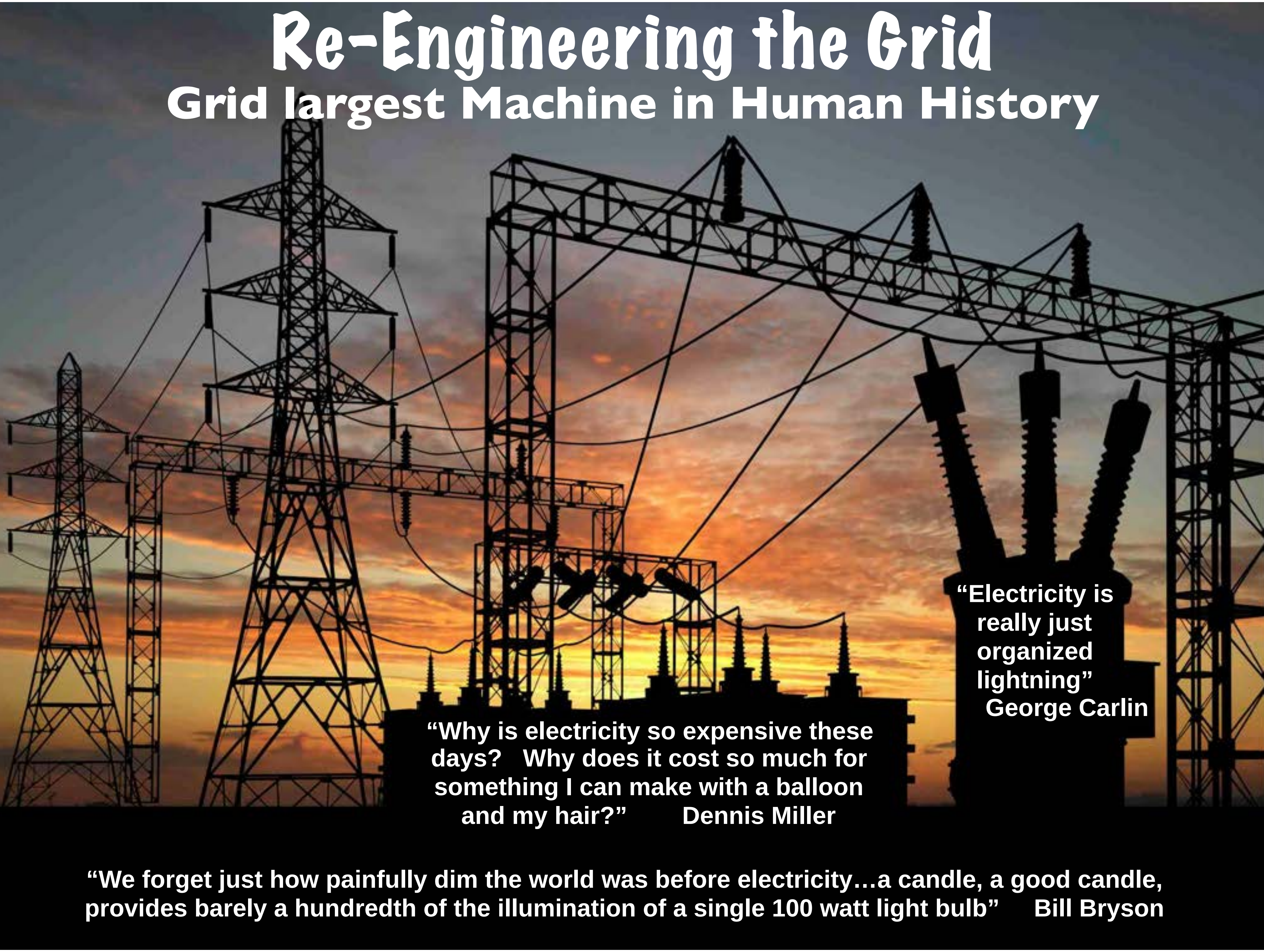

Re-Engineering the Grid
Grid largest Machine in Human History
"Electricity is really just organized lightning" George Carlin
"Why is electricity so expensive these days? Why does it cost so much for something I can make with a balloon and my hair?" Dennis Miller
"We forget just how painfully dim the world was before electricity…a candle, a good candle, provides barely a hundredth of the illumination of a single 100 watt light bulb" Bill Bryson

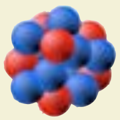
Categorical Energy Sources

Prizes for Additional Components

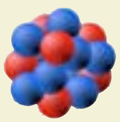
Energy **efficiency** + **demand** response easier, cheaper, faster:
'negawatts' + **'flexiwatts'** + 'negabarrels'

Current solar energy [almost] all sustainable energy types: biofuel, hydropower, wave power, ocean thermal energy conversion, photovoltaic, concentrating solar, wind

Ancient solar energy consists of all fossil fuels: coal, natural gas, conventional oil, bitumen oil, kerogen oil

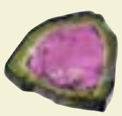


Nuclear power results of ancient type II supernovas producing 90-Th + 92-U + 94-Pu [basis of fuel cycles]

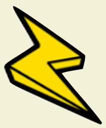


Geothermal energy originates from compressive accretional formation of planet, coupled with extensive suite of radioactive substances decaying over eons

Tidal energy derives at root solely from gravitational interactions of Earth + Moon + Sun



Piezoelectric + **thermoelectric** + **thermomagnetic** + **triboelectric** generation from material science



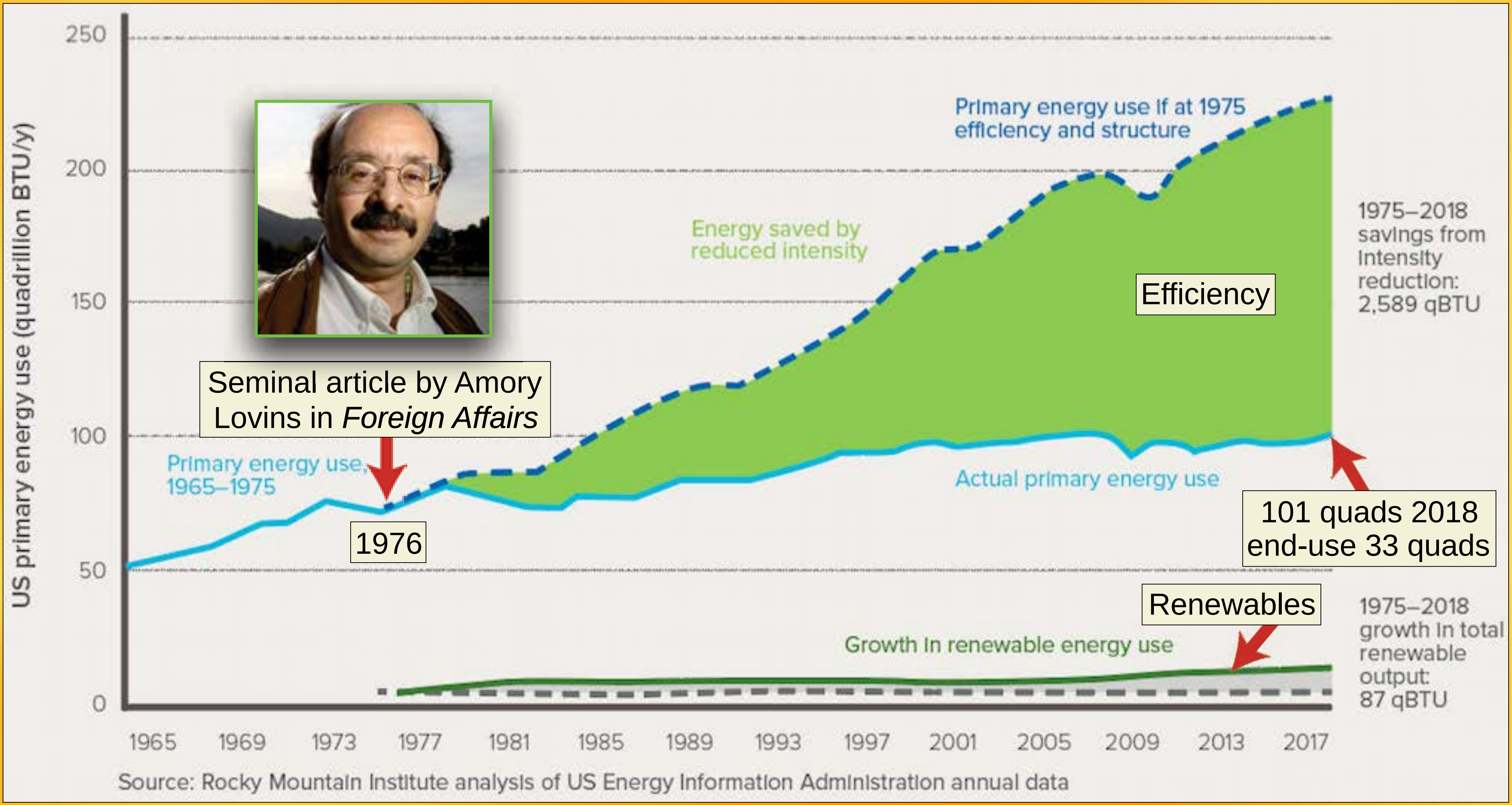
Hydrogen [fuel cells] + **electricity** secondary forms of energy

Current exclusions:

- fusion power
- captured **lightning**
- other exotic energy sources

Perpetual motion machines

Reduced Energy Intensity 30-fold greater Impact than Renewables in US from 1965-2018



Points worthy of emphasis:
- focusing on all non-animate energy in US
- electricity only 1/5 energy utilization
- renewables critical but efficiency often *invisible*
- not weather-normalized

Kilowatt vs. Kilowatt-hour

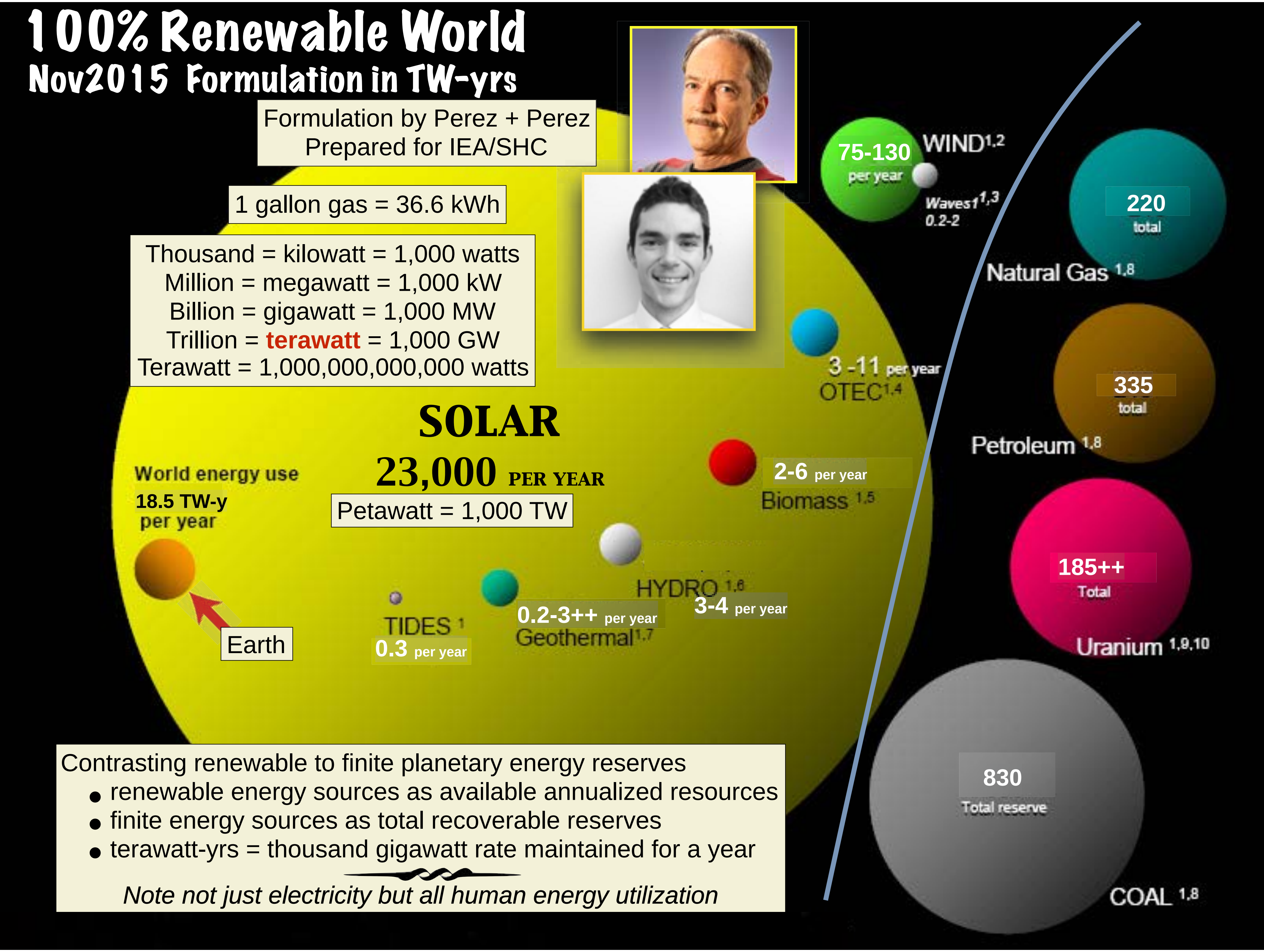
Power vs. Energy

10 *old-fashioned* 100 watt incandescent bulbs require 1,000 watts of power

x

= 1 kWh

x 60 MINUTES = 1 kWh


100% Renewable World
Nov2015 Formulation in TW-yrs
Formulation by Perez + Perez
Prepared for IEA/SHC
1 gallon gas = 36.6 kWh
Thousand = kilowatt = 1,000 watts
Million = megawatt = 1,000 kW
Billion = gigawatt = 1,000 MW
Trillion = terawatt = 1,000 GW
Terawatt = 1,000,000,000,000 watts
SOLAR
23,000 PER YEAR
Petawatt = 1,000 TW
World energy use
18.5 TW-y
per year
Earth
TIDES [1]
0.3 per year
0.2-3++ per year
Geothermal [1,7]
HYDRO [1,6]
3-4 per year
2-6 per year
Biomass [1,5]
3 -11 per year
OTEC [1,4]
75-130
per year
WIND [1,2]
Waves [1,3]
0.2-2
220
total
Natural Gas [1,8]
335
total
Petroleum [1,8]
185++
Total
Uranium [1,9,10]
830
Total reserve
COAL [1,8]
Contrasting renewable to finite planetary energy reserves
● renewable energy sources as available annualized resources
● finite energy sources as total recoverable reserves
● terawatt-yrs = thousand gigawatt rate maintained for a year
Note not just electricity but all human energy utilization

Concept Crunching

US total generating capacity **1,187 GW** as of 2017

Typical US household uses **8,079 lbs** coal for generation

Major weather-related power outages [> 50k people] surged in 2000's

Ohm's Law: I = V/R or **current** = **voltage** / **resistance**

- I = current [amperage]
- V = voltage or 'electromotive force' [EMF]
- R = resistance [by convention held constant]

Obvious implication "higher voltage allows higher electron flux"

Ma Bell once rented out phones to us + enjoyed perfect monopoly:

- broken up by antitrust action
- *never saw* cellular revolution coming
- electric utilities achieving dawning realization of their risk?

Questions:

- ready for time-of-use [TOU] electric rates?
- could your water heater be a battery?
- could your freezer be a battery?
- could your car battery be integrated into grid?
- how could you *maximize* residential PV value?

Principles:

- efficiency = "negawatts"
- demand response = "flexiwatts"
- deep decarbonization
- electrification transportation
- distributed renewable energy or DRE
- distributed storage likewise
- energy independence plus democratization = microgrids

Radical goal = efficient, decentralized, multidirectional, decarbonized, denuclearized, renewable, islandable EMP-hardened grid

Alessandro Volta

1745-1827 Battery Inventor

Redox potential:

- zinc's tendency to donate electrons = **oxidation**
- copper's tendency to gain electrons = **reduction**
- brine = conductor

Naturalist during fertile age of discovery following Isaac Newton:

- 1775 perfected electrophorus (reliable static electricity)
- 1778 discovered methane gas
- 1800 invented **voltaic pile** or early chemical battery

Stack alternating metal discs separated by brine-soaked material

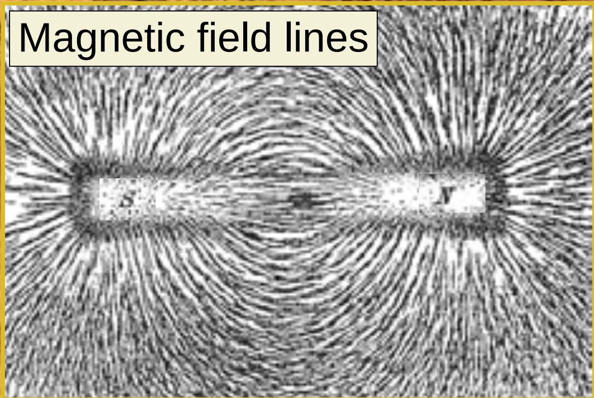
- for decades only reliable way to produce constant electricity
- electrolysis of water
- research on electric arcs

Volt: measure of electric potential or electromotive force [EMF]

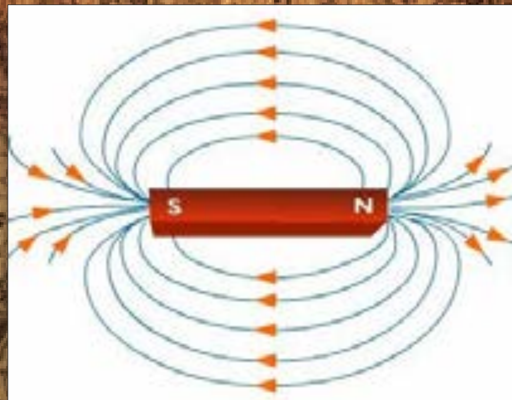
1801 demonstrated battery for Napoleon + promptly earned gold medal, declared count + made senator for Kingdom of Lombardy

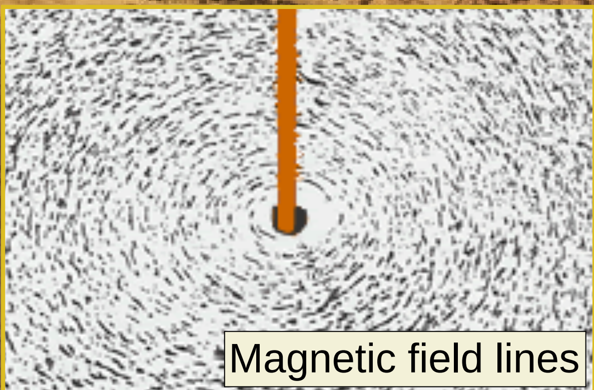
Permanent Magnets + Electromagnets

Magnetism + Navigation

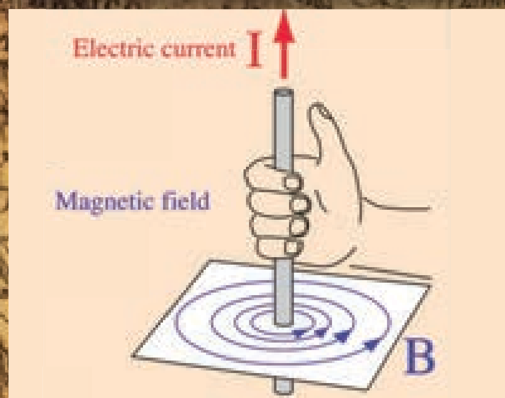


Magnetic field lines





Magnetic field lines



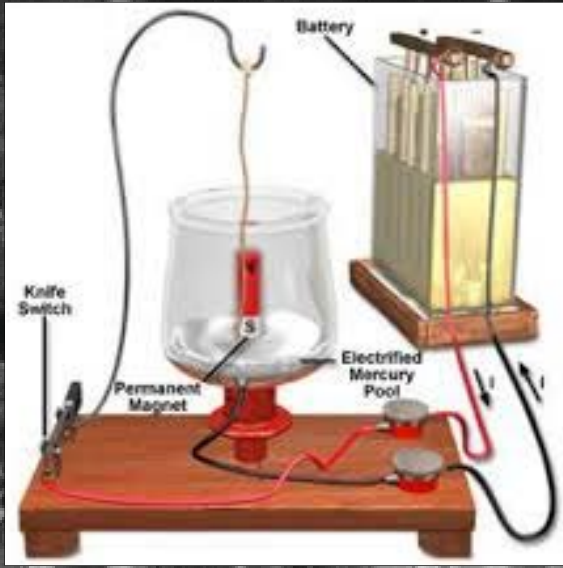
Ferromagnetic materials (such as Fe):

- form permanent magnets
- simply respond to magnetic field

1821 first use term electromagnetism

Lodestone

Michael Faraday
1791-1867



1821 invention electromagnetic rotary devices = electric motor technology

- English experimentalist conveyed ideas in clear + simple language
- scientist elucidated electromagnetism + electrochemistry
- mathematical abilities limited to simplest algebra

Demonstrated that changing magnetic field produces electric field:

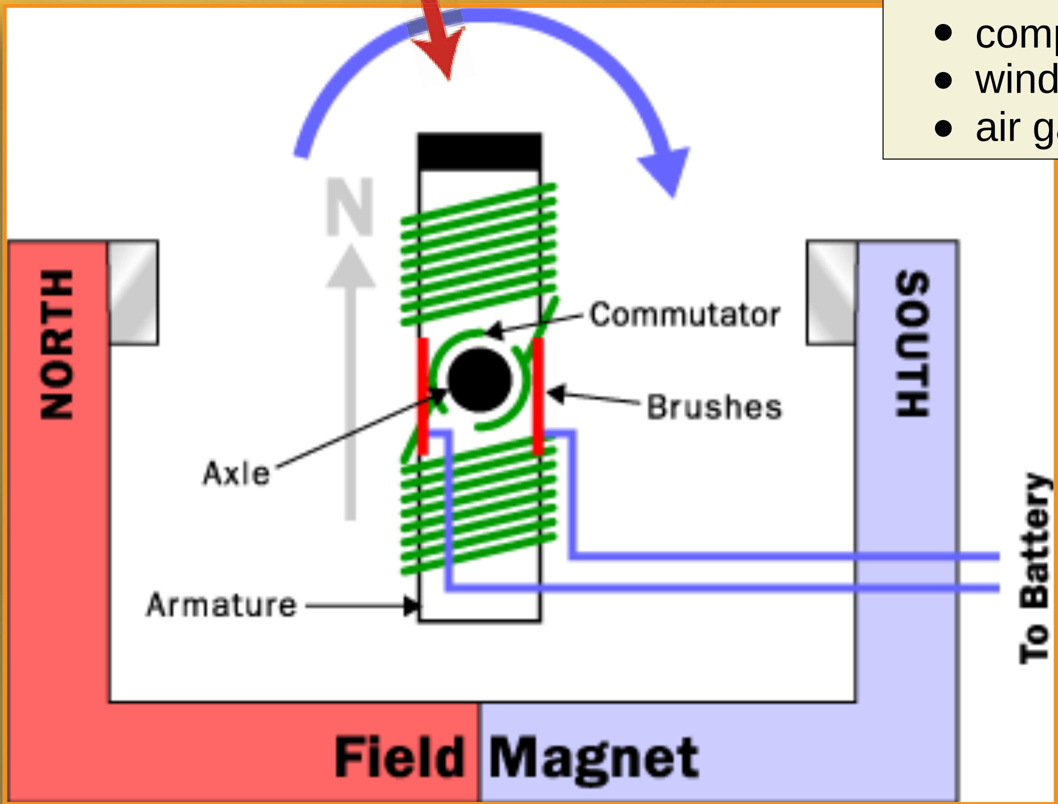
- relation modeled mathematically by James Clerk Maxwell
- subsequently became one of 4 Maxwell equations
- evolved into generalization known today as field theory

*SI unit of capacitance named **farad***

Motor Diagram

Key in Industrial Revolution

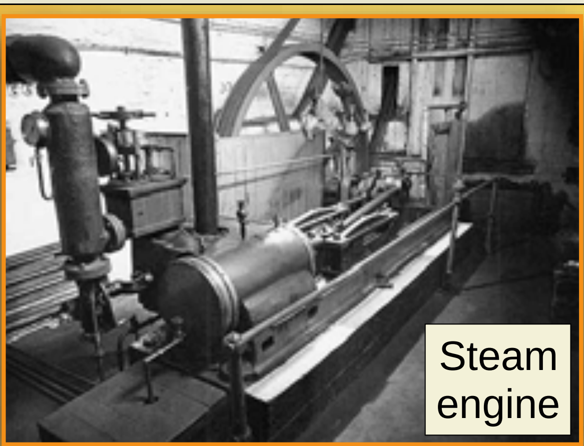
Rotor 'rotates' shaft



Stator simply 'stationary'

Stator:
- comprises either windings or permanent magnets
- windings around laminated soft iron core
- air gap = distance between rotor + stator

Rotor shaft delivers mechanical power:
- windings = wires laid in coils
- alternative single permanent magnet
- **commutator** current reversal with rotation



Steam engine

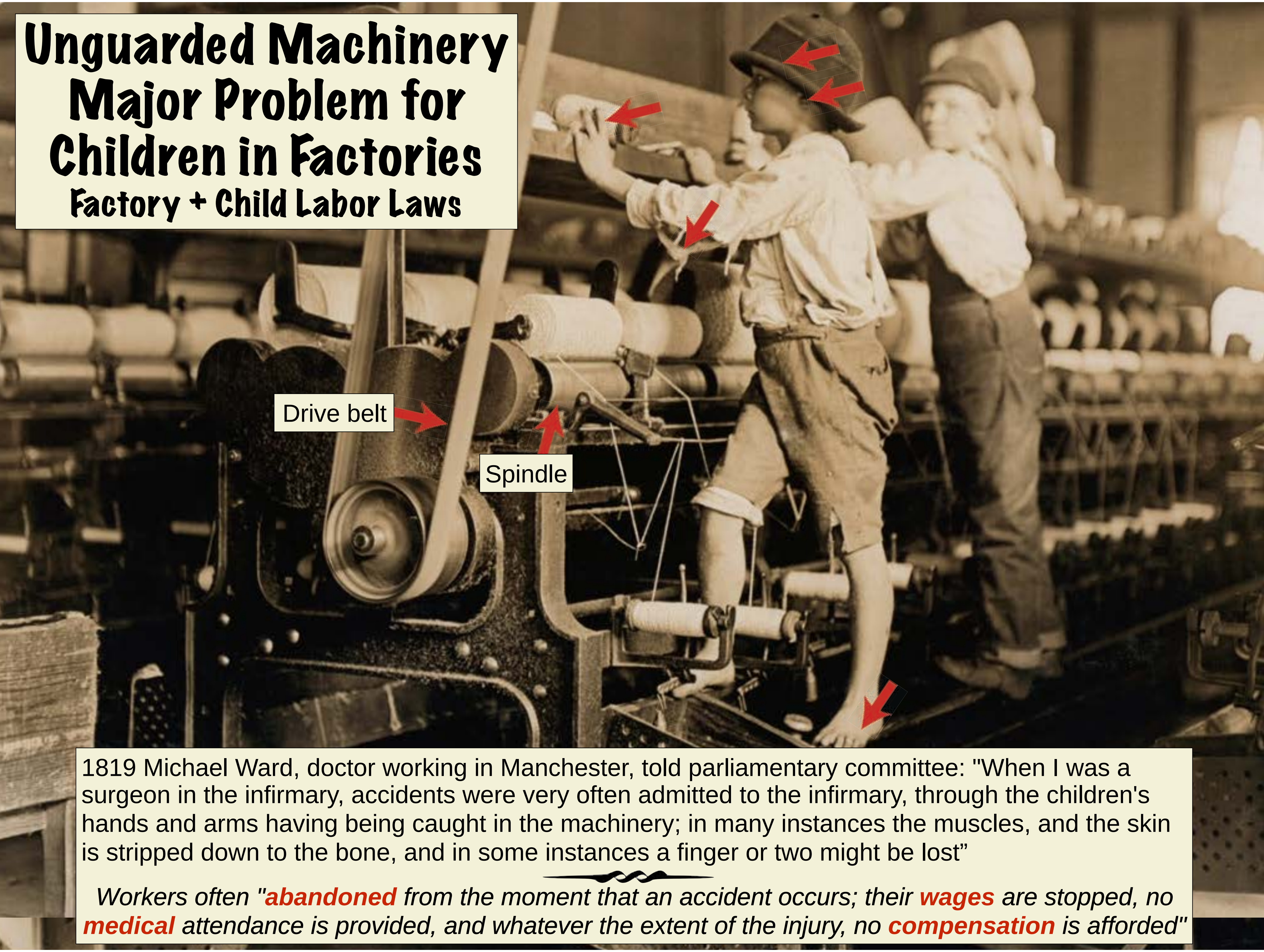
Factories not limited to steam engines, line shafts, belts, compressed air, hydraulics
- general-purpose models standardized dimensions + characteristics convenient
- largest for ship propulsion, pipeline compression, pumped-storage applications
- tiniest for non-digital watch

Every machine equipped with own electric motor:
- precise control at point of use
- improved power efficiency
- enhanced safety

