Solar + Storage + IoT + LED = $30 Trillion

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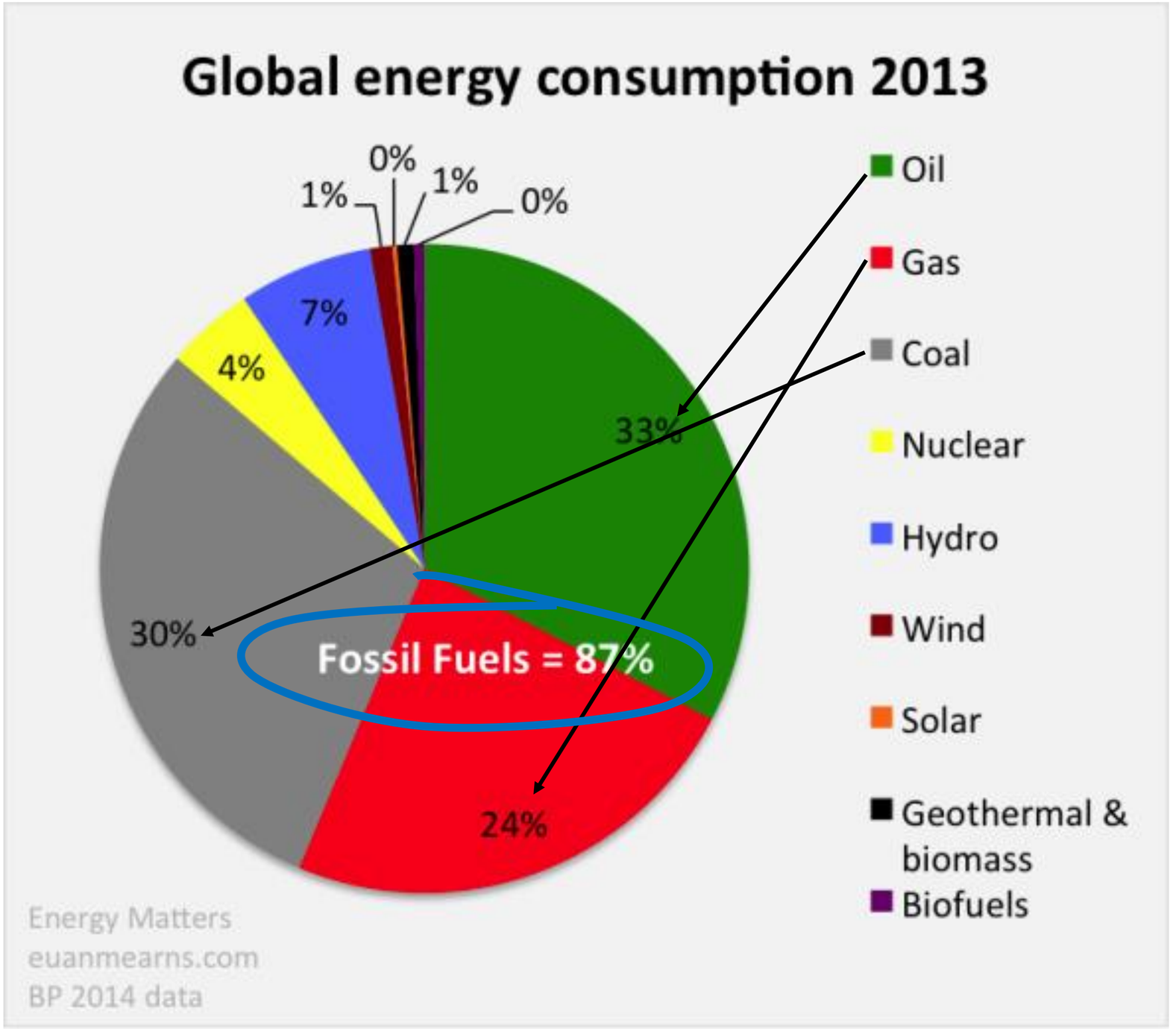
