Electrical Power Systems - How they work, Present Status in MN and the Future with Renewables

Presented by –
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Minnesota House Energy and Climate Committee
State Capitol, St. Paul, MN
January 24, 2019

Ned Mohan

Oscar A. Schott Professor of Power Electronics and Systems

University of Minnesota

Mark Ahlstrom

VP, Renewable Energy Policy

NextEra Energy Resources, WindLogics

Jukka Kukkonen

PlugInConnect

Outline –

- Electricity - Integrating Renewables
- Renewables as “Modern Power Plants
- Prospects for EVs

Humility

"Everything we hear is an opinion, not a fact. Everything we see is a perspective, not the truth."

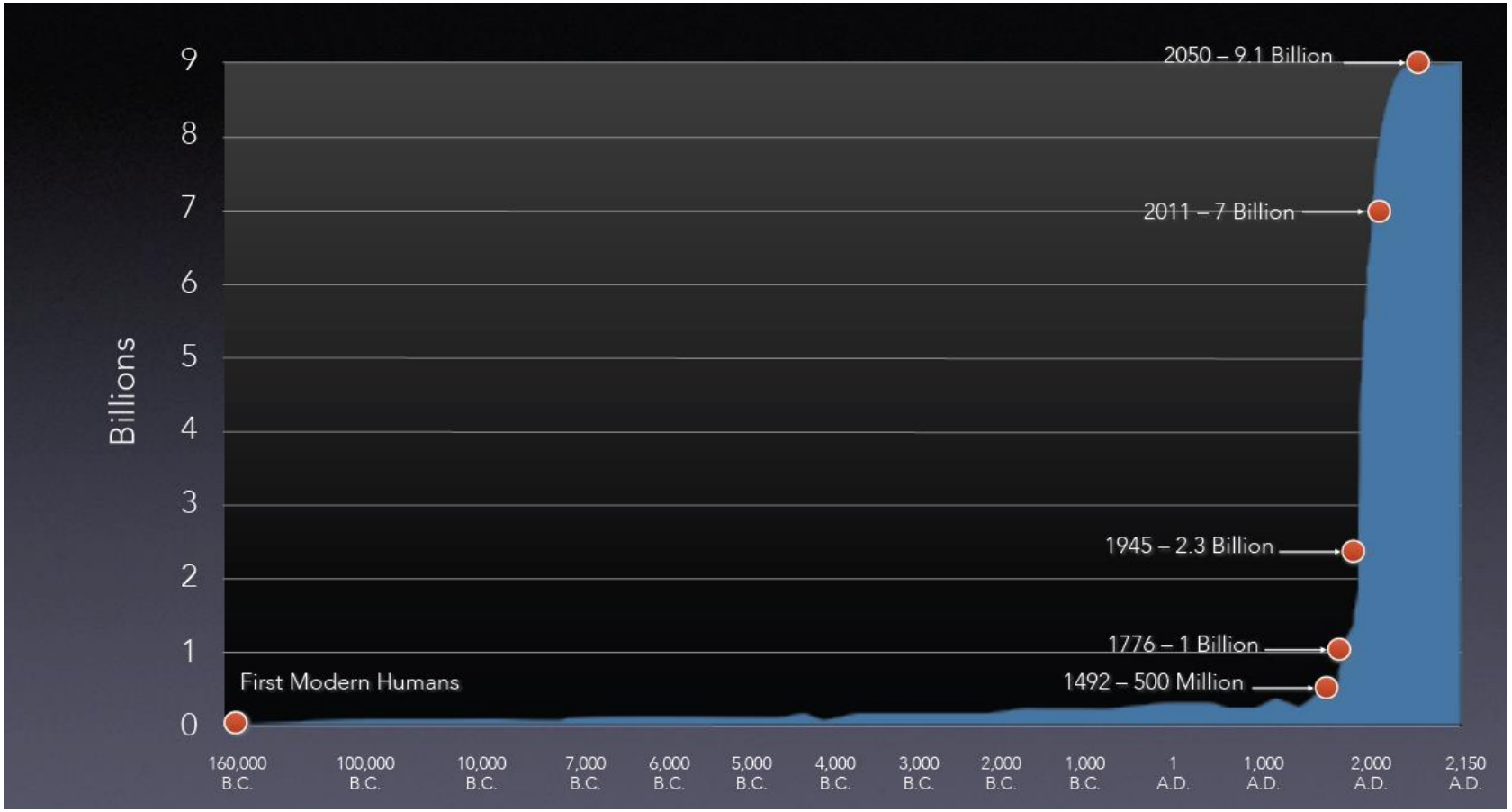
Marcus Aurelius, *Meditations*

"The greatest accomplishment of 20th century science has been the discovery of human ignorance."

Lewis Thomas

Electricity – A Basic Human Right

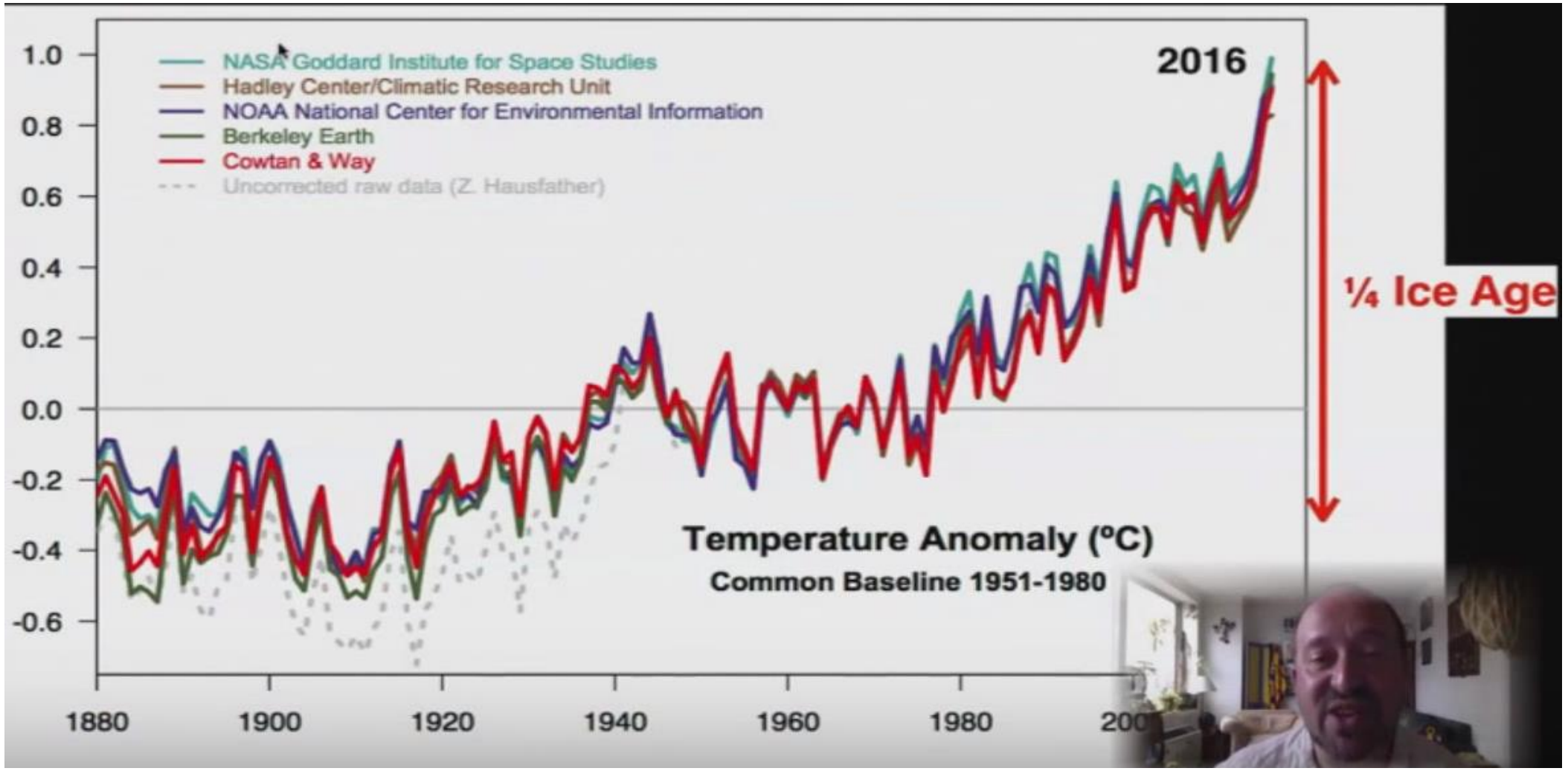
- **1.3 Billion people (1/6th of humanity) have no access to it**
- **Over 1 Billion more will be joining us in just ten short years**

