



# An Industrial Perspective on the Energy Challenges of Today

James Maughan  
Senior Executive and General Manager  
Cores and Castings  
GE Power

Meet The Energy Leaders  
TU Delft  
November 17, 2017

An item of interest  
from reading the  
news on the way  
over



Nelson Bryant (USA) receiving from André Duijghuisen (NL)  
the knife he lost when parachuting into the Netherlands on  
Sept 17, 1944.

# Agenda

- GE's role in power generation
- Is the future like the past in power generation?
- Two awesome power technologies
- Fossil fuels vs renewable energy
- What choice would you make?



# GE Power



# GE Power – equipment for any fuel, any region, any need

**AERO  
ENGINES**



**SOLAR PV**



**GAS  
TURBINES**



**ONSHORE  
WIND**



**GE HITACHI  
NUCLEAR**



**POWER  
CONVERSION**



**OFFSHORE  
WIND**



**STEAM  
TURBINES**



**PLANT EQUIPMENT**



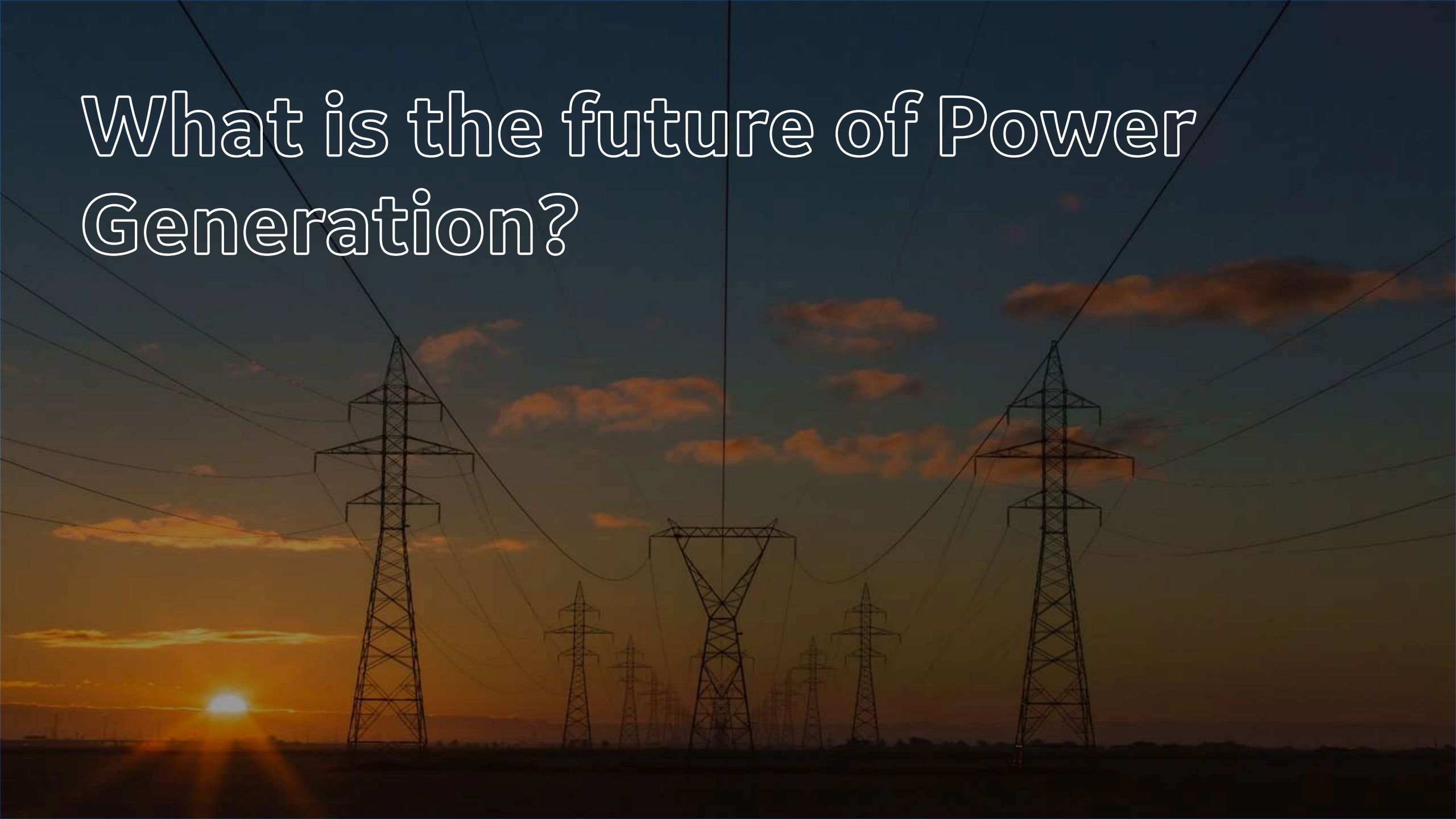
**HYDRO**



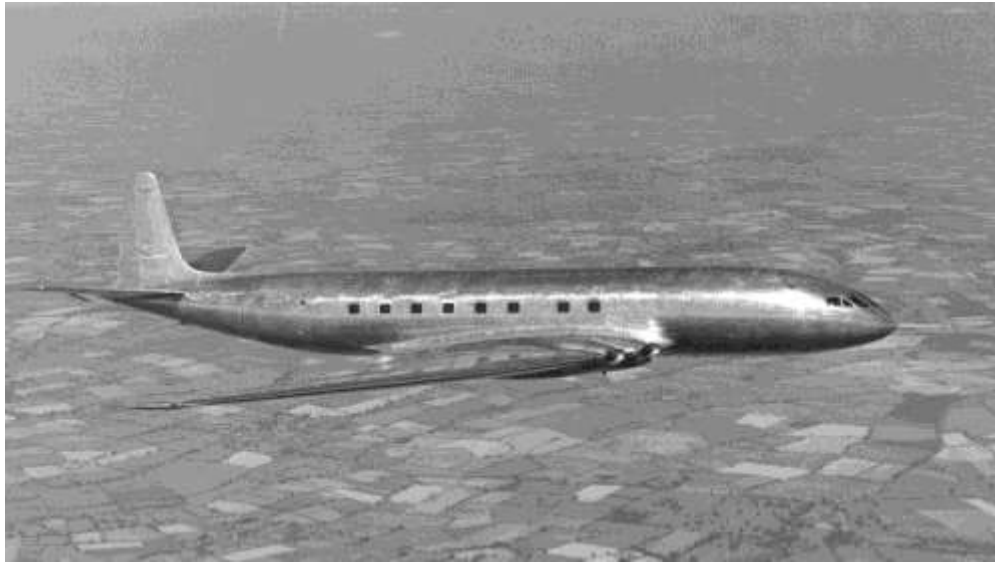
- \$49B revenue
- Expansive global reach... >150 countries
- Leading technology, >1/3 of the world's power
- ~2,500 GW installed capacity
- >950,000 installed assets
- #1 gas turbine supplier, #4 steam, #2 wind



# What is the future of Power Generation?



# How did Aviation thinks its future would change in 50 yrs?



de Havilland Comet, 1946

How much will Power and Aviation change in the next 50 years? What technologies will win and lose?

Speculation



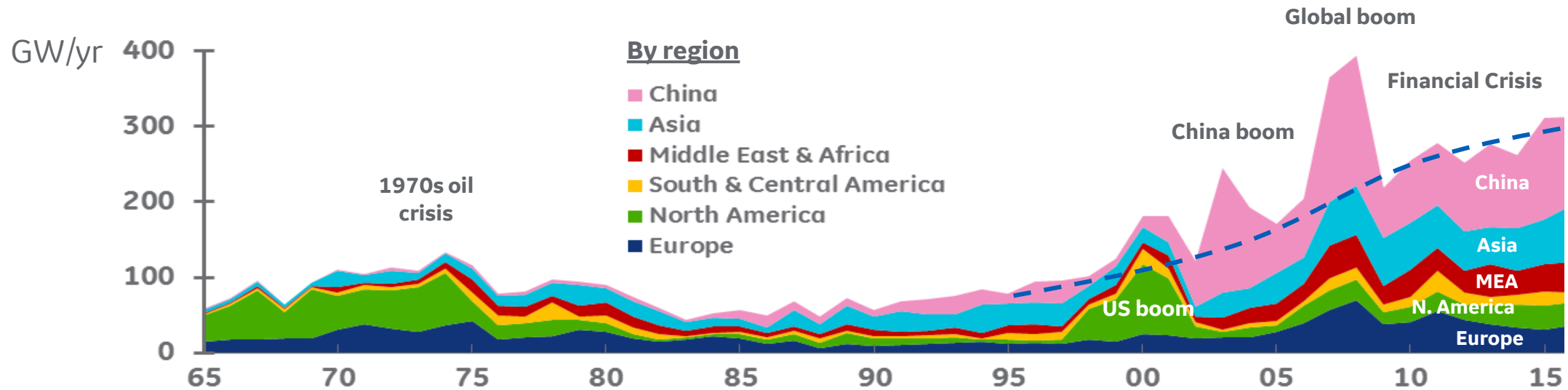
Reality



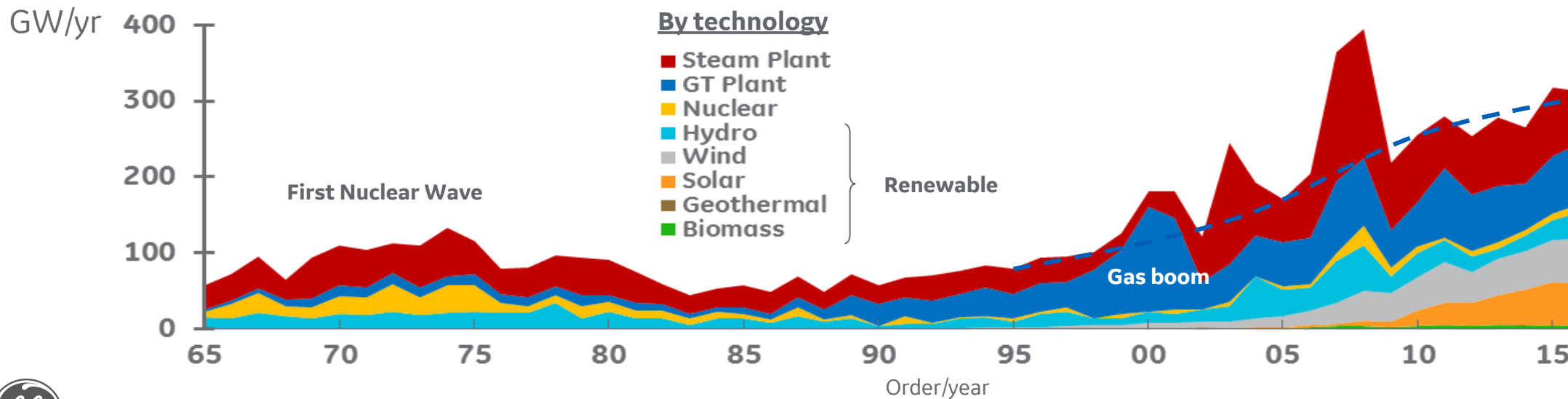
Boeing 787 Dreamliner, 2016



# Power generation orders in the last 50 years



The Future ?



The Future ?





