Act 1.

The possibility

This may be a pivotal moment in our nation’s history

Scientific American @sciam · 6h

The outcome of today's election may determine Canada's actions to combat climate change bit.ly/1RRZbmv #climateaction

30 8

Foreign Policy @ForeignPolicy · Oct 16

How Canada's election will decide the fate of the world. atfp.co/1PkRGWW

40 19

~~This may be a pivotal moment in our nation's history~~

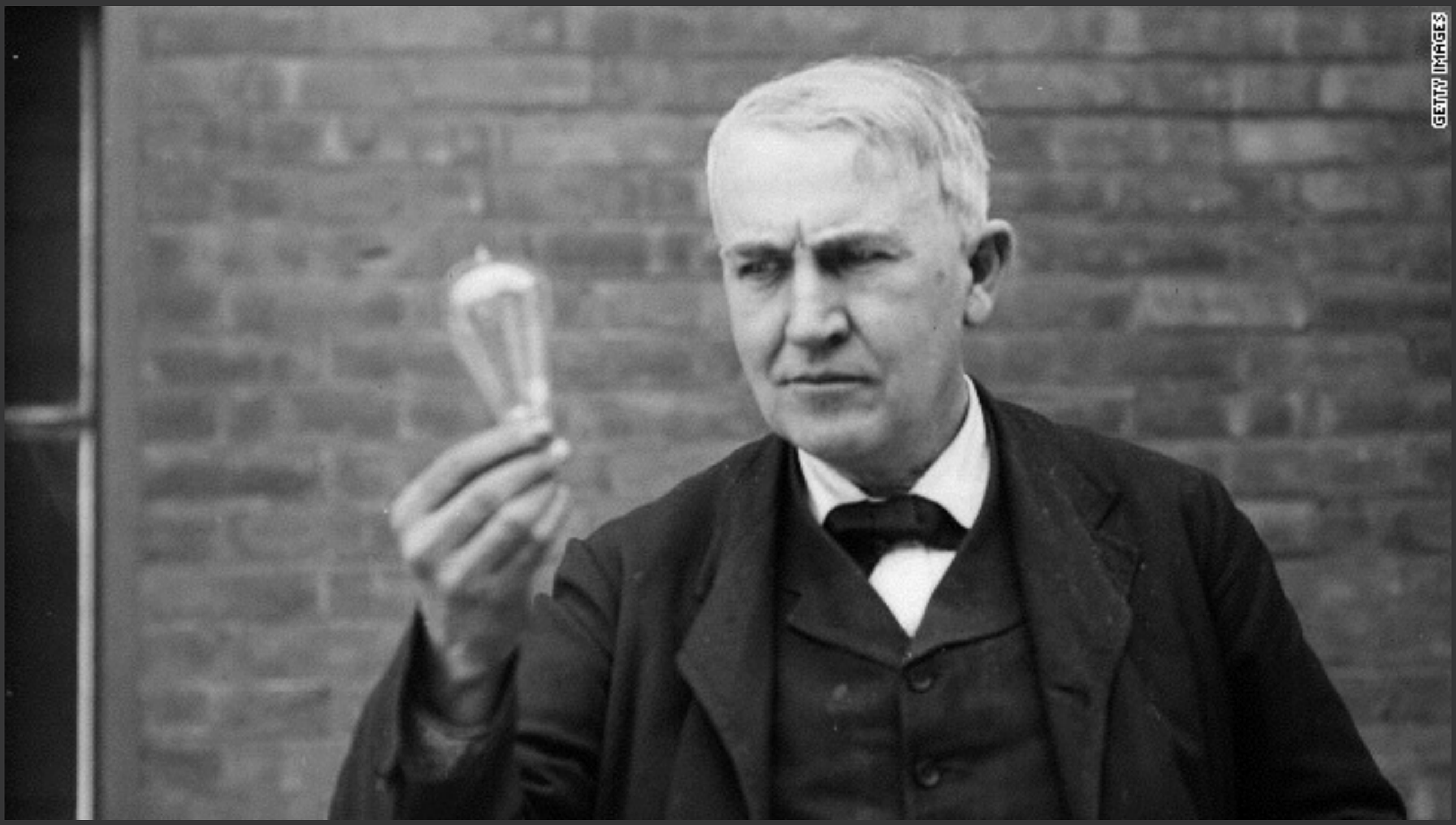
This is a pivotal moment in the world's history

Danielle Fong, Cofounder and Chief Scientist, LightSail Energy

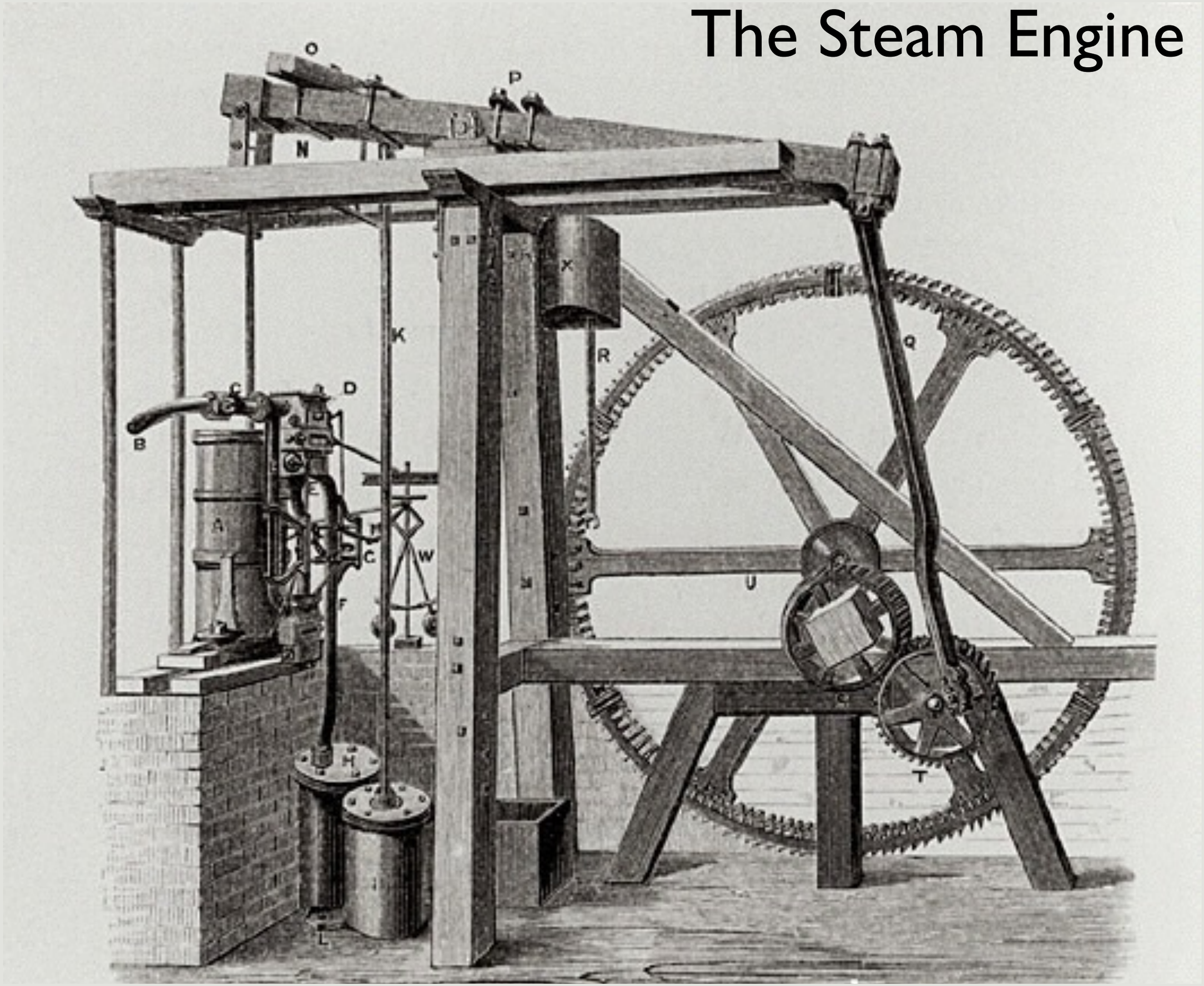
“The Time Machine”

If you could travel through time…
into the past…
carrying only your **knowledge** with you,

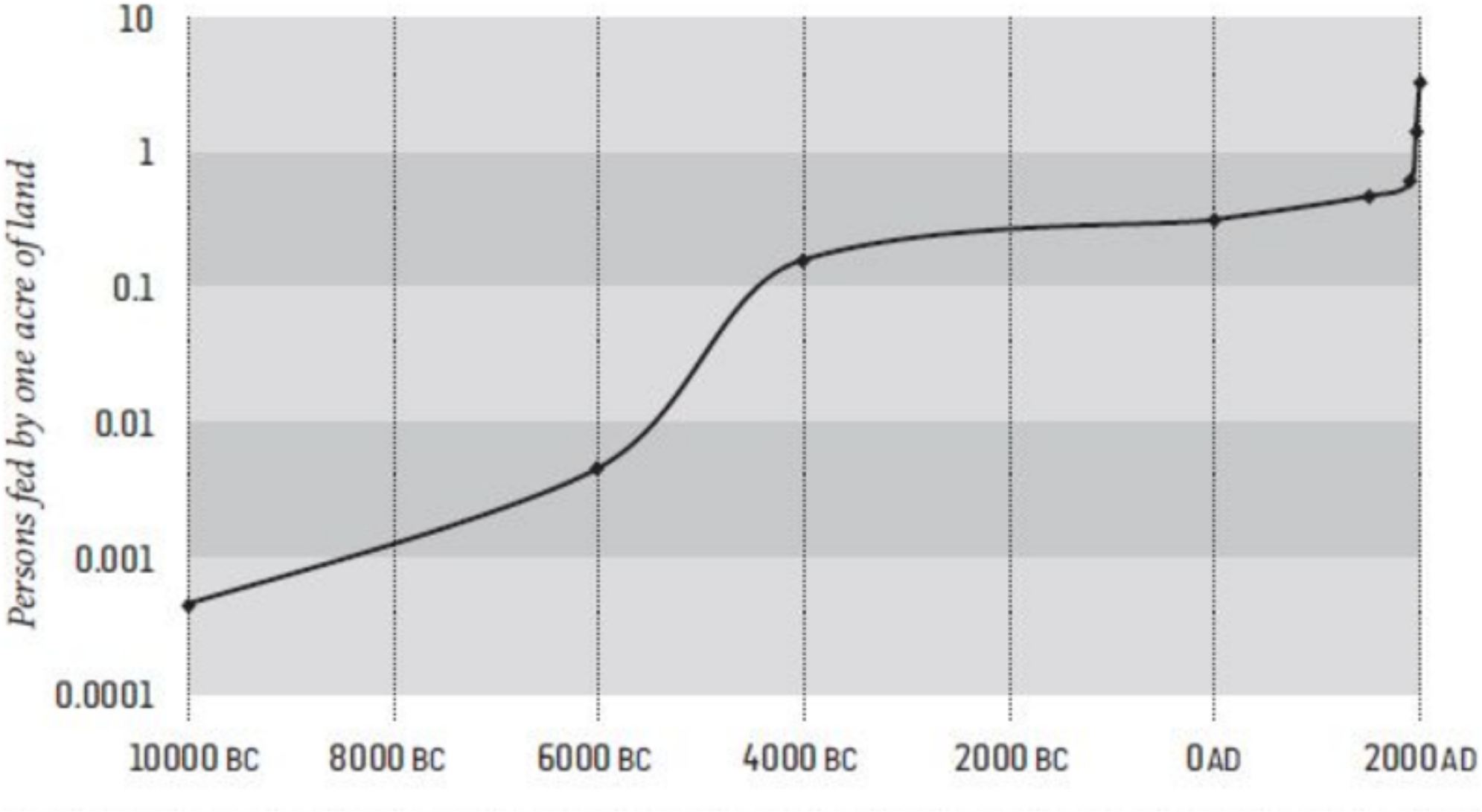
How far could you bring civilization forward?
How much could you change history?


GETTY IMAGES

The Steam Engine



Agriculture is the enabling technology of civilization



Agriculture was the efficient power of its day

Credit: Ramez Naam, "Infinite Resource"

Hunting and Gathering

Solar energy,
processed through plants and animals

Limited by biology and ecology

Diffuse

Agriculture

Solar energy,
More directly harnessed

Limited by technology

Distributed

Agriculture

Brought us from diffuse bands of hundreds
and populations of few millions

To connected, urban, technological communities of billions

We overcame our constraints
It unlocked the potential of humanity

Fossil Fuels

Solar energy,
processed through plants and animals
…and geologic processes

Limited resources

You have to go find it

Diffuse and poorly distributed

Renewables

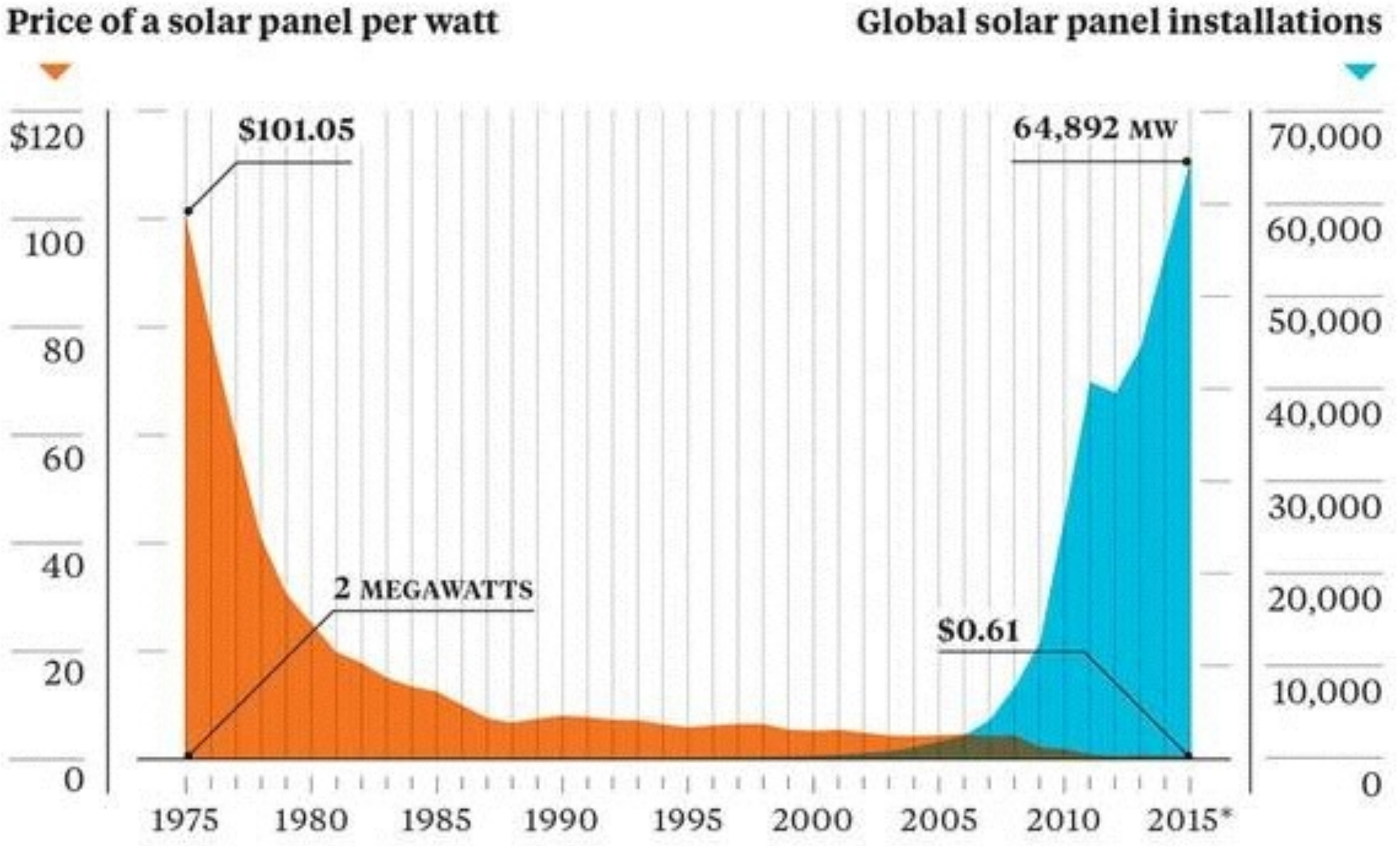
Solar energy,
More directly harnessed

Limited only by technology

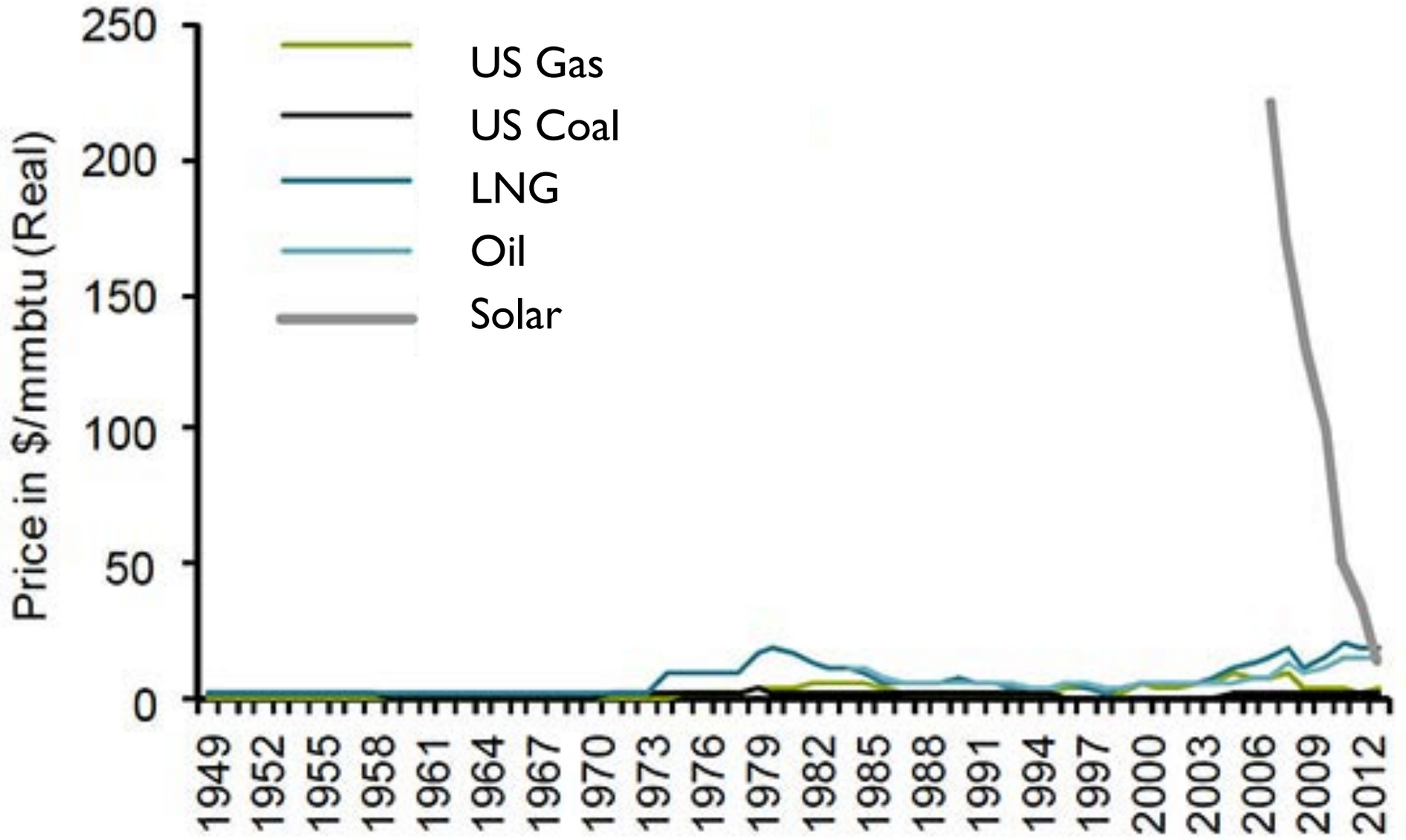
Distributed everywhere

You need **storage**

We may be at a similar time in history

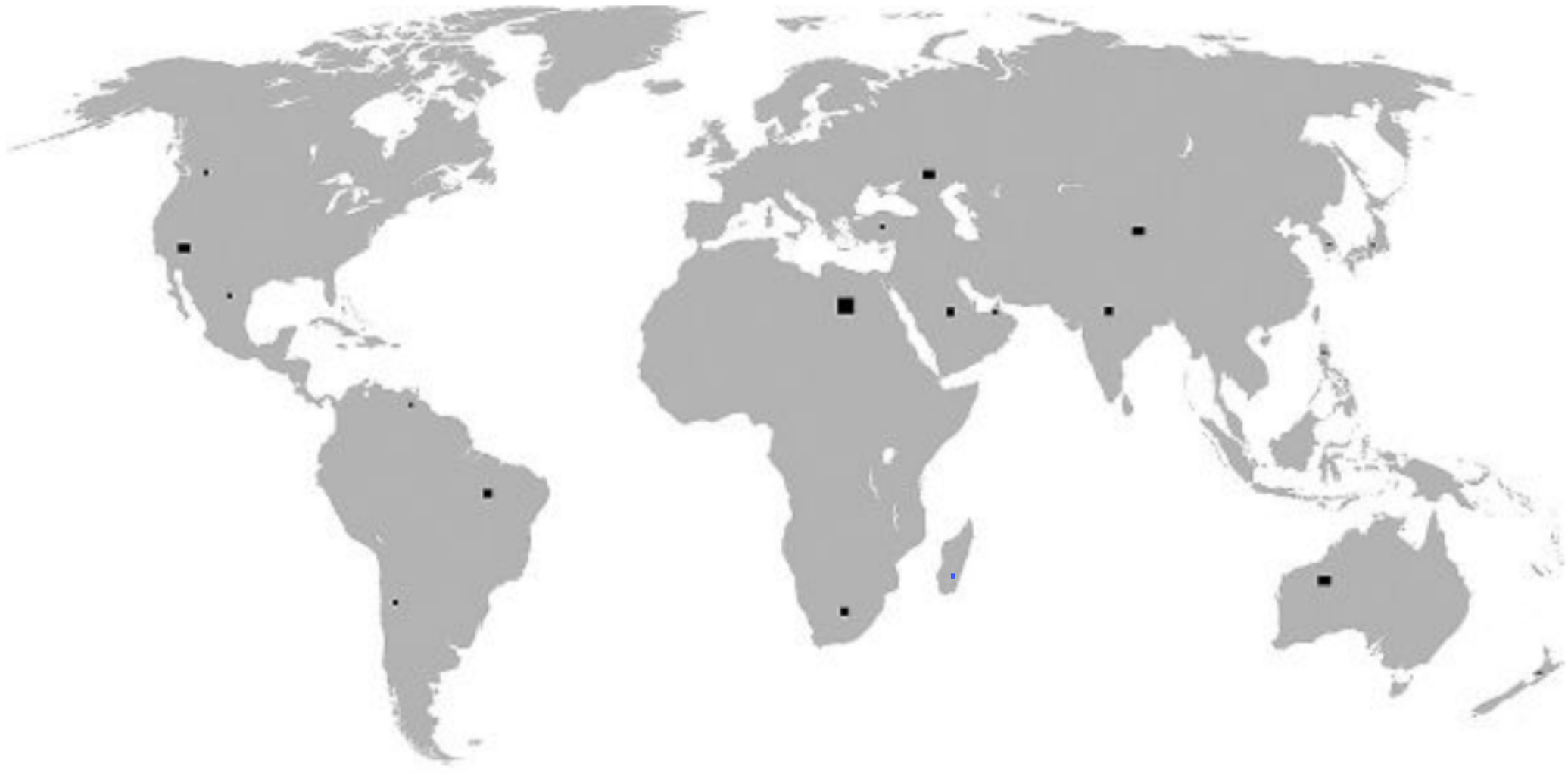


The price of solar power has fallen meteorically.



The Price of Solar versus Fossil Fuels

Only 0.5% of our land would be required
to power all our energy needs
less than 2% of our agricultural land use



We could transcend our past energetic limitations
And power amazing futures

Act 2.

The challenges

the powerplants being built now will define the biosphere for the next 5000 years

How Many Gigatons of Carbon Dioxide...?

have we released to date*?

1565 $GtCO_2$

fossil fuel burning and land use change

added 1850–2000

405

added since 2000

more can we "safely" release**?

860

our 'carbon budget'

Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/

How Many Gigatons of Carbon Dioxide...?

have we released to date*?

1565 $GtCO_2$

fossil fuel burning and land use change

added 1850-2000

405

added since 2000

more can we "safely" release**?

860

our 'carbon budget'

are left to release?