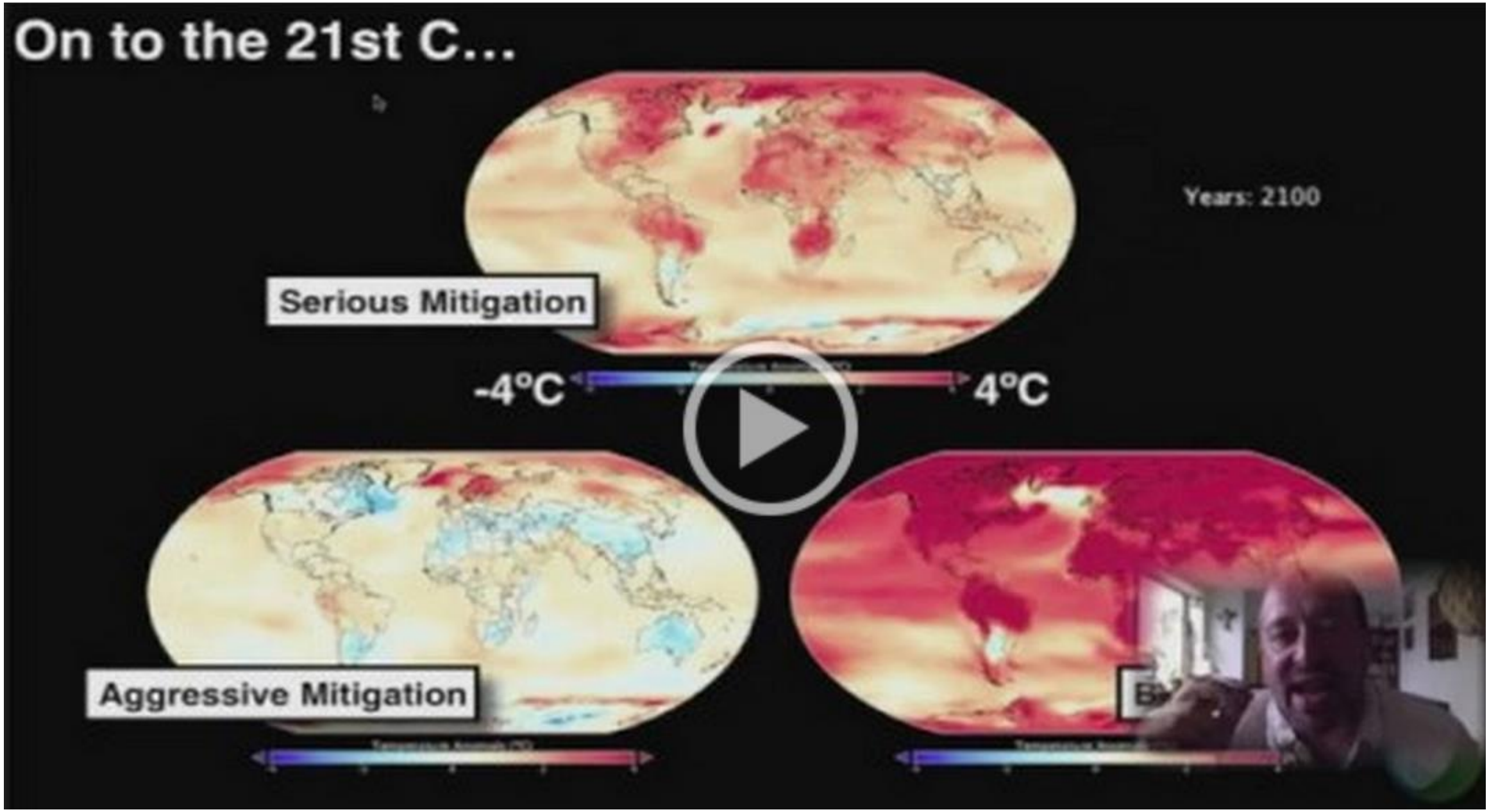


Climate Change – Attribution and Prediction

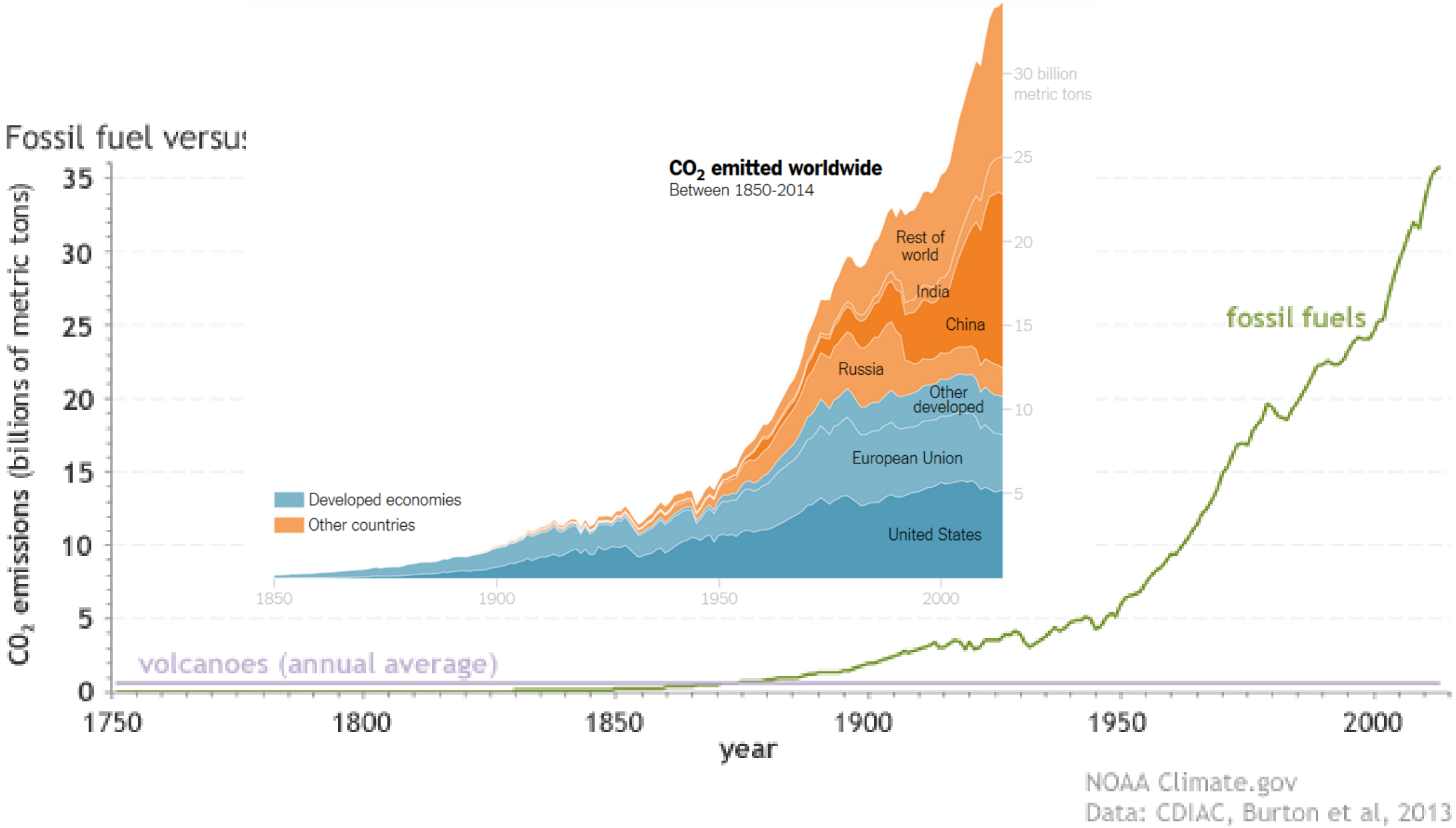
https://z.umn.edu/GavinSchmidt

- Poorest of the poor are at the front line

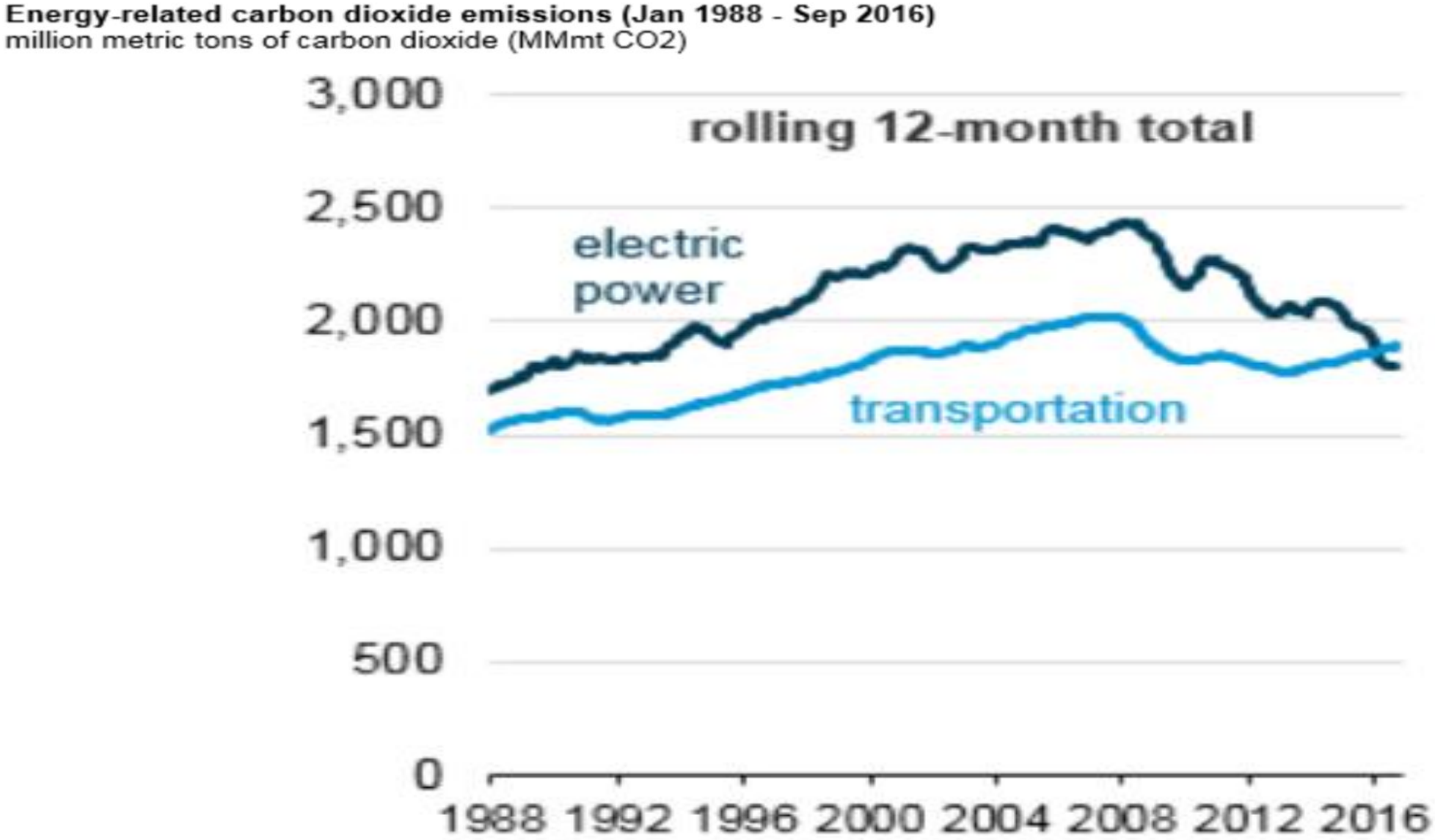



On to the 21st C...
Years: 2100
Serious Mitigation
-4°C
4°C
Aggressive Mitigation

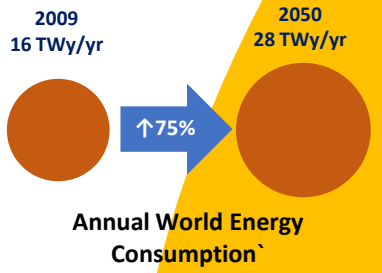
Human Activity



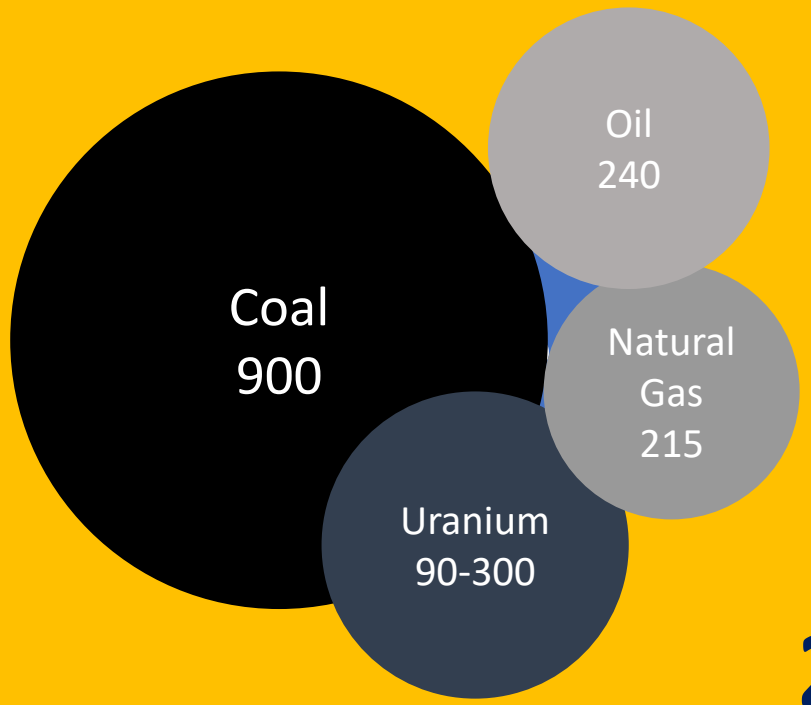
Transportation versus Electric Power Sector



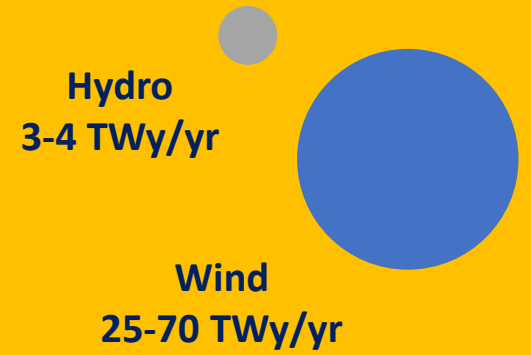
Solar Resource is Very Abundant …



Fossil Fuel Reserves (TWy)



Renewables per Year



Solar
23,000 TWy/y

Source: R. Perez et al, “Renewable Energy Our Solar Future”

So the answer is…….

- Shift all our Energy Use to Electricity
- Generate Electricity from Renewables
- Conservation
- Sustainability mindset

Science Alone Cannot Stop Global Warming

- human attitudes must change.

How “clean” are Renewables?

~1000 g CO_2eq/kWh

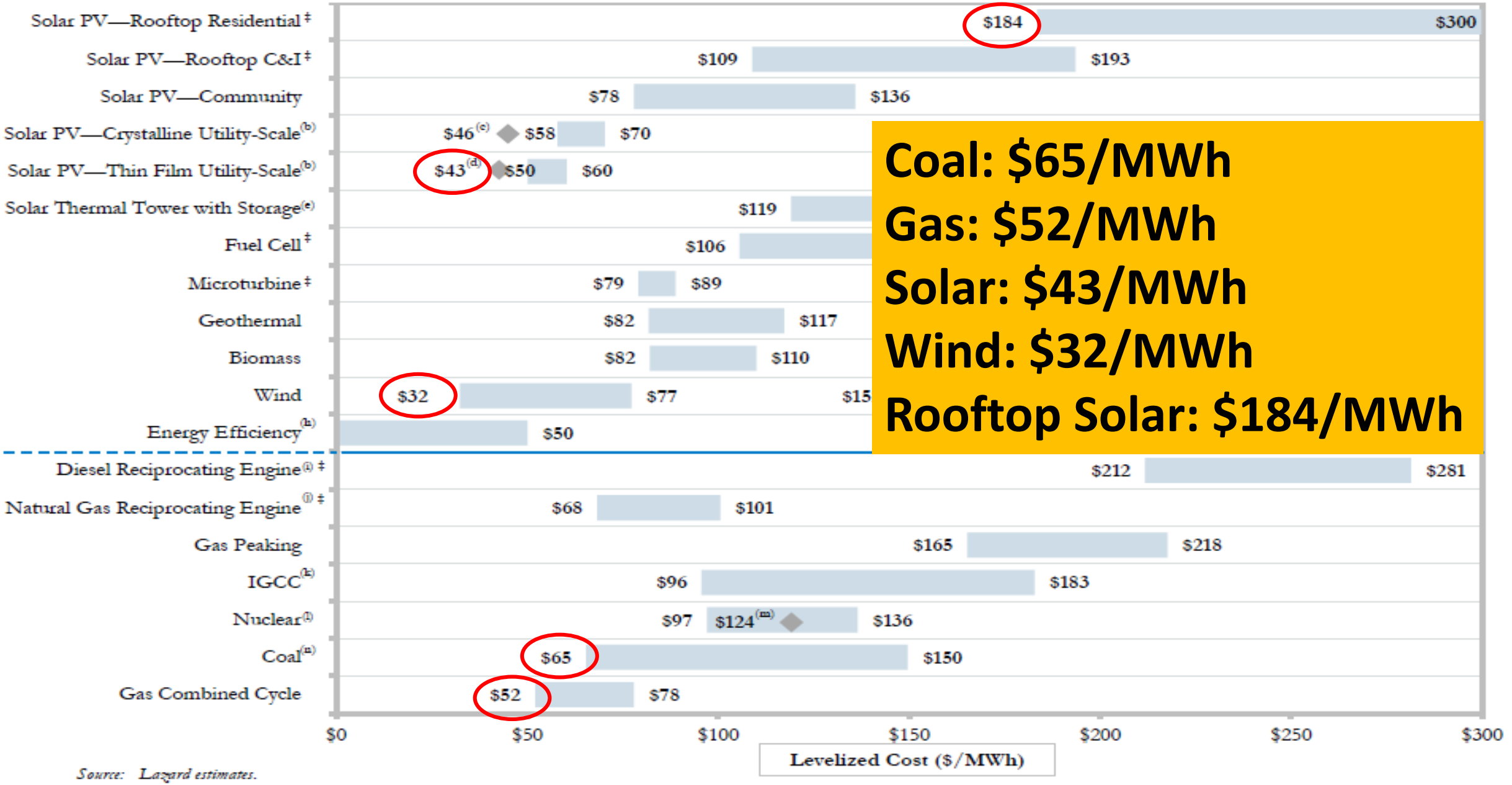
~10 g CO_2eq/kWh

Photovoltaics (PV)