Two awesome technologies:

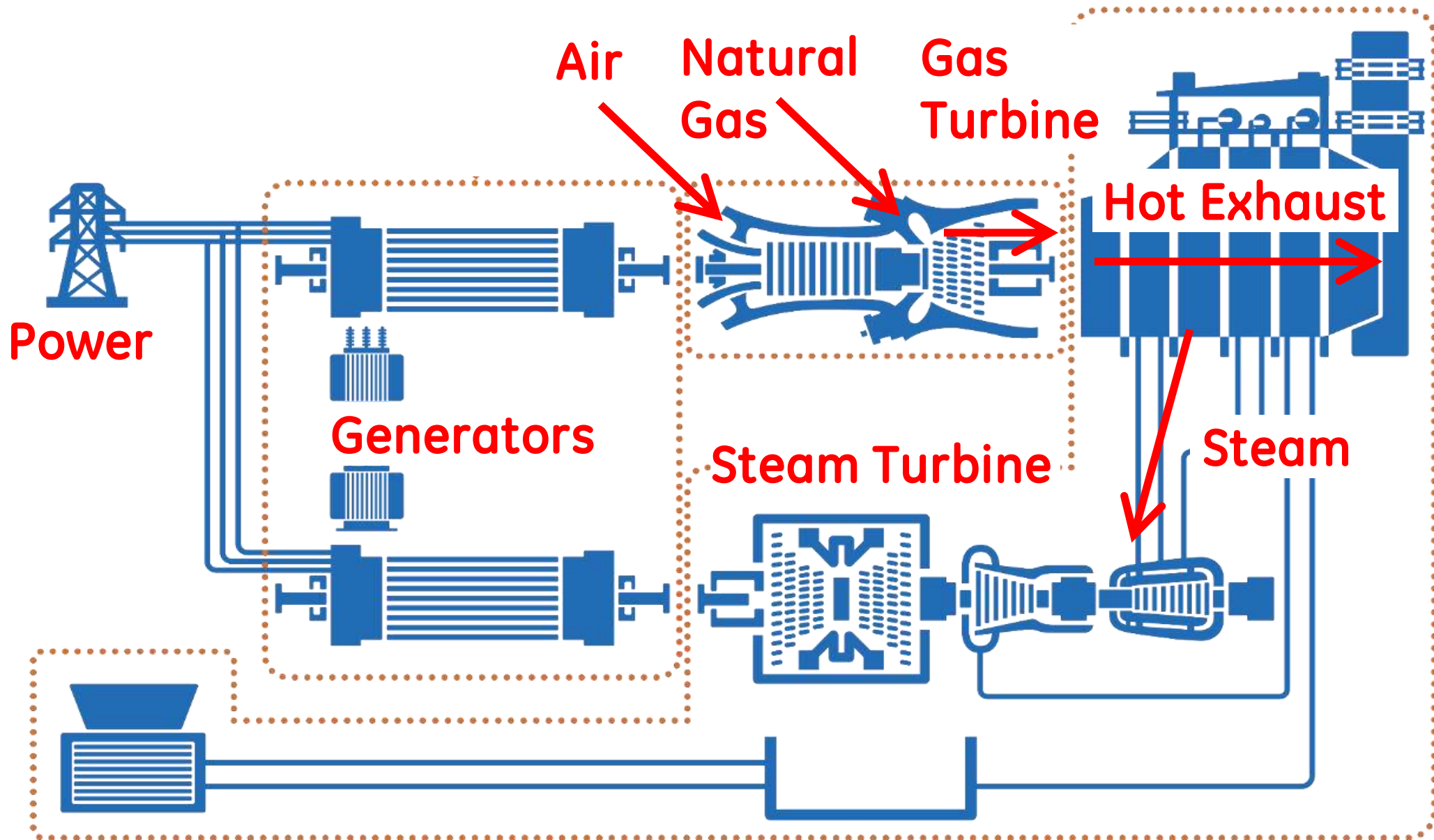
1. Gas Turbines





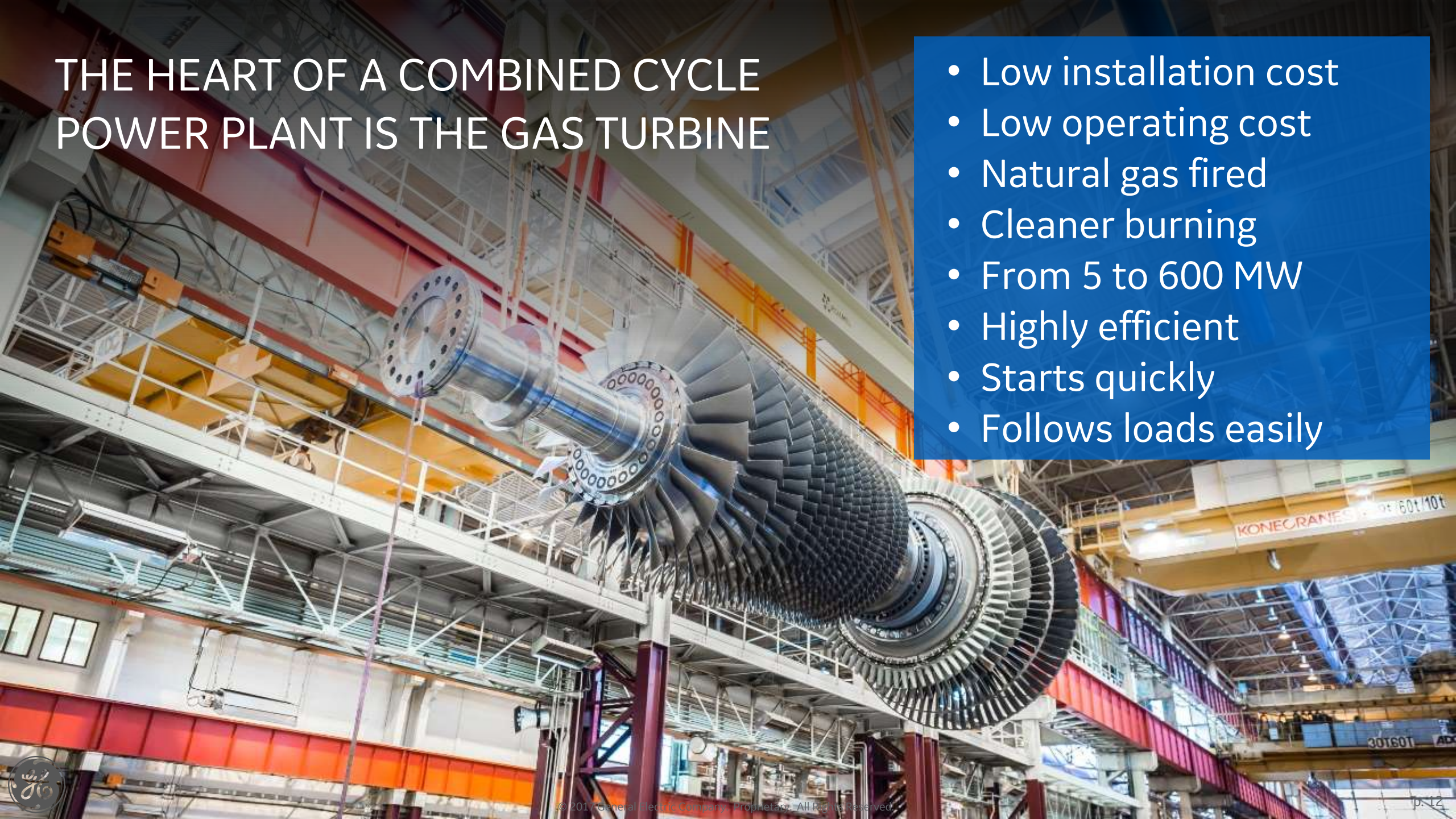
GE 9HA Gas Turbine

# Gas Turbine Combined Cycle for Power Generation



# THE HEART OF A COMBINED CYCLE POWER PLANT IS THE GAS TURBINE

- Low installation cost
- Low operating cost
- Natural gas fired
- Cleaner burning
- From 5 to 600 MW
- Highly efficient
- Starts quickly
- Follows loads easily



# How do you ship something that weighs 800 tons?



# World's Most Efficient Power Plant

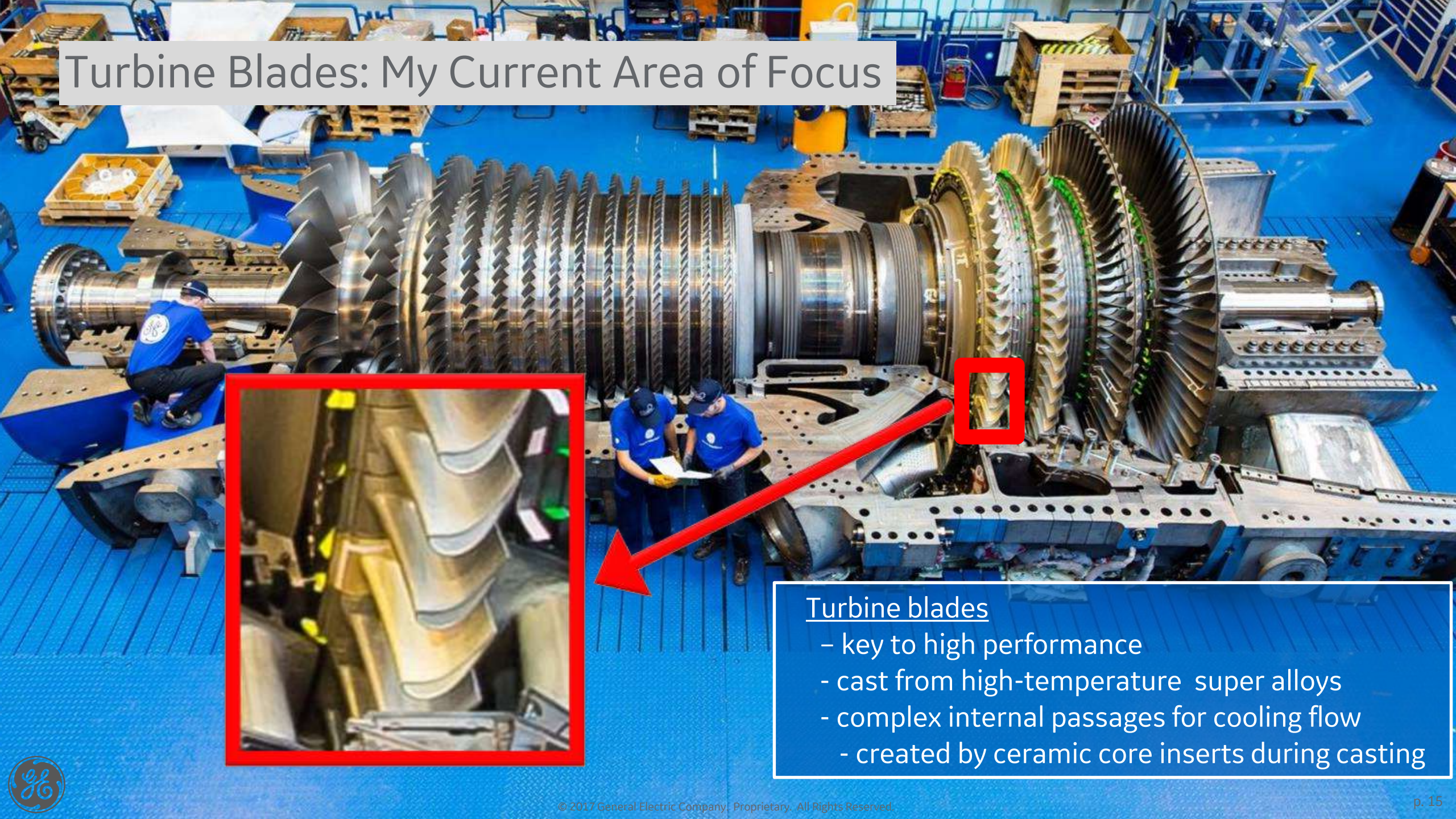


62.22%

**EDF Bouchain in France**  
GE 9HA.01, 605-MW



# Turbine Blades: My Current Area of Focus



## Turbine blades

- key to high performance
- cast from high-temperature super alloys
- complex internal passages for cooling flow
- created by ceramic core inserts during casting



# GE Cores and Castings: State of the Art facility for the design and development of gas turbine cores and blades



GE Plant, Bldg 66, Schenectady, NY





Wax is injected around the 3D advanced core in the exact shape of the blade and wax patterns are assembled for shelling



Thumbnail video



# Wax trees are dipped in multiple layers of ceramic slurry



Thumbnail video



Multiple layers make a complete shell, and the internal wax is melted and removed.