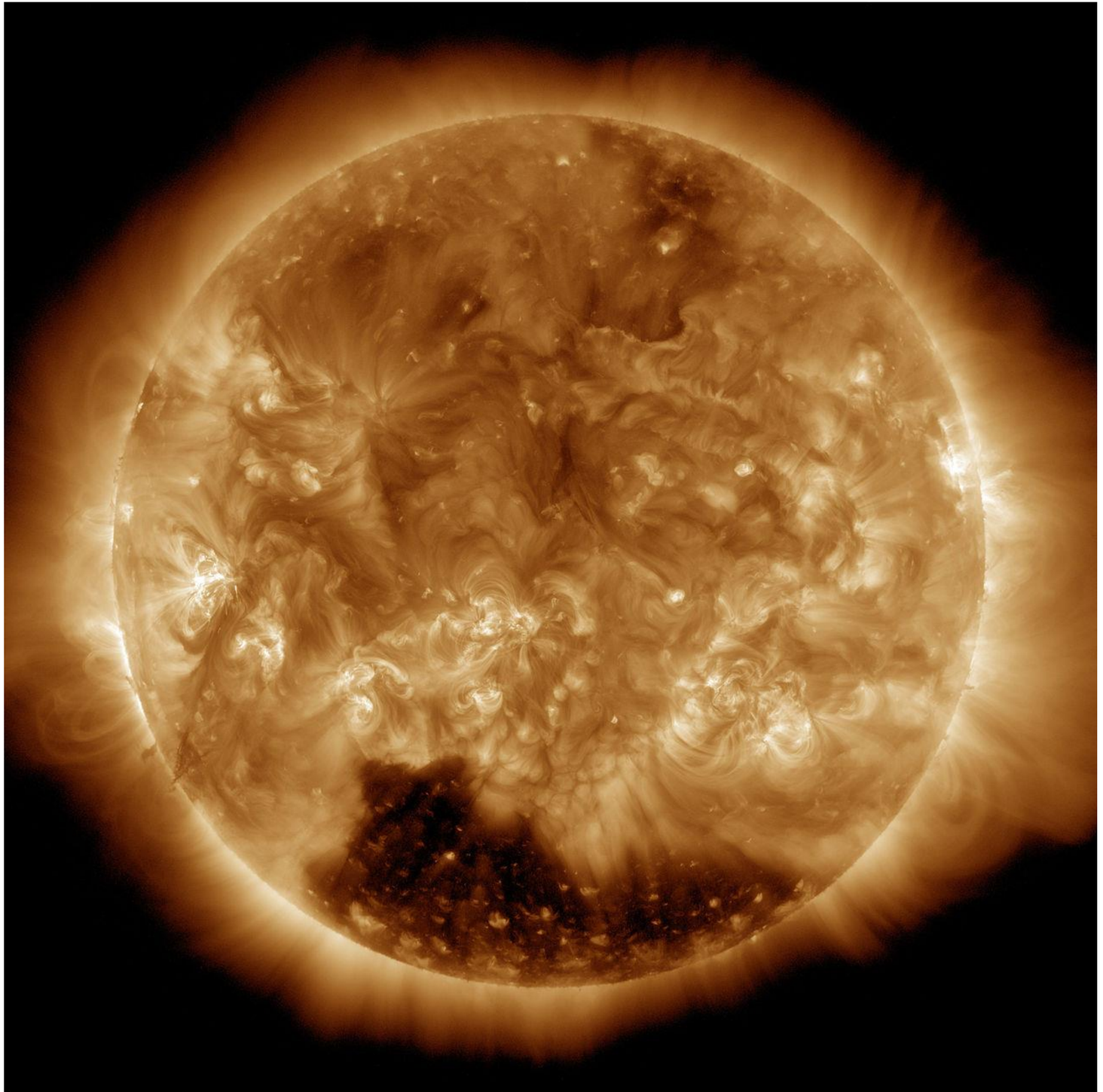
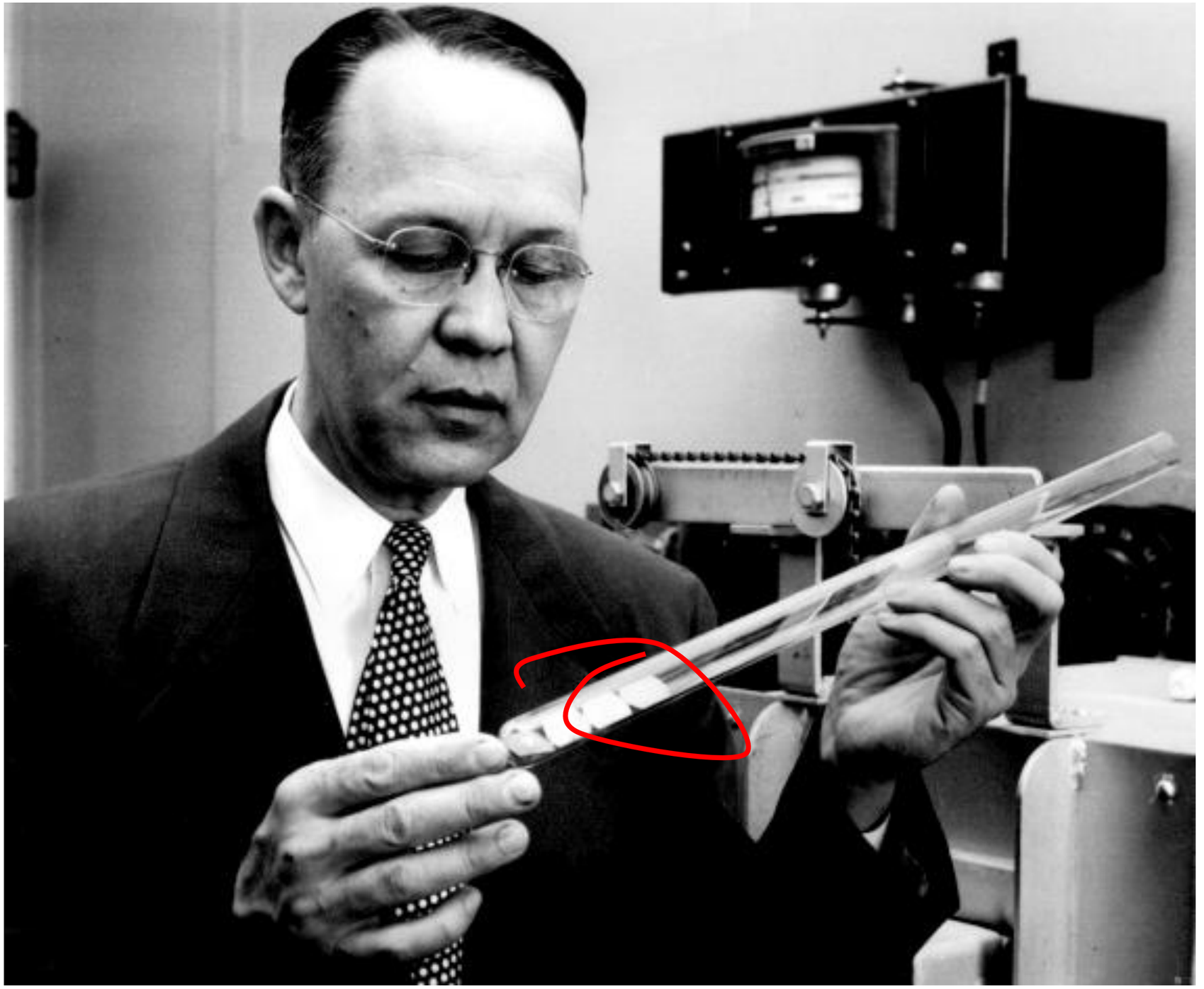
http://iss4e.ca