2860

760

in fossil fuel reserves of energy companies

780

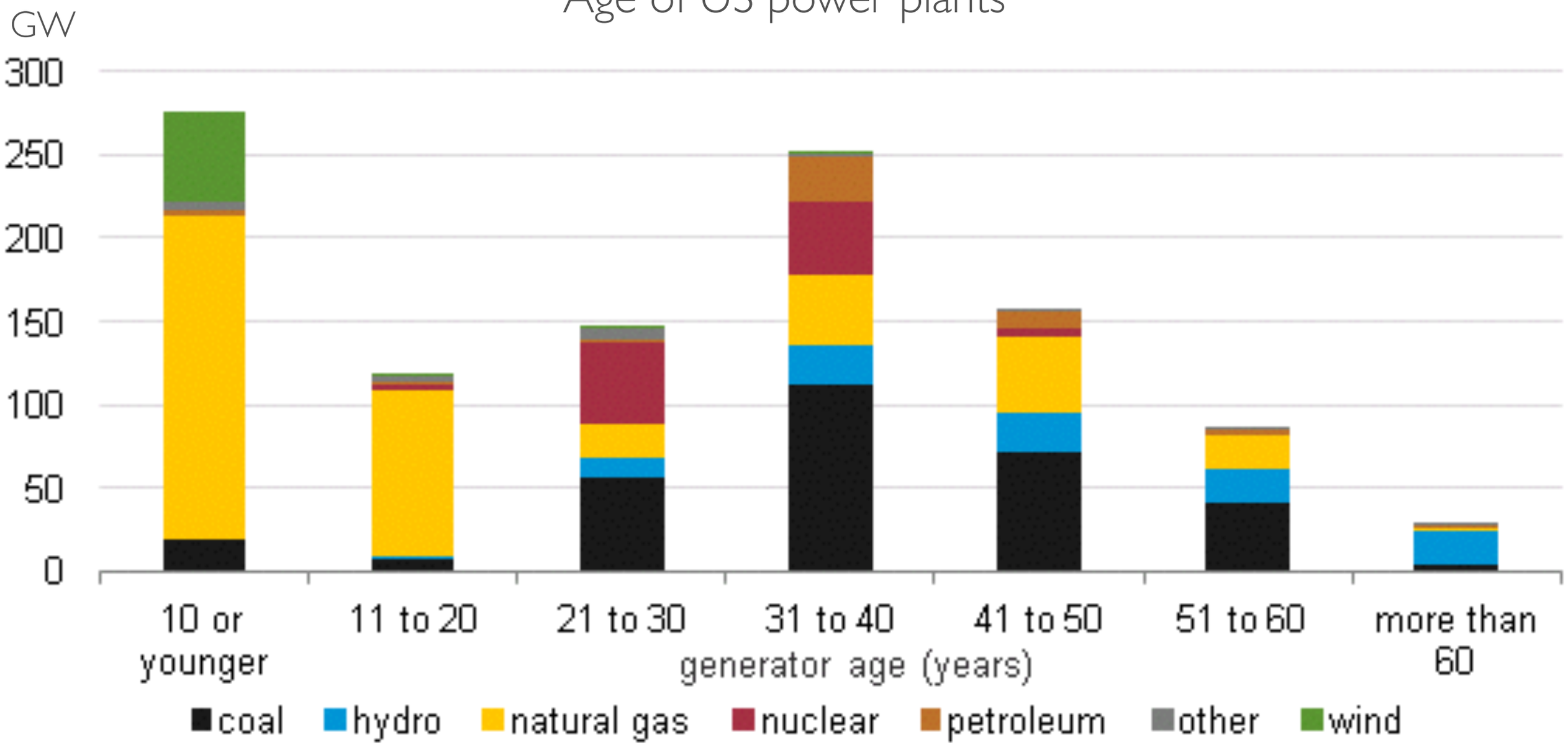
remaining company reserves that could be developed

1,320

other reserves including state-owned

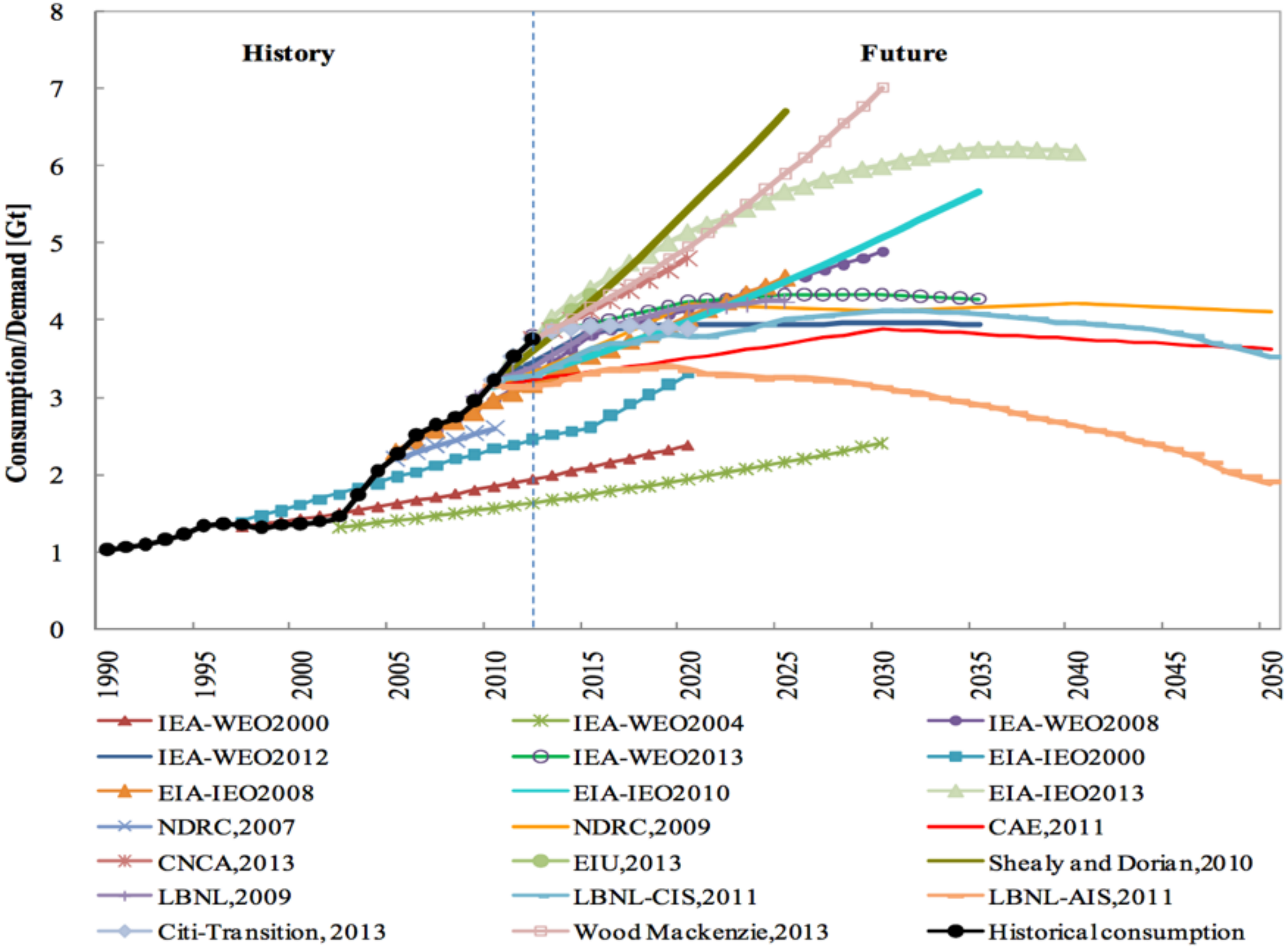
Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/

Power Plants Last 60+ Years



Source: EIA

Chinese Coal Demand is Growing Tremendously



Source: Wang Juanliang, 2014, Grantham Institute

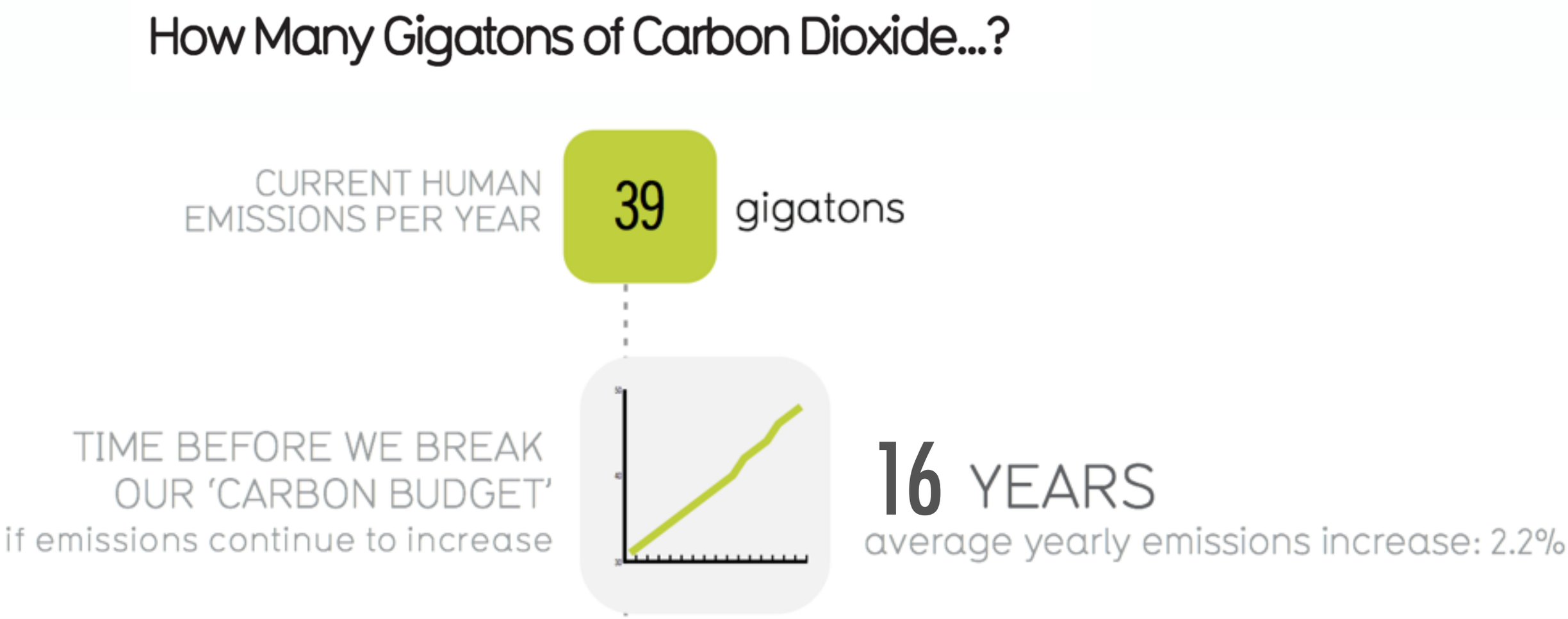
If the Chinese Coal Plants Built since 2000 by 2030
last for 50 more years
we **burn through ≈3/4** of our carbon budget

We do not lack for coal
Even we are unwilling to shut coal plants down

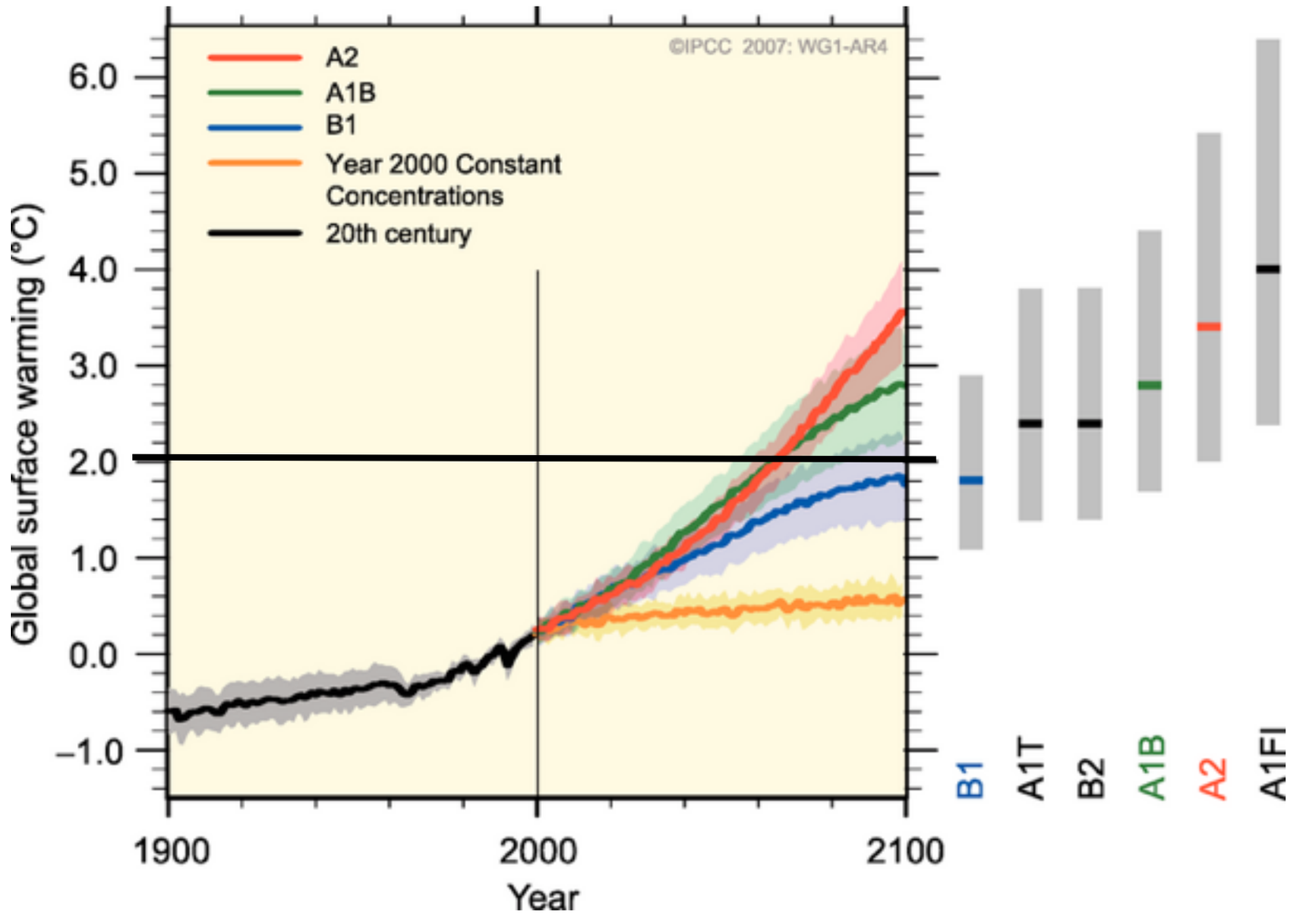
≈ 2 Gigatonne increase in Chinese Coal Demand 2005-2030
1 Gigatonne Coal ≈ 2.1 Gigatonne CO2

as the world lights up, where will the power come from?

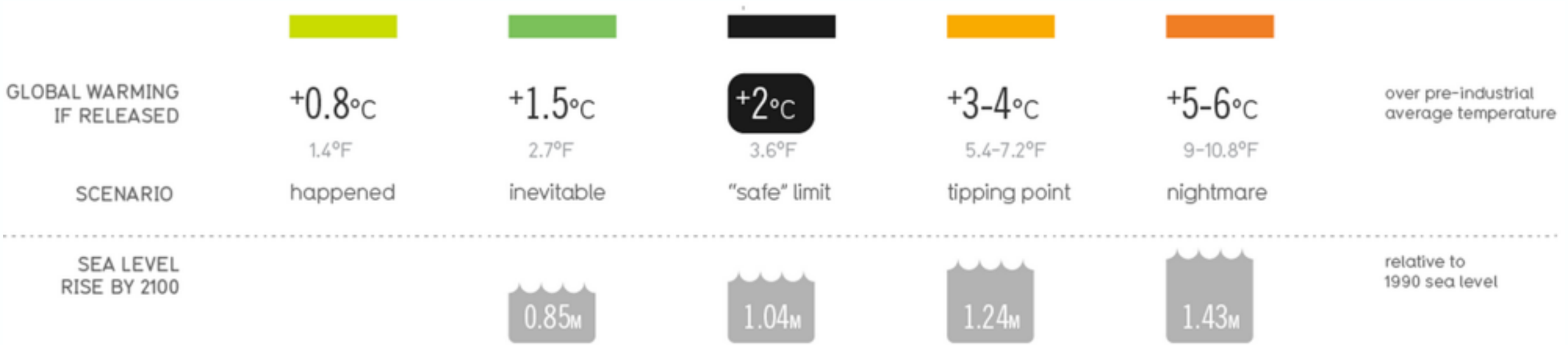
…Just in time…
We are rapidly approaching climatic limitations



Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/


©IPCC 2007: WG1-AR4
A2
A1B
B1
Year 2000 Constant Concentrations
20th century
Global surface warming (°C)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
−1.0
1900
2000
2100
Year
B1
A1T
B2
A1B
A2
A1FI

Climate Effects



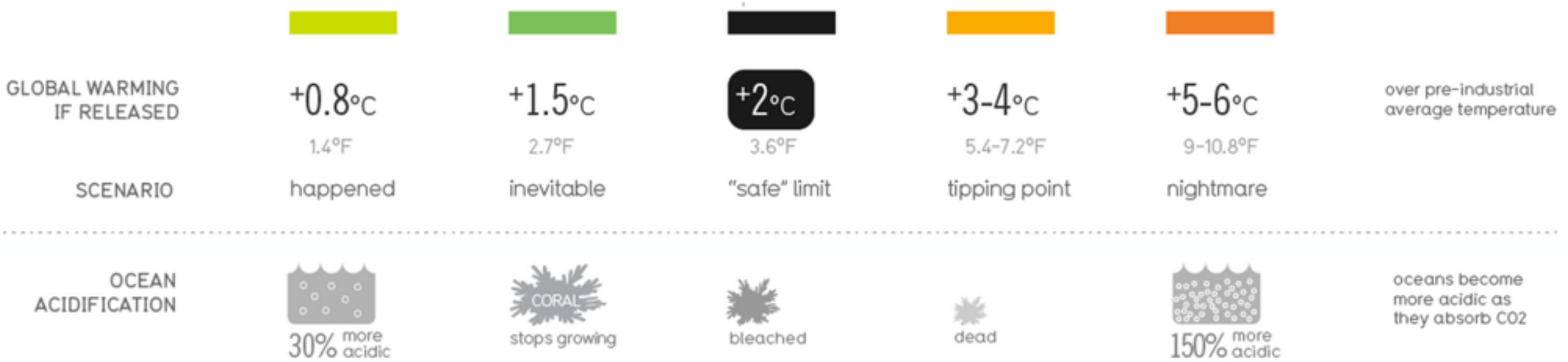
Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/

GLOBAL WARMING IF RELEASED	+0.8°C 1.4°F	+1.5°C 2.7°F	+2°C 3.6°F	+3-4°C 5.4-7.2°F	+5-6°C 9-10.8°F	over pre-industrial average temperature
SCENARIO	happened	inevitable	"safe" limit	tipping point	nightmare	
SEA LEVEL RISE BY 2100	0.85M	1.04M	1.24M	1.43M		relative to 1990 sea level
DROWNING CITIES		Amsterdam	New York	Bangkok		serious inundation

Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/

GLOBAL WARMING IF RELEASED	+0.8°C 1.4°F	+1.5°C 2.7°F	+2°C 3.6°F	+3-4°C 5.4-7.2°F	+5-6°C 9-10.8°F	over pre-industrial average temperature
SCENARIO	happened	inevitable	"safe" limit	tipping point	nightmare	
HEAT	more severe heat waves	every Euro summer a heatwave	Italy, Spain, Greece deserts	unknown		

Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/



Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/

GLOBAL WARMING IF RELEASED	+0.8°C	+1.5°C	+2°C	+3-4°C	+5-6°C	over pre-industrial average temperature
	1.4°F	2.7°F	3.6°F	5.4-7.2°F	9-10.8°F	
SCENARIO	happened	inevitable	"safe" limit	tipping point	nightmare	
CORN & WHEAT YIELDS	-10%	-20%	-30-40%	unknown		US and African corn, Indian wheat

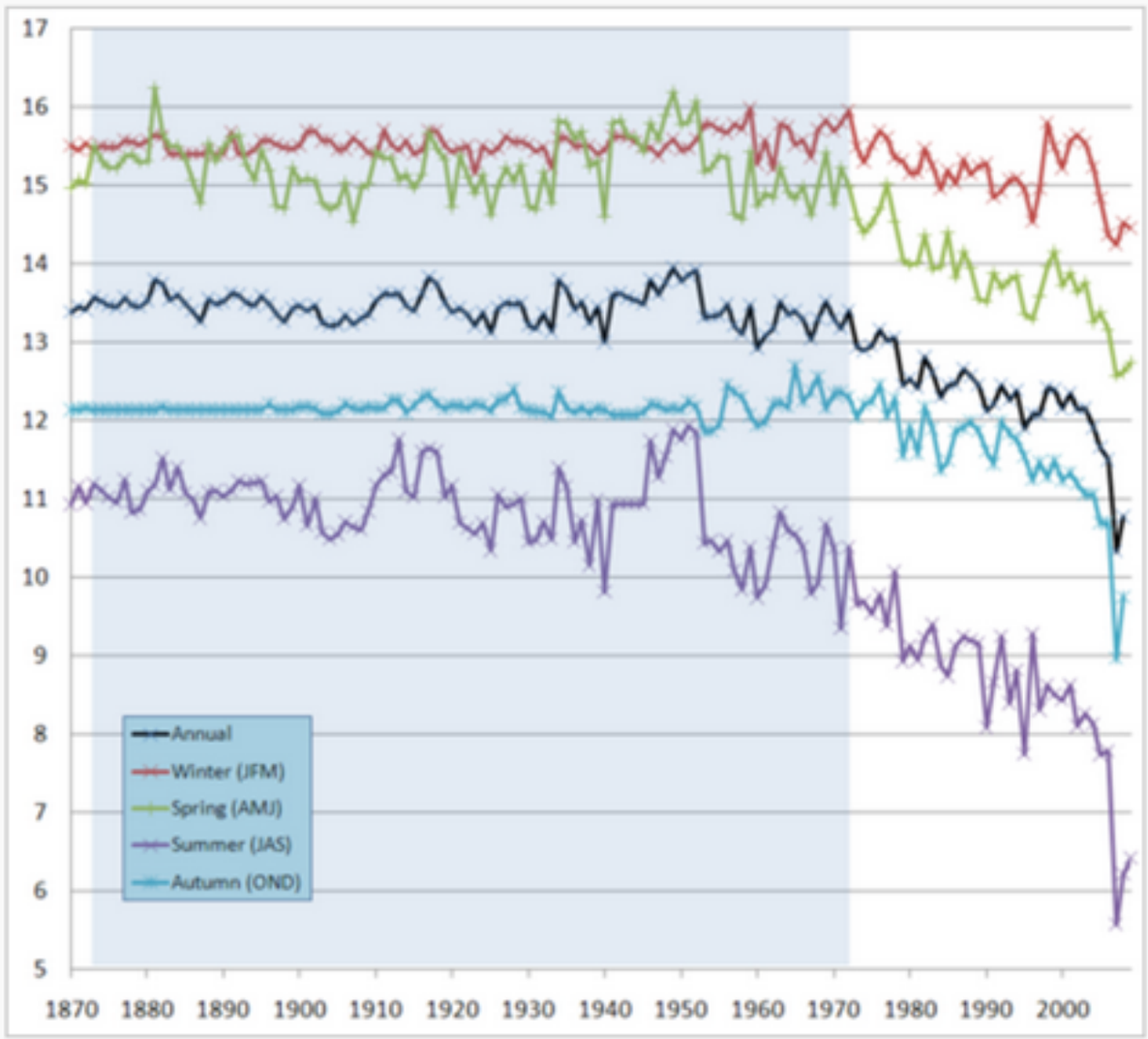
Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/

GLOBAL WARMING IF RELEASED	+0.8°C	+1.5°C	+2°C	+3-4°C	+5-6°C	over pre-industrial average temperature
	1.4°F	2.7°F	3.6°F	5.4-7.2°F	9-10.8°F	
SCENARIO	happened	inevitable	"safe" limit	tipping point	nightmare	
INCREASE IN HURRICANE DESTRUCTIVE POWER	+7.5%	+15%		+22.5-30%	+37.5-45%	

Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/

GLOBAL WARMING IF RELEASED	+0.8°C 1.4°F	+1.5°C 2.7°F	+2°C 3.6°F	+3-4°C 5.4-7.2°F	+5-6°C 9-10.8°F	over pre-industrial average temperature
SCENARIO	happened	inevitable	"safe" limit	tipping point	nightmare	
SPECIES AT RISK OF EXTINCTION			up to 30%	40%	unknown	

Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/

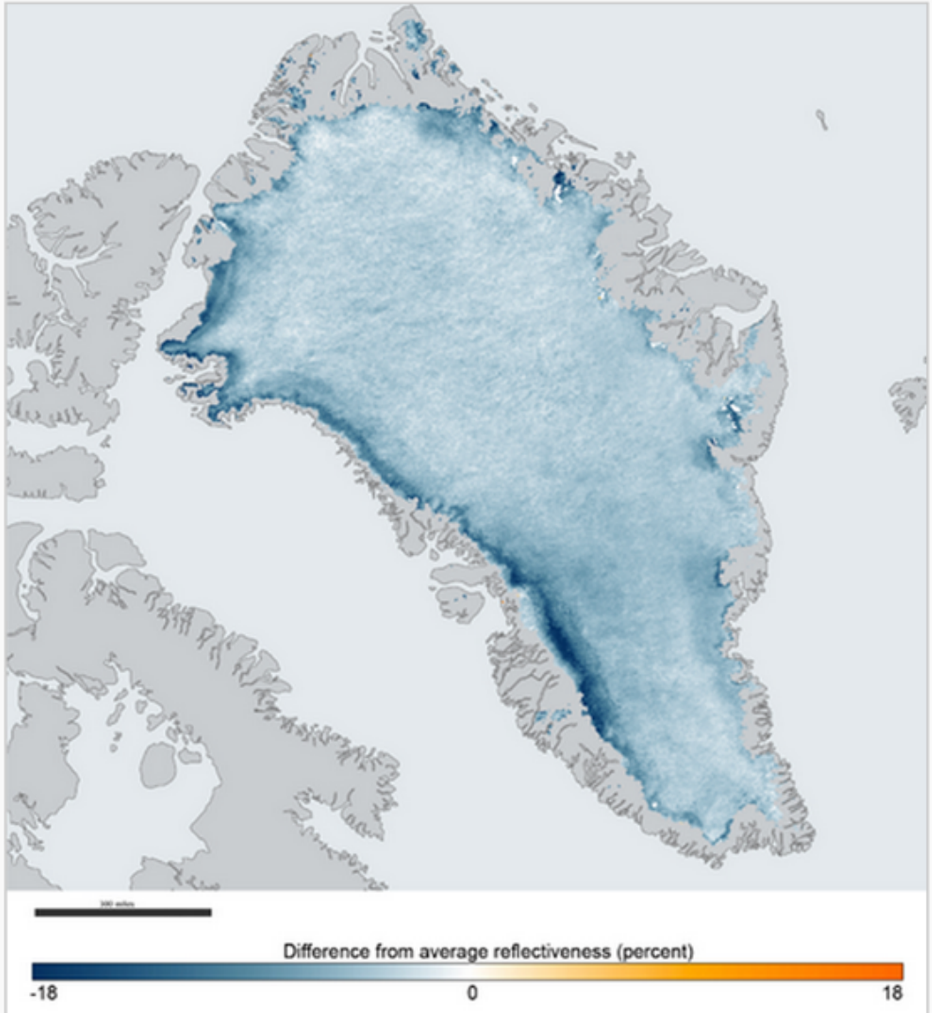


1870-2009 Northern hemisphere sea ice extent in million square kilometers. Blue shading indicates the pre-satellite era; data then is less reliable. In particular, the near-constant level extent in Autumn up to 1940 reflects lack of data rather than a real lack of variation.

Ice-albedo feedback

From Wikipedia, the free encyclopedia

Ice-albedo feedback (or **snow-albedo feedback**) is a positive feedback climate process where a change in the area of snow-covered land, ice caps, glaciers or sea ice alters the albedo. This change in albedo acts to reinforce the initial alteration in ice area.



