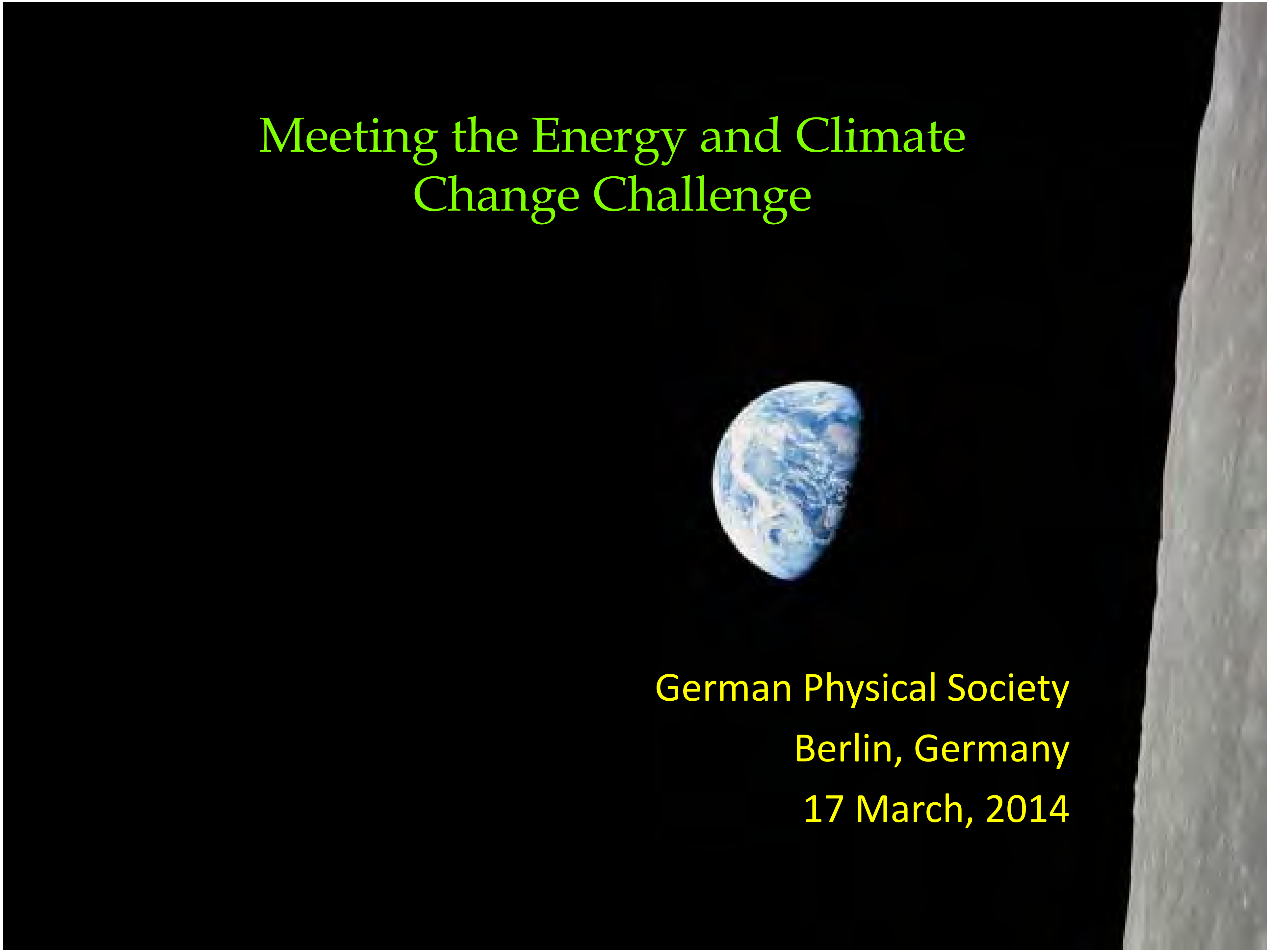
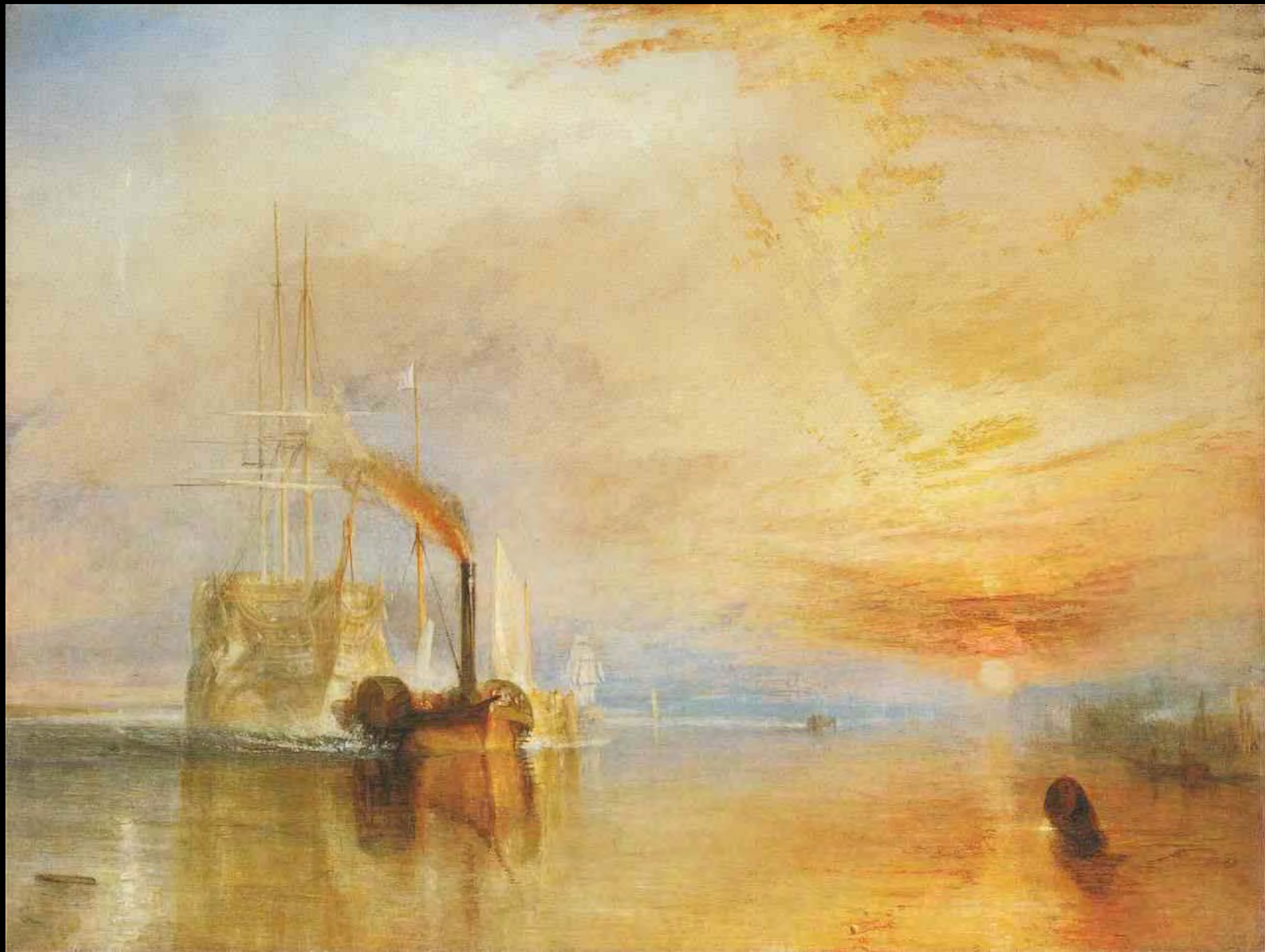

Meeting the Energy and Climate Change Challenge
German Physical Society
Berlin, Germany
17 March, 2014

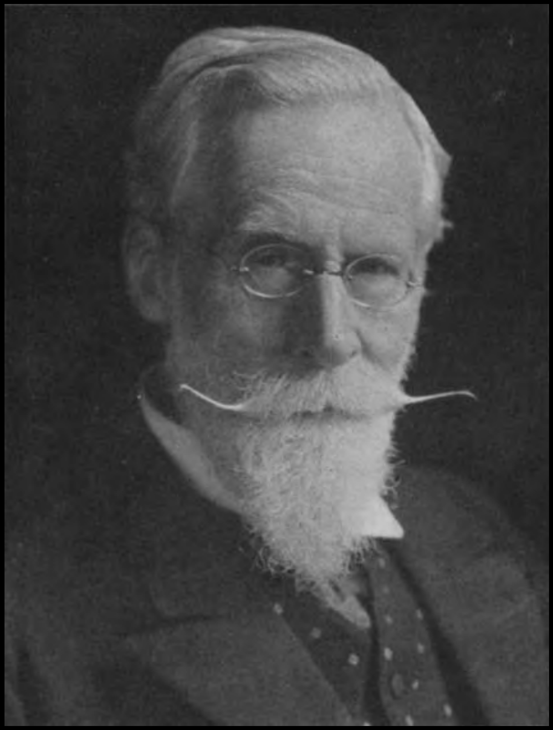
Innovations in energy transformed the world

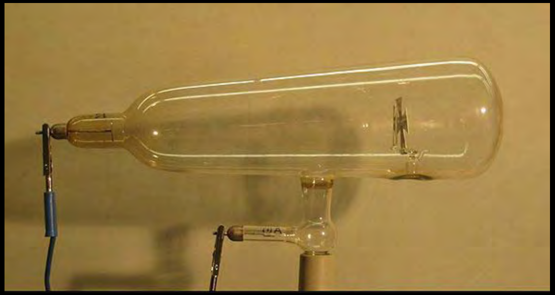
The sailing warship H.M.S. Temeraire, towed to be broken up for scrap.



J.M.W. Turner (1839)

Innovations in agriculture

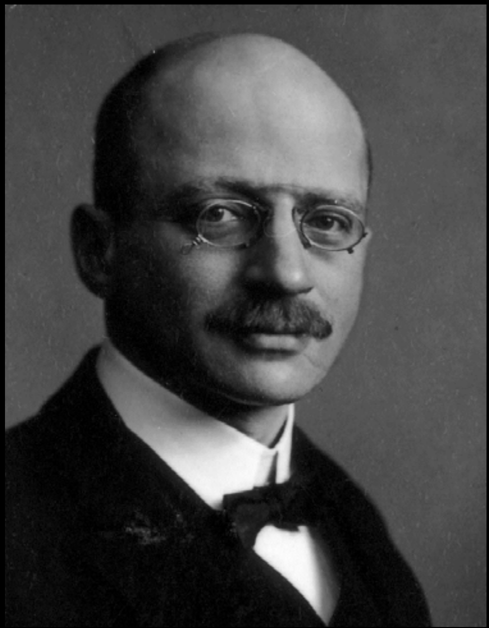




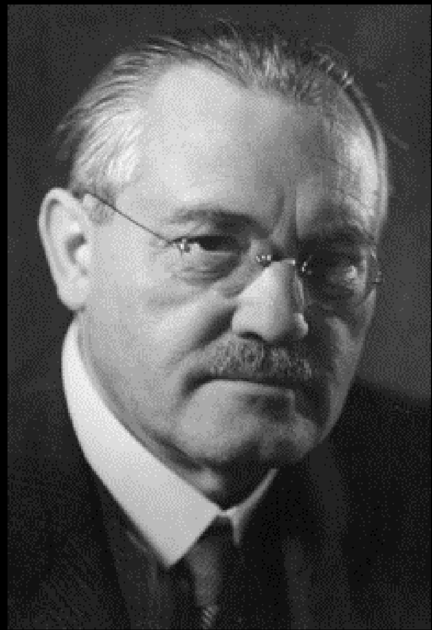
In 1898, Sir William Crookes (inventor of the "Crookes tube") delivers his inaugural lecture as President of the British Association for the Advancement of Science.

"England and all civilized countries are in deadly peril"

"It is the chemist who must come to the rescue…before we are in the actual grip of actual death, the chemist will step in and postpone the day of famine ..."



Fritz Haber: 1918

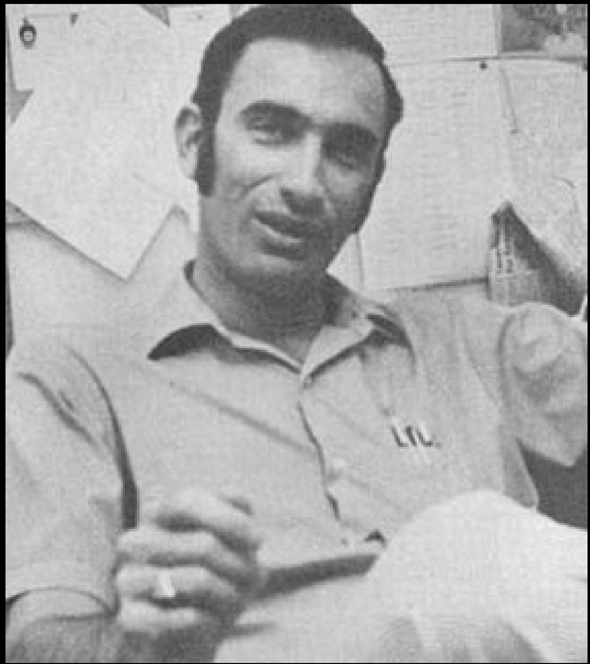


Carl Bosch: 1931

At the beginning of the industrial revolution there were 700 M people.

The Haber-Bosch process enabled us to feed a world that ***doubled*** in population.

Gerhard Ertl: 2007



Prof. Paul Ehrlich
Stanford Biologist
The Population Bomb
(1968)

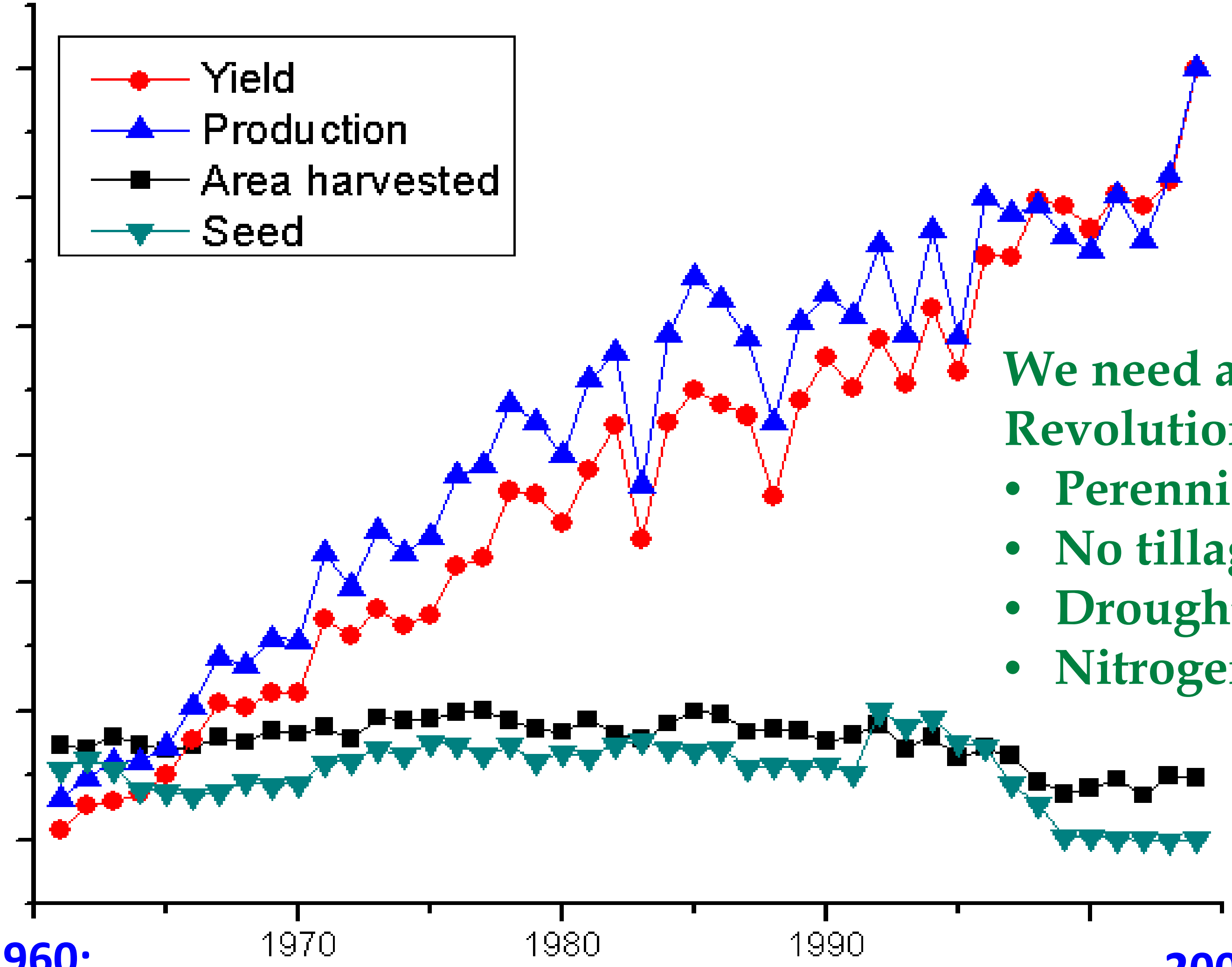
"The battle to feed all of humanity is over ... In the 1970s and 1980s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now."