All images from Wikipedia unless otherwise specified


Global energy consumption 2013
0%
1%
1%
0%
7%
4%
33%
30%
24%
Fossil Fuels = 87%
Oil
Gas
Coal
Nuclear
Hydro
Wind
Solar
Geothermal & biomass
Biofuels
Energy Matters
euanmearns.com
BP 2014 data

But we have a choice…



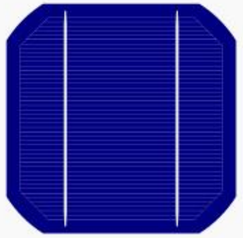


25 April 1954
Bell Laboratories

Chapin, Fuller and Pearson.

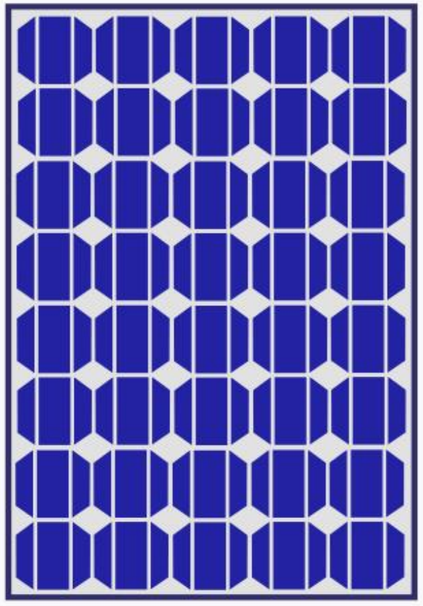
http://free-energy-ltd.com/freeenergy-solar-power.html

