’s electricity generated by steam turbines driving rotary generators
- Turbines extract energy from fluid flow and convert it to **useful work**
  - Fluid flow acts on the turbine blades to produce rotation of a shaft (rotor) attached to generator
- Prime Mover: the mechanical means of turning the generator rotor
  - **STEAM** Turbine: Steam raised in a boiler which is heated by the combustion of coal, gas, or biomass
  - **GAS/DIESEL** Turbine: flow of gas caused by the combustion of fossil fuels
  - **WIND** Turbine: air flow caused by sun’s uneven heating of earth’s surface
  - **HYDRO** Turbine: water flow from run-of river, dam, or artificial pumped water storage



Adaptation of centuries-old technology



A Peek Inside the Turbine

Turbine Blade Cross-section

Gas-fired Turbine Generator

Steam Turbine Generator

Wind Turbine Generator

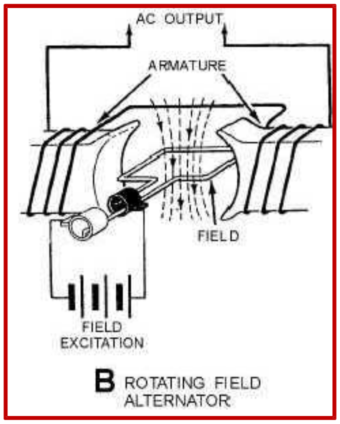
What's Going on *Inside* the Generator?

A conductive coil is rotated within a magnetic field

Dynamic interaction between coil and field induces voltage

The voltage pushes on & dislodges free electrons in the conductor (wire)

Copper is a highly efficient conductor due to molecular structure



Electricity = flow of electrons

Other Generation Modalities

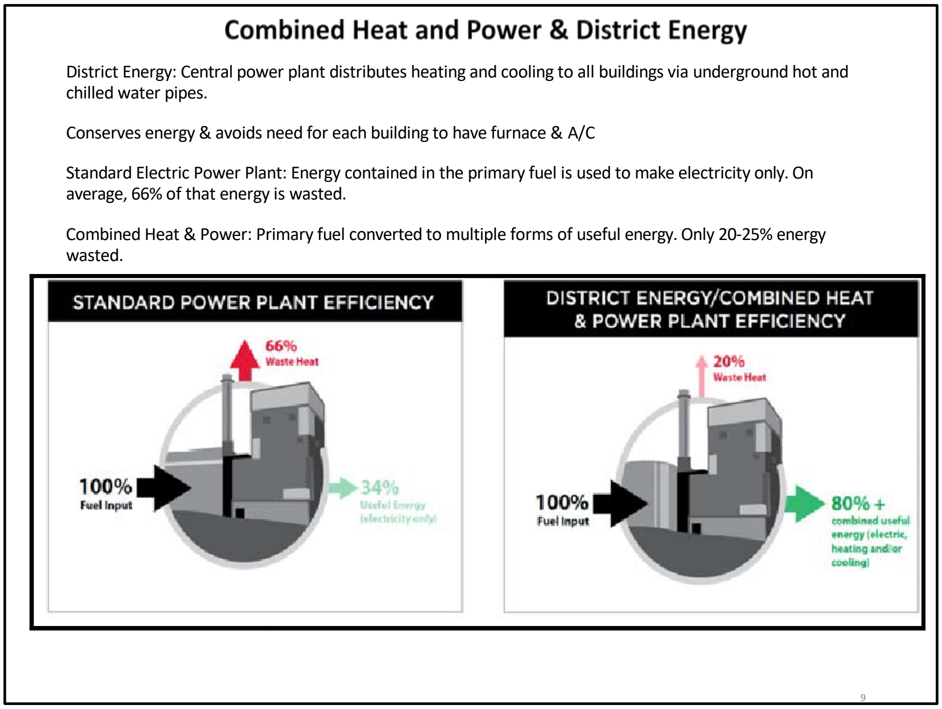
Solar PV: Direct conversion of solar irradiance into electricity. No generator needed.

- PV panels contain silicon layers which carry a negative and positive charge
- Silicon molecules, like copper, are prone to losing electrons
- Photons from the sun dislodge electrons in the atoms from the negative layer

- Electron ping-pong game ensues
- Conductors embedded
- in panel collect the flowing electrons
- Output from all panels is combined and sent to grid

Electricity = flow of electrons

EU Electrical Generation & Distribution



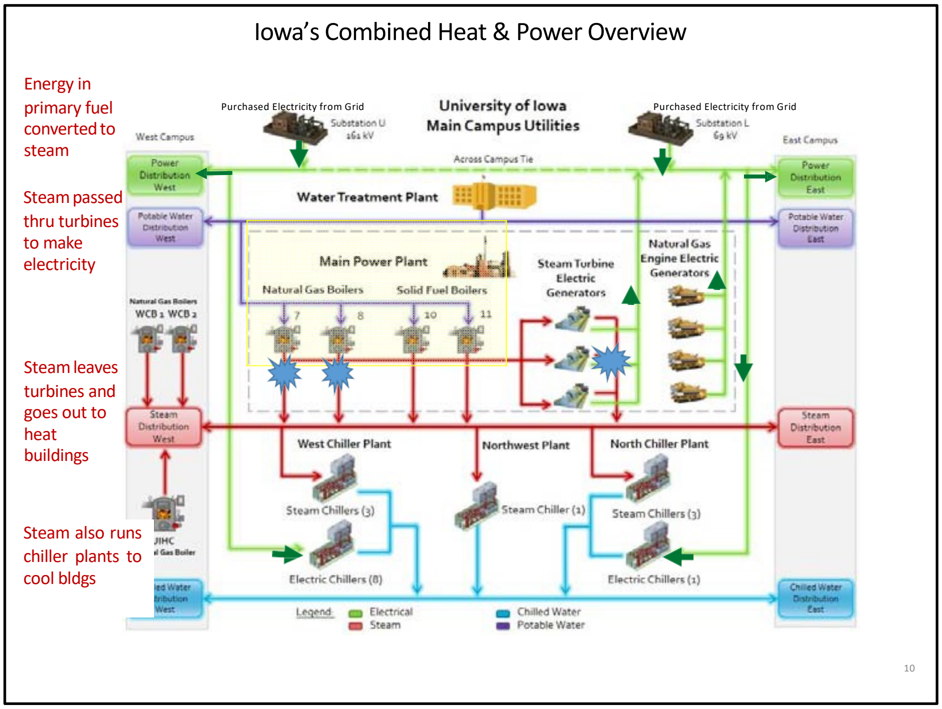
Combined Heat and Power & District Energy