What happened?

Norman Borlaug is awarded the Nobel Prize in 1970

Borlaug bred disease-resistant, dwarf strains of wheat with thick stems that could support heavier kernels and growth spurts due to artificial fertilizer used in the poor soils.

World Production of Grain (1961 – 2004)



We need a 2nd Green Revolution

- Perennial crops
- No tillage
- Drought resistant
- Nitrogen fixation

1960:
Population = 3 B

2005:
Population = 6.5 B

Source: Food and Agriculture Organization (FAO), United Nations

Incumbent industries have an understandable internal conflict in seeing the potential of a new potentially technology

Incumbent industries usually do not embrace new technologies

Reaction to Alexander Graham Bell's patent for the telephone by the **Chief Engineer** of the British Post Office:

"The Americans have need of the telephone, but we do not. We have plenty of messenger boys."

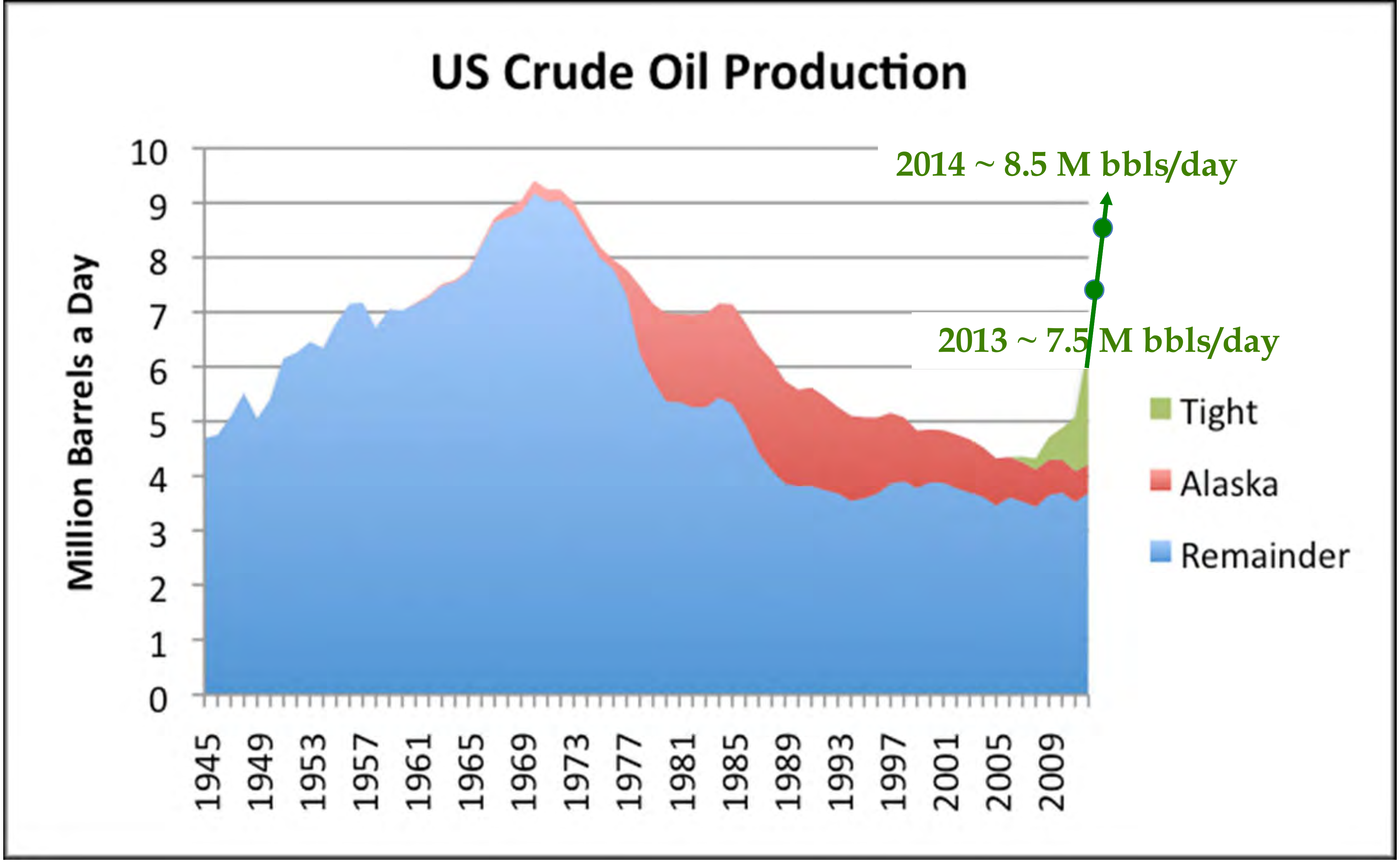
What use could this company make of an electrical toy?

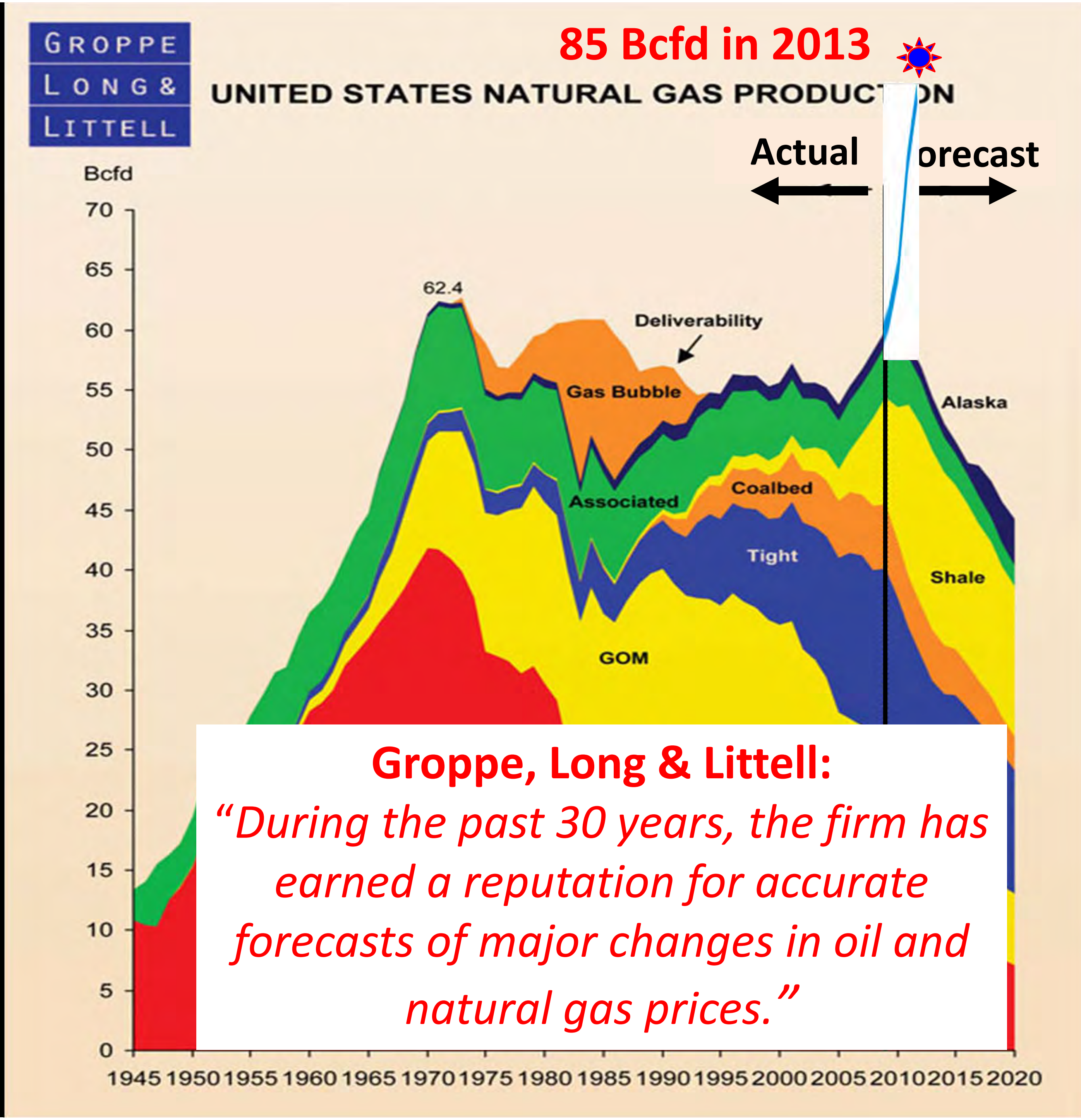
- Western Union president William Orton, responding to an offer from Alexander Graham Bell to sell his telephone company to Western Union for $100,000.

"Our ability to find and extract fossil fuels continues to improve, and economically recoverable reservoirs around the world are likely to keep pace with the rising demand for decades."

Steven Chu and Arun Majumdar, *Nature* (2012)

U.S. Oil Production (1945 – 2012)
U.S. is the biggest producer of oil + nat. gas liquids + ethanol

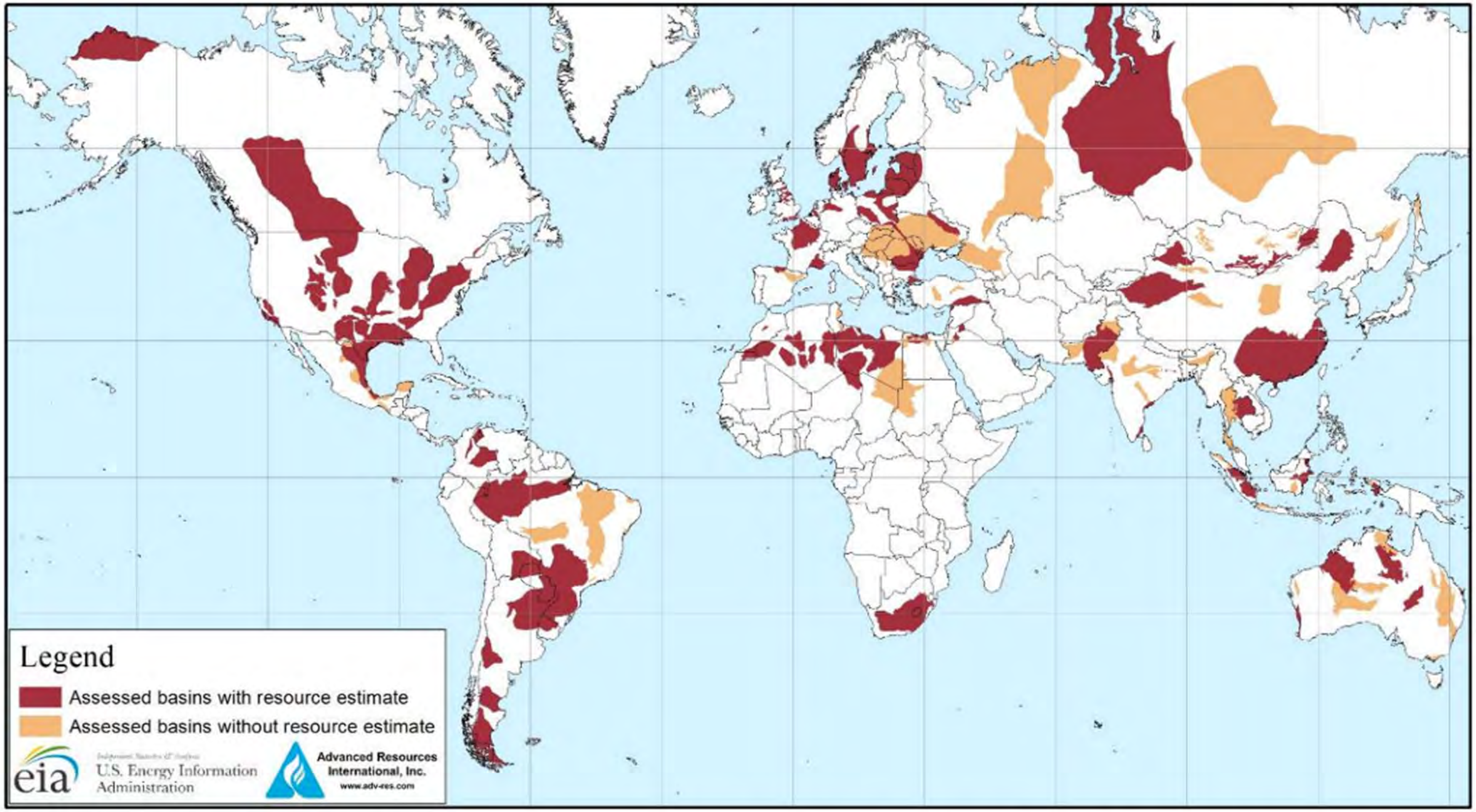




85 Bcfd in 2013
GROPPE
LONG &
LITTELL
UNITED STATES NATURAL GAS PRODUCT ON
Actual
orecast
Bcfd
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
62.4
Deliverability
Gas Bubble
Alaska
Associated
Coalbed
Tight
Shale
GOM
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Groppe, Long & Littell:
"During the past 30 years, the firm has earned a reputation for accurate forecasts of major changes in oil and natural gas prices."

Potential shale gas and tight oil reservoirs can change the energy landscape of the Americas, Asia and Europe.