The shell is filled in a vacuum furnace with molten alloy that solidifies into a single crystal



hot shell on plate from below



metal pour



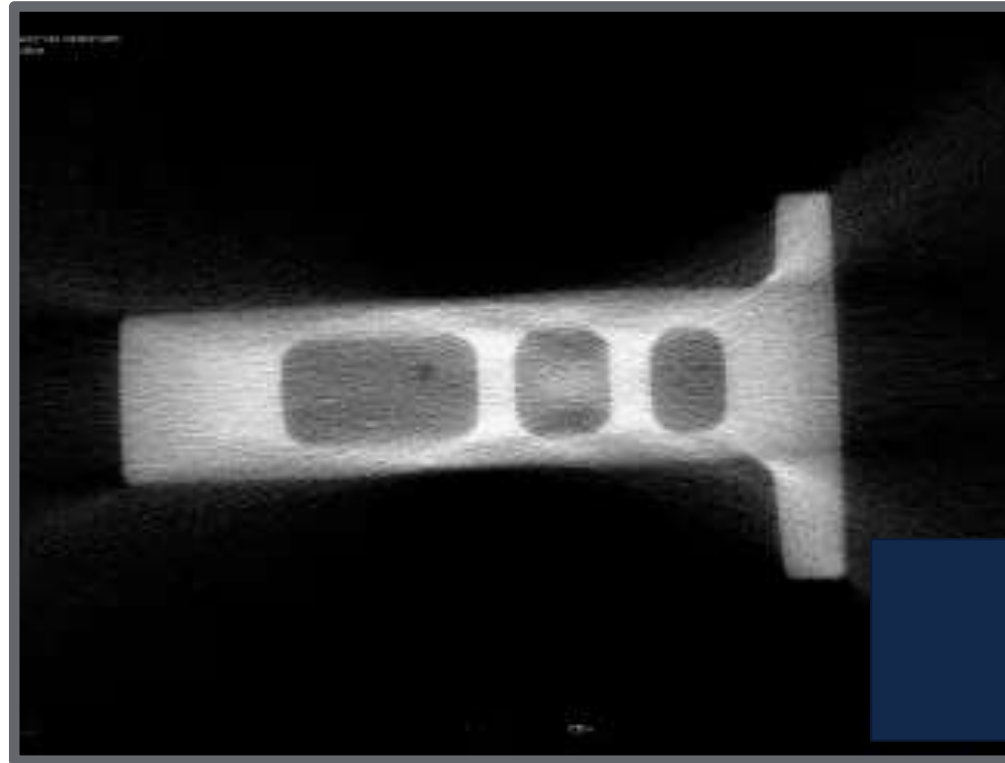
shell after casting



Removing the ceramic shell and leaching out the internal core reveals the gas turbine blade within

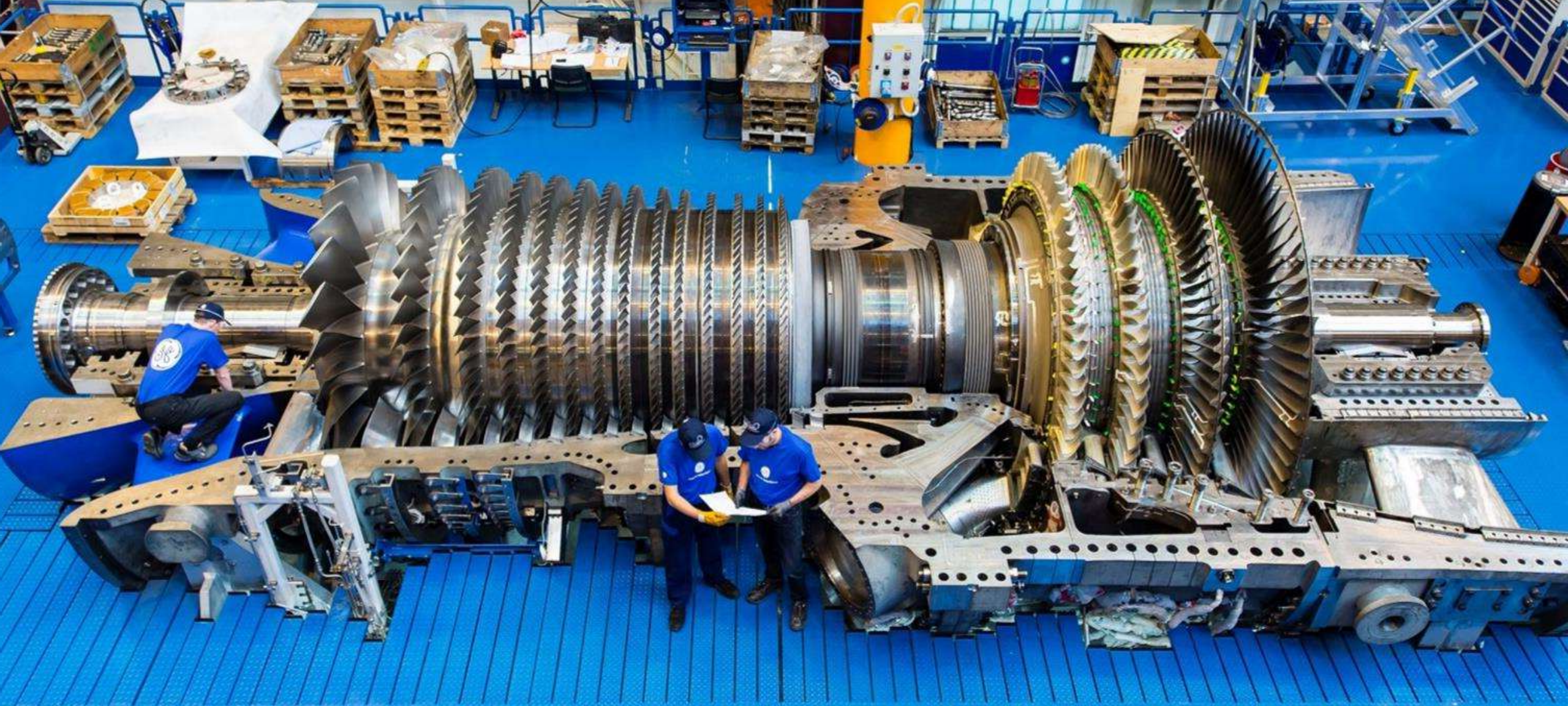


A CT scan shows the detail of the complex internal cooling passages



Thumbnail video of 7HA casting  
- root to tip





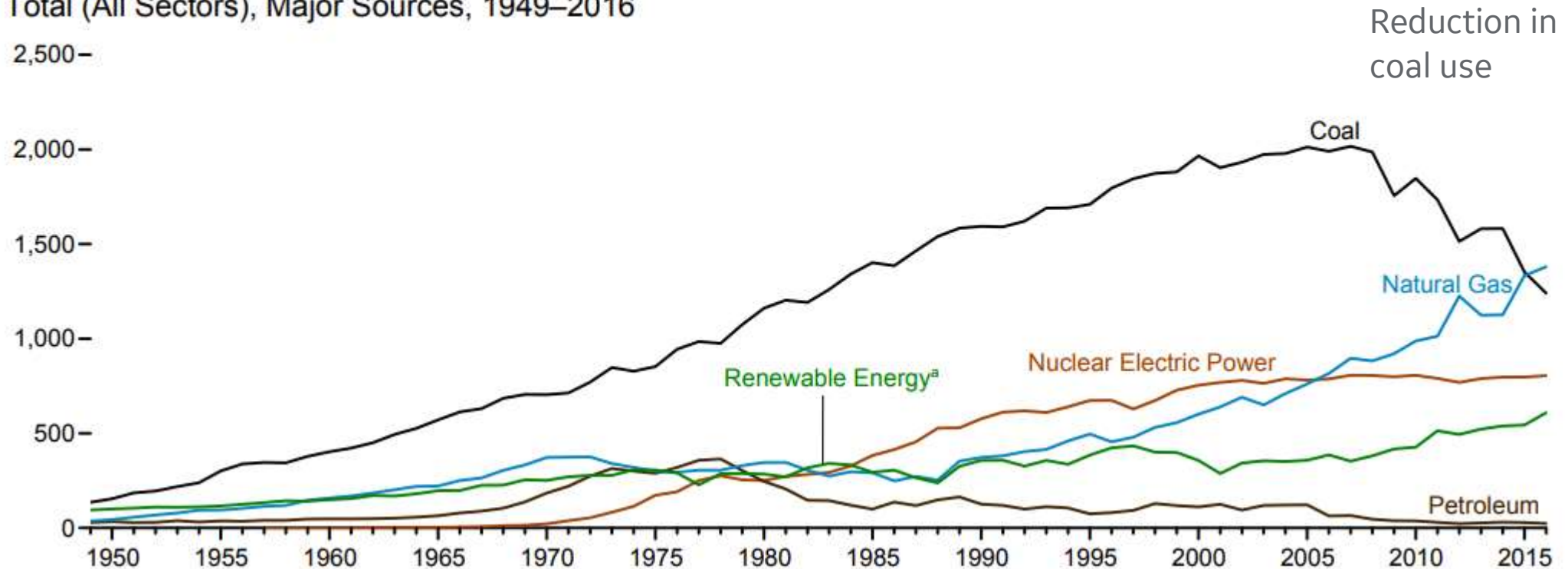
An awesome piece of machinery



Even better, efficient gas turbines are replacing coal for power generation, in the US and elsewhere...

**Figure 7.2 Electricity Net Generation**  
(Billion Kilowatthours)

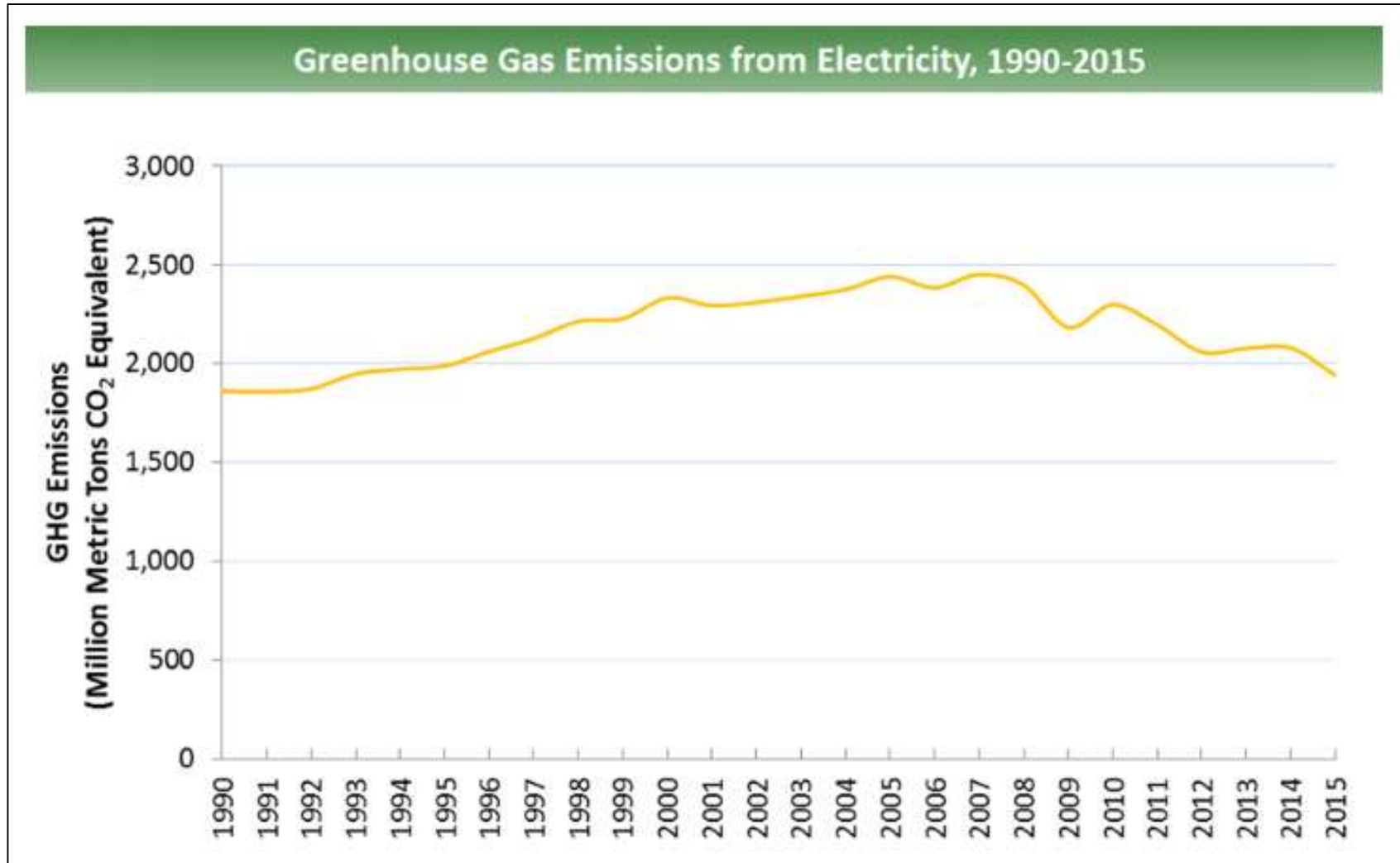
Total (All Sectors), Major Sources, 1949–2016