~40 g CO_2eq/kWh

- **Wind 100 times cleaner**
- **Solar 25 times cleaner**

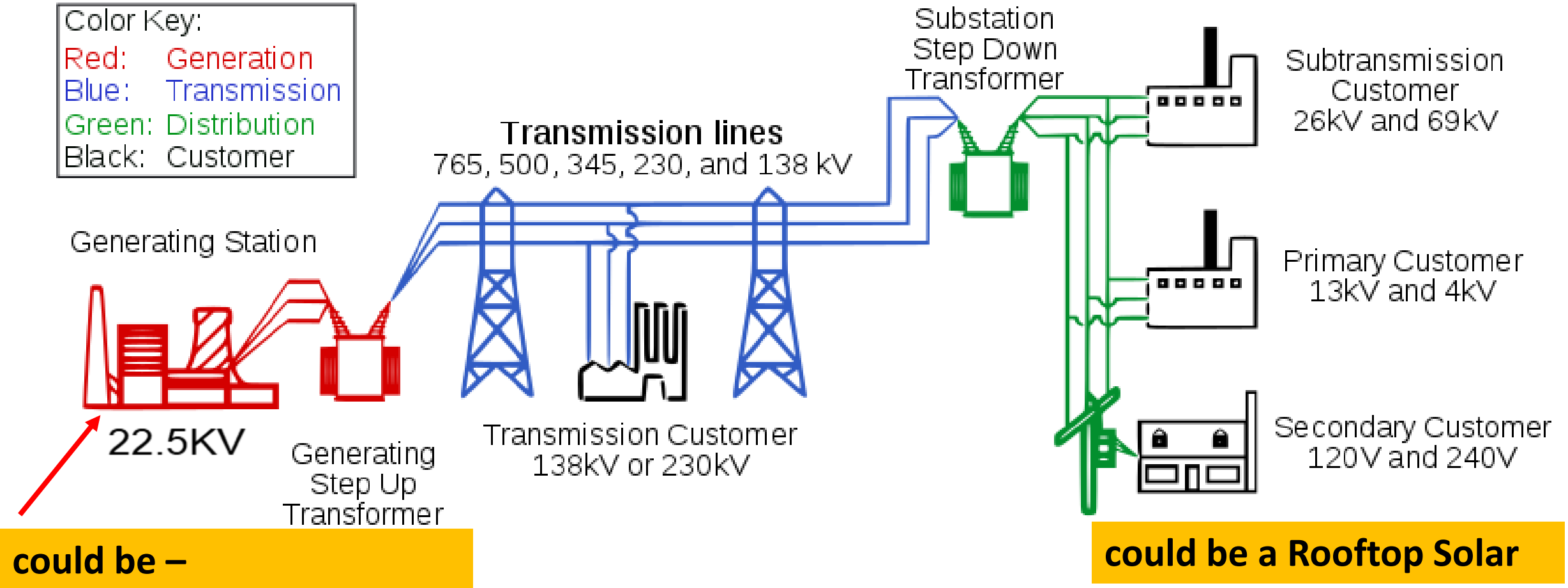
Comparative Cost of Energy: How Wind and Solar Stack Up



Source: Lazard estimates.

Very basic ideas, terminologies, and apparatus in electric power systems

Electric Power Systems - AC



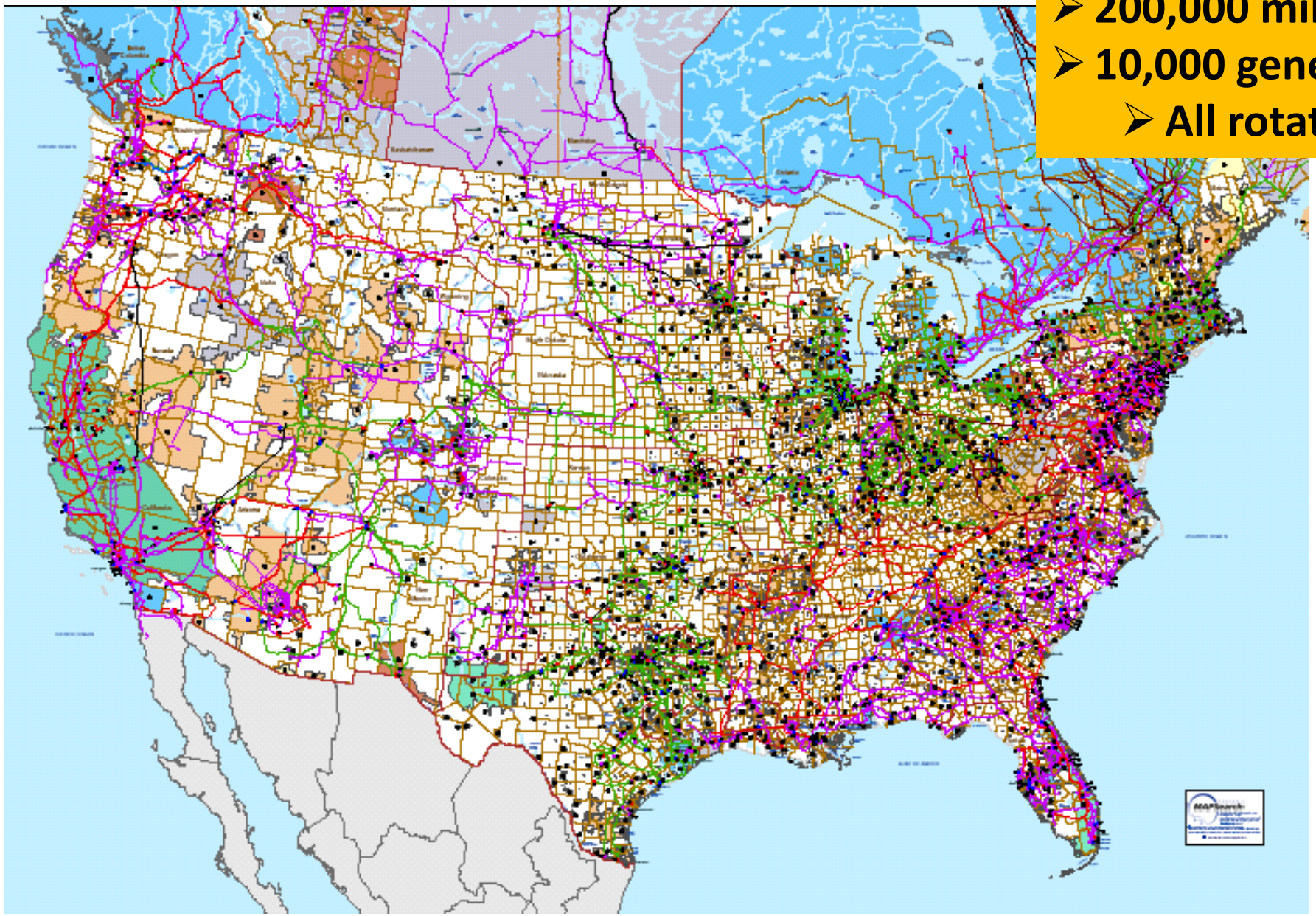
could be –

- A Wind Power Plant

- A Solar Power Plant

could be a Rooftop Solar

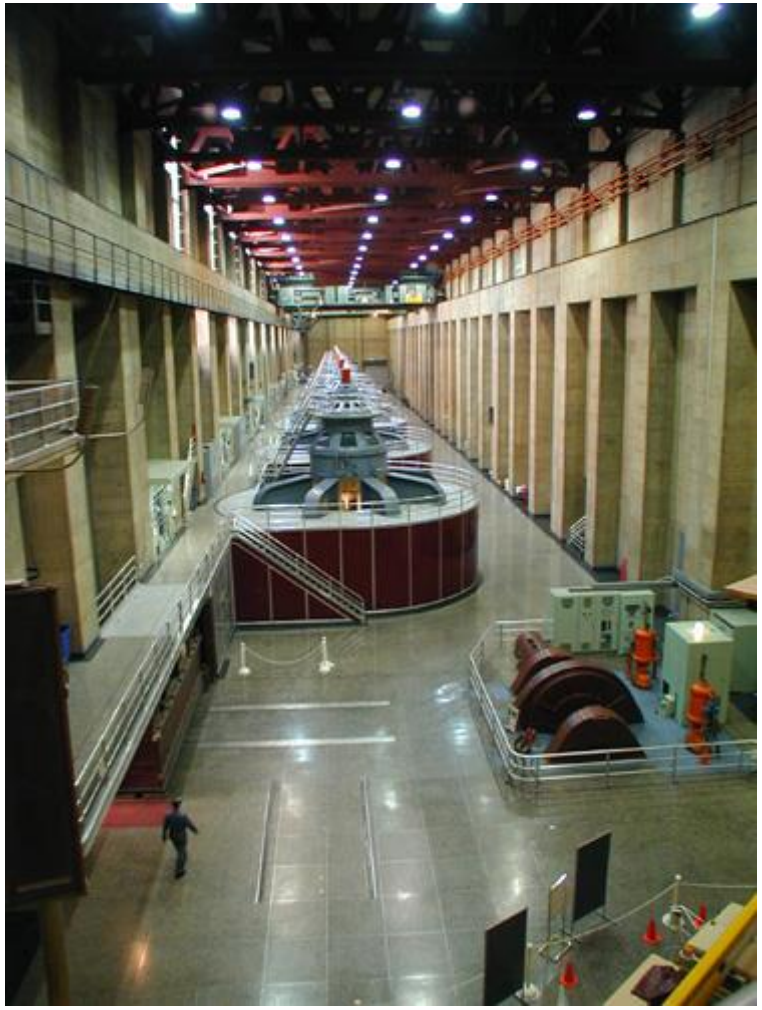
Interconnected North American Power Grid



- 200,000 miles of transmission lines
- 10,000 generators
  - All rotating in synchronism