Figure 1. Map of basins with assessed shale oil and shale gas formations, as of May 2013



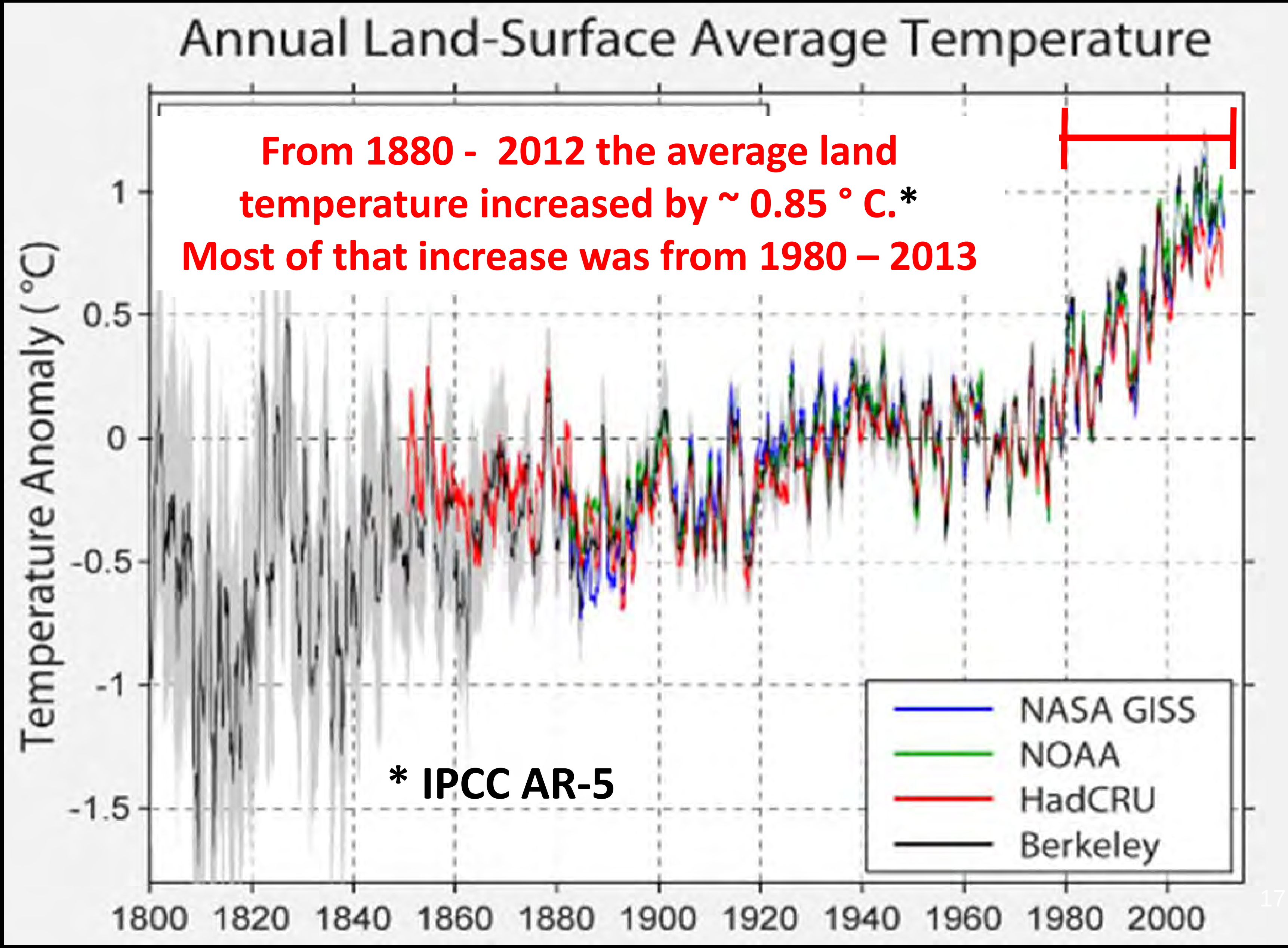
Source: United States basins from U.S. Energy Information Administration and United States Geological Survey; other basins from ARI based on data from various published studies.

Technically recoverable shale oil and shale gas (Proved and unproved) may reshape natural gas supplies

Unproved shale oil and gas world reserves may increase 48% overall reserves

	Crude oil (billion barrels)	Wet natural gas (trillion cubic feet)
Outside the United States		
Shale oil and shale ga	287	6,634 tcf
Other proved reserve	1,617	6,521
Other unproved reso	1,230	7,296
Total	**3,134**	**20,451**
Increase in total reso	**10%**	**48%**
Shale as a percent of total	**9%**	**32%**
United States		
EIA shale / tight oil and shale gas proved reserves[3, 4]	n/a	97
EIA shale / tight oil and shale gas unproved resources[5]	58	
EIA other proved reserves[6]	25	664 tcf
EIA other unproved resources[5]	139	1,546
Total	**223**	2,431
Increase in total resources due to inclusion of shale oil and shale gas	**35%**	**38%**
Shale as a percent of total	**26%**	**27%**
Total World		

The temperature record 1800 - 2011



Selected IPCC summary points (2014)

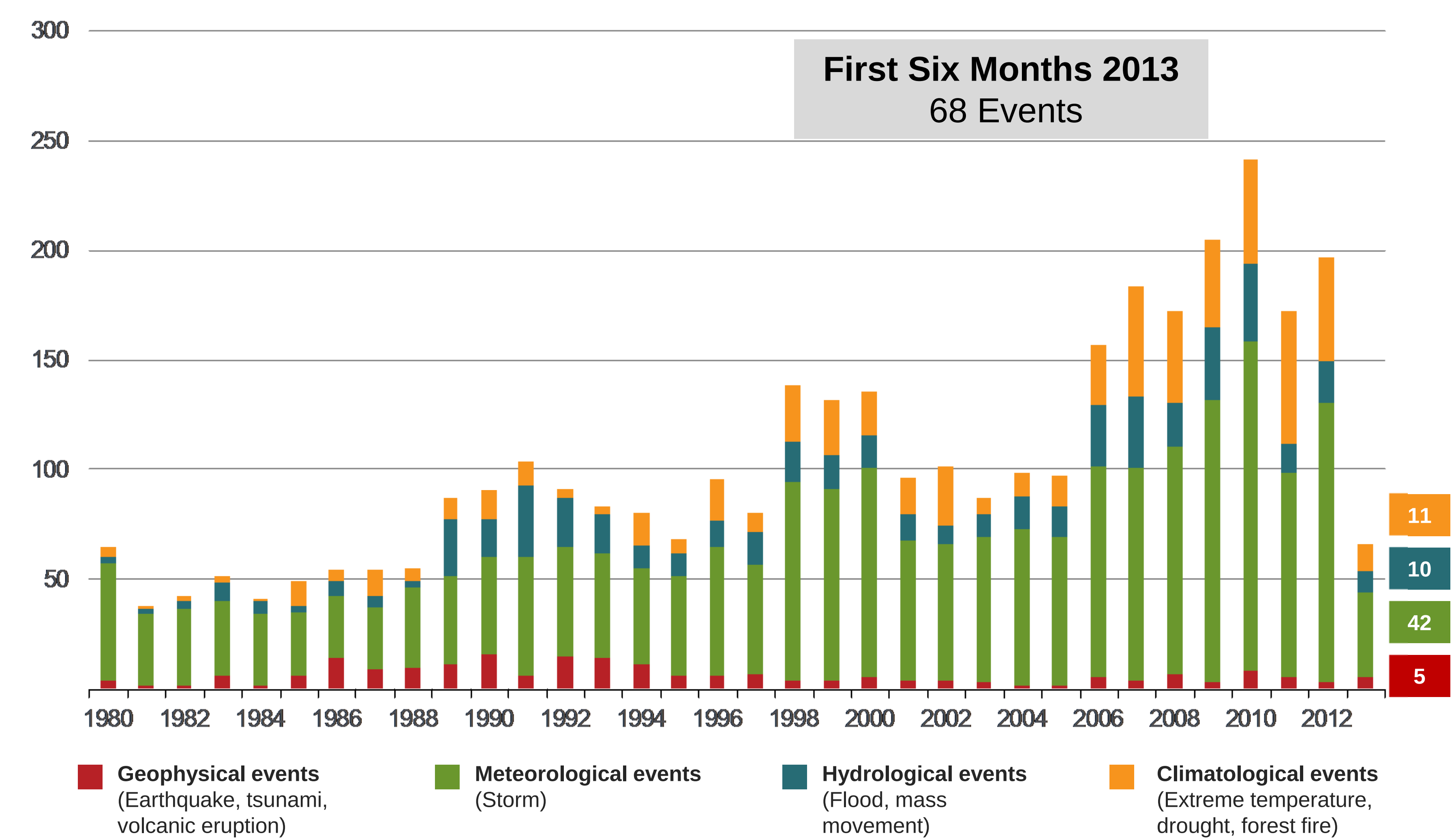
- Temperature increase: (1880 – 2012) = 0.85 ° C
- Temperature of ocean: (upper 75m) = 0.11° C
- Extreme weather changes: 90% due to human activity.

- Ice sheet loss

Ice sheet loss	Greenland	Antarctic
1992 – 2001:	34Gt	30 Gt
2002 – 2011:	215 Gt	147 Gt

Natural Disasters in the United States, 1980 – 2013

Number of Events (Annual Totals 1980 – 2012 vs. First Six Months 2013)

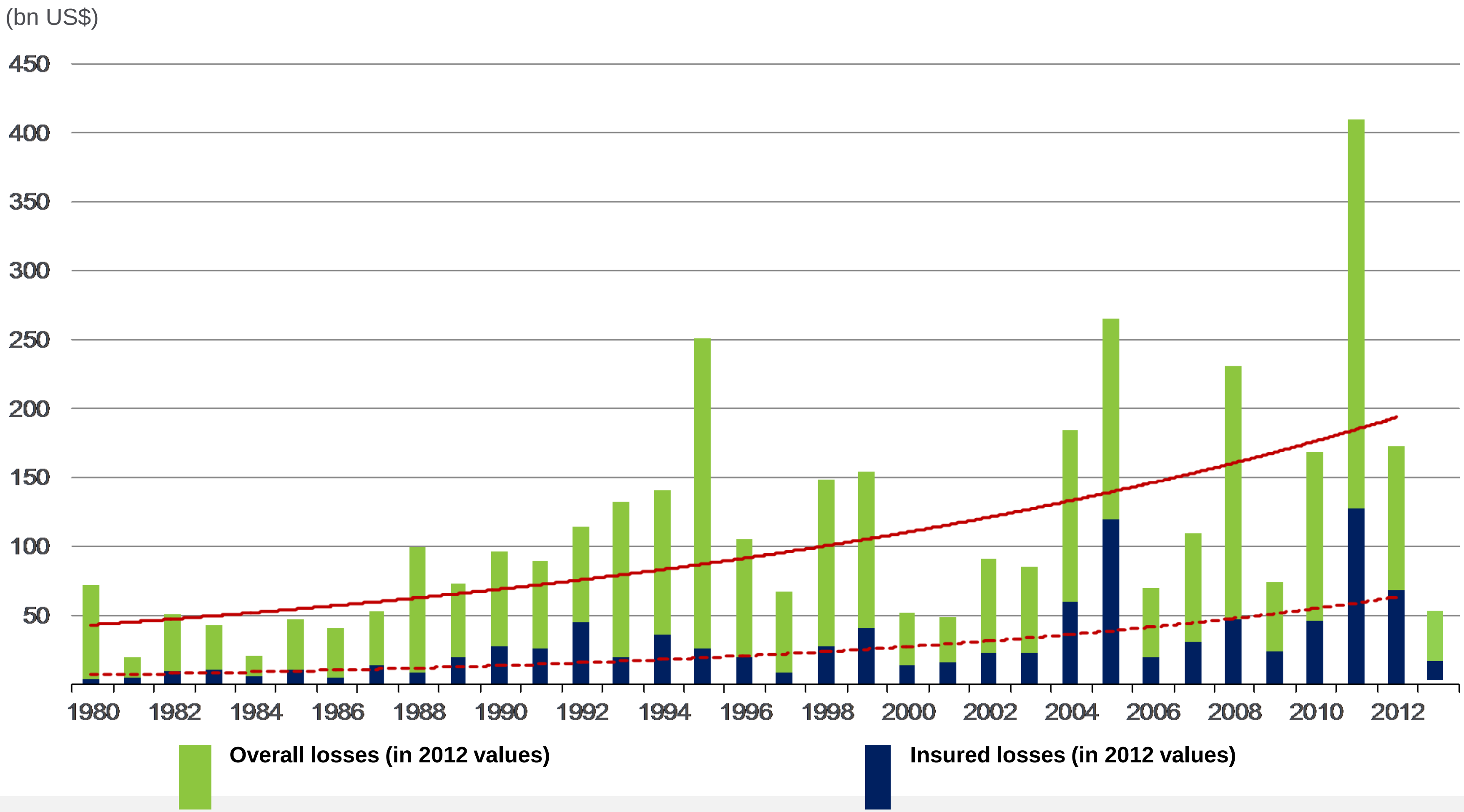


Source: MR NatCat*SERVICE*

Natural Catastrophes Worldwide 1980 – 2013

Overall and Insured Losses (Annual Totals 1980 – 2012 vs. First Six Months 2013)

Overall losses totaled US$ 45bn; Insured losses totaled US$ 13bn



Source: MR NatCatSERVICE

Costliest Natural Catastrophes Since 1950

Rank by Insured Losses

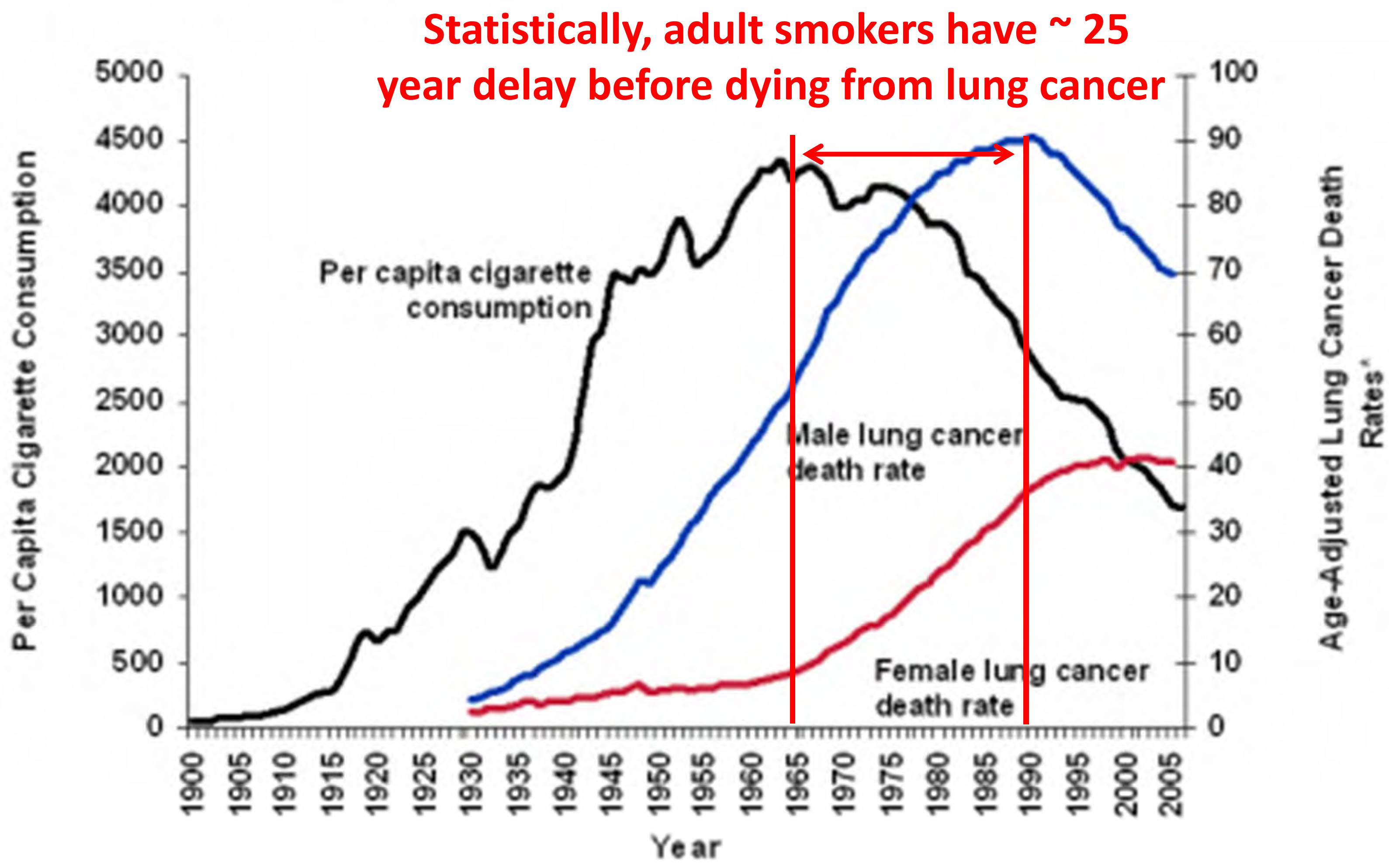
Munich RE

Since 1950 (63 years), 7 of the costliest natural disasters were due to weather. 6 out of 7 of those weather events occurred in the past 8 years

			US$m (in original values)
2005	Hurricane Katrina	USA	62,200
2011	EQ, tsunami	Japan	40,000
2012	Hurricane Sandy	USA, Caribbean	30,150
2008	Hurricane Ike	USA, Caribbean	18,500
1992	Hurricane Andrew	USA	17,000
2011	Floods	Thailand	16,000
2012	Drought	USA	16,000
1994	EQ Northridge	USA	15,300
2004	Hurricane Ivan	USA, Caribbean	13,800
2011	EQ Christchurch	New Zealand	13,000

Source: MR NatCatSERVICE

Tobacco Use in the US, 1900-2005



*Age-adjusted to 2000 US standard population.