*Electric motors now consume **3/5 global** electricity, mostly in industry*

Unguarded Machinery Major Problem for Children in Factories

Factory + Child Labor Laws

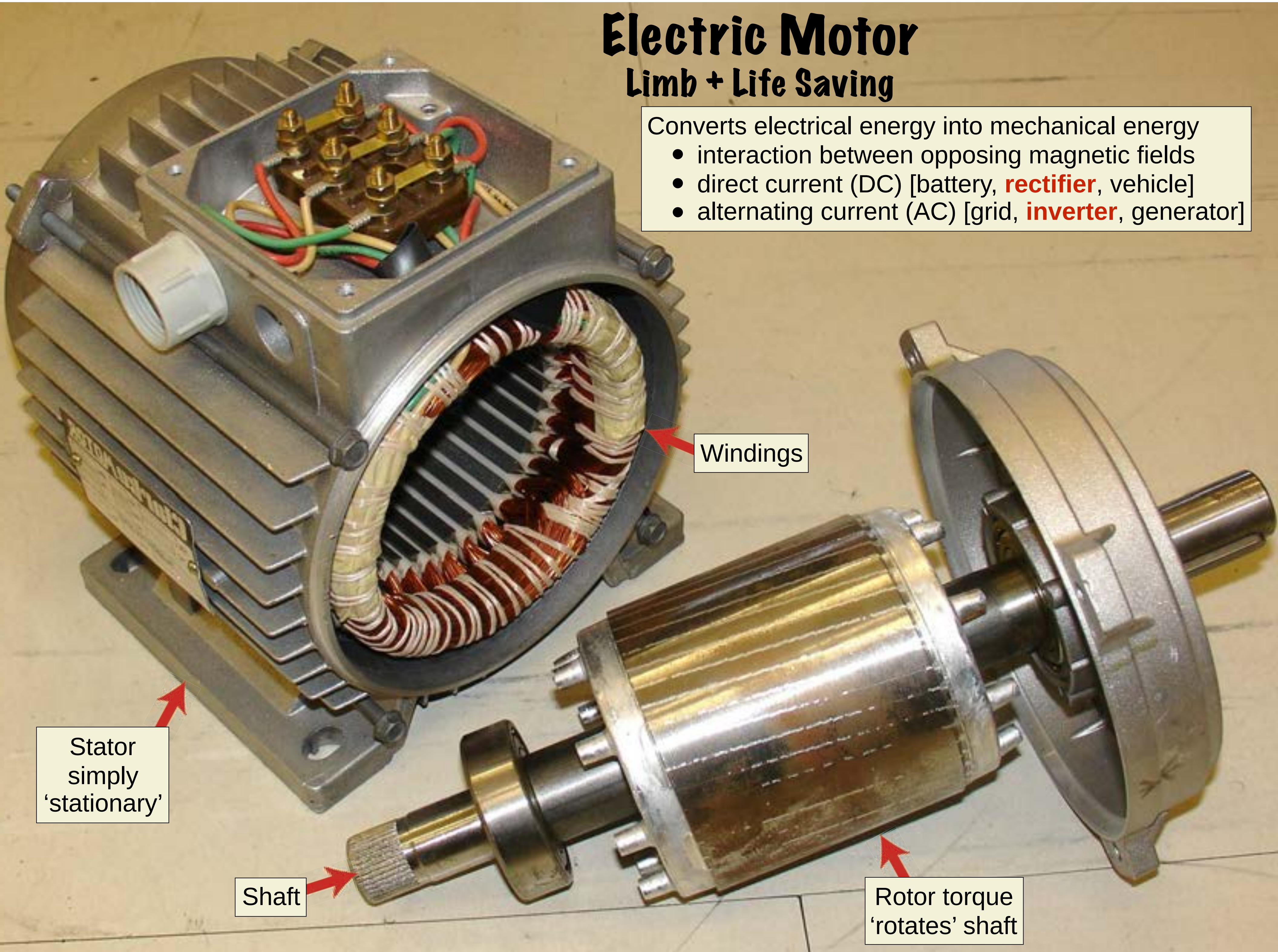


1819 Michael Ward, doctor working in Manchester, told parliamentary committee: "When I was a surgeon in the infirmary, accidents were very often admitted to the infirmary, through the children's hands and arms having being caught in the machinery; in many instances the muscles, and the skin is stripped down to the bone, and in some instances a finger or two might be lost"

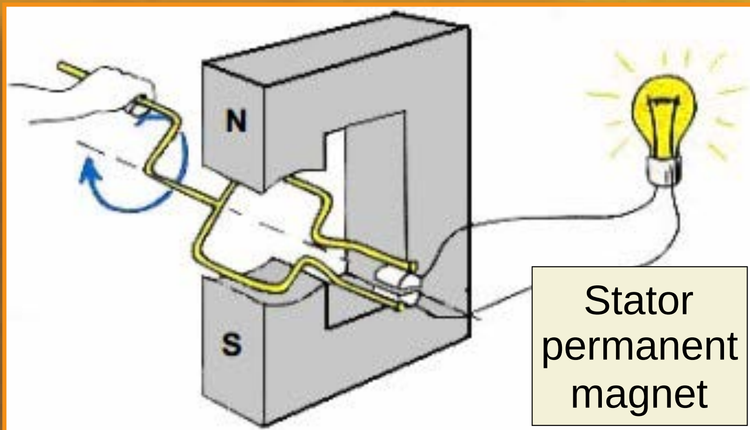
*Workers often "**abandoned** from the moment that an accident occurs; their **wages** are stopped, no **medical** attendance is provided, and whatever the extent of the injury, no **compensation** is afforded"*

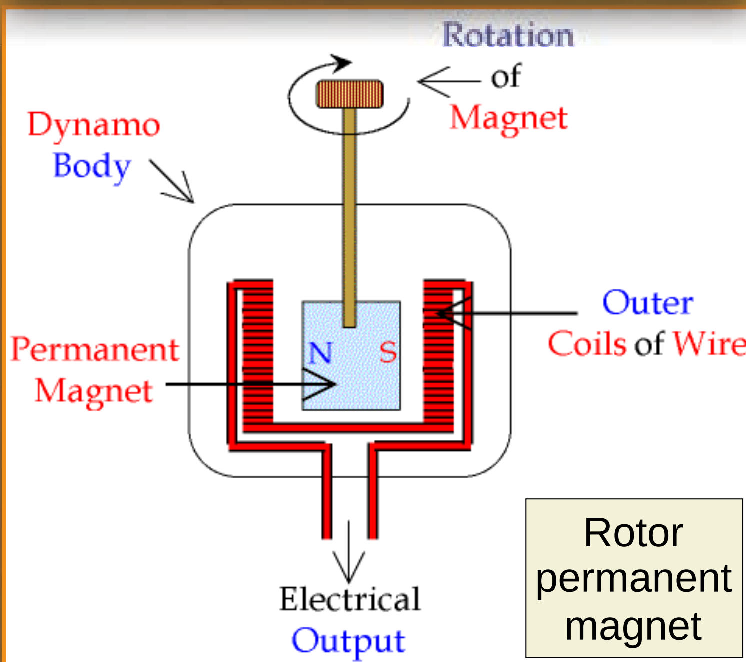
Electric Motor
Limb + Life Saving

Converts electrical energy into mechanical energy
- interaction between opposing magnetic fields
- direct current (DC) [battery, **rectifier**, vehicle]
- alternating current (AC) [grid, **inverter**, generator]



Electric Generator
Electric Motor in Reverse





Generator design determines power output:
- DC or direct current
- AC or alternating current

Either stator or rotor may incorporate windings

Efficiency faster, cheaper, easier:
- energy efficiency = **negawatts**
- demand response = **flexiwatts**

Primary energy converted by turbogenerator:
- biofuel + biomass
- bitumen oil [tar sands]
- coal
- concentrating solar
- geothermal [electric, not thermal]
- hydropower
- kerogen oil [oil shale]
- natural [methane] gas
- nuclear
- ocean thermal energy conversion [OTEC]
- petroleum [conventional]
- tidal
- wave
- wind

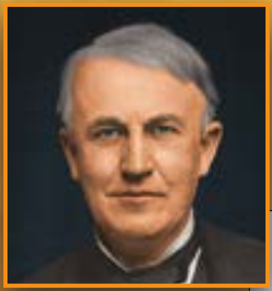
Primary energy directly converted to current:
- photovoltaic
- piezoelectric
- thermoelectric
- other novel technologies

Secondary forms energy:
- electricity
- hydrogen [fuel cell]

Future energy:
- fusion [speculative]
- lightning capture
- imagination run riot

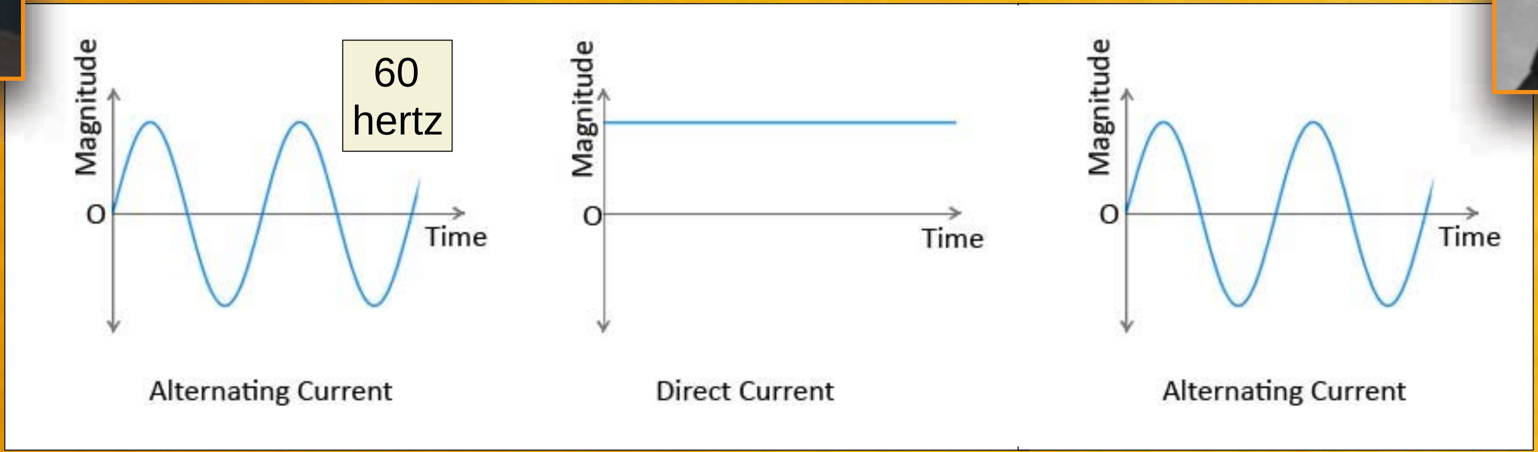
Direct Current vs. Alternating Current

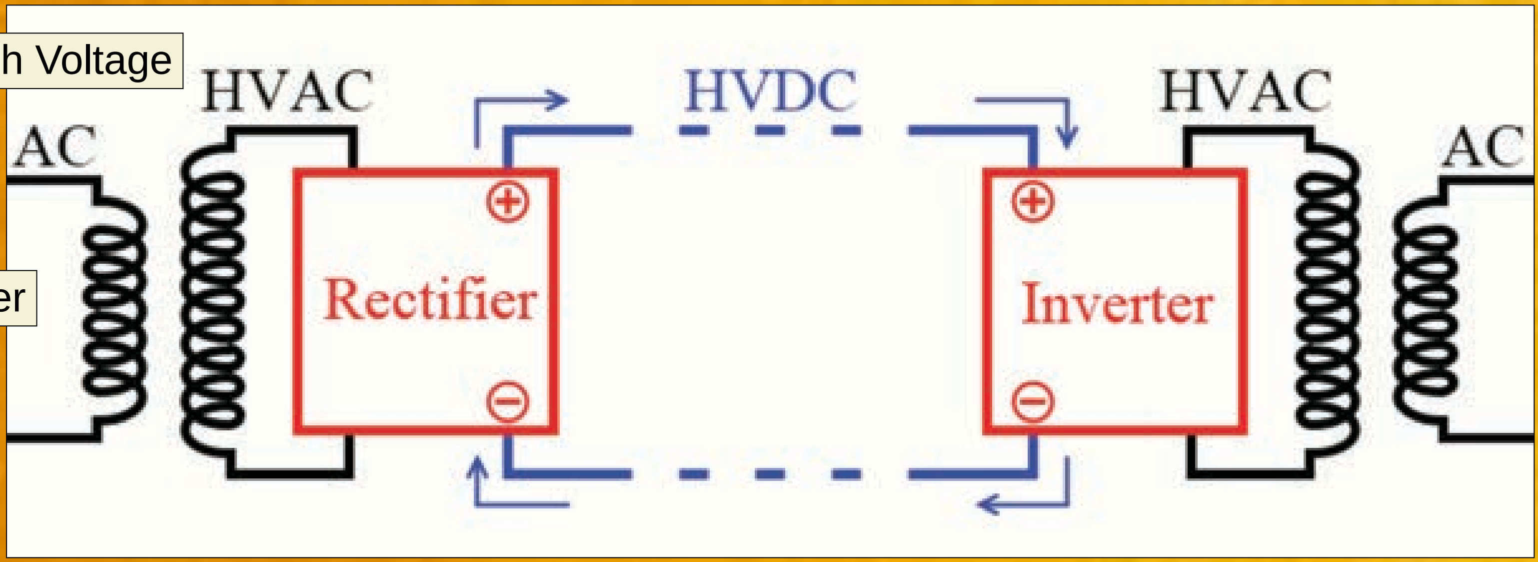
Rectifier vs. Inverter



Thomas Edison + DC

Nikola Tesla + AC





Interconversion of direct + alternating current *thermodynamically* entails some energy loss, mainly heat

- **inverter** converts direct current [or variable frequency current] into 60 hertz alternating current
- **rectifier** 'returns' alternating current into direct current
- generator controlled by governor at 3,600 rpm provides current at frequency = **60 cps** = **60 hertz**

Consider complexity of synchronization between linked AC systems

Pearl Street Station

Birth of an Industry in Manhattan

Genesis + proof of concept for modern electrical grid:

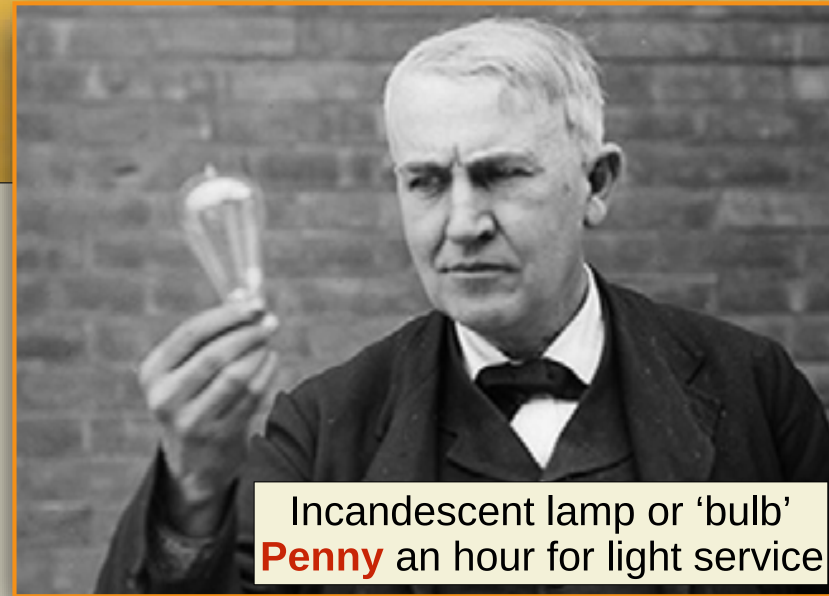
- 1882 first central plant initiated DC generation
- 255 – 257 Pearl Street in Manhattan
- initially served **85** customers + lit **400** lamps

Pearl Street Station electrical grid wildly successful

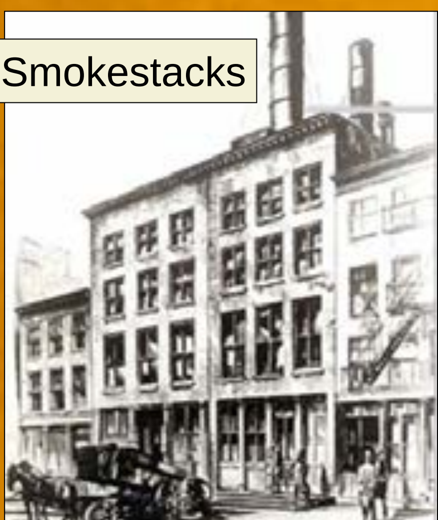
Edison Illuminating Company developed similar grids:

- 1882 Shamokin, PA
- 1883 Sunbury, PA + Brockton, MA + Mount Carmel, PA
- 1884 Pearl Street Station added 3 more generators with **10,164** lamps
- 1885 Tamaqua, PA

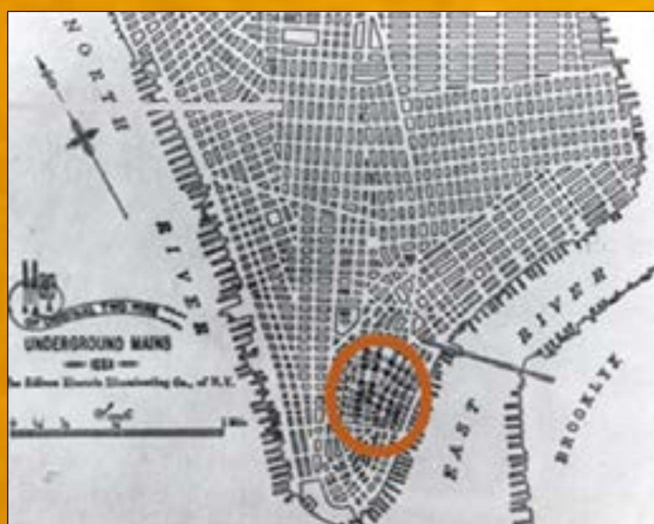
NYT described light as "soft, mellow and graceful to the eye…without a particle of flicker to make the head ache"



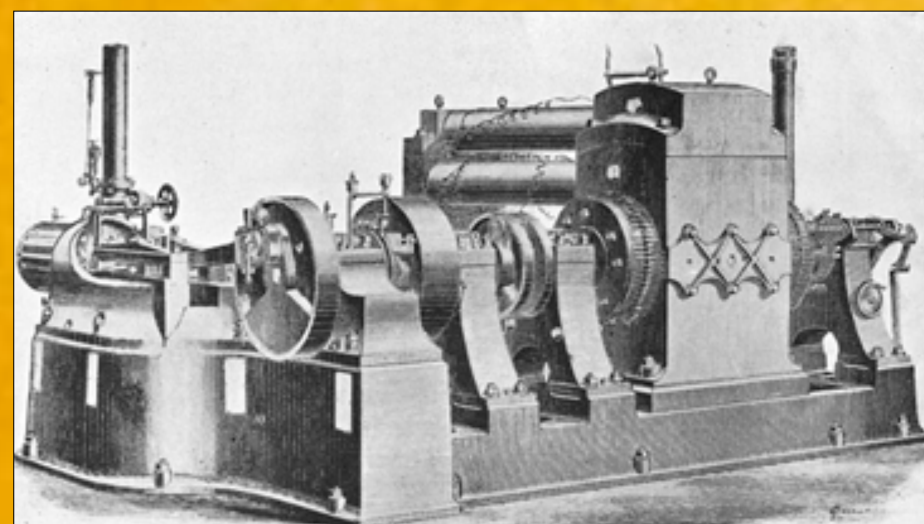
Incandescent lamp or 'bulb'
Penny an hour for light service



Pearl Street Station, coal-fired



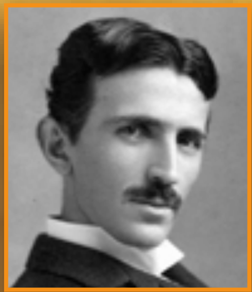
Lower Manhattan



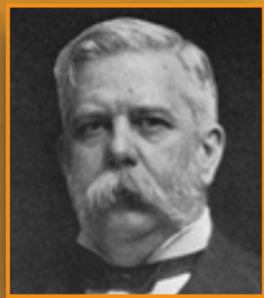
27-ton constant-voltage "Jumbo" dynamo [generator]

War of the Currents

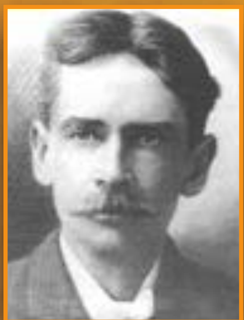
Edison vs Tesla / Westinghouse + First Mover Advantage



Nikola Tesla



George Westinghouse



William Stanley, Jr.

AC decided advantage over DC for transportation electricity long distance:

- easier + cheaper to "step-up" + "step-down" voltage
- Ohm's law: **I = V/R**
- where I = current, V = voltage, R = resistance [held constant]

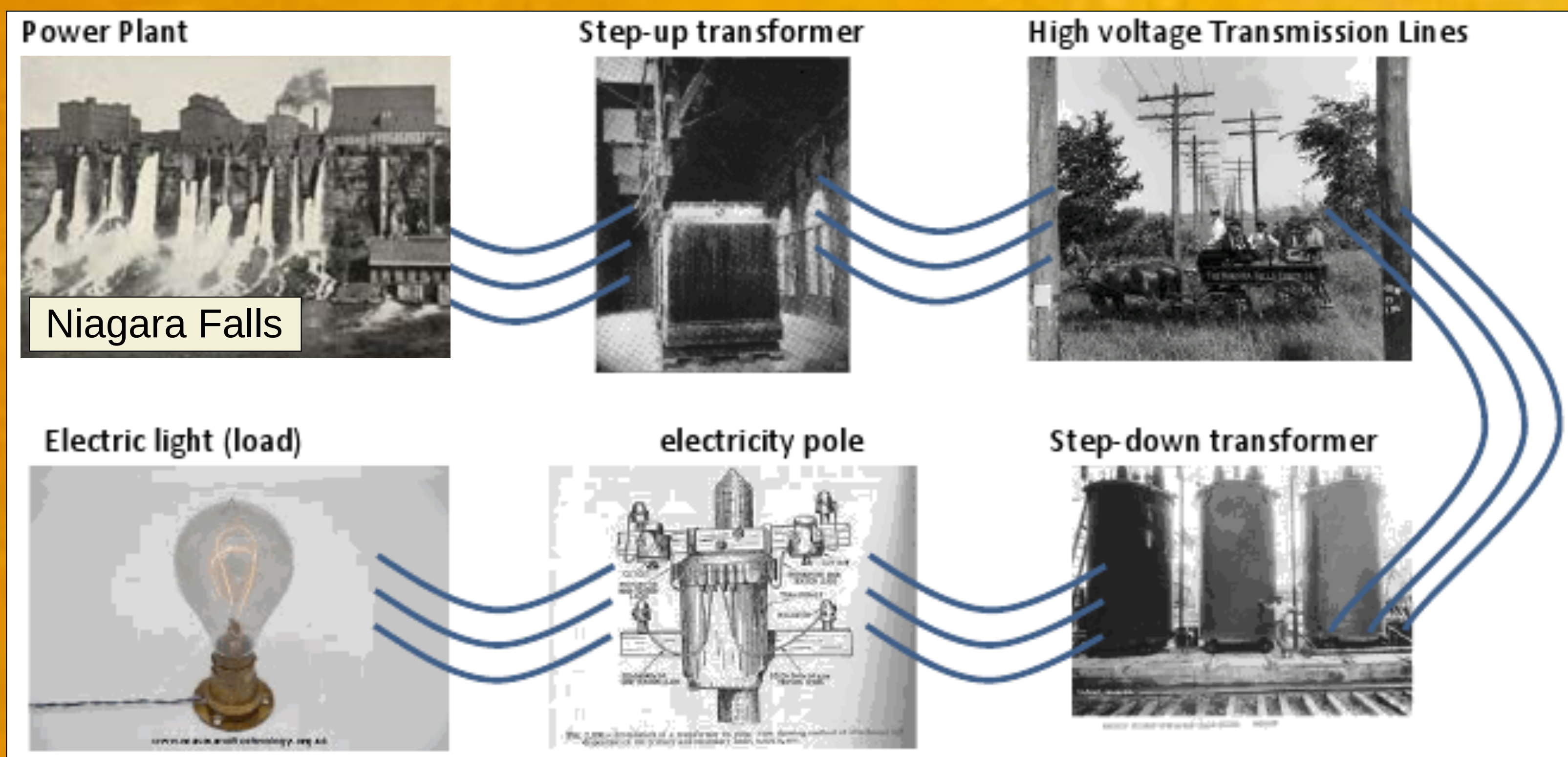
Increasing voltage *increases current*

- resistance wastes power as heat + deteriorating wire
- higher voltage thus smaller wire sufficient

Actually William Stanley built first generator using alternating current

AC grids nearly 10 yrs behind DC in late 1800s

Just before turn of century Westinghouse built hydroelectric power plant at Niagara Falls with AC technology sending electricity ***21 miles*** *to Buffalo*



Age of Private Electric Companies
1900 - 1932

Patchwork of DC + AC grids, competing in market, privately owned + *totally unregulated*
- entrepreneurs figured out economies of scale
- sought concentrations of population
- best locations Boston, New York, Philadelphia

Competing electric companies would run wire to same buildings
- with competition…like cellular now…*could pick which one you wanted*
- local + state governments struggled to cobble together **regulations** + **commissions**

Great Depression brought end to this era
- dismal economy greatly reduced number of people who could afford electricity
- many private electric companies bankrupted

*Silver lining for Kennedy family was chance to leverage money from **bootlegging** into controlling interest in same electric companies, gambling on economic recovery*

Literate kid


Dust Bowl


Soup line

New Deal under FDR

Creation of a National Social Compact

Businessmen ruthless in crafting elaborate + powerful monopolies

- public outrage at subsequent costs came to head during Great Depression
- sparked federal regulations + federal projects
- Tennessee Valley Authority + other rural electrification

1934 **Public Utility Holding Company Act**

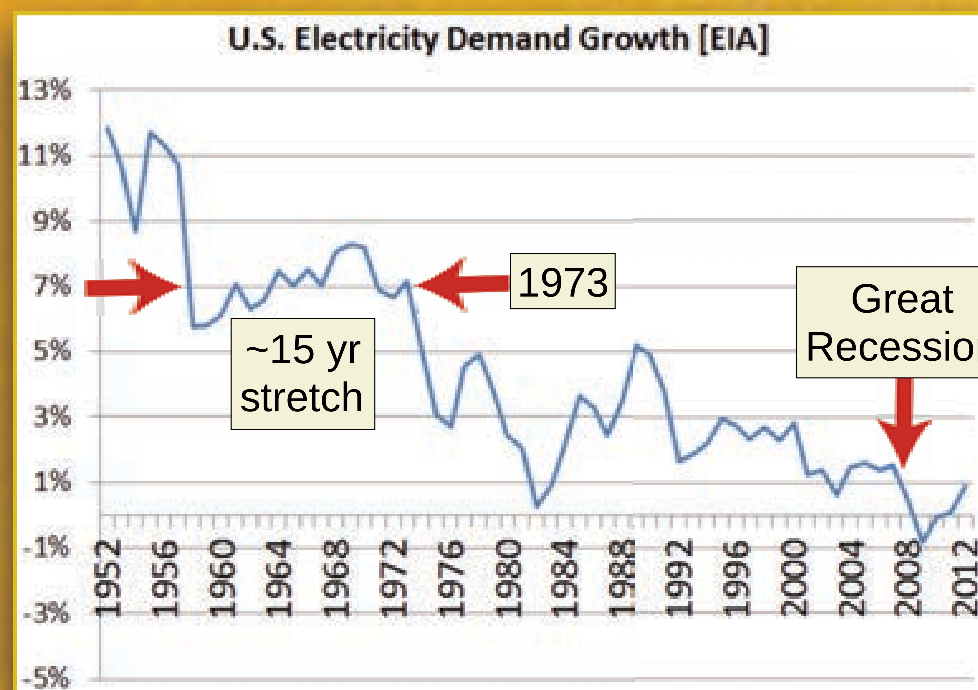
- electric utilities recognized as important *public goods*
- outlined restrictions + regulatory oversight of operations
- states created public utility commissions [UTC in Washington State 1961]

Grand social compact nearly a century:

- regulated monopoly = *vertically-integrated utility*
- *both* capital projects + rates or tariffs controlled by regulatory commissions
- guaranteed rate of return for both components, plus **growth** + **capture**

≥ 7% rate electric demand growth for decades until 1973

FDR signing ceremony



LED represents Photovoltaic in Reverse

Efficiency always faster, easier, cheaper

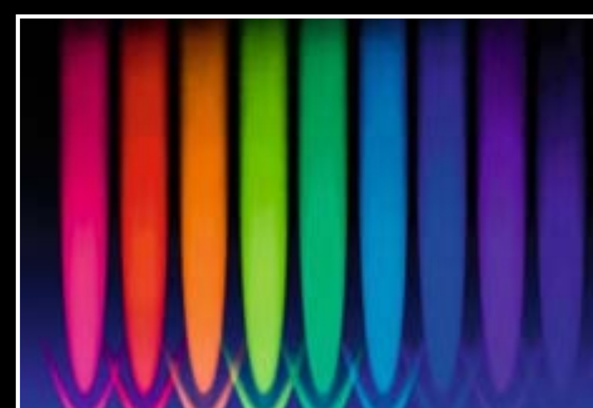
High brightness **ultraviolet + visible + infrared**

Color (linked photon energy) set by band gap

Advantages over incandescents:

- **85-90% lower** energy consumption
- 50,000 hr lifetime
- physically robust
- tolerate temp extremes
- switch faster
- rheostat dimming

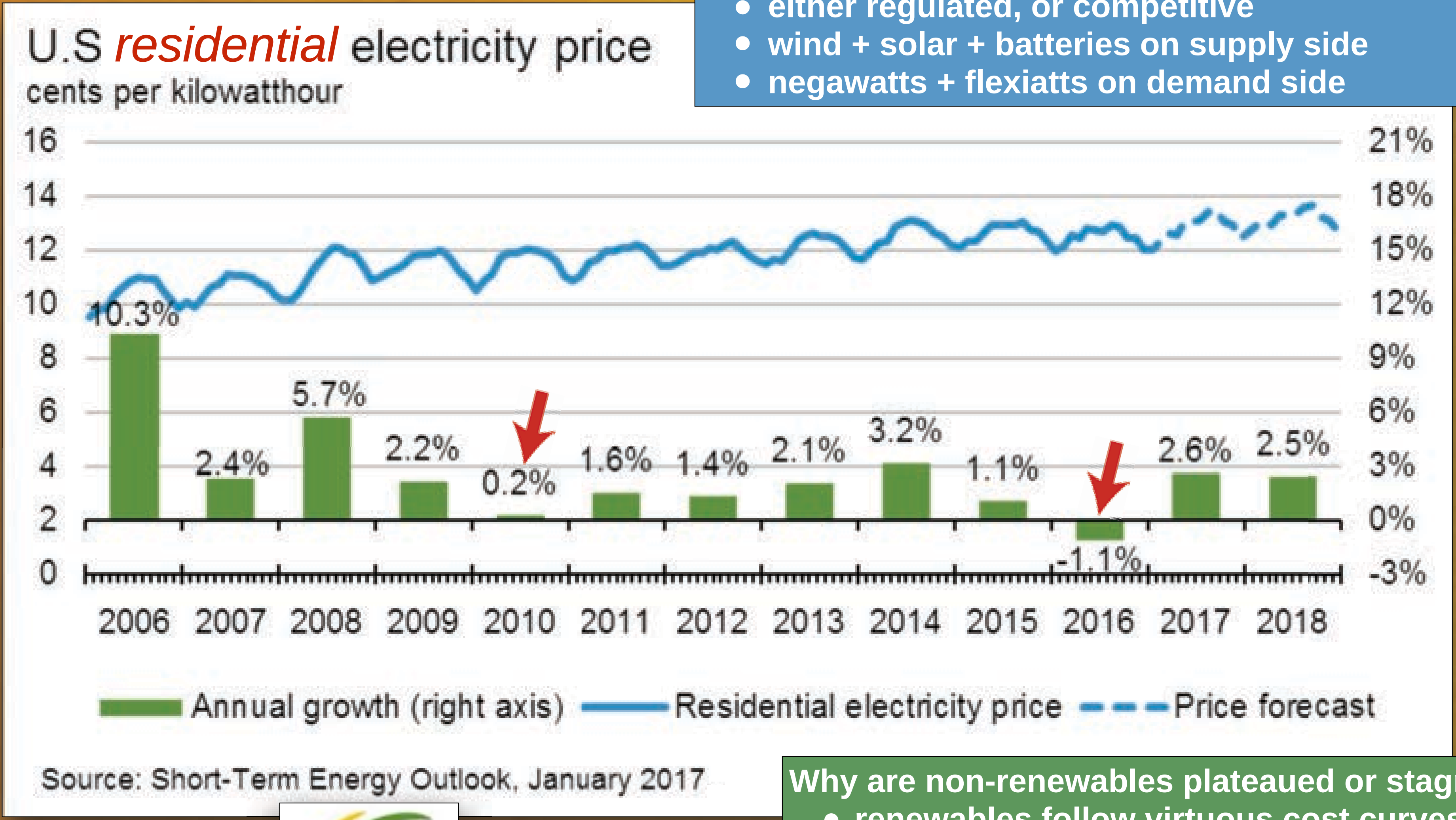
Unlike fluorescents no mercury



Energy Efficiency Trumps All

Faster, Easier, Cheaper + often Permanent

Why is mean residential electricity cost rising so slowly?
- **either regulated, or competitive**
- **wind + solar + batteries on supply side**
- **negawatts + flexiatts on demand side**