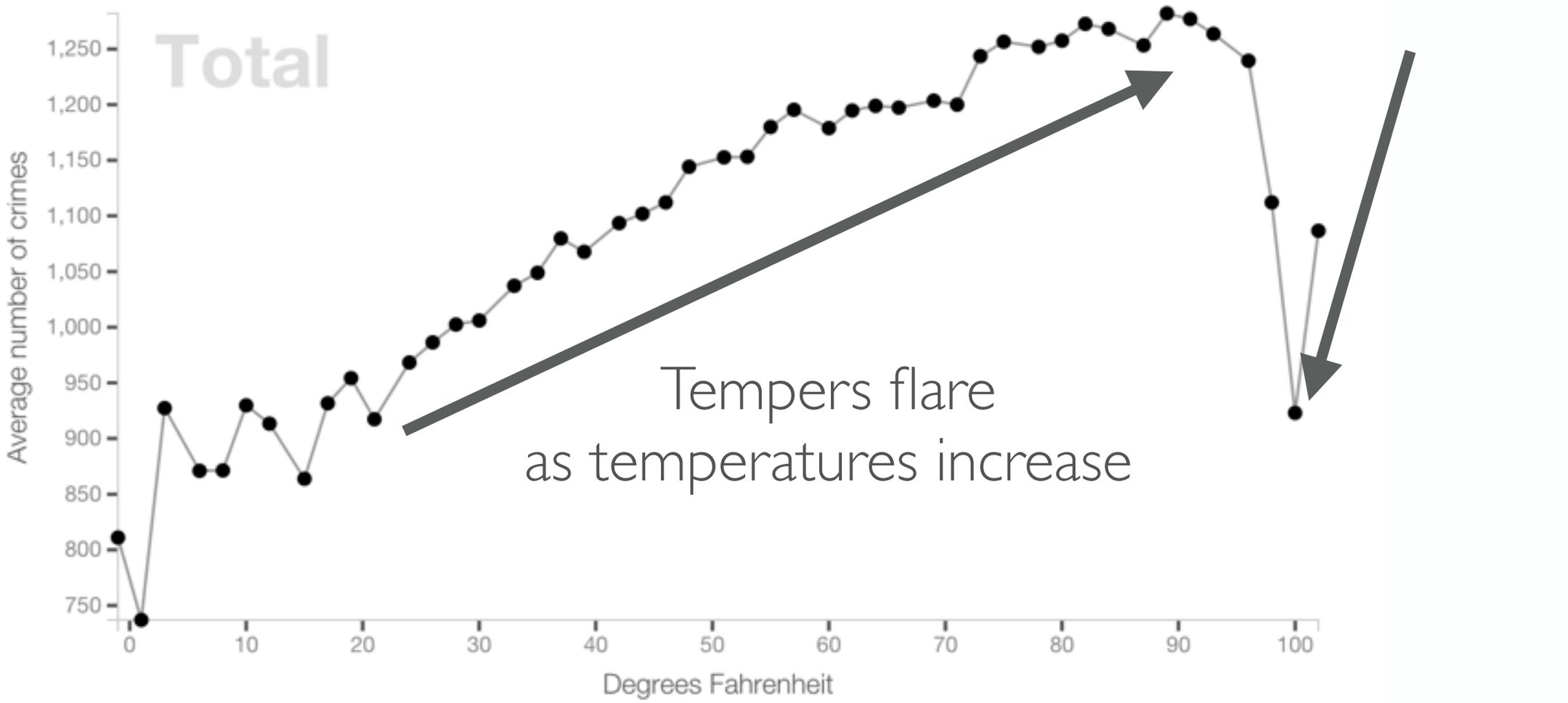
Albedo Change in Greenland

Permafrost Thaw Pools in Canada

A hidden danger lurking underground and undersea.
No, it's not Godzilla.
It's methane clathrate.

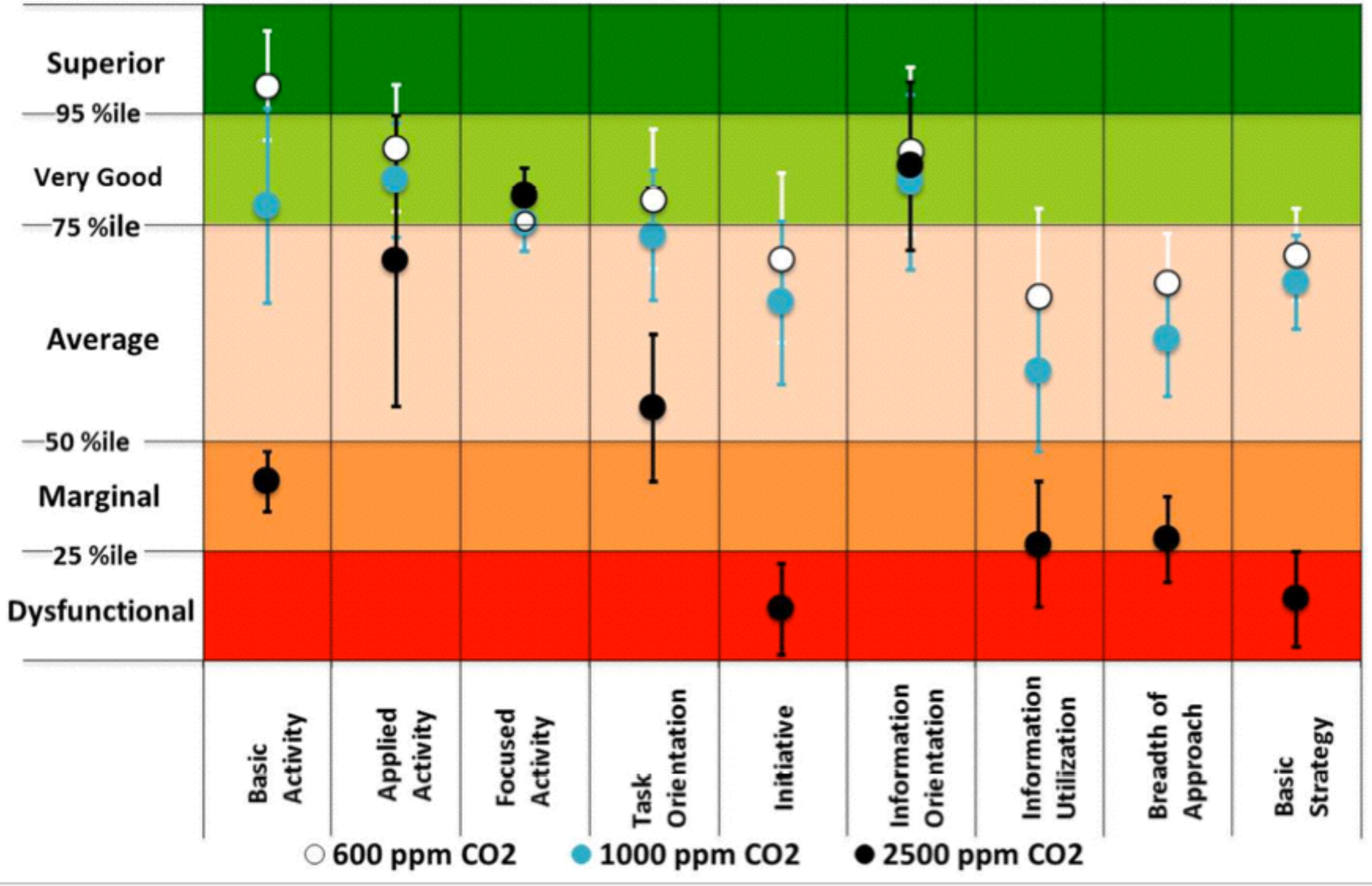
To which, I must add…

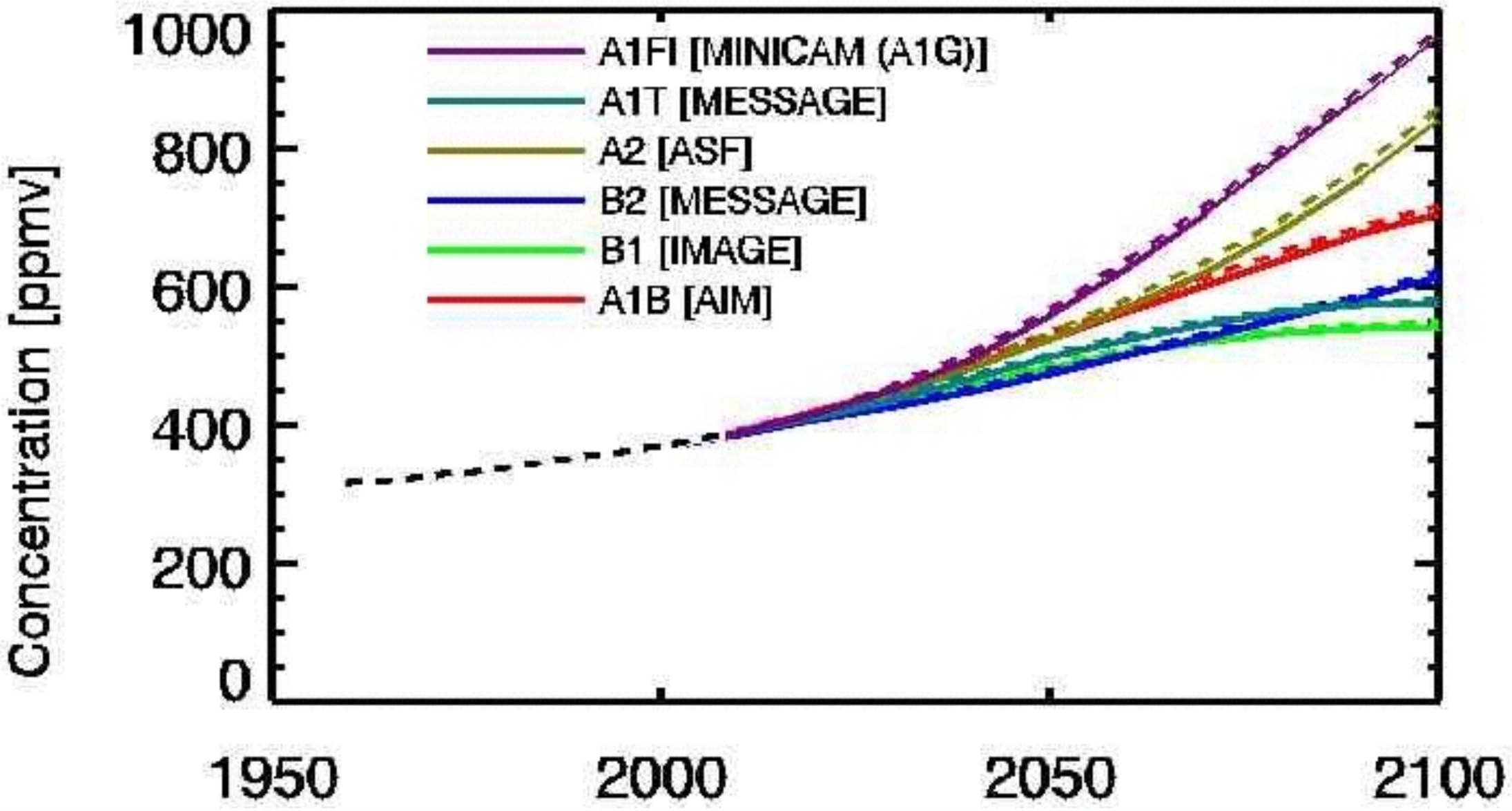
Crimes versus temperature



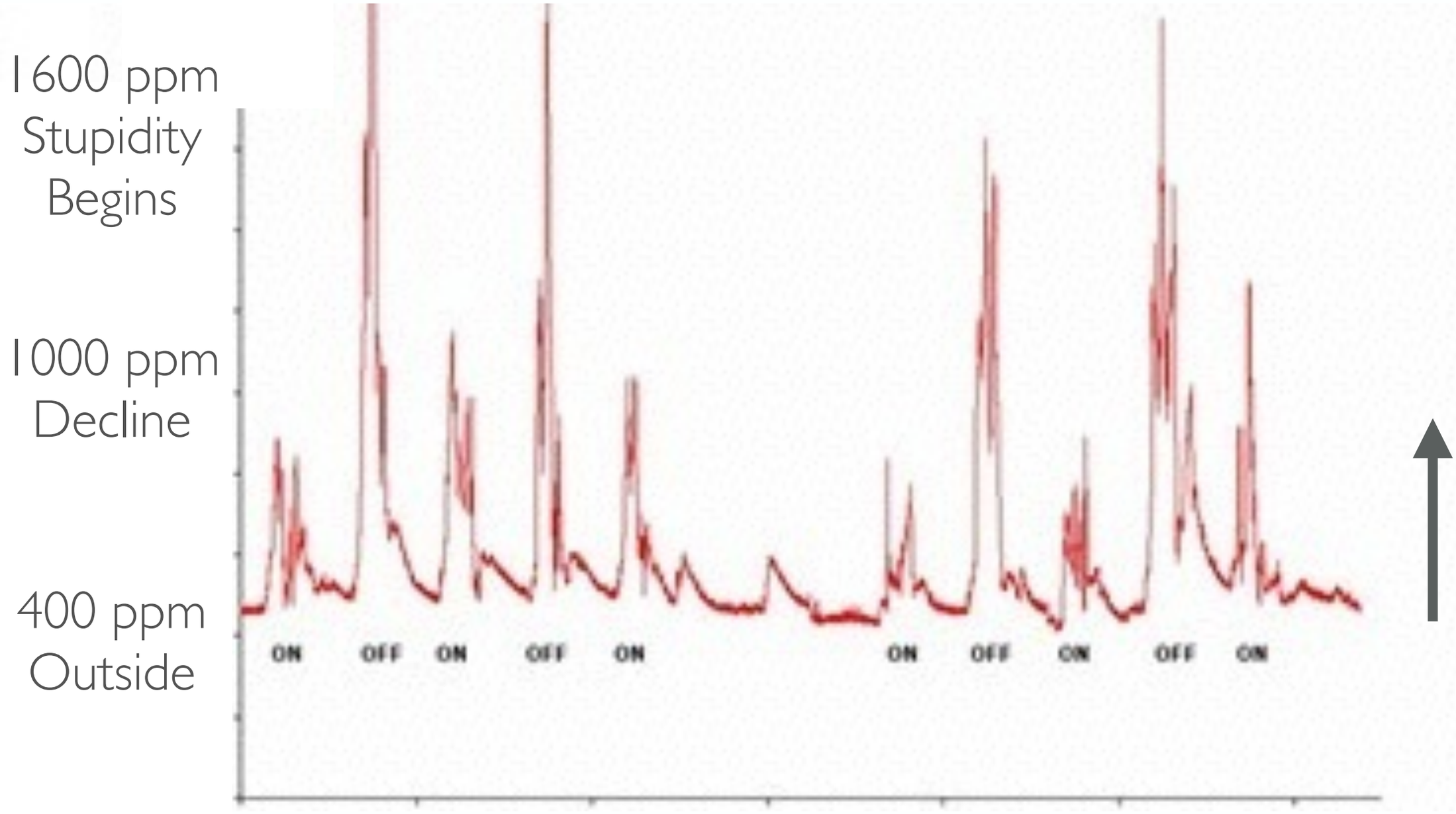
Data from Chicago

Impact of CO_2 On Human Decision Making Performance




A1FI [MINICAM (A1G)]
A1T [MESSAGE]
A2 [ASF]
B2 [MESSAGE]
B1 [IMAGE]
A1B [AIM]
Concentration [ppmv]
1000
800
600
400
200
0
1950
2000
2050
2100

Classroom CO2 Levels

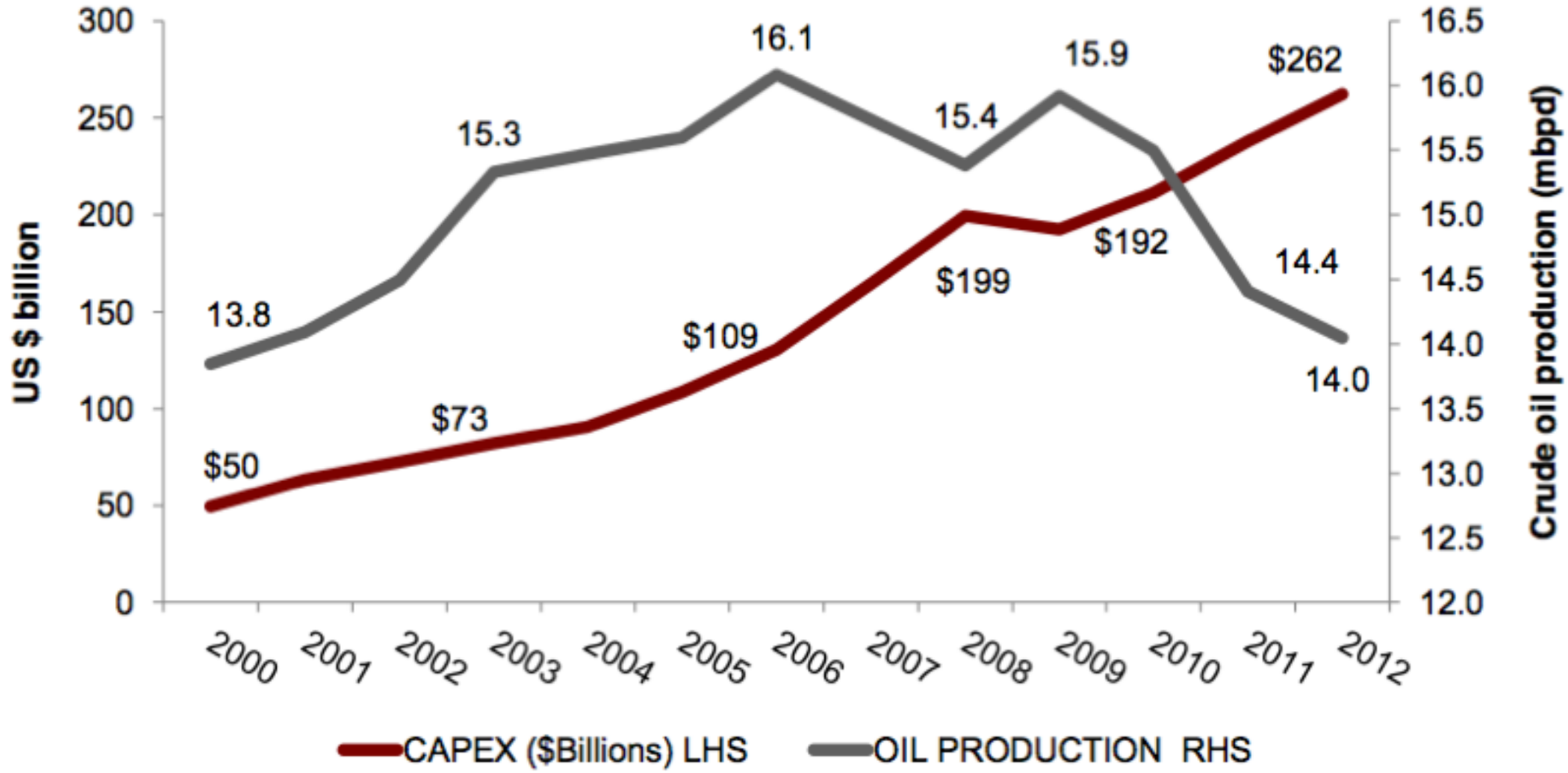


But perhaps more important,
we are quickly encountering supply limits

The world needs so much more energy
And we have been running out of fossil fuels

Douglas – Westwood

Listed Oil Majors: Capex and Crude Oil Production



Crude Oil Production and Capex

Combined data for BG, BP, COP, CVX, ENI, OXY, PBR, RDS, STO, TOT, XOM
Source: Bloomberg via Phibro Trading LLC

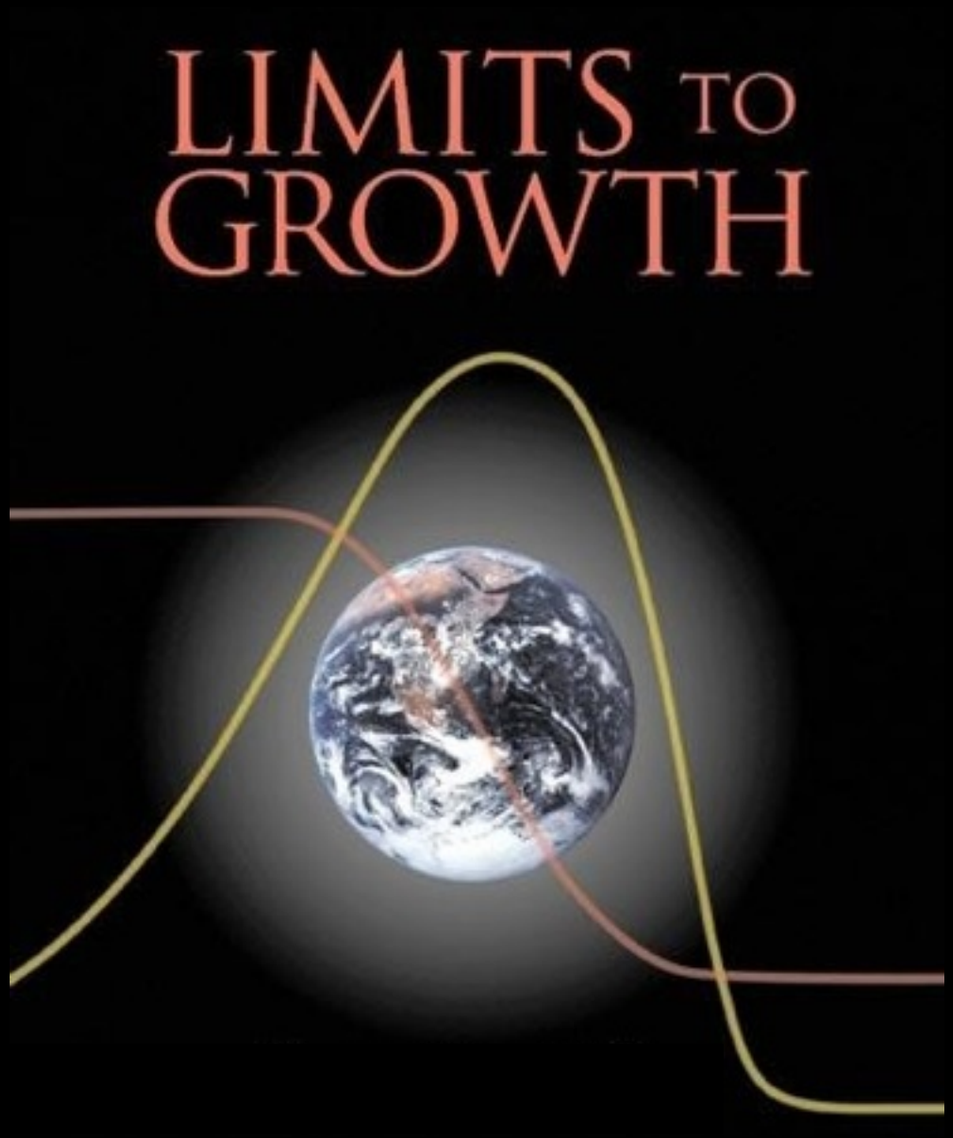
- Oil production has faltered, even as capex has soared
- Capex productivity has fallen by a factor of five since 2000
- Observed decline trend now approaching 5% per year

We have never before spent so much searching and found so little

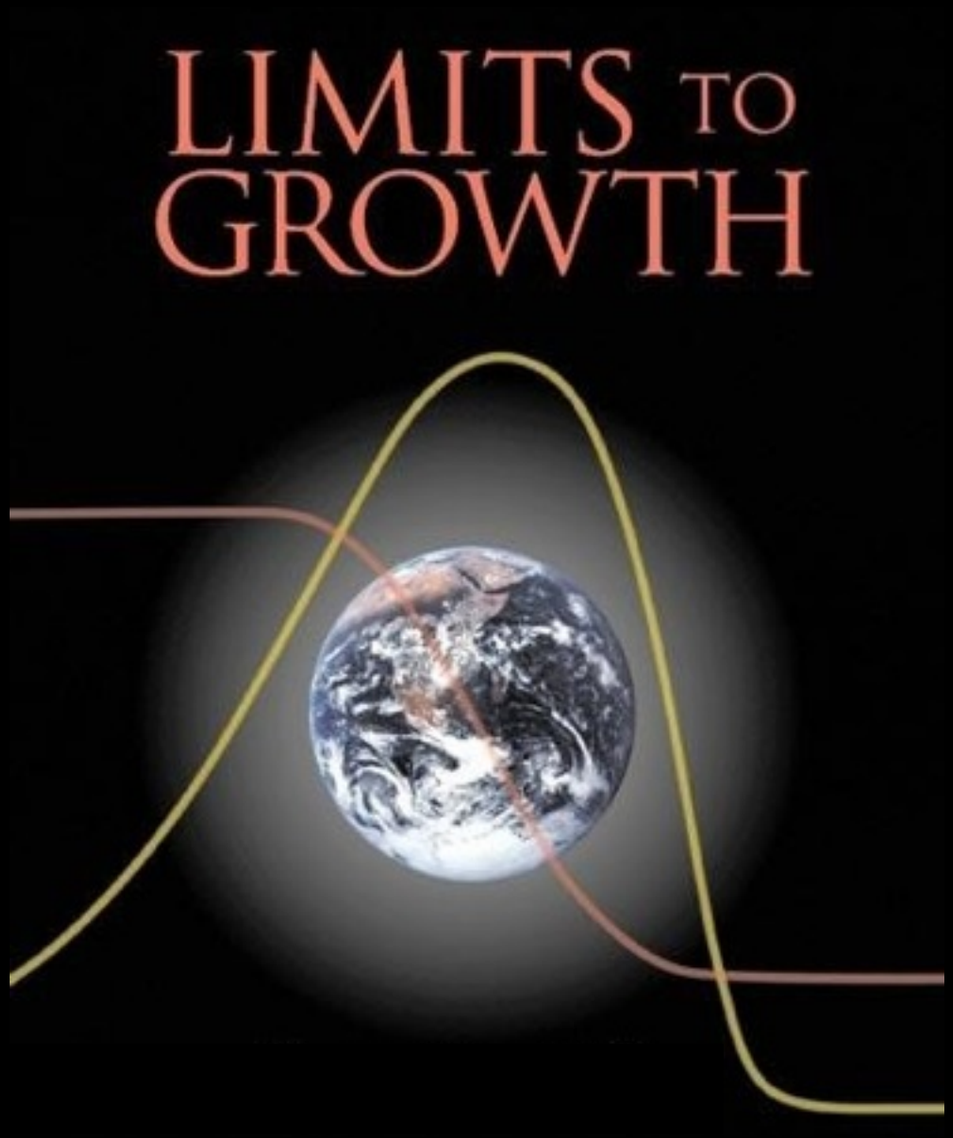
We spent a record $700 billion search for oil last year

Replacing only 4.5 months of production in 12 months

Oil is half the world's commodity trade and half the cost structure of the other half



"Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist" - Kenneth Boulding



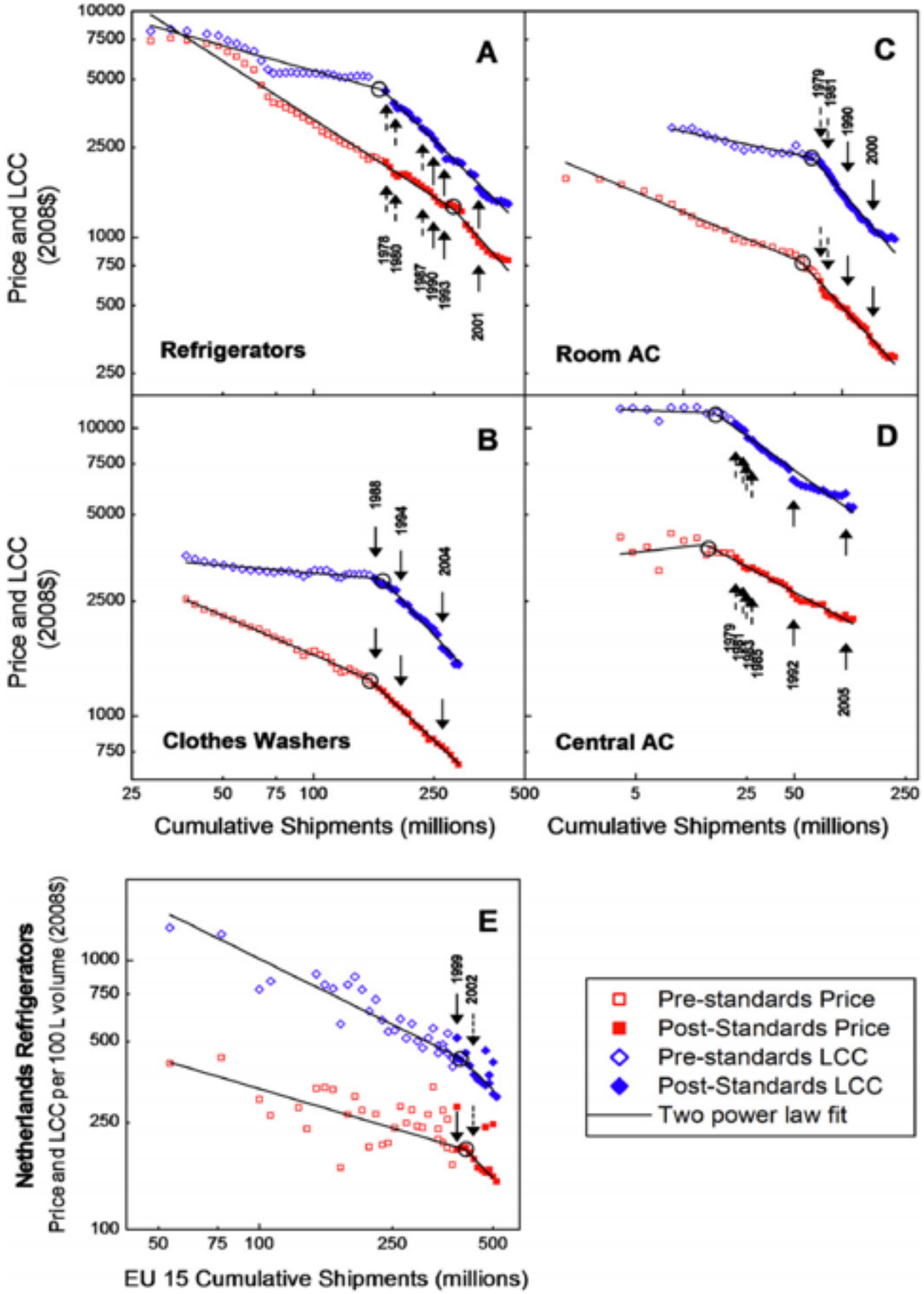
"Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist" - Kenneth Boulding