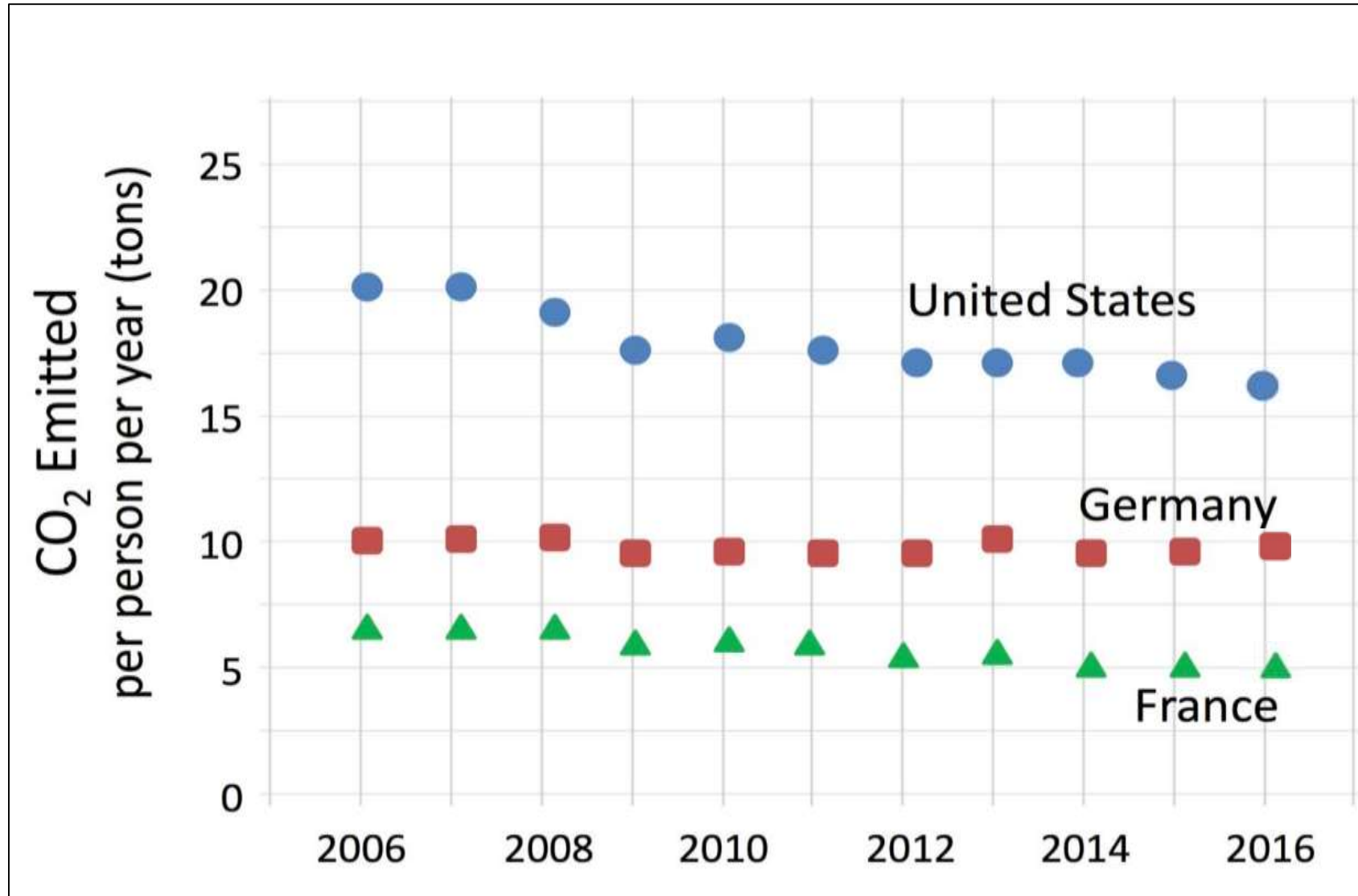


# And help reduce GHG emissions in the US

*The switch to natural gas and better efficiency have the biggest impact*



To everyone's surprise, the US has been reducing GHG intensity



A recent letter from the local paper with dialogue on global warming

# Global warming is a matter of fact, not faith

Facts confirm climate change

Letter To The Editor | October 16, 2017

THE DAILYGAZETTE

THE DAILYGAZETTE | Thursday, November 2, 2017

OPINION

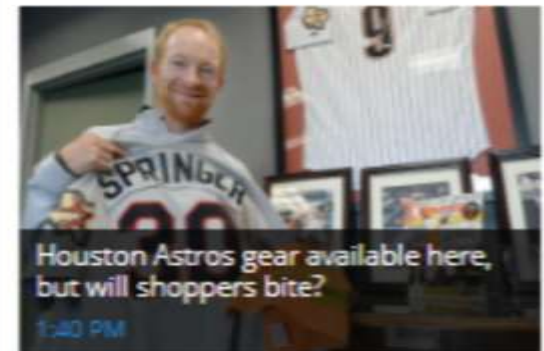
SHARE



In an Oct. 9 letter criticizing an earlier letter to the editor, Bob Lindinger said he was “not a global warming believer or a global warming denier..” I found his choice of the word “believer” an interesting one, since it implies that global temperatures are something that can’t be measured, but must rather be taken on faith.

Personally, I use a device called a thermometer to measure temperature. It tends to take all the believing and non-believing out of the process.

Mr. Lindinger went on to say, “Climate change proponents have made their cause a matter of faith” (again, an interesting choice of words), citing “a great physicist like



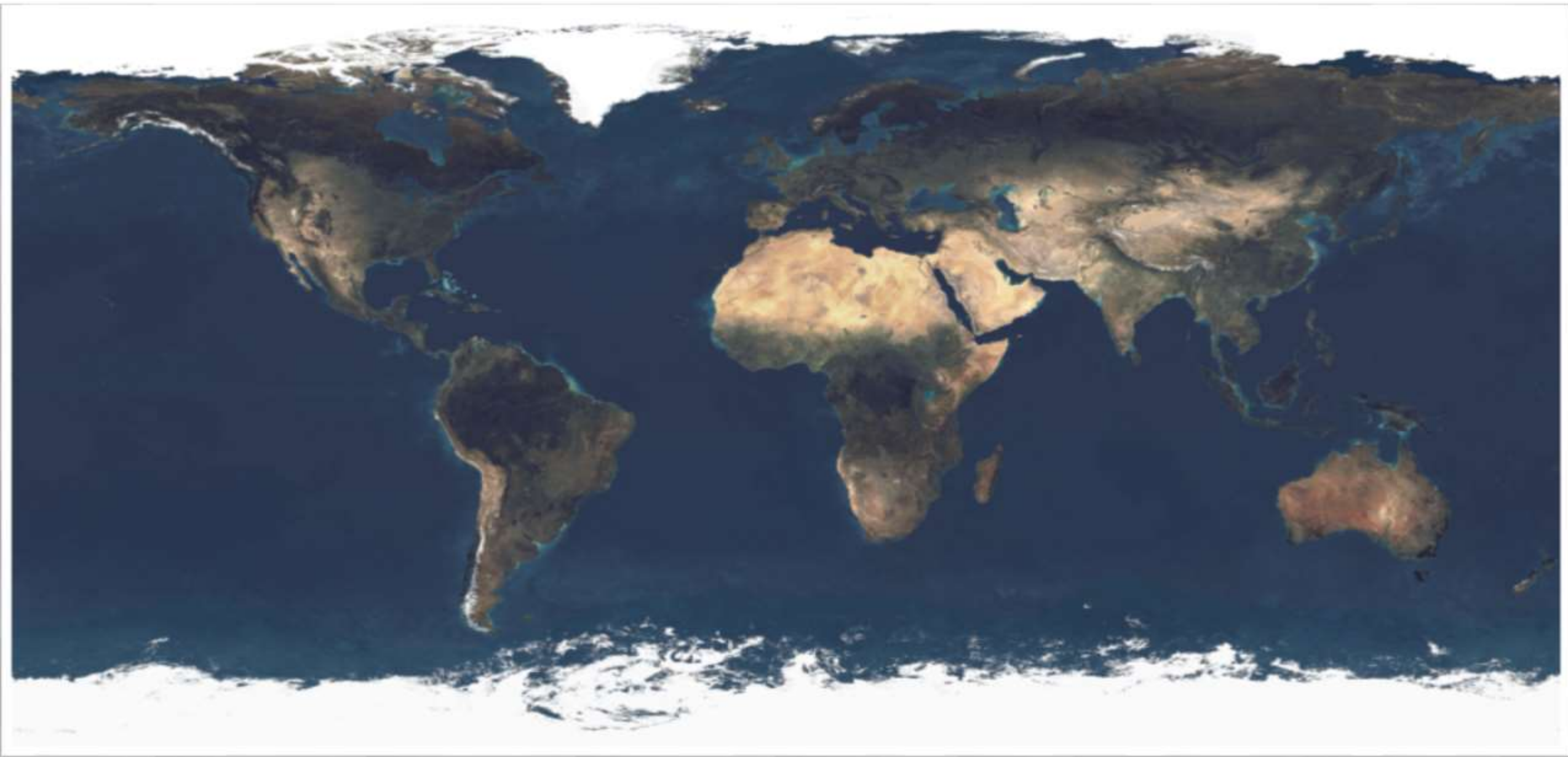
As engineers and scientists, we need to ensure we stay credible here



# How do you measure the temperature of a gas turbine combustor?



How do you measure the temperature of the earth?



Two awesome technologies:

2. Wind Turbines



# GE is big in Renewable Energy



## Onshore Wind

**35,000 turbine  
#2 Global supplier**

## Offshore Wind

**Setting the benchmark  
for the marine energies industry  
First US offshore site**

## Hydro

**Collaborating with customers as  
a leading player in the  
hydropower market**

## LM Wind Power

**Insourcing blade mfg. to  
strengthen GE's supply chain**

**\$10B sales, 80+ countries, 22,000 employees, 400GW installed base**



GE wind turbines are awesome machines...

## **GE's 2.0-116 onshore turbine**

- 2 MW and 116m rotor diameter
- 53.3% gross capacity factor at 7.5 m/s
- 57 meter blades
- 127m tower heights
- sophisticated technology for loads, wake control, and reliability



...and I love climbing them and spreading the word



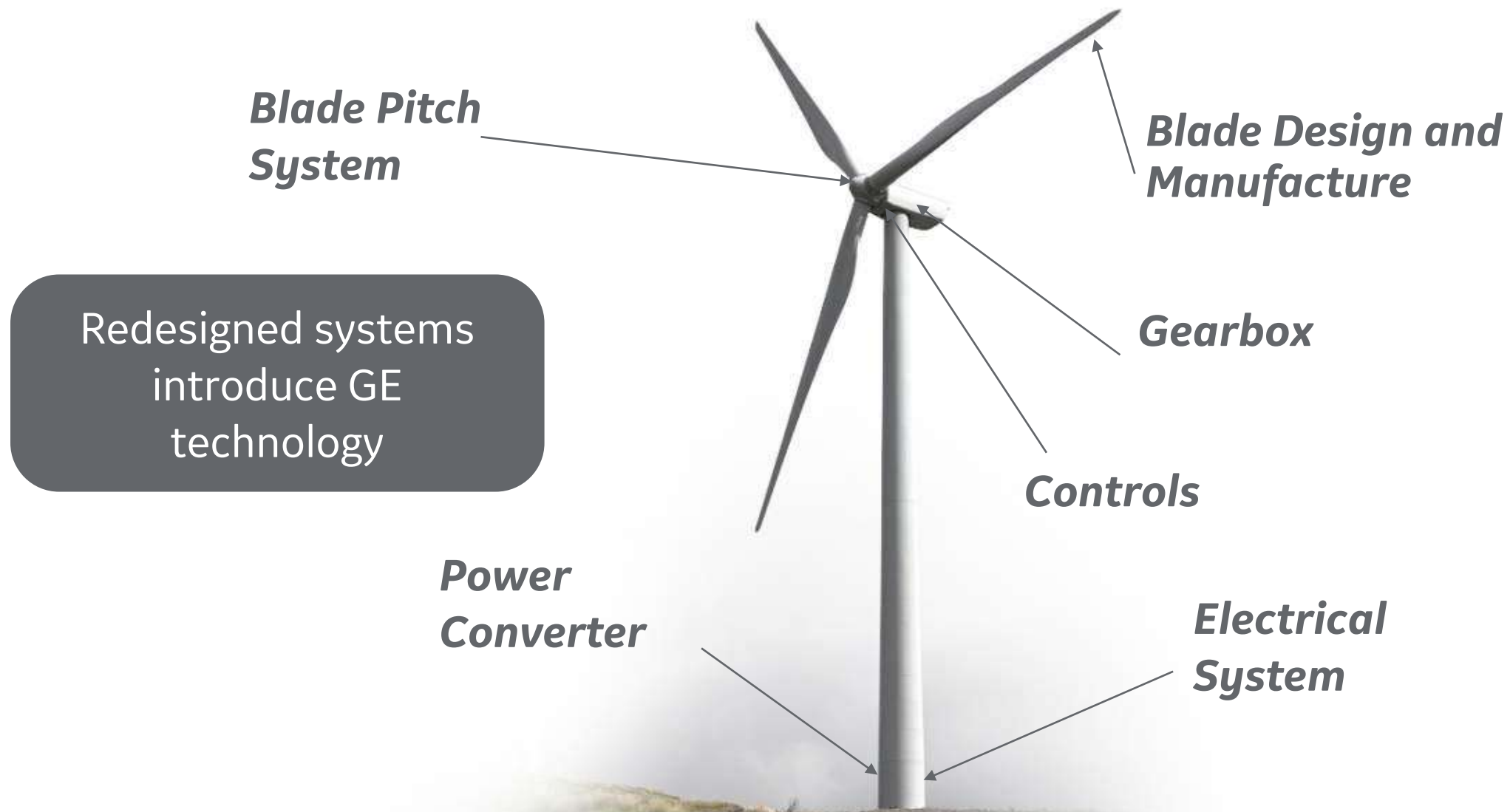
...and I thought you might enjoy a brief tour