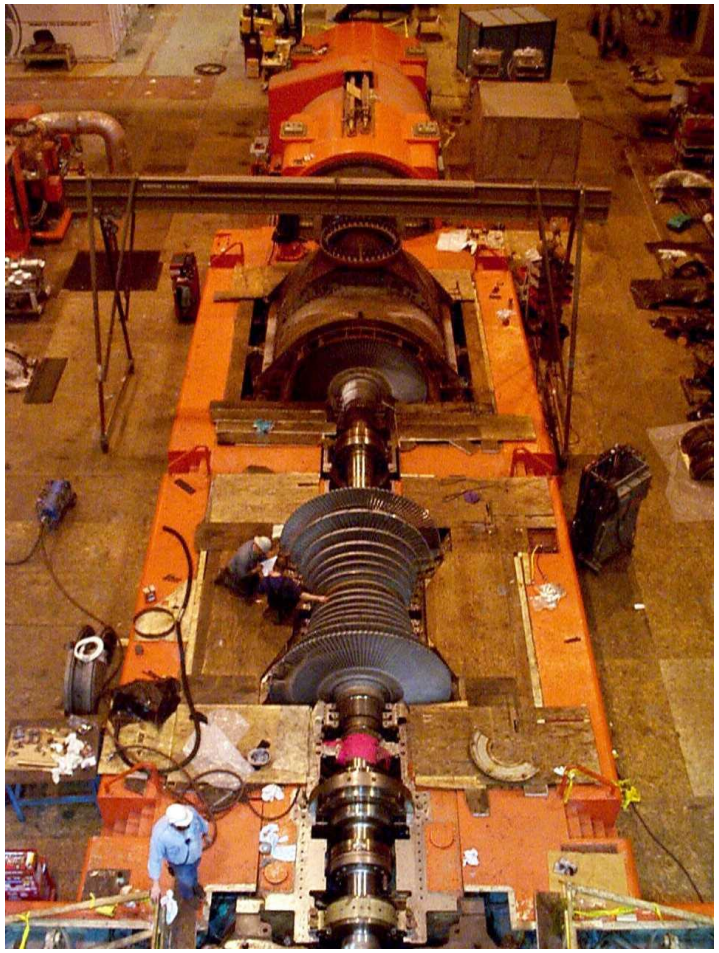
Coal and Gas Power Plants

Hydro Power Plants

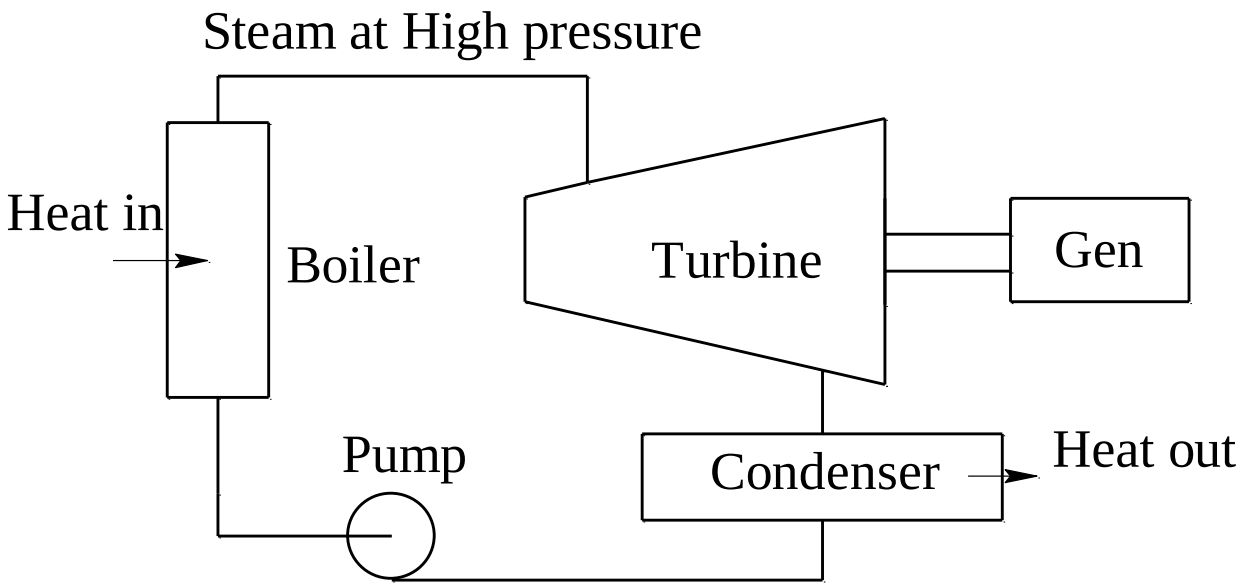


Nuclear Power Plants

Inside a Steam Power Plant

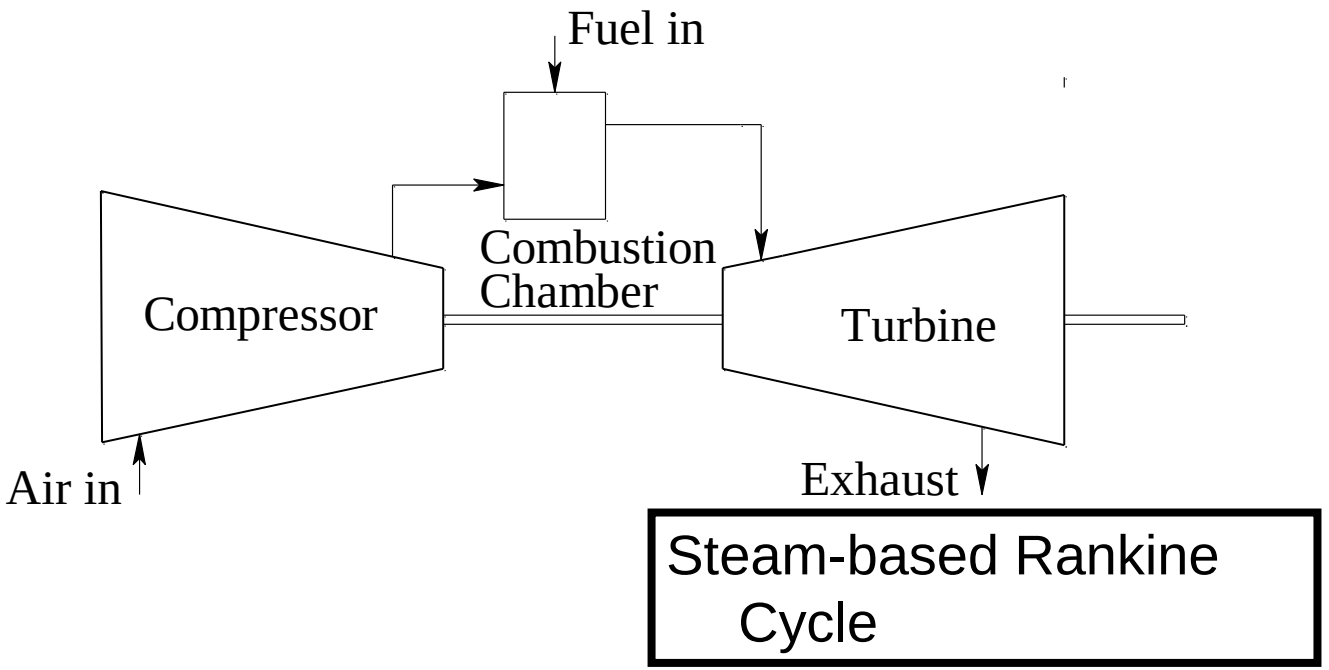


Rankine Thermodynamic Cycle in Coal and Nuclear Power Plants



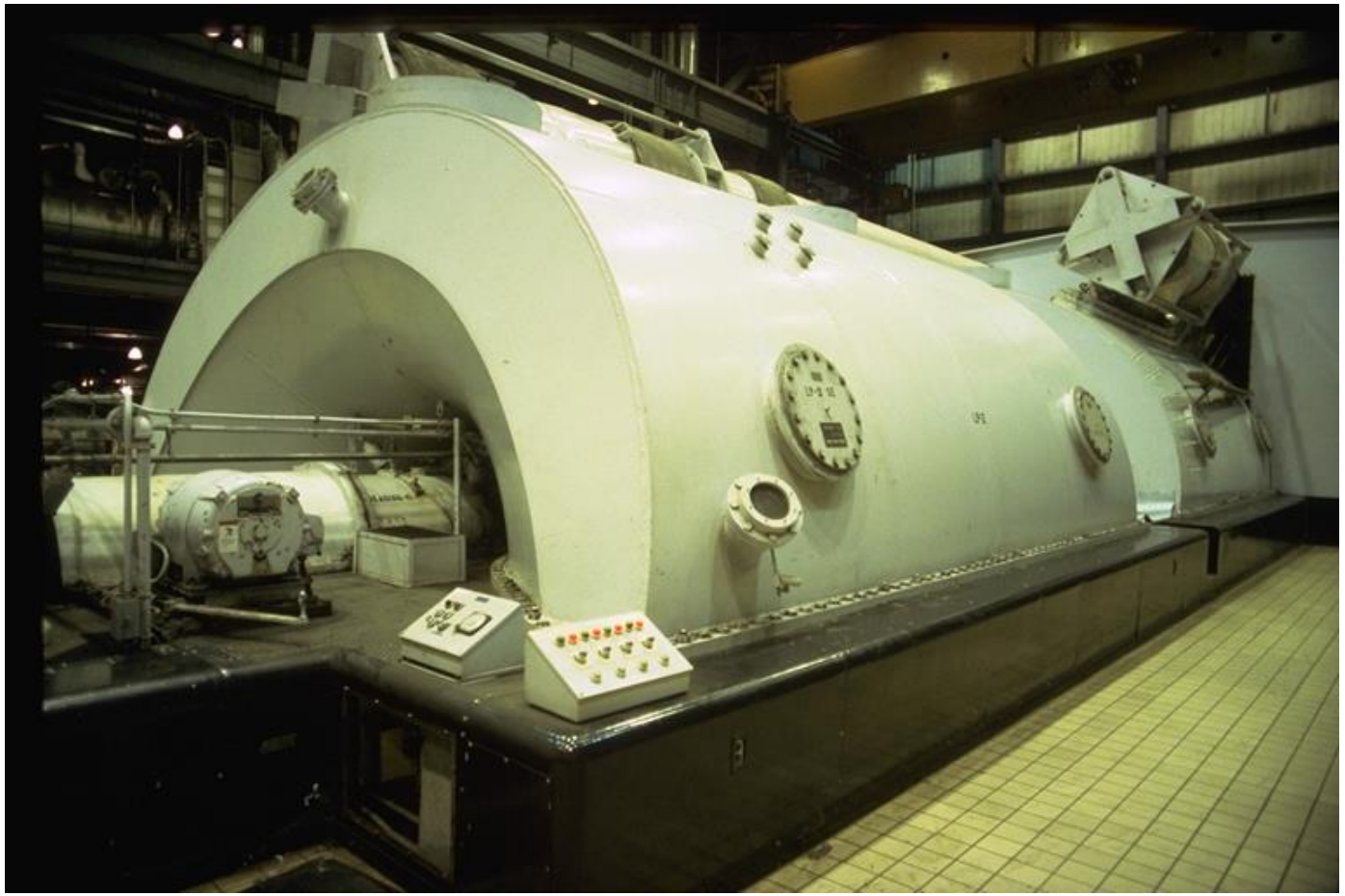
Typical Efficiency: 35-40%

Combined-Cycle Gas Turbines



Typical Efficiency: 55-60%

Power Generation



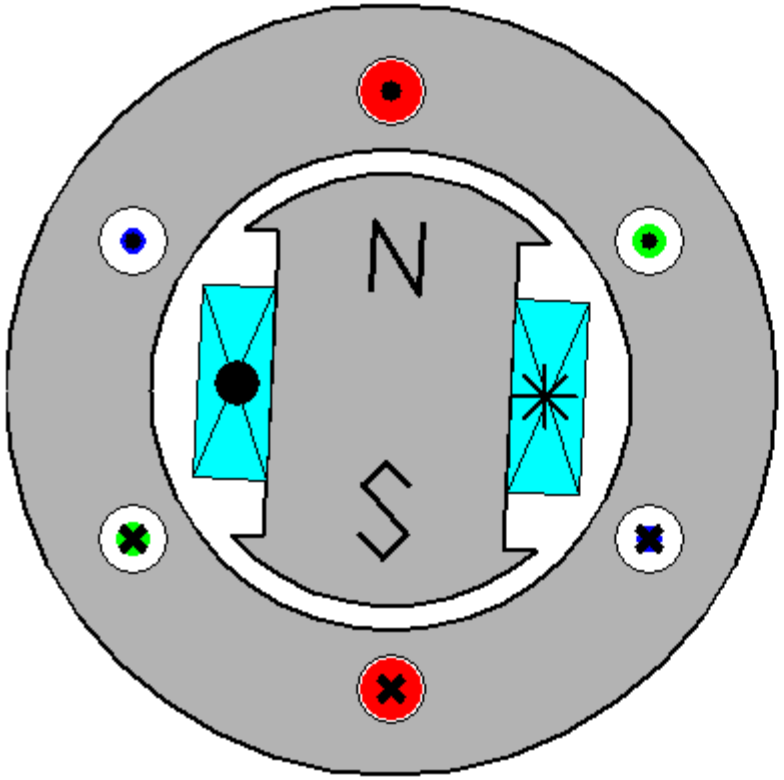
Power Transformers

High Voltage Transmission Lines

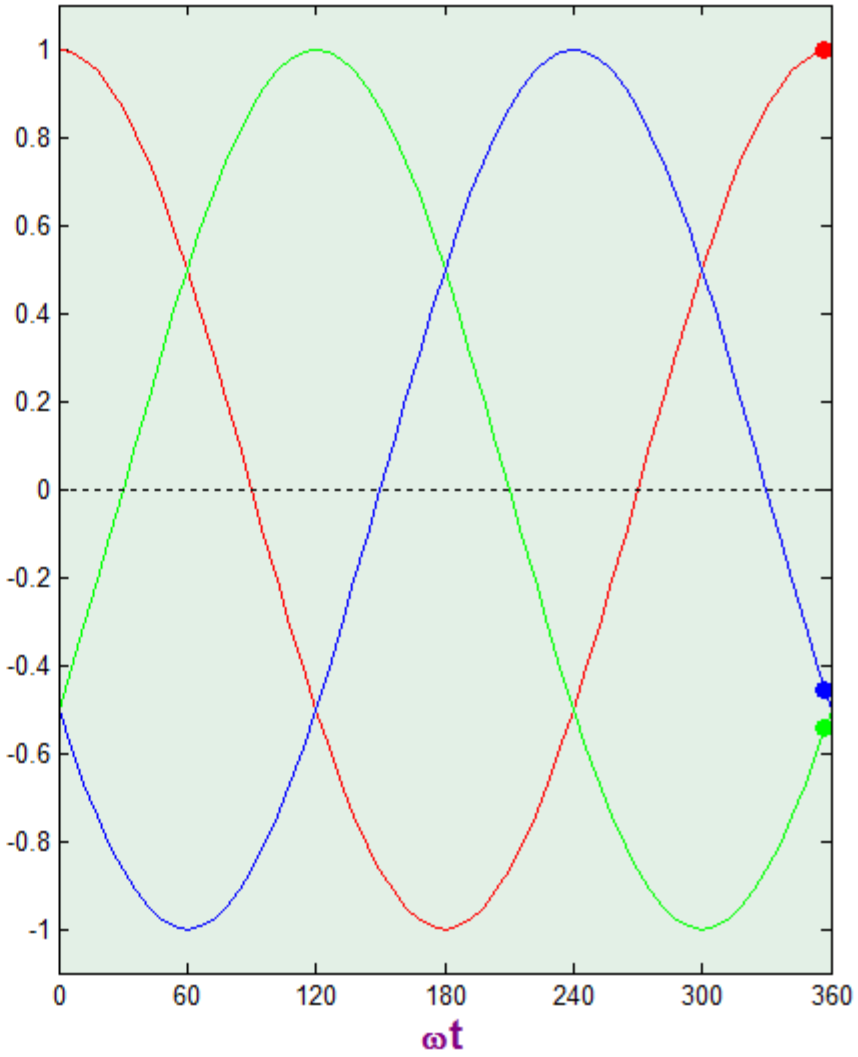
What is a 3 Phase AC system?

- Three phase is generated by a generator with three sets of independent windings which are physically spaced 120 degrees around the stator.
- Voltages are labeled phase-a, phase-b, and phase-c and are the same magnitude but differ in phase angle by 120 degrees.

Three-Phase Generator:



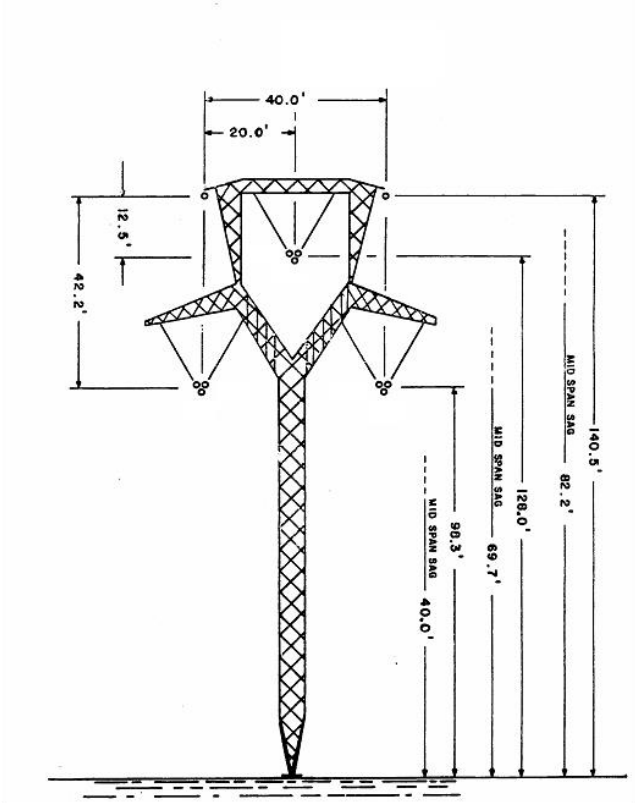
Phase A Phase B Phase C



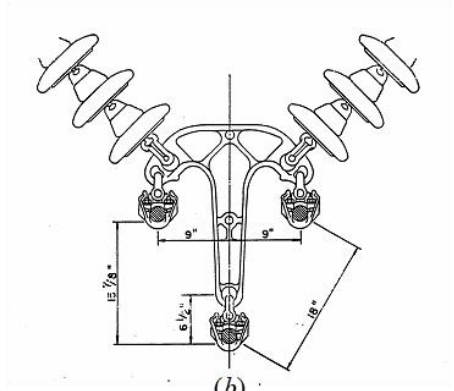
http://www.ece.umn.edu/users/riaz/animations/alternator.html

High Voltage Power Transmission

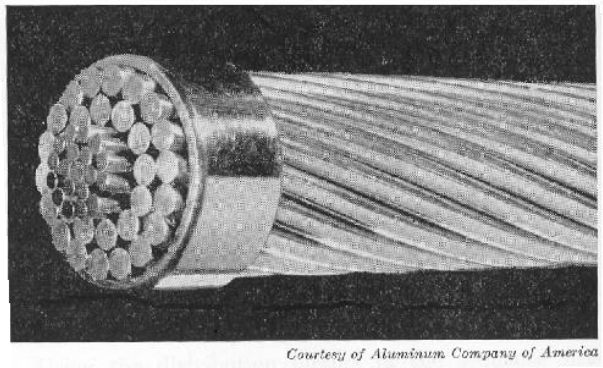
- Reduces power losses
- Transmission conductor can have a smaller cross-section