Source: Death rates: US Mortality Data, 1960-2005, US Mortality Volumes, 1930-1959, National Center for Health Statistics, Centers for Disease Control and Prevention, 2006. Cigarette consumption: US Department of Agriculture, 1900-2007.

U.S. Surgeon General Report (2014)

20% of all deaths in the U.S. is attributed to smoking.

Smoking increases the risk of

- **Lung cancer: 25x**
- **Coronary heart disease: 2x - 4x**
- **Stroke: 2x – 4x**

More than 10 times as many U.S. citizens have died prematurely from cigarette smoking than have died in all the wars fought by the United States during its history.

Smoking causes about 90% of all lung cancer deaths in men and women. More women die from lung cancer each year than from breast cancer.

“If we don’t change direction, we’ll end up where we are heading.”

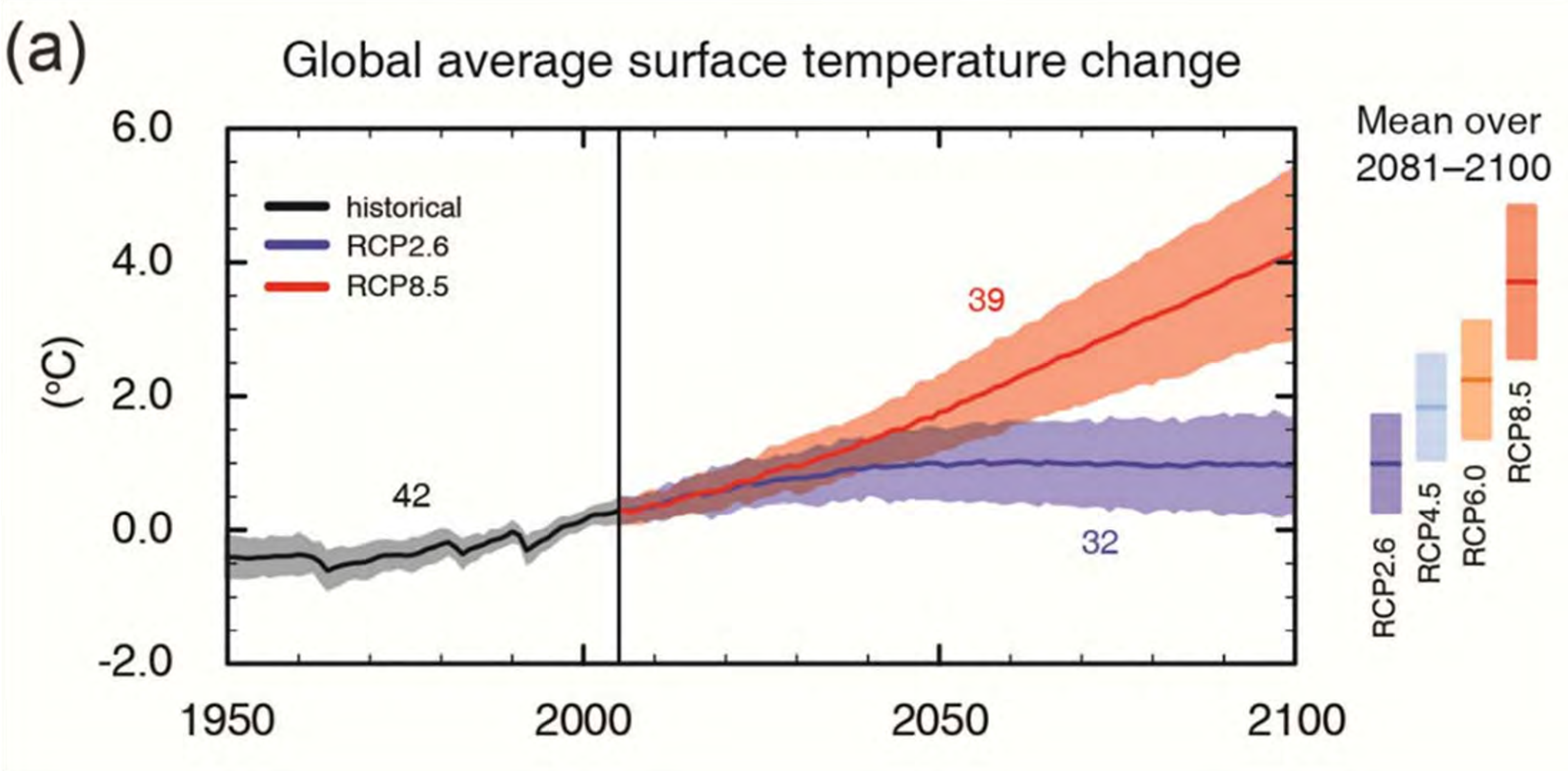


Figure 1: 29 Companies disclose using an internal price on carbon*

Consumer Discretionary

Delphi Automotive Plc

Consumer Sta

Energy

Exxon Mobil	$60 by 2030
Royal Dutch Shell	$40
BP	$40
Conoco Phillips	$8 – 46
Devon Energy	$15
Total	$40
Chevron	$?
Hess	$?

Financials

Wells Fargo & Company

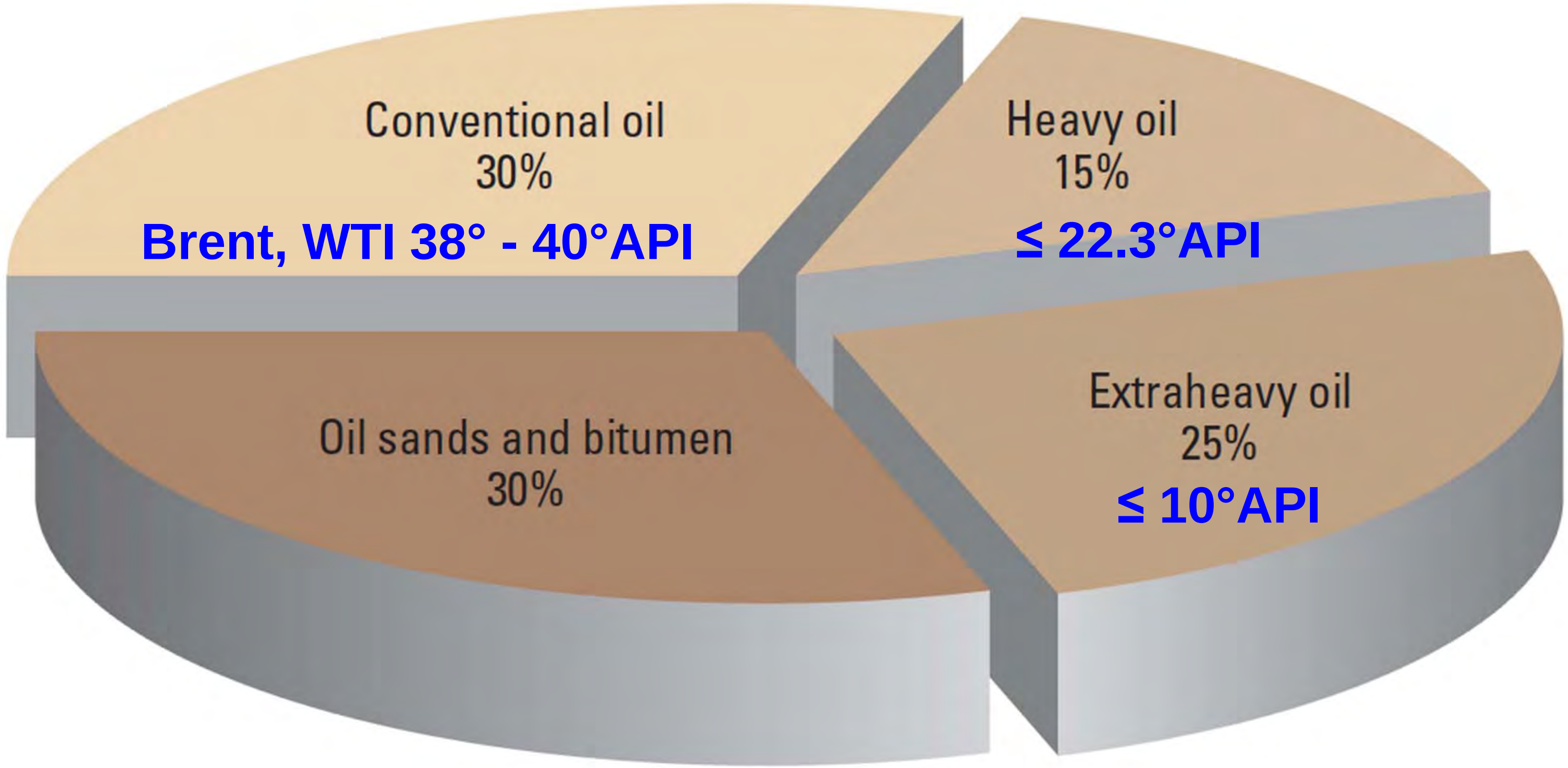
Industrials

Cummins Inc.

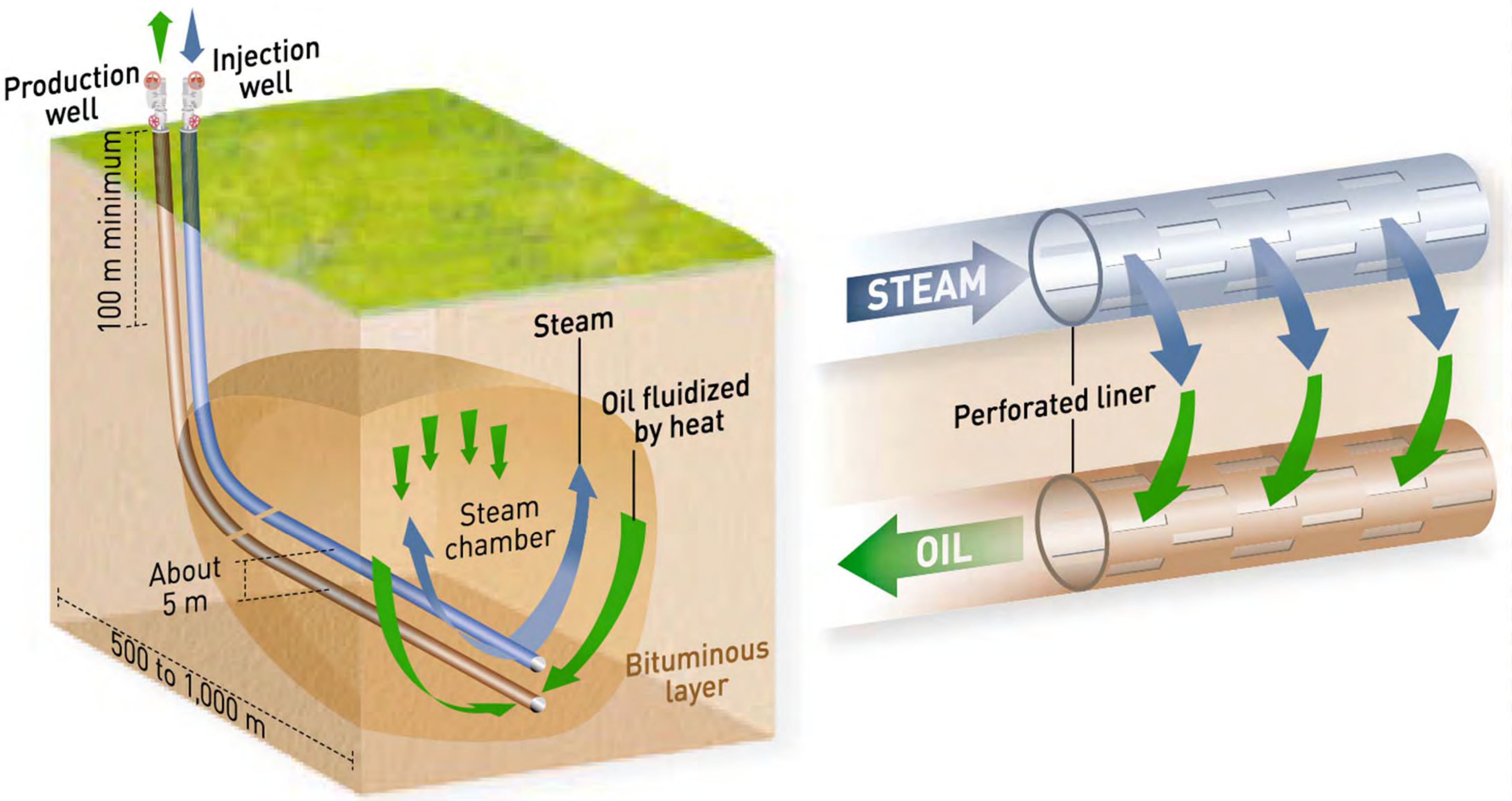
Delta Air Lines

General Electric Company

~ 70% of the total world oil reserves is heavy, extra-heavy, oil sands and bitumen



Steam-assisted gravity drainage (SAGD)
Estimated recovery 50% - 60%



Can a mixture of steam and CO_2 allow lower temperatures to decrease energy use and increase oil production?

Is it possible to use oil and natural gas in a highly carbon-constrained world? (A 20 - 40 year view)

- CCUS **(carbon capture, utilization and sequestration)** will help demonstrate new capture technologies.

- Advances in mid-IR spectroscopy will allow inexpensive, sensitive, and quasi-remote sensing of CO_2 and methane. If we can detect CO_2 leakage, we can assign credit for carbon sequestration for non-recovered/non-leaked CO_2.

- ***Non-biodegradable* materials (e.g. plastics, building materials) is a form of carbon sequestration.** At what carbon price will it be more economical to use composite materials, rather than steel and cement in construction?

“The Stone Age came to an end not for a lack of stones and the oil age will end, but not for a lack of oil.”

- Sheik Ahmed Zaki Yamani, former Saudi Oil Minister

We transitioned to better solutions.

Science and technology must help change the current path we are on.