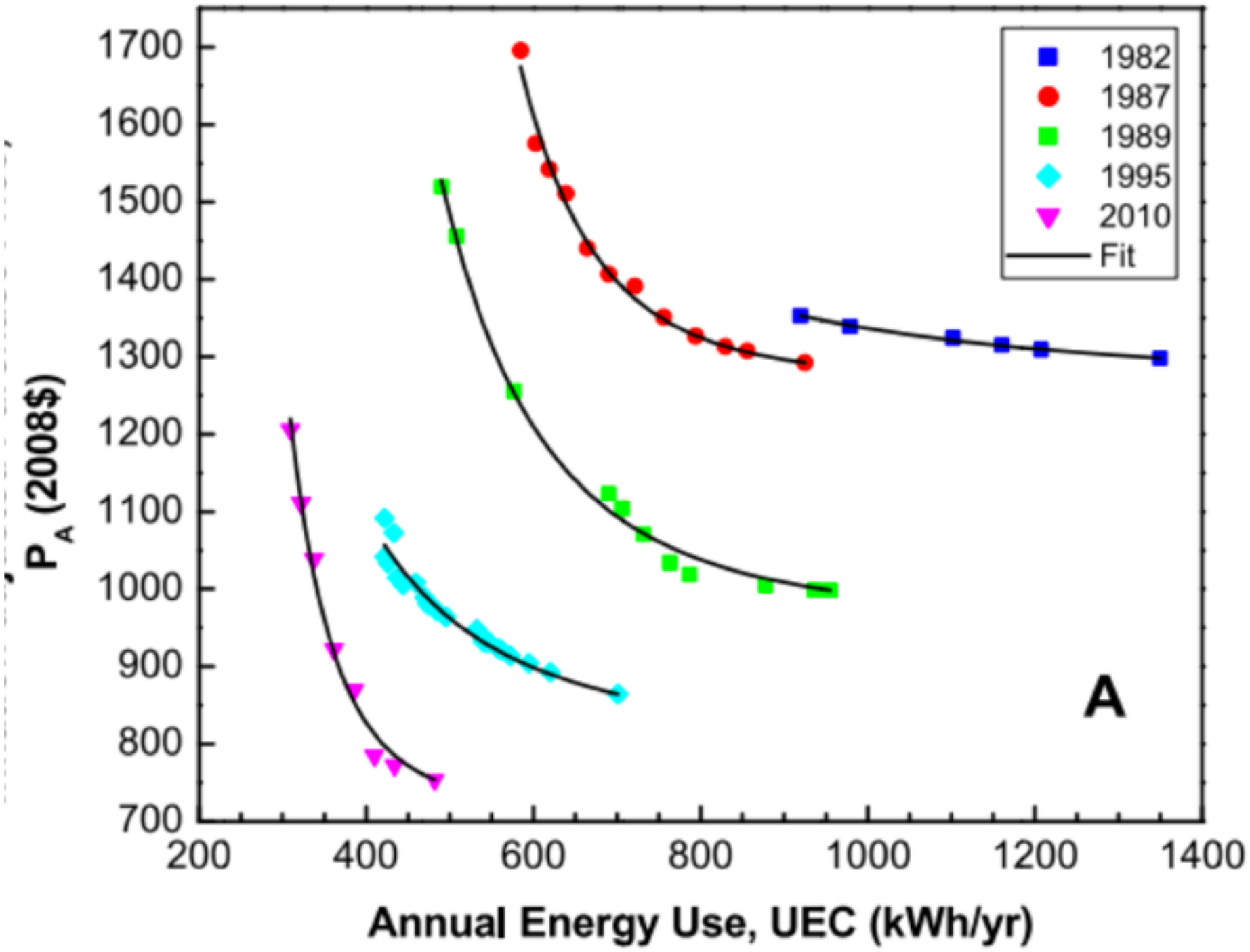
"…or a technologist, who sees how technology can transcend our past limitations" - Danielle Fong

Act 3.

Getting to work

Won’t all this efficiency be awfully expensive?


A
Refrigerators
Price and LCC (2008$)
10000
7500
5000
2500
1000
750
500
250
1978
1980
1987
1990
1993
2001
C
Room AC
1979
1981
1990
2000
B
Clothes Washers
1988
1994
2004
D
Central AC
1979
1981
1983
1985
1992
2005
25
50
75
100
250
500
5
Cumulative Shipments (millions)
E
Netherlands Refrigerators
Price and LCC per 100 L volume (2008$)
1999
2002
100
EU 15 Cumulative Shipments (millions)
Pre-standards Price
Post-Standards Price
Pre-standards LCC
Post-Standards LCC
Two power law fit


1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
200
400
600
800
1000
1200
1400
1982
1987
1989
1995
2010
Fit
A
Annual Energy Use, UEC (kWh/yr)

~~There is no free lunch~~

This lunch will buy you dinner

Thomas Edison's
First Powerplant

Pearl Street Station

In a sense more efficient
Than most modern
power plants

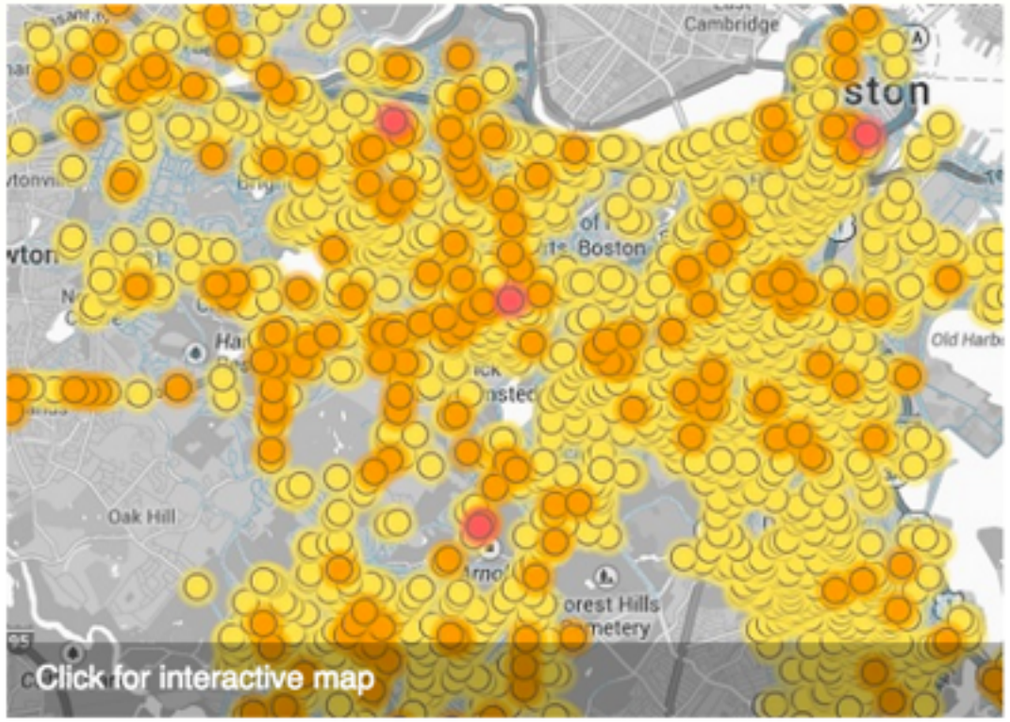
Don't just waste the heat,
harness it

Natural gas: Local leaks impact global climate

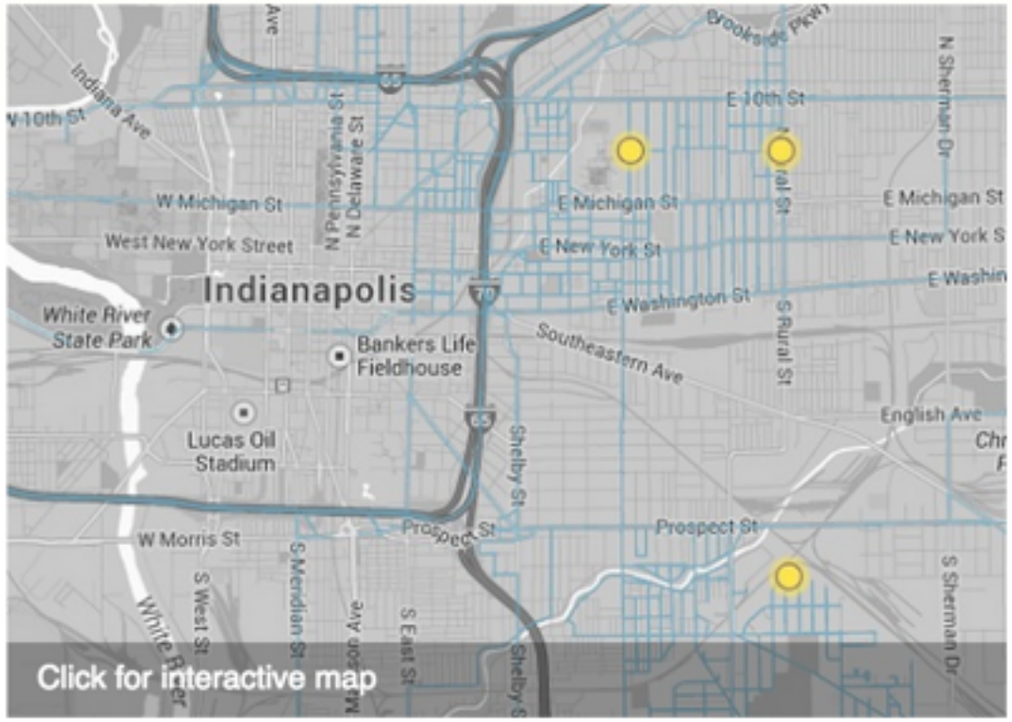
EDF and Google Earth Outreach use new approach to pinpoint climate pollution

Natural gas heats our homes and cooks our dinner. But when natural gas—mostly methane—leaks into the air, it's a big problem for the climate. So EDF and Google Earth Outreach teamed up to build a faster, cheaper way to find and assess leaks under our streets and sidewalks. We tested it as part of a pilot mapping program, and here's what we found.

Boston: Older pipes, more leaks



Indianapolis: Newer pipes, fewer leaks



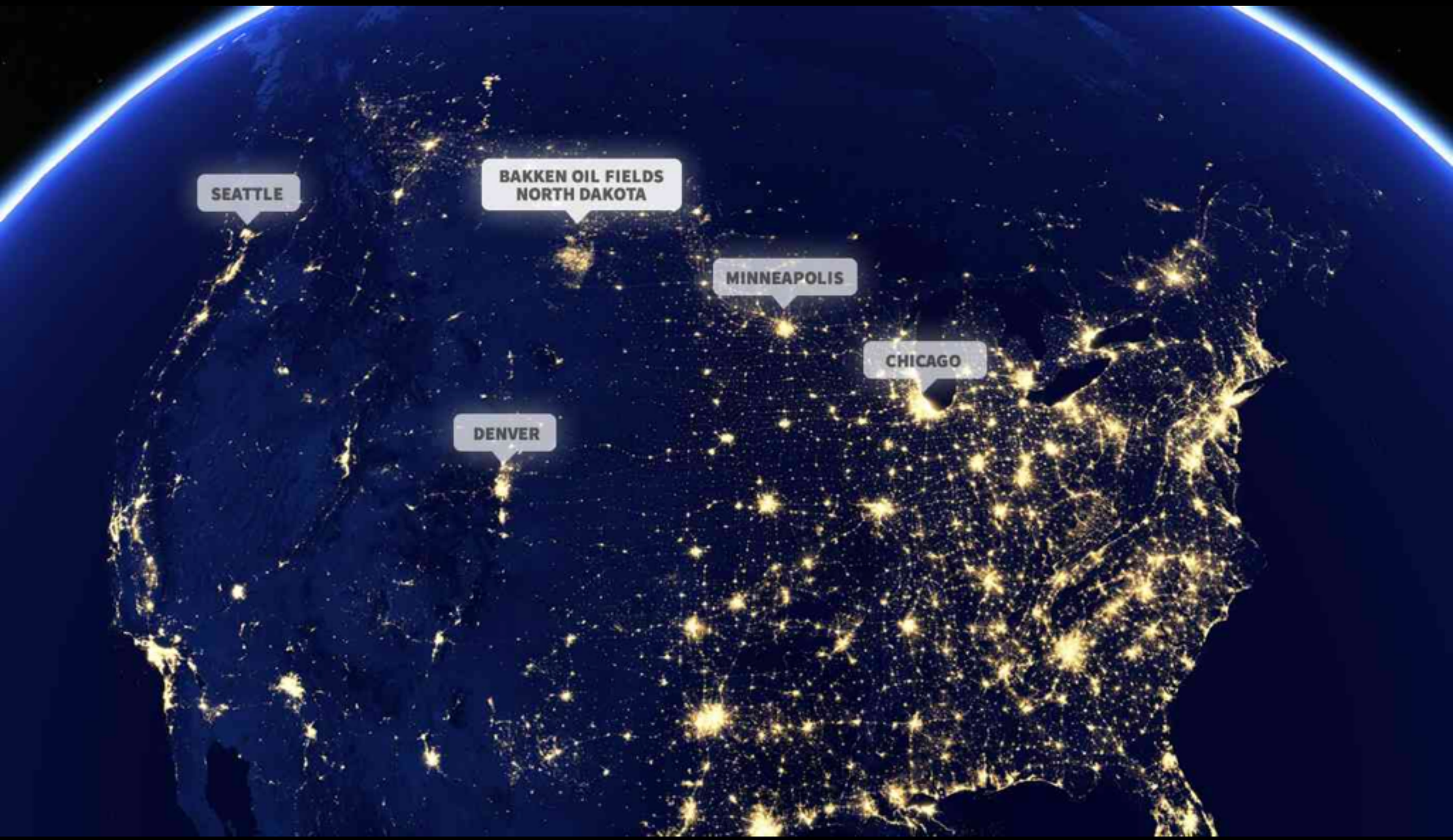
Alberta's Oil Sands Raise Flaring Emissions as Rules Lag

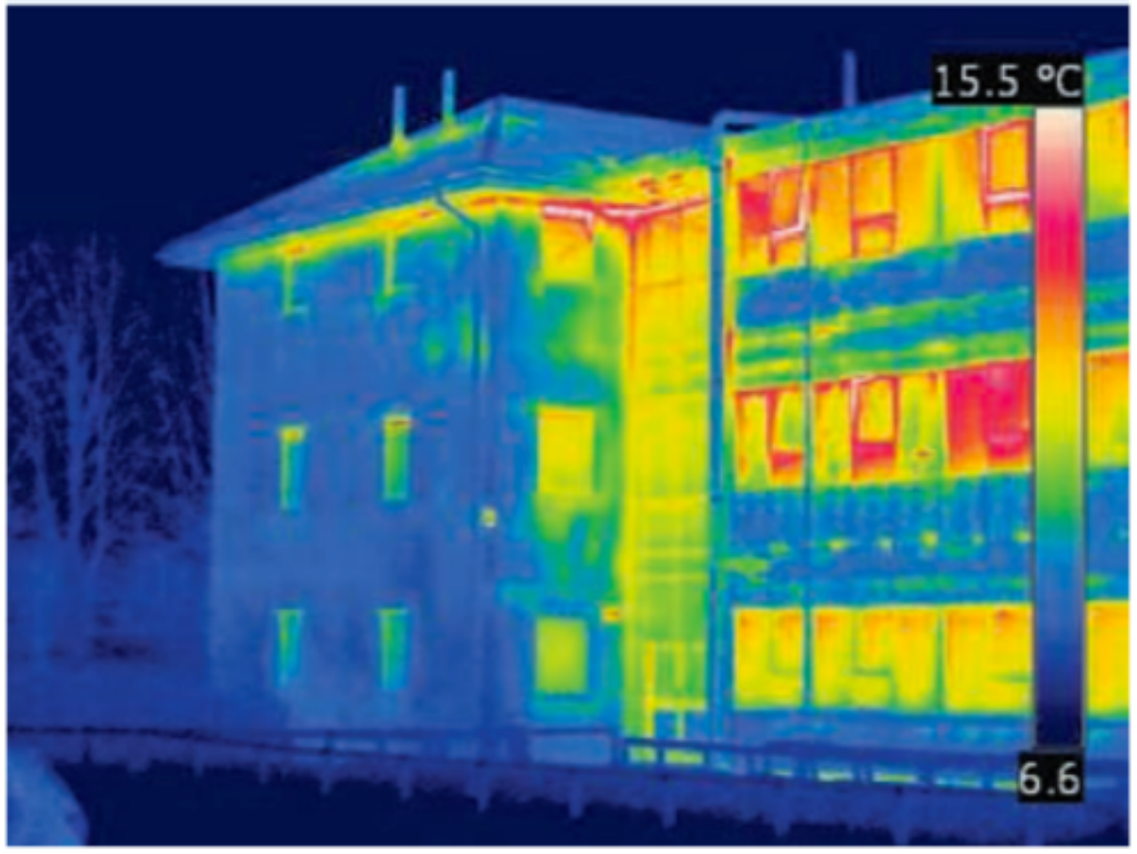
by Jeremy van Loon

June 17, 2013 — 9:00 PM PDT

The World Bank estimates that over 150 billion cubic metres of natural gas are flared or vented annually. This amount of gas is worth approximately 30.6 billion dollars and is equivalent to 25 percent of the United States's yearly gas consumption or 30 percent of the European Union's annual gas consumption.[10]

Emissions from flaring, or burning of natural gas, methane and hydrogen sulphide associated with oil production, have risen in each of the last three years. Photographer: Lucas Schifres/Bloomberg


SEATTLE
BAKKEN OIL FIELDS
NORTH DAKOTA
MINNEAPOLIS
CHICAGO
DENVER



Snapshot of waste. Infrared cameras quickly show where heat is escaping from a building. The older building on the right, for instance, has leaky windows.

If you could travel through time…

from the future into the present…

carrying only your **knowledge** with you,

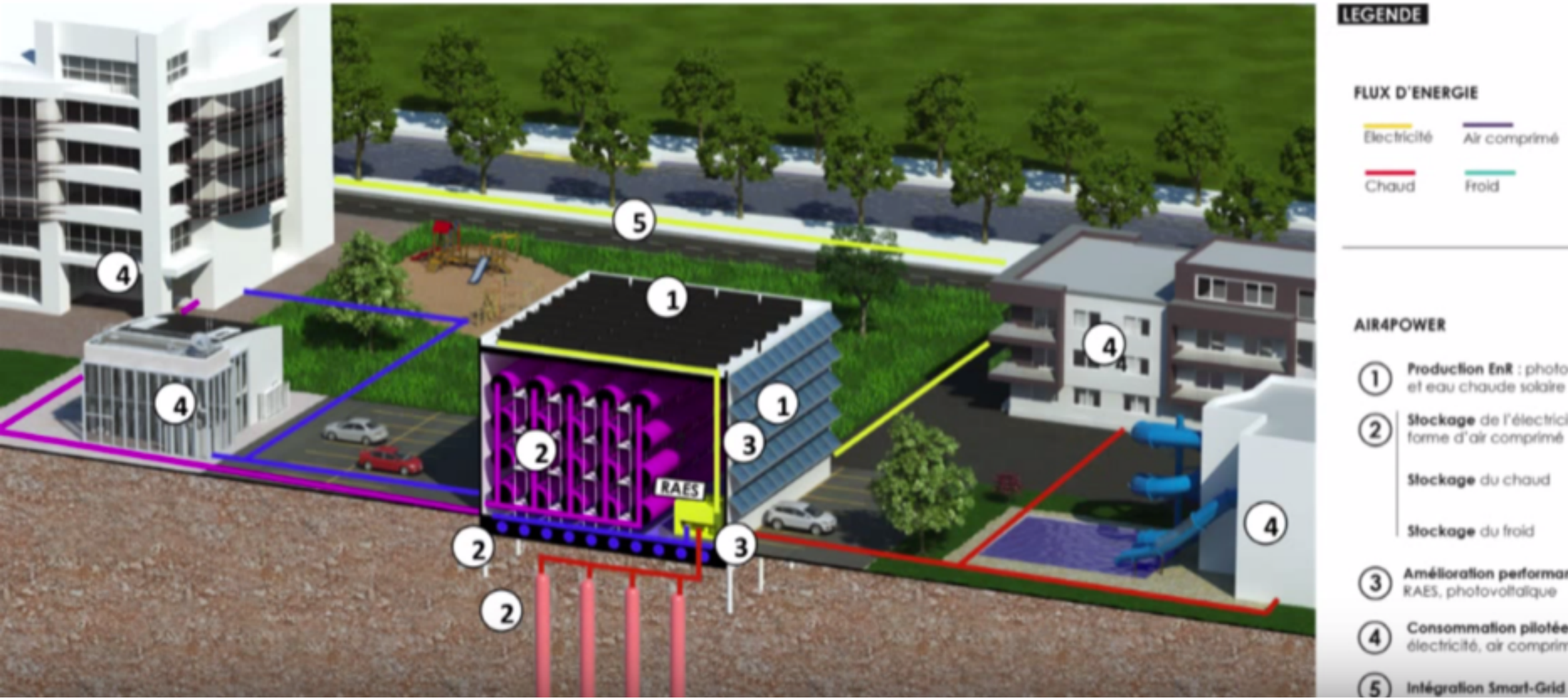
You would already know what could work

What would you build?

How far could you bring civilization forward?

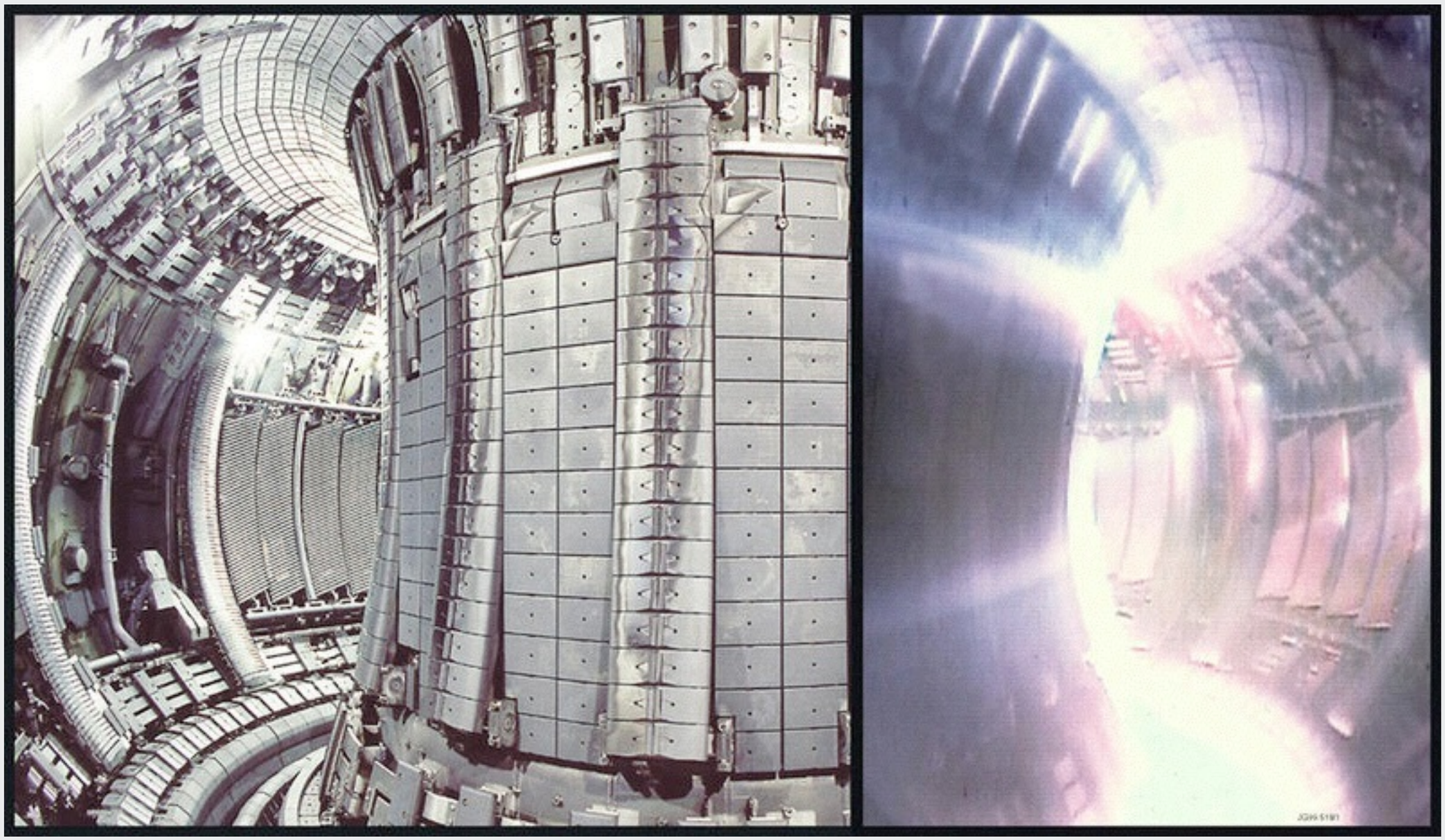
And what would you need to know?