From a solar cell to a PV System

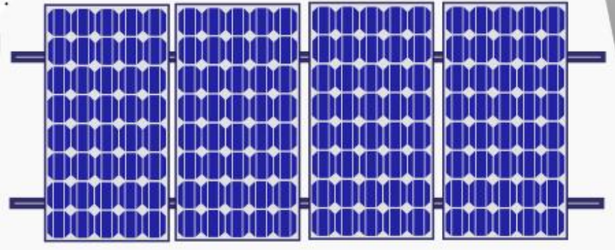


Solar Cell

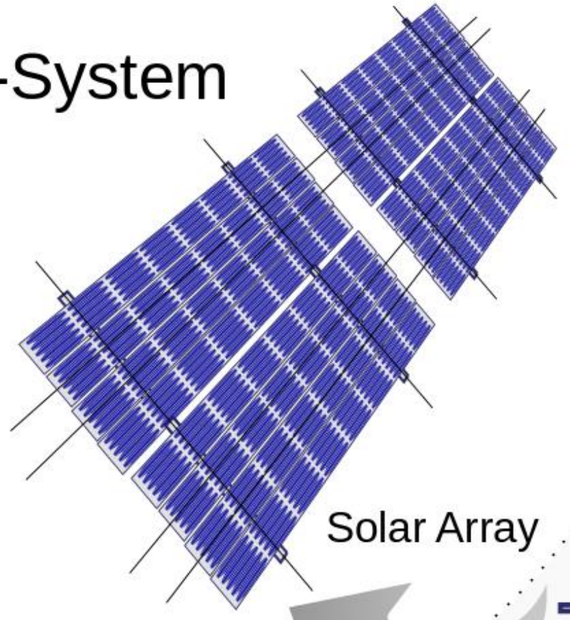
Solar Module



Solar Panel



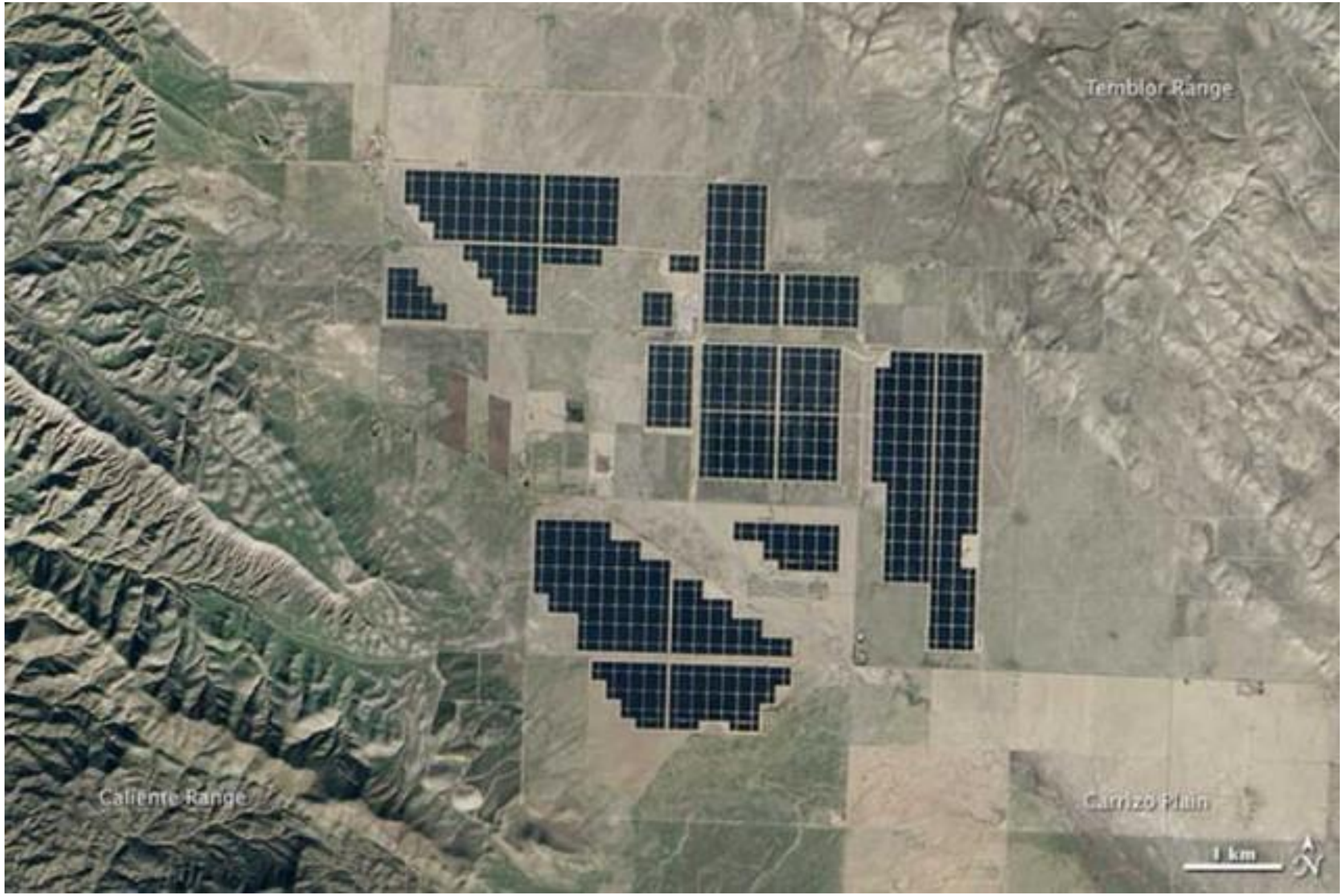
Solar Array



PV-System

- Electricity Meter
- AC Isolator
- Fusebox
- Inverter
- Battery
- Charge Controller
- Generation Meter
- DC Isolator
- Cabling
- Mounting
- Tracking System