District Energy: Central power plant distributes heating and cooling to all buildings via underground hot and chilled water pipes.

Conserves energy & avoids need for each building to have furnace & A/C

Standard Electric Power Plant: Energy contained in the primary fuel is used to make electricity only. On average, 66% of that energy is wasted.

Combined Heat & Power: Primary fuel converted to multiple forms of useful energy. Only 20-25% energy wasted.



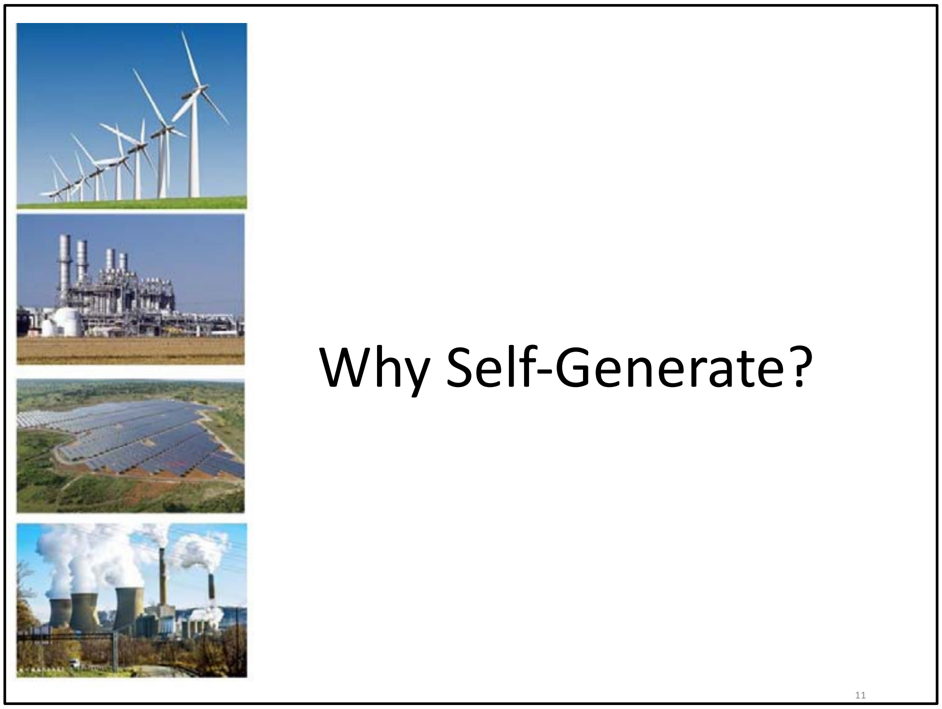
Iowa’s Combined Heat & Power Overview

Energy in primary fuel converted to steam

Steam passed thru turbines to make electricity

Steam leaves turbines and goes out to heat buildings

Steam also runs chiller plants to cool bldgs



Why Self-Generate?

The Case for Self-Generation

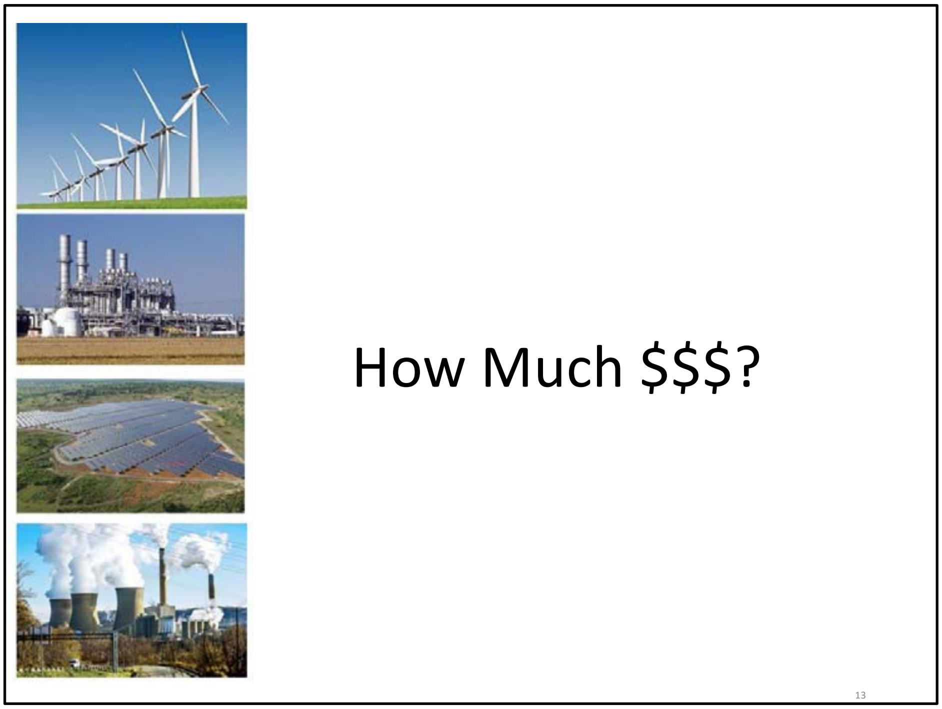
<u>Continuity of service despite grid outages</u>