Why are non-renewables plateaued or stagnating?
- **renewables follow virtuous cost curves**
- **renewables mainly technologies, not fuels**
- **non-renewables follow *negative* learning curves**

Nuclear Power + AEC + NRC

Negative Learning Curve

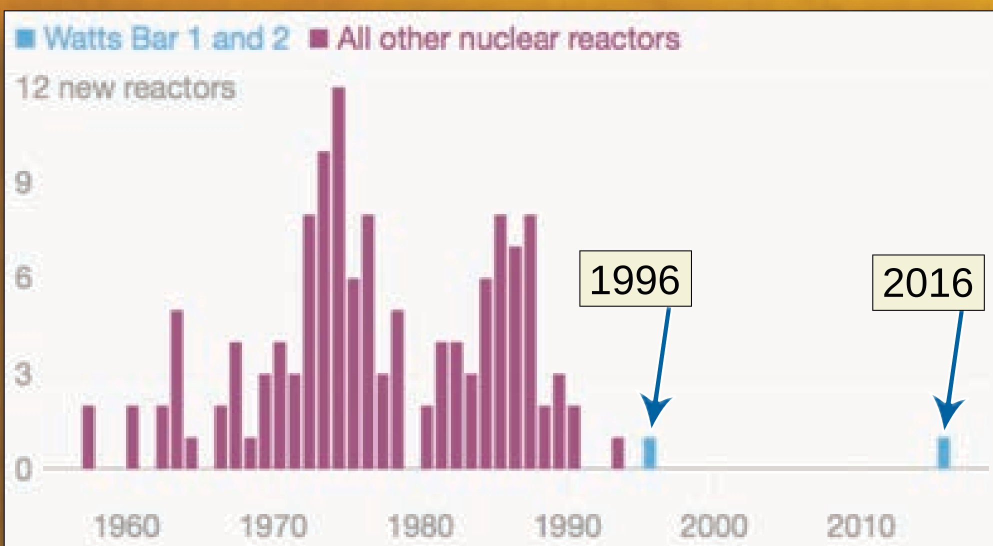
Atomic Energy Commission [AEC] established after WWII to foster + control atomic technology

- abolished by Energy Reorganization Act of 1974
- established Nuclear Regulatory Commission [NRC]
- AEC Chairman Lewis Strauss 1954 coined phrase, "***too cheap*** *to meter*"

1973 AEC predicted that, 'by the turn of century, ***one thousand*** *reactors would be producing electricity for homes + businesses across US'*

But after 1973 reactor orders declined sharply:

- rise of demand slowed
- construction costs rose
- many orders + number partially completed plants cancelled

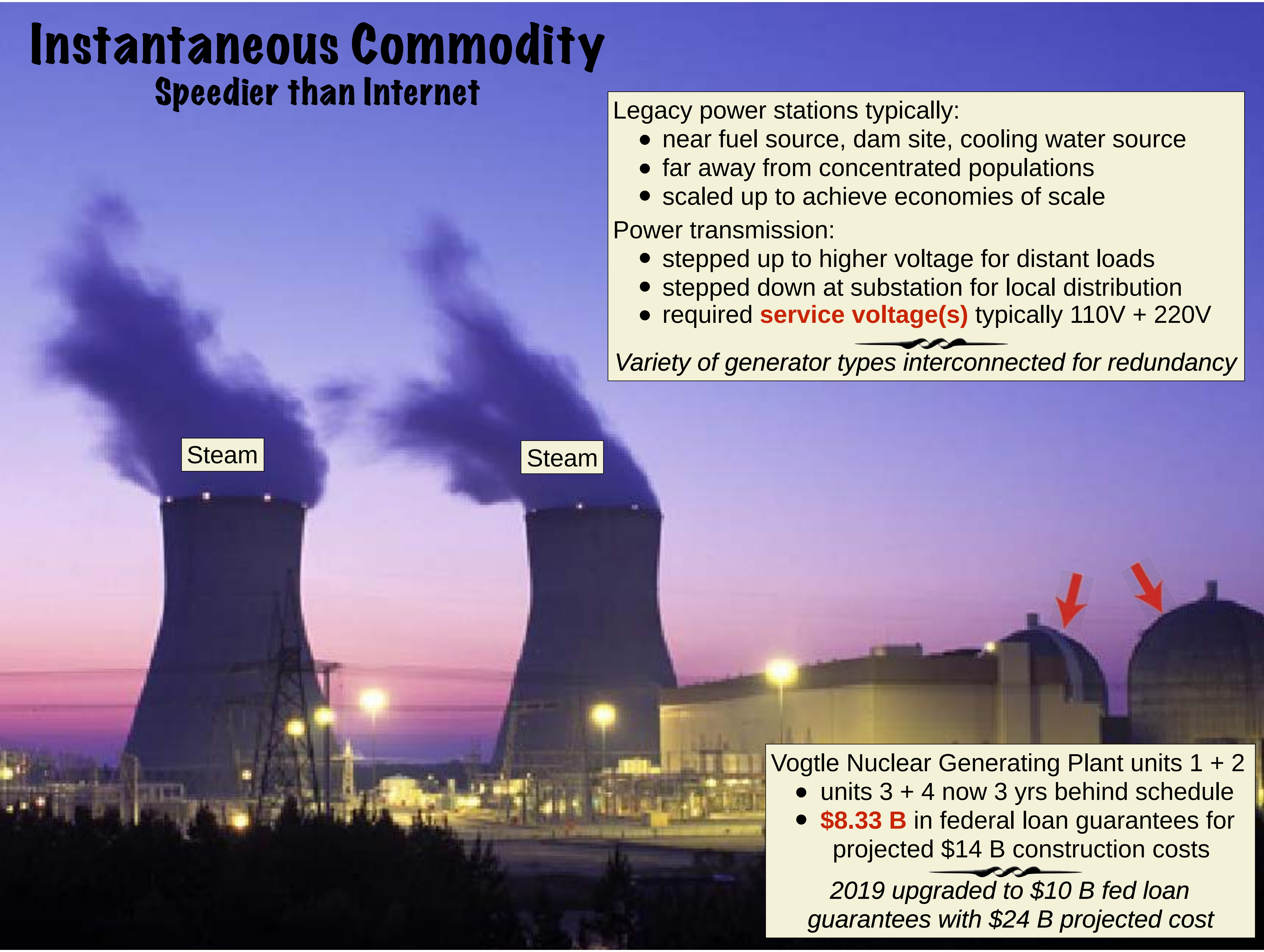


Watts Bar 1 + 2 last new reactors
Second one took 43 yrs

Nuclear share electricity
1975-2015

Instantaneous Commodity

Speedier than Internet



Legacy power stations typically:

- near fuel source, dam site, cooling water source
- far away from concentrated populations
- scaled up to achieve economies of scale

Power transmission:

- stepped up to higher voltage for distant loads
- stepped down at substation for local distribution
- required **service voltage(s)** typically 110V + 220V

Variety of generator types interconnected for redundancy

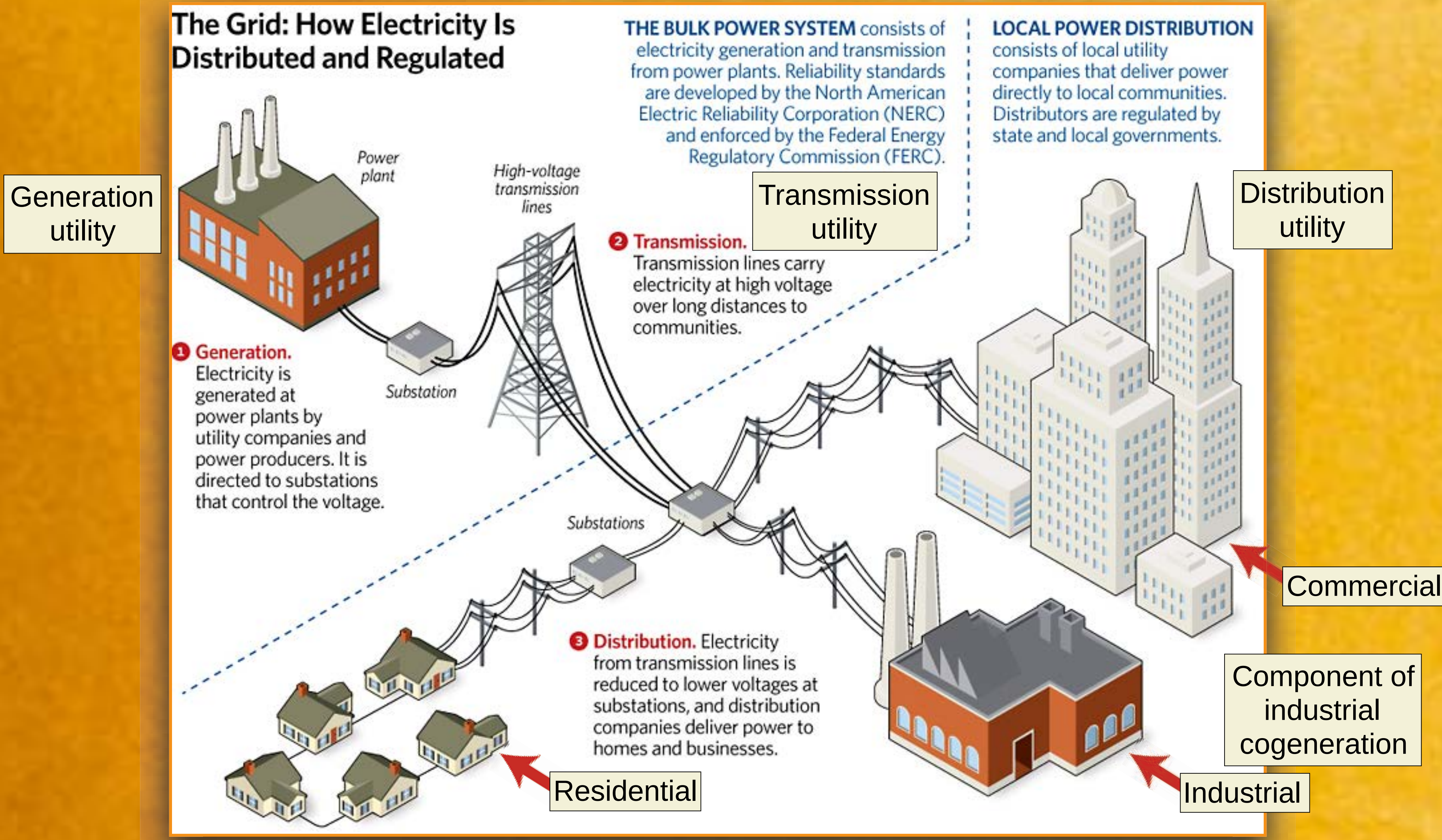
Vogtle Nuclear Generating Plant units 1 + 2

- units 3 + 4 now 3 yrs behind schedule
- **$8.33 B** in federal loan guarantees for projected $14 B construction costs

2019 upgraded to $10 B fed loan guarantees with $24 B projected cost

Historical Grid

Grid Architecture Hierarchial + Unidirectional



Distribution utilities:
- *neither* **build** or **own** an independent generator
- *cannot* **dispatch** an independent generator
- instead nonprofit RTO or ISO *allocates* power

Distributed generation + **storage** + microgrids:
- residential, community level
- commercial sector
- industrial concerns with cogeneration

Centralized, top-down power grid is outdated

Make Way for Distributed Energy Resources (DERs)

David Roberts at Vox.com + Utility Dive

Time for a **bottom-up** redesign

By some estimates US power grid largest machine in world:

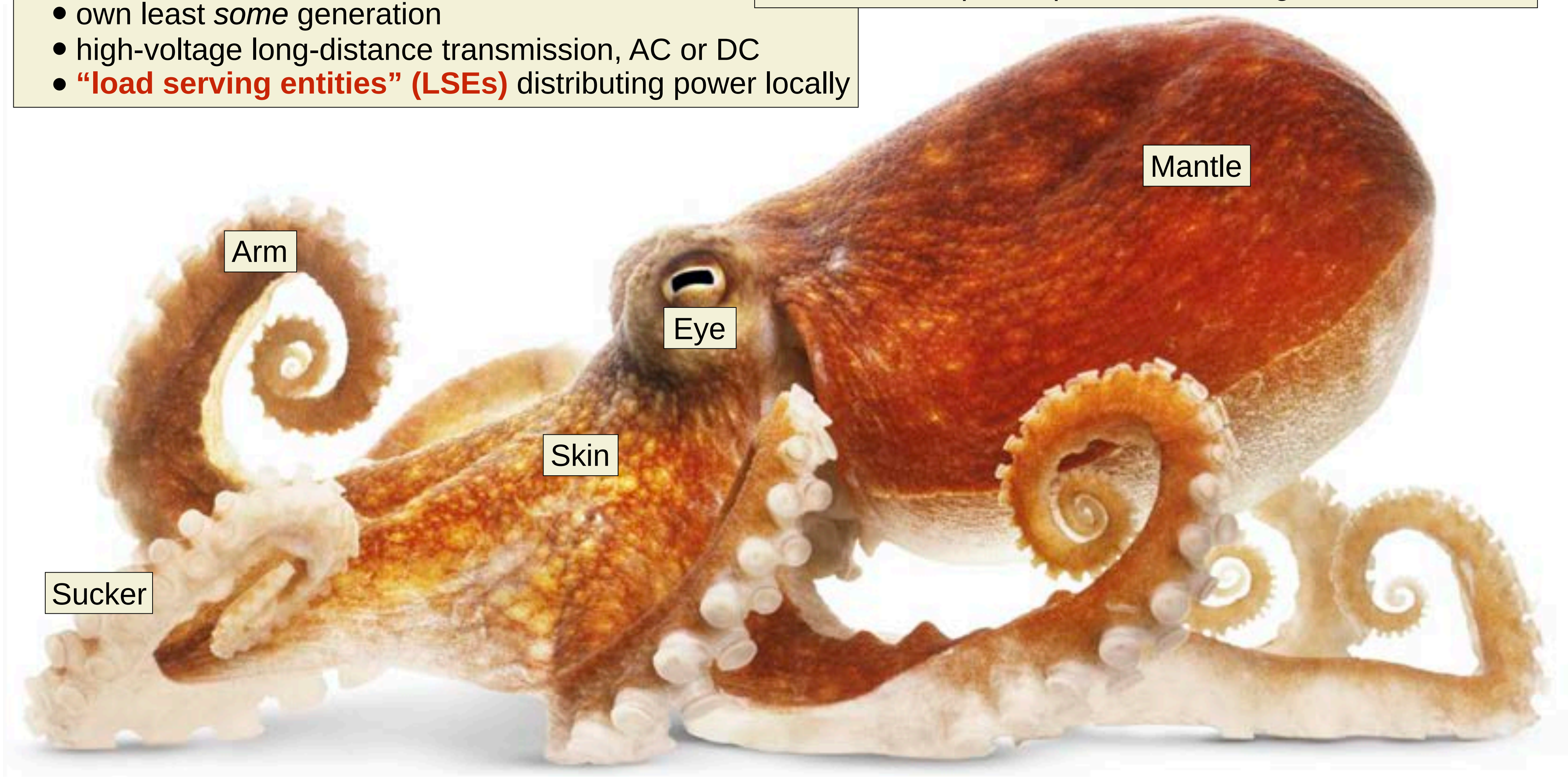
- only instantaneous commodity
- negligible energy storage [previously]
- precise AC synchronization

Utilities morphing from vertically integration:

- own least *some* generation
- high-voltage long-distance transmission, AC or DC
- **"load serving entities" (LSEs)** distributing power locally

US ~ 2/3 population served by "restructured" utilities

- splitting top + middle + bottom apart
- follow rules by FERC + NERC
- wholesale power purchased from *"gencos"* at auction



Centralized, top-down power grid is outdated

Make Way for Distributed Energy Resources (DERs)

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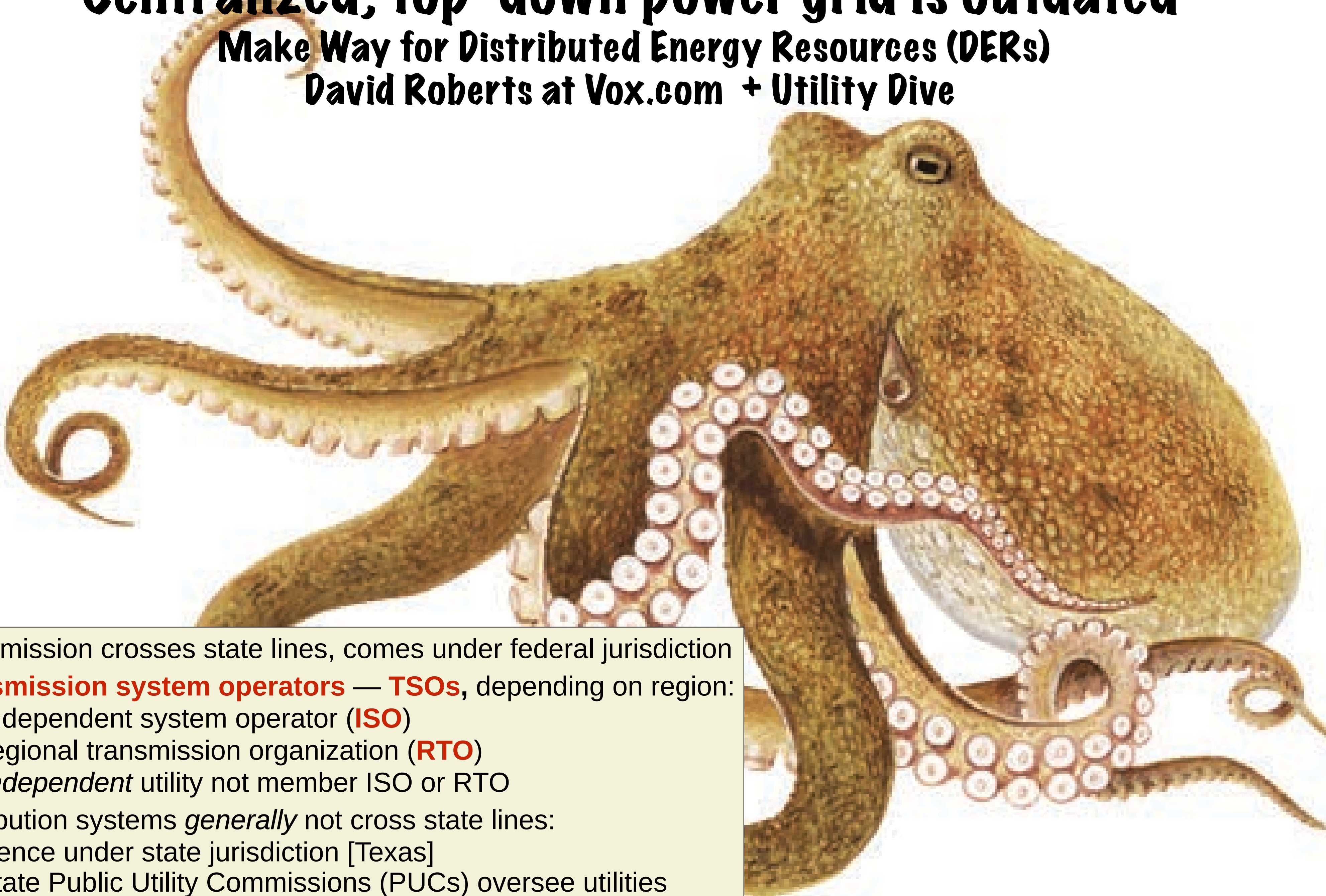


Transmission crosses state lines, comes under federal jurisdiction

Transmission system operators — **TSOs,** depending on region:

- independent system operator (**ISO**)
- regional transmission organization (**RTO**)
- *independent* utility not member ISO or RTO

Distribution systems *generally* not cross state lines:

- hence under state jurisdiction [Texas]
- state Public Utility Commissions (PUCs) oversee utilities
- state legislators pass laws governing utilities

Municipal utilities + electric cooperatives:

- also operate distribution systems
- subject **local** governing bodies, *not* state commissions

Centralized, top-down power grid is outdated

Make Way for Distributed Energy Resources (DERs)

David Roberts at Vox.com + Utility Dive

Blue Ringed Octopus

Distributed Energy Resources (DERs) or *grid edge* technologies

Electron flux now becoming bidirectional

Smaller-scale devices often (not always) found "behind the meter"

- some DERs generate energy, like solar modules, microturbines, microhydro, fuel cells
- some DERs store energy, like batteries, fuel cells, or *thermal* storage [water heaters or ice]
- some DERs monitor + manage energy, like smart thermostats, smart meters, smart chargers

*Oldest + still most **common** DER = **diesel** generators, obviously suboptimal re´ climate*

Energy Storage Revolution

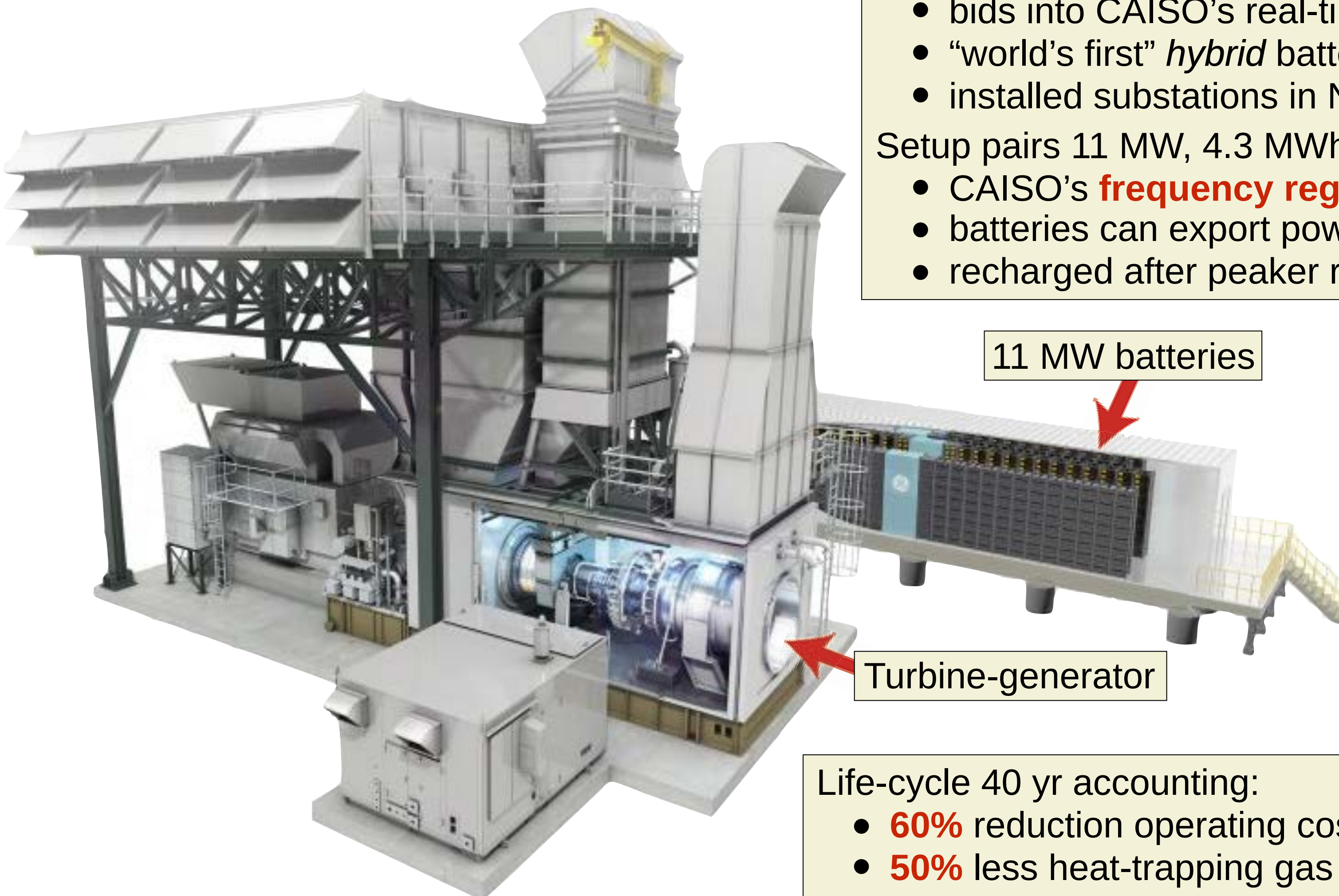
Incorporated into All Levels of Grid
Both In-Front-of-the-Meter + Behind-the-Meter

Southern California Edition still owns generation assets

- bids into CAISO's real-time + DA energy markets
- "world's first" *hybrid* battery storage-gas turbine peaker
- installed substations in Norwalk + Rancho Cucamonga

Setup pairs 11 MW, 4.3 MWh battery with 50 MW peaker

- CAISO's **frequency regulation** or **peaking** market
- batteries can export power immediately
- recharged after peaker ramps up **5 or 10 min**



Life-cycle 40 yr accounting:

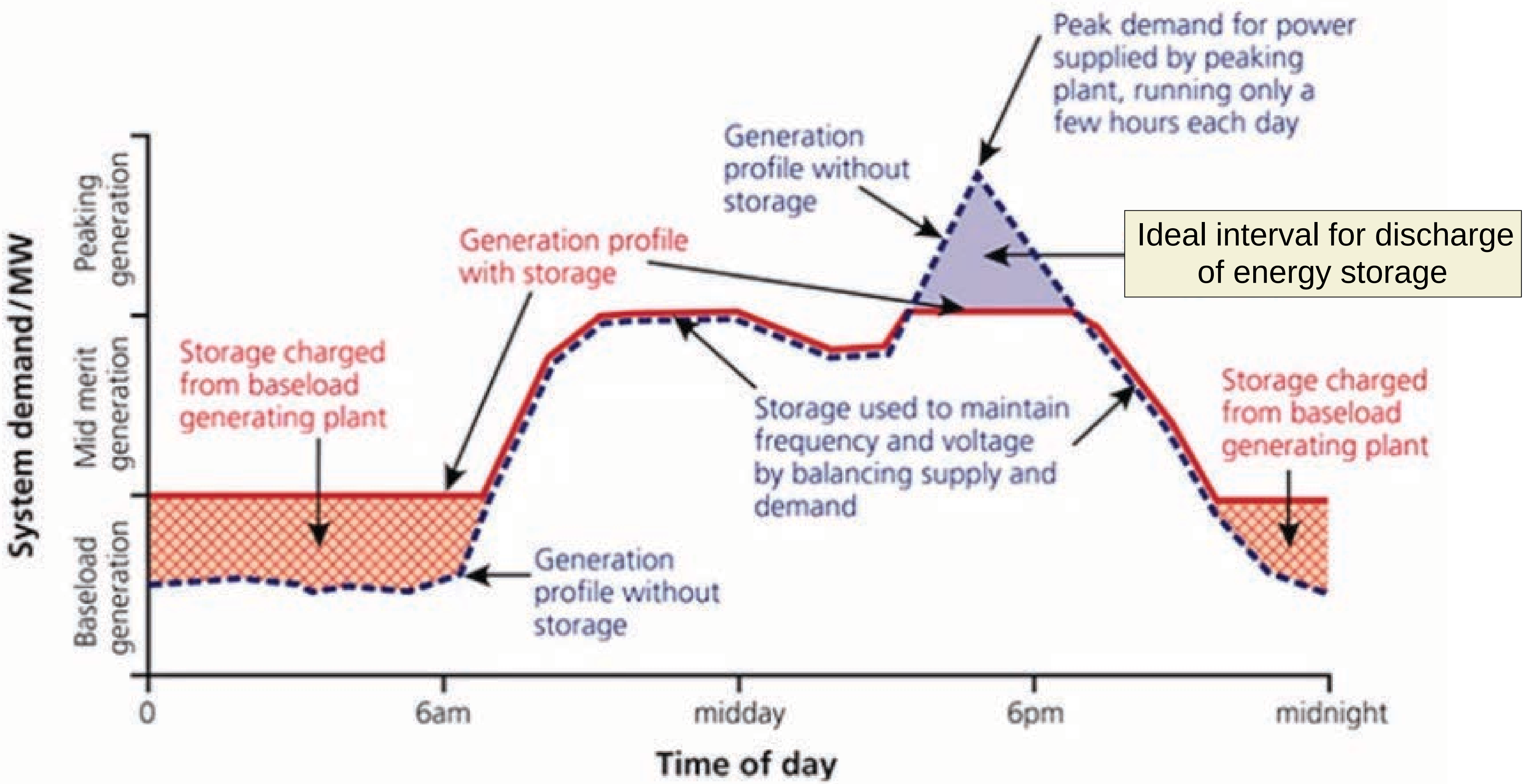
- **60%** reduction operating costs
- **50%** less heat-trapping gas or HTG emissions
- **45%** decreased water demand

SCE contemplating adding storage even to hydroelectric plants:

- eminently dispatchable since ramps up quickly
- hence traditionally used for frequency response
- storage enhances **hydro asset's** response time

Energy Storage Revolution

Incorporated into All Levels of Grid
Both In-Front-of-the-Meter + Behind-the-Meter



Storage advantages:

- **leveling** of demand for generation
- prevention of **curtailment** of renewables
- near **instantaneous** backup in outage

Modalities of Energy Storage

Definitely Thinking Outside of the Battery Box

Electromagnetic

- Supercapacitors
- Superconducting Magnetic Energy Storage (SMES)

Thermal

- Molten Salt
- Chilled Water/Ice

Electrochemical

- Li-ion Battery (LIB)
- Pb-Acid Battery
- Flow Battery
- Molten Sodium Battery (NAS/ZEBRA)
- Nickel-based

Mechanical

- Pumped Hydro Storage (PHS)
- Flywheels
- Compressed Air Energy Storage (CAES)
- Advanced Rail Energy Storage (ARES)

Chemical

- Hydrogen
- Methane

Storage metrics:

- absolute capacity
- charging rate
- discharging rate [power]
- component availability limits
- cost structure with target < $100 per kWh

Vanadium flow batteries particularly interesting

Case for storage 3 predominant categories:

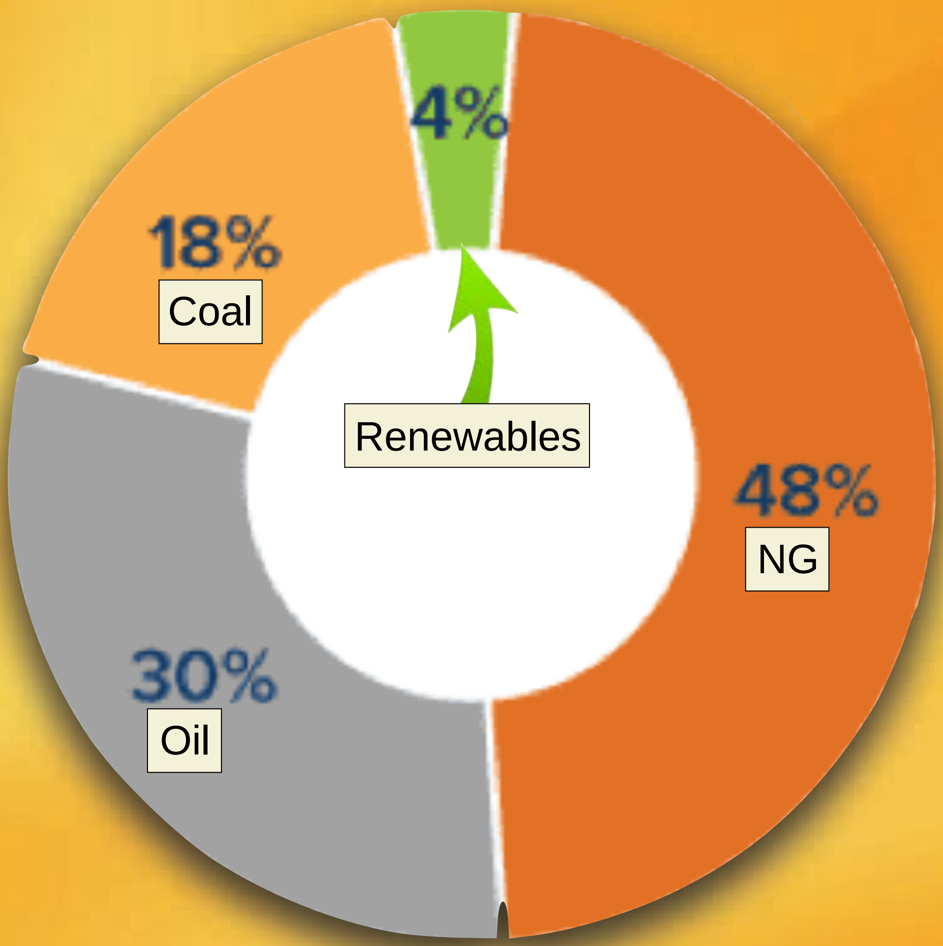
- **utility-scale**
- transportation [aviation]
- behind-the-meter

Last category either residential, commercial, industrial

Hydrogen Part of Energy Transition

Blend of Alternative Fuels + Electrification

Can Make Hydrogen without Emitting CO_2



Major sources commercial FF hydrogen production:

- **steam methane reformation (SMR)**
- oxidation
- gasification

Hydrogen categories:

- FF source with CO_2 emission = **grey hydrogen**
- FF source with CCU or S = **blue hydrogen**
- renewable electrolysis = **green hydrogen**

Solution = *renewable-energy-powered* electrolysis

Hydrogen 'new kid on block' low-carbon alternatives:

- transportation
- shipping
- industrial processing
- heavy transport

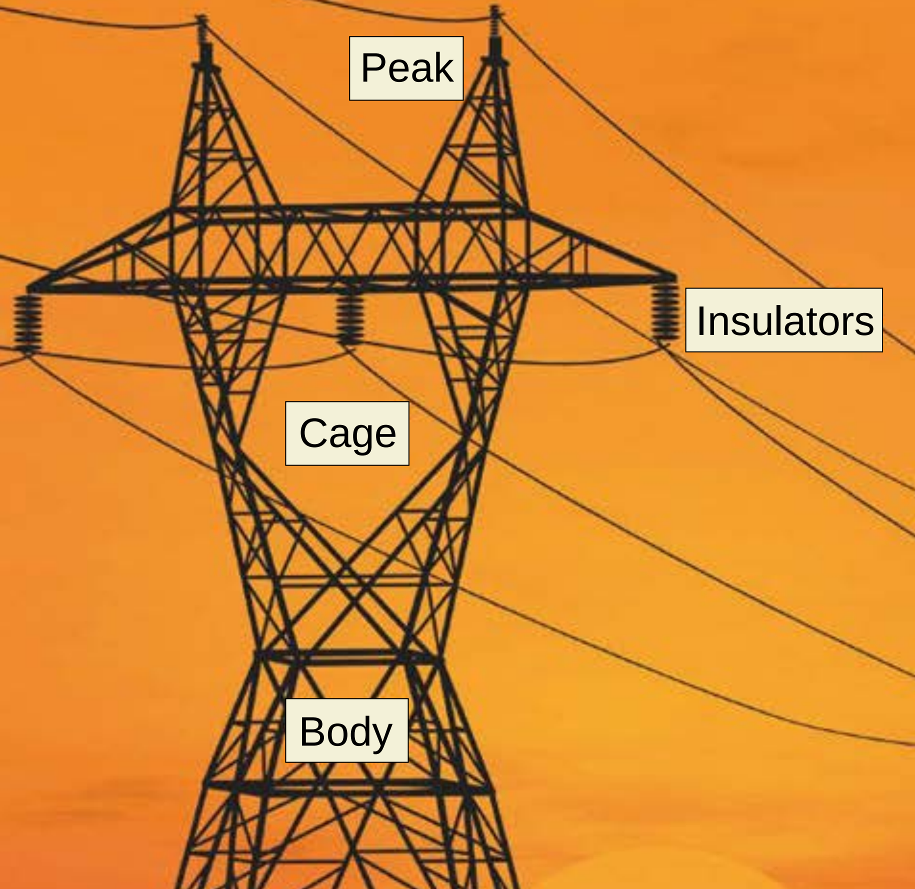
Other functions:

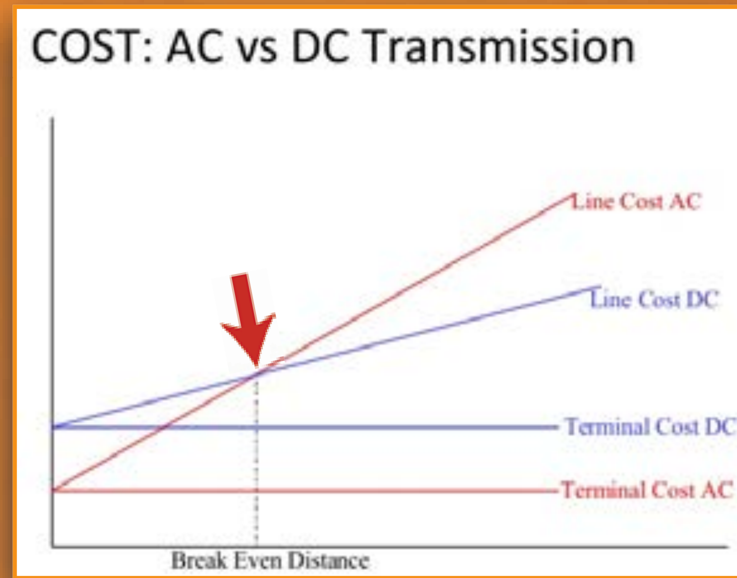
- fuel cell electricity
- heat
- NG-blended to help decarbonize *existing* pipelines
- chemical feedstocks such as ammonia

Hydrogen fuel cell buses typically 500 km range, versus electric buses 200 km

HVAC vs. HVDC Transmission

High Voltage Long-Distance Transmission





USA transmission:

- **~ 16k** miles HV lines
- 3 times length interstate highways
- but million miles lower voltage lines

HVDC technology efficient alternative:

- asynchronous interconnection of grids, even different frequencies
- 2 conductors per DC circuit vs. 3 conductors in 3 phase AC circuit
- line-supporting towers smaller thus lesser right-of-way

Over specific **break-even** distance HVDC line cheaper

- overhead lines ~ 600 km or 373 miles
- submarine lines ~ 50 km or 31 miles [offshore wind]
- efficient production HVDC not accomplished until 1960s

HVDC actually complement for AC systems rather than rival

Quandries in High-Voltage Transmission

Skin Effect, Proximity Effect, Corona Effect

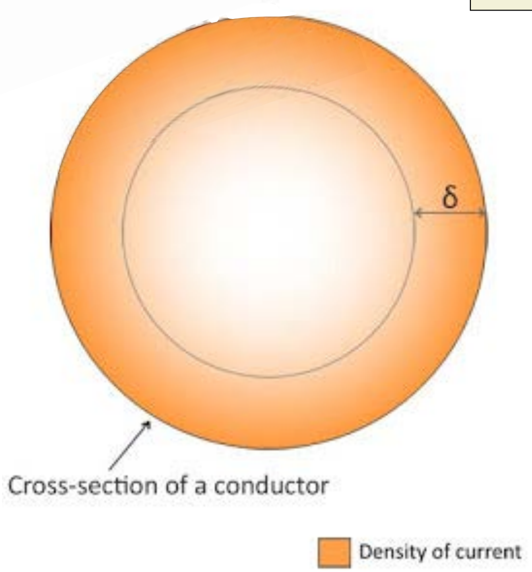
Proximity effect absent in DC lines

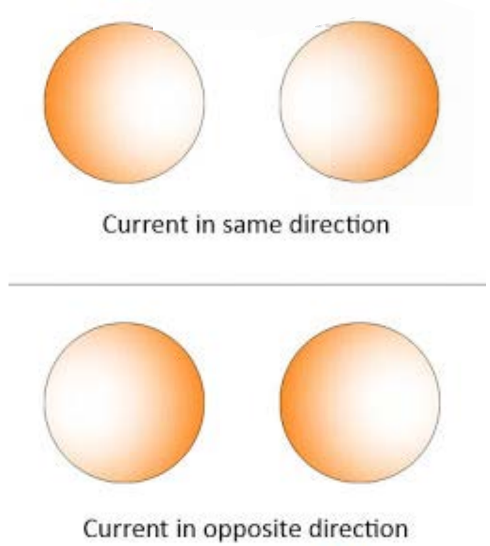
≥ 2 conductors carrying AC close to each other:

- varying magnetic fields affect current distribution
- induce **eddy currents** in adjacent conductors
- effective conductor resistance enhanced

Adjacent conductors carrying current:

- same direction then concentrated far sides
- opposite direction then concentrated near sides





Skin effect:

- electrons in conductor concentrate near surface
- effective cross-section reduced
- effective resistance slightly increased
- higher inductance + reactance internally

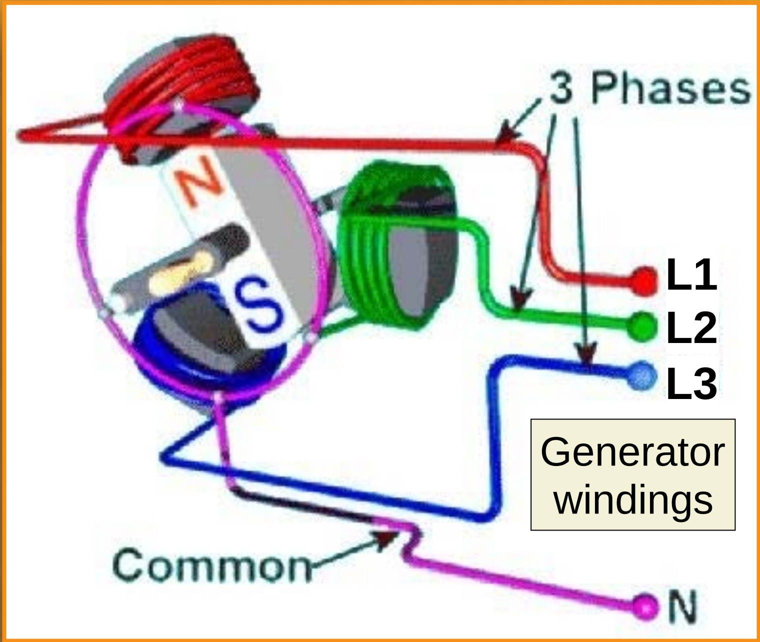
Skin effect less for stranded vs. solid conductors

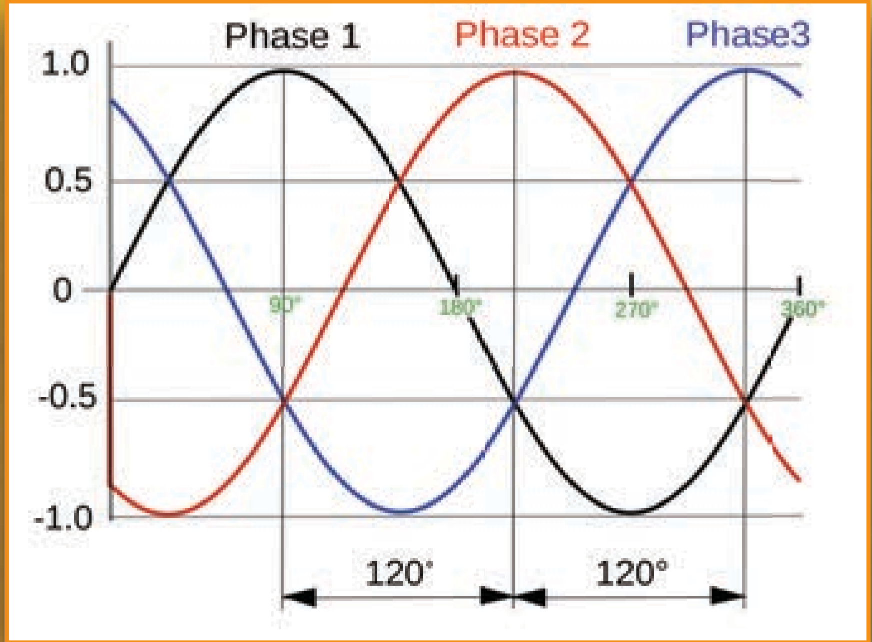
Corona discharge due ionization nearby air:

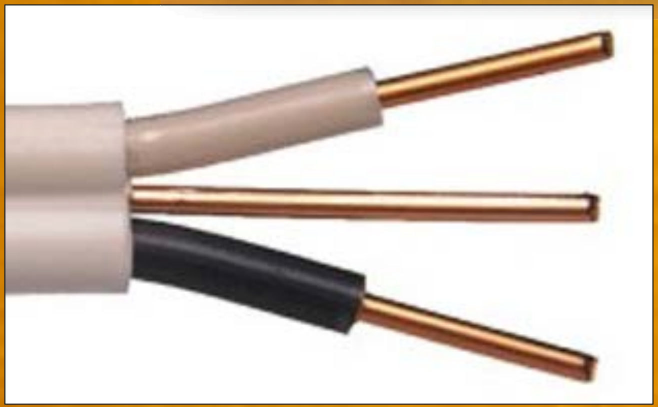
- faint luminescence + hissing noise
- radio interference AM + FM
- diminished by spacing + corona rings

Threshold potential ~ 33 kV

Stepped-Down Voltage
"Behind the Meter"

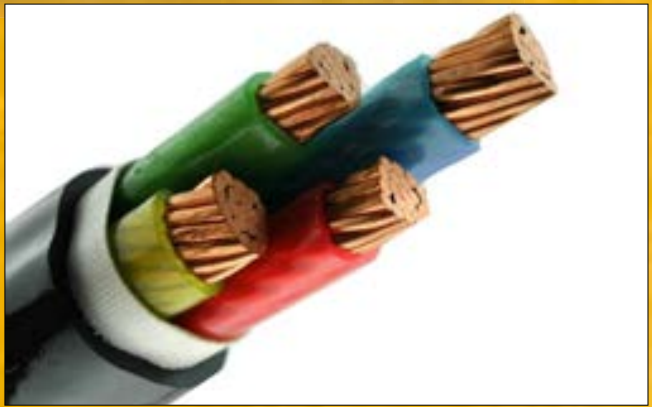






1 phase cable:
- hot conductor L1
- neutral + ground wires
- 120 volts

1 or 2 phase cable:
- hot conductors L1, L2
- neutral + ground wires
- 120/240 volts



3 phase cable:
- hot conductors L1, L2, L3
- neutral + ground wires
- 277/480 volts

High Voltage Transmission Cable

Steel + Aluminum vs. Copper

High-voltage overhead conductors *not* covered by insulation:

- conductor material nearly always aluminum alloy
- multiple bundled strands
- often reinforced with central steel strands

Copper sometimes used for overhead transmission:

- aluminum lighter
- yields only marginally reduced performance
- costs much less

Thicker wires:

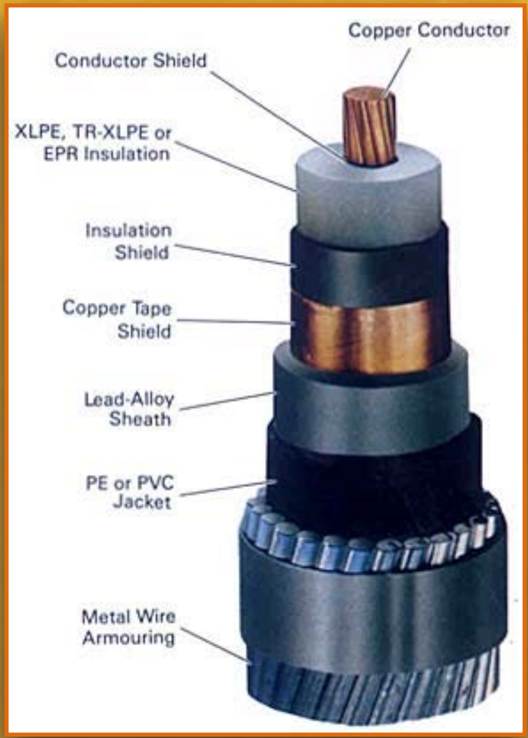
- relatively small increase in capacity due *skin effect*
- multiple parallel bundle cables for higher capacity
- high voltages reduce energy loss from *corona discharge*

Transmission-level voltages usually ≥ 110 kV

- ≥ 765 kV considered extra-high voltage
- 66 kV and 33 kV usually subtransmission voltages
- < 33 kV usually for distribution

*Oscillatory motion of physical line termed **gallop** or **flutter**, depending on frequency + amplitude*

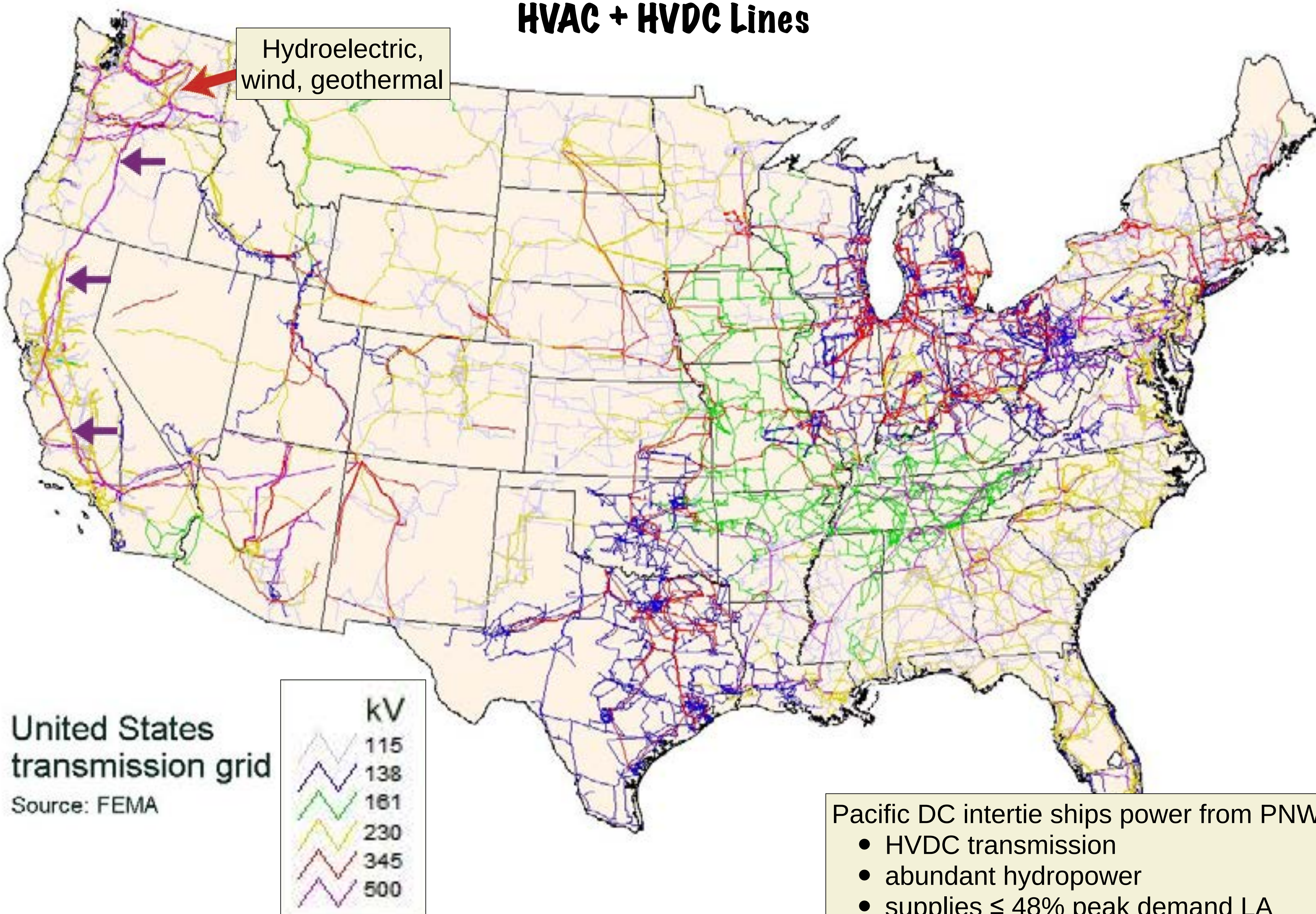
Overhead high voltage cable



Underground high voltage cable

High-Voltage Long-Distance Tranmission

HVAC + HVDC Lines



Hydroelectric, wind, geothermal

Pacific DC intertie ships power from PNW

- HVDC transmission
- abundant hydropower
- supplies ≤ 48% peak demand LA

Grid Command & Control
Multiple interlinked Players

Independent system operator (ISO)
- typically coordinates + controls *single* state
- administers region's wholesale markets
- *reliability* planning bulk wholesale electricity

*One ISO + encompassed utilities independent FERC authority: **Electric Reliability Council of Texas** (ERCOT)*

Regional transmission organization (RTO)
- coordinates, controls, monitors *multi-state* grid
- promotion efficiency, reliability, *non-discrimination*
- responsibility for high-voltage *transmission*

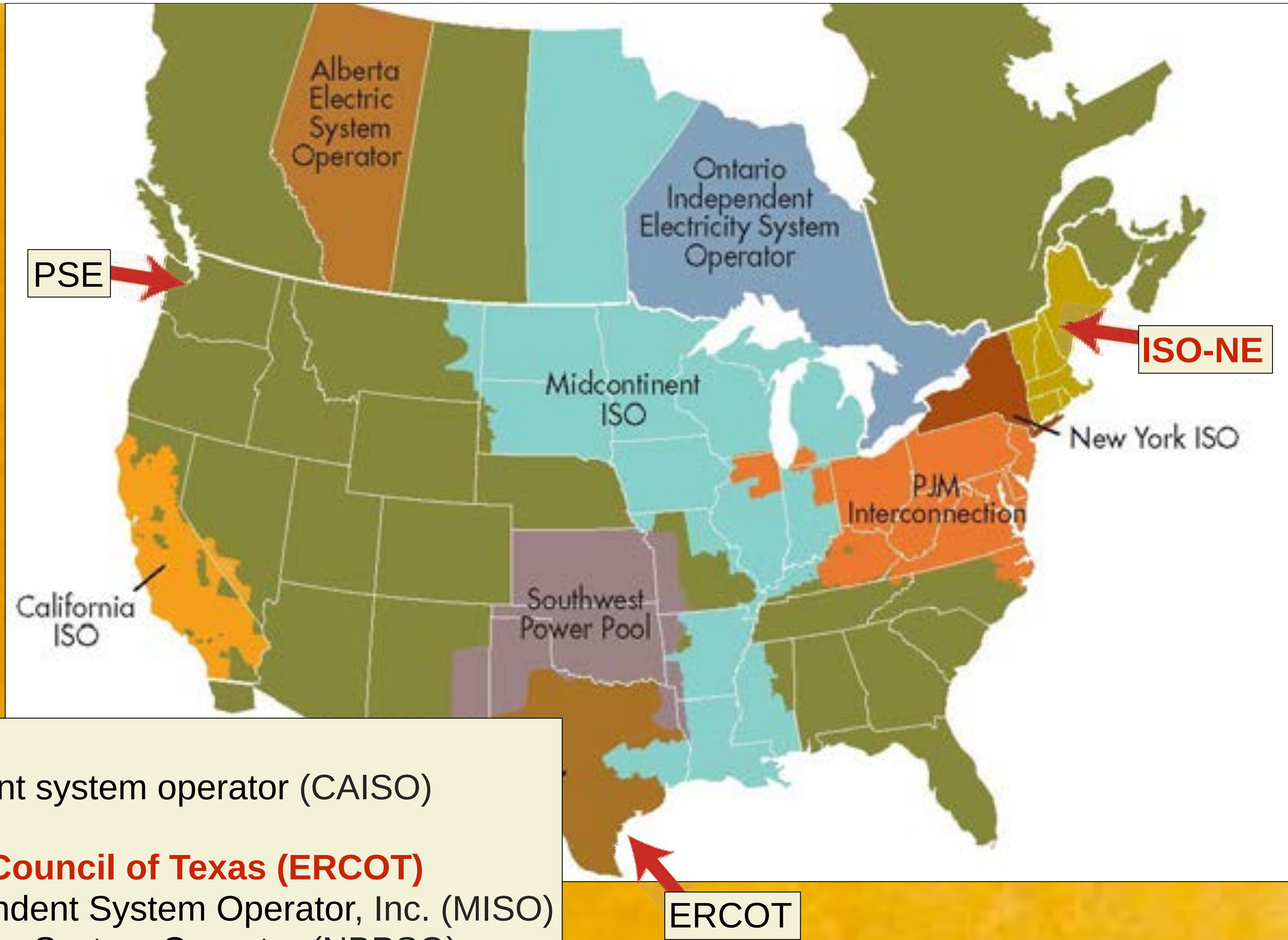
Federal Energy Regulatory Commission (FERC)
- load balancing between states considered *interstate* commerce
- ‘re-regulation’ more than ‘deregulation’ opened up choices for consumers
- opportunities in generation, transmission, distribution for entrepreneurs

***North American Electric Reliability Corporation** (NERC)*
includes Mexican utility + several Canadian utilities

1996 FERC issued 2 orders resulting in competitive environment for **~60%** of generators:
- radical change in generation, transmission, distribution
- **Order No. 888** addressed "Promoting Wholesale *Competition* Through Open Access Non-discriminatory Transmission Services by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities”
- **Order No. 889** added + amended existing rules for “Open Access Same-time *Information* System (OASIS) (formerly real-time information networks) + Standards of Conduct"

Assets of distributed energy resources [DER] may be aggregated + offered to utilities by **distribution system operators** [DSO]

RTOs & ISOs
Minute-to-Minute



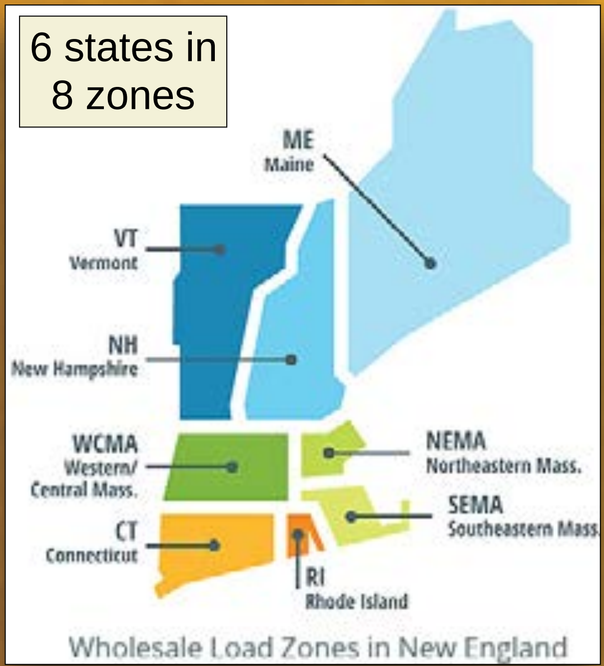
ISOs:

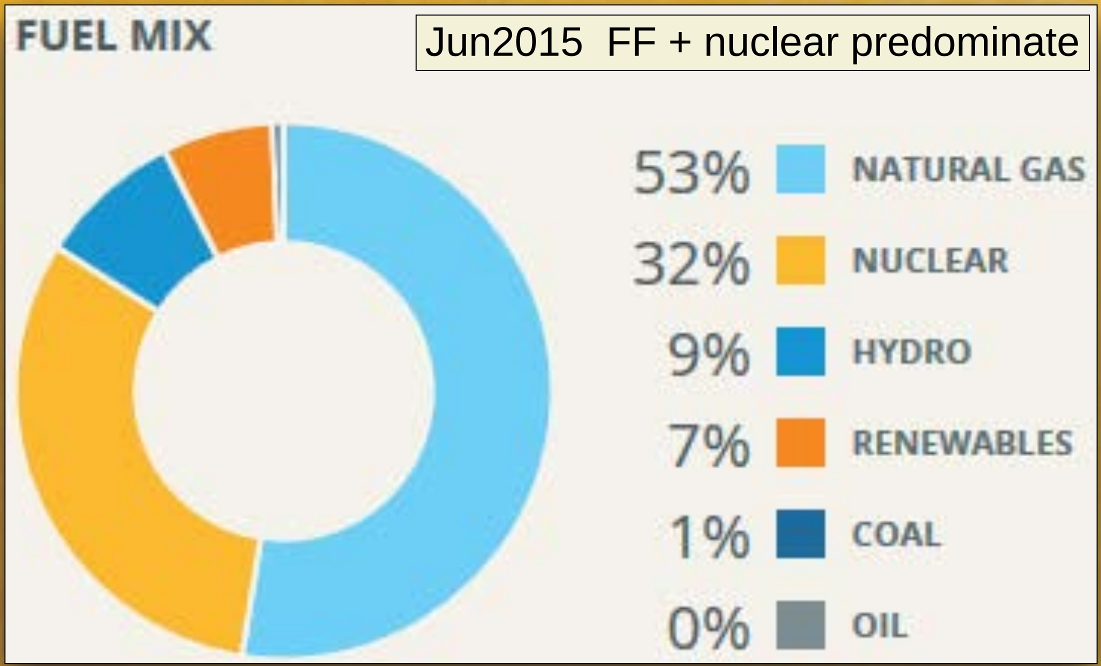
- California independent system operator (CAISO)
- New York [NYISO]
- **Electric Reliability Council of Texas (ERCOT)**
- Midcontinent Independent System Operator, Inc. (MISO)
- New Brunswick Power System Operator (NBPSO)
- New York Independent System Operator (NYISO)
- **New England (ISO-NE)**
- Alberta Electric System Operator (AESO)
- Ontario Independent Electricity System Operator (IESO)
- PJM Interconnection (PJM)
- Southwest Power Pool (SPP)

Non-RTO transmission organizations:

- **ColumbiaGrid [includes PSE]**
- Northern Tier Transmission Group [primarily wind]

ISO New England
Accelerating Evolution





ISO-NE serves Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont

- oversees operation of **32 GW** bulk electric generation, plus transmission lines
- tariffs or prices, terms, conditions of supply
- manages comprehensive regional planning processes

New England's electric power industry changed dramatically during past few decades

- until 1970s utilities handled every aspect of providing electricity
- **Northeast Blackout of 1965** marked turning point

1996 FERC Order 888 deregulated portions of wholesale electric power market:

- encouraging states to require utilities to sell off power plants
- eliminate regulator-set rates in favor of prices determined by markets
- model of transportation, telecommunications, financial services

Can you anticipate planning response on part of ISO-NE?