We can provide energy storage, heating, hot water, and air conditioning for profound increases in efficiency

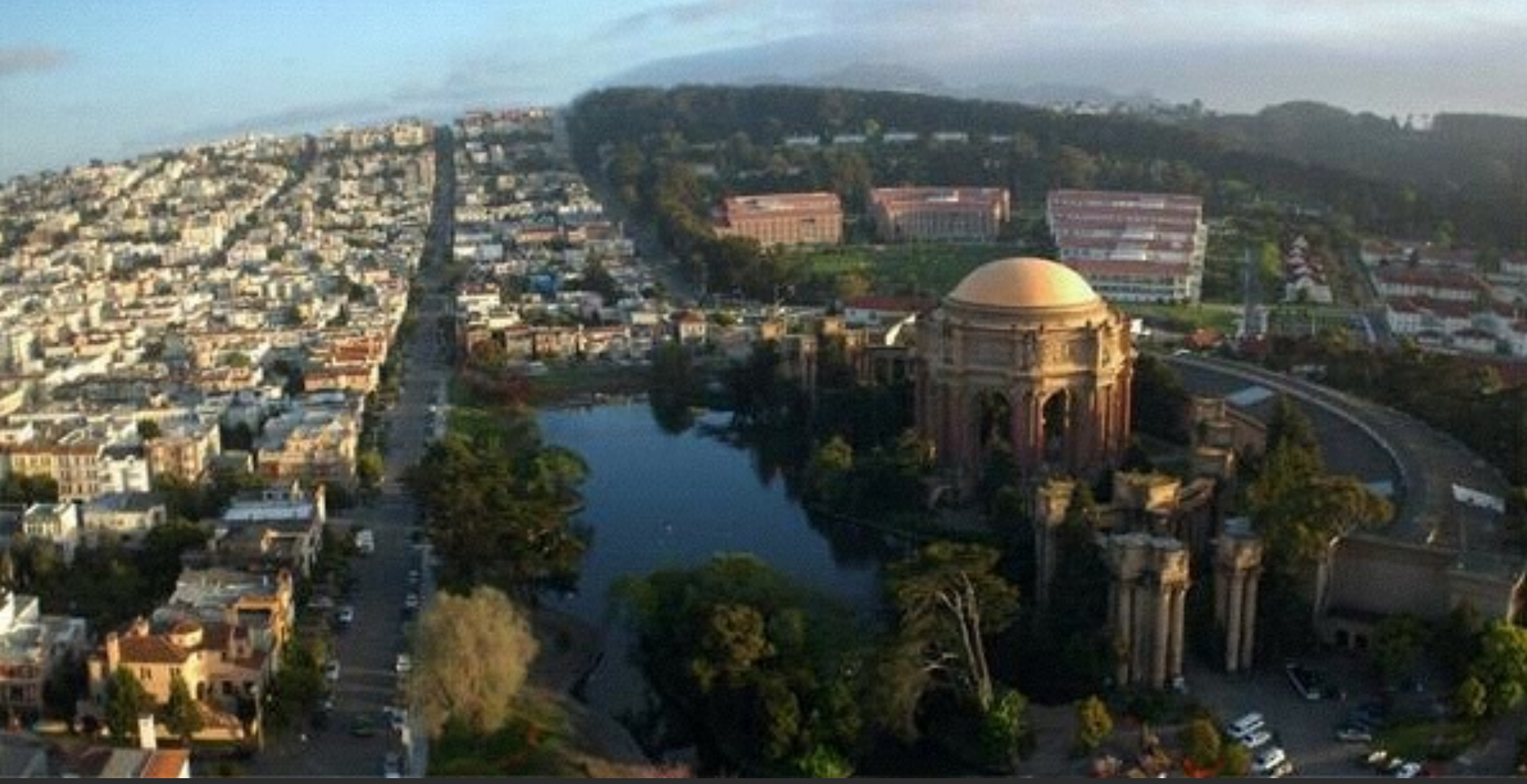


My own story…

2000: age 12
physics at dalhousie university



2005: begin PhD at Princeton University
Studying energy with nuclear fusion

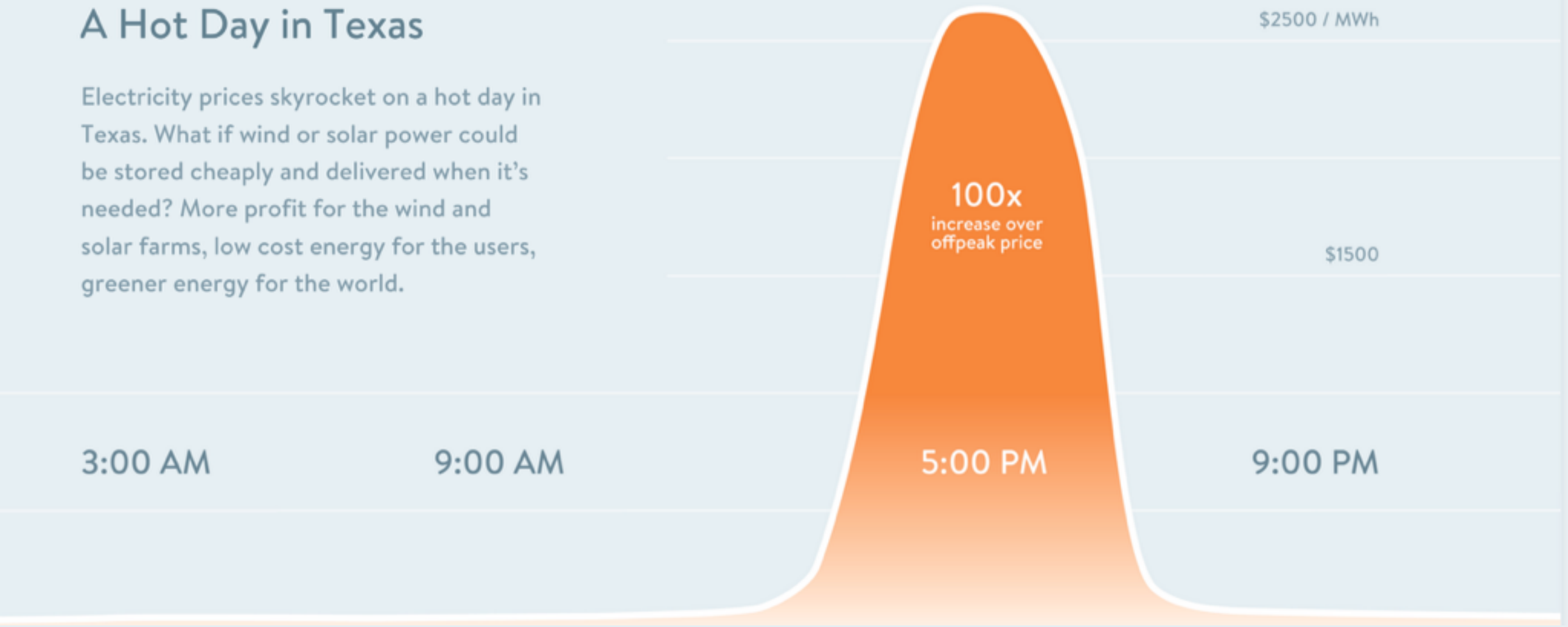


2007: Decide it is not fast enough, move to Silicon Valley to become and entrepreneur and chase my destiny

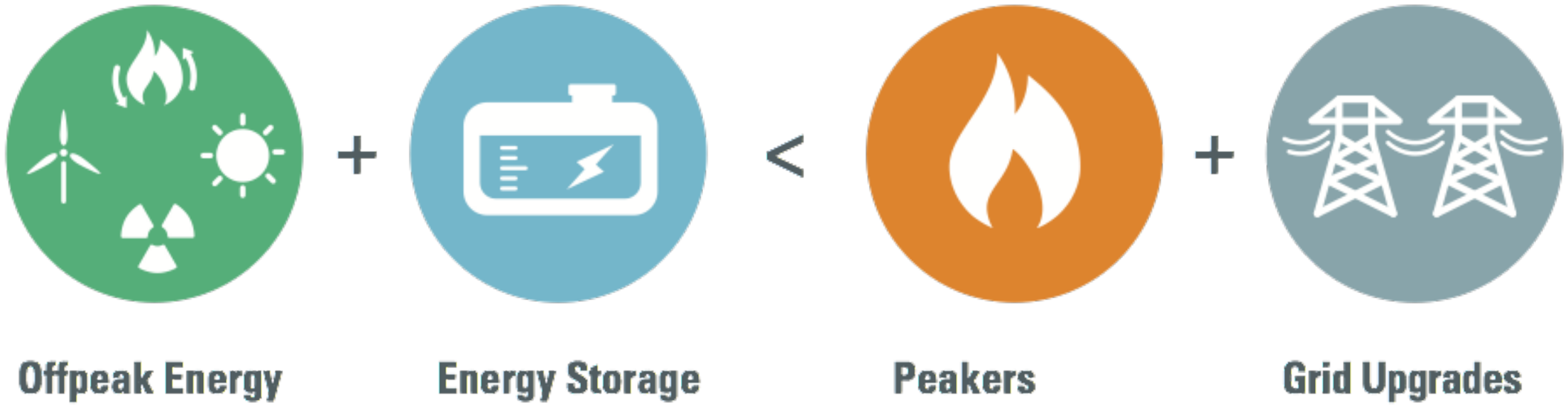
Problem:
Renewable Energy is Intermittent
We Need to Store the Energy

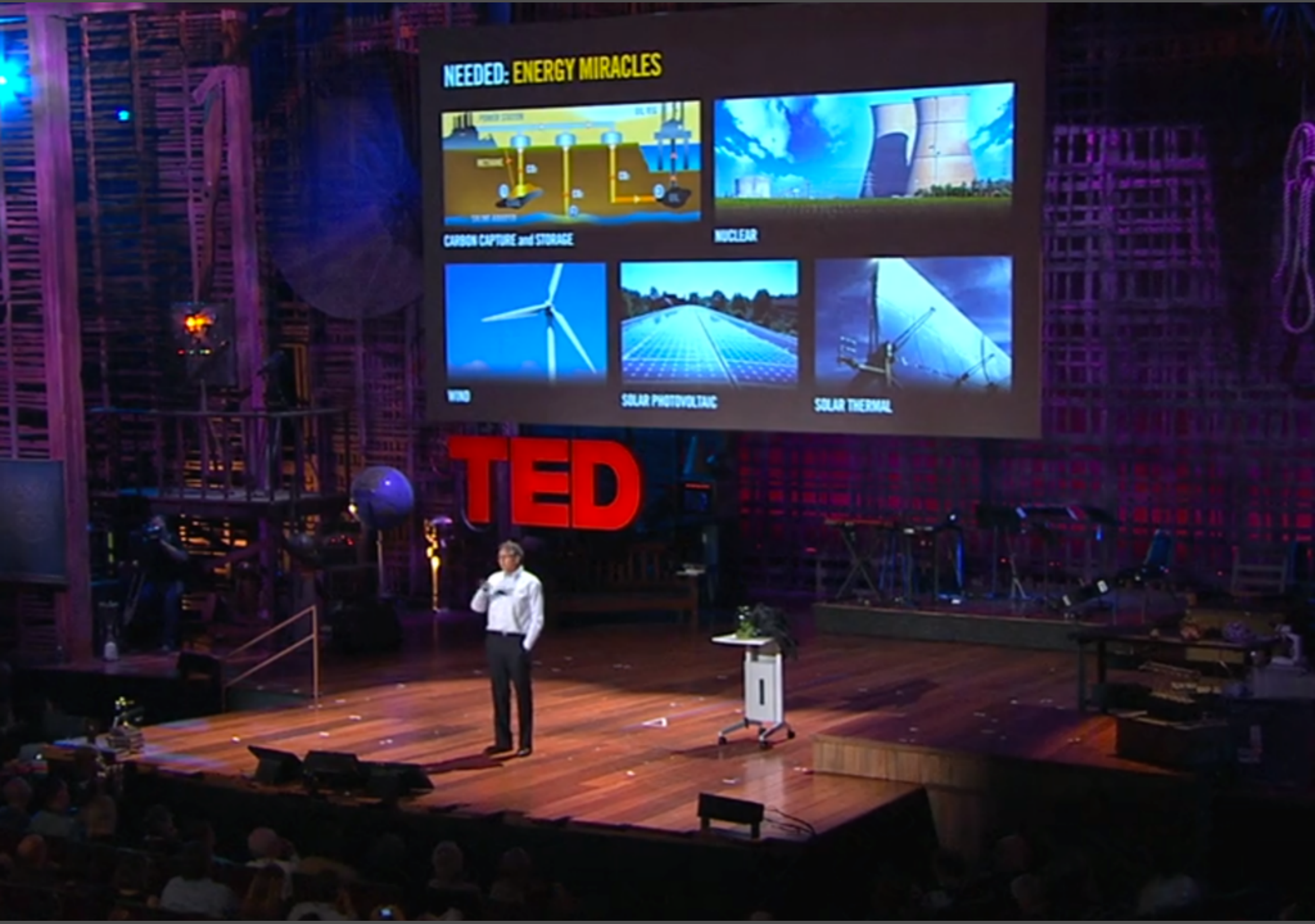
A Hot Day in Texas

Electricity prices skyrocket on a hot day in Texas. What if wind or solar power could be stored cheaply and delivered when it's needed? More profit for the wind and solar farms, low cost energy for the users, greener energy for the world.

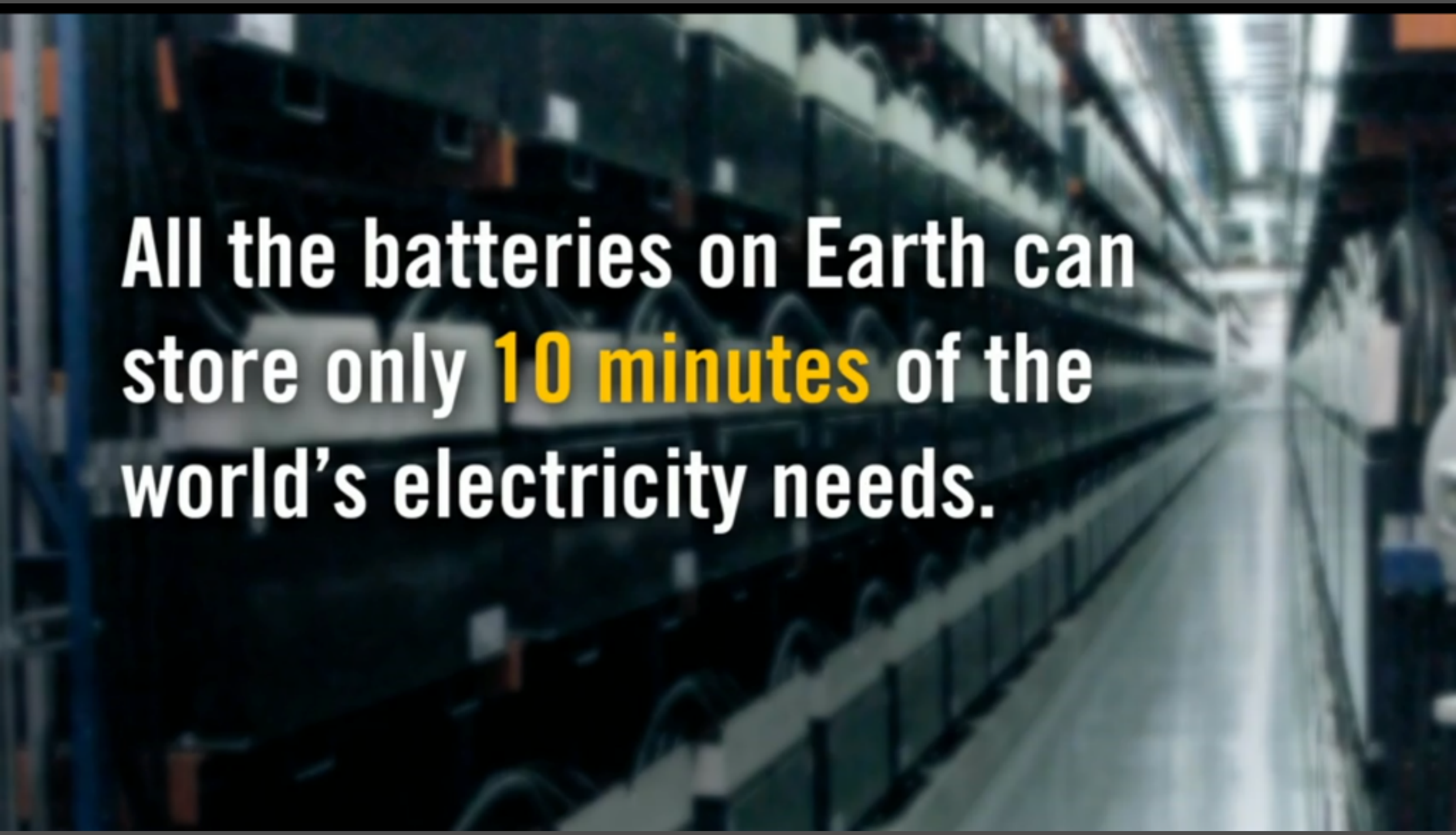


A solar powered world is inevitable — *if* energy storage can be made economical at scale.

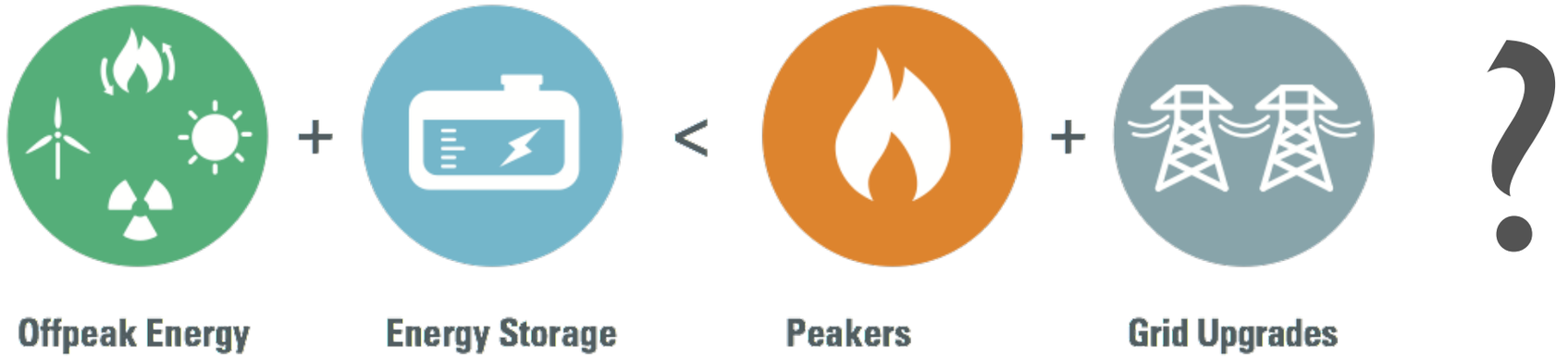


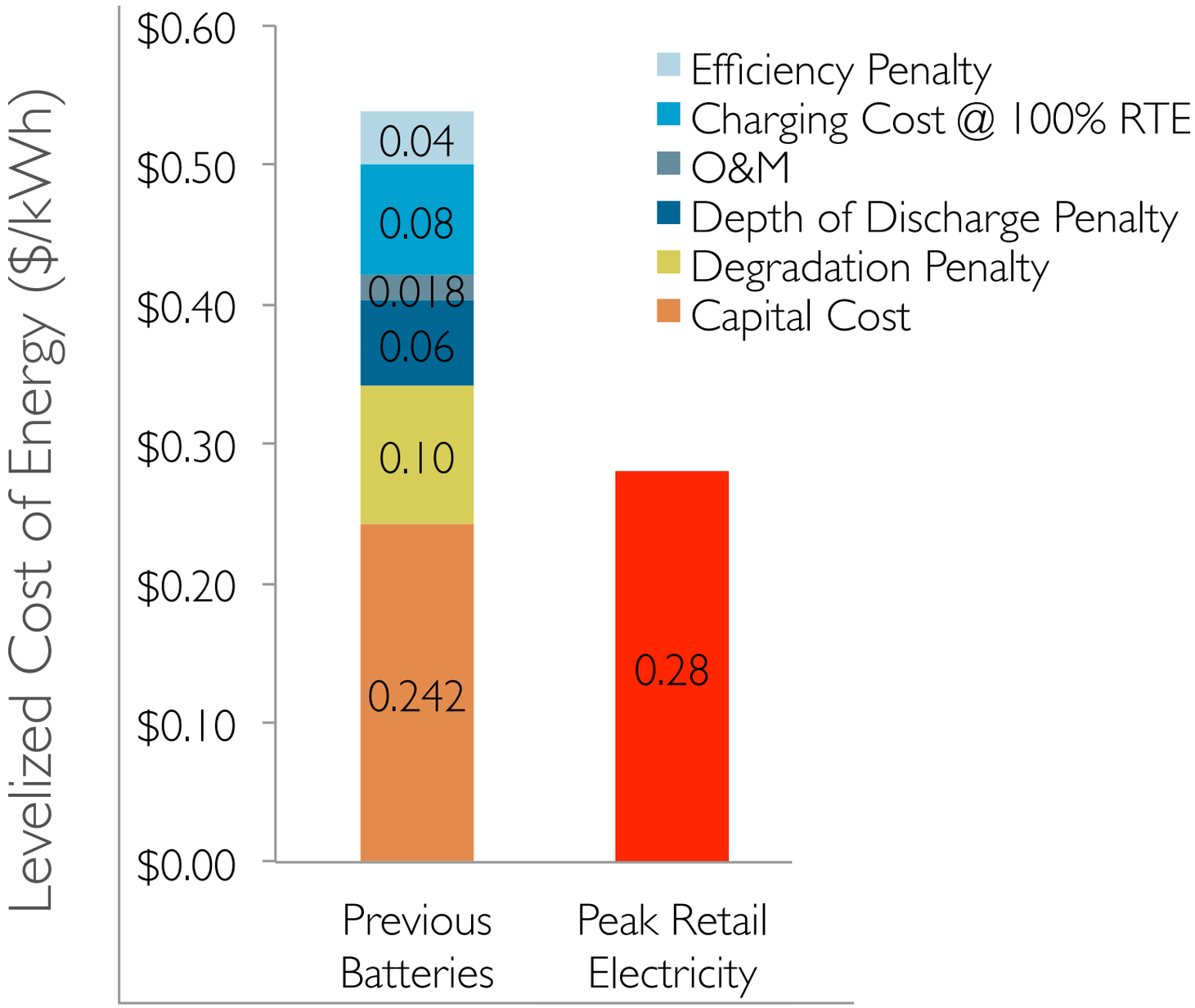


Bill Gates, TED, 2010, Innovating to Zero



Bill Gates, TED, 2010, Innovating to Zero


Offpeak Energy
Energy Storage
Peakers
Grid Upgrades


Levelized Cost of Energy ($/kWh)
$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
0.04
0.08
0.018
0.06
0.10
0.242
0.28
Previous Batteries
Peak Retail Electricity
Efficiency Penalty
Charging Cost @ 100% RTE
O&M
Depth of Discharge Penalty
Degradation Penalty
Capital Cost


SCRAP MATERIAL


MBLY POINT

We need technology that is

Low Capital Cost

Long Service Life

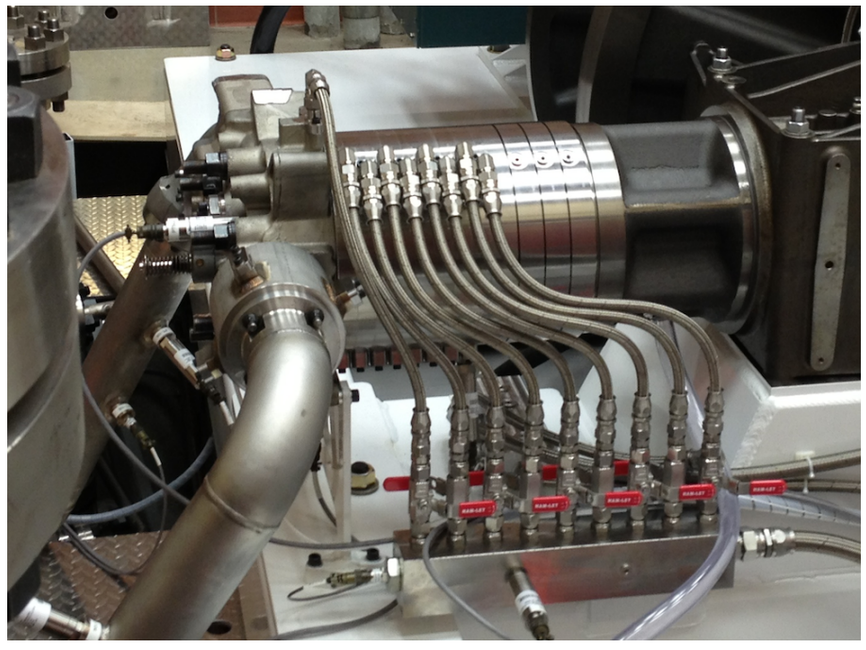
Available at Global Scale

Efficient Enough

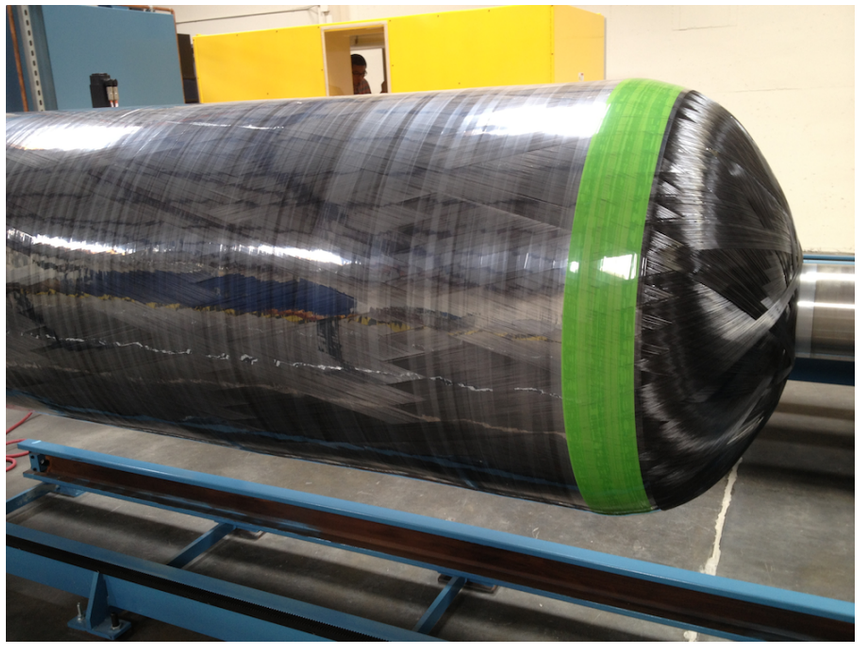
We have discovered how to do this with compressed air

Low Capital Cost	Long Service Life	Available at Global Scale	Efficient Enough
< 1/3rd the cost of batteries	20-30 year lifetime	Harnessing engine manufacturing	From 25% efficiency historically
Target cost < $100 / kWh	20000+ cycles	Only need ~1% of manufacturing capacity	to
	Tanks already certified		60 - 70% efficiency 90+% w/ waste heat

LightSail's breakthrough solution:
Regenerative air energy storage (RAES)