Energy efficiency

Clean energy sources

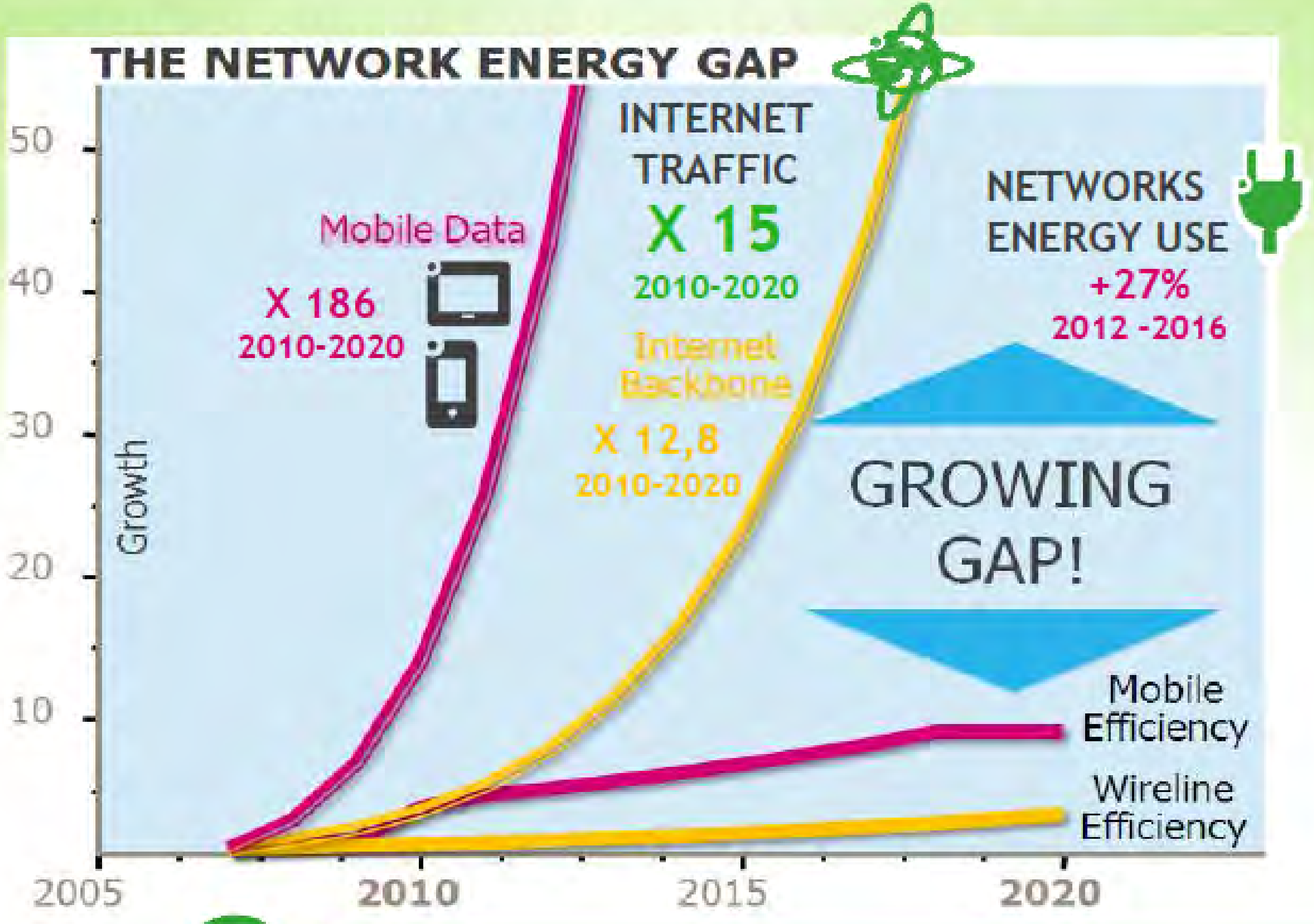
Data centers (world-wide) consume > 30 GW.

The majority of energy consumed in most data centers is used to keep idling servers at full-power in case of a surge in activity

McKinsey estimates that the centers use 6 – 12% of their electricity to actually perform computations.

Typically, 30 -50% more power is used for cooling.

DOING NOTHING IS NOT AN OPTION



Energy Efficiency is a Necessity for the ICT Industry

GreenTouch

TEGRA K1

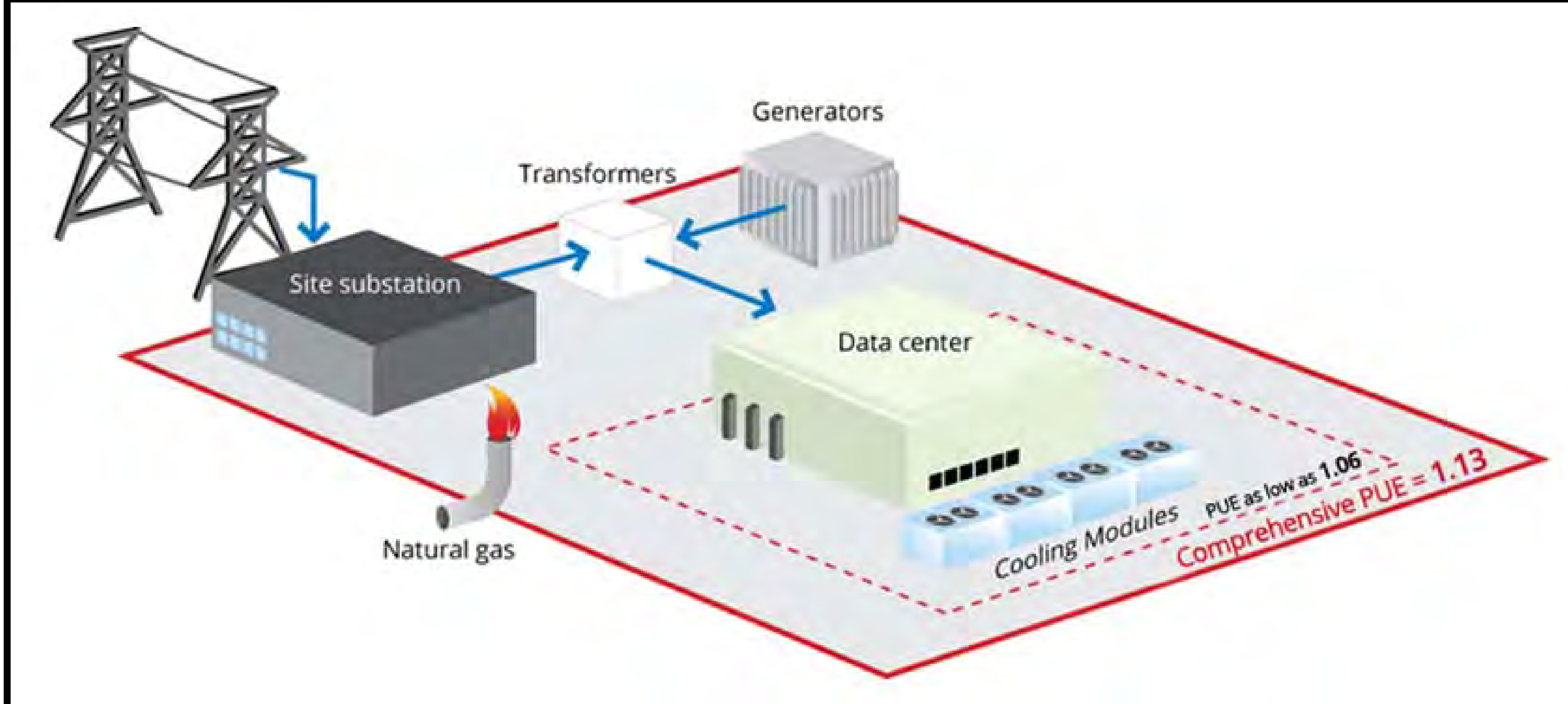
Console in the Palm of Your Hand

NVIDIA

	Xbox 360	PS3	TEGRA K1
GPU Features	DX9	DX9	DX11
GPU Horsepower	240	192	365
CPU Horsepower	3600	1200[1]	5600
Power	100W	100W	5W

Google's Power usage effectiveness (PUE) is 1.13. (1.06 if one does not include the sub-station, transformer and generator losses)

Global average PUE: 1.8 – 1.89



How science and technology may change the world.

Energy efficiency

Clean energy sources

Wind turbines are more reliable, efficient and bigger

L.C.O.E. of **land** wind: Class 3, 4 sites (6.5– 7.5 m/s) = $0.075/kWh ➔ $0.06/MWh. Prediction: 20% -30% decline in price in 10 -15 years.

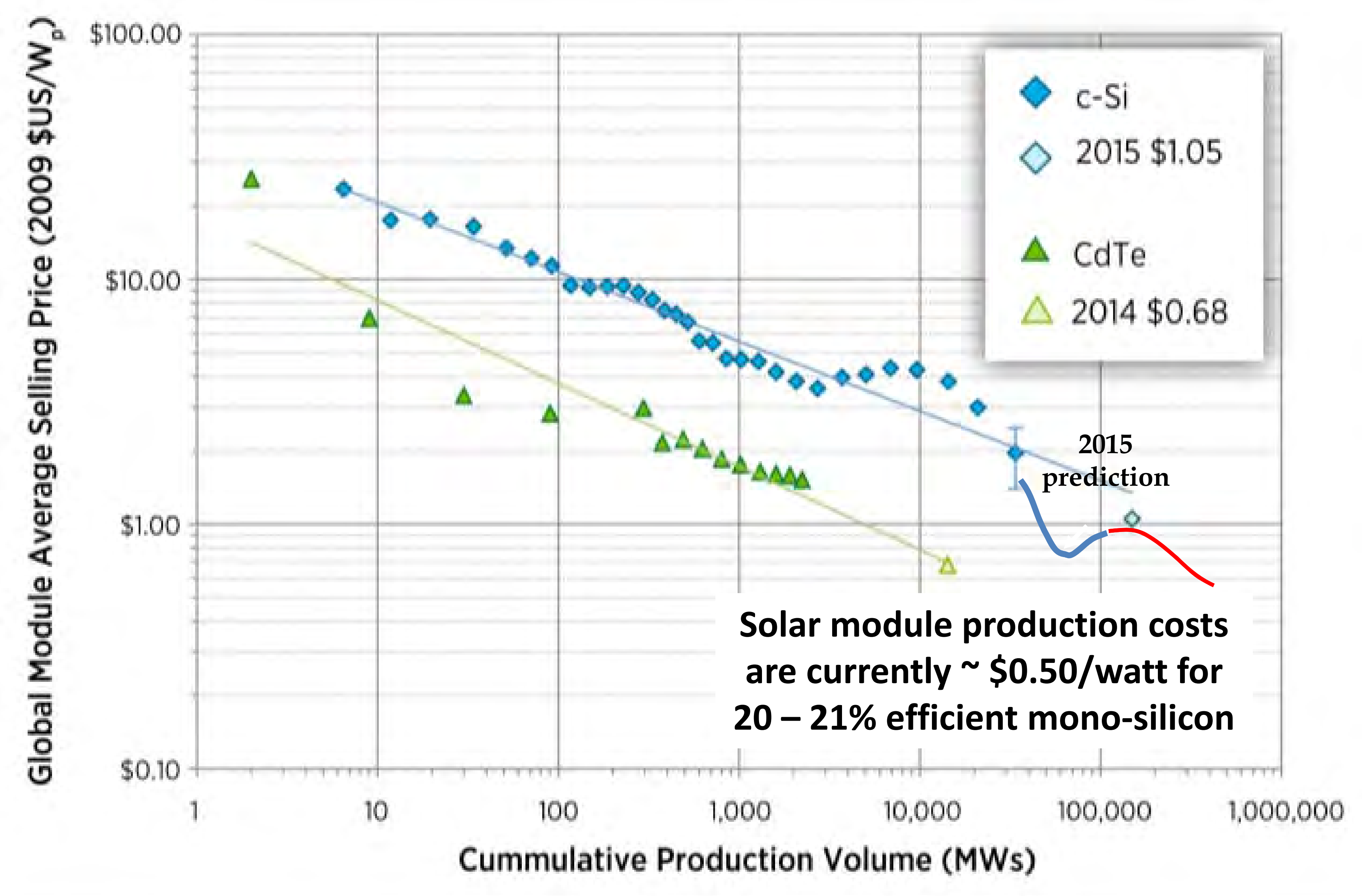
100 meter wind tower

2.3 MW turbine: 93 meter diameter blades, 115 meters high.

Solar energy

SunShot
U.S. Department of Energy

Cost of PV modules are dropping below the power law experience curve **SunShot goal $1/watt = L.C.O.E. 6.5¢/kWh**



Soft costs

"Unlike physics, where we can fundamentally figure out the upper limit for the efficiency of solar cells, there is no such limit to bureaucracy."

Minh Le

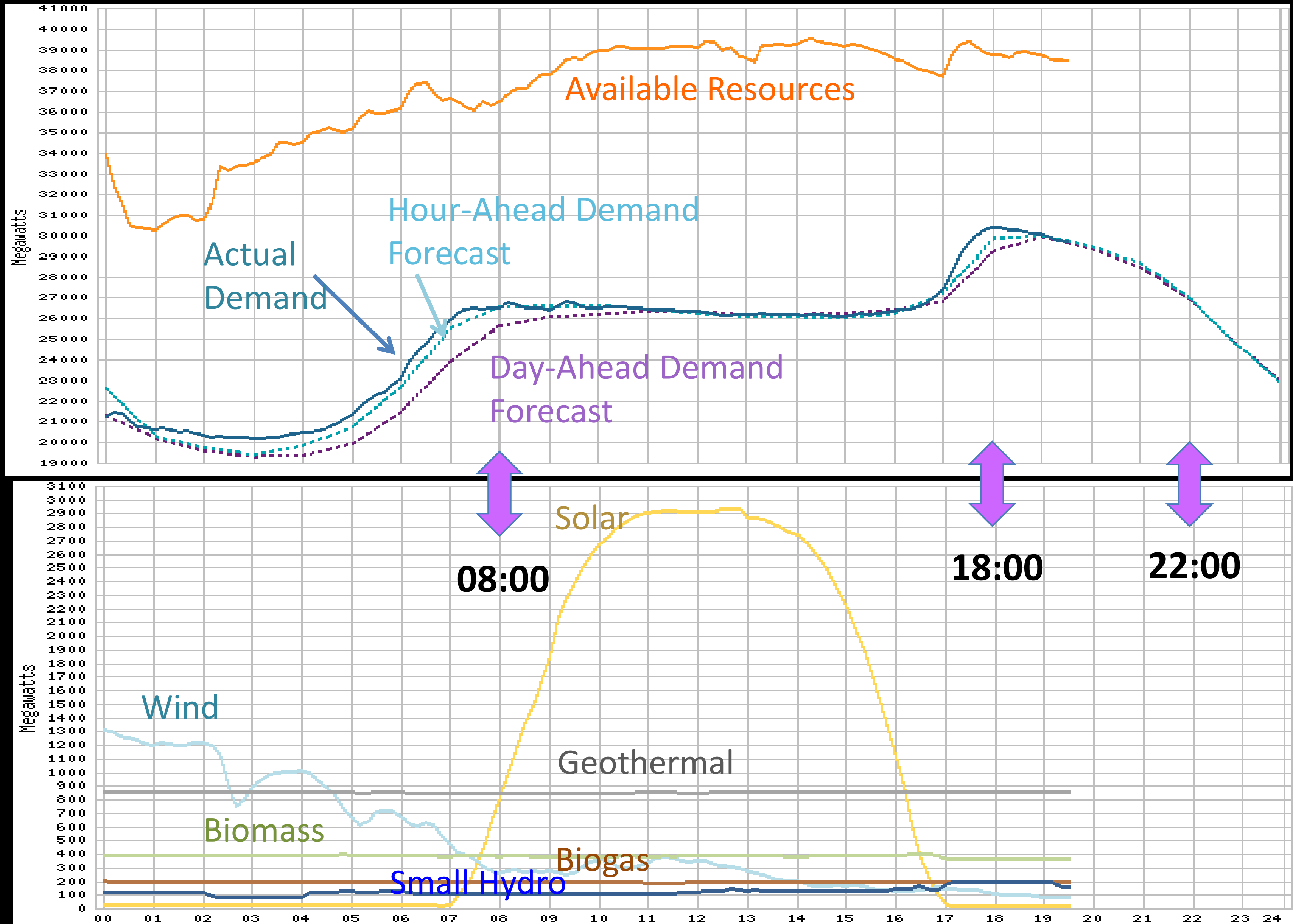
Program Manager SunShot

Why can't the installation of a PV system on your roof be handled like the installation of a gas water heater?