ISO New England

Accelerating Evolution

ISO-NE now oversees $10 B in wholesale electricity transactions yearly

- 5/6 states required utilities to sell off [some] power plants
- **88%** of region's generation unregulated, most in nation
- ~ 400 participants in **Day Ahead** [DA] + **Hour Ahead** [HA] markets
- January **Year Ahead** *forward capacity auction* to secure resources
- 2016 > 1,400 MW *new* generating capacity

Generator availability [*not* capacity] increased from 81% to 89%

- economic incentives to keep their plants running
- schedule planned maintenance during off-peak periods
- reduction in consumer cost of electricity

Before establishment markets customers paid full cost of plants + fuels:

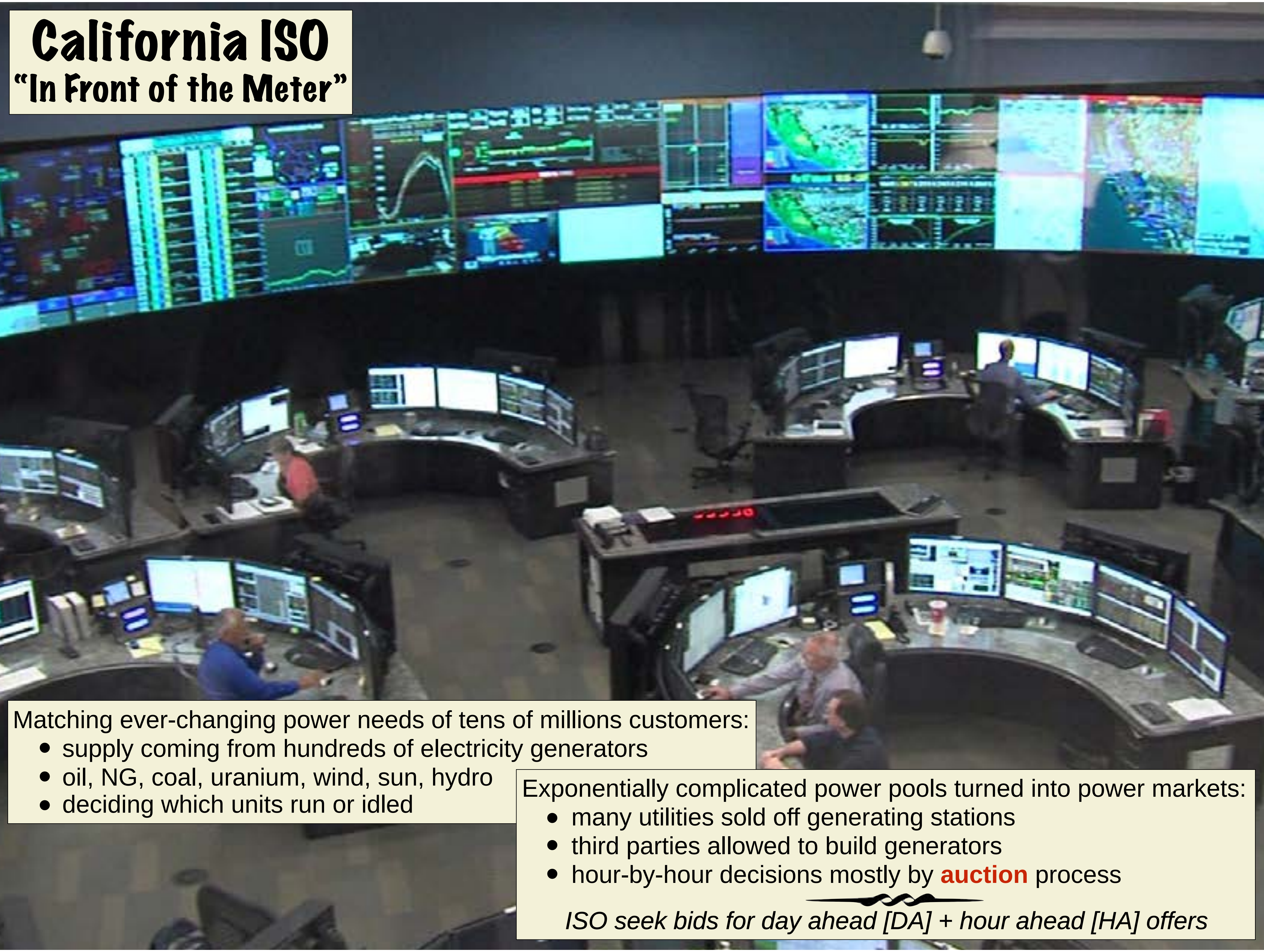
- volatility in price of natural gas + oil
- fuels > 60% of region's generating units
- kept overall wholesale electricity prices high

Individual + entrepreneurial opportunities:

- *negawatt* + *flexiwatt* enhancements in homes + businesses
- distributed generation + distributed storage
- community or aggregator bundling of these energy services
- rapid integration of renewables into grid

Lights stayed on in almost all of New England during 2003 blackout

California ISO
"In Front of the Meter"

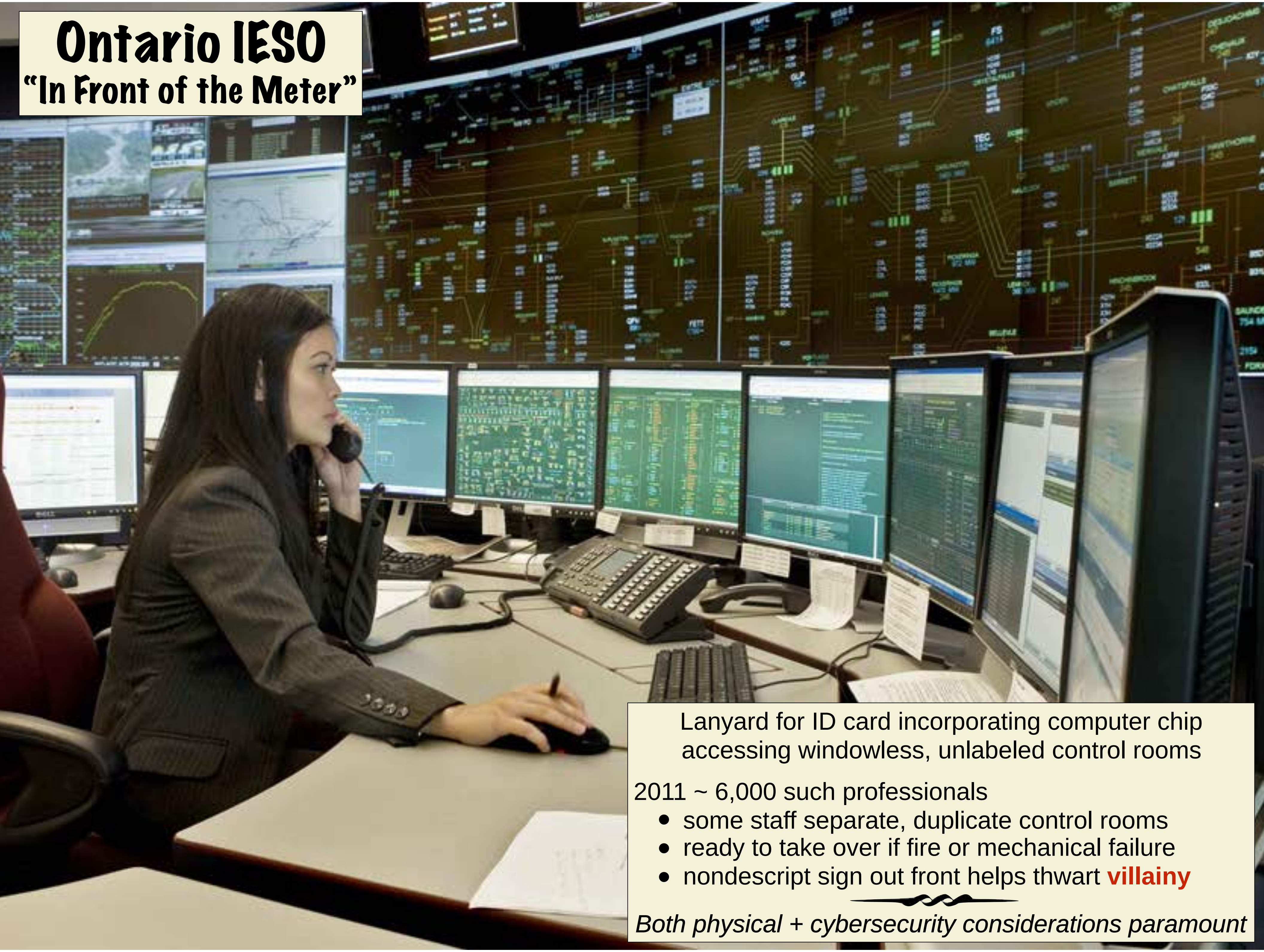


Matching ever-changing power needs of tens of millions customers:
- supply coming from hundreds of electricity generators
- oil, NG, coal, uranium, wind, sun, hydro
- deciding which units run or idled

Exponentially complicated power pools turned into power markets:
- many utilities sold off generating stations
- third parties allowed to build generators
- hour-by-hour decisions mostly by **auction** process

ISO seek bids for day ahead [DA] + hour ahead [HA] offers

Ontario IESO
"In Front of the Meter"



Lanyard for ID card incorporating computer chip accessing windowless, unlabeled control rooms

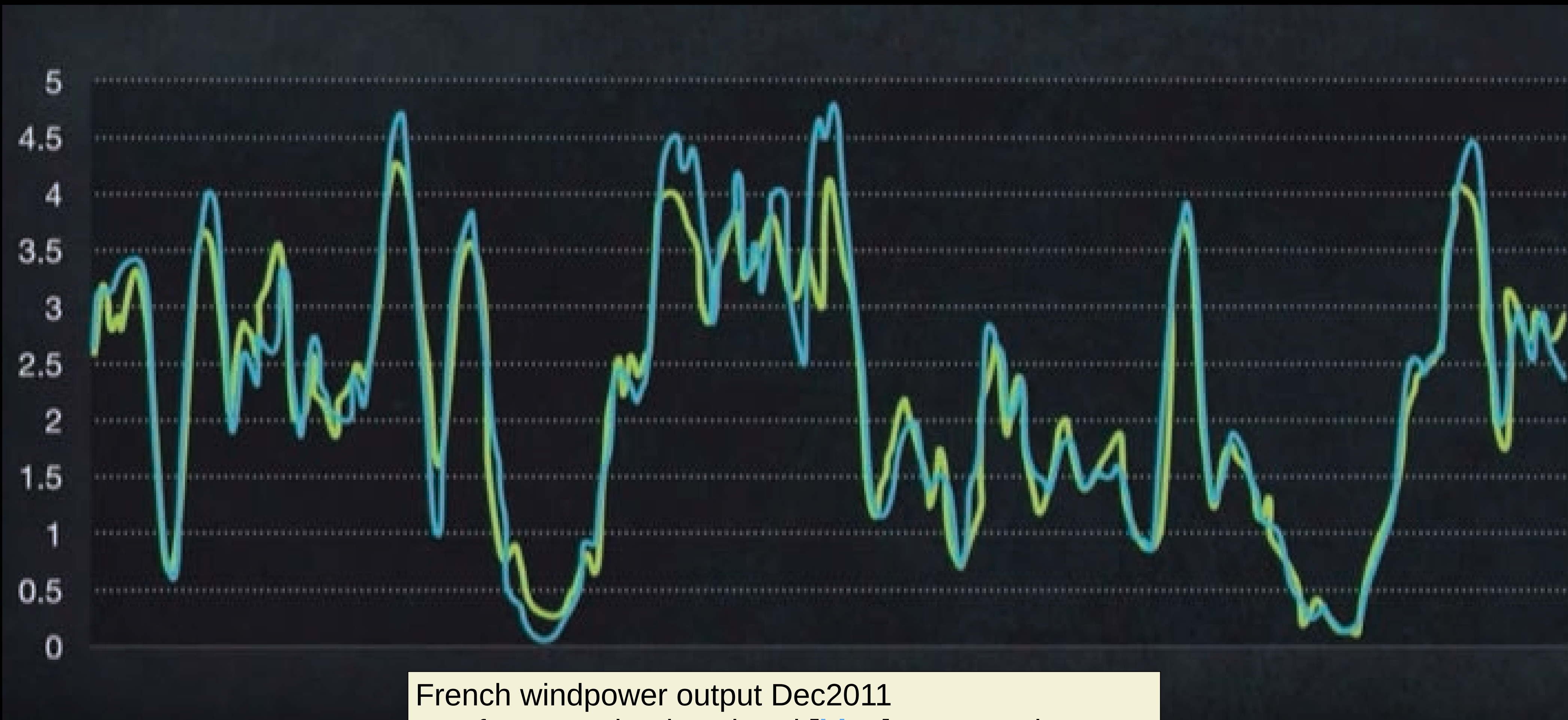
2011 ~ 6,000 such professionals

- some staff separate, duplicate control rooms
- ready to take over if fire or mechanical failure
- nondescript sign out front helps thwart **villainy**

Both physical + cybersecurity considerations paramount

Variable Renewables Forecast vs. Actual

Even Demand Forecasting often less Accurate

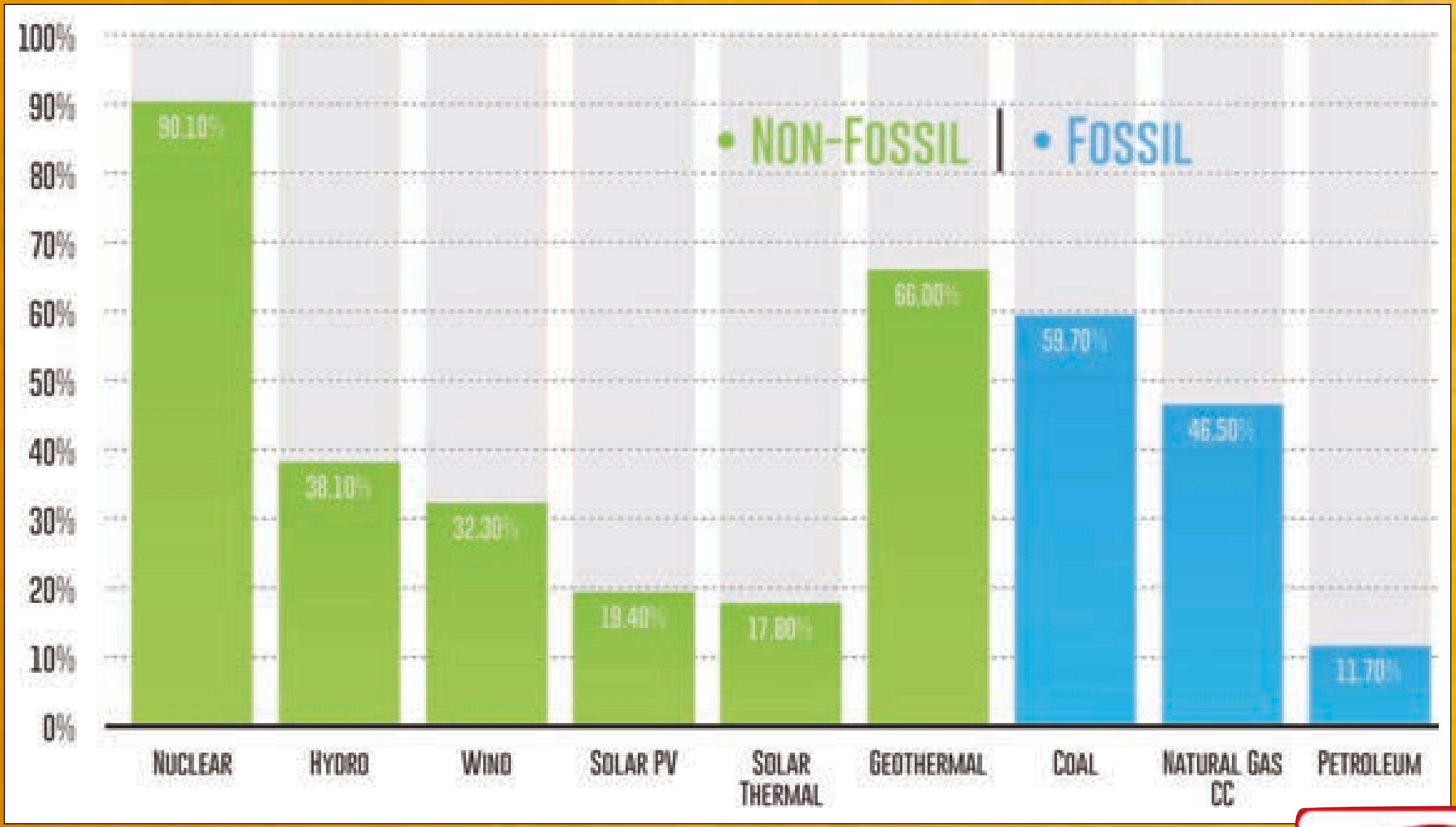


French windpower output Dec2011

- forecasted 1 day ahead [blue] = DA auction
- actual wind resource [green]
- up to **95%** power bought in DA market

Renewable energy *may be variable but neither* ***unpredictable*** *nor* **unreliable** *on daily or hourly basis*

Generator Capacity Factors
Nameplate vs. Achieved 2013 by EIA



Definitions of capacity factor [CF]:

- **nameplate** capacity = rating of maximum output
- actual or **achieved** capacity = real world experience
- proportion of time generators available *exceeds* demand

Other caveats:

- solar thermal with storage now extends output ≥ 6 hrs/day
- hydropower multitasks plus **dispatchable**
- geothermal classically baseload or dispatchable
- curtailment affects renewables harmlessly but fuel always free
- wind + solar PV resource varies geographically
- petroleum as diesel or fuel oil **≤ 1%** + diminishing

Caveat of idling vehicles engine for heating or cooling

Generators Face Competition

Customers can also Play

Levelized Cost of Energy or LCOE = total cost of installing + operating any project over full lifetime, expressed in dollars per MWe:

- installation costs
- financing costs
- federal + state taxes
- operation + maintenance [O&M] costs
- incentives or subsidies
- revenue requirements
- quantity electricity generated
- depreciation schedules
- decommissioning or salvage

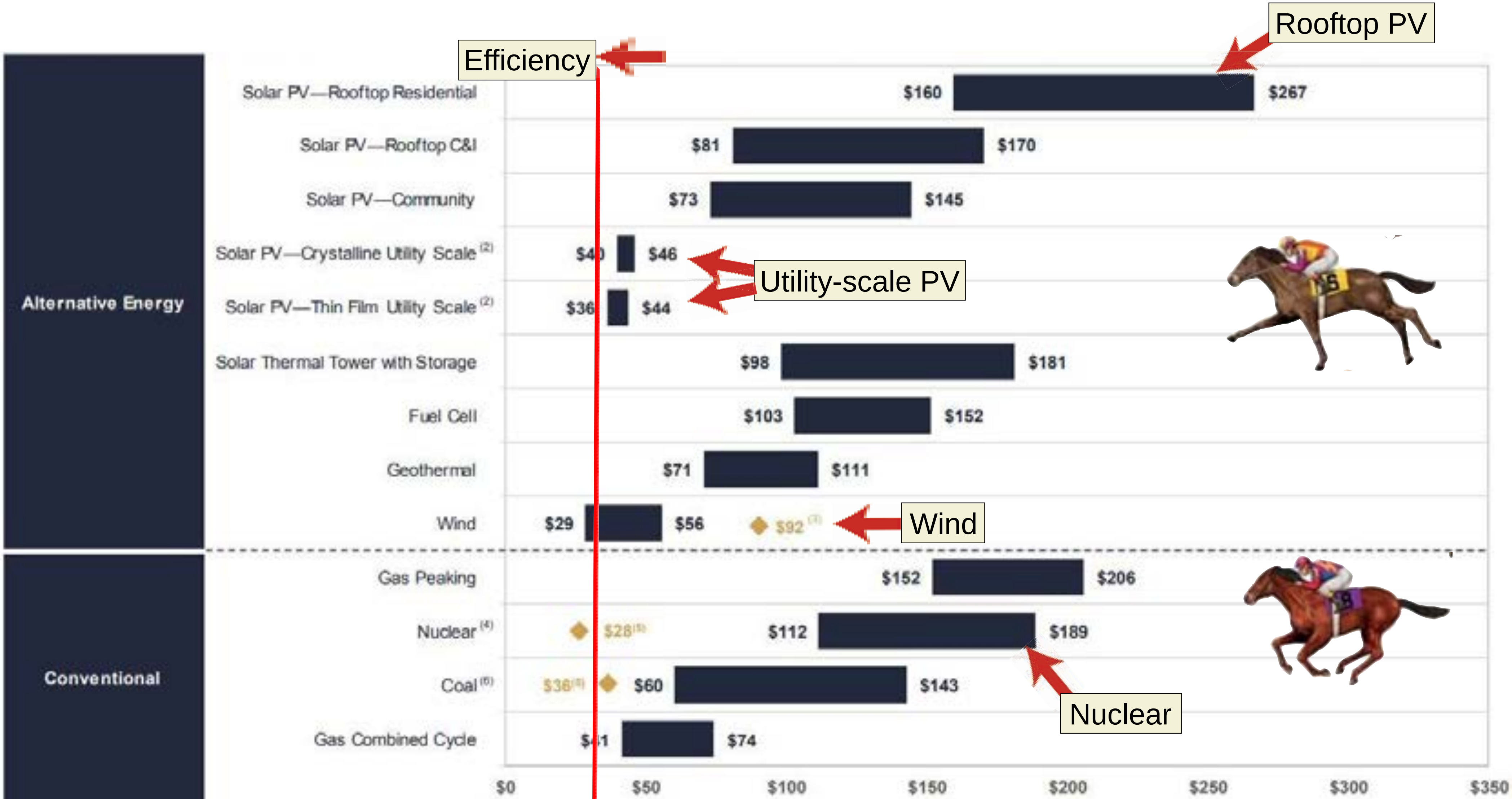
Financial metrics:

- real LCOE =constant dollar [inflation-adjusted] value
- nominal LCOE = current dollar value
- **unsubsidized** LCOE levels the playing field

Recall ***~60%*** *American utility generators now face real-time competition*

Lazard Generator Ranking by Unsubsidized Analysis

Renewables often 20-30 yr Power Purchase Agreement or PPA



3¢ per kWh

$30/MWh = $0.03/kWh

2016 Dubai solar PV reached 2.9¢ per kWh = $29 per MW
2016 Morocco wind reached 3.0¢ per kWh = $30 per MW
Peru + Mexico comparably low wind prices

2018 data

Storage also a Race
Lithium Supply not Limiting

Lazard's **Levelized Cost of Storage** (LCOS):

- -12% peaker replacement over last yr
- -24% deferral transmission
- -11% residential use

Li could last for **431 yrs** compared:

- 39 yrs copper reserves
- 15 yrs zinc reserves
- note all largely *recyclable*

China, Chile, Argentina, Australia > 90% supply:

- new production from Mexico + Serbia
- result in "overwhelming surpluses"
- plenty of room new players = Bolivia

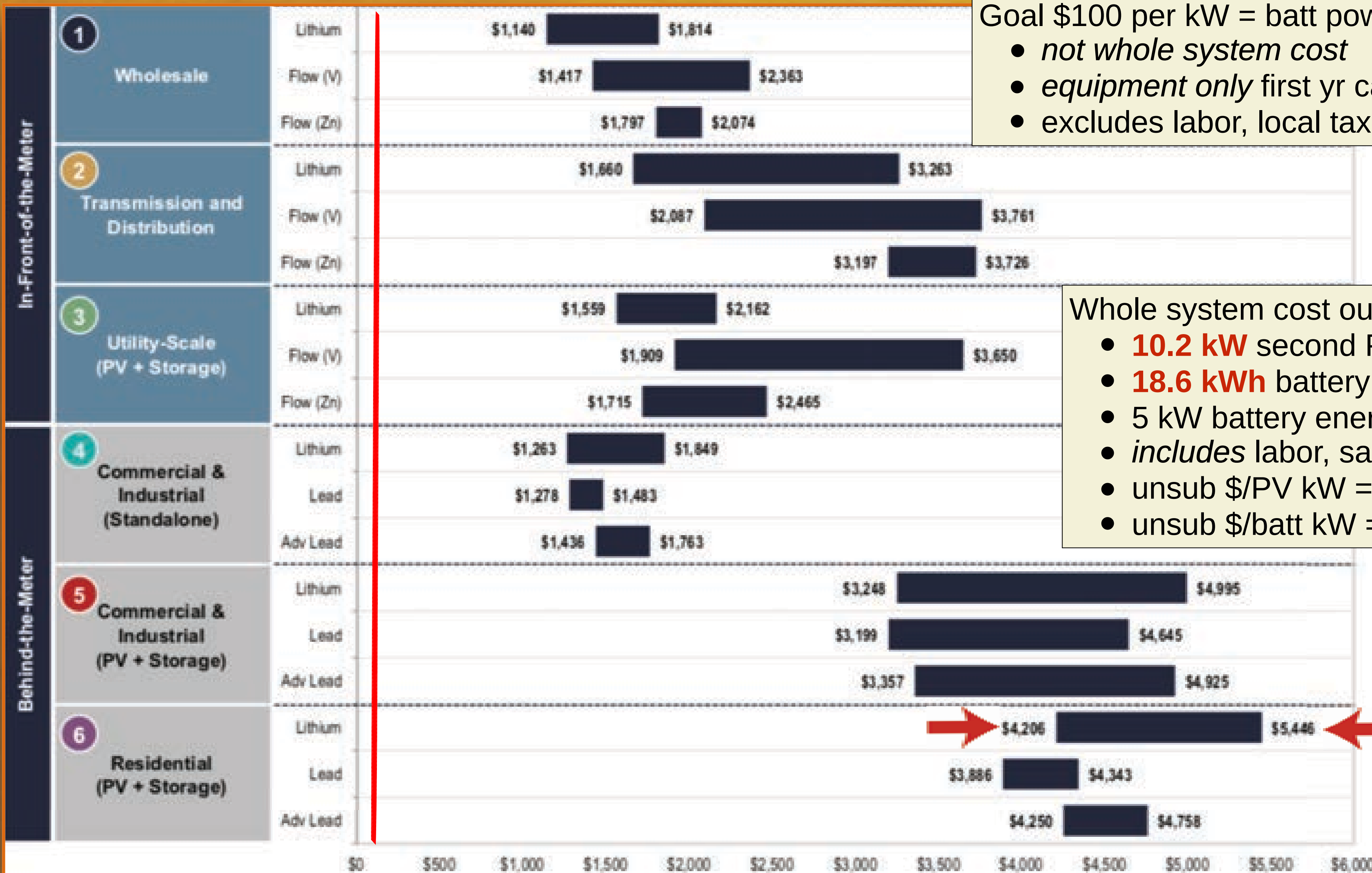
Tesla's Nevada "giga" factory gets media attention:

- only 1/14 mega factories under construction
- 9 of those in China

Lithium + minerals ***cobalt****,* ***nickel****,* ***graphite***
key battery components

Lazard Storage Ranking by Unsubsidized Analysis

Whole System Capital Cost Comparison in USD per kW



Goal $100 per kW = batt power alone:
- *not whole system cost*
- *equipment only* first yr capex
- excludes labor, local taxes

Whole system cost our home:
- **10.2 kW** second PV array
- **18.6 kWh** battery capacity
- 5 kW battery energy
- *includes* labor, sales tax
- unsub $/PV kW = $3991/kW
- unsub $/batt kW = $2782/kW

Generator last home:
- 8 kW [slow] automatic relay
- propane automatic wkly 20 min
- annual maintenance $287

2018 data
Lazard.com
Version 4.0

Value Streams for Storage

Opportunities for Direct Income from Utility

Service	Description	Potential Value	Grid Scale	Commercial Scale	Residential Scale
Avoided renewable energy curtailment and increased self-consumption	System owners avoid curtailing their own renewable generation when system load is low and renewable generation is high	Medium	✔	✔	✔
Supply capacity and resource adequacy	Uses storage to meet peak-load growth and defer need for new generating capacity	Site Specific	✔		
Transmission and distribution upgrade deferral	Defers the need for transmission or distribution system upgrades (e.g., via utility system-peak shaving)	Site Specific	✔		
Transmission congestion relief	Utilities can avoid extra transmission charges from Independent System Operators during times of congestion by deploying strategically located storage	Site Specific	✔		