(a)



(b)

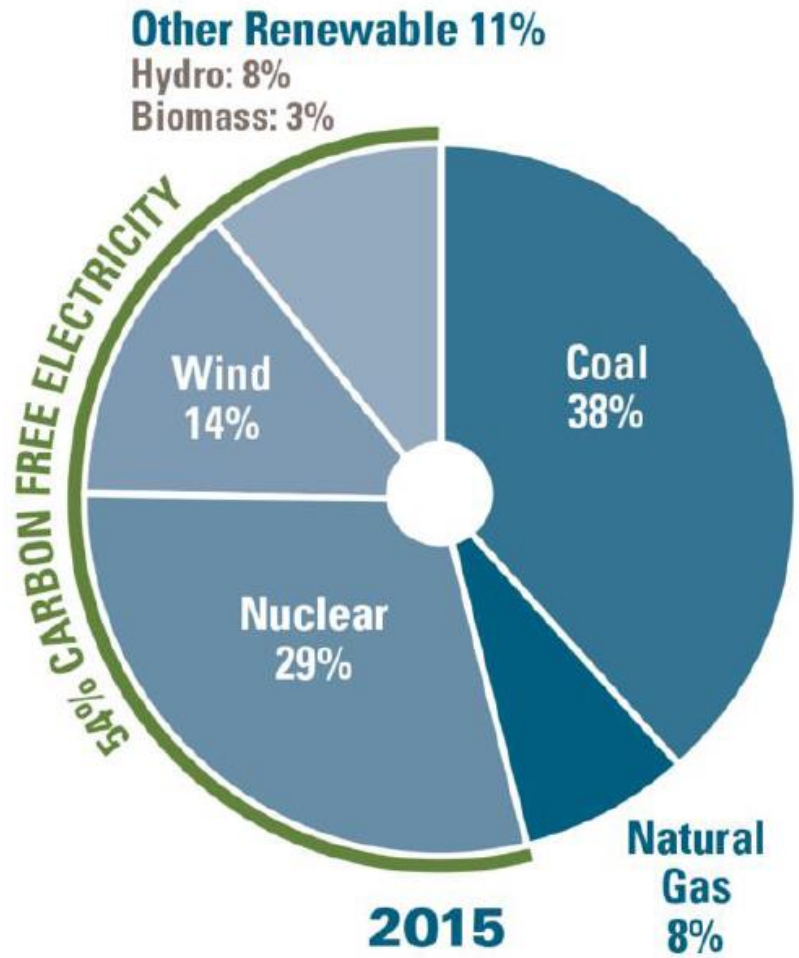


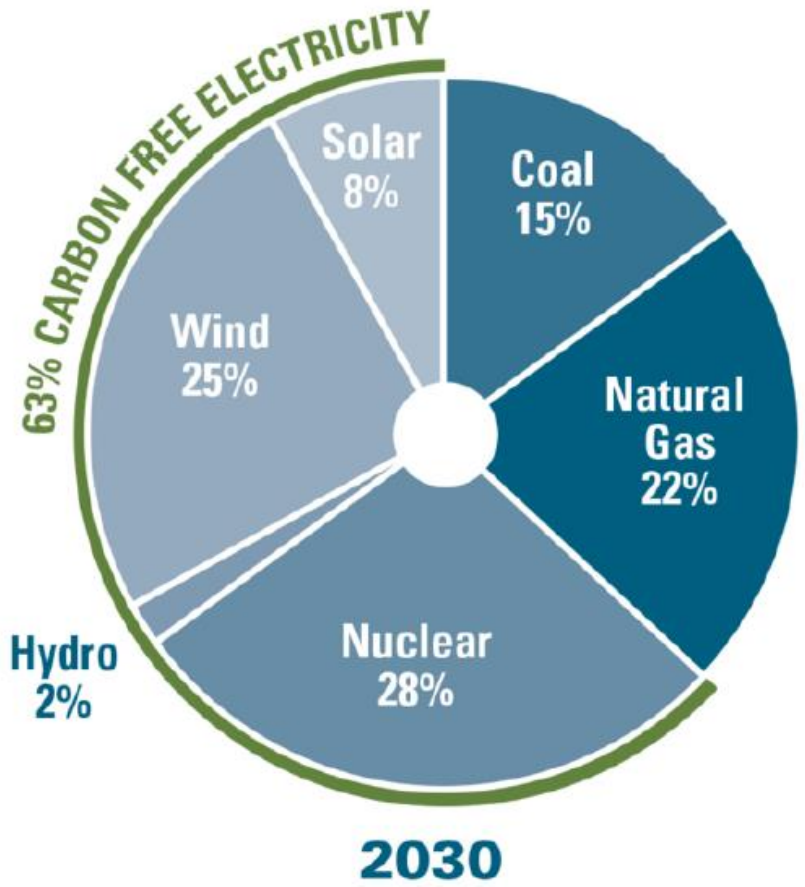
(c)

Power Transformers

- Step-up the voltage
- Step-down the current

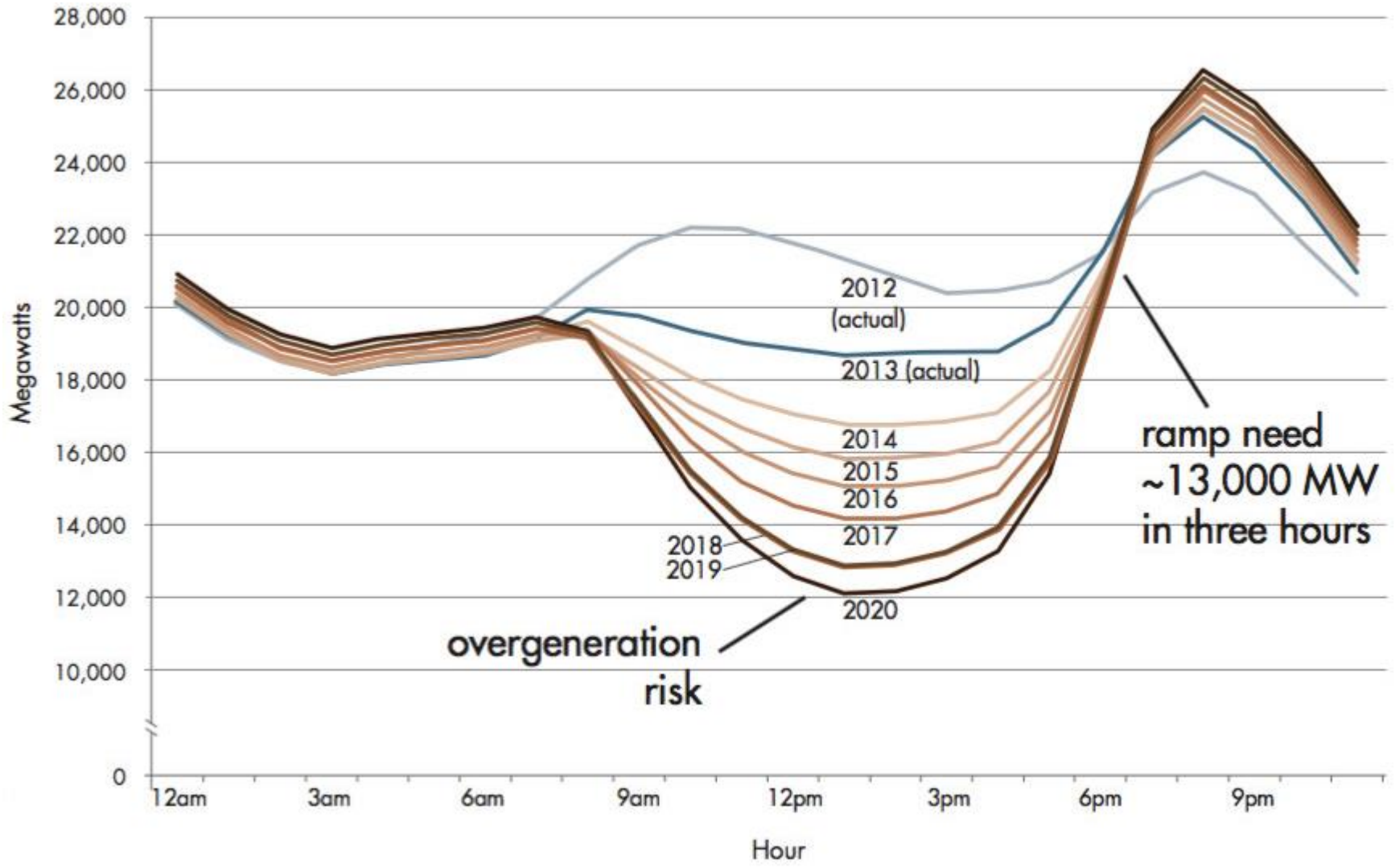
Xcel Energy 15-year plan proposes cost-effective shift to renewables