<u>Agile response to market conditions</u>

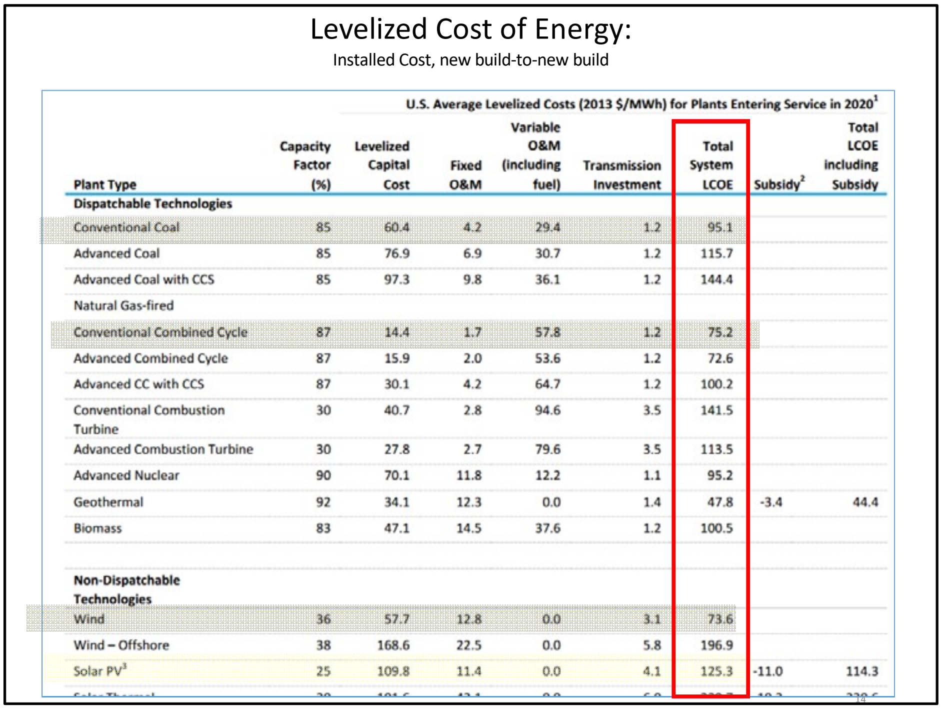
Time of Day and Seasonal pricing factors
- Rates vary by on-peak/off-peak periods, and summer/winter

Demand Response/Curtailment Agreement
- Lower rates/rebates utility for curtailment (load reduction)
- Curtailment triggered by congestion, wholesale market price spikes, grid reliability concerns
- University of Iowa’s 2015 rebate: $1,012,000

Base Load Generation vs. Peak Shaving
- Base Load: Continuous operation serving all or most of campus demand
- Peak Shaving: Rapid response generation to offset load during high demand hours
- Energy Storage is another tool to achieve peak shaving—system costs rapidly coming down



How Much $$$?



Levelized Cost of Energy:

Installed Cost, new build-to-new build

U.S. Average Levelized Costs (2013 $/MWh) for Plants Entering Service in 2020[1]

Plant Type	Capacity Factor (%)	Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System LCOE	Subsidy[2]	Total LCOE including Subsidy
Dispatchable Technologies								
Conventional Coal	85	60.4	4.2	29.4	1.2	95.1		
Advanced Coal	85	76.9	6.9	30.7	1.2	115.7		
Advanced Coal with CCS	85	97.3	9.8	36.1	1.2	144.4		
Natural Gas-fired								
Conventional Combined Cycle	87	14.4	1.7	57.8	1.2	75.2		
Advanced Combined Cycle	87	15.9	2.0	53.6	1.2	72.6		
Advanced CC with CCS	87	30.1	4.2	64.7	1.2	100.2		
Conventional Combustion Turbine	30	40.7	2.8	94.6	3.5	141.5		
Advanced Combustion Turbine	30	27.8	2.7	79.6	3.5	113.5		
Advanced Nuclear	90	70.1	11.8	12.2	1.1	95.2		
Geothermal	92	34.1	12.3	0.0	1.4	47.8	-3.4	44.4
Biomass	83	47.1	14.5	37.6	1.2	100.5		
Non-Dispatchable Technologies								
Wind	36	57.7	12.8	0.0	3.1	73.6		
Wind – Offshore	38	168.6	22.5	0.0	5.8	196.9		
Solar PV[3]	25	109.8	11.4	0.0	4.1	125.3	-11.0	114.3

Technology Selection and System Size:

Consider Efficiencies and Net Capacity Factors

Efficiency– how much of the primary energy stored in the fuel is converted to useful power?

Natural Gas	32-38%
Coal	39-47%
Solar	18-20%
Wind	35-55%
CHP	80-85%

Net Capacity Factor

Ratio of *actual* output to its *potential* output if operating continuously at full capacity

For renewable energy, NCF demonstrates the impact of intermittent resource on output

Captures how many hours/year the facility is expected to produce energy

Solar PV NCF: 15-35%

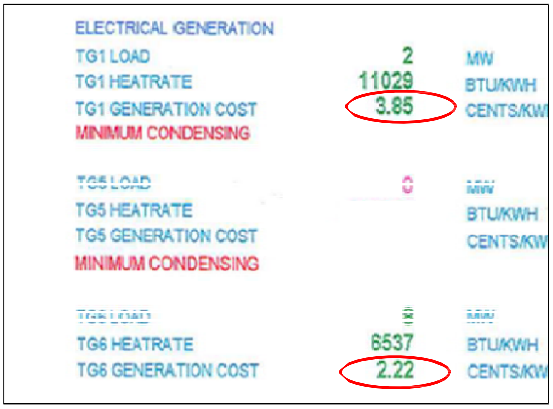
Varies by region. Tracking can add ~10%.