Residential PV in Germany costs ~$2.50/W

Residential PV in the US costs ~$5/W

California ISO Data (01/13/2014)



Advanced Research Projects Agency – Energy (ARPA-E)

(Short term, ***high risk - high reward*** research projects)

The first round of investments

Energy Innovation Hubs

(Multi-disciplinary, highly **collaborative teams** ideally working under one roof)

Miniature (Fast) Magnetics Needs Fast Switches

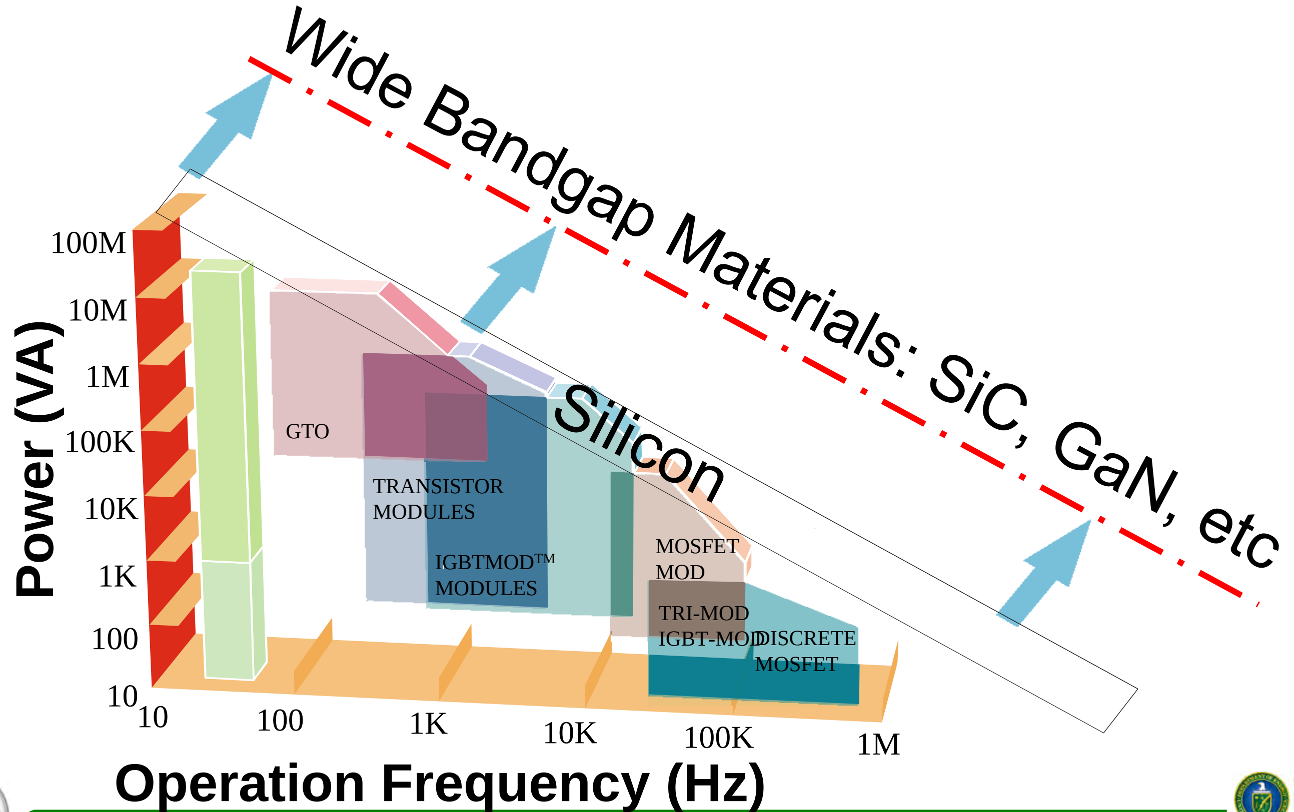
Bandgap (energy to 'free electron') increases
⇩
Breakdown voltage increases
⇩
Drift region can be decreased

}

Reduces transit time

Increases frequency

Reduces on-resistance



Power Conversion & Energy Storage

Today

Future

And Smart!

70,000 lbs

100 lbs

Anywhere In the world

$100/kWh

$100/kWh

Progress in Batteries

DOE's "EV Everywhere set goals for battery cost, energy density, durability.

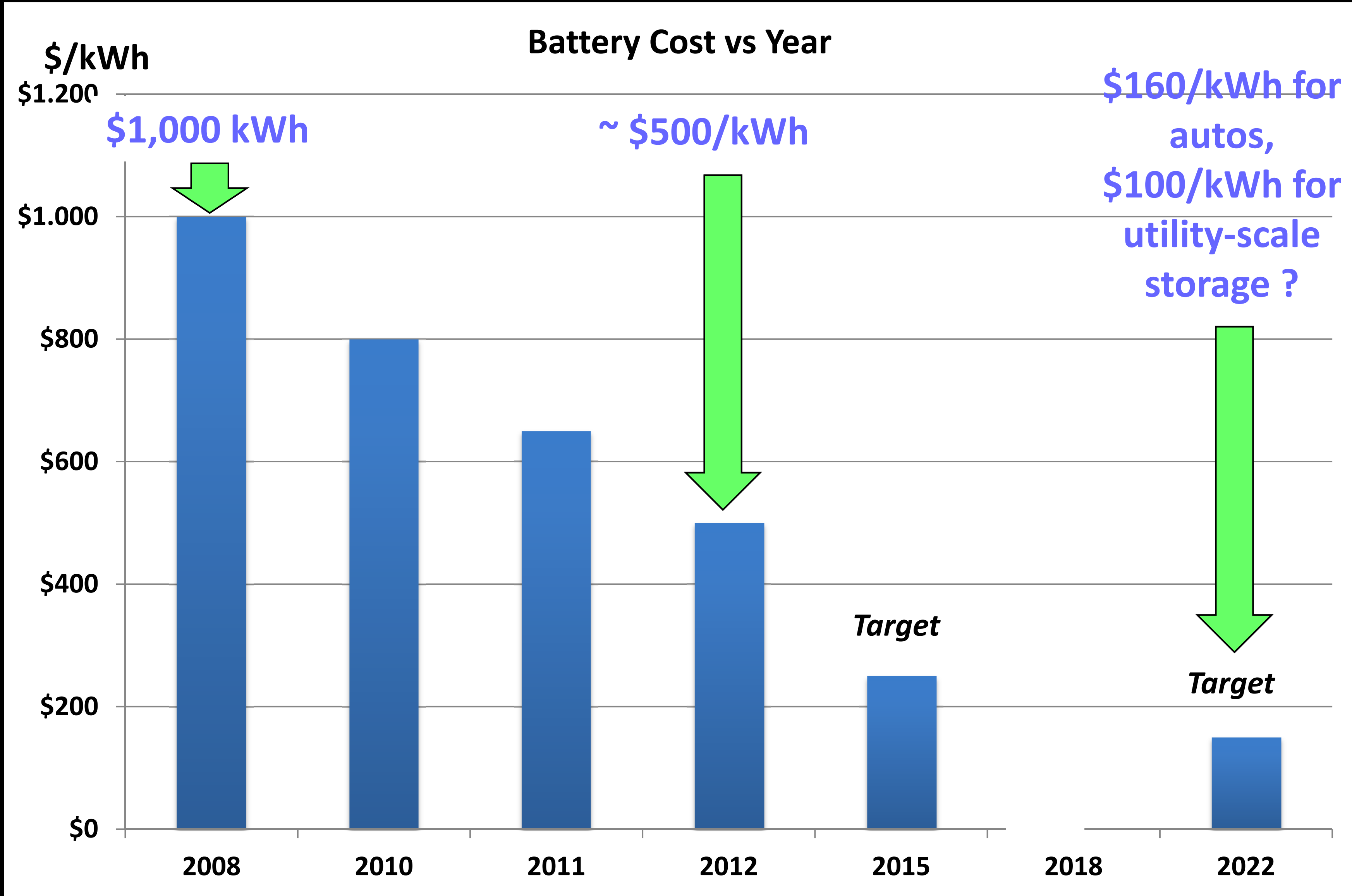
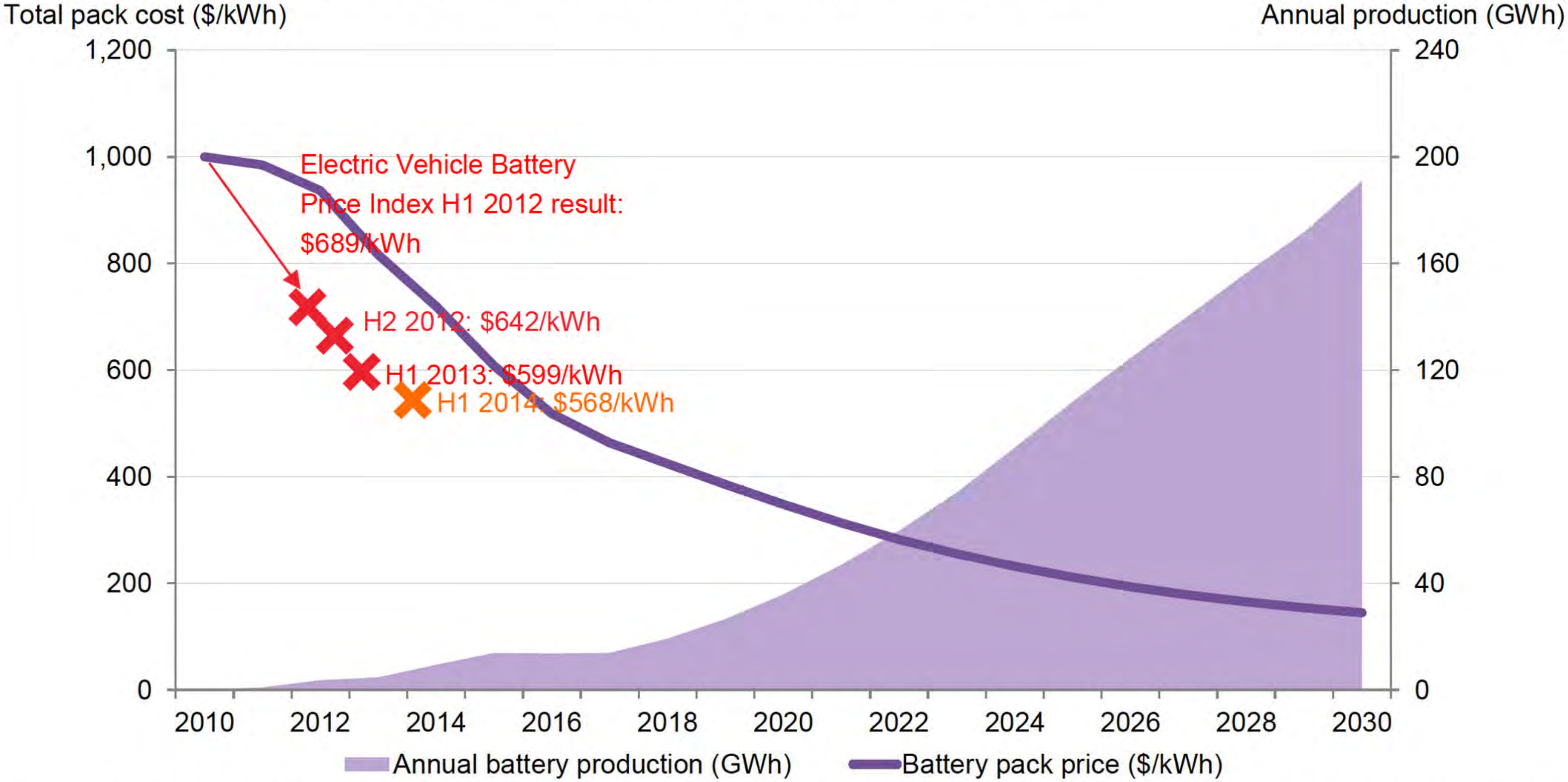


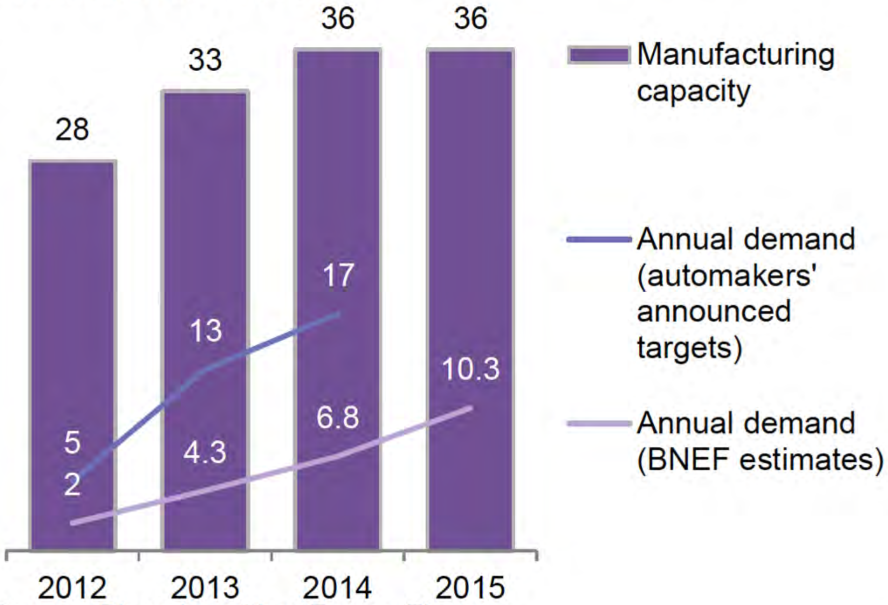
Figure 4: Total lithium-ion battery pack cost and traction battery production, 2010-30



Source: Bloomberg New Energy Finance. Note: Some of the data points we have collected represent prices for contracts that might last 1-2 years, refer to Methodology for details. The battery pack price line in the chart is projected cost based on the learning curve of EV lithium-ion batteries.