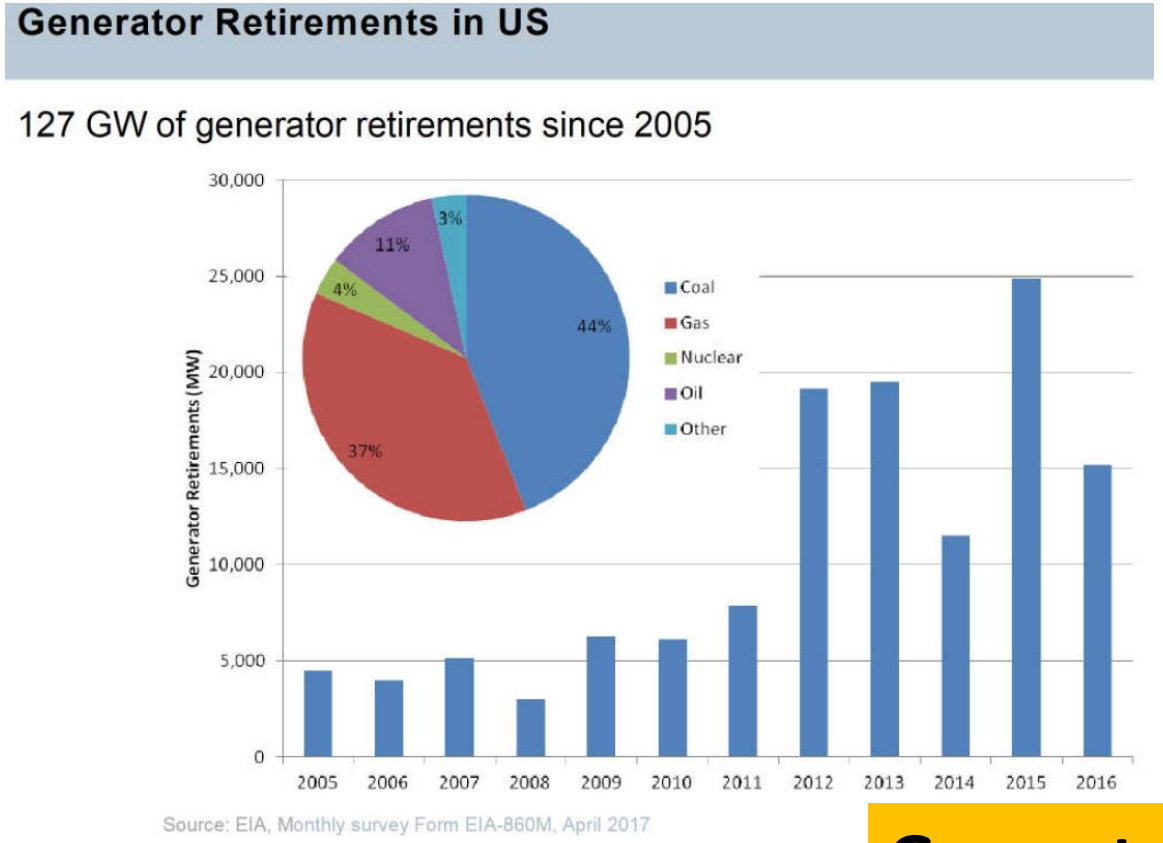


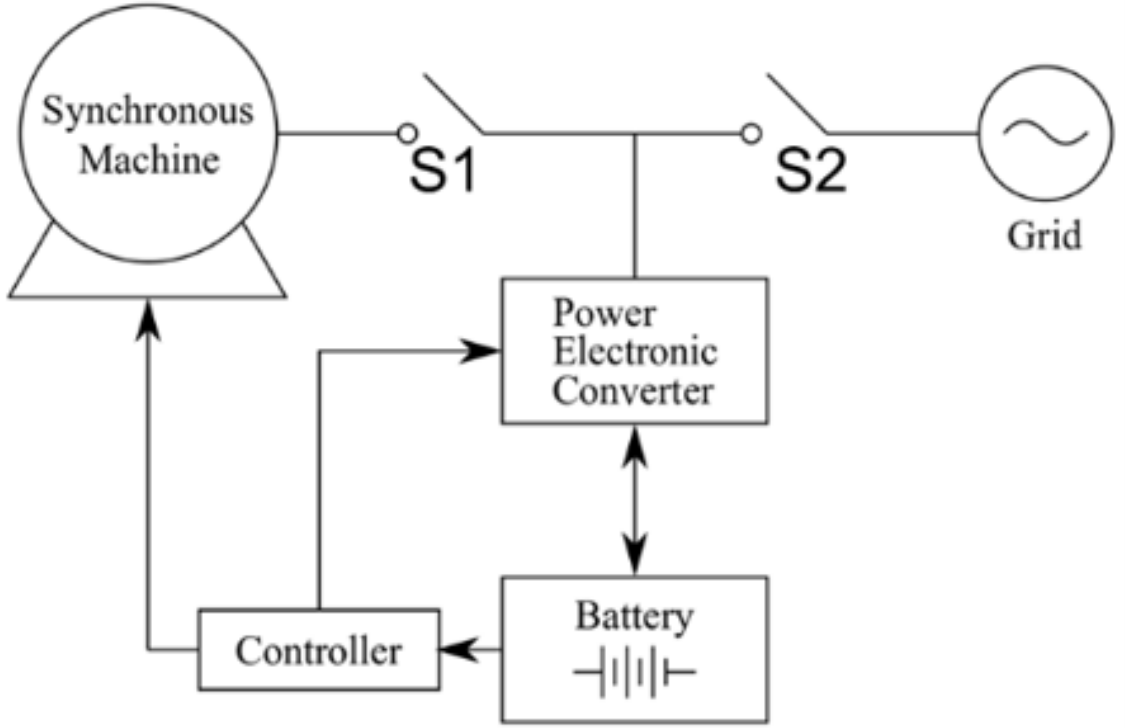
Source: Xcel Energy

100% by 2045 renewable energy bill introduced in California



Can We Follow California's Lead? Use of Retiring Assets

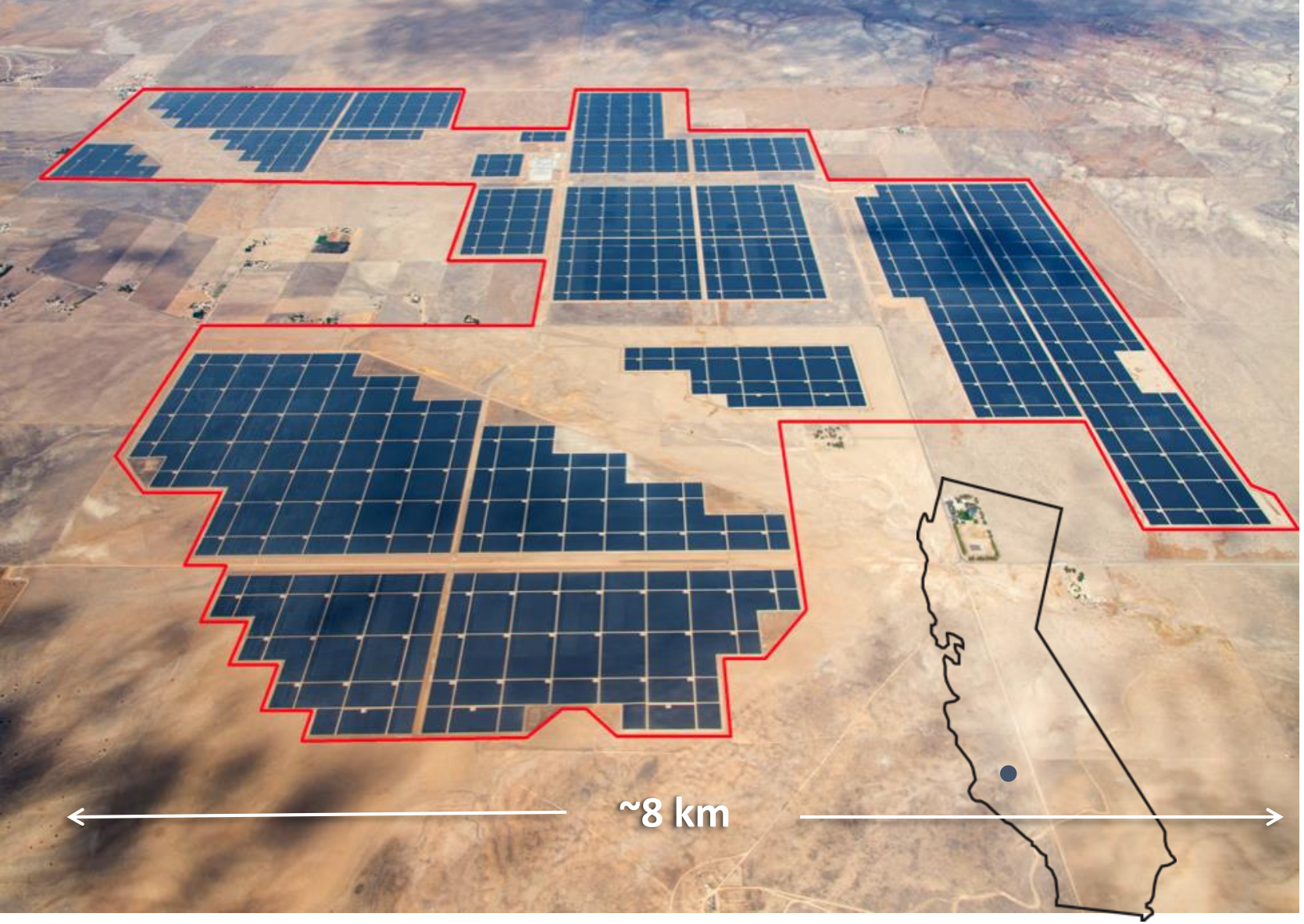




Generators as synchronous condensers:

- **Frequency regulation**
- **Voltage support**

Batteries for Real Power Exchange for damping



San Luis Obispo County, California

Customer: MidAmerican

Size: 550MW (AC)

Construction Time: 2011—2015

Acres: ~7,500 site

Modules: ~9 million

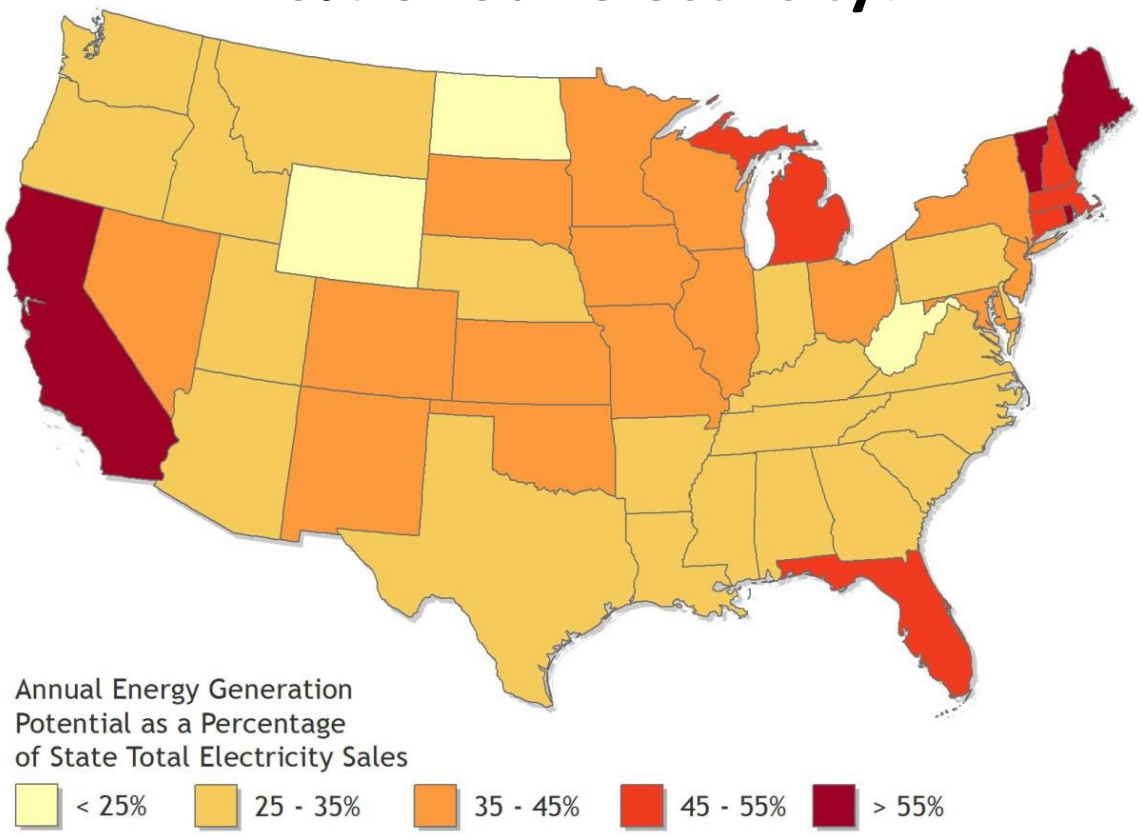
Equivalent to:

Residential PV Systems:

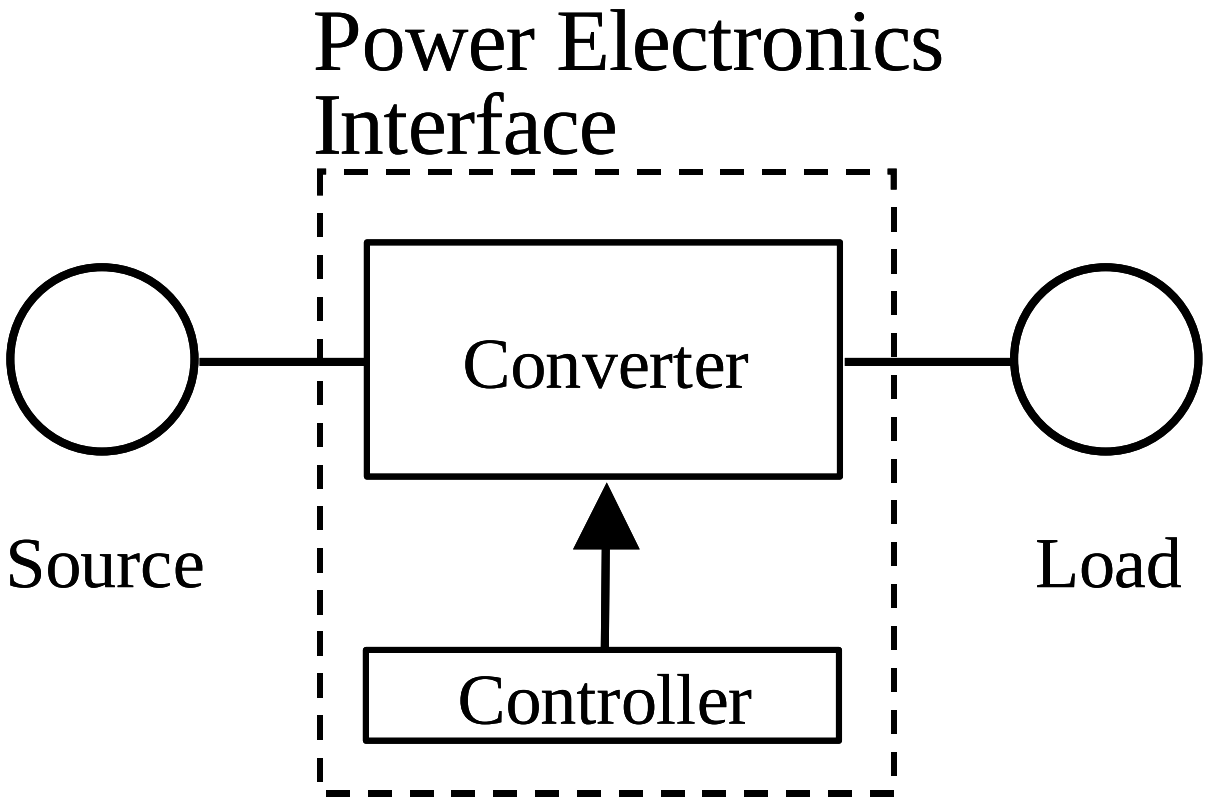
55,000

Topaz Solar Farm

Rooftop solar can generate ~40% of our electricity!