Windpower NCF: 35-50%

Highly site specific. Many options to boost NCF (tower height, blade length, turbine mfr.)

Cost Avoidance

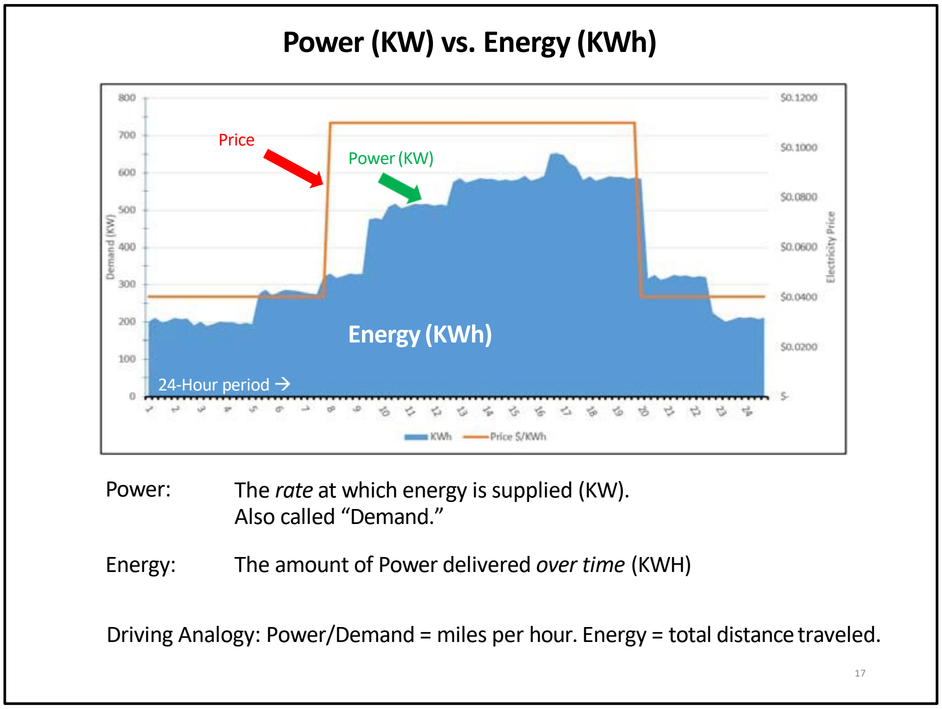
Cost of Generation



ELECTRICAL GENERATION		
TG1 LOAD	2	MW
TG1 HEATRATE	11029	BTU/KWH
TG1 GENERATION COST	3.85	CENTS/KW
MINIMUM CONDENSING		
TG5 LOAD	0	MW
TG5 HEATRATE		BTU/KWH
TG5 GENERATION COST		CENTS/KW
MINIMUM CONDENSING		
TG6 LOAD	[illegible]	MW
TG6 HEATRATE	6537	BTU/KWH
TG6 GENERATION COST	2.22	CENTS/KW

Purchased Electricity

Rate Type	cents/KWh
Summer On Peak Rate	11.022
Summer Off Peak Rate	4.142
Winter On Peak Rate	4.024
Winter Off Peak Rate	3.836

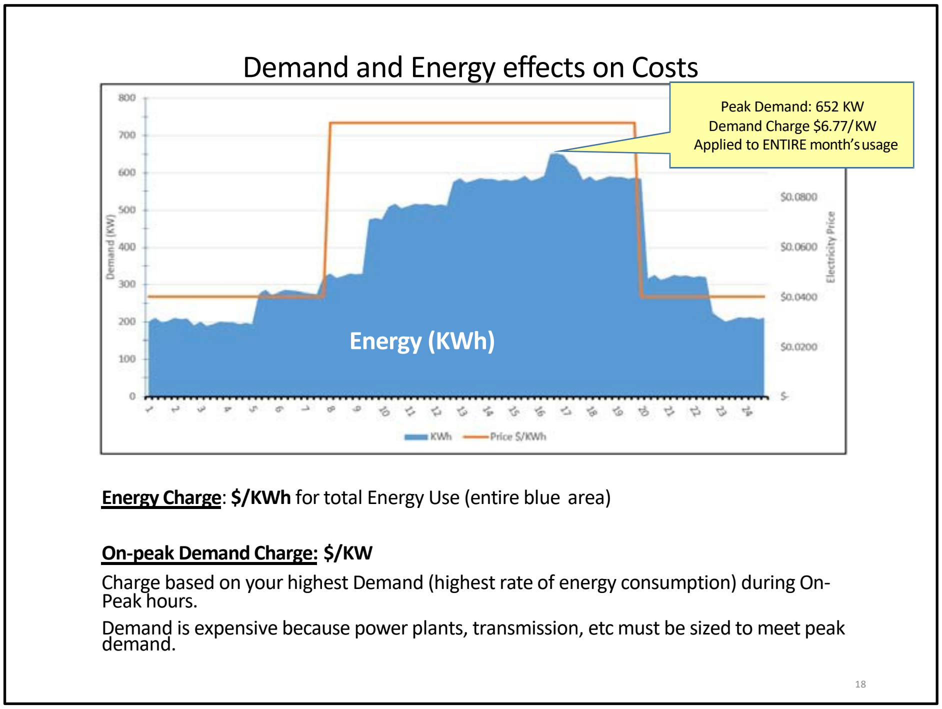


Power (KW) vs. Energy (KWh)

Power: The *rate* at which energy is supplied (KW).
Also called "Demand."