Prevent curtailment renewables
"Store it to not waste it"

Batteries as 'peaker plants'
"Obviate need new generation"

Dispersed utility storage
"Avoids new transmission + distribution assets"

Again, dispersed utility storage
"Utility heads off congestion pricing by ISO or RTO"

Value Streams for Storage

Opportunities for Direct Income from Utility

Service	Description	Potential Value	Grid Scale	Commercial Scale	Residential Scale
Demand response	Storage used to support participation in utility programs that pay customers to lower demand during system peaks	High		✔	✔
Frequency regulation	Stabilizes frequency on moment-to-moment basis	High	✔	✔	
Reserve markets	Supply spinning, non-spinning reserves	Medium	✔	✔	
Black start	Helps restore system to operations after a blackout	Low	✔		
Voltage support	Inserts or absorbs reactive power to maintain voltage within required ranges on distribution or transmission system	Low	✔		

Help shave grid peak
"Rent out your batteries"

Help stabilize grid frequency
"Rent out your batteries"

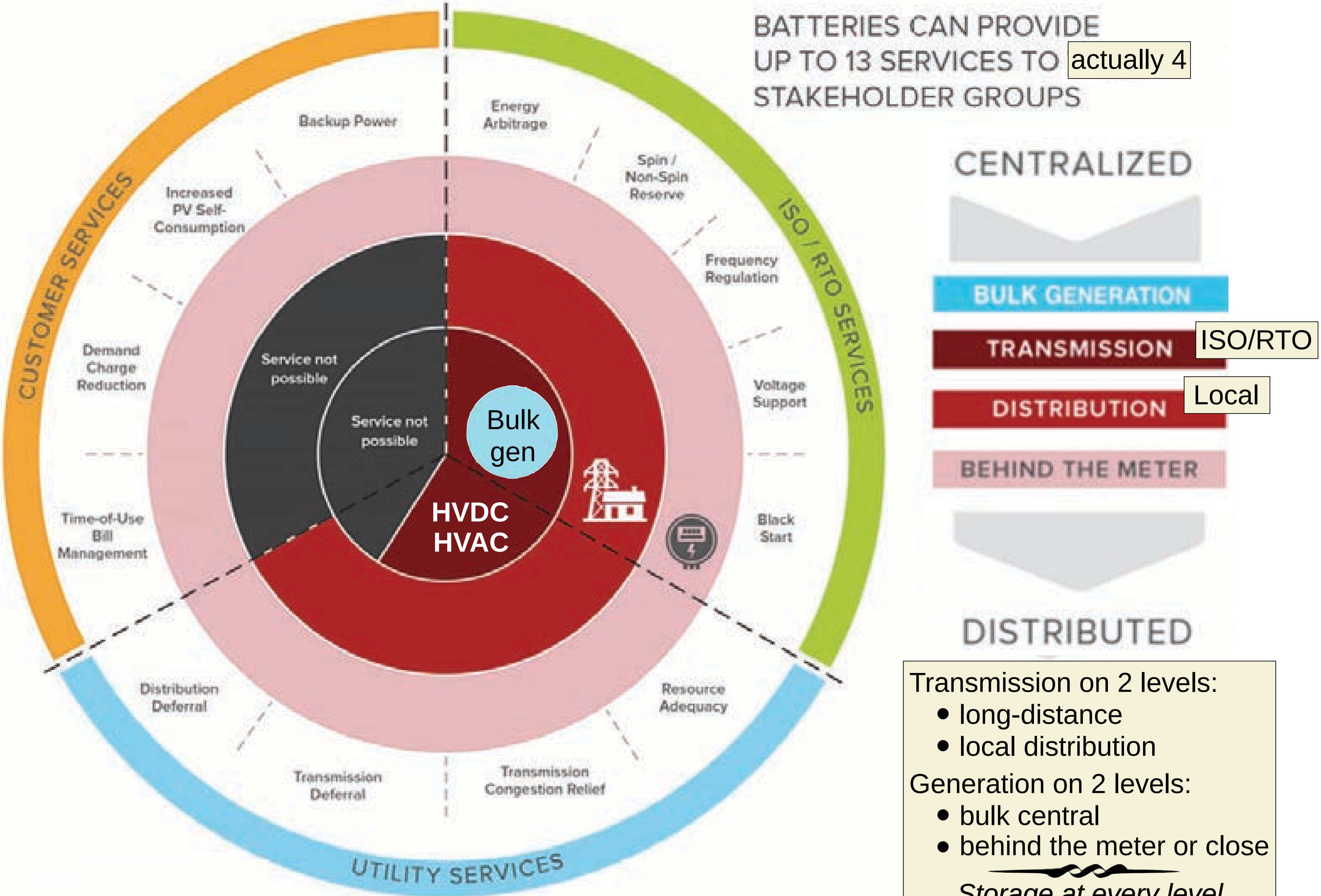
Supply non-spinning reserve
"Rent out your batteries"

Black start post **blackout**
"Rent out your batteries"

Prevent **brownout**
"Rent out your batteries"

Value Streams for Storage

It's a Win-Win-Win-Win



Transmission on 2 levels:

- long-distance
- local distribution

Generation on 2 levels:

- bulk central
- behind the meter or close

Storage at every level

Innovative Underground Heat Storage

First focus Novel Seasonal Design
Second focus Non-electric Heat

German climate policy focuses on electricity sector
But electricity constitutes only **1/5** total energy services

Hamburg = district heating capital of Germany

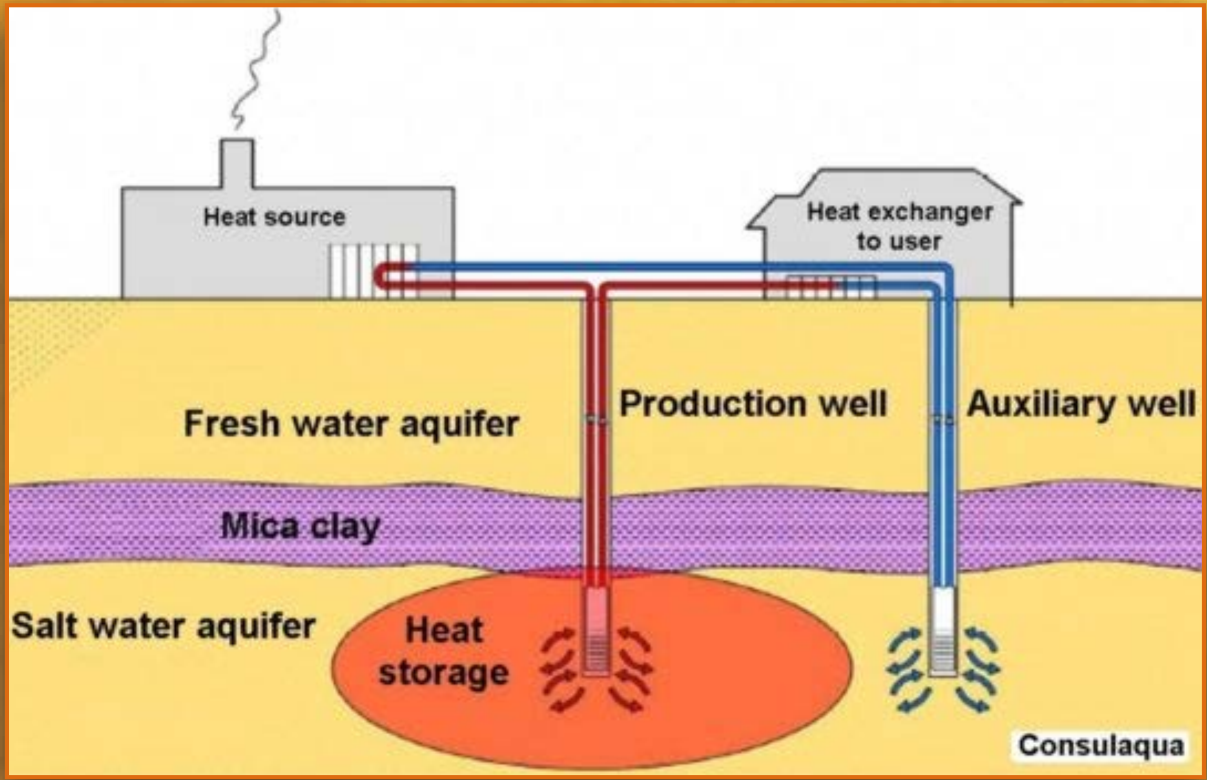
- district heating < widespread compared some EU countries
- vast district heating network supplying **19%** homes
- goal of 50.000 additional households by 2020

Hamburg + Elbe River above 2 expansive sand aquifers:

- fresh water on top
- salt water on bottom
- intervening nearly impervious clay layer

Innovative Underground Heat Storage

First focus Novel Seasonal Design
Second focus Non-electric Heat



Warm months cold saltwater pumped to surface:

- heated by waste incinerators, gas plants, surplus renewables
- notably Aurubis copper smelter + ArcelorMittal steelworks
- electronic data centers + refrigerated warehouses
- summer warming **Elbe River**

Aquifer temps 70-80ºC

- storage cost 1¢ per thermal kWh including losses
- another 1¢ covering **unaccountable** inaccuracies
- industrial waste heat 1–2¢/kWh

*Total maximally **4¢**, half that prior district heating*

Texas Utility Nighttime Special

Time-of-Use or TOU Pricing

Texas wind farms generating so much energy 2015:

- some utilities giving some power away
- time-of-day pricing commercial + industrial
- coming to your residence soon

Bold attempt by utility to change how people consume energy:

- TXU Energy notified customers anything after 9pm *free*
- free overnight plan coupled with slightly higher daytime rates
- dozens offered by > 50 *distribution* utilities in Texas over 3 yrs

EIA data Jan2016 **65 M** customers experience time-varying rates:

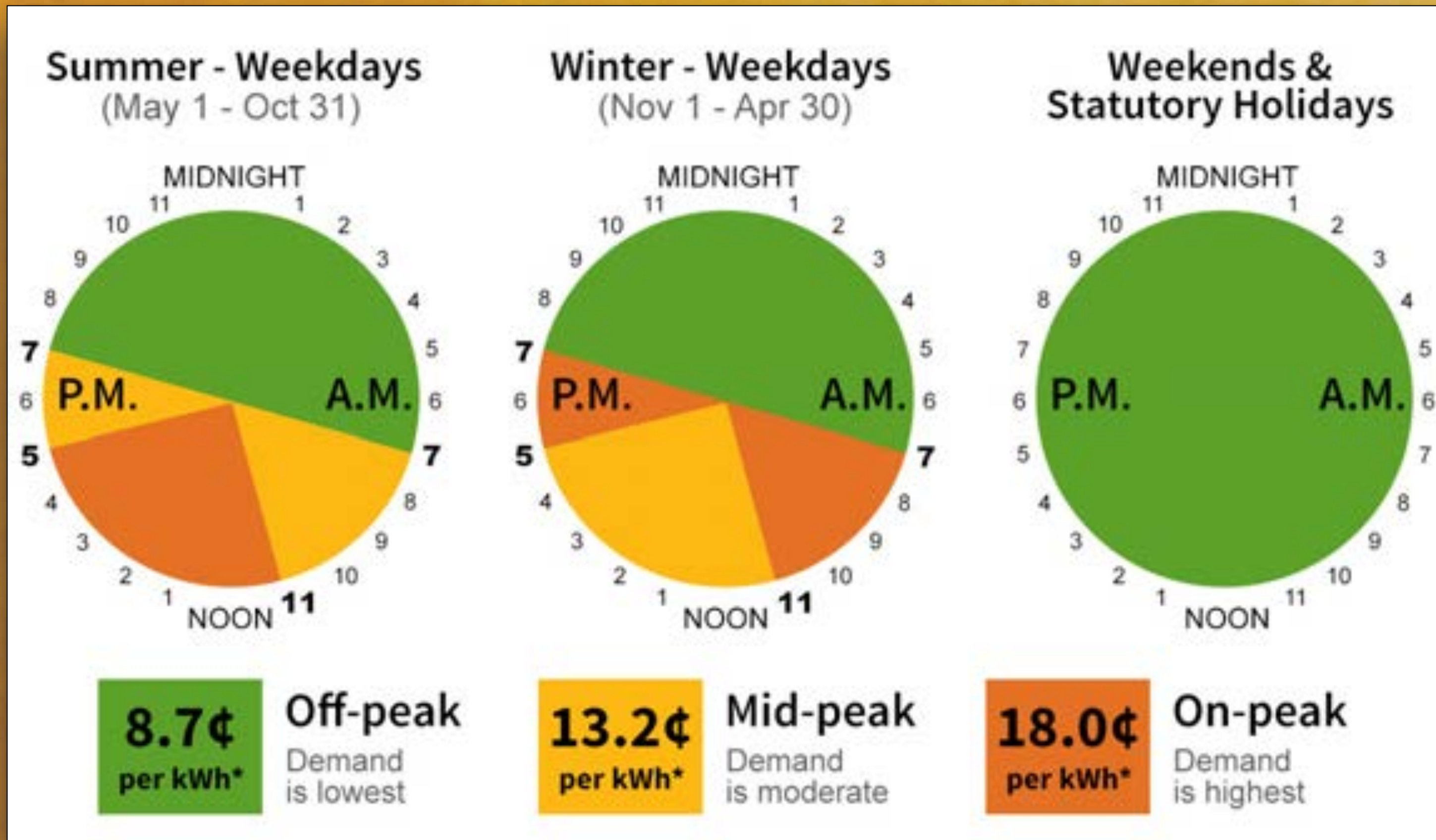
- time-of-use (TOU) rates
- real-time pricing rates (vary even hourly based wholesale prices)
- peak pricing rates (more expensive critical peak times]

Utility advantages:

- overall lower wholesale prices
- alternatives **wheeling** or **curtailment**
- possible capital project avoidance multi-billion new power plant

Ontario Time-of-Use or TOU Rates

Power worth more some times than others



Smart meters exponentially increase value both sides of meter

TOU rates create certain opportunities:

- flattening of peak generation valuable to utility
- certain times of service more valuable to customer
- bidirectional information flow between user + utility

Rates vary depending:

- time of day
- day of week
- season of year

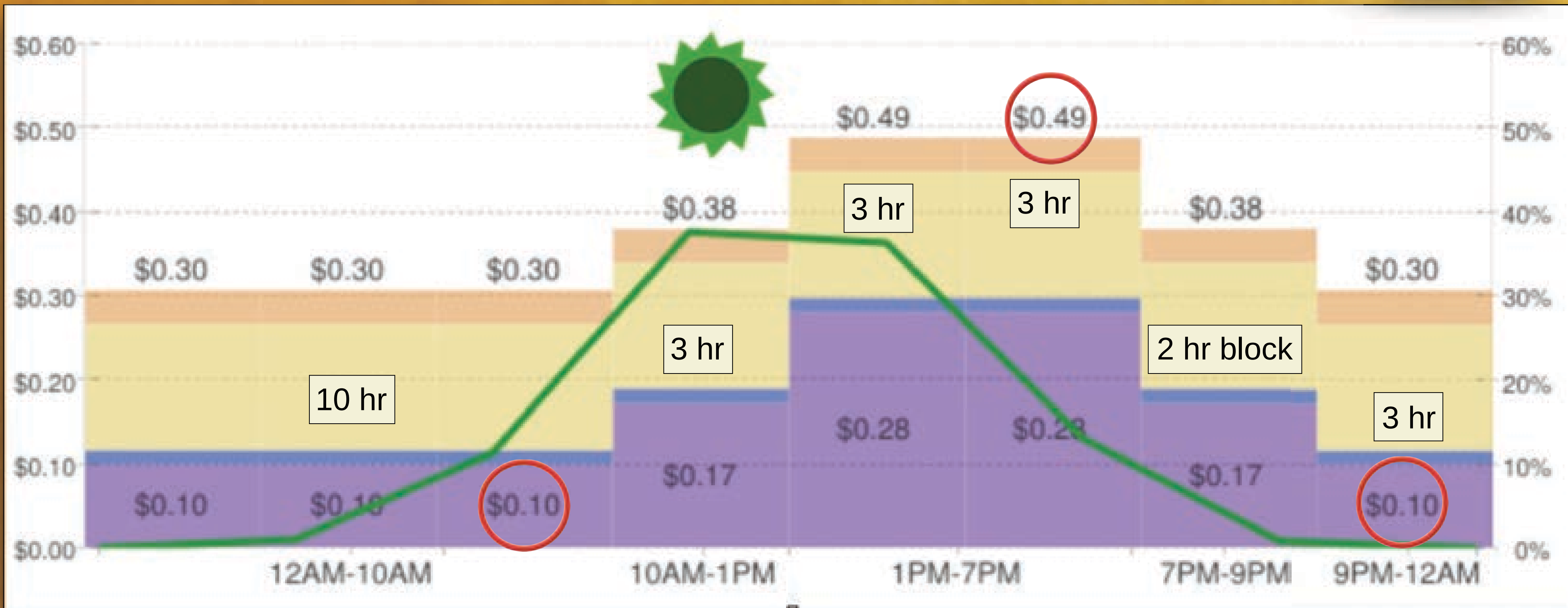
Online access to monitor + record TOU each period

- graphics of usage by hr, day, week, month
- set consumption + energy cost alerts
- tools + tips helping manage energy consumption

Happy coincidence switching to alternative rate structures often increases awareness of consumption patterns

California Multi-Tier Rates

TOU + Multi-Tier rates good fit with Solar PV



Pacific Gas & Electric residential TOU + multi-tier tariffs:

- tier 1   < 3,000 kWh/yr
- tier 2   3,000-3,900 kWh/yr
- tier 3   3,900 to 7,700 kWh/yr
- tier 4   7,700 - 23,300 kWh/yr

Green = percent daily solar occurring in each time block

Personal experience < 6,000 kWh/yr….but we produce ~ 95% of it with PV….even with 2 EVs

Analog vs. Digital Meters

Realtime Interactivity

Historically utilities acquired singular data point monthly:

- even bimonthly
- **analog** meters read manually
- customer feedback *delayed* by billing cycle

Customers ignorant of issues “in front of meter”

- sources of primary energy
- decisions by public utility commissions
- risks of brownout, blackout, cyberintrusion

Utilities ignorant of issues “behind the meter”

- peak use + consumption patterns over 24 hrs
- efficiency = **negawatt** opportunities
- demand response = **flexiwatt** opportunities

Electronic device gathering data for remote reporting:

- consumption intervals of **≤ 1 hour**
- communicates least daily for monitoring + billing
- 2-way communication between meter + utility

Smart **digital** meter based Open Smart Grid Protocol (OSGP) in Europe, capable:

- reduce load
- disconnect-reconnect remotely
- interface also with gas + water meters

Reports by telemetry least daily

Home Power Monitoring

Information is Power…on both sides of Meter

Home energy monitor provides:

- feedback on both *supply + demand*
- cost of energy used
- estimated GHG emissions

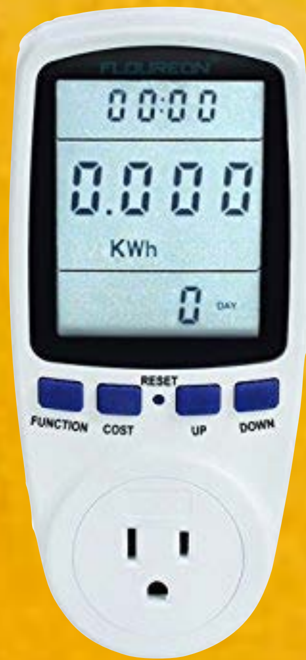
Electricity measured:

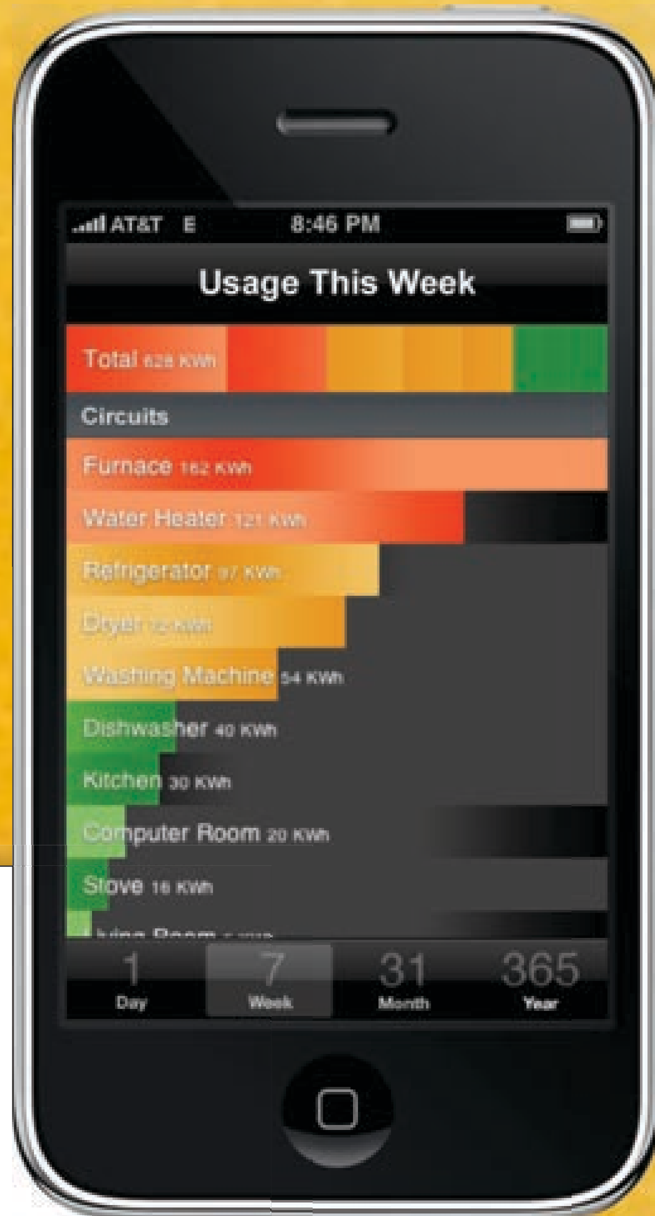
- inductive clamp around electric main
- via conventional electric meter
- communicating with smart meter

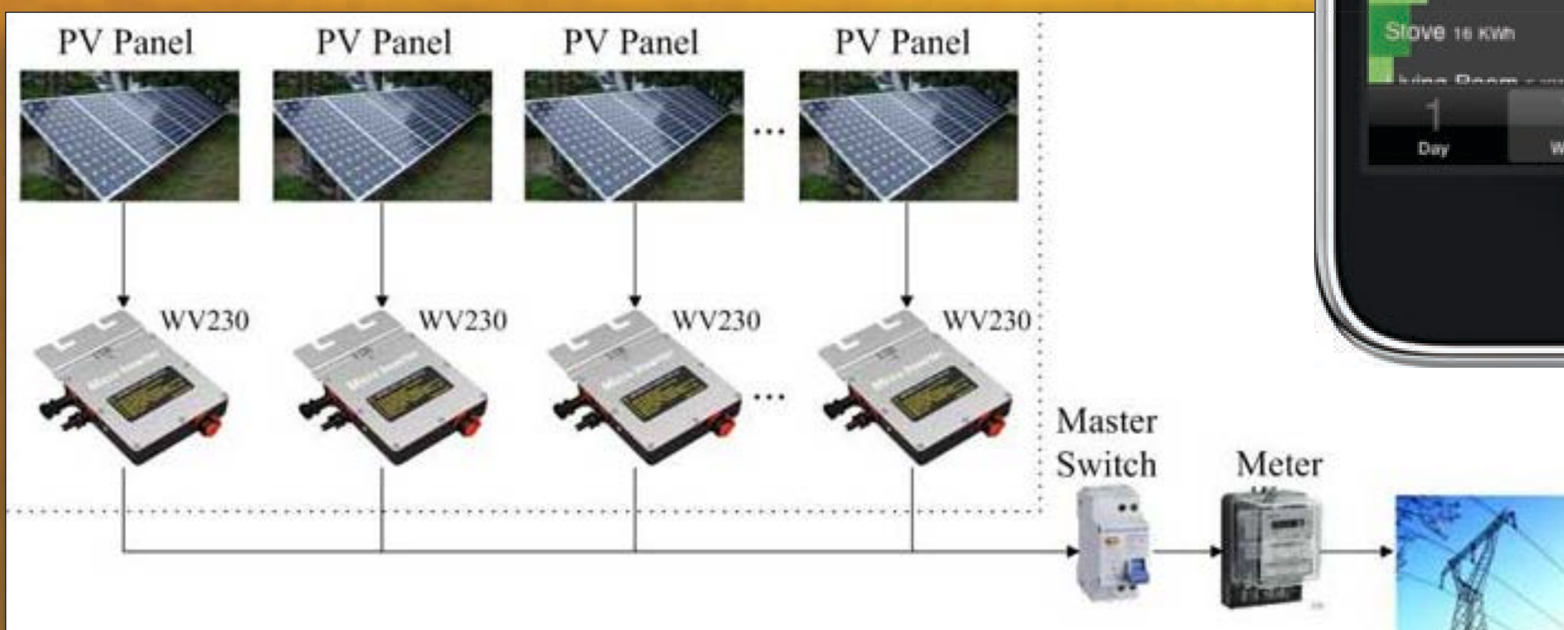
Display remote from measurement:

- direct cable
- wifi connection
- power line communications

*Studies show power reduction **4-15%** due straight-forward behavioral change*

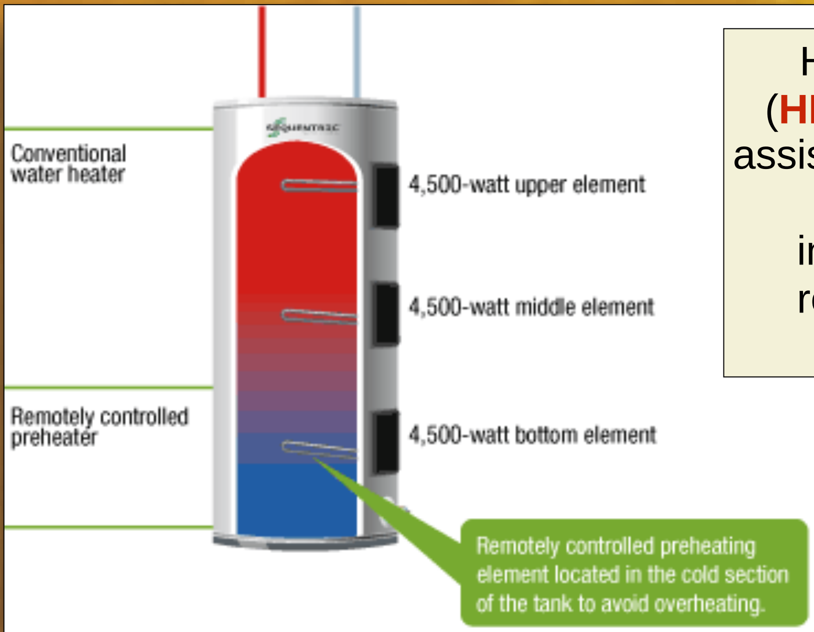




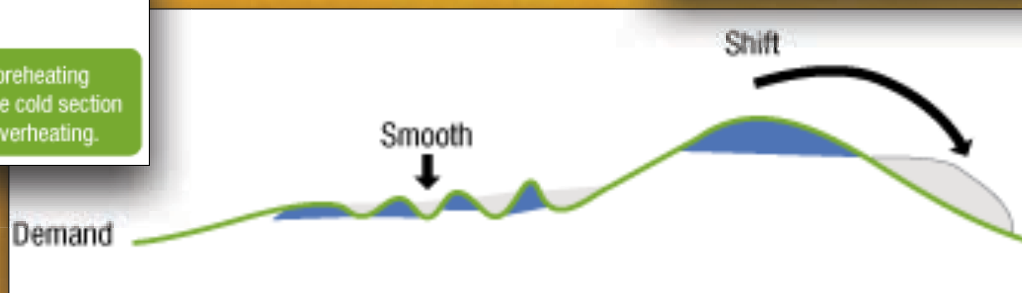


Aggregated Grid-Interactive Water Heaters or GIWH

Putting Information to work by Shaving the Peak



Heat pump water heater (**HPWH**) efficient but cannot assist with frequency regulation or grid stabilization like immediate on-off electric resistance water heaters [**ERWH**]



Traditional batteries supply power when generation low + absorb power when generation high

Grid-interactive water heater (**GIWH**) same functionality by reversing equation:

- changes load to balance generation
- surplus power, switches on + uses excess
- sagging power, switches off + sheds load

Great River Energy generation + transmission co-op in Minnesota currently controls ~ 70,000 heaters