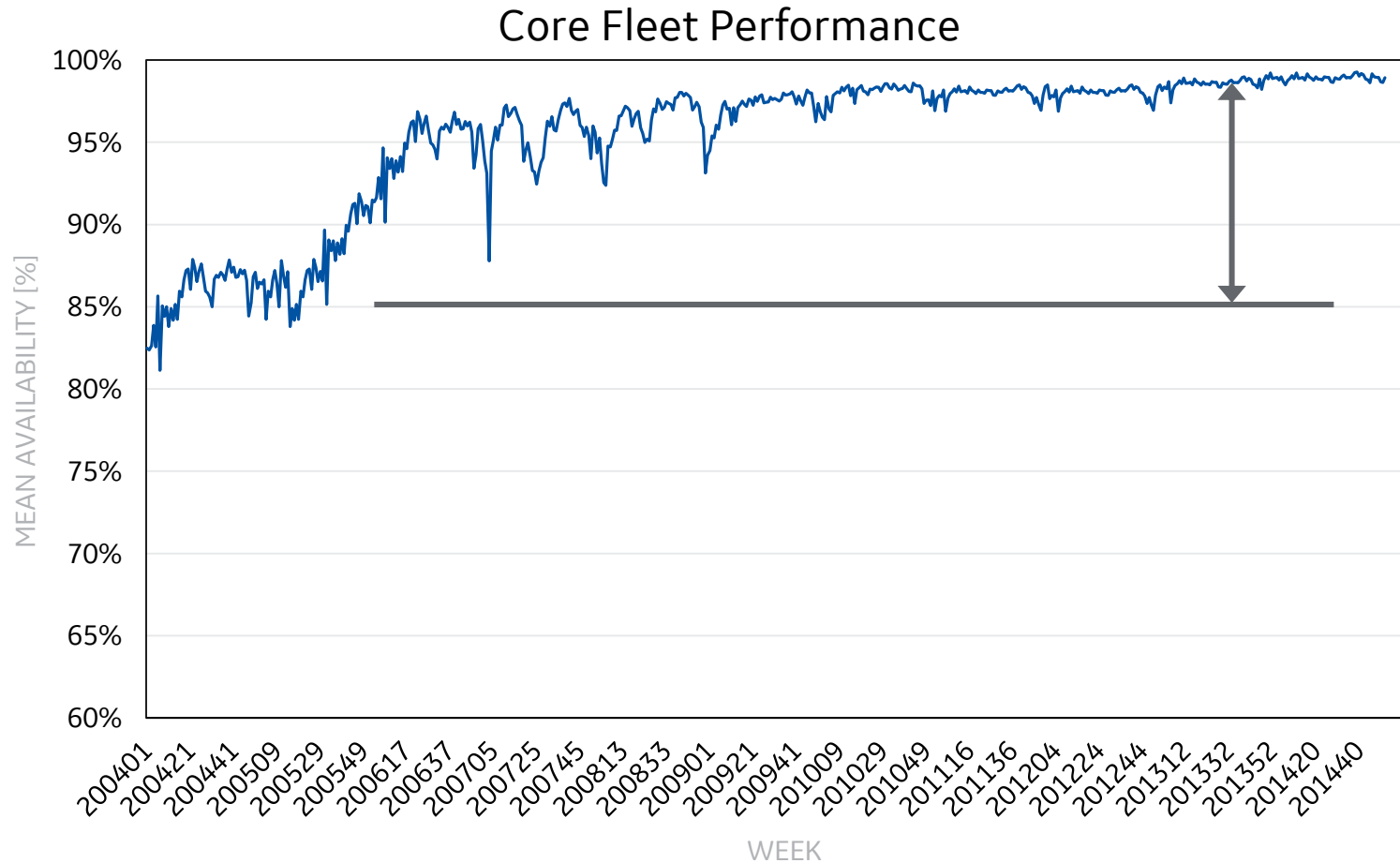
But they weren't always awesome:



GE gradually replaced everything with our designs,  
internal manufacture



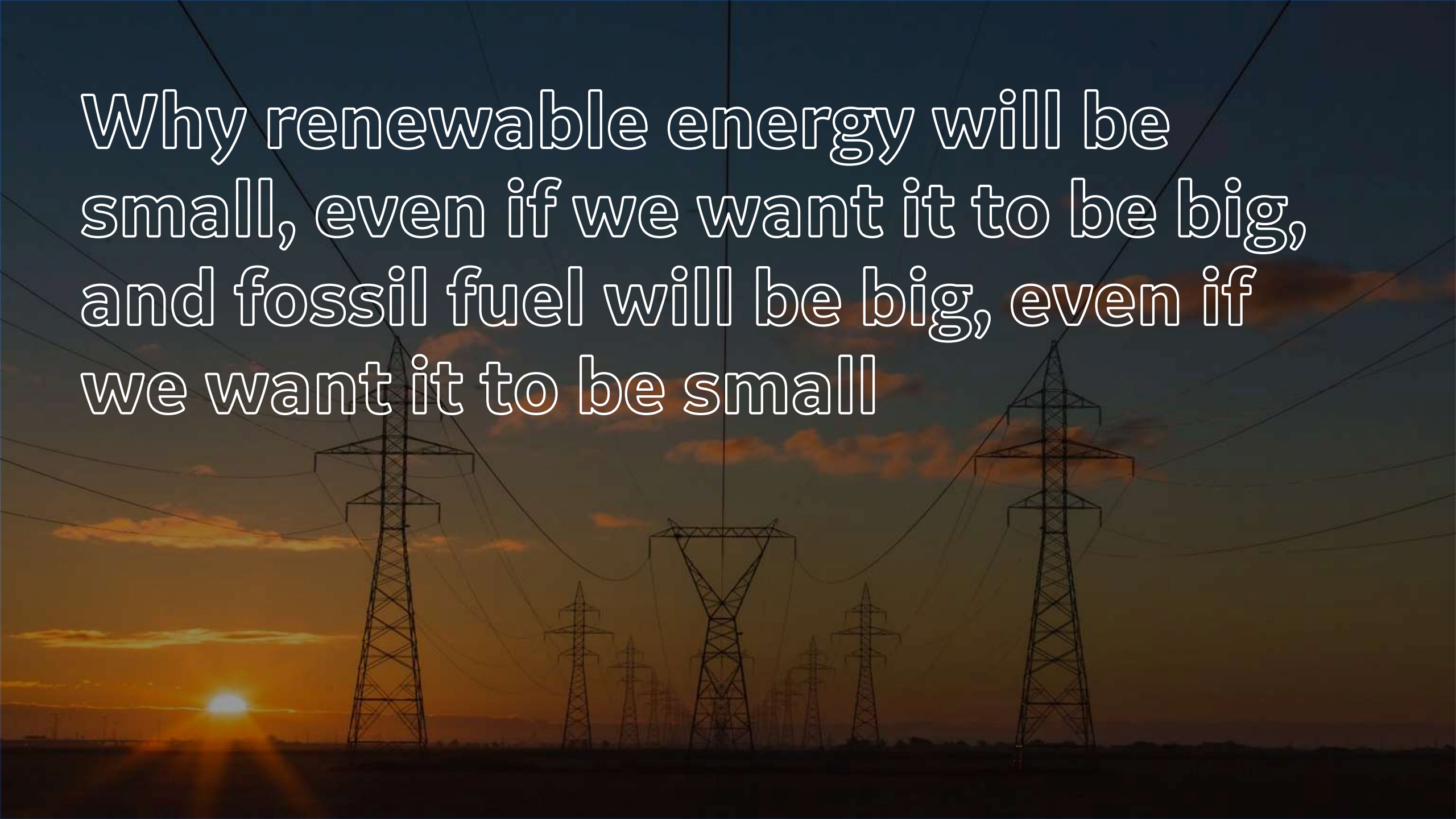
# And the result was a huge increase in turbine availability



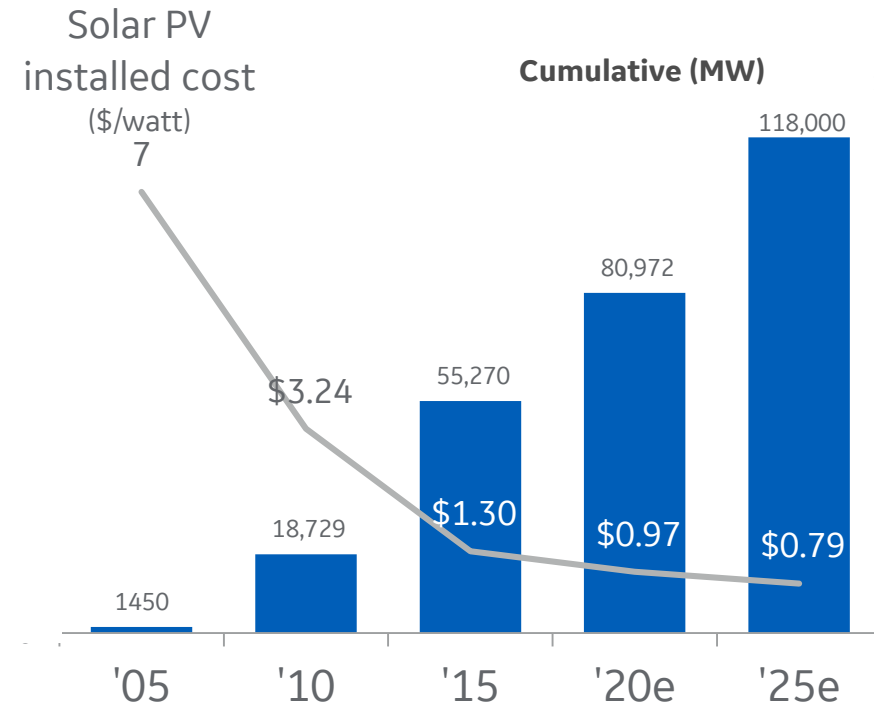
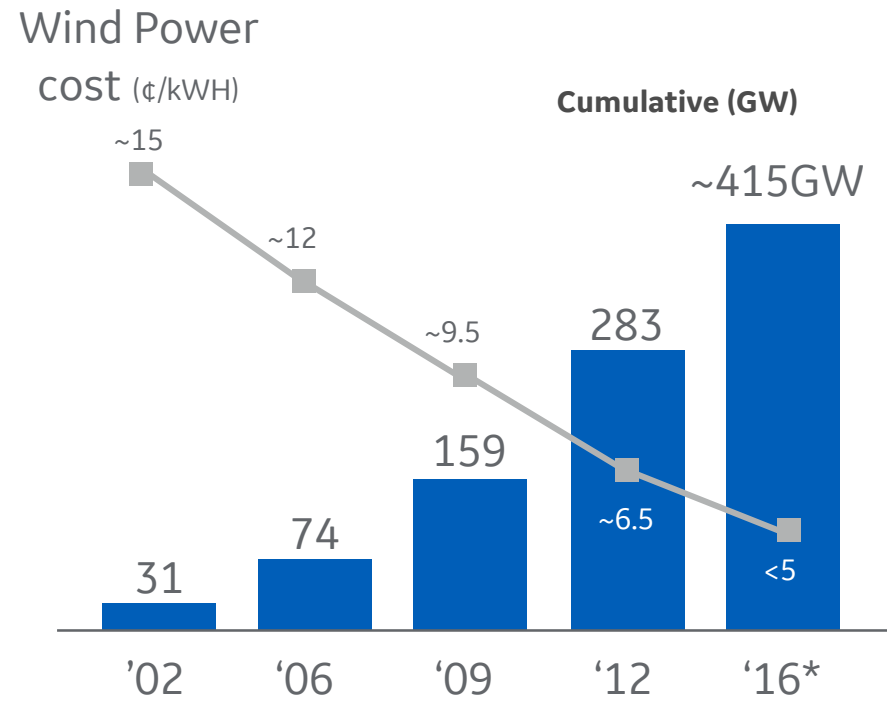
equal to output of 4,000 turbines



Why renewable energy will be small, even if we want it to be big, and fossil fuel will be big, even if we want it to be small



# Wind and Solar costs keep dropping and installations keep growing



# And countries keep setting records for wind and solar output



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## Germany Breaks A Solar Record — Gets 85% Of Electricity From Renewables

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May 8th, 2017 by Steve Hartley

On April 30, Germany established a new national record for renewable energy use. Part of that day (during the long May 1 weekend), 85% of all the electricity consumed in Germany was being produced from renewables such as wind, solar, biomass, and hydroelectric power. Patrick Gratchen of Agora Energiewende Initiative says a combination of breezy and sunny weather in the north and warm weather in the south saw Germany's May 1 holiday weekend powered almost exclusively by renewable resources. [Note: This paragraph has been updated to correct an error.]