Energy: The amount of Power delivered *over time* (KWH)

Driving Analogy: Power/Demand = miles per hour. Energy = total distance traveled.



Demand and Energy effects on Costs

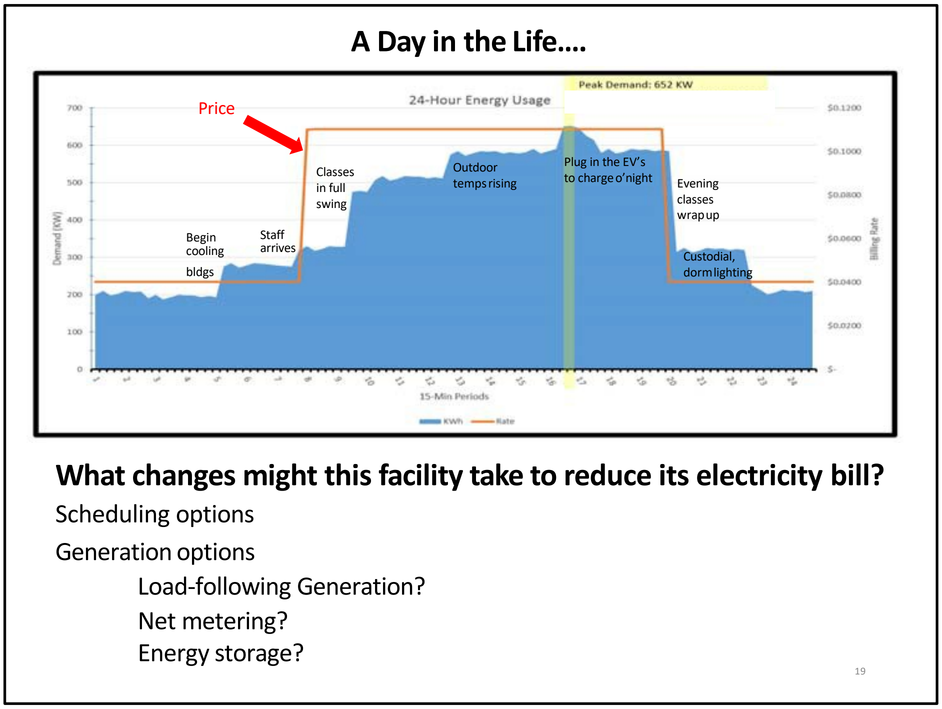
Peak Demand: 652 KW
Demand Charge $6.77/KW
Applied to ENTIRE month's usage

Energy Charge: **$/KWh** for total Energy Use (entire blue area)

On-peak Demand Charge: $/KW

Charge based on your highest Demand (highest rate of energy consumption) during On-Peak hours.

Demand is expensive because power plants, transmission, etc must be sized to meet peak demand.



A Day in the Life….

What changes might this facility take to reduce its electricity bill?

Scheduling options

Generation options
  - Load-following Generation?
  - Net metering?
  - Energy storage?

Which Kind?

Purchase or Generate? And Which Technologies?

Consider institutional priorities

Utilities Cost Reduction

Budget Stability

- Fixed Costs – Construction & Regulatory
- Marginal Costs – Fuel and O&M

Energy Security

Continuity of Services/Emergency Power

Environmental Impacts

University branding

Research and Learning opportunities

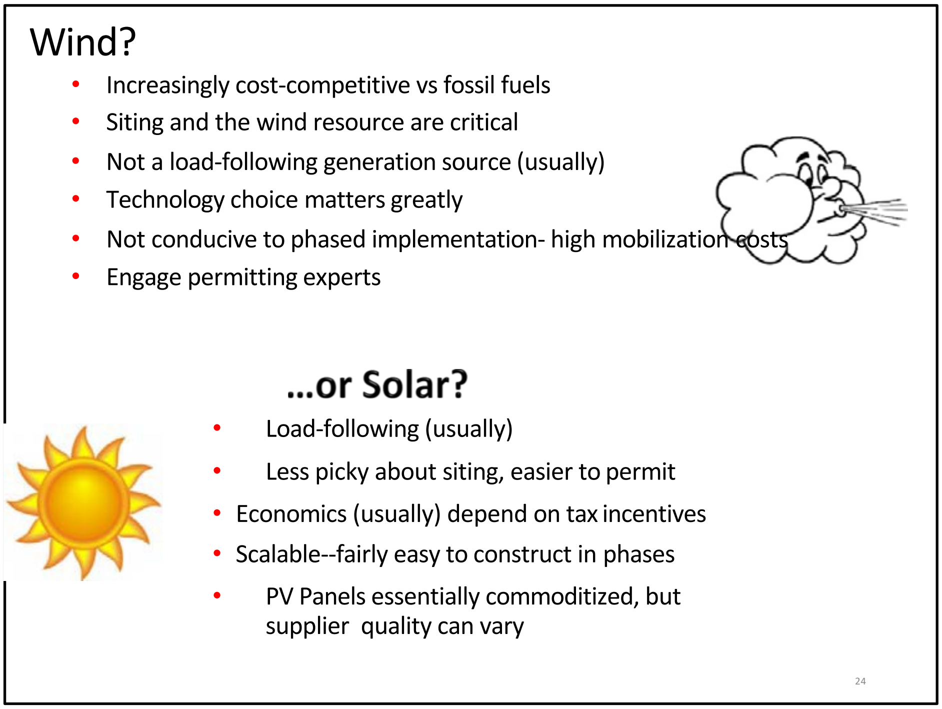
Purchase or Generate? And Which Technologies?