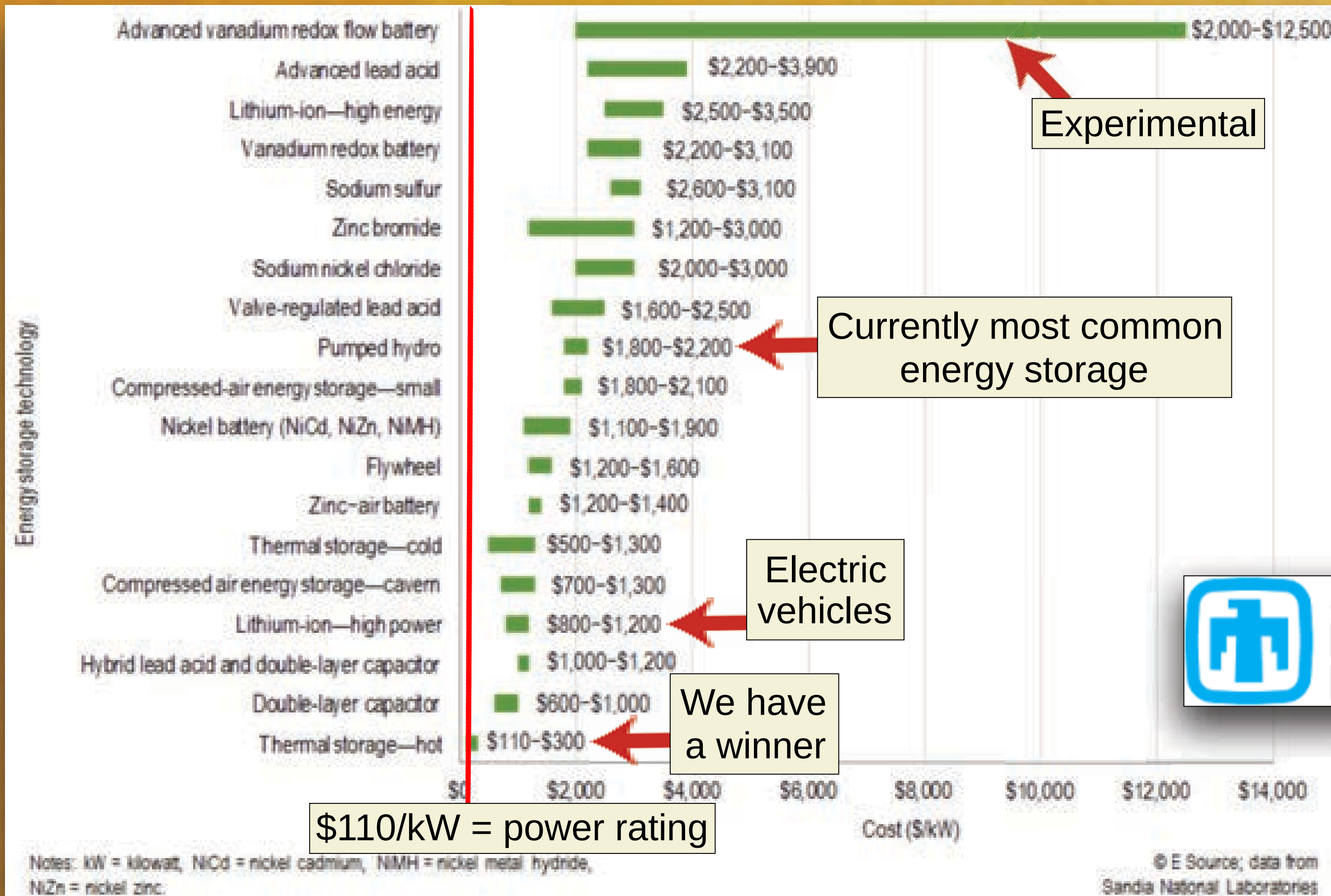
Dairyland Power Cooperative generation + transmission company in Wisconsin also large fleet heaters + AC, reducing demand [plus control irrigation pumps + grain dryers]:

- **~ 80 MW** summer
- **160 MW** winter
- predominantly during peak use hours—typically between 3pm - 9pm

DAIRYLAND POWER COOPERATIVE 1941 75 2016 Living... the Cooperative Advantage

Comparison of Battery Chemistries

Batteries + Equivalents Scalable + Distributable



Sandia National Laboratories

GIWHs currently **least expensive** form energy storage available

Fleets of grid-enabled water heaters:

- demand response or *flexiwatts*
- arbitrage of wholesale prices minute-to-minute
- ancillary services [second-by-second matching]
- response large unexpected grid-stabilization events

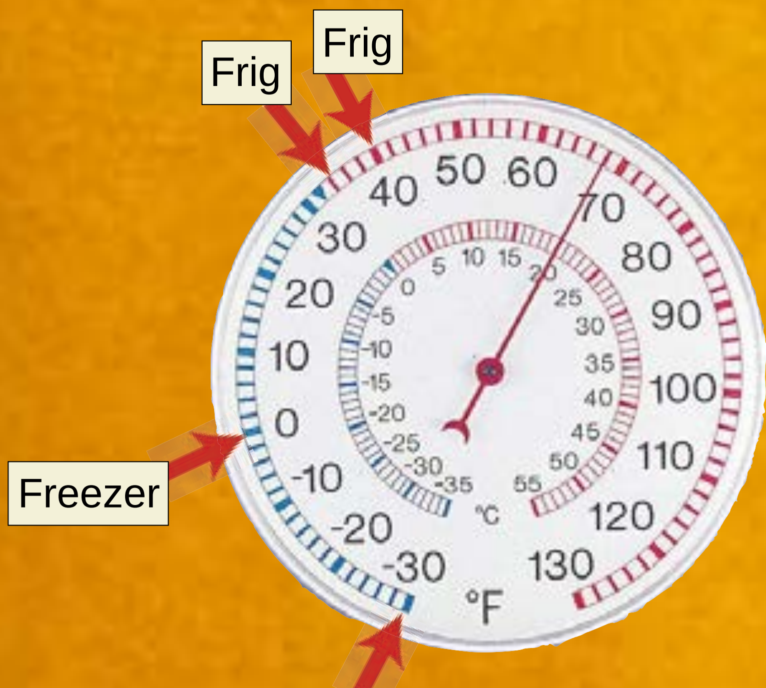
Bidirectional control turns water heater into virtual battery

Refrigerator Flexiwatts

TOU or Contracted Demand Response

Temp settings refrigerator + freezer compartments given arbitrary numbers 1 thru 9:

- target temperatures + ranges
- ideal refrigerator temp 35°F, cycling 34º - 40ºF
- freezer best set to ≤ 0°F



Freezer temp < 0ºF arbitrage opportunity:

- surplus power, switches on + uses excess
- sagging power, switches off + sheds load
- arbitrage in front of or behind meter

1913 refrigerators for home use invented

1940 home freezers as separate compartments

Modern computerized refrigerators lack damper system

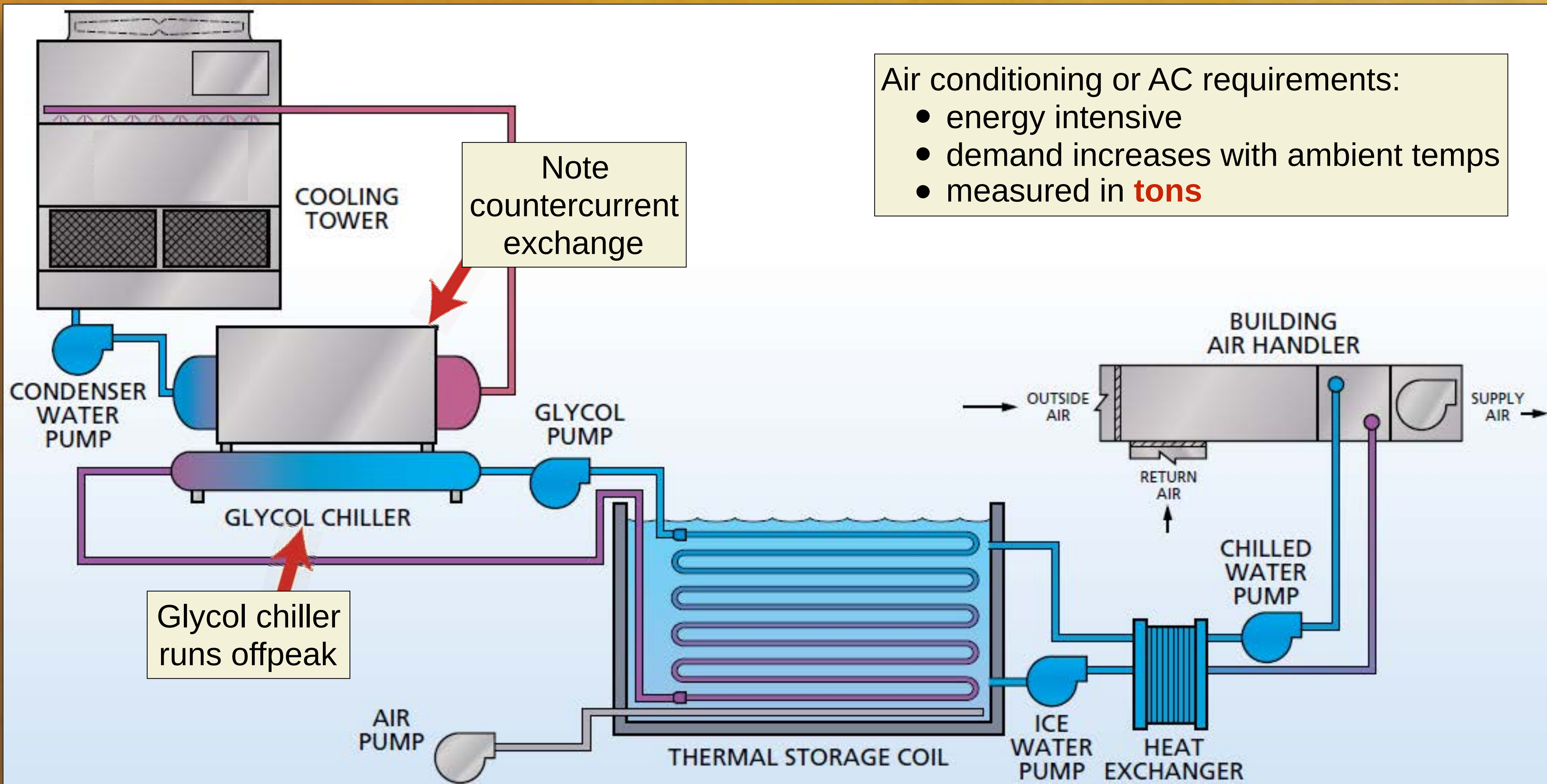
- few manufacturers offer **dual compressor** models
- freezer + frig compartments operate independently
- ideal humidity levels + tighter temperature control

Requires much less energy:

- each compressor + coolant system optimized temp
- opening door not affect temperature or humidity other part
- ideally compressors + condensers mounted on cabinet top

HVAC Ice Storage

IceBank Energy Storage™



Summertime air conditioning **> 30%** electricity hottest days

Most building engineers over-design HVAC for peak load AC

- may occur 50-100 hrs/yr
- ice [or antifreeze solution storage] cost-effective
- negligible cost or payback 1-2 yrs

Ludicrous to only create cooling when people arrive for work

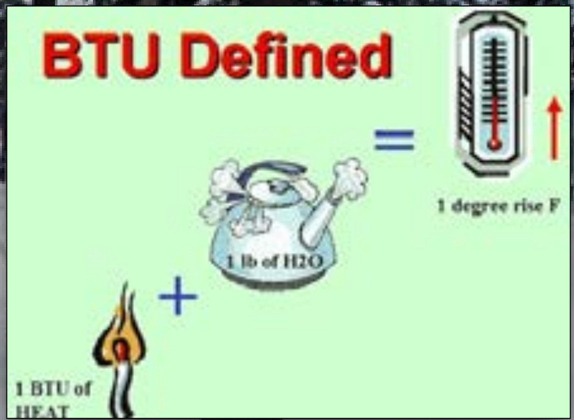
Tons of Cooling
Archaic Nomenclature

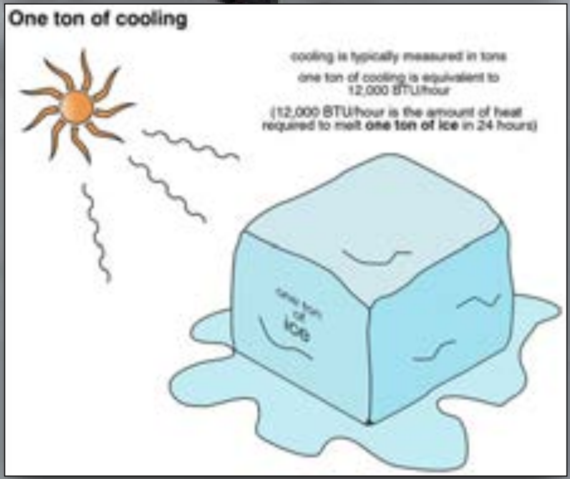
One ton of cooling = energy melting 1 ton of ice:

- Btu = heat from 1 wooden match
- equivalent 1 lb water raised 1ºF
- 1 short ton = 2,000 lbs

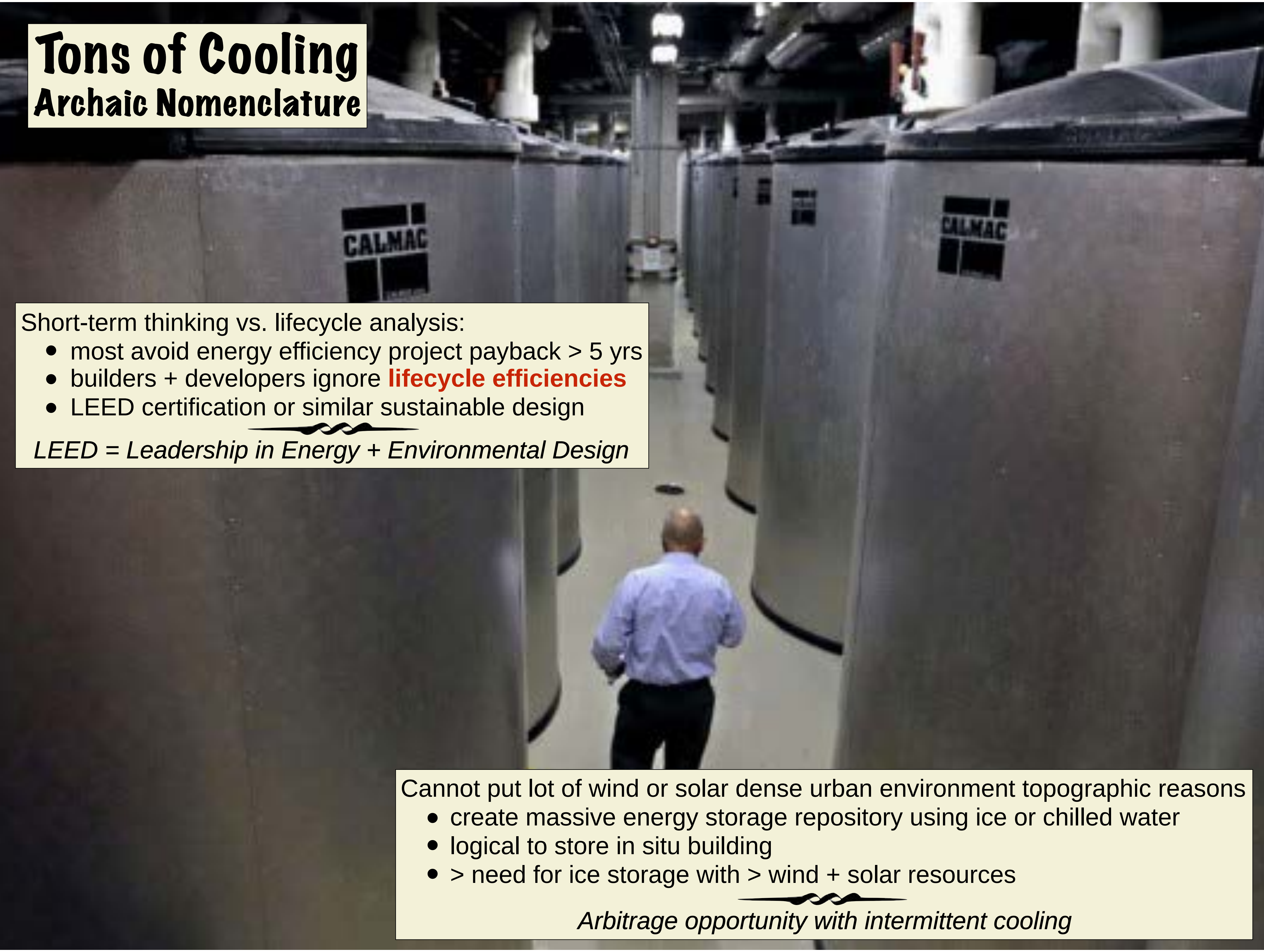
Ton of cooling requires ***12,000 Btu***

Short ton?





Tons of Cooling
Archaic Nomenclature



Short-term thinking vs. lifecycle analysis:

- most avoid energy efficiency project payback > 5 yrs
- builders + developers ignore **lifecycle efficiencies**
- LEED certification or similar sustainable design

LEED = Leadership in Energy + Environmental Design

Cannot put lot of wind or solar dense urban environment topographic reasons

- create massive energy storage repository using ice or chilled water
- logical to store in situ building
- > need for ice storage with > wind + solar resources

Arbitrage opportunity with intermittent cooling

Home-based Lithium Ion Batteries

Again Scalable + Distributable

How many lead-acid batteries?

How many Li-ion batteries?

Manual, photocell, battery controller, PV inverter, TOU, automatic switching:

- pure backup for grid outages
- wall-mounted battery charging
- EV charging
- appliances DHW, freezer, AC
- algorithmic avoidance peak + TOU charges
- social utility of supporting grid

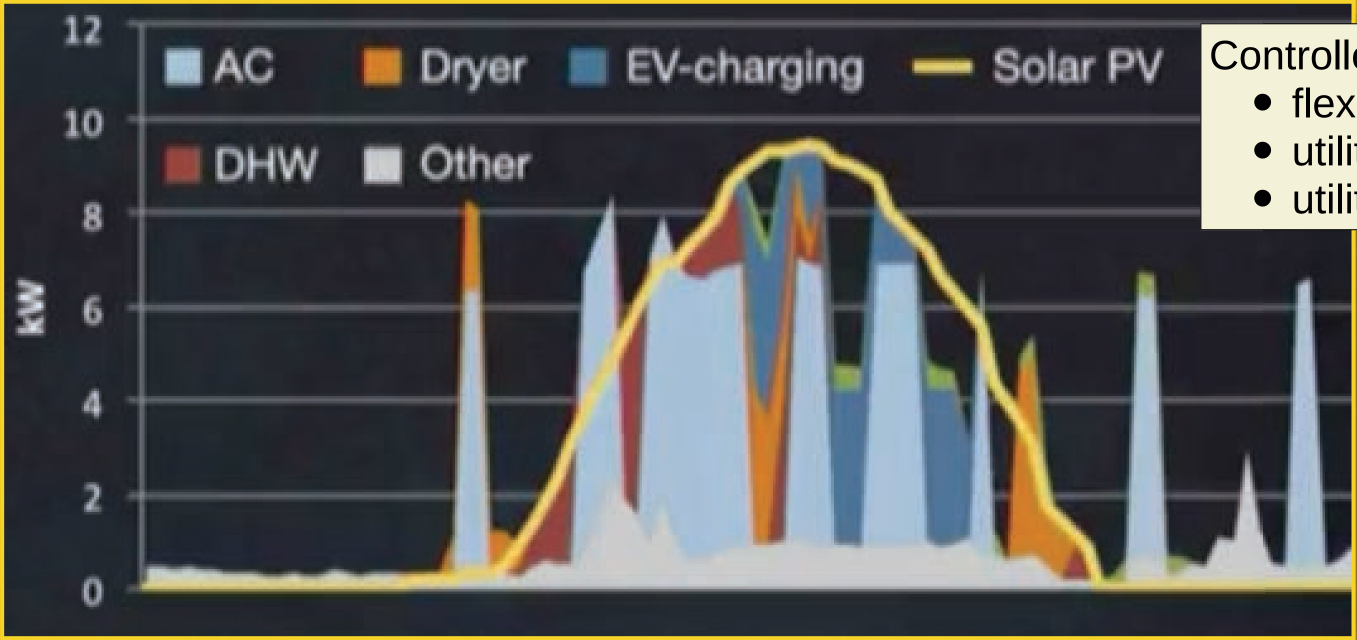
Aggregator or utility control contractually limited
to certain circuits or time-of-day

Load Control + PV makes Grid [almost] Optional

Summertime Dancing behind the Meter

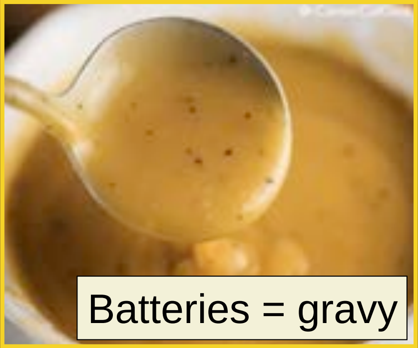
Uncontrolled home electric demand:

- **~50%** solar PV sent to grid
- assume utility under-reimburses
- craft homeowner response



Controlled home electric demand:

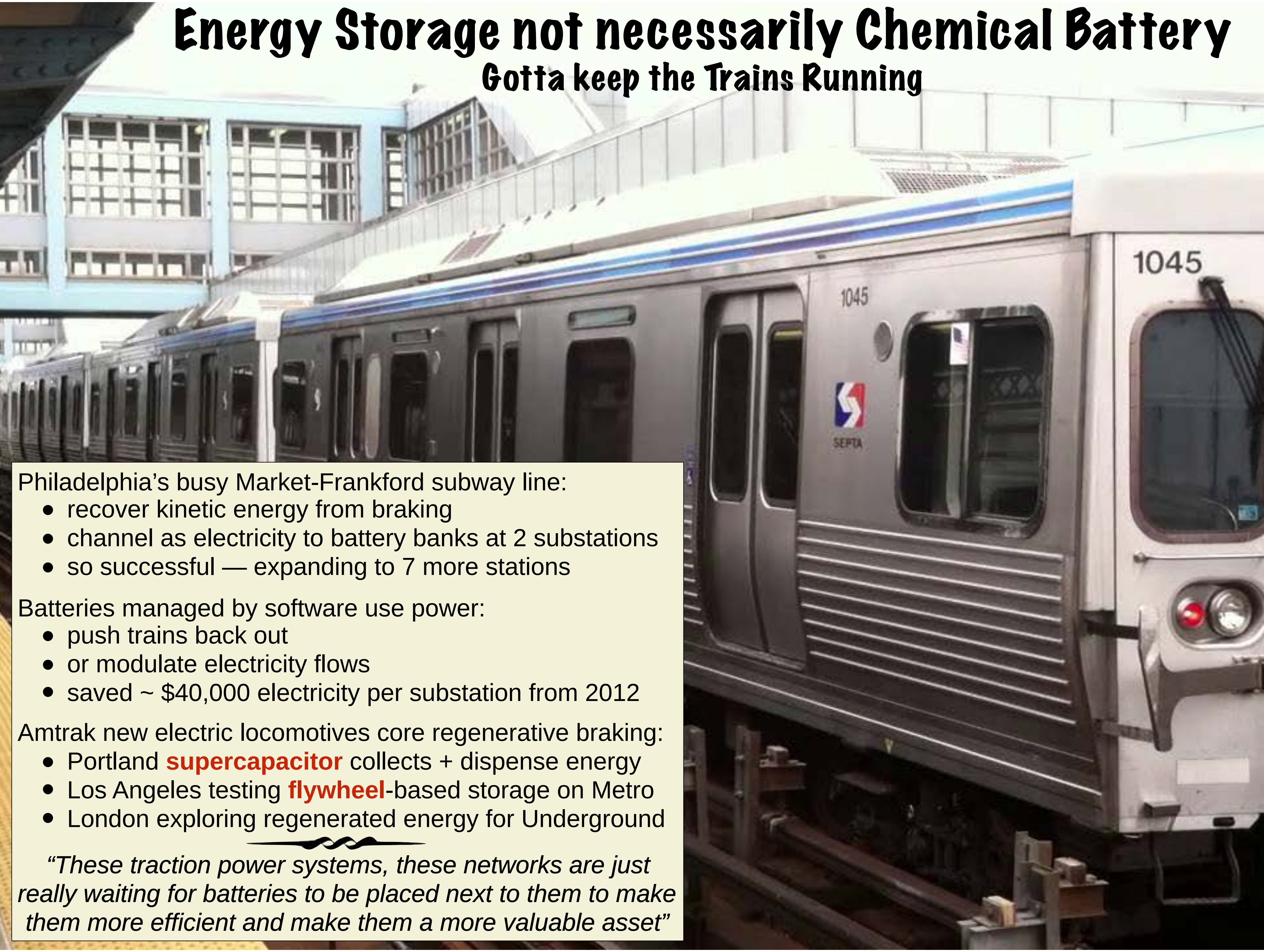
- flexible load uses **80-90%** PV
- utility loses nearly all windfall
- utility loses most ordinary revenue



Batteries = gravy

Energy Storage not necessarily Chemical Battery

Gotta keep the Trains Running



Philadelphia's busy Market-Frankford subway line:

- recover kinetic energy from braking
- channel as electricity to battery banks at 2 substations
- so successful — expanding to 7 more stations

Batteries managed by software use power:

- push trains back out
- or modulate electricity flows
- saved ~ $40,000 electricity per substation from 2012

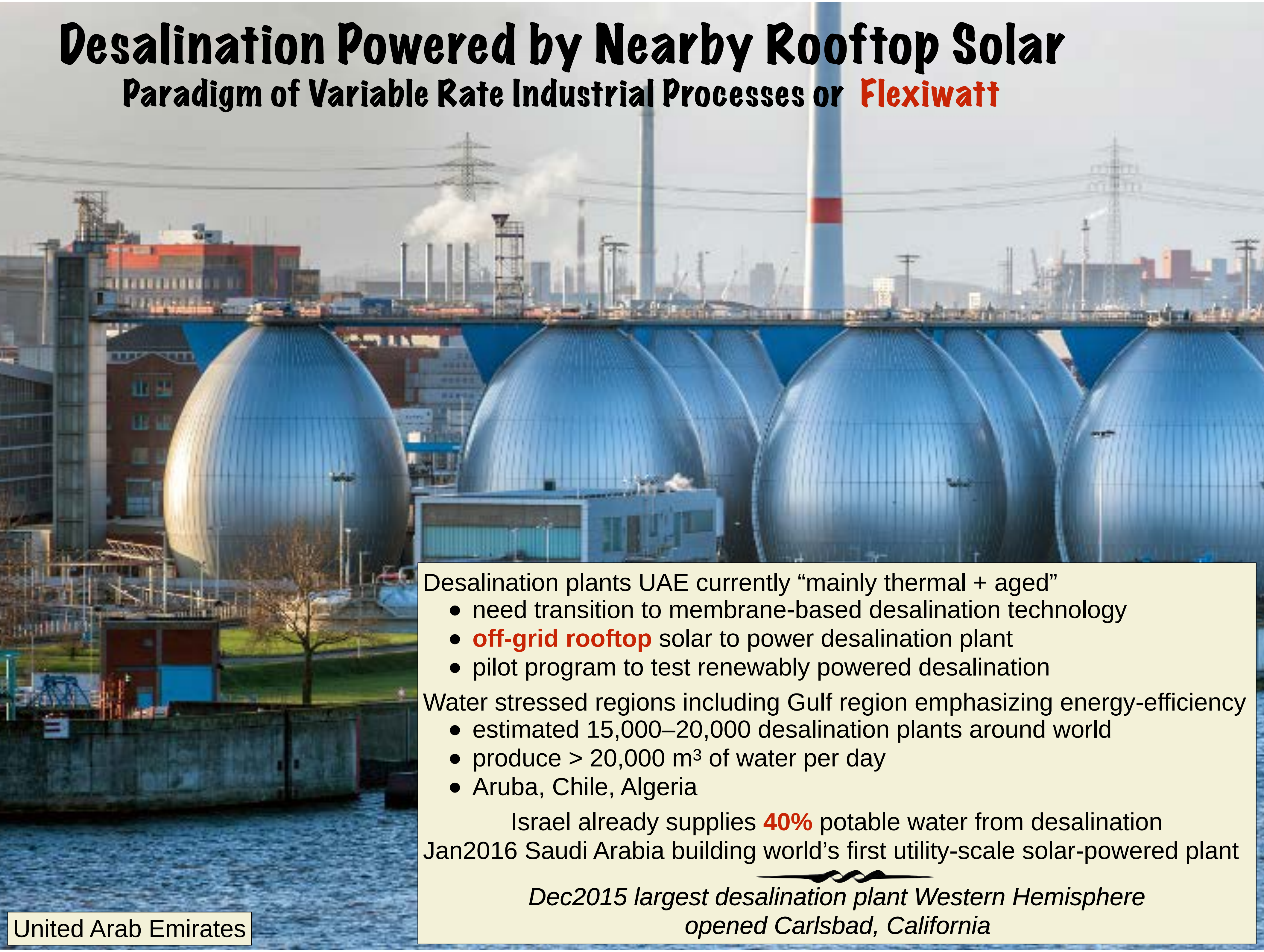
Amtrak new electric locomotives core regenerative braking:

- Portland **supercapacitor** collects + dispense energy
- Los Angeles testing **flywheel**-based storage on Metro
- London exploring regenerated energy for Underground

"These traction power systems, these networks are just really waiting for batteries to be placed next to them to make them more efficient and make them a more valuable asset"

Desalination Powered by Nearby Rooftop Solar

Paradigm of Variable Rate Industrial Processes or Flexiwatt



Desalination plants UAE currently “mainly thermal + aged”

- need transition to membrane-based desalination technology
- **off-grid rooftop** solar to power desalination plant
- pilot program to test renewably powered desalination

Water stressed regions including Gulf region emphasizing energy-efficiency

- estimated 15,000–20,000 desalination plants around world
- produce > 20,000 m^3 of water per day
- Aruba, Chile, Algeria

Israel already supplies **40%** potable water from desalination

Jan2016 Saudi Arabia building world’s first utility-scale solar-powered plant

Dec2015 largest desalination plant Western Hemisphere
opened Carlsbad, California

United Arab Emirates

Sustainable Solar Hydrogen

'Natural' Gas not the 'Natural' Source for Hydrogen

Hydrogen most abundant element in universe
[fatuous argument supporting its use as energy carrier]
But problematic, as NG main source **methane**

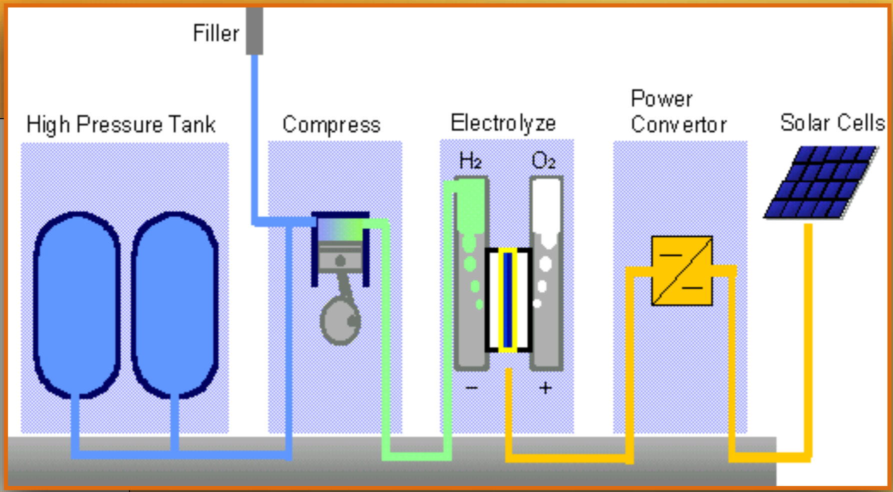
Hydrogen as chemical feedstock:

- petroleum refining, metallurgy, plastics, fertilizers
- food processing (think hydrogen peroxide)

Hydrogen as fuel:

- used directly **combustible fuel** [vehicles]
- used in chemical reaction in **fuel cell** [cogeneration heat + power]