"Most of Germany's coal-fired power stations were not even operating on Sunday, April 30th, with renewable sources accounting for 85 per cent of electricity across the country," he said. "Nuclear power sources, which are planned to be completely phased out by 2022, were also severely reduced."



Gratchen says days like April 30 will become

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electrek

Automobile All Transport Autonomous Driving Energy

OCTOBER 31

## Wind powered a record of nearly 200 million European households on Saturday

John Fitzgerald - Oct 31st 2017 11:55 am ET @SolarMASS



121 Comments Facebook Twitter Google+ Pinterest LinkedIn YouTube

On Saturday, a record 24.5% of total electricity came from wind power sources in the 28 countries of the European Union. The majority of this wind electricity was generated onshore (88.7%) vs offshore (11.3%).

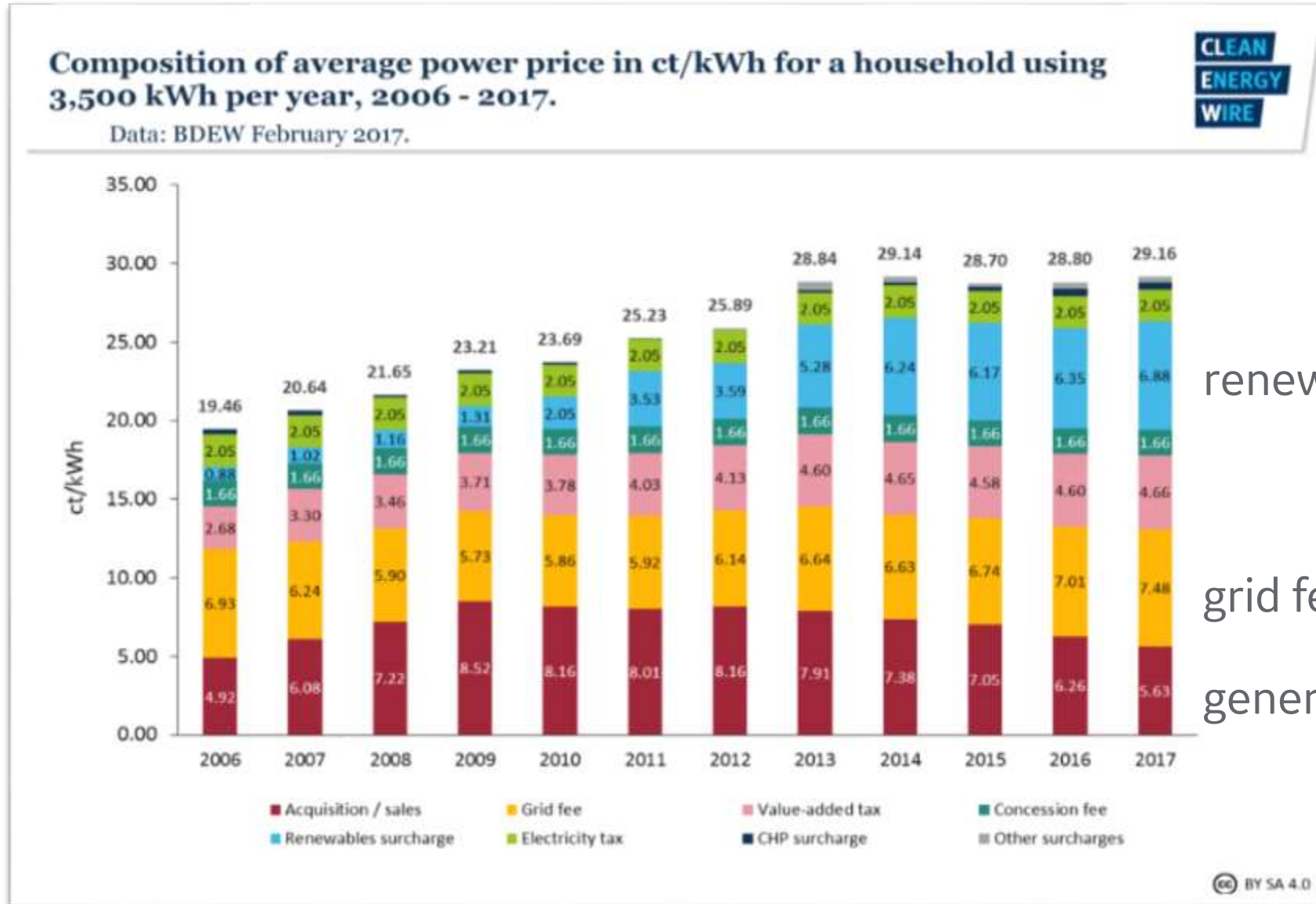
With Europe moving into the high wind production winter period, we expect a new season of records being broken. And with massive scale construction continuing for offshore wind farms, these records of 2017 will soon look quaint.

The amounts of electricity generated were enough to power 197 million European households or 68%

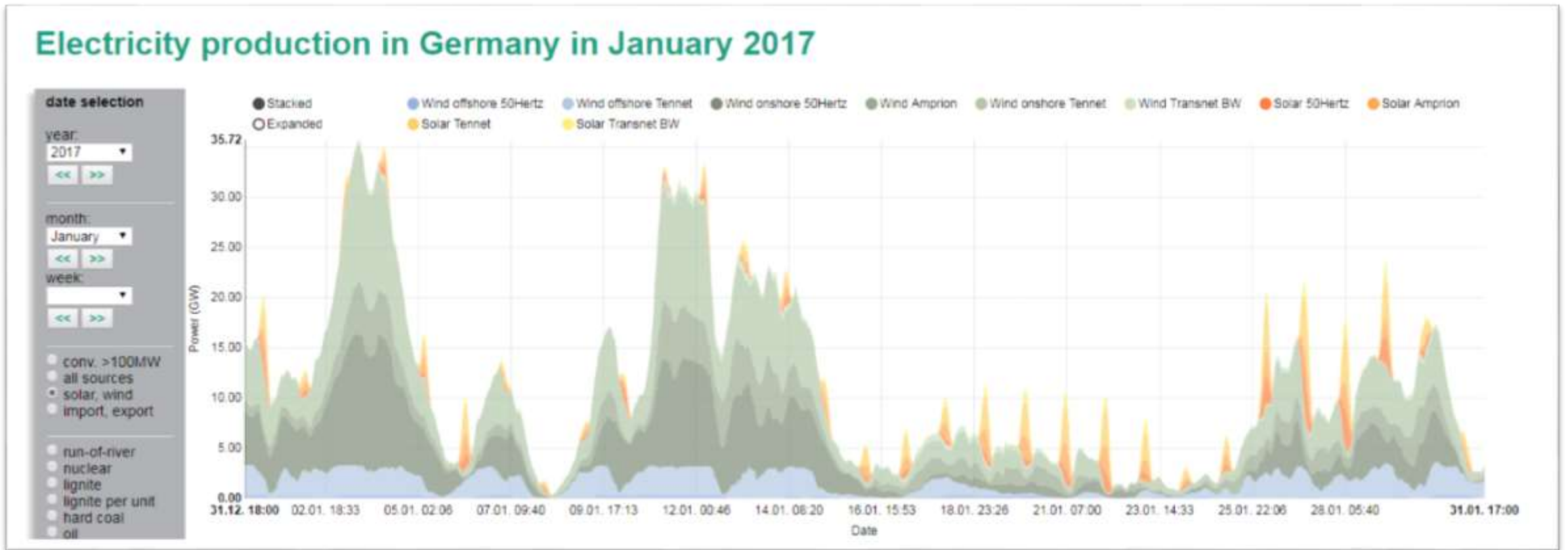




# So why do electricity prices keep going up?



Renewables is *duplicate* capacity not *additional* capacity.



- What is the *minimum*, not the *maximum*?
- Conventional fuels are used less but everything still needed as backup.



# Even renewable energy advocates like me want reliable power



I don't want to use my factory just 32% of the time.



I don't want to turn off appliances on calm days?

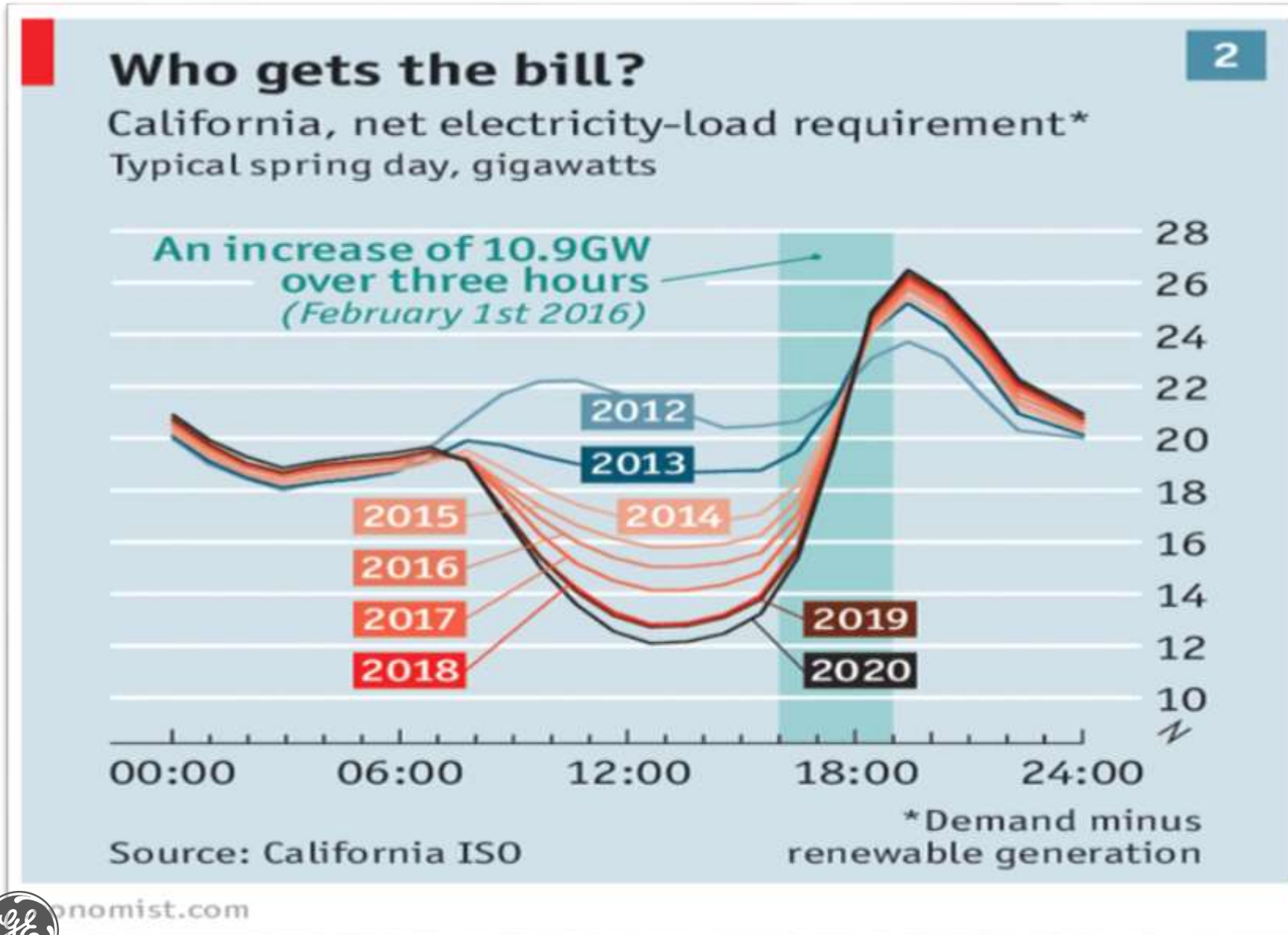


I won't buy a car that starts just 11% of the time?

The reality is, you and I need dependable power



In addition, wind and solar put pressure on the grid....