Consider limitations

- Available Capital
- Regional Energy Resources
- Physical Space / Existing Infrastructure
- Permitting Regime
- Community Support
- Timeline, Scalability
- Staffing & In-house Expertise
  - Bring in third party operators?
  - Sell utilities enterprise entirely?

How About Renewable Energy?

- Intrinsic environmental benefits
- Branding: students expect and demand it
- Dramatic CoE reductions- some regions at grid parity
- Understand available incentives and market value of Renewable Energy Credits
- Seek partners with tax appetite for CAPEX reduction
- Forward curve projections of coal/gas prices: a flat PPA may be a great bet. (…Or it may not.)
- What's your clout with your utility? Get them to do the heavy lifting!



Wind?

- Increasingly cost-competitive vs fossil fuels
- Siting and the wind resource are critical
- Not a load-following generation source (usually)
- Technology choice matters greatly
- Not conducive to phased implementation- high mobilization costs
- Engage permitting experts

…or Solar?

- Load-following (usually)
- Less picky about siting, easier to permit
- Economics (usually) depend on tax incentives
- Scalable--fairly easy to construct in phases
- PV Panels essentially commoditized, but supplier quality can vary

Windpower Success Story

HEARTLAND
COMMUNITY COLLEGE

- $5.2MM to install one 1.65MW Vestas turbine
- Serves 41% of campus load
- 15-year payback period
- Projected 4.3MWh annual production (actual: 4.8 MWh)
- Utility offers favorable net metering at retail rate
- Financing: $950k US DoE grant & $512k IL Clean Energy Community Foundation grant.
- College-issued bonds will be repaid with energy cost savings

Annual expense $755k → $420k
(while other HCC campuses went up 40%-65%)

Solar Parking Canopies

- Control energy costs, reduce carbon footprint, and develop real-world teaching tools.
- Highly visible demonstration of commitment to RE (but what are campus planning implications?)
- Solar carports shade and protect cars from the elements
- Reduce parking lot temperatures
- Michigan State University: will cover 5 parking lots with 10 megawatts of solar PV panels. Expected to meet 5% of the campus load.
- University of Massachusetts: 11.6 acres of solar carports financed through a 20-year power purchase agreement.

Upcoming EPA Webinar:
September 26, 2017
12:00pm CDT

EPA GREEN POWER PARTNERSHIP

Solar Carports: Turning University Parking Facilities into Renewable Electricity Plants

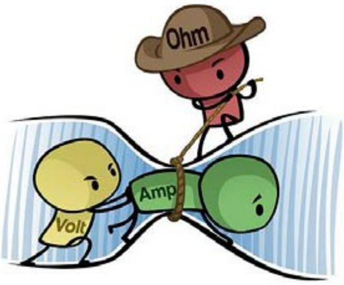
26

Electrical Distribution

Distribution Topics to Cover

- Getting Electricity from A to B: The Basics
- Distribution vs. Transmission
  - High Voltage Transmission
  - Medium – Low Voltage Distribution
- Key Components
  - Xxxx
  - Xxxx
- Outage Recovery (i.e. “You only care about us when we’re gone.”)

Voltage vs Current vs Resistance



- Voltage (volts)= potential energy created by difference in charge between two points
- Current (amps) = rate at which the charge is flowing
- Resistance (ohms) = the material’s tendency to resist the flow of charge.

Plumbing analogy: Voltage = water pressure. Current = flow rate. Resistance = pipe size.

Now it’s time to geek out:

Voltage = Current x Resistance

Electrical Power

Power is the rate that electrical energy is converted into something useful (heat, mechanical energy, etc.)

Measured in watts (kilowatts, megawatts)

More geek stuff:

Power = Voltage x Current

(Pressure x Flow)

More plumbing analogies: Increasing Power

You need to wash off a grimy lawn chair with a garden hose.
You give the hose spigot a few turns, and the water runs over the chair -- but it's not getting much crud off. You need more power.

What are two things you might do to get the dirt off?

- Put your thumb over part of the hose opening = Increased pressure(voltage)
- Go to the spigot and turn it all the way open= Increased flow (Current)

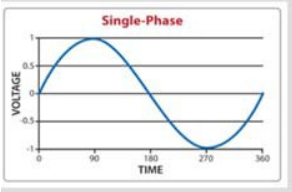
Captain Kirk: Arm your Phasers!

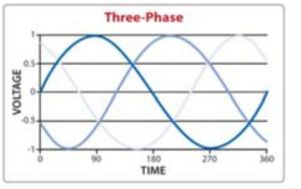
Single Phase Power:

- Two wires (phase and neutral) to complete a circuit
- Appropriate for residential and low commercial loads
- Delivers power in pulses (50-60 cycles per second).

Three-Phase Power:

- Three phase wires
- More efficient and cost-effective
- Delivers 3x power vs. single-phase
- Better for large loads and motors; delivers continuous flow of power

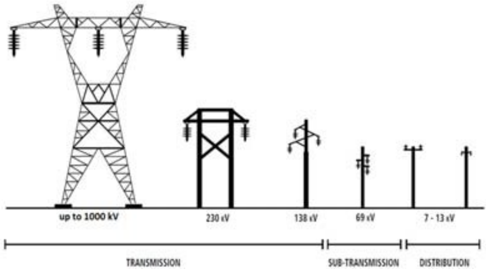




Transmission vs. Distribution

High Voltage Transmission lines:

- 69,000 volts and up
- Installed overhead for cost and efficiency.
- Not insulated.
- Insulation = resistance = wasted energy in the form of heat
- Heavy load causes lines to sag



Distribution lines (Medium Voltage):

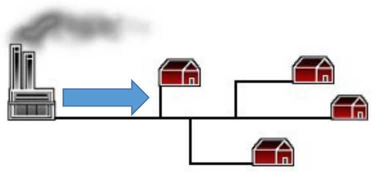
- Common voltages: 7,200-13,800 volts
- May be overhead or underground. U/G is much more reliable but up to 10X the cost of O/H. (Campus aesthetics another consideration!)
- If U/G, conduit may be direct buried, or encased in concrete “duct bank”.
- Different utilities often share the same pole. Highest voltage electrical lines are always on top. Fiber optic, cable TV, telephone lines are installed below

Cable is a major cost for any utility. Copper 15-kv cable runs ~$30 per foot.