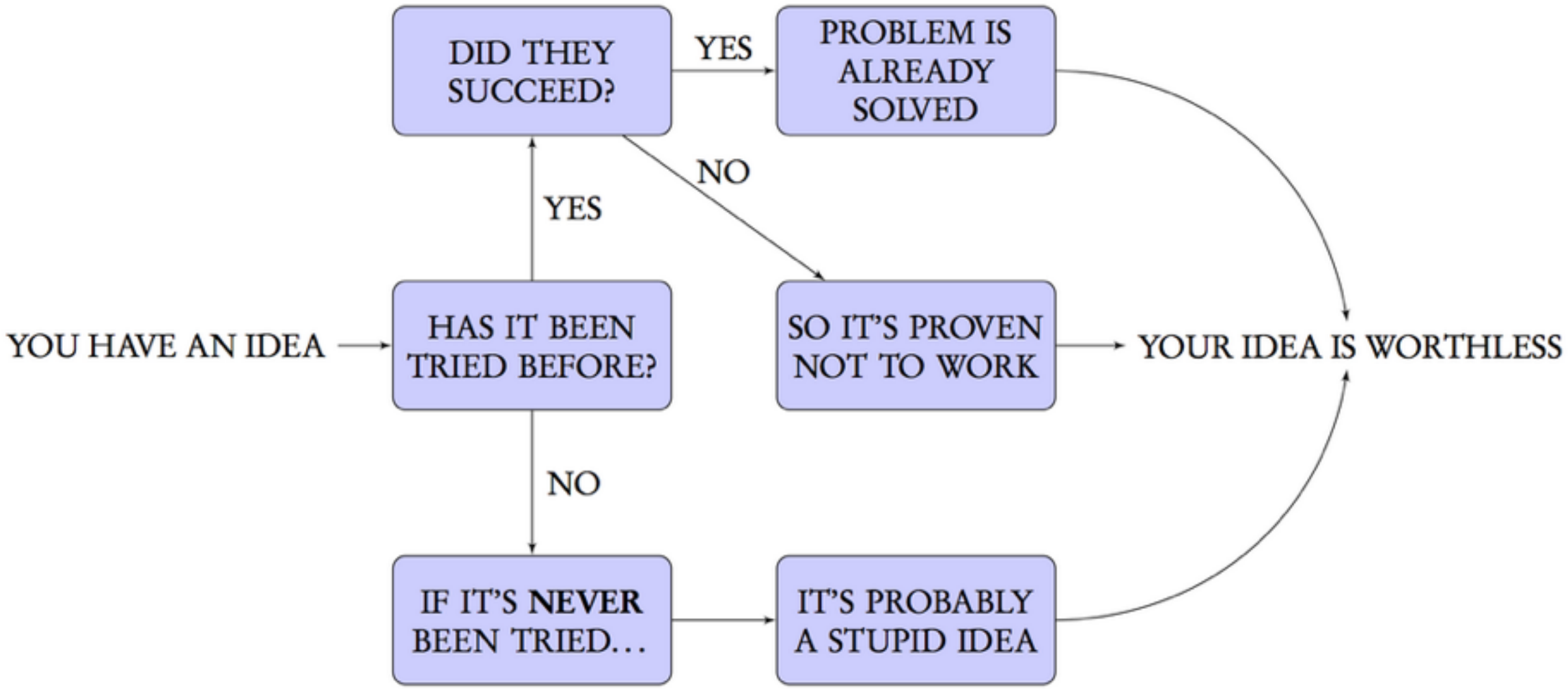
The RAES air compressor / expander:
a major thermodynamic innovation



LightSail's proprietary air storage
technology can be sited anywhere

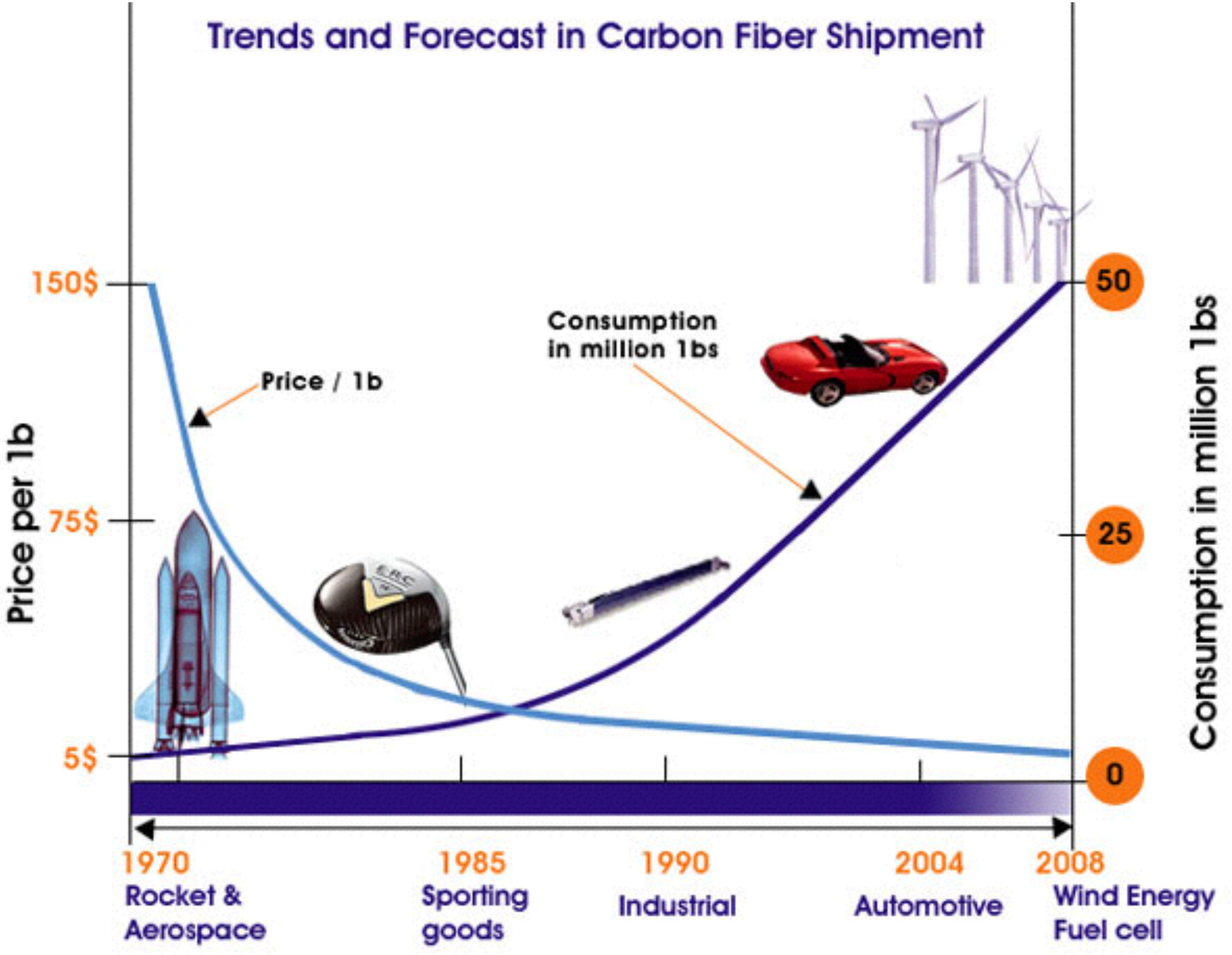
Major advances in both compressor design and air storage technology

Even if you know what to build,
it was a long road



How the world criticizes ideas…

Trends and Forecast in Carbon Fiber Shipment



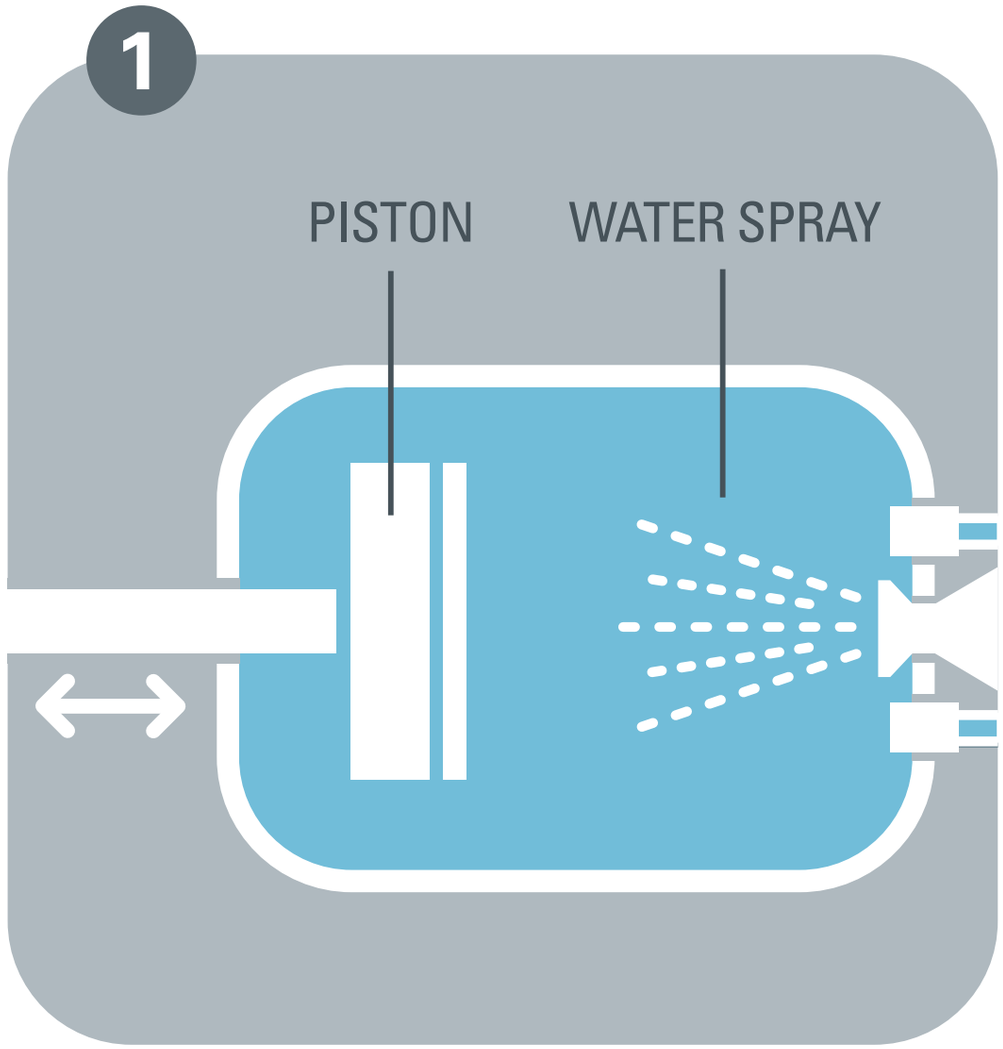
why don't people already use compressed air?
thermodynamics fights you

PV = NRT

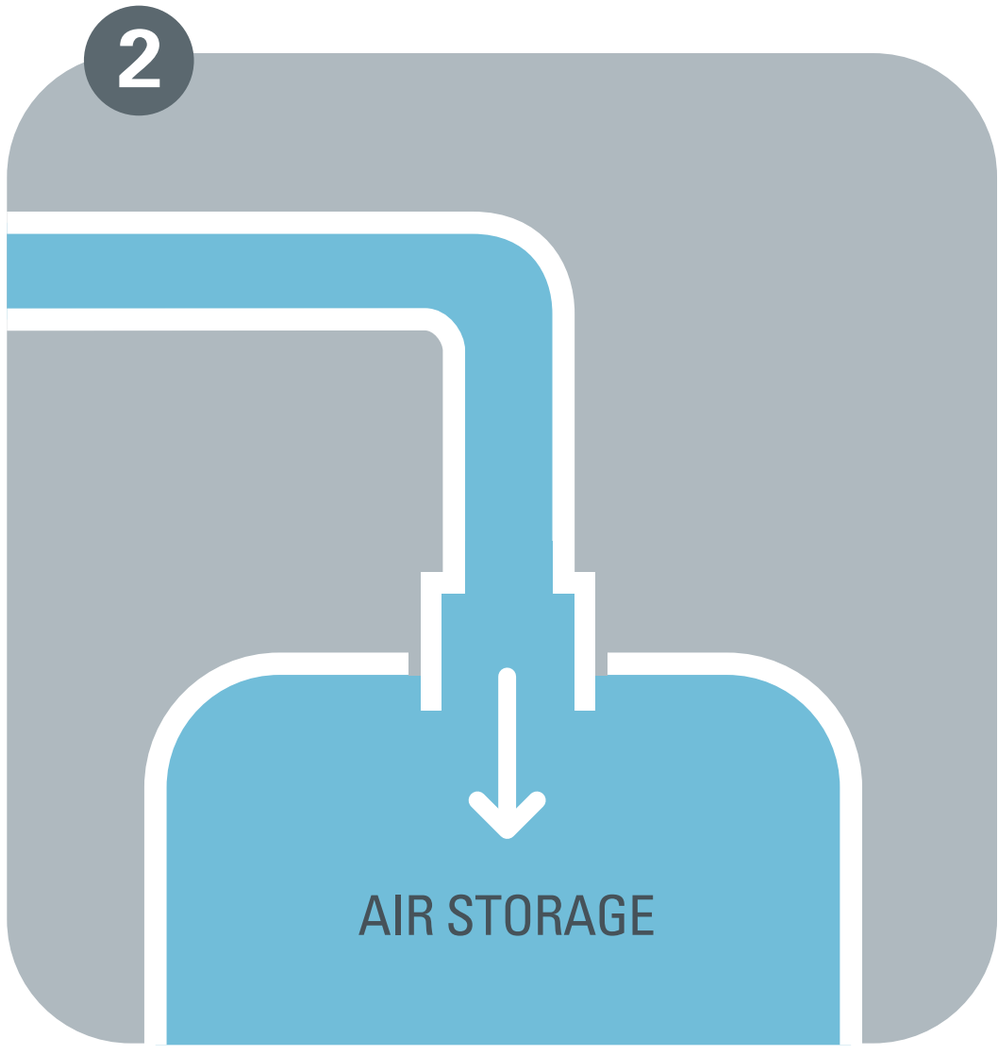
compress air and it gets hot, and fights the compression

when compressing, you want the air to be as ***cool*** as possible
when expanding, you want the air to be as ***warm*** as possible
nobody had yet made this practical

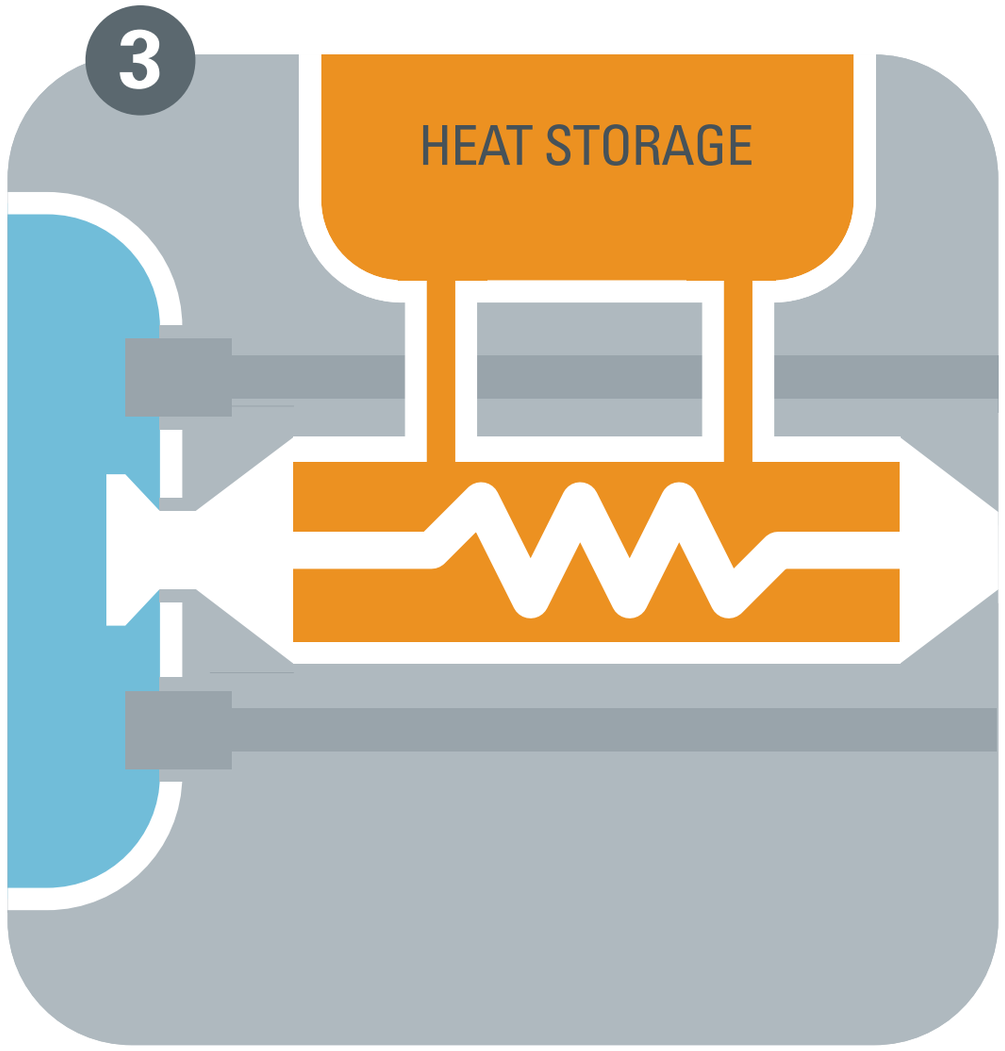
to fight the heat of compression
we use water spray



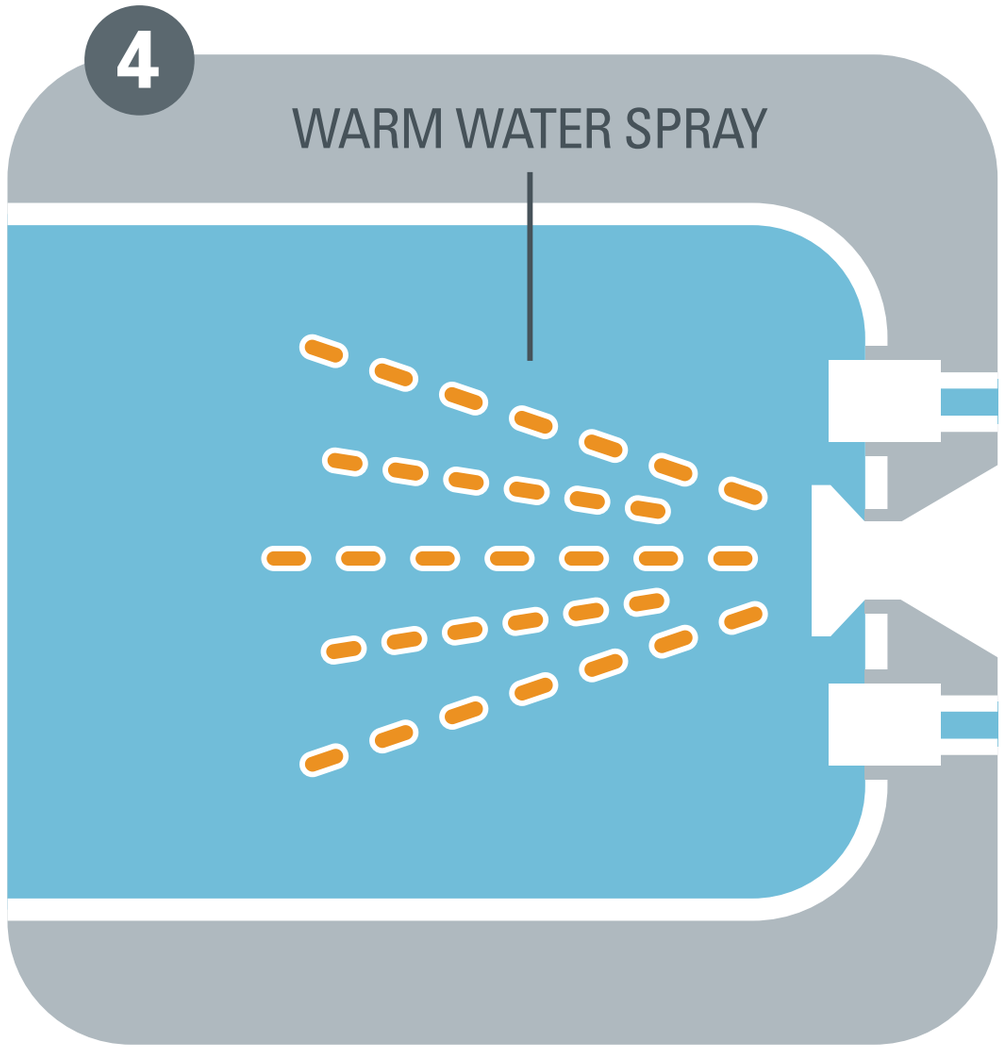
During air compression, mechanical energy is converted into heat. Spray water directly into the air during compression.



Store the compressed air in a tank.



Exchange heat between the water and heat storage.

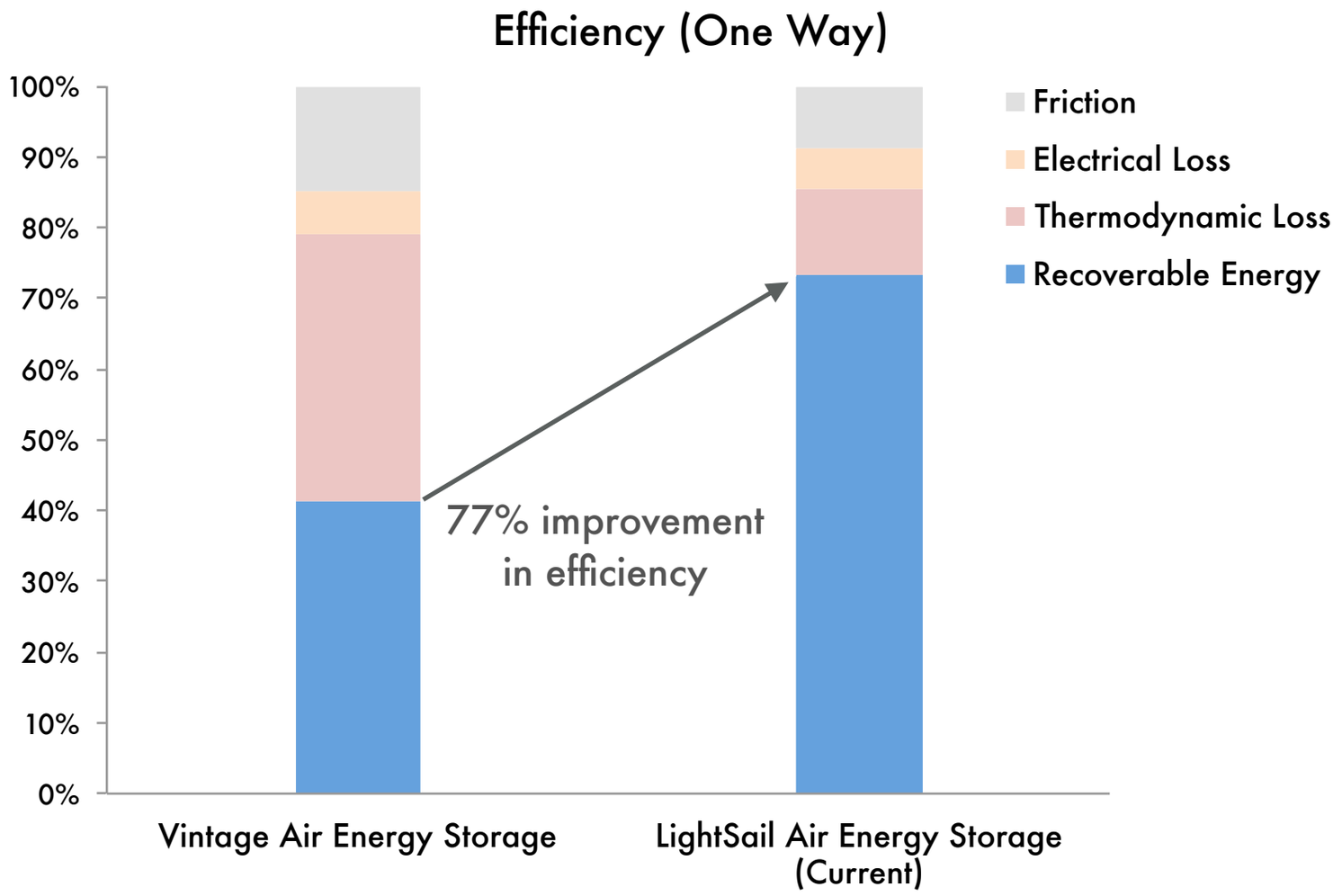


During air expansion, spray warm water into the expanding air. Heat energy in the water is absorbed by the air and is converted into mechanical energy.

why don't people already use compressed air?
thermodynamics fights you

PV = NRT

compress air and it gets hot, and fights the compression



Danielle Fong
Cofounder, CSO

Began PhD at 17
Princeton Plasma Physics Lab

Dr. Steve Crane
Cofounder, CEO

Physics at MIT,
Caltech, and the
Scripps Institute

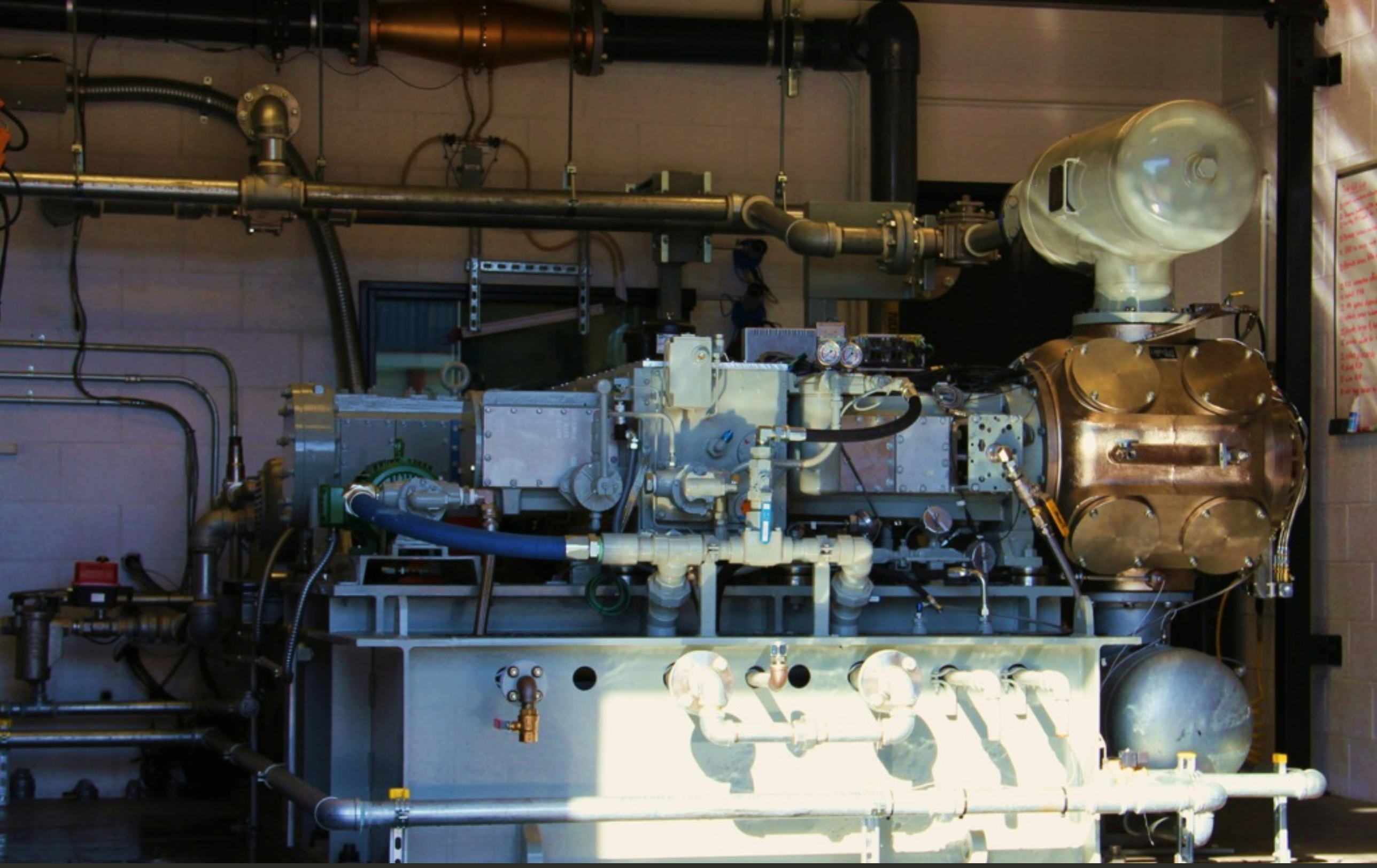
Ed Berlin
Cofounder, CTO

MIT electrical engineer;
Engineer of the Year,
Grumman Aerospace

Kevin Walter
VP Mechanical Dev

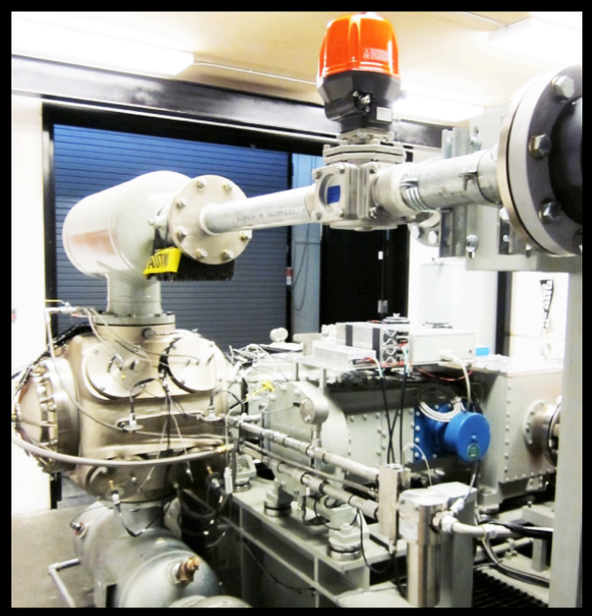
Protege of Roger Penske
Developed engines which
won racing championships