- Mid-day excess solar power can drive conventional production and prices down
- Conventional sources must ramp power quickly as sun sets

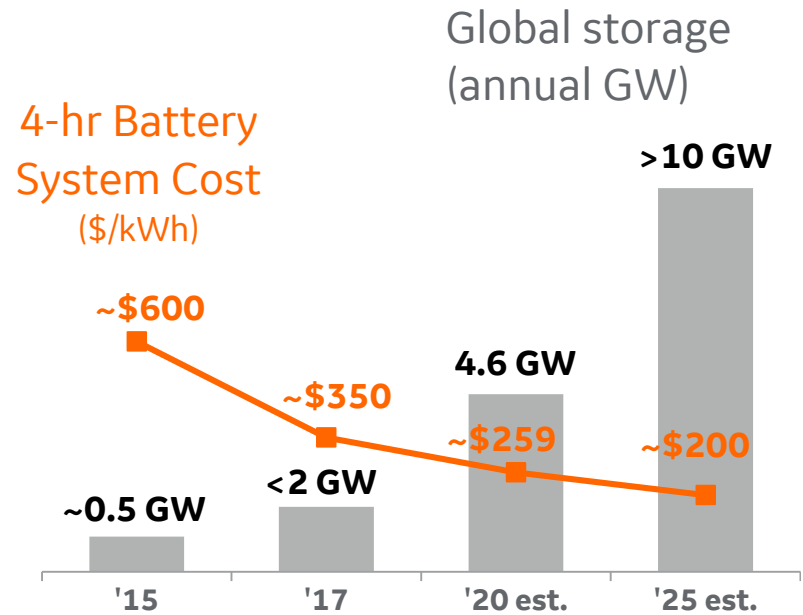
...and put pressure on conventional power producers



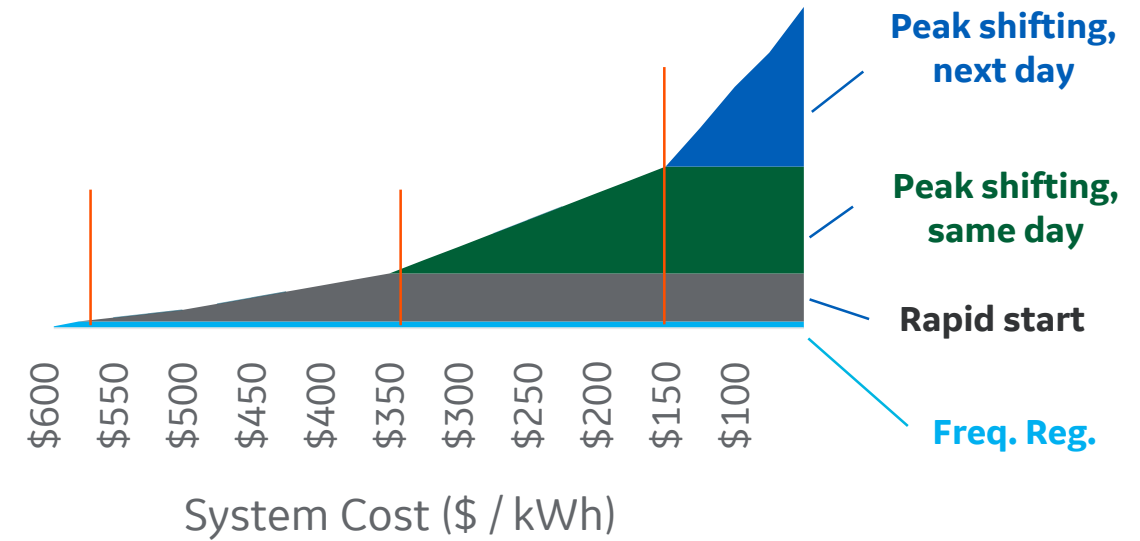
- RWE pays for the same assets but gets less revenue.
- Can Germany allow RWE to go bankrupt?



# But what about storage?



Potential for storage applications (cumulative, US)

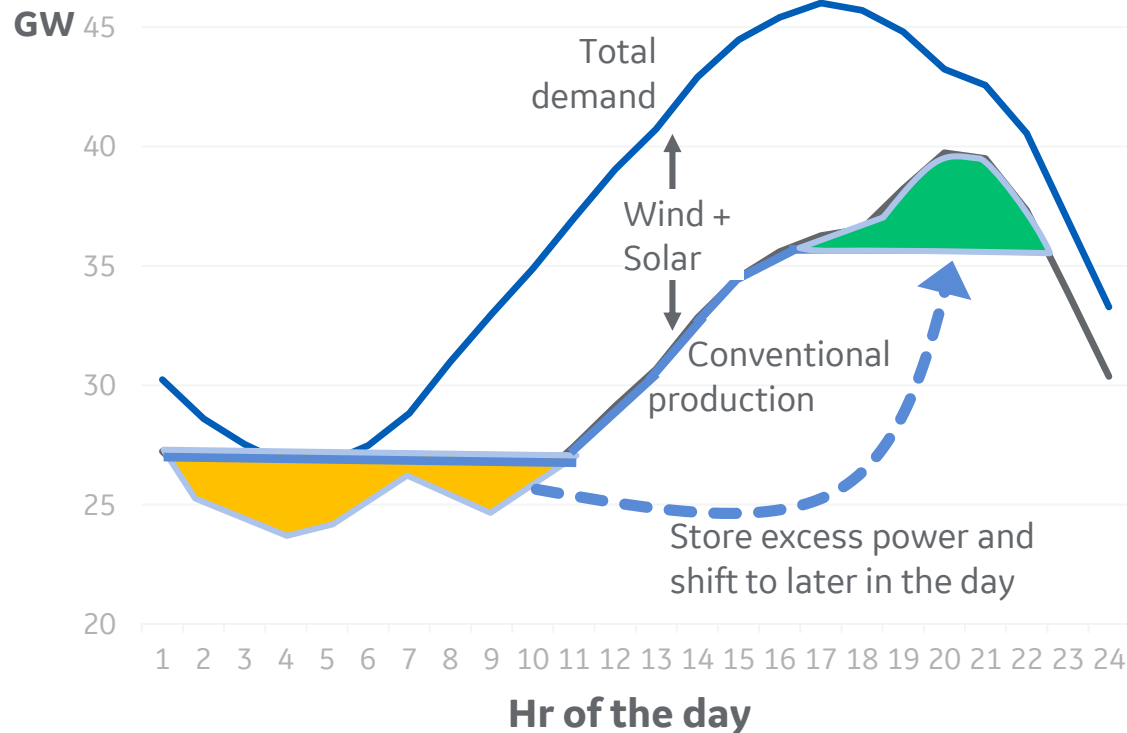


As costs comes down, opportunities go up.



# But even significant battery storage has a small impact on overall grid

California Peak Demand Day (July 27, 2016)\*



- 20% solar and wind
- Potential for 4GW to battery storage early in day
  - \$4.5B
  - appx 2x total global capacity today
- 14.7 GWhr of shift that day
  - 3% of total CA annual demand
- Need smaller peak in conventional production later in day.
- Gas turbine capacity factor drops from 46 to 43%

\* Based on CAISO data. 231 TWh of total annual load in 2016, with ~13% coming from solar and 7% from wind generation. Renewable generation based on CAISO daily renewables watch for July 27 2016.



# Renewables costs are getting competitive

## Equipment and installation cost

Technology	First available year	Size (MW)	Lead time (years)	Base overnight cost in 2016 (2016 \$/kW)	Project Costing Factor <sup>a</sup>	Technological Optimism Factor <sup>a</sup>	Total overnight cost in 2016 <sup>a</sup> (2016 \$/kW)	Variable O&M <sup>b</sup> (2016 \$/MWh)	Fixed O&M (2016\$/kW/yr)	Heat rate <sup>c</sup> (Btu/kWh)
Coal with 30% carbon sequestration	2020	650	4	4,566	1.07	1.03	5,090	3.06	69.66	9,750
Coal with 60% carbon sequestration	2020	650	4	5,072	1.07	1.03	5,362	3.54	80.78	11,050
Coal with 90% carbon sequestration	2020	650	4	5,072	1.07	1.03	5,362	3.54	80.78	11,050
Coal Gas/OM Comb	2019	700	3	623	1.05	1.00	660	3.48	10.93	6,400
Coal (CC)	2019	428	3	1,013	1.08	1.00	1,094	3.89	9.94	5,300
Adv CC with carbon sequestration	2019	340	3	1,517	1.08	1.08	2,150	3.06	33.21	7,525
Conv Comb Turbine <sup>d</sup>	2019	100	2	1,040	1.05	1.00	1,092	3.48	17.39	5,500
Adv Comb Turbine	2018	237	2	640	1.05	1.00	672	3.63	6.76	5,900
Fuel Cells	2019	10	3	6,252	1.05	1.18	7,221	44.81	0.00	5,500
Adv Nuclear	2022	2,334	6	5,091	1.10	1.05	5,450	2.39	99.69	10,400
Distributed Generation - Base	2019	3	3	1,463	1.05	1.00	1,536	6.10	18.23	6,981
Distributed Generation - Peak	2018	3	2	1,757	1.05	1.00	1,845	6.10	18.23	6,975
Biomass	2020	50	4	1,540	1.07	1.00	1,648	5.49	110.04	15,900
Geothermal <sup>e</sup>	2020	50	4	2,186	1.06	1.00	2,319	0.00	173.96	6,510
MSW - Landfill Gas	2019	50	3	8,059	1.07	1.00	8,623	9.14	410.52	16,000
Conventional Hydropower <sup>f</sup>	2020	500	4	2,220	1.10	1.00	2,442	3.66	14.91	6,510
Wind <sup>g</sup>	2019	100	3	1,576	1.07	1.00	1,686	0.00	46.71	6,510
Wind Offshore	2020	400	4	4,448	1.10	1.25	6,091	0.00	77.80	6,510
Solar Thermal <sup>h</sup>	2019	100	3	1,908	1.07	1.00	2,042	0.00	70.20	6,510
Photovoltaic (PV) <sup>i</sup>	2018	150	3	1,149	1.06	1.06	1,217	0.00	11.66	6,410

Coal \$ 3,100 /kw  
 Nat gas \$ 970  
 Nuclear \$ 5,800  
 Wind \$ 1,700  
 Solar PV \$ 2,300

## Operating cost

Table 1b. Estimated LCOE (simple average of regional values) for new generation resources, for plants entering service in 2022

U.S. Average LCOE (2016 \$/MWh) for Plants Entering Service in 2022

Plant Type	Capacity Factor (%)	Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System LCOE	Levelized Tax Credit <sup>a</sup>	Total LCOE including Tax Credit
<b>Dispatchable Technologies</b>								
Coal 30% with carbon sequestration <sup>b</sup>	85	94.9	9.3	34.6	3.2	142.0	NA	142.0
Coal 90% with carbon sequestration <sup>b</sup>	85	78.0	10.8	55.1	5.2	129.2	NA	129.2
<b>Natural Gas-Fired</b>								
Conventional Combined Cycle	87	13.8	1.4	40.8	3.2	57.3	NA	57.3
Advanced Combined Cycle	87	13.8	1.3	38.1	3.2	56.5	NA	56.5
Advanced CC with CCS	87	29.5	4.4	47.4	3.2	82.4	NA	82.4
Conventional Combustion Turbine	30	40.7	6.0	58.6	3.5	109.4	NA	109.4
Advanced Combustion Turbine	30	25.9	2.6	62.7	3.5	94.7	NA	94.7
Advanced Nuclear	90	73.6	12.6	11.7	3.1	99.1	NA	99.1
Geothermal	91	32.2	12.8	0.0	3.5	48.5	-3.2	45.3
Biomass	83	44.7	15.2	41.2	3.3	102.4	NA	102.4
<b>Non-Dispatchable Technologies</b>								
Wind - Onshore	39	47.2	15.7	0.0	2.8	65.7	-11.6	52.2
Wind - Offshore	45	133.0	19.6	0.0	4.8	157.4	-11.6	145.9
Solar PV <sup>c</sup>	24	70.2	10.5	0.0	4.4	85.0	-18.2	66.8
Solar Thermal	30	191.9	44.0	0.0	5.1	241.0	-57.6	184.4
Hydroelectric <sup>d</sup>	58	56.2	3.4	4.8	1.8	66.2	NA	66.2