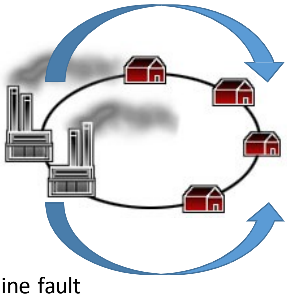
University of Iowa has 30 *miles* of 15kV cable installed on campus.

Distribution: Radial vs. Loop Topology

Radial



Loop



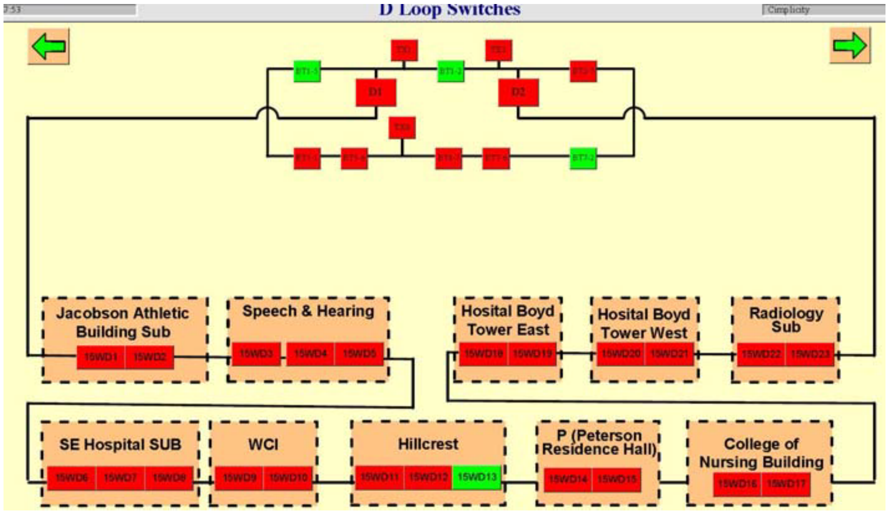
Radial: One feeder line from generation to each load.

- Simple, lower cost, but inflexible in the event of a line fault
- No way to divert power through other feeders to keep power on

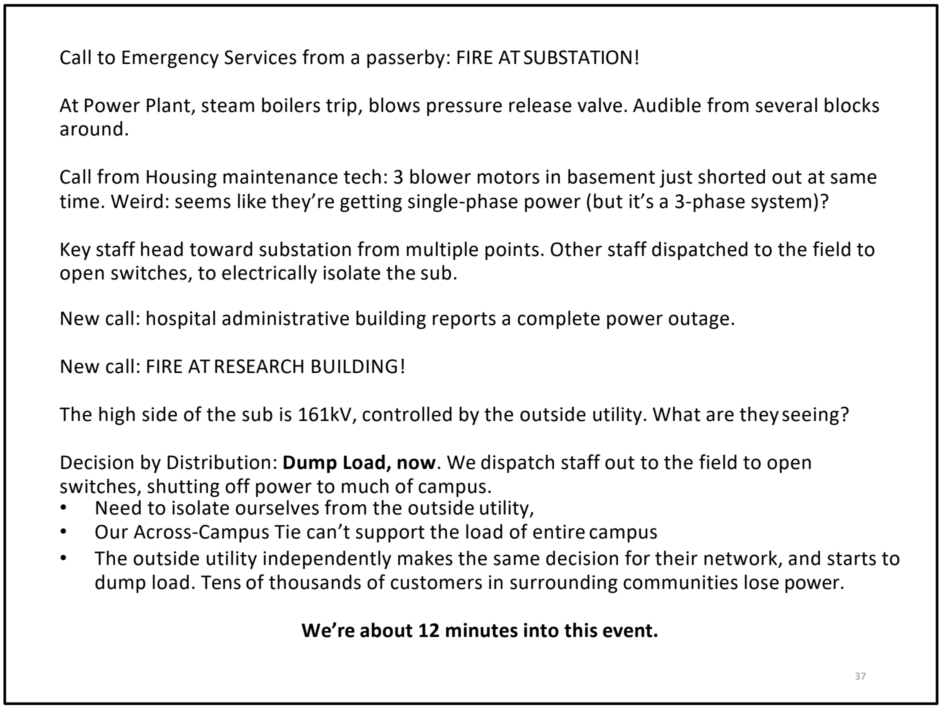
Loop: Multiple feeder lines, allowing power to flow to load from either direction

- Managed via switchgear (breakers, switches, etc) to allow or block the flow

Example of a Campus Loop



Power Outages



Call to Emergency Services from a passerby: FIRE AT SUBSTATION!

At Power Plant, steam boilers trip, blows pressure release valve. Audible from several blocks around.

Call from Housing maintenance tech: 3 blower motors in basement just shorted out at same time. Weird: seems like they're getting single-phase power (but it's a 3-phase system)?

Key staff head toward substation from multiple points. Other staff dispatched to the field to open switches, to electrically isolate the sub.