2009: Combined with world class cofounders

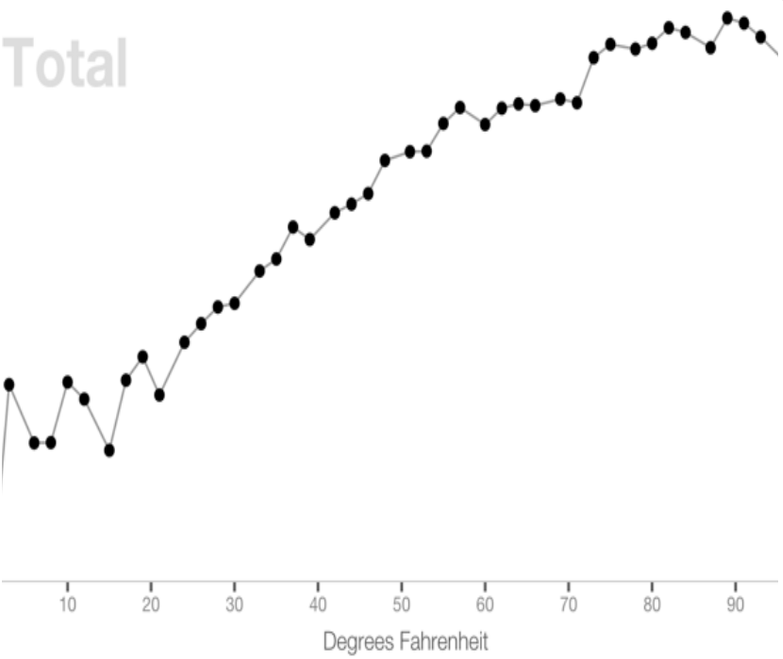


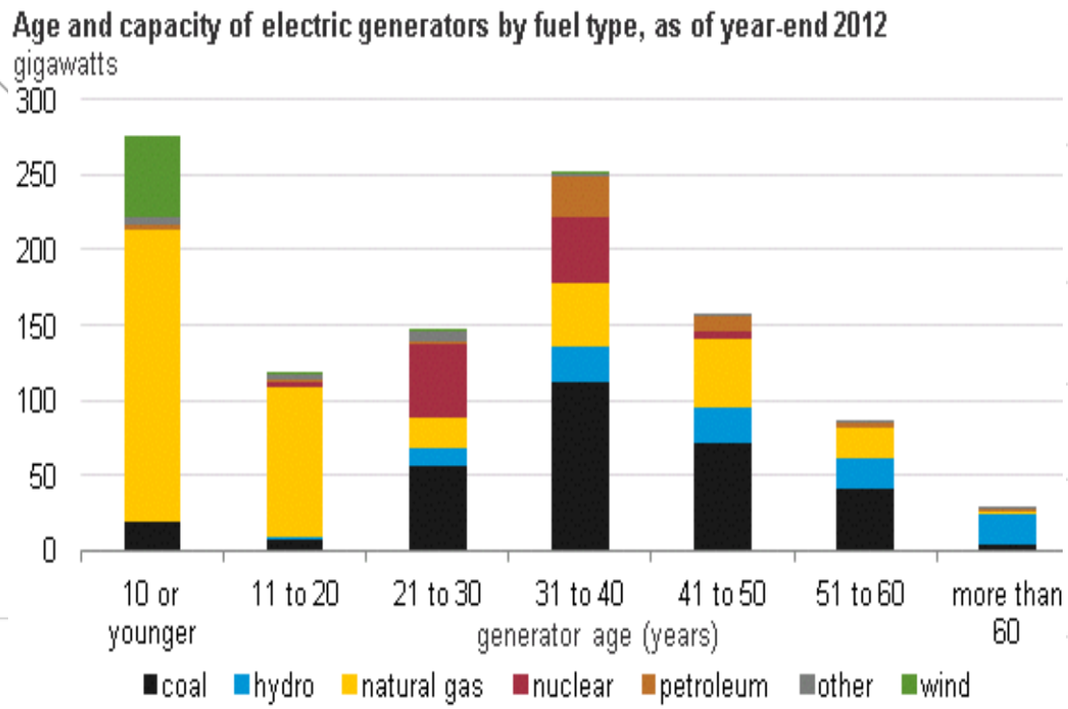
2010: industrial scale proof of concept

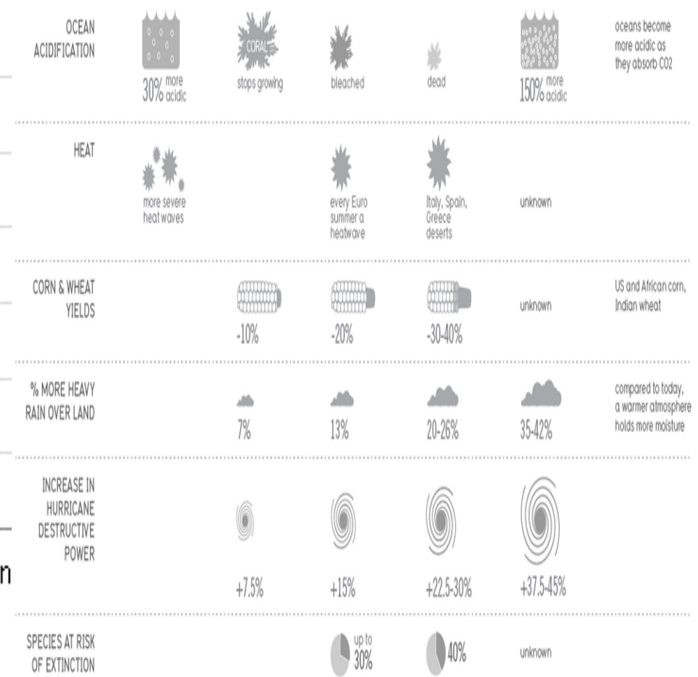


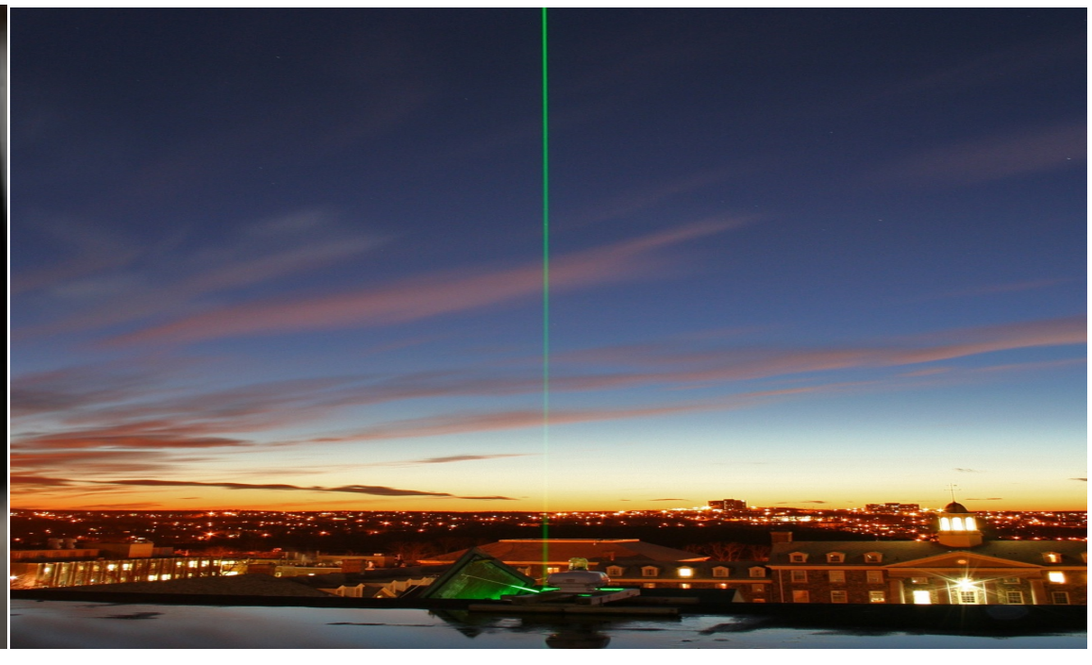


2011: complete scientific demonstration

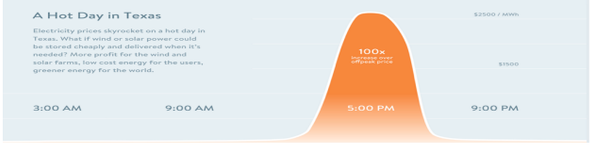






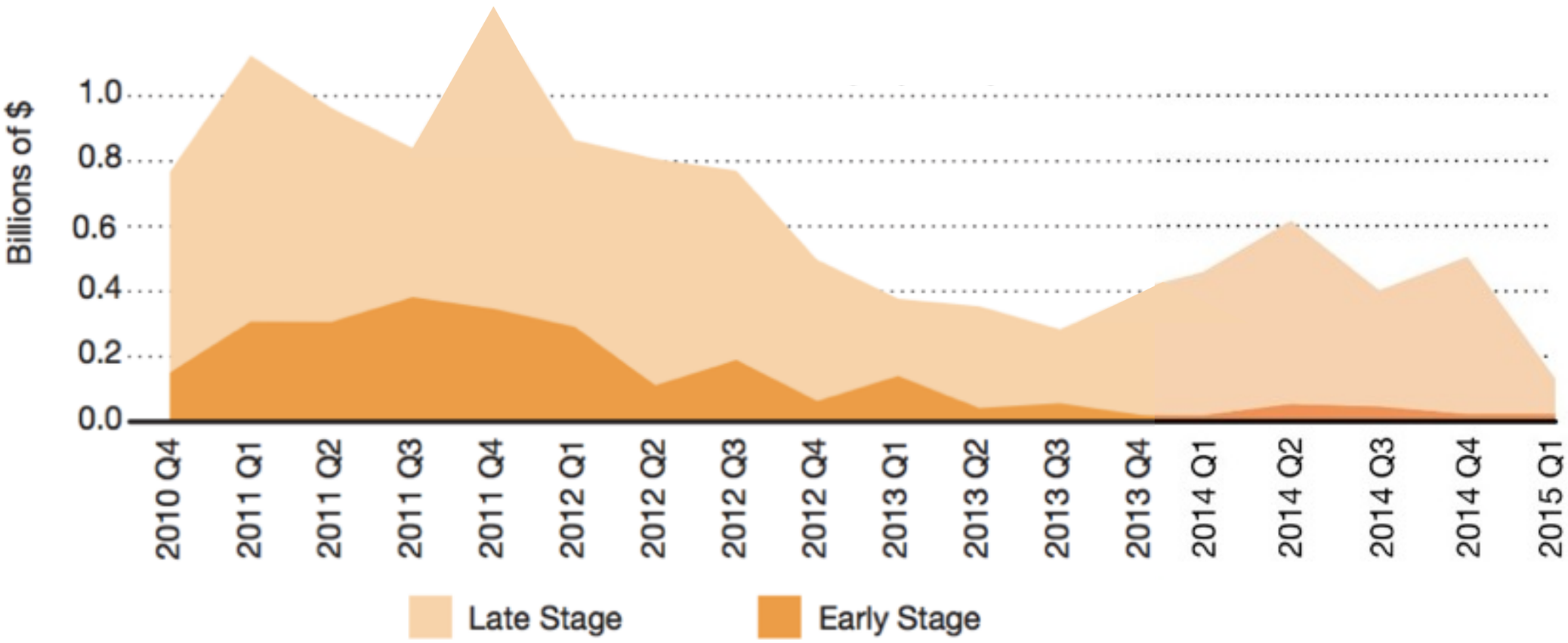


Silicon Valley Bank

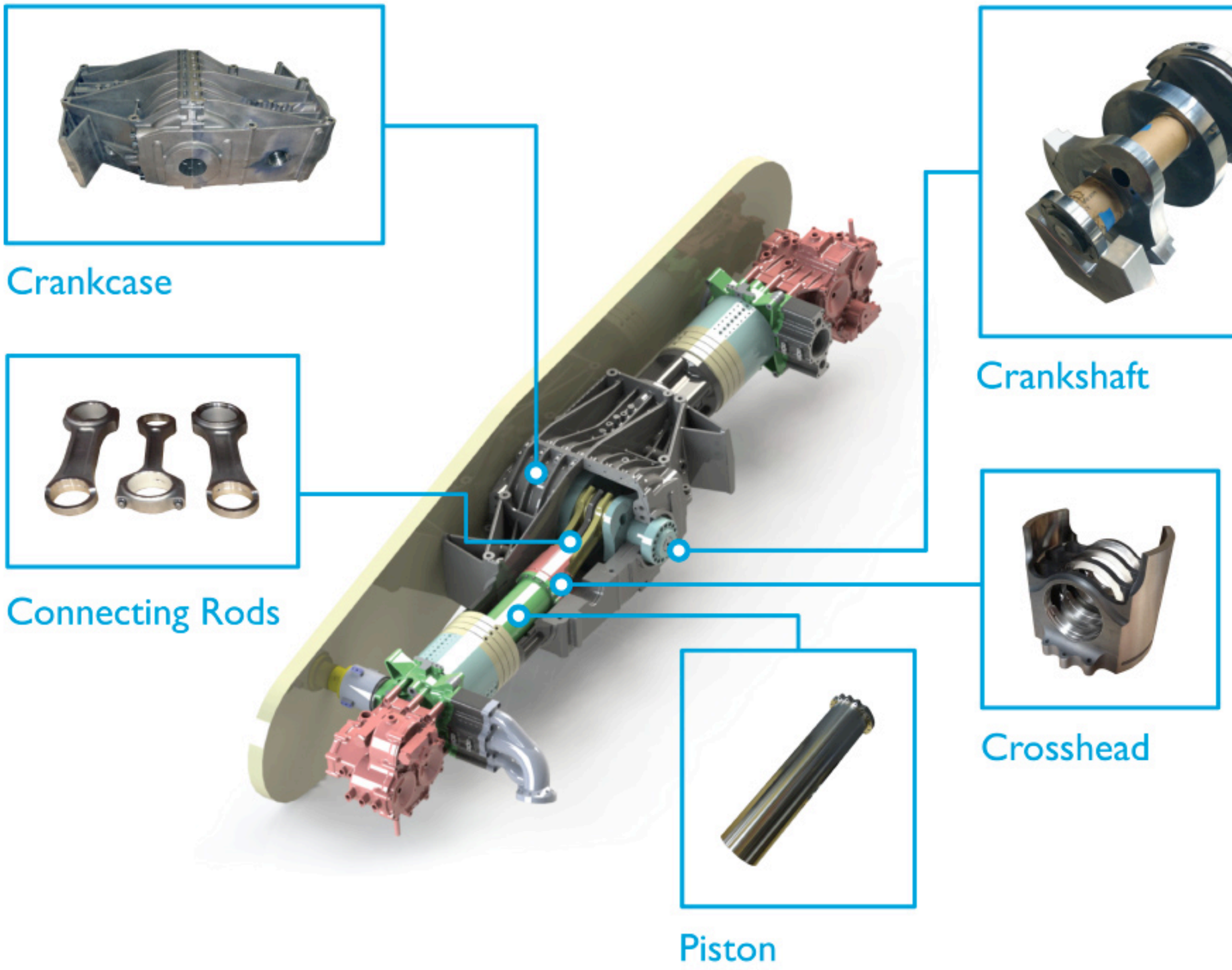


2012: secure backing

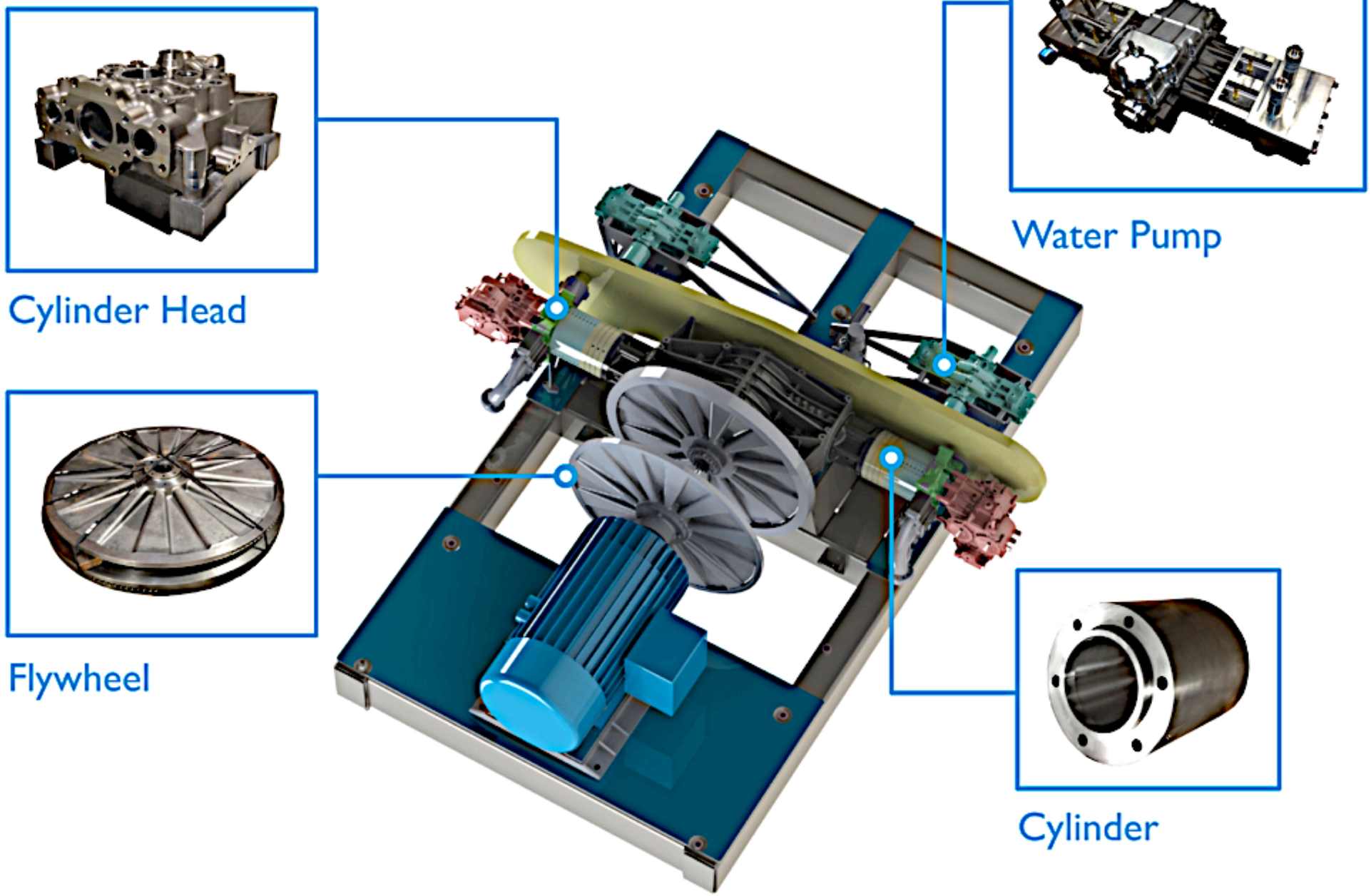
US Cleantech Venture Capital Investment: 2010 - 2015



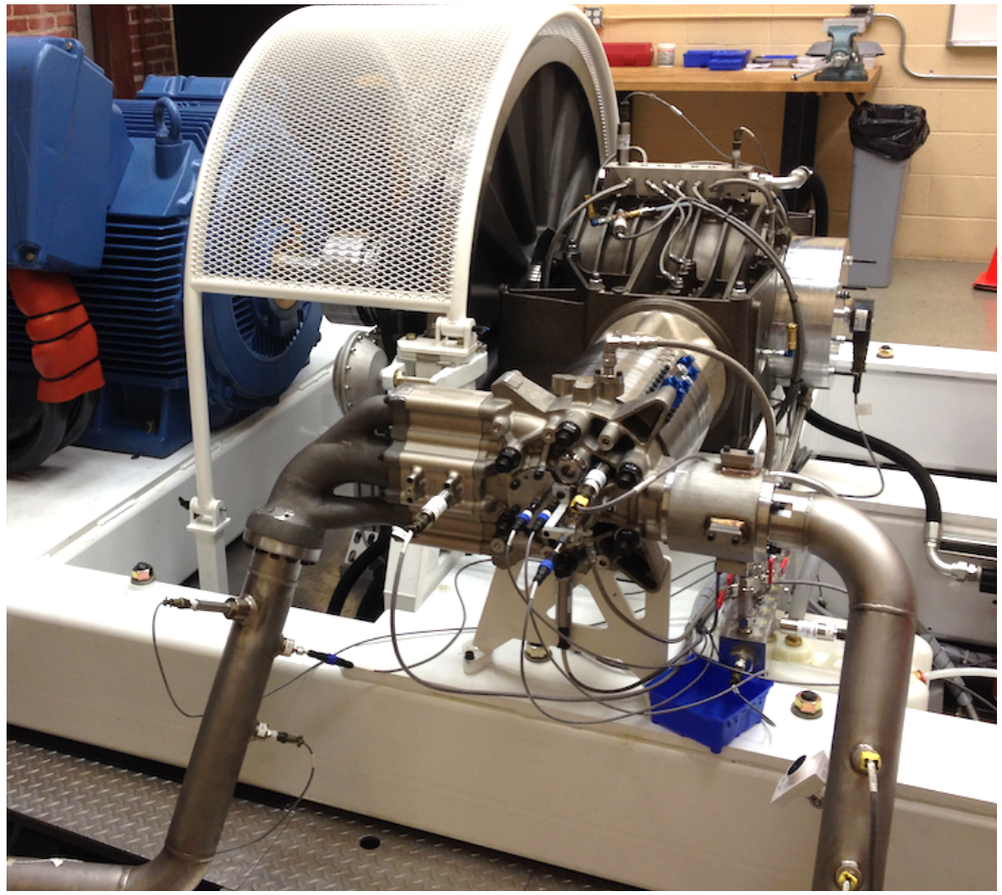
Lesson: secure backers allows you to beat the odds