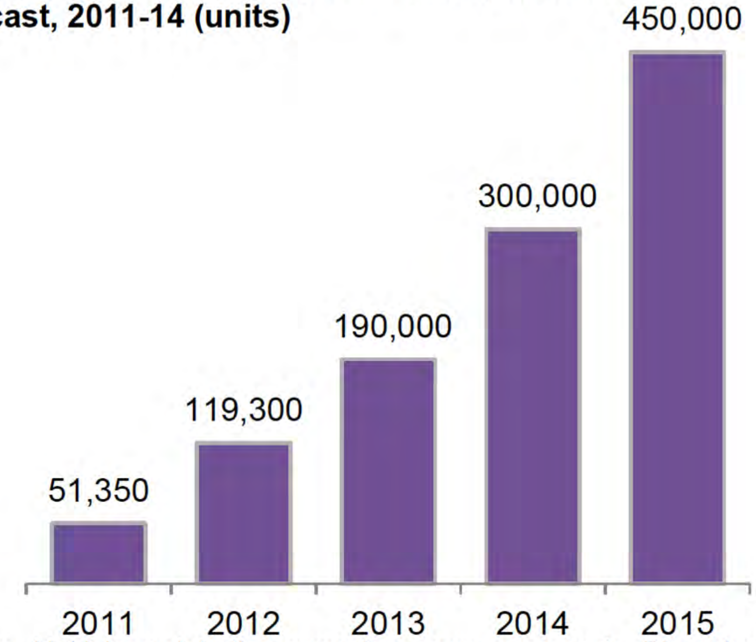
Tesla projecting 100,000 cars/year by 2016

Figure 5: EV lithium-ion battery short-term supply and demand, 2012-14 (GWh)



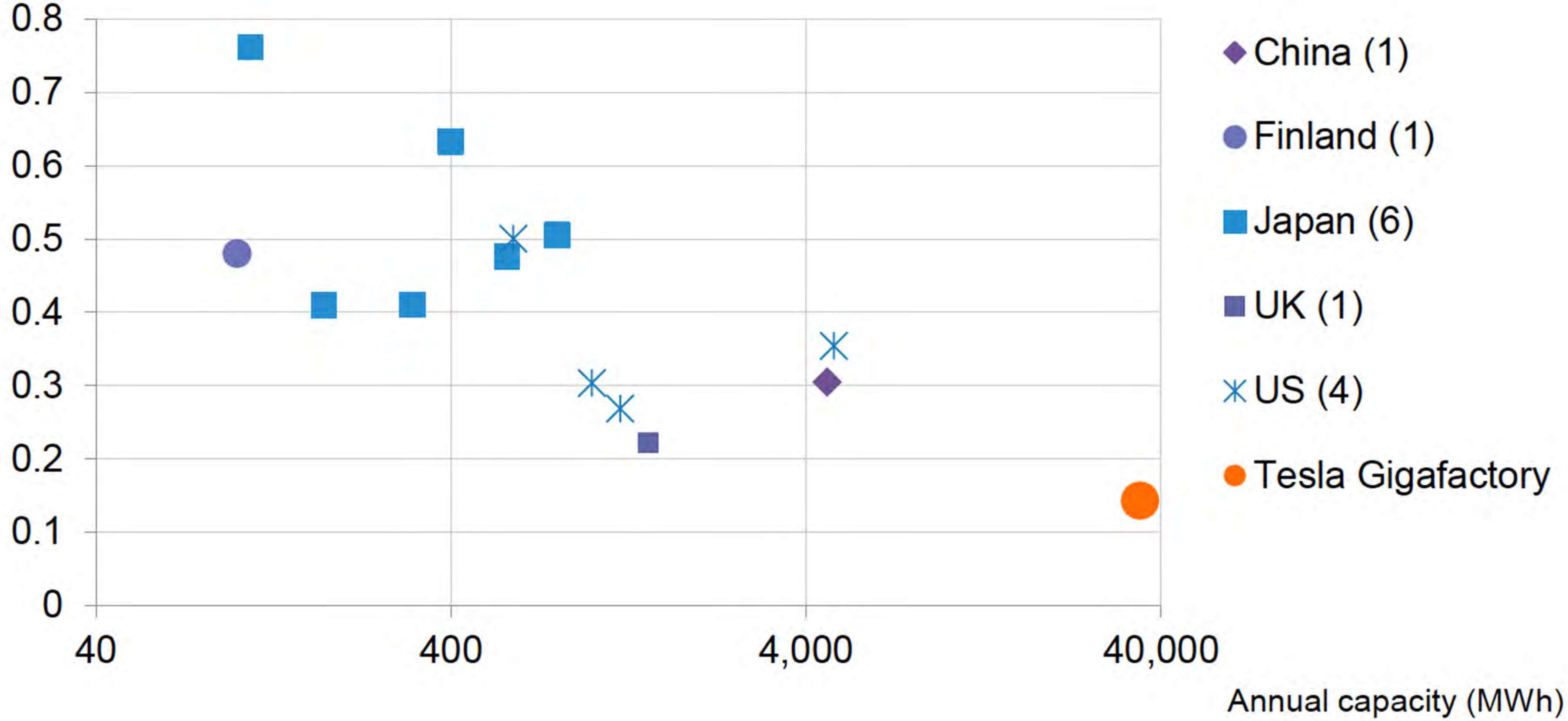
Source: Bloomberg New Energy Finance.

Figure 6: Global passenger EV sales, historical and forecast, 2011-14 (units)



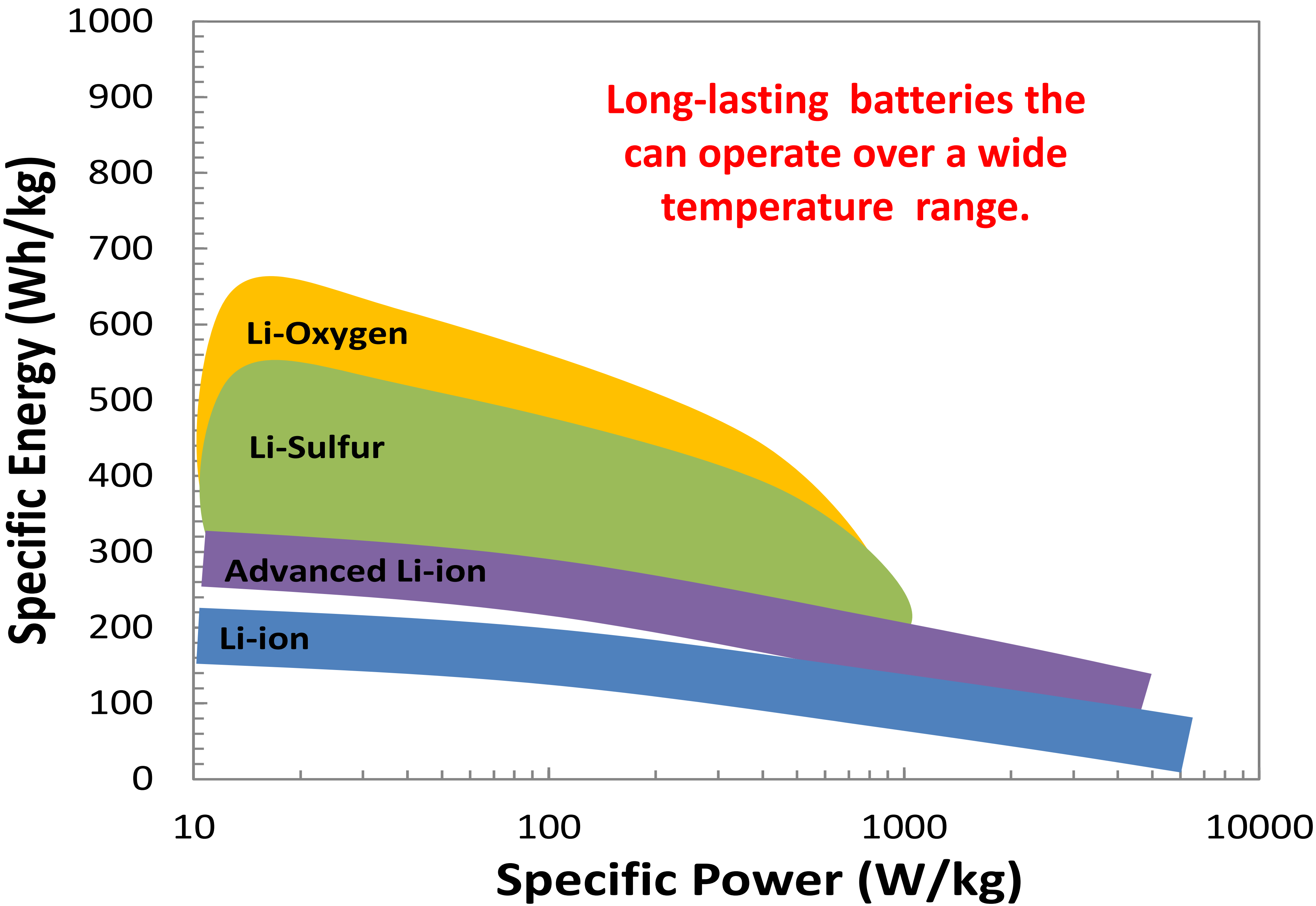
Source: Vehicle registration agencies, company reports, Bloomberg New Energy Finance.

Figure 2: Comparison of existing EV LiB plants' capex and Tesla's proposed Gigafactory ($/Wh)



Source: Bloomberg New Energy Finance based on information disclosed by each company. Note: Investment capital is calculated based on the exchange rate on the date of investment announcement.

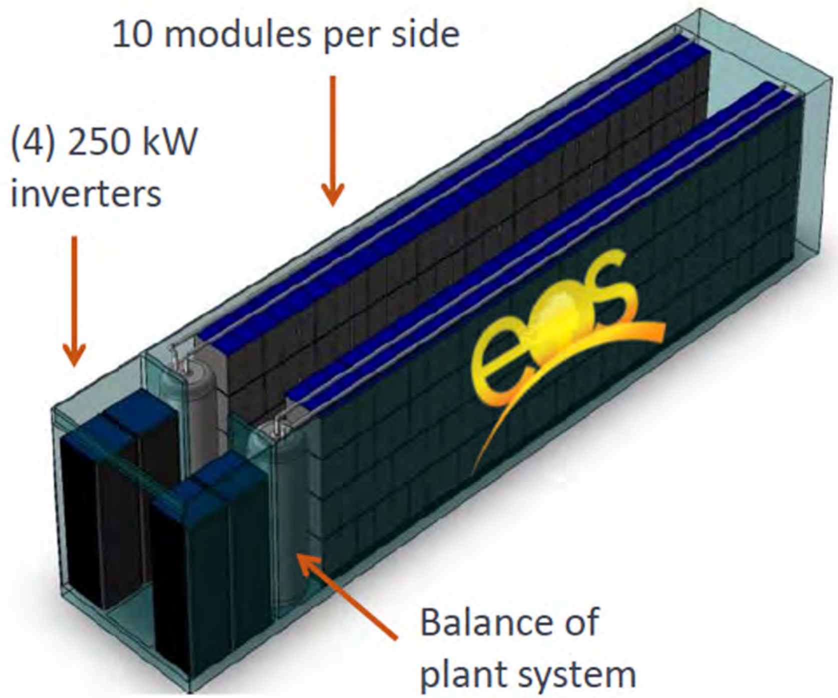
Technologies Beyond Li-Ion



Eos Aurora 1000|6000

Targeted applications define technology characteristics required for profitability

Technology Attributes	
Low-Cost	**$1,000/kW and $160/kWh**
Long Life	**10,000 cycles (30 years)**
Ample Storage	1 MW for 6 hours = 6MWh in a 40' ISO shipping container
Efficient	75% round-trip efficiency
100% Safe	Non-toxic, non-combustible, no risk of catastrophic failure

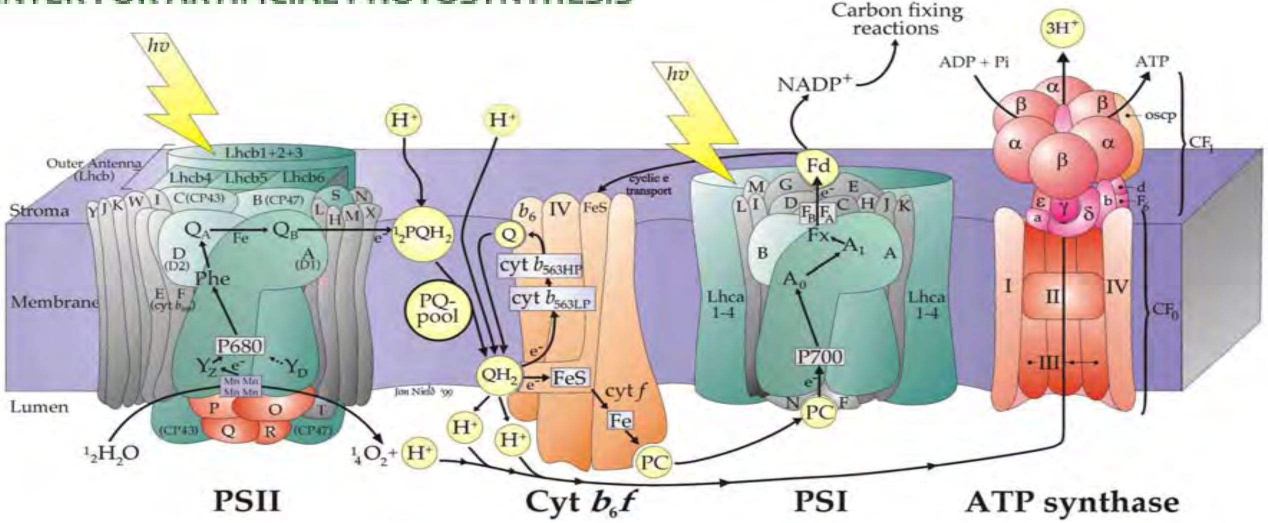


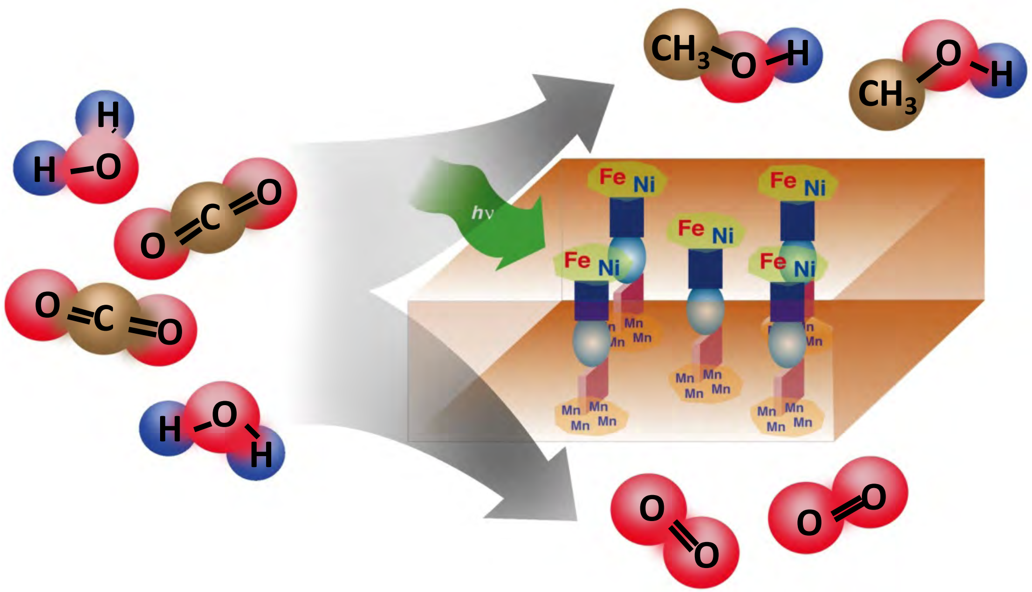
Texas Medical Center district cooling: 48 MW **combined heat and power** with 32,000 tom chiller capacity and 8.8 M gal thermal energy storage tank