New call: hospital administrative building reports a complete power outage.

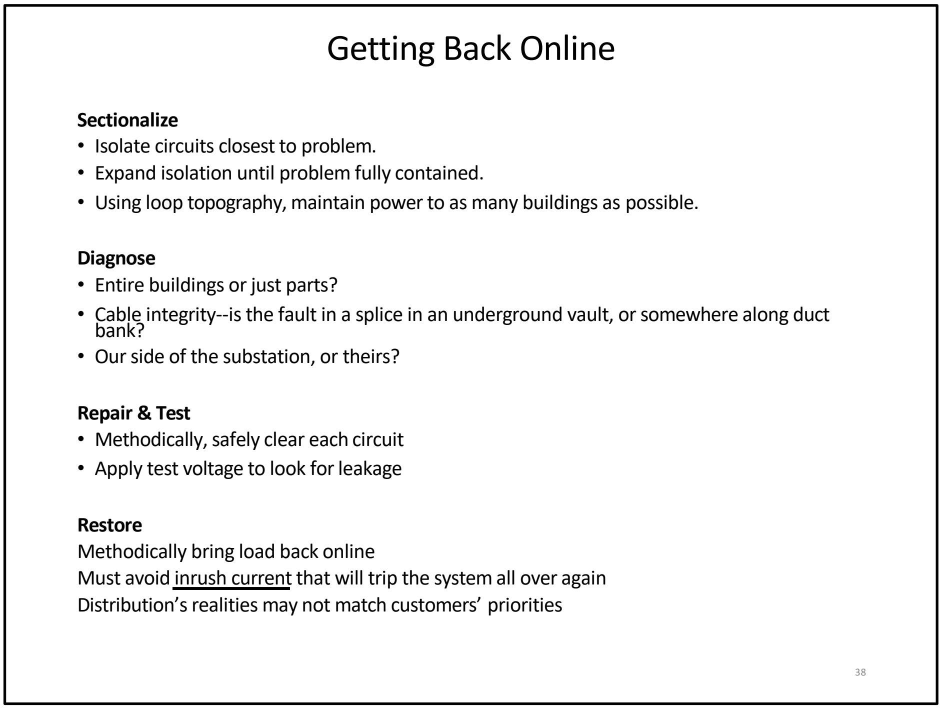
New call: FIRE AT RESEARCH BUILDING!

The high side of the sub is 161kV, controlled by the outside utility. What are they seeing?

Decision by Distribution: **Dump Load, now**. We dispatch staff out to the field to open switches, shutting off power to much of campus.

- Need to isolate ourselves from the outside utility,
- Our Across-Campus Tie can't support the load of entire campus
- The outside utility independently makes the same decision for their network, and starts to dump load. Tens of thousands of customers in surrounding communities lose power.

We're about 12 minutes into this event.



Getting Back Online

Sectionalize

- Isolate circuits closest to problem.
- Expand isolation until problem fully contained.
- Using loop topography, maintain power to as many buildings as possible.

Diagnose

- Entire buildings or just parts?
- Cable integrity--is the fault in a splice in an underground vault, or somewhere along duct bank?
- Our side of the substation, or theirs?

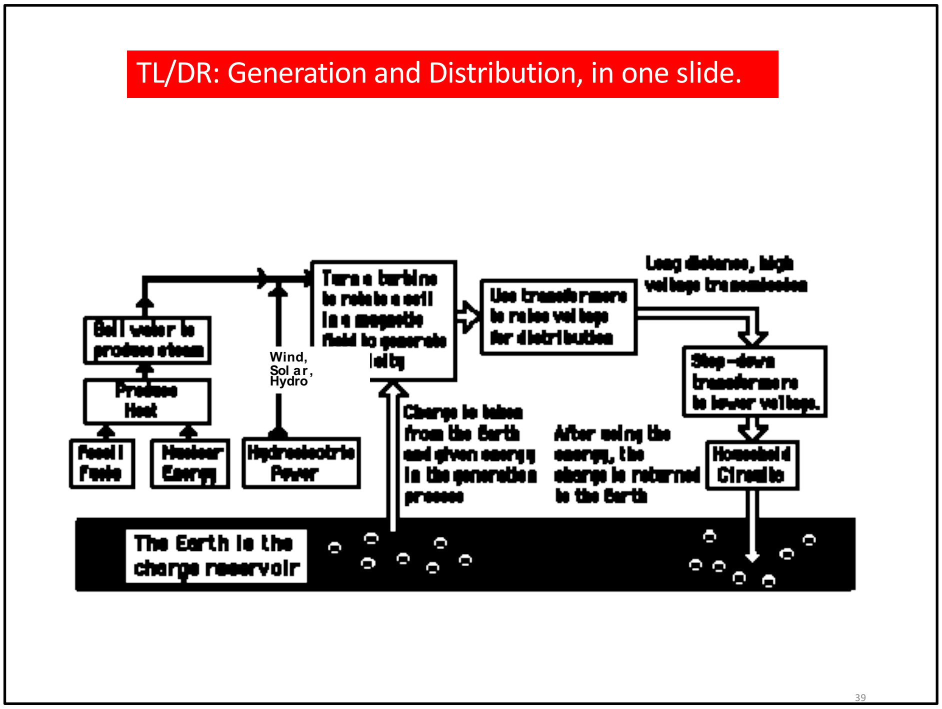
Repair & Test

- Methodically, safely clear each circuit
- Apply test voltage to look for leakage

Restore

Methodically bring load back online
Must avoid inrush current that will trip the system all over again
Distribution's realities may not match customers' priorities

EU Electrical Generation & Distribution



TL/DR: Generation and Distribution, in one slide.