2012: design of product



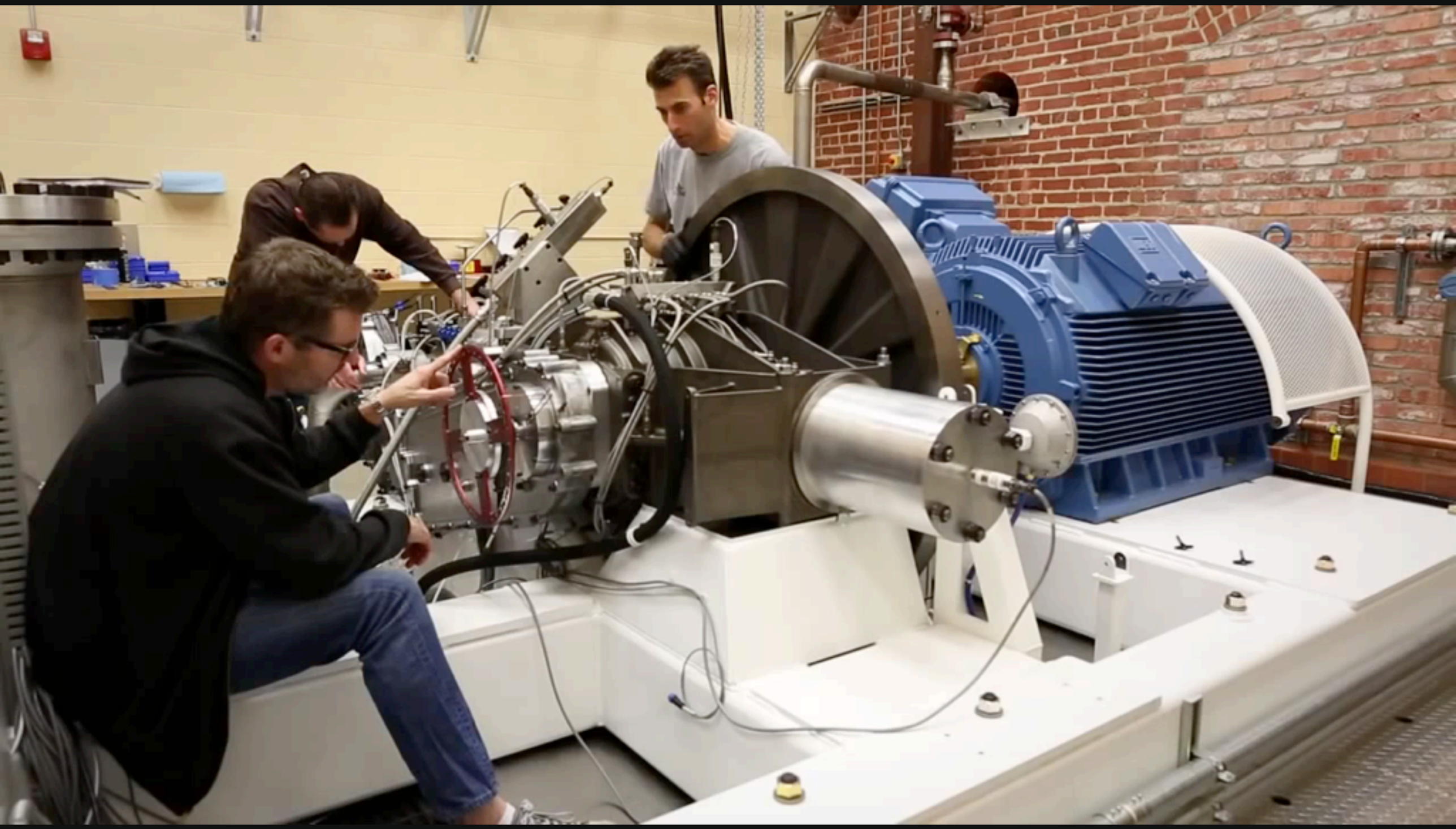
2013: build product prototype



Full scale 200 atmosphere compressor/expander prototype
500 kW, 1200 RPM

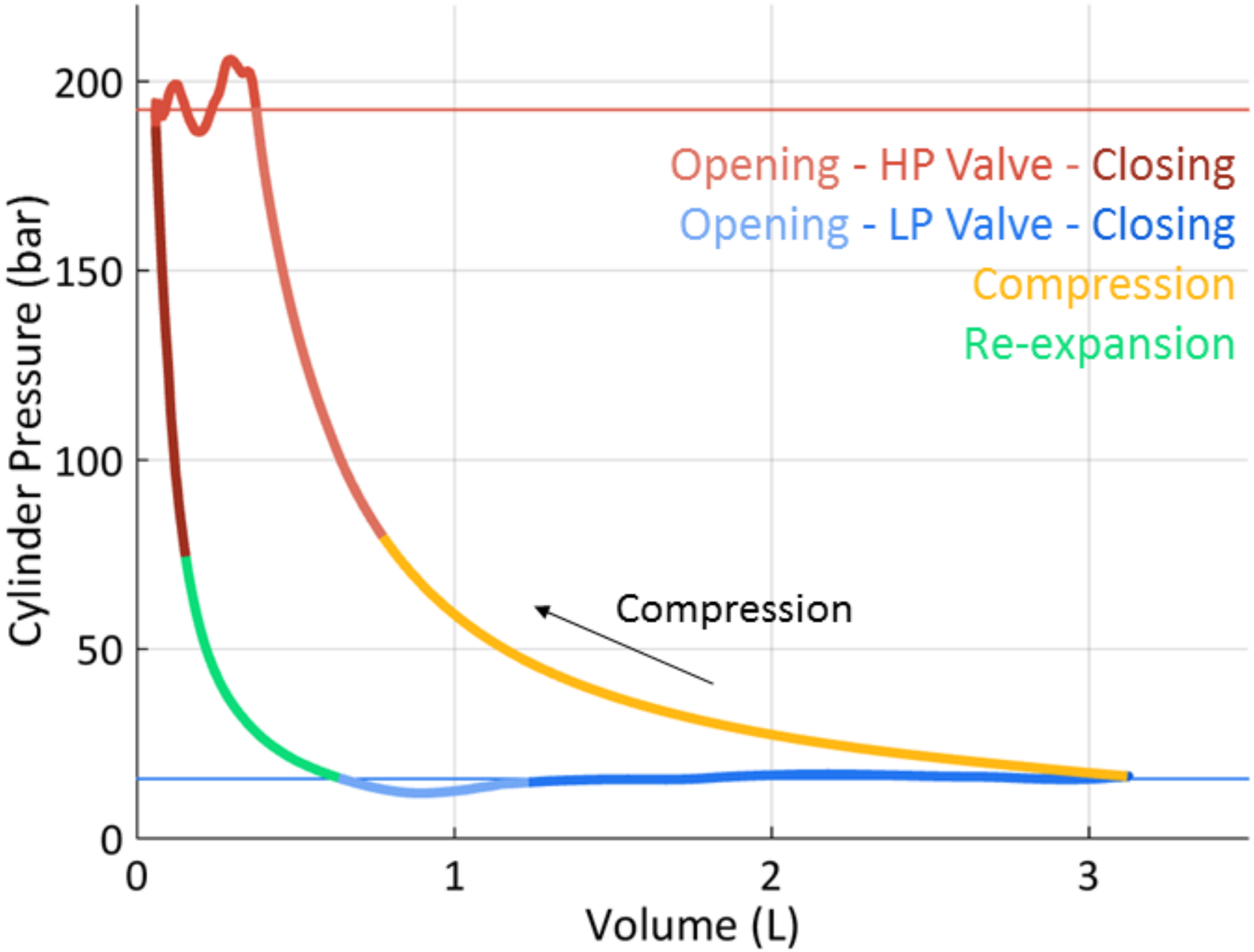
Full scale carbon fiber pressure vessel prototype
Lighter, more inexpensive than anything before

2014: we demonstrated the technological breakthrough



we built it

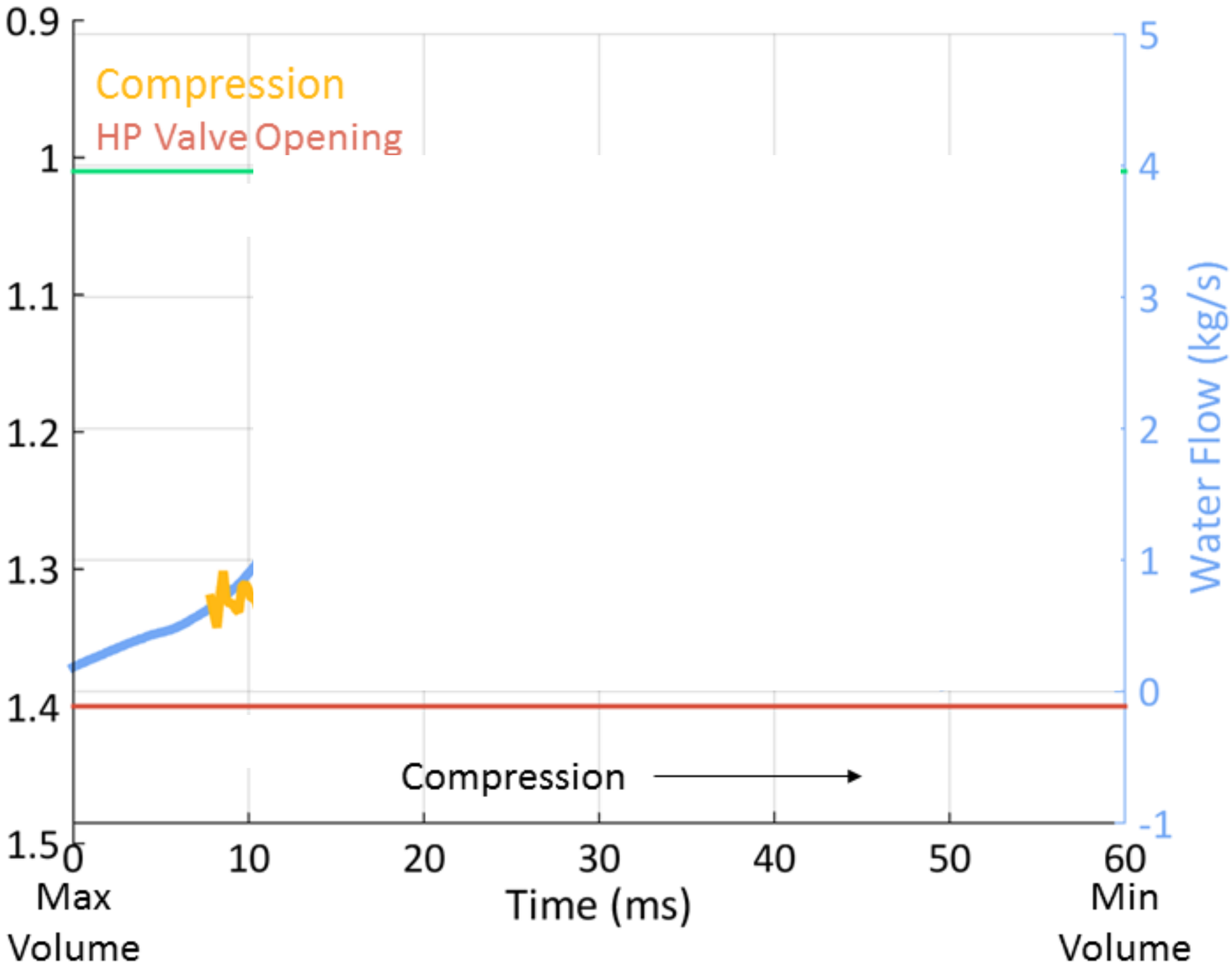
The compression process, at full pressure



How water spray effects efficiency

Absolute Thermodynamic Ideal

Before "Adiabatic"



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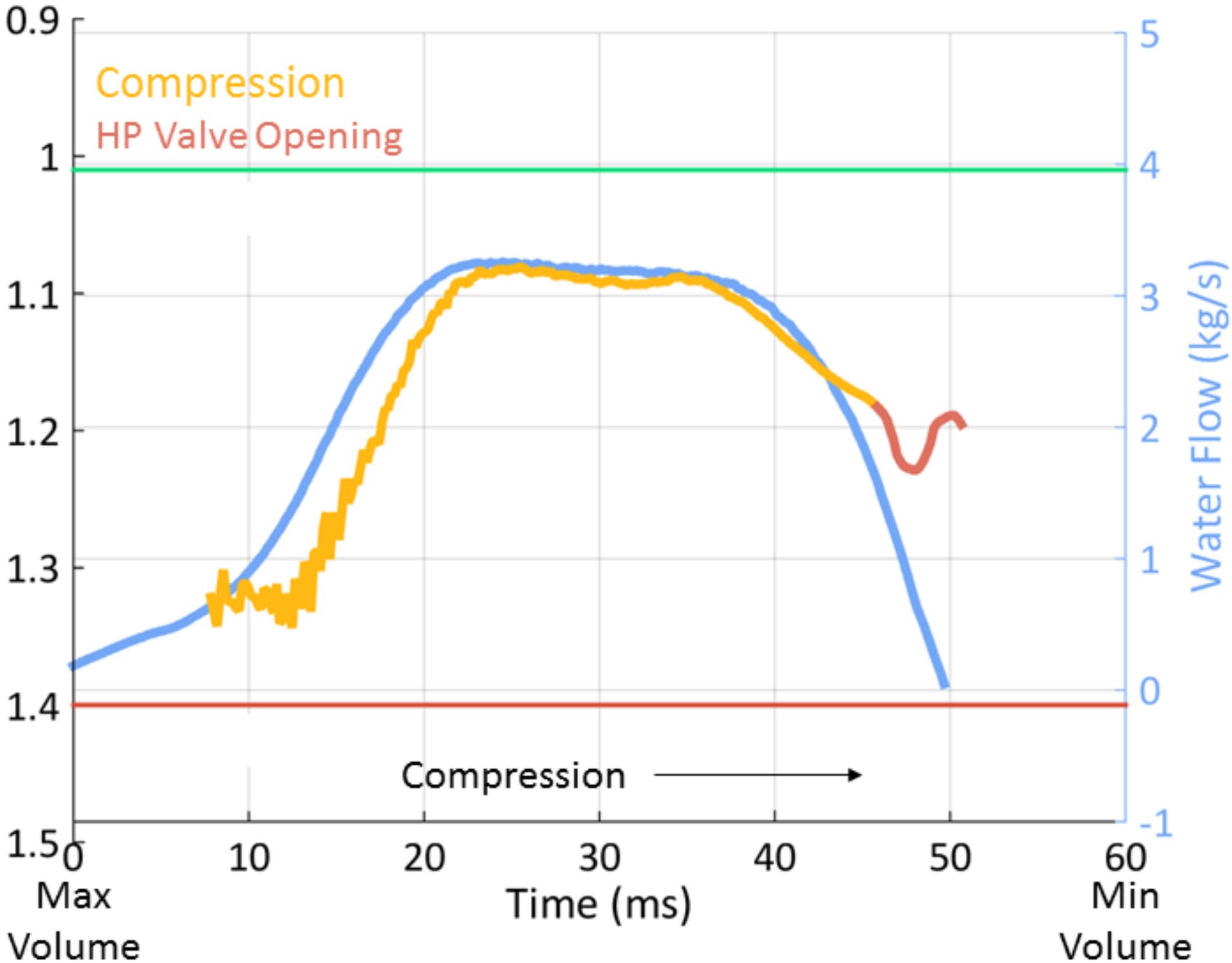

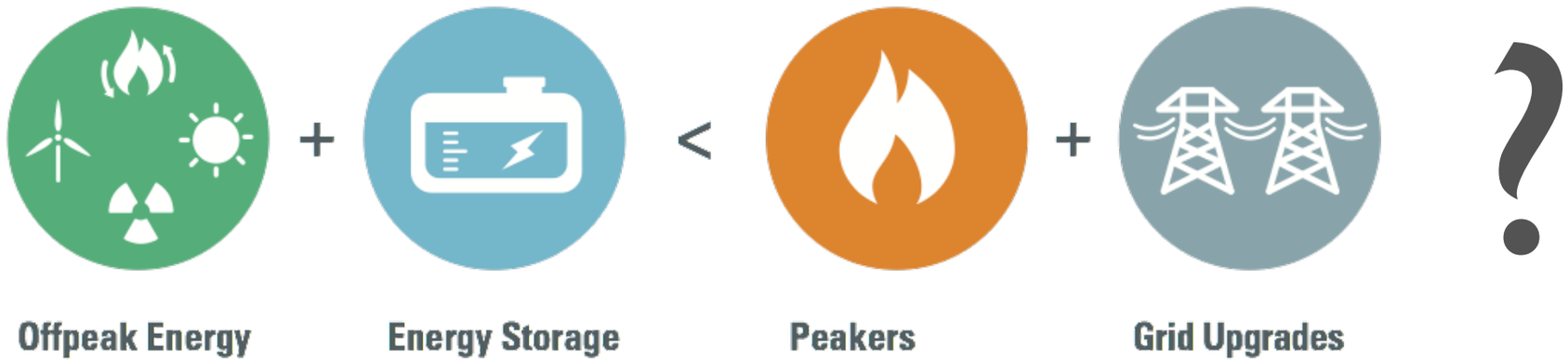
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+
?
Offpeak Energy
Energy Storage
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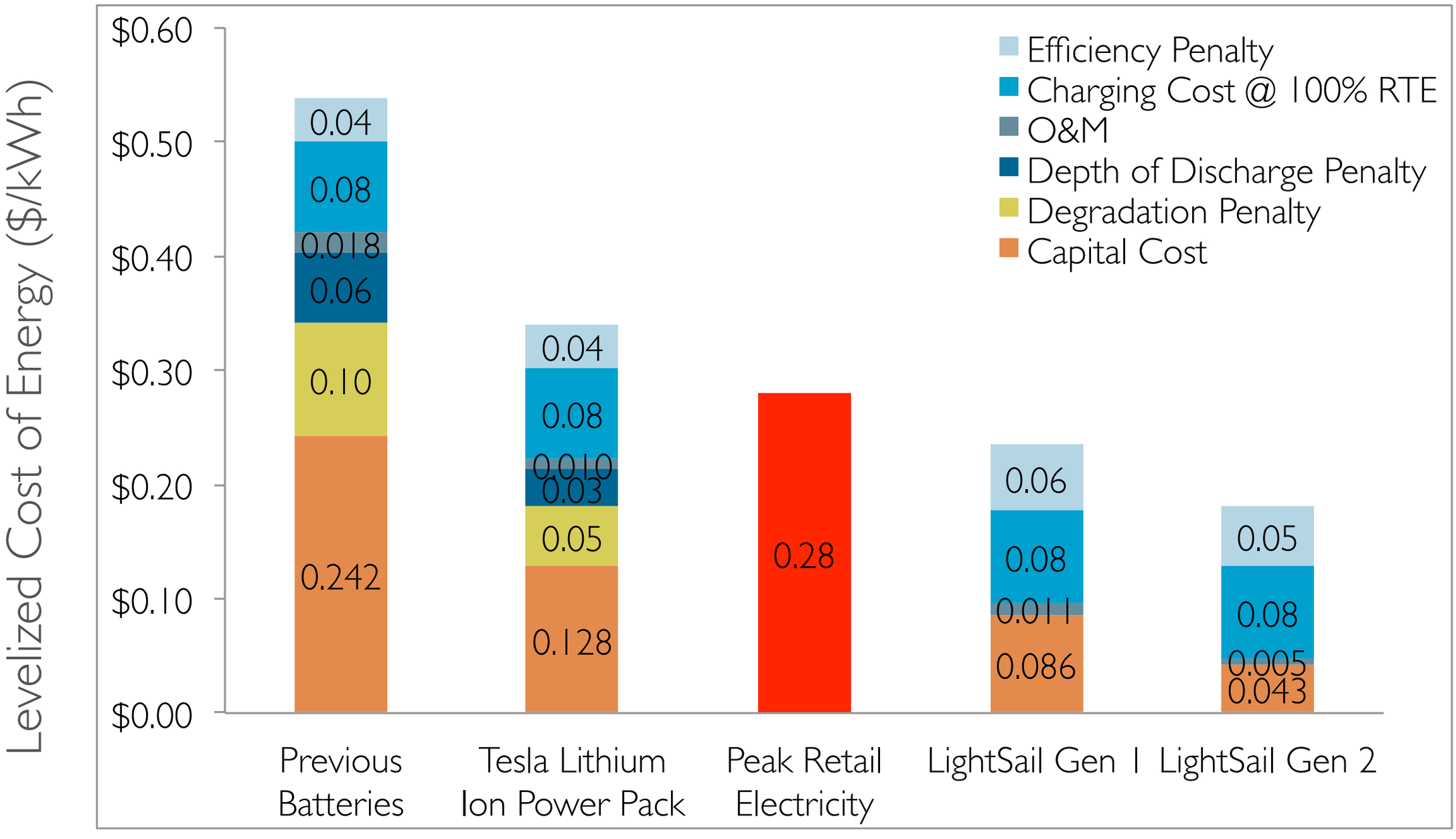
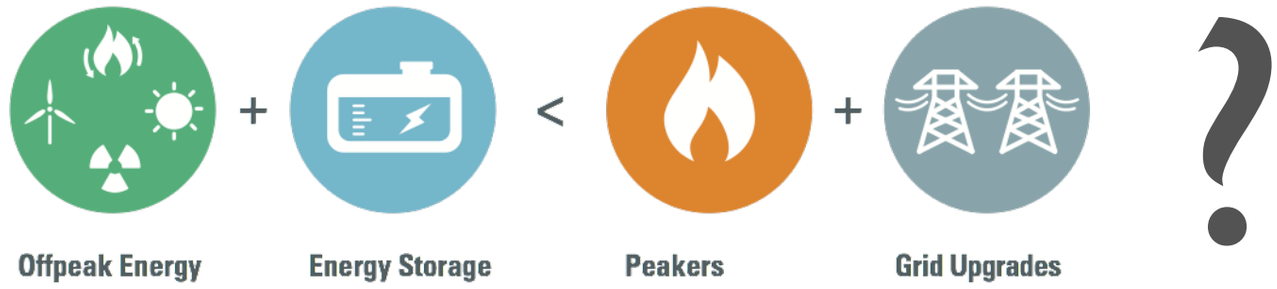
Grid Upgrades


Levelized Cost of Energy ($/kWh)
$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
0.04
0.08
0.018
0.06
0.10
0.242
0.04
0.08
0.010
0.03
0.05
0.128
0.28
0.06
0.08
0.011
0.086
0.05
0.08
0.005
0.043
Efficiency Penalty
Charging Cost @ 100% RTE
O&M
Depth of Discharge Penalty
Degradation Penalty
Capital Cost
Previous Batteries
Tesla Lithium Ion Power Pack
Peak Retail Electricity
LightSail Gen 1
LightSail Gen 2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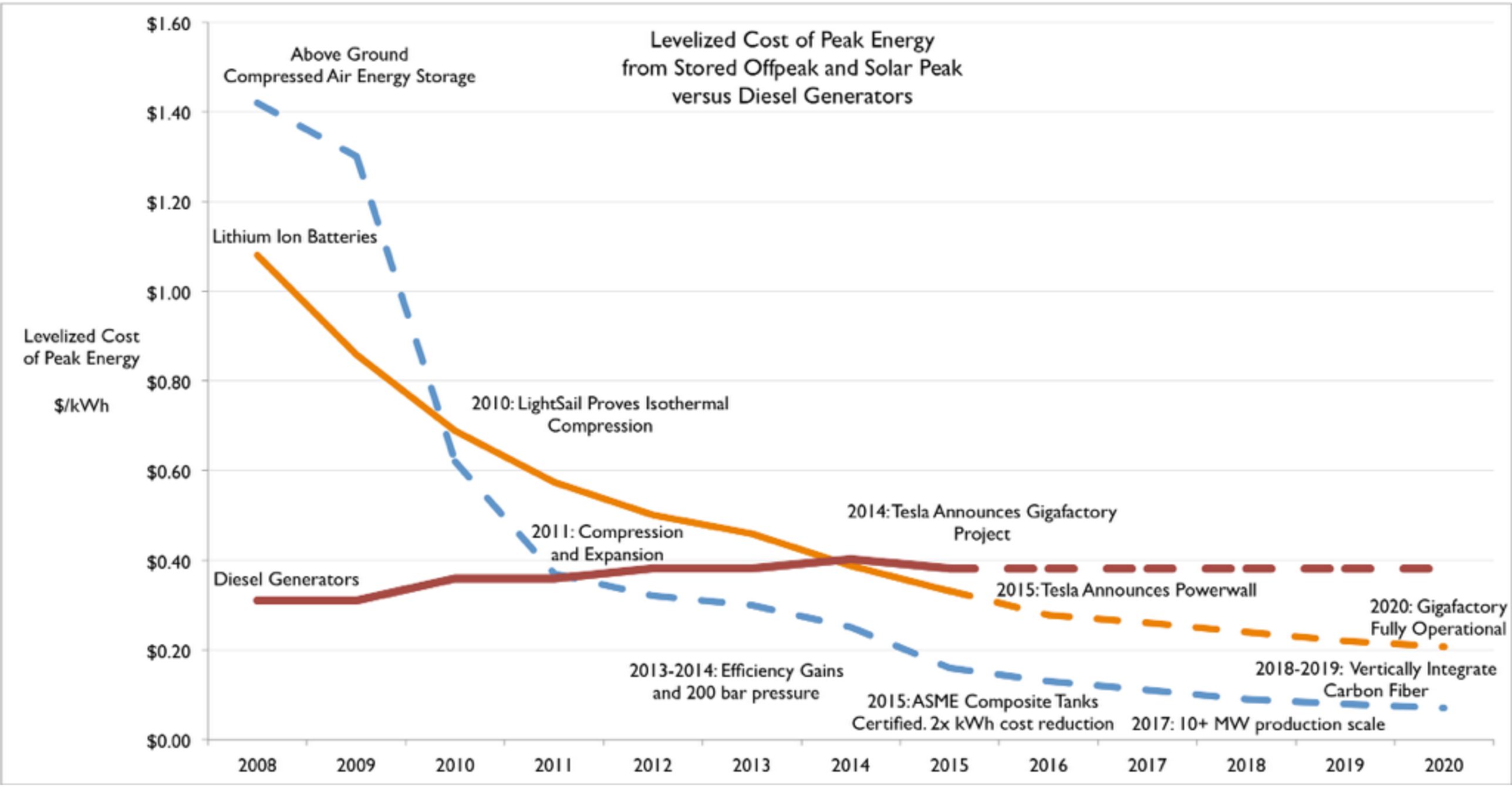
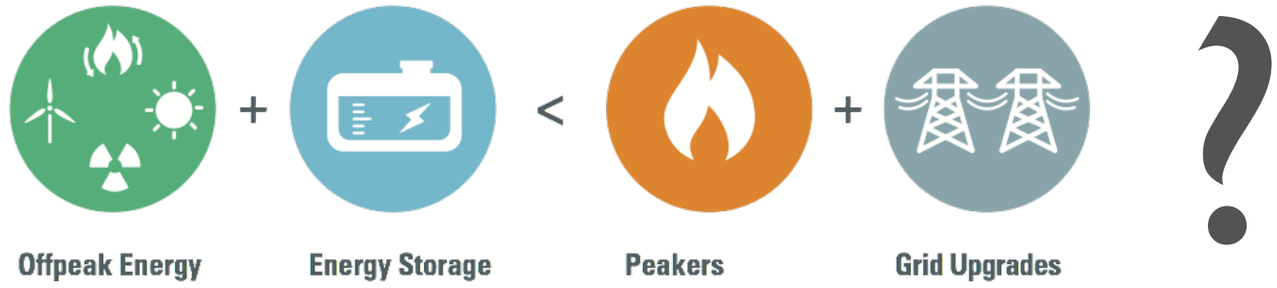
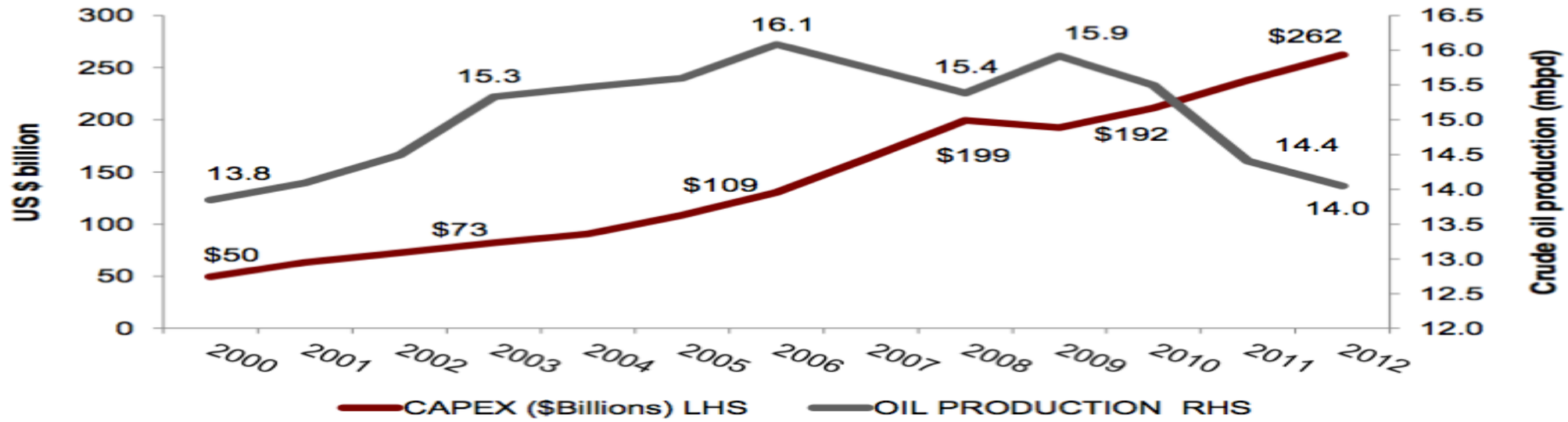

Levelized Cost of Peak Energy from Stored Offpeak and Solar Peak versus Diesel Generators
Levelized Cost of Peak Energy
$/kWh
$1.60
$1.40
$1.20
$1.00
$0.80
$0.60
$0.40
$0.20
$0.00
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Above Ground Compressed Air Energy Storage
Lithium Ion Batteries
Diesel Generators
2010: LightSail Proves Isothermal Compression
2011: Compression and Expansion
2013-2014: Efficiency Gains and 200 bar pressure
2014: Tesla Announces Gigafactory Project
2015: Tesla Announces Powerwall
2015: ASME Composite Tanks Certified. 2x kWh cost reduction
2017: 10+ MW production scale
2018-2019: Vertically Integrate Carbon Fiber
2020: Gigafactory Fully Operational



Douglas – Westwood

Listed Oil Majors: Capex and Crude Oil Production



Crude Oil Production and Capex

Combined data for BG, BP, COP, CVX, ENI, OXY, PBR, RDS, STO, TOT, XOM
Source: Bloomberg via Phibro Trading LLC

- Oil production has faltered, even as capex has soared
- Capex productivity has fallen by a factor of five since 2000
- Observed decline trend now approaching 5% per year


Us

LightSail Energy

Yes, we are raising a funding round. dfong@lightsailenergy.com