Load smoothing options

JCAP

JOINT CENTER FOR ARTIFICIAL PHOTOSYNTHESIS

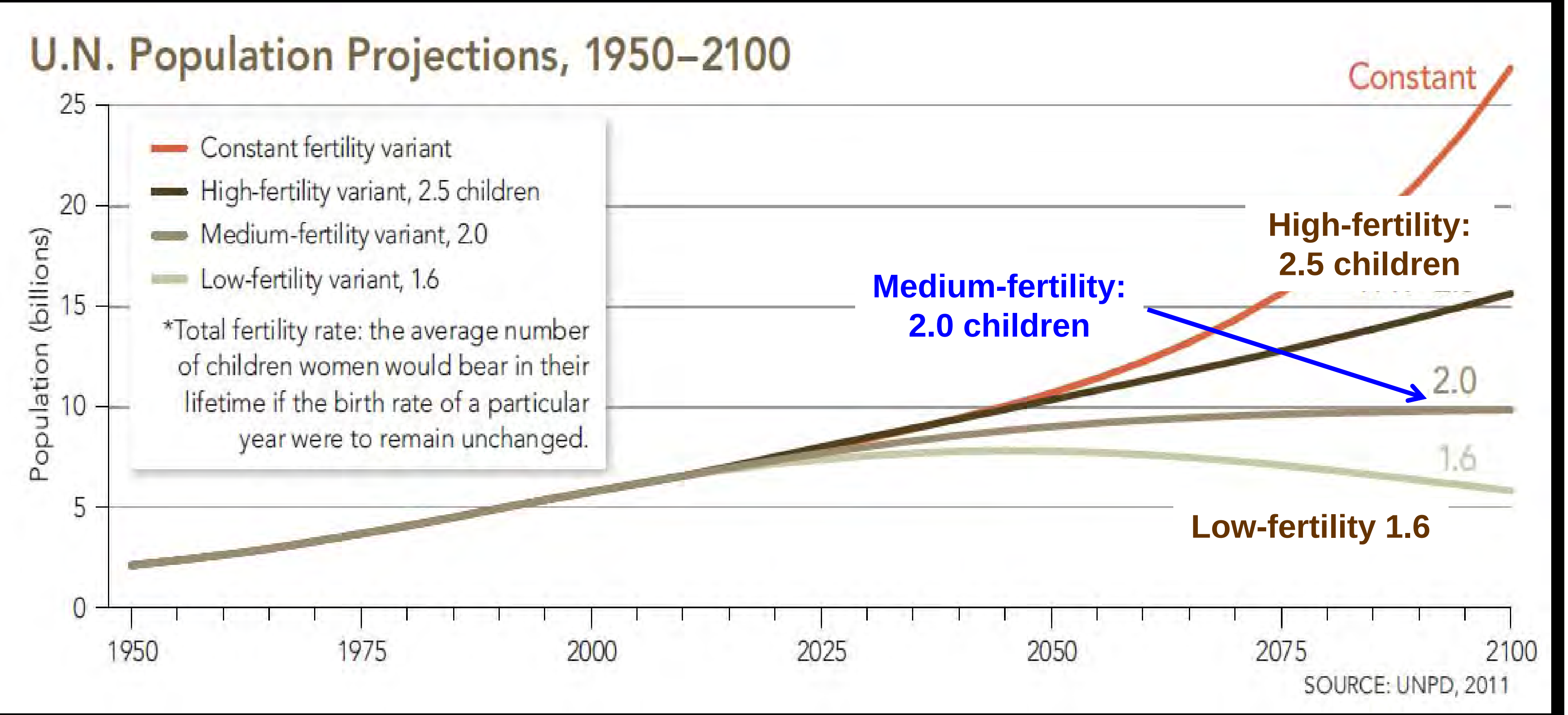




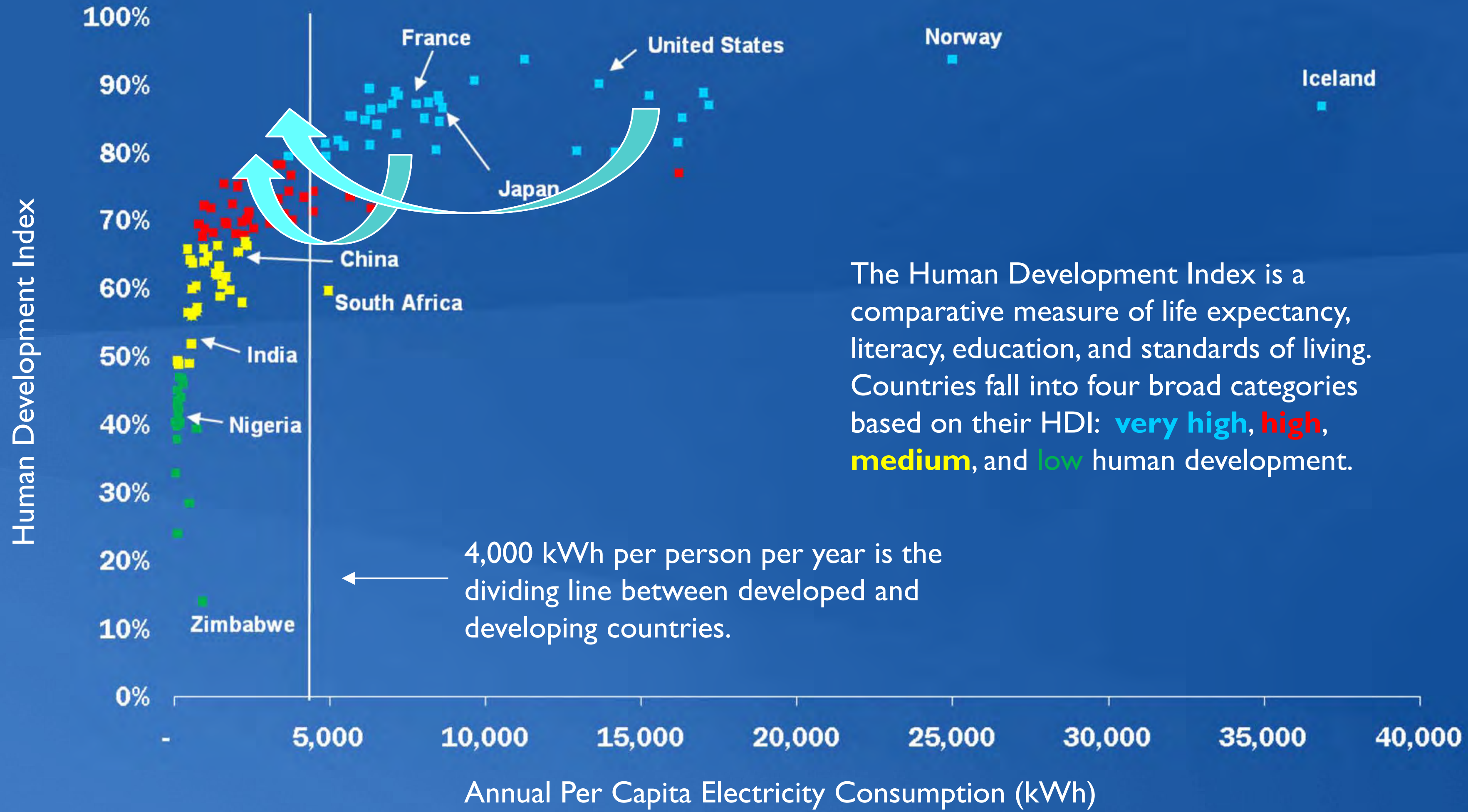
“The greater danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieving our mark.”

Michelangelo

Today, there are ~7 billion people.
By ~2025 we will grow to 8 billion.
Are technological "fixes" merely postponing the population disaster?



Correlation Between Human Development and Per Capita Electricity Consumption



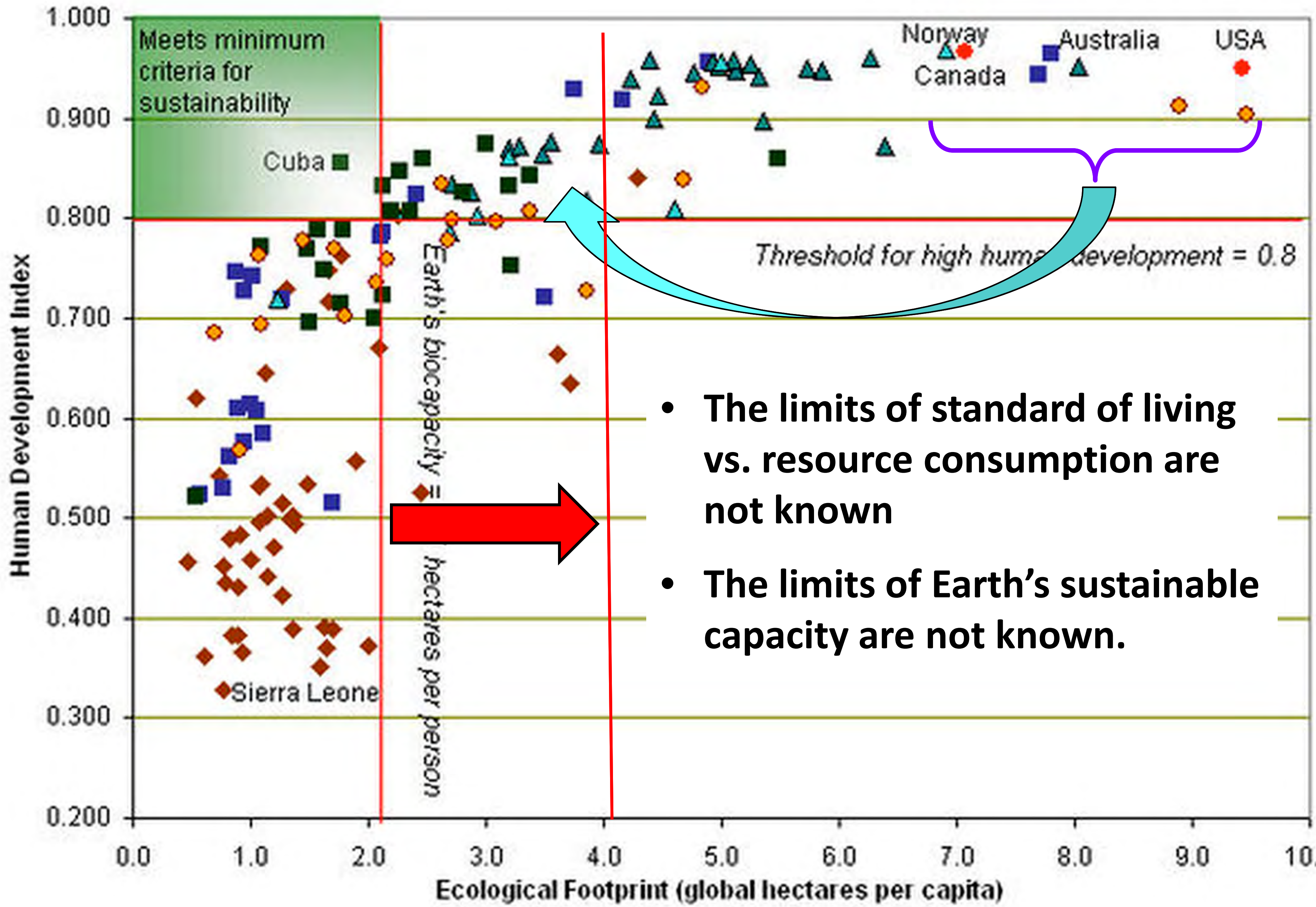
The Human Development Index is a comparative measure of life expectancy, literacy, education, and standards of living. Countries fall into four broad categories based on their HDI: **very high**, **high**, **medium**, and low human development.

4,000 kWh per person per year is the dividing line between developed and developing countries.

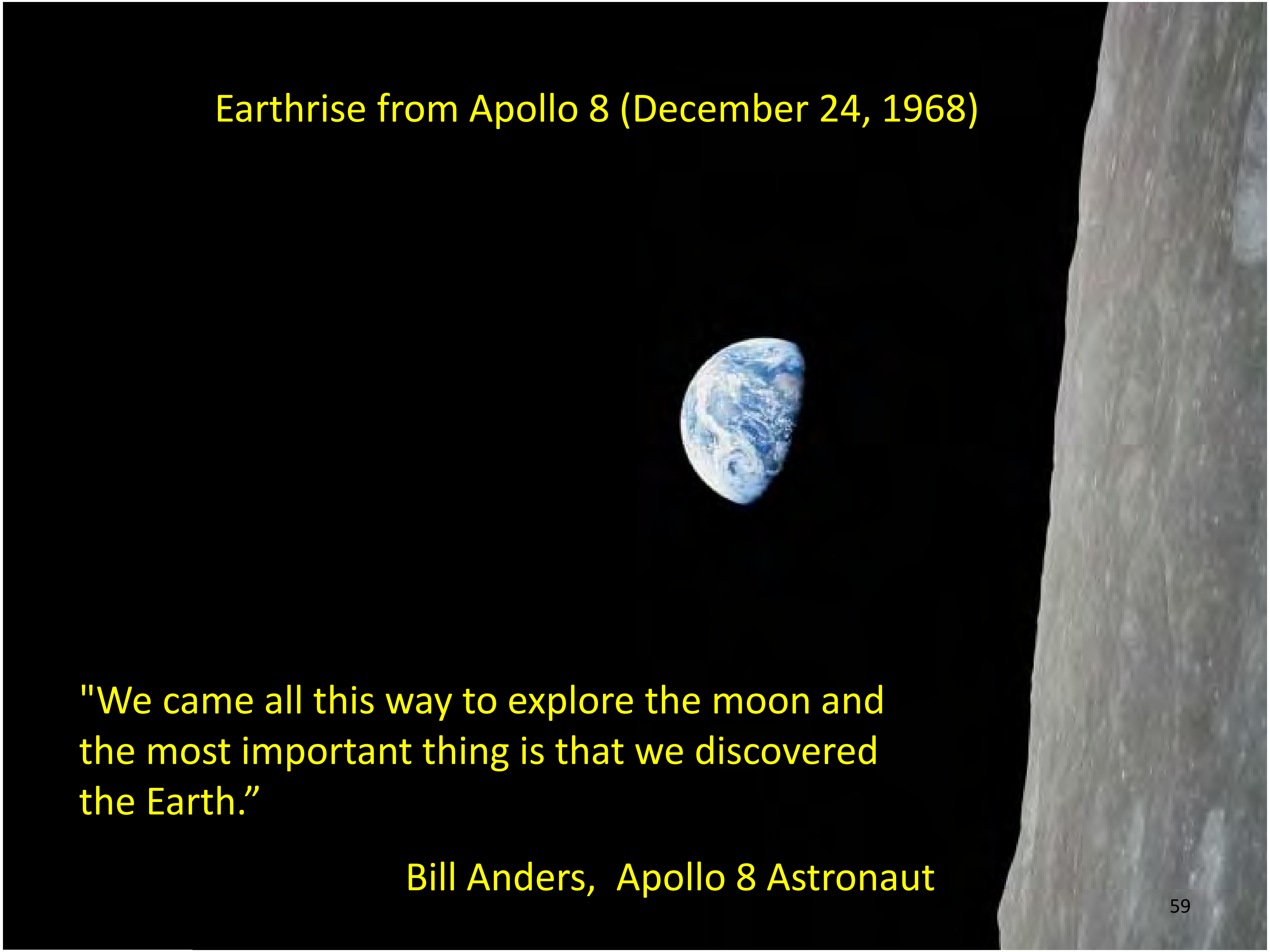
Source: Human Development Index – 2010 data United Nations; Annual Per Capita Electricity Consumption (kWh) - 2007 data World Bank

Updated: 4/11

Human Development Index versus Ecological Footprint



- **The limits of standard of living vs. resource consumption are not known**
- **The limits of Earth's sustainable capacity are not known.**



Earthrise from Apollo 8 (December 24, 1968)

"We came all this way to explore the moon and the most important thing is that we discovered the Earth."

Bill Anders, Apollo 8 Astronaut