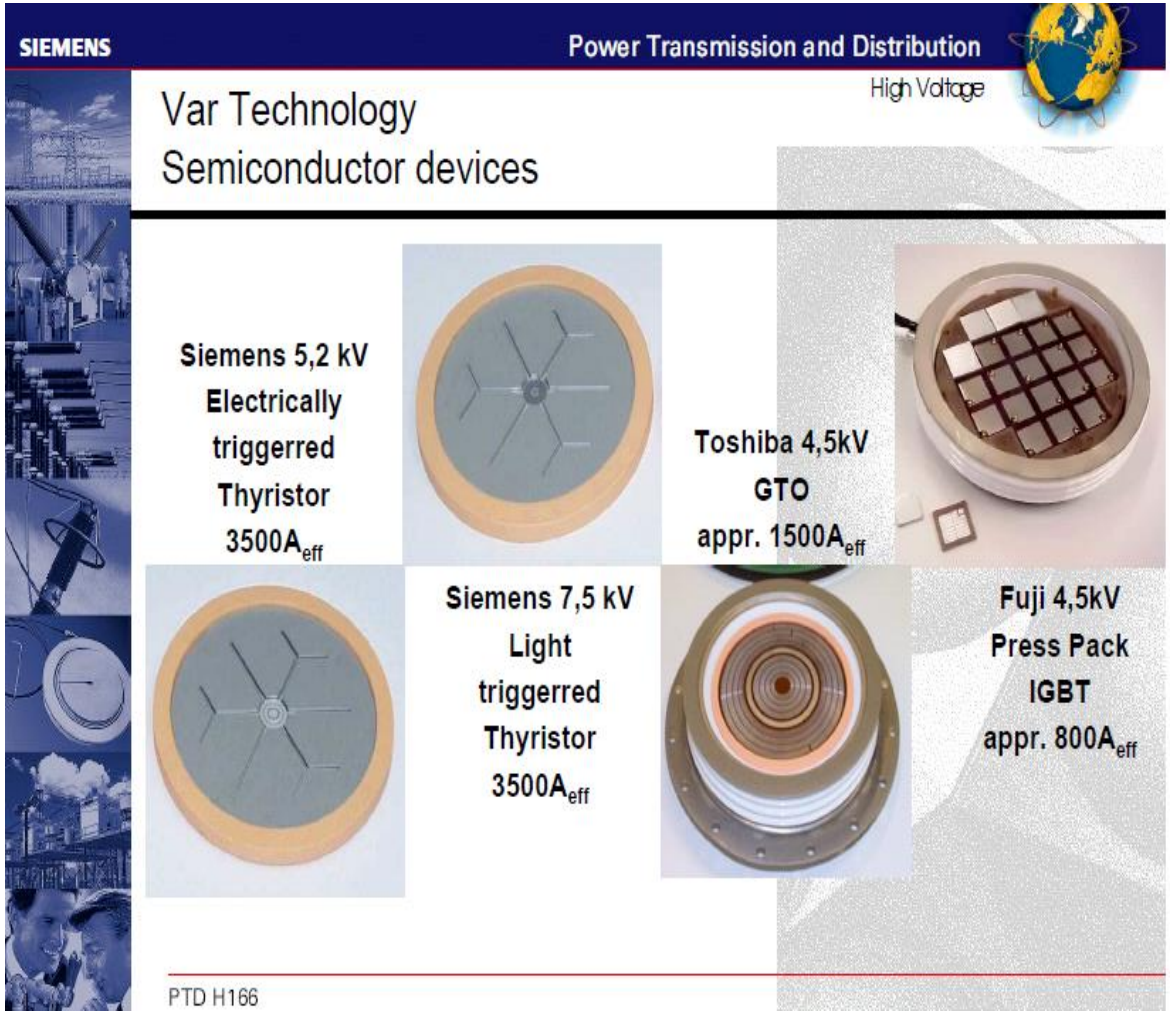
Power Electronics – An Interface



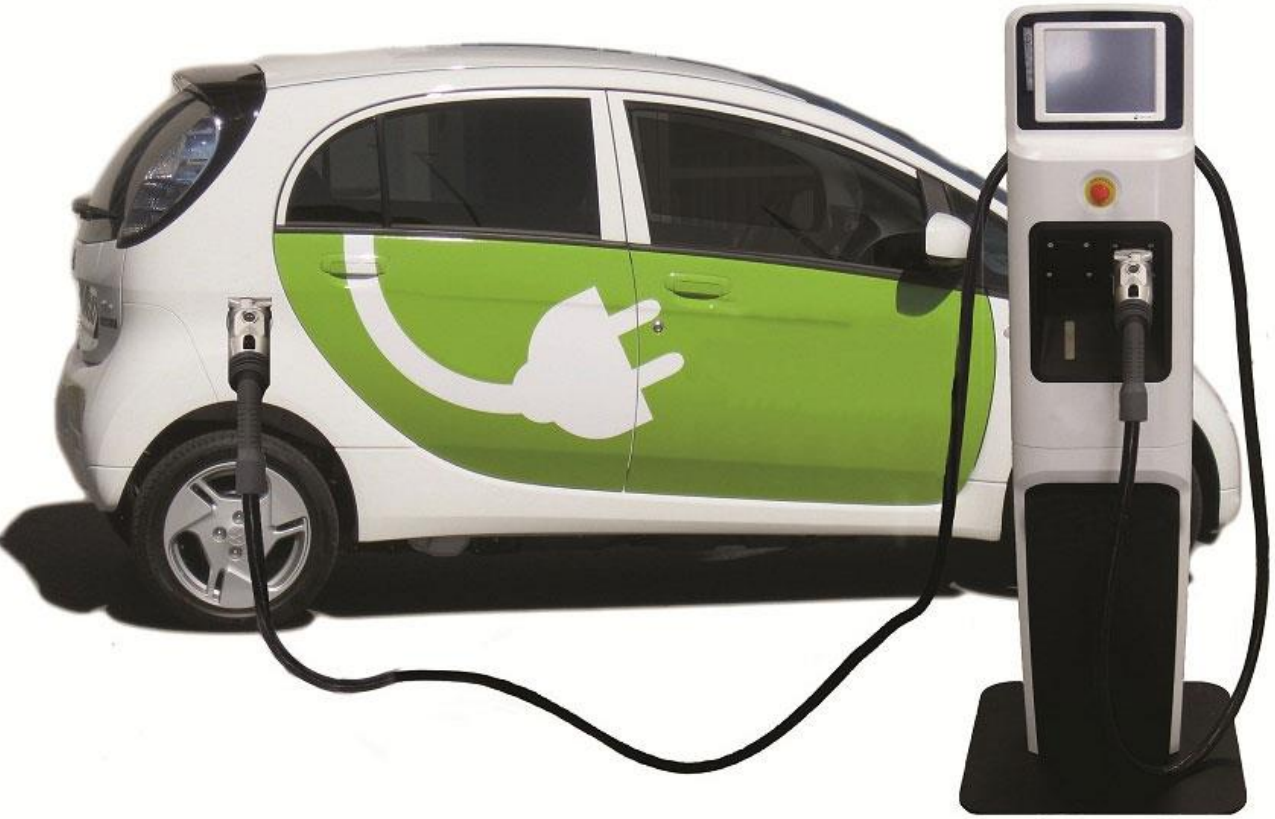
Interface between different characteristics
- Bi-directional Power Flow possible
- Energy Efficiency: 95-98 percent

Realizing Power Electronics Interface

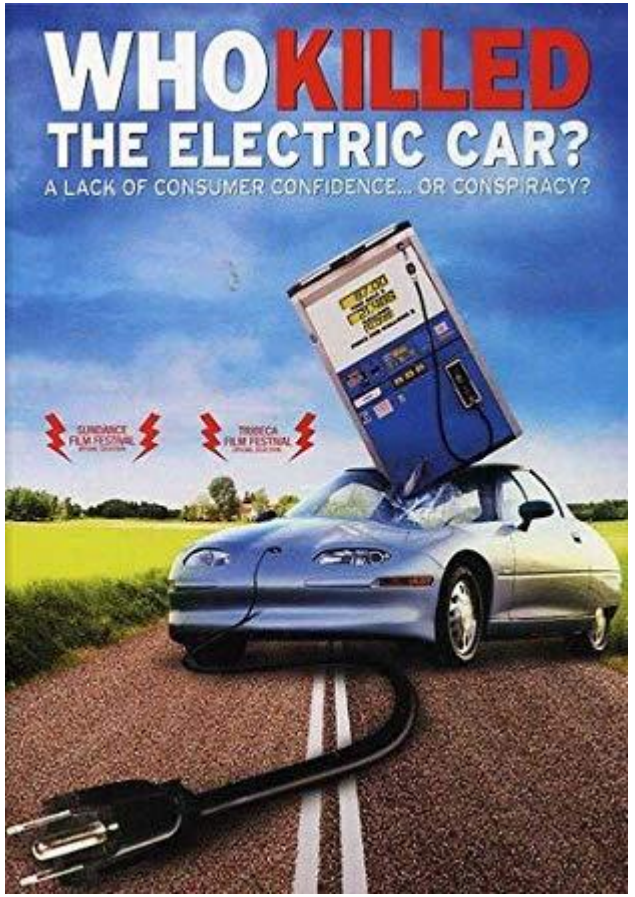
Transistors



EVs



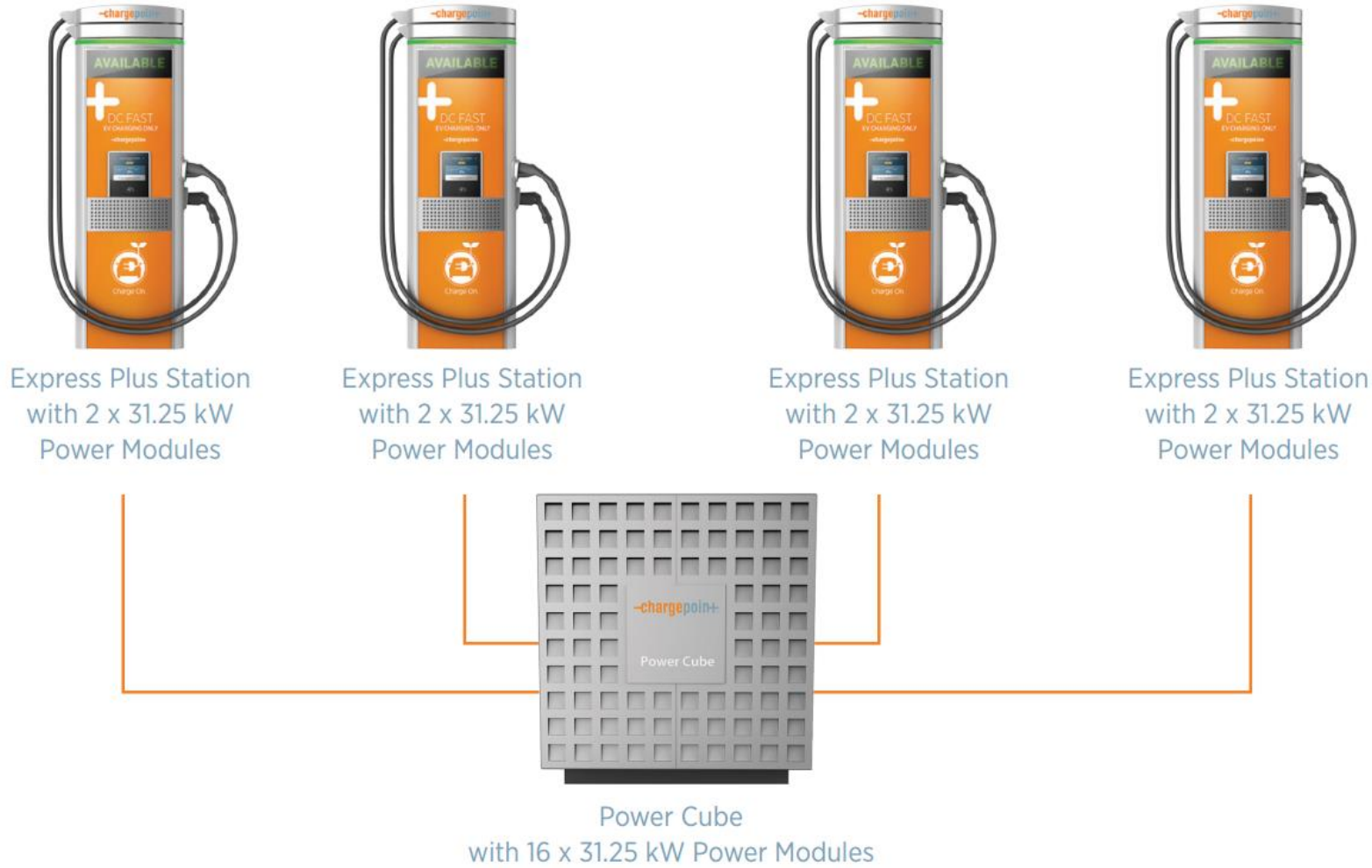
Minnesota Rectifier



Electrifying Transportation

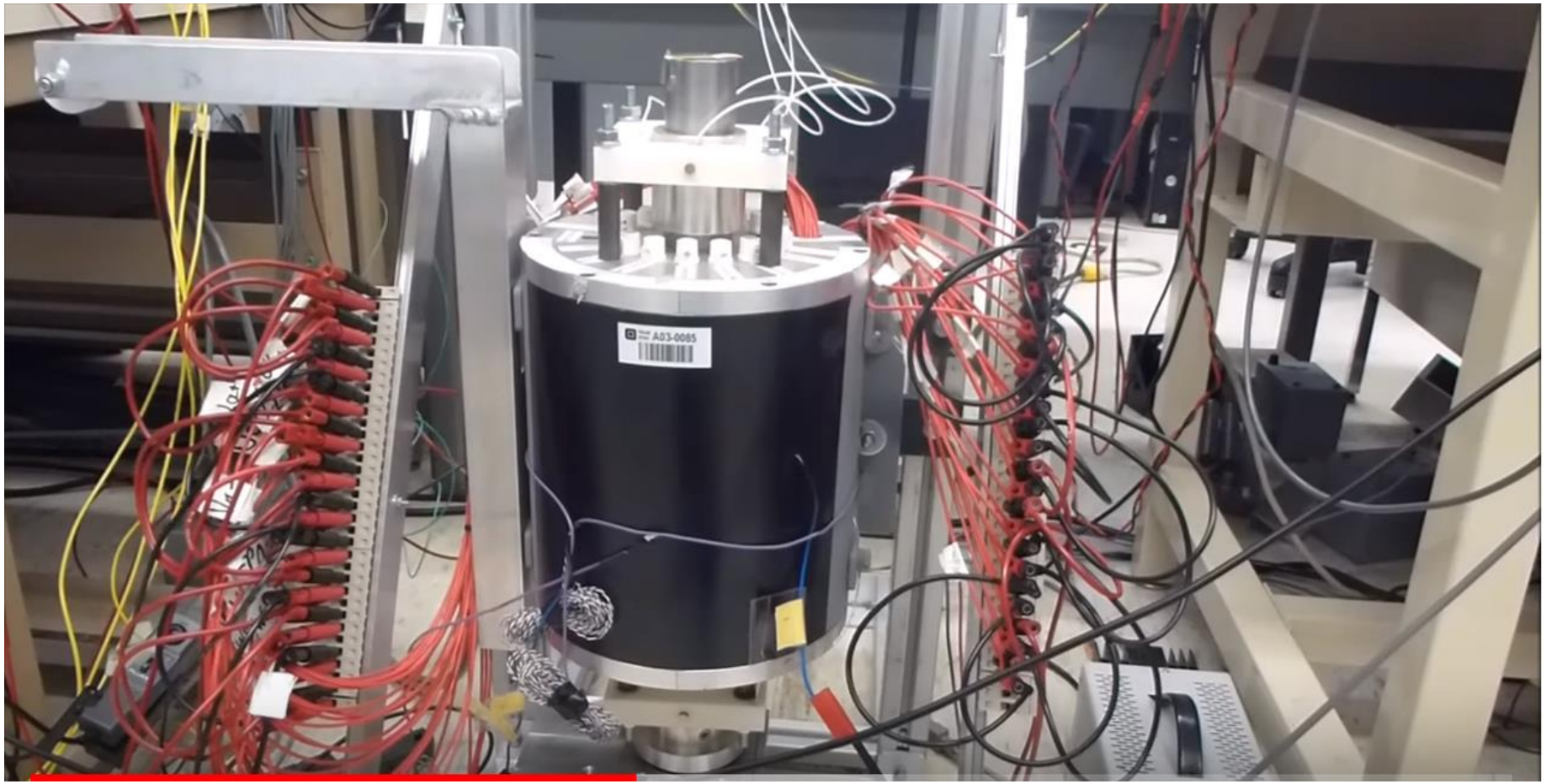
Charging Stations

DC Fast-Charging Infrastructure



https://www.chargepoint.com/files/datasheets/ds-expressplus.pdf

Flywheel Storage



https://www.youtube.com/watch?v=Pi5amZP5yhE

Power Electronics Group at UofM

- Over 150 MS students
- 46 PhDs so far
- 8 PhD, several MS and 3 post-docs at present

Sponsors:

- UMCEE University of Center for Electric Energy
  - Since 1981
  - Supported by 6 regional utilities
- ONR, NSF, DOE, EPRI, RDF/Xcel Energy

Our Responsibility –

There is no Planet B.