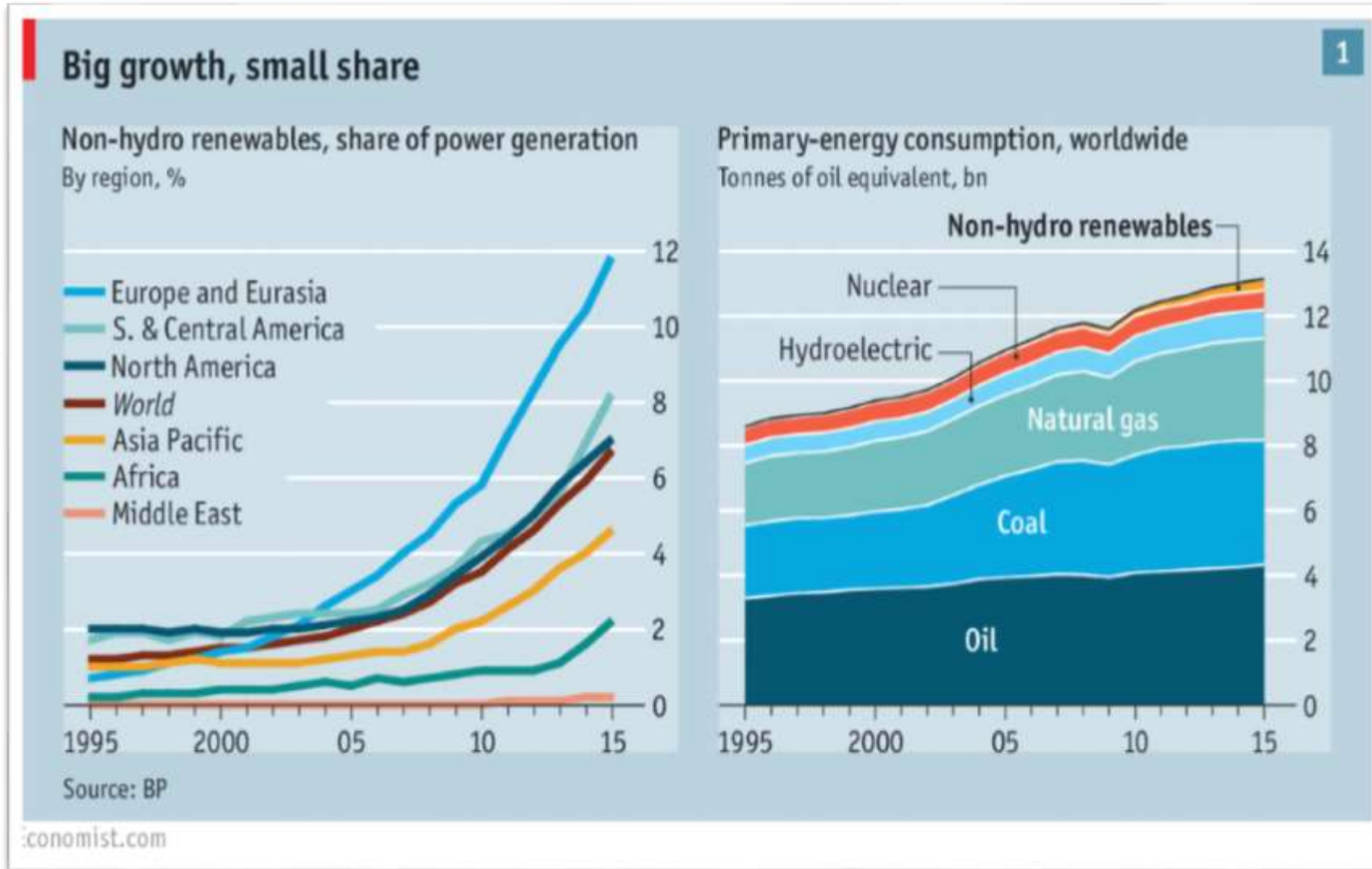
Coal \$ 35 /MWhr  
 Nat gas \$ 35  
 Nuclear \$ 20  
 Wind \$ 12  
 Solar PV \$ 9

But, again, is cheap intermittent power as good as expensive reliable power?





Consequently, renewables is growing fast but is a small slice of total pie



# Competing objectives:

What problem are you trying to solve?

What would you do?



# Problem 1: Human suffering

*The Economist*, Chart of the Day,  
November 8, 2017

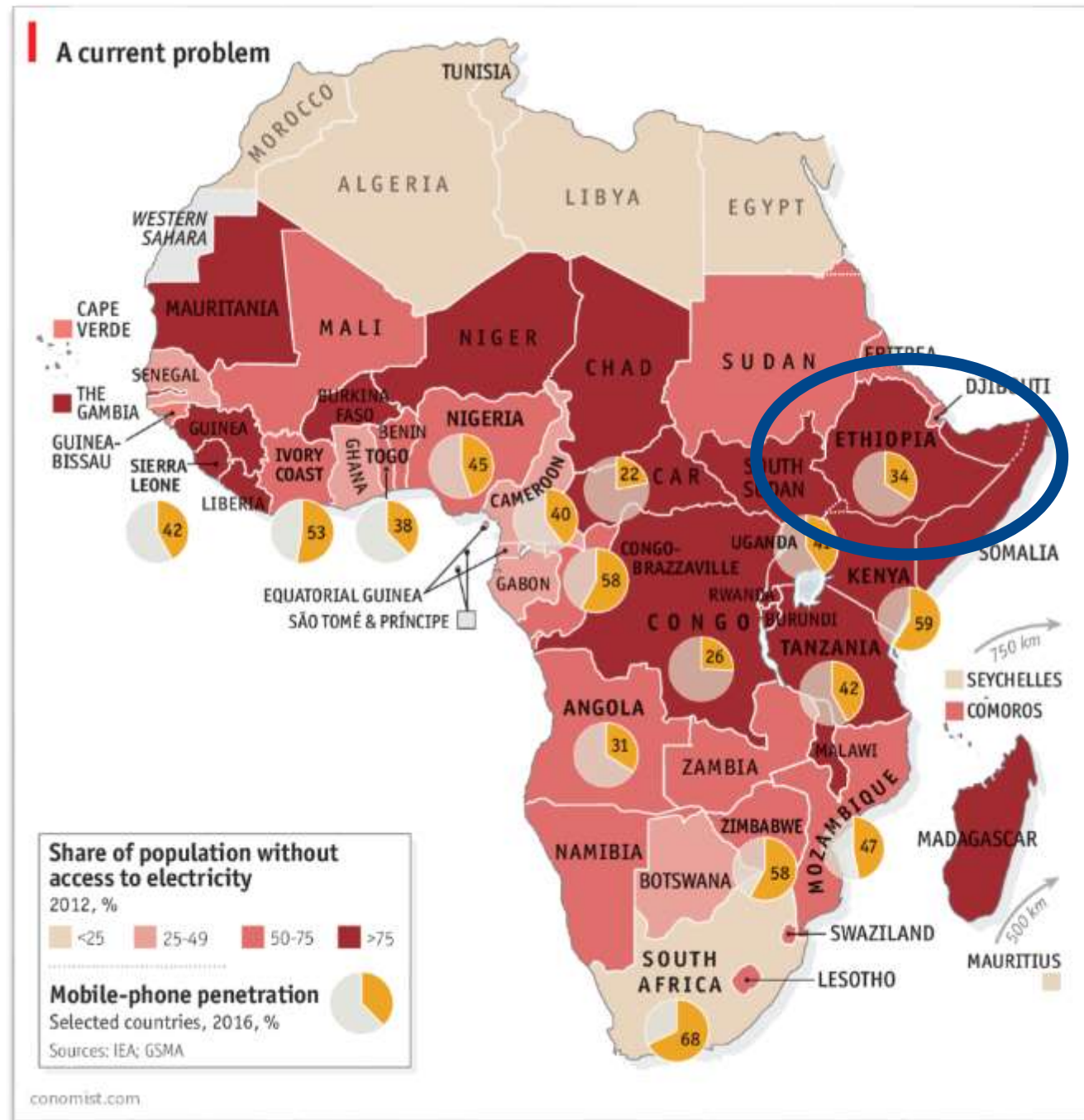
## Africa

- more people in Ethiopia have cell phones than access to electricity
- ~600,000/yr die from indoor cooking

## India

*“It’s a matter of shame that 68 years after independence we have not been able to provide a basic amenity like electricity.”*

- Piyush Goyal, Minister of Power, India



## Problem 2: Long term global impact



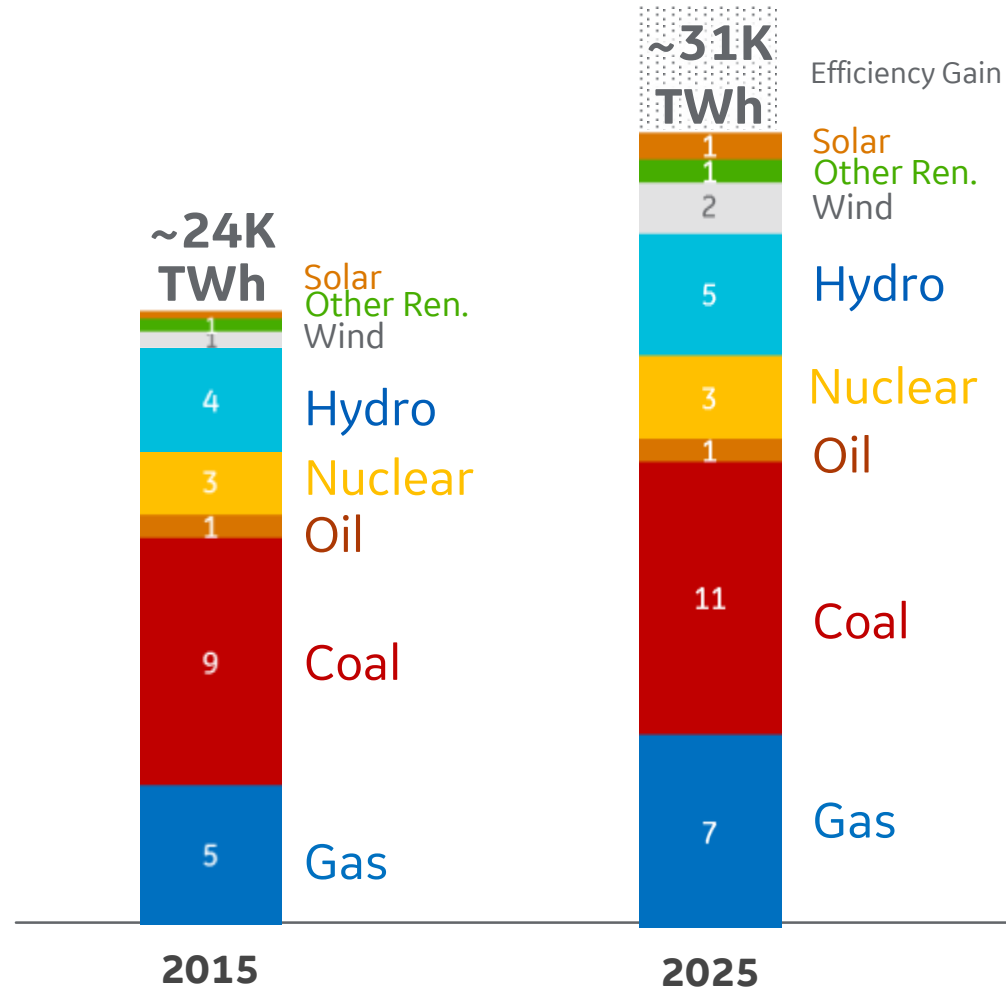
# So, what would *you* do with \$1B?

<b>choice of power source</b>	<b>households that will get power</b>	<b>availability of that power</b>	<b>fuel cost</b>	<b>availability of fuel</b>	<b>greenhouse gas impact</b>
coal	700,000	98%	\$4/MW hr	good	very high
natural gas	1,900,000	98%	\$3/MW hr	pipeline or LNG tanker	high/moderate
nuclear	350,000	98%	\$1/MW hr	good	none
solar	880,000	15%	free	most locations	none
solar - with storage	40,000	70%	free	most locations	none

The answer is not obvious

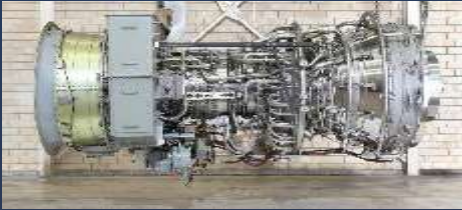


My guess is that the future will not be too different from the past  
*global electricity generation by fuel*



# All this and more will be part of the solution.

**AERO  
ENGINES**



**SOLAR PV**



**GAS  
TURBINES**



**ONSHORE  
WIND**



**GE HITACHI  
NUCLEAR**



**POWER  
CONVERSION**



**OFFSHORE  
WIND**



**STEAM  
TURBINES**



**PLANT EQUIPMENT**



**HYDRO**



- Remarkable advances in the past; progress still being made
- We will need multiple options
- And engineers like us will be part of the solution



A sunset scene with power lines and towers silhouetted against a dark blue and orange sky. The text "Thank you" is centered in white.

Thank you