Hydrogen can be stored + distributed as gas or liquid



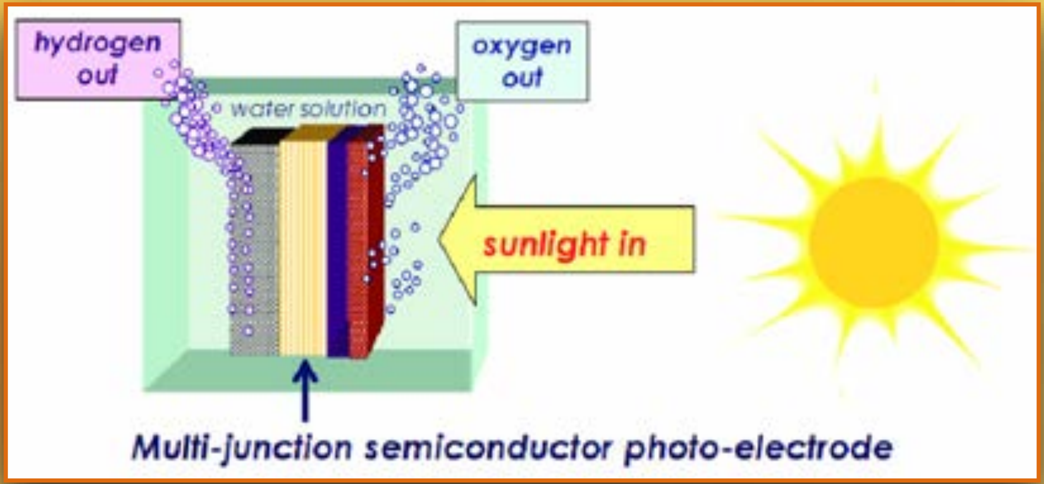
USDoE promoting H_2 from "splitting" water

- **microbial** digestion
- **photochemical** reactions
- **electrolysis** most commonly

Superior alternative **thermochemical** H_2 production:

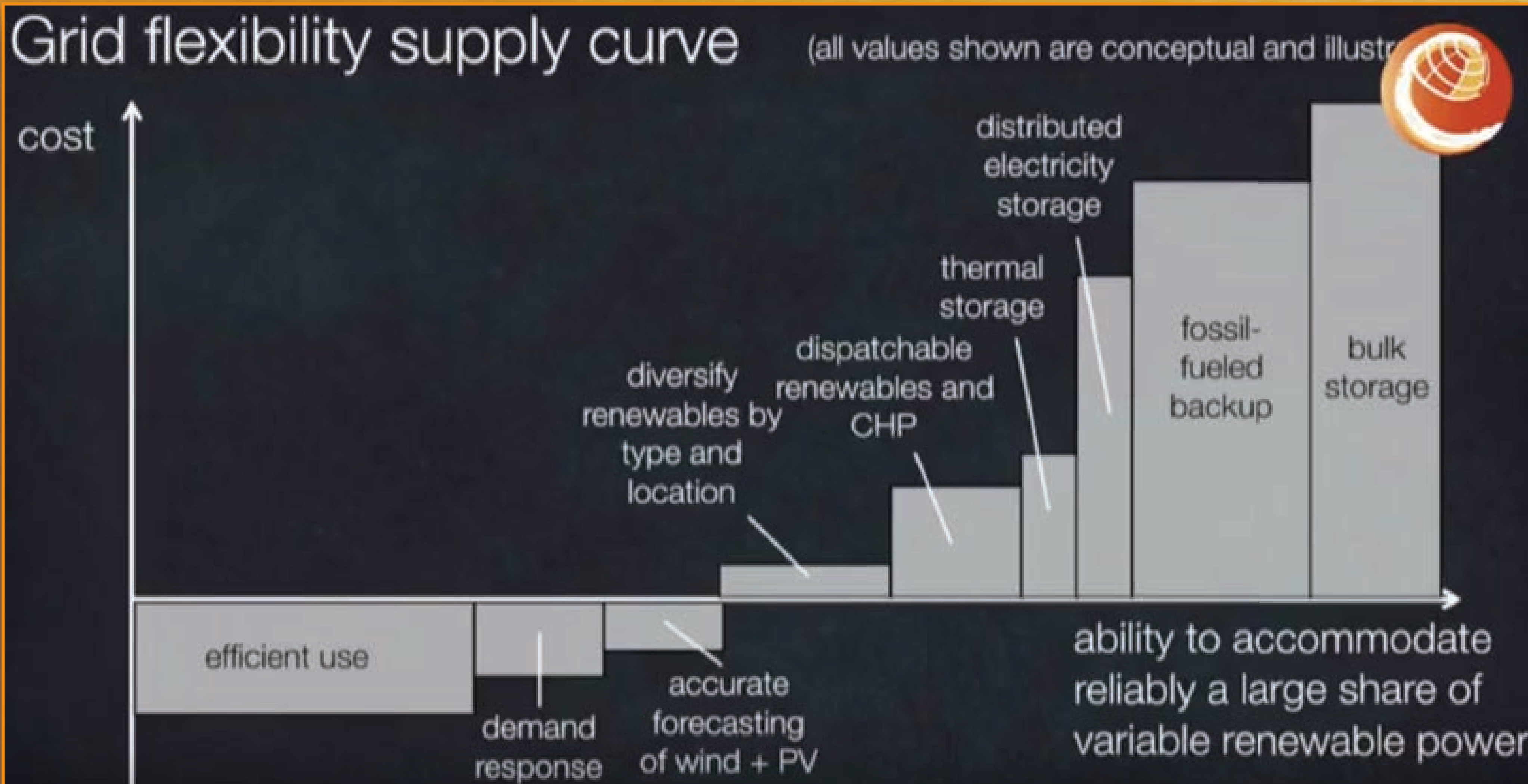
- concentrating solar power can reach 1500ºC
- electrolysis efficiency only 12 to 14%
- thermochemical water-splitting can reach **≥ 60%**

Power-to-hydrogen *projects taking off,*
where excess renewable electricity,
separates hydrogen electrolytically



Cost-effective Measures First

Concentrate on the Low-hanging Fruit



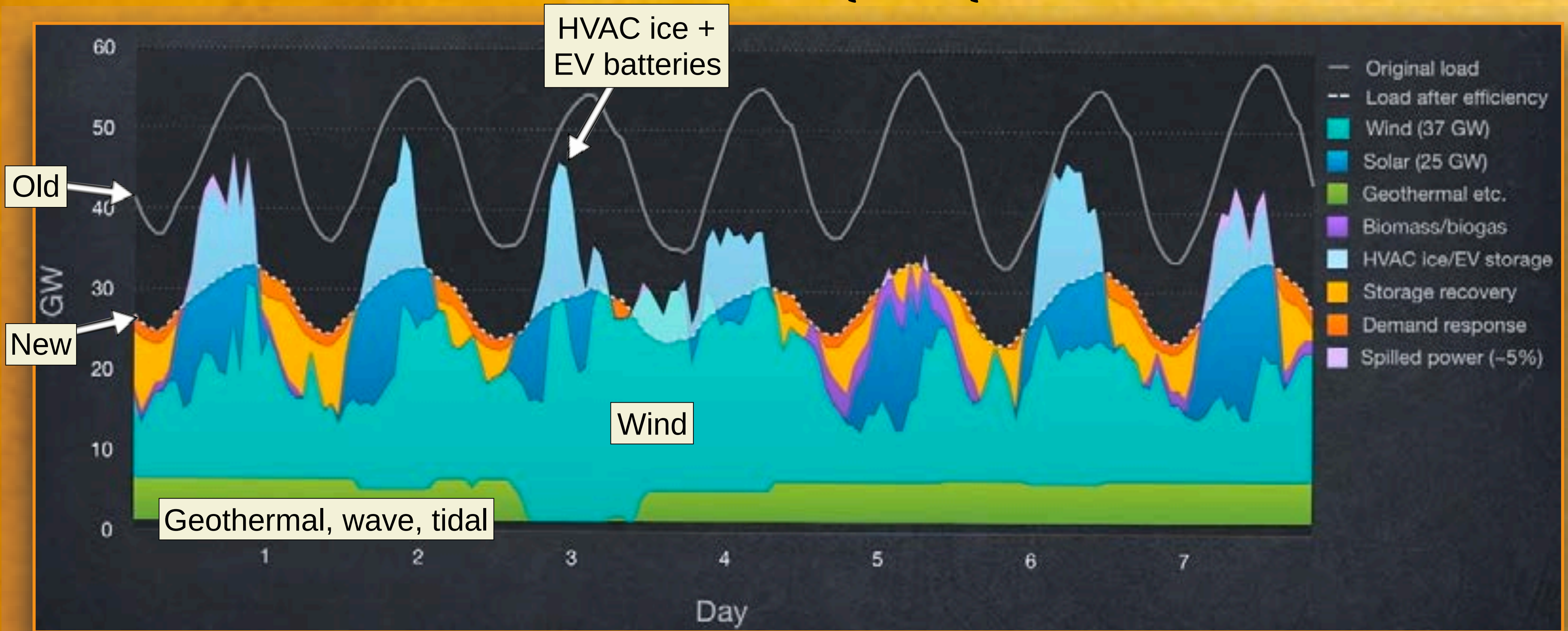
Note caveat about status as conceptual + illustrative:

- first focus on efficiency = **negawatts**
- second install demand response = **flexiwatts**
- all measures contribute to resilient, stable grid

Note goal of accommodating larger share of variable renewable power

Choreographing Variable Renewable Generation

RMI simulation ERCOT power pool 2050



All-expenses trip to Texas for a week:

- but it is summertime + it is *goldang hot*
- goal **~45%** reduction peak demand
- no conventional batteries required [except EVs]

Advantages:

- no FF or nuclear needed
- essentially no GHG production
- finally…energy independence

Renewables alone can form grid if forecasted, integrated, diversified by type + location

Grid Vulnerabilities

Microgrids, Resiliency, Islanding

Clearly electric grid not adequately protected physical or cyberattacks

2013 Jon Wellinghoff San Francisco energy law attorney + former FERC chair, called "very well planned, coordinated and executed attack on a major piece of our electric grid infrastructure"

- **PG&E** substation near San Jose
- 150 rounds over 20 min destroyed 17 transformers
- FBI determined incident vandalism, not terror

Wellinghoff urging Congress to fill void in federal law:

- no federal agency oversees substation security
- barely protected with chain-link fence + cameras
- cameras failed to capture details outside fence

San Jose substation

Utilities urged to enact low-cost improvements:

- replacing chain-link fencing with opaque barriers
- movable concrete Jersey barriers as perimeter
- extend lighting + cameras beyond fence yard

Nearby AT&T fiberoptic phone cable cut in underground vault

*2014 **Arkansas** saw multiple attacks on power lines + grid infrastructure, with millions of dollars damage + brief power outages*

Aurora Generator Test
SCADA never designed for Security

Test attack Idaho National Laboratory for DHS

Video simulated hacker attack on power station
- diesel generator spins out of control
- spits out pieces of turbine
- smoke before disintegration

Programming vulnerability in SCaDA:
- systems that control electric, water, chemical plants
- remote digital attack by hackers with real-world damage
- programming flaw since fixed

2002 government officials claimed *al Qaeda* explored SCaDA:
- SCaDA never designed with security in mind
- experts disagree about risks of cyberattack
- cyberarmageddonists likely exaggerate risk

SCaDA = Supervisory Control and Data Acquisition

"Video is not a realistic representation of how the power system would operate," Stan Johnson, manager at North American Electric Reliability Corp, charged with overseeing power grid

"Is this something we should be concerned about? Yes," Homeland Security Department official, Robert Jamison, "[b]ut we've taken a lot of risk off the table"

Rehabilitating Puerto Rico with Microgrids

Control Capability for Autonomous Operation from Central Grid

Grid of interconnected microgrids could assist Puerto Rico post Hurricane Maria 2017

- **green**, **reliable**, **resilient**
- initially off-grid microgrids for quick access to power
- subsequent interconnection microgrids

Microgrid *fractal model* of national [island] grid:

- power source[s], controllers, connectors, storage, power users
- microgrid = community scale
- nanogrid = single building

Picogrid = 1 person,
backpack solar panel, laptop

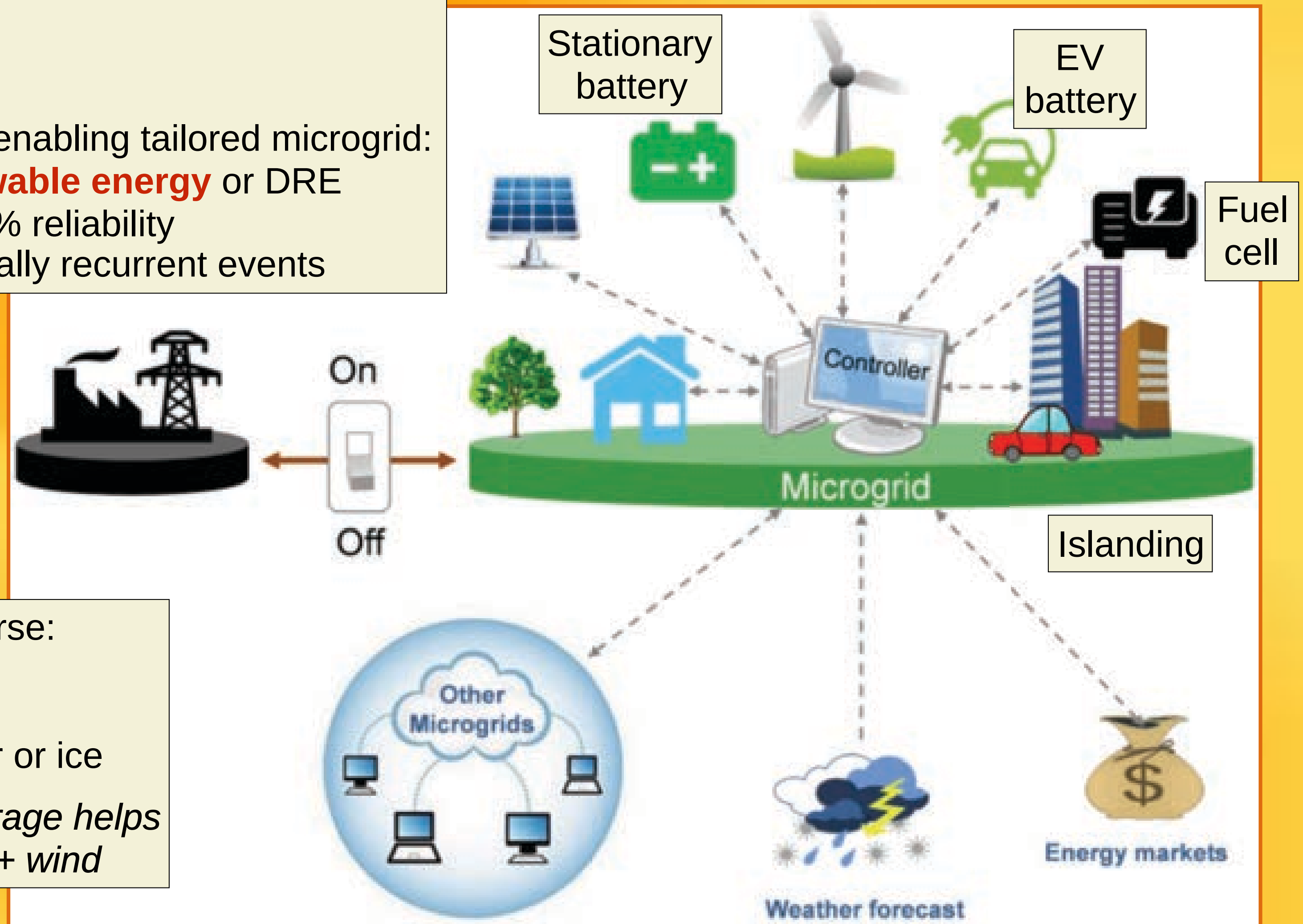
Most microgrids ***embedded*** *inside bigger grid, like any other utility customer*

Difference: flip switch + “island” from parent grid in ***blackout***

Rehabilitating Puerto Rico with Microgrids
Control Capability for Autonomous Operation from Central Grid

Power sources, small-scale:
- solar arrays
- microturbines
- fuel cells
- microhydro

Software, AI, machine learning enabling tailored microgrid:
- integrate **distributed renewable energy** or DRE
- provide "six nines" 99.9999% reliability
- maximize resilience, especially recurrent events



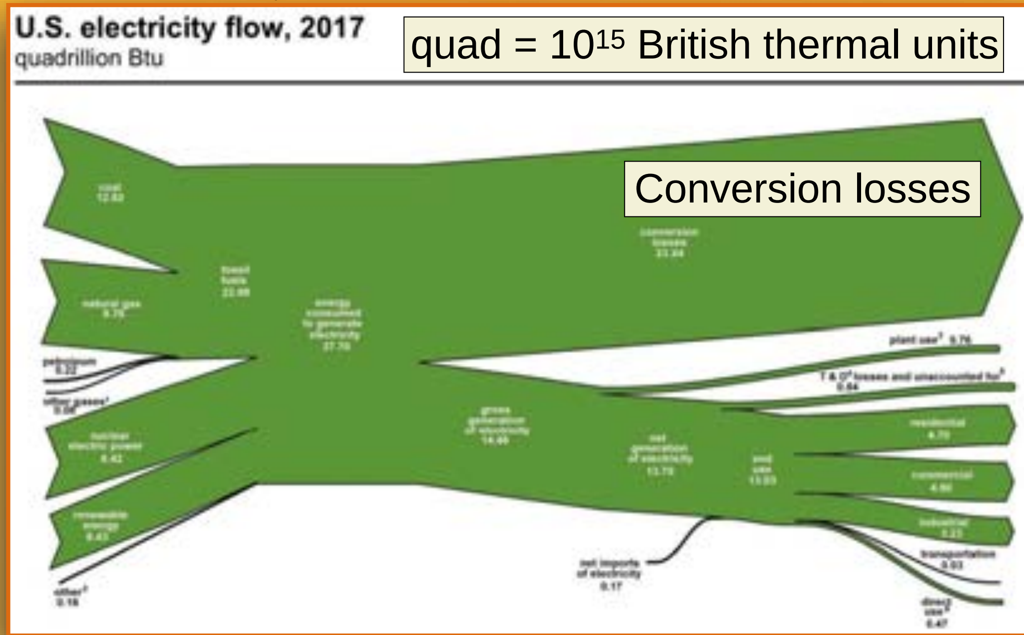
Energy storage, cheaper + diverse:
- chemical batteries
- renewable hydrogen
- thermal storage in hot water or ice

Each additional aliquot new storage helps smooth out variations solar + wind

*White House only gave Puerto Rico 10-day waiver from **Jones Act***
Shipping regulation allowing only US-built ships transport goods between US ports

Current Utilization of Electricity Actually Wasteful

Electricity in its Natural State is Chaotic



Even smart meters still employ **root mean squared (RMS)** method measurement, averaging a sampling to estimate power traversing meter — developed in **1890s**

Lots electricity goes to waste:

- generation **thermodynamic** losses [**62%** waste heat with coal, nukes]
- intrinsically within grid
- end-use devices like incandescents [only **5%** light]

Transmission losses may be ameliorable:

- transforming voltages up + down
- interconverting AC + DC
- along miles of wires

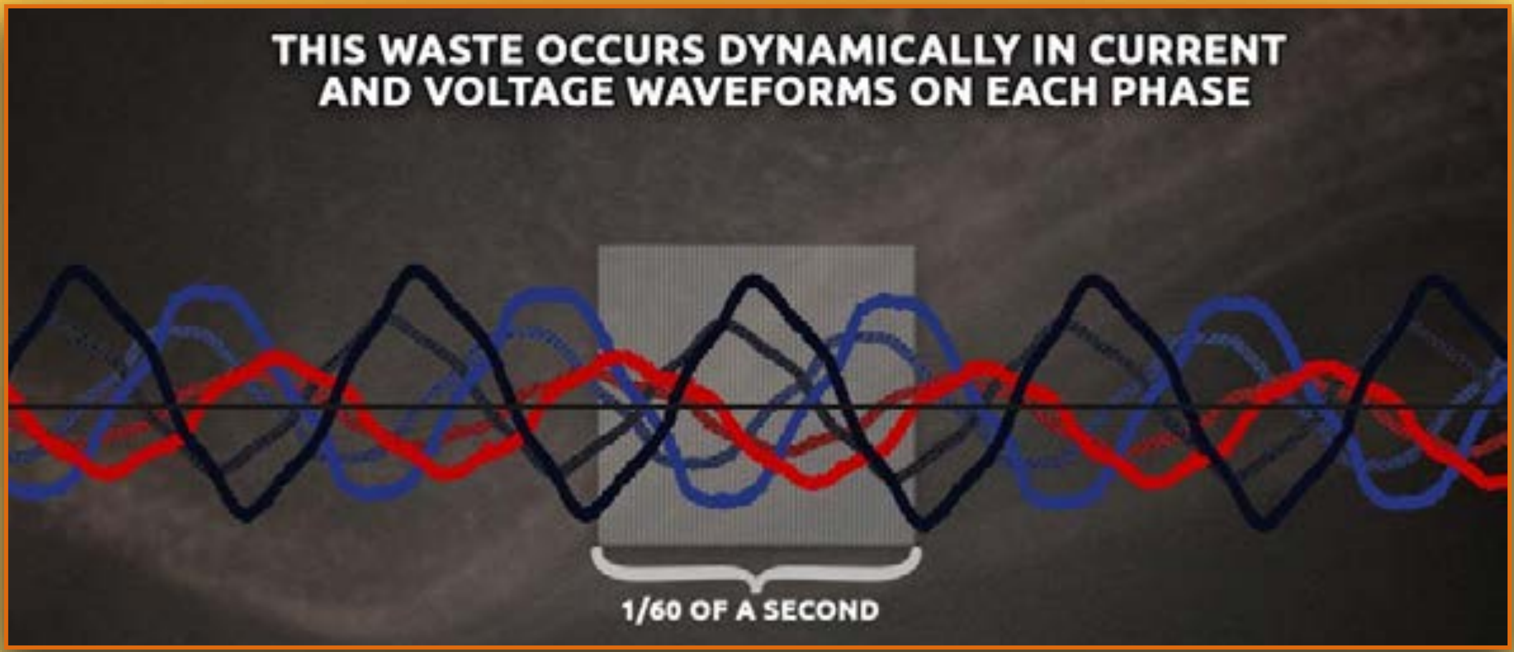
3DFS = digital feedback suppression??

Provision of power to devices could be more sophisticated

- company **3DFS** claims could potentially **double** grid efficiency
- commercializing technology to *measure* + *manage* electricity
- flash energy storage system (FESS) **injects** or **extracts** microamps from 3-phase signal, radically boosting power quality + synchronization

Current Utilization of Electricity Actually Primitive

"Software-defined" Electricity [David Roberts writing about 3DFS]



"Today, power quality loss measurements are rounded and approximated in every industry, in every instrument, and in every tool," Doerfler

"Smart meters are a few hundred bucks because they do not have processors inside them…this is how you know electricity is measured in an analog way: the lack of processing power"

First 3DFS breakthrough:

- measures **26** separate parameters, in **24-bit** resolution, in real time
- parameters = voltage, phase **angle**, phase **imbalance**, **active** power, **reactive** power, **harmonics**, power **factor** + more
- single **1/60th sec** [cycle gathers + analyzes **> M** data points [~16,667 microseconds]

"We have a perfect *digital* replica of the *analog* signal, without any flaws or errors, **zero** noise, within a few nanoseconds after its produced" [billionth of a second]:

- series of analytic + predictive algorithms
- extract usable information, then discard 99% data
- machine learning + AI rapidly acquire information [30 min] then progressively improve

3DFS Tackling Problem of Poor Power Quality

Implications of "software-defined electricity" or SDE

Recovering some or most of lost electricity would amount to finding huge new source [true] zero-carbon power

"Operating system for electricity"

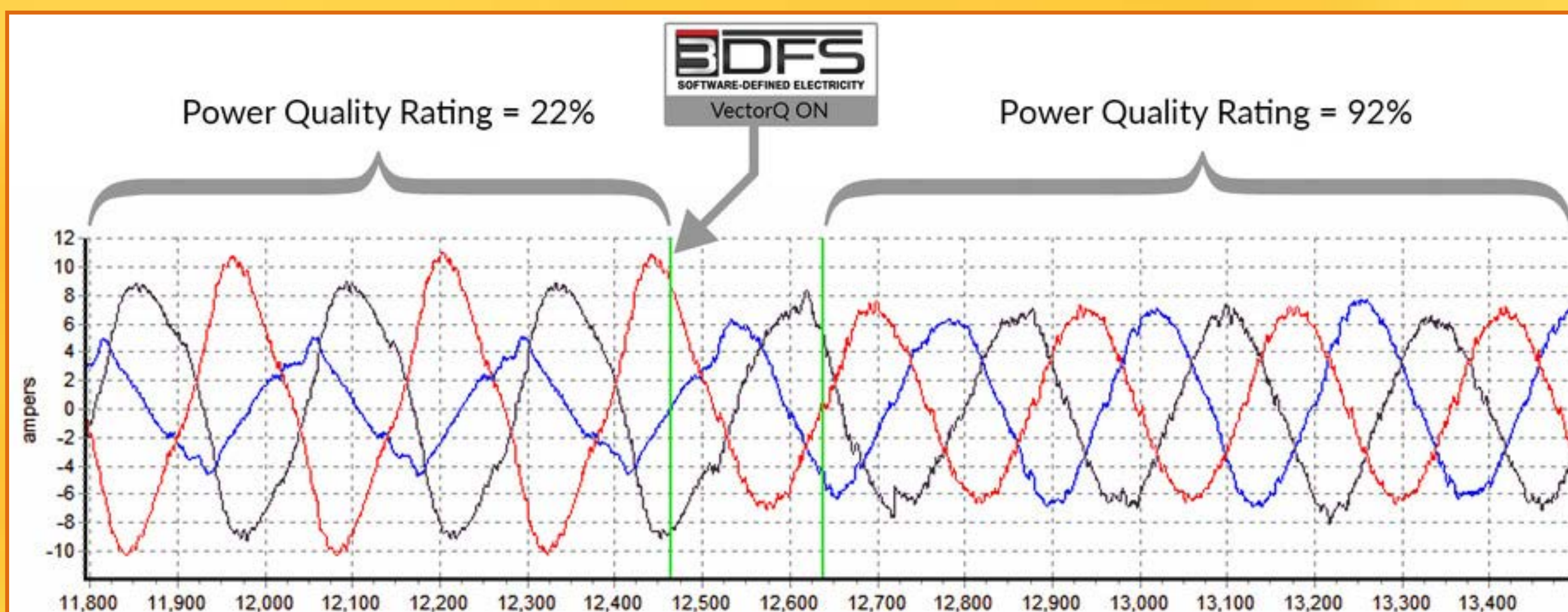
- *tracks* sine wave distortions nanosecond to nanosecond
- *corrects* sine wave from microsecond to microsecond
- **adapts** it to loads it serves, eliminating waste

SDE promises to improve efficiency both ends + in middle:

- making generators more efficient
- reducing consumption + waste heat
- boosting performance of every end-use device

Other benefits:

- '**batteries included'** in enhanced performance
- protection against **lightning** + other surges
- immediate detection of **hacking** attempts



3DFS Tackling Problem of Poor Power Quality

Power needs to be Synchronized

Buzzing, humming, heat at any stage of electricity system signal of unsynchronized power

3DFS tech installed on electrical panel:

- installation non-intrusive
- no interruption in power
- takes ~ half-hour

Analyzes + corrects electron flux:

- 3DFS-developed artificial intelligence algorithms
- creates perfectly accurate digital profile each load
- down to individual circuit board component

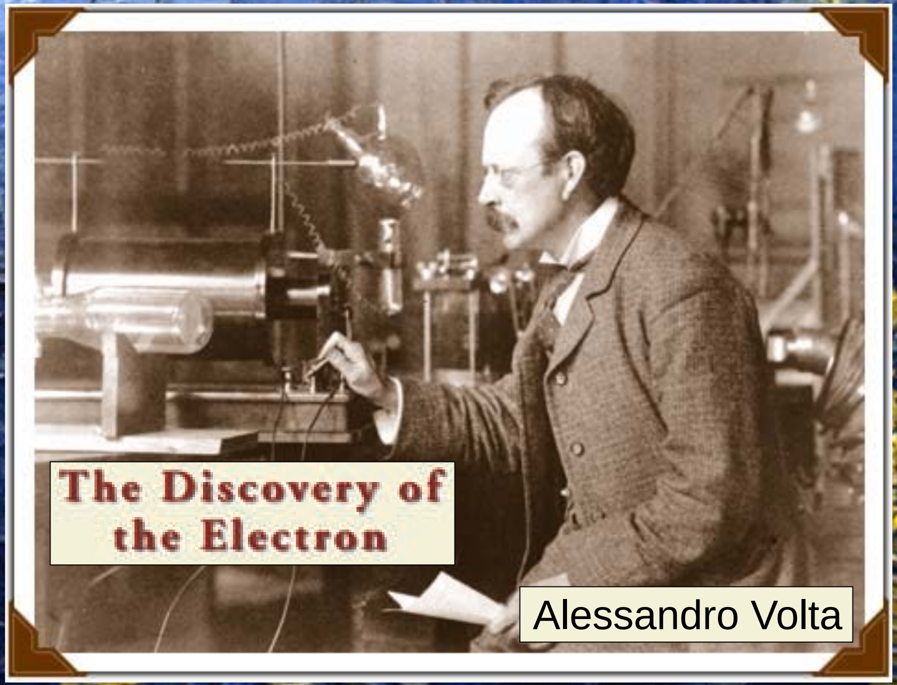
Applications innumerable:

- **data centers** [10-15% less load]
- electrical substations
- motors [20% less load]
- pumps
- **batteries**
- **inverters**
- **ship** = floating microgrid
- international space station

3DFS vision = technology small enough to fit on chip

SDE chip *(like* ***wifi chip****) could become commonplace on all electronic devices*

So what have we learned?



Time for the review….
or perchance questions?

American grid largest global infrastructure construction, but antiquated + in disrepair
Danish + German grid **10-fold** more reliable

Electricity used to produce spin, light, heat, electronics

Upgrading + extending **> 200,000** miles high-voltage transmission lines critical

Electricity a uniquely instantaneous commodity…only comparison the internet
Electricity + hydrogen forms of secondary energy, not primary sources
Pace of energy system transitions set not by **incumbents** but by **insurgents**
No requirement for break-throughs in storage, although would be welcome

Bulk electricity storage + FF/nukes most inflexible + expensive way to design system
Electrification of residential, commercial, industrial, ground transportation sectors
Renewables first strategy can both power load + keep spilled power to only **~ 5%**
Air transportation + high-temperature industrial processes probably require biofuels

Distributed, diffuse, renewable energy production + storage critical to resilience
Energy democratization associated with distributed energy resources + control

Decarbonization + *electrification critical in mitigation* + *adaptation to climate change*