Carl Sagan: There is no hint that help will come from elsewhere to save us from ourselves.

44

Thank You!

Bio of Ned Mohan:

Ned Mohan joined the University of Minnesota in 1975, where he is Oscar A. Schott Professor of Power Electronic Systems. He received his undergraduate education in India. He came to the University of Wisconsin in 1969 and earned his Masters in Nuclear Engineering, and PhD in electrical engineering under the supervision of Prof. Harold Peterson.

He has written 5 textbooks; cumulatively they have been translated in to nine languages. He has several U.S. Patents and has supervised nearly 150 graduate students, 46 of them PhDs including 11 who are working in the Twin Cities. He maintains a strong research program that at present consists of 8 PhD students and 3 post-docs.

Prof. Mohan is a Morse-Alumni Distinguished Professor and a member of the Academy of Distinguished Teachers UMN. Prof. Mohan is a Fellow of the IEEE and a member of the National Academy of Engineering.

Bio of Mark Ahlstrom

Mark Ahlstrom is President of the Board of the Energy Systems Integration Group, the non-profit educational association for the engineers, researchers, technologists and policymakers working on our evolving electricity and energy systems. ESIG's (www.esig.energy)history spans 30 years, starting as the Utility Wind Interest Group (UWIG) in 1989.

Based in Saint Paul, Mark was CEO of WindLogics and has been involved with numerous renewable integration studies including the Xcel Wind Integration Study (2004) and Minnesota Wind Integration Study (2006). WindLogics was acquired in 2006 by NextEra Energy, a leading clean energy company and the world's largest generator of renewable energy from the wind and sun. WindLogics continues to grow in Saint Paul as NextEra Analytics, a cutting-edge center for advanced meteorology, data science & optimization for energy and storage systems.

Mark is now Vice President of Renewable Energy Policy for NextEra Energy Resources ((www.nee.com). He is actively involved in many activities across North America to support the economic and reliable use of higher levels of clean energy.

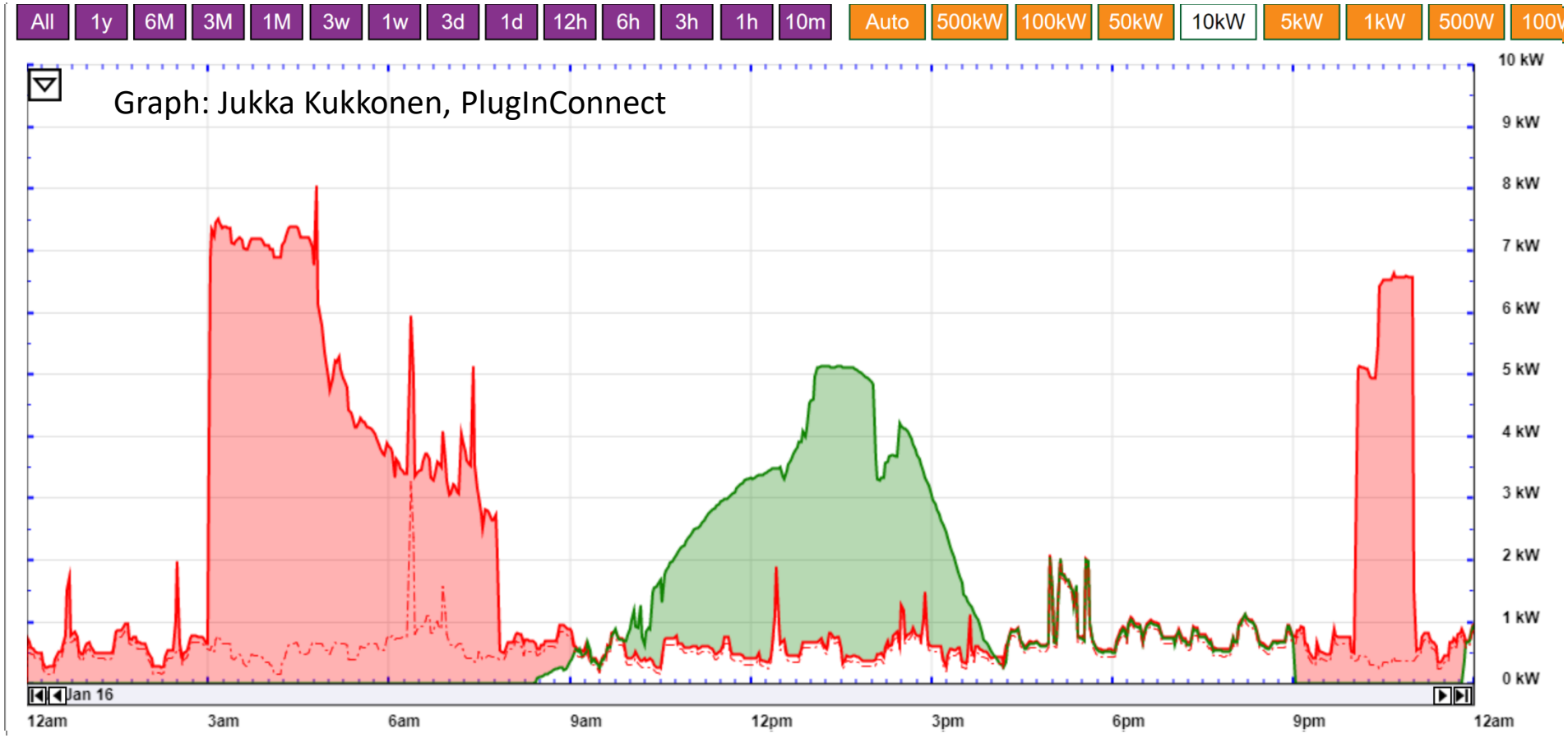
Bio of Jukka Kukkonen:

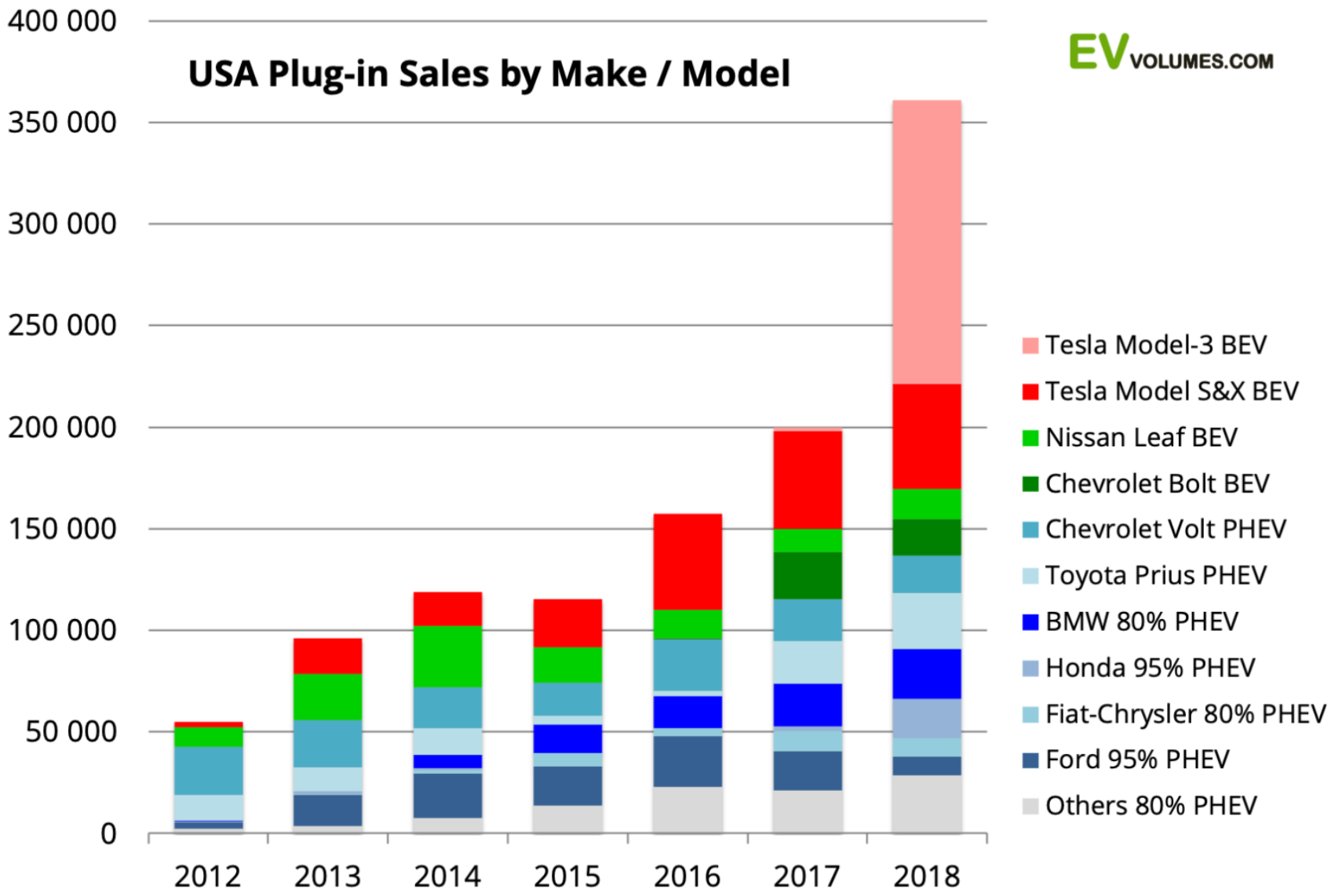
Jukka Kukkonen from PlugInConnect is an EV market and business solutions consultant. Jukka has deep knowledge of the electric vehicle market and he specializes in market dynamics and real-life user perspectives.

He has built programs for utility companies, condominium and apartment building charging, workplace charging, DC fast charging, outreach and education and smart grid integration. He also teaches "EV Market and Technologies" graduate course at the University of Saint Thomas.

You can find out more about his work by visiting www.PlugInConnect.com

Residential household




USA Plug-in Sales by Make / Model
EVVOLUMES.COM
400 000
350 000
300 000
250 000
200 000
150 000
100 000
50 000
0
2012
2013
2014
2015
2016
2017
2018
Tesla Model-3 BEV
Tesla Model S&X BEV
Nissan Leaf BEV
Chevrolet Bolt BEV
Chevrolet Volt PHEV
Toyota Prius PHEV
BMW 80% PHEV
Honda 95% PHEV
Fiat-Chrysler 80% PHEV
Ford 95% PHEV
Others 80% PHEV

Plug-in vehicles available in Midwest (January 2019)

Midwest EVOLVE

Manufacturer										Range			Charging speed (miles/hr)			Performance				
Name	Model	Photo	Seating	PEV Type	FWD/ RWD/ AWD	Base MSRP	Federal tax credit	Price after federal tax credit	Battery size (kWh)	Electric Range (miles)	Total Range (miles)	Level 2 Charging Rate (kW)	Level 1 120v	Level 2 240v	DCFC 400+v	MPGe/MPG	Top Spd (mph)	0-60 mph (sec)	Towing capacity (lbs)	NHTSA Crash Rating
Audi	A3 E-Tron		5	PHEV	FWD	$38,900	$4,168	**$34,732**	9	17	430	3.3	3	8	N/A	86/39	130	7.6	0	NR
BMW	i3		4	BEV	RWD	$44,450	$7,500	**$36,950**	42	153	153 (200)	7.4	4	27	166	124 (39)	93	6.9-7.2	0.0	4 star
BMW	i8		4	PHEV	AWD	$147,500	$3,793	**$143,707**	7.2	15	330	3.3	3	7	N/A	76/28	155	4.2	0	NR
BMW	X5 xDrive40e		5	PHEV	AWD	$62,100	$4,700	**$57,400**	9	14	540	3.3	2	5	N/A	56/24	130	6.5	0	NR
BMW	330e		5	PHEV	RWD	$45,600	$4,000	**$41,600**	7.6	14	350	3.7	3	8	N/A	72/31	130	5.9	0	NR
BMW	530e		5	PHEV	RWD/ AWD	$53,400	$4,200	**$49,200**	9.2	16	370	3.5	3	7	N/A	72/29	146	6	0	NR
BMW	740e		5	PHEV	RWD/ AWD	$90,700	$4,200	**$86,500**	9.2	14	340	3.7	2	7	N/A	64/27	130	5.1	0	NR
Chevrolet	Bolt EV		5	BEV	FWD	$37,495	$7,500	**$29,995**	60	238	238	7.2	4	25	159	119	98	6.5	0	5 star
Chevrolet	Volt		4.5	PHEV	FWD	$33,170	$7,500	**$25,670**	18.4	53	420	3.3	4	10	N/A	106/42	98	8.4	0	5 star
Chrysler	Pacifica Hybrid (PHEV)		7	PHEV	FWD	$42,000	$7,500	**$34,500**	16	33	570	6.6	3	16	N/A	84/32	107	7.8	0	NR
Ford	Fusion Energi		5	PHEV	FWD	$31,120	$4,007	**$27,113**	7.6	21	610	3.3	3	10	N/A	97/42	85	8.5	0	5 star
Honda	Clarity PHEV		5	PHEV	FWD	$33,400	$7,500	**$25,900**	17	48	340	6.6	4	22	N/A	110/42	110	8.8	0	NA
Jaguar	I-PACE		5	BEV	AWD	$69,500	$7,500	**$62,000**	90	234	234	7	4	18	180	76	124	4.5	0	NR
Kia	Niro PHEV		5	PHEV	FWD	$27,900	$4,543	**$23,357**	8.9	26	560	3.3	4	10	N/A	105/46	107	9	0	NA
Mini	Cooper S E ALL4		5	PHEV	FWD	$36,900	$4,001	**$32,899**	7.6	12	270	3.3	4	8	N/A	65/27	NA	6.8	0	NR

This table was updated by Jukka Kukkonen, PlugInConnect. Photos and information sources: Manufacturers' websites and www.fueleconomy.gov Find the latest version by visiting: www.pluginconnect.com/MNpevmodels.html