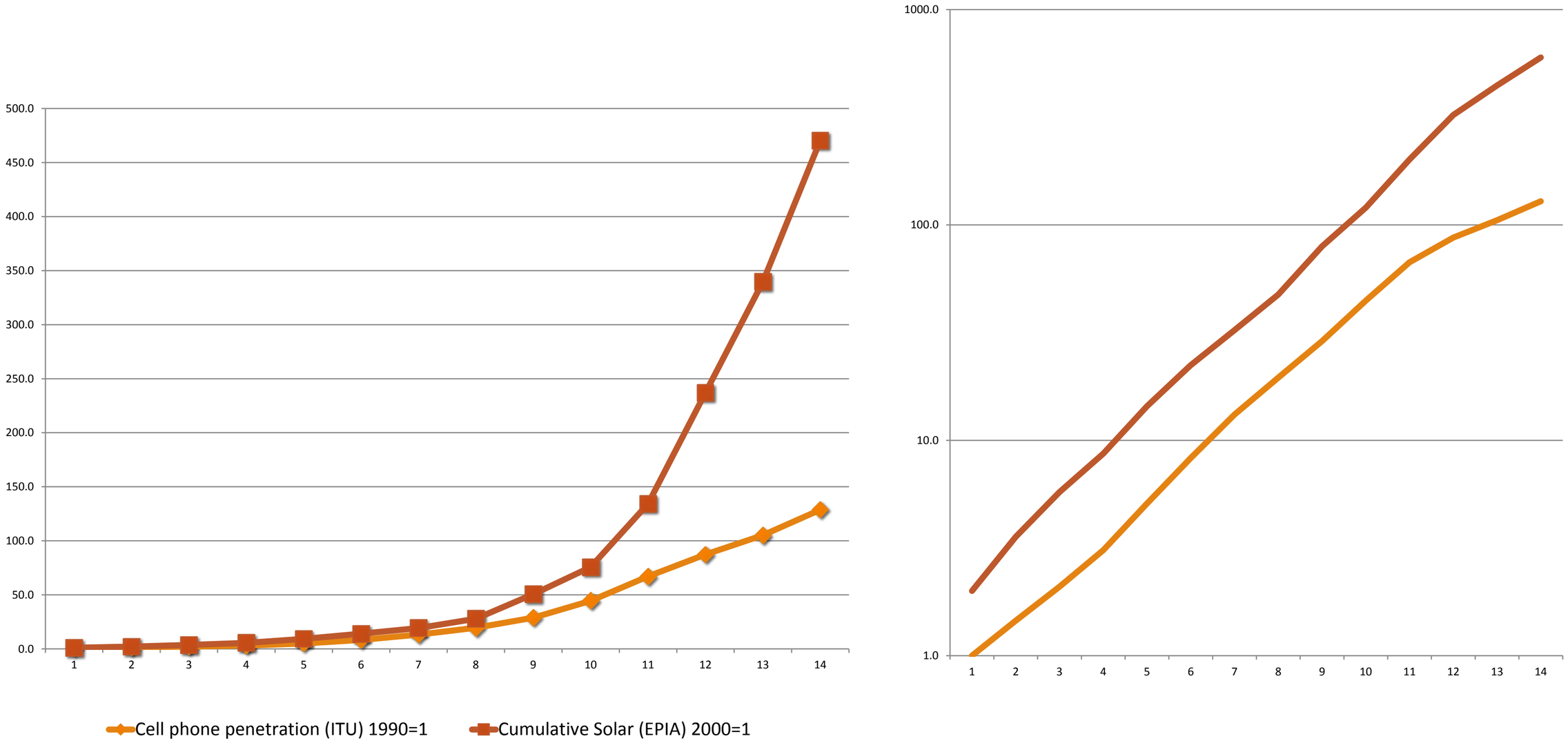

Energy Installs @ 2015



Topaz solar farm, California 25.6 km^2 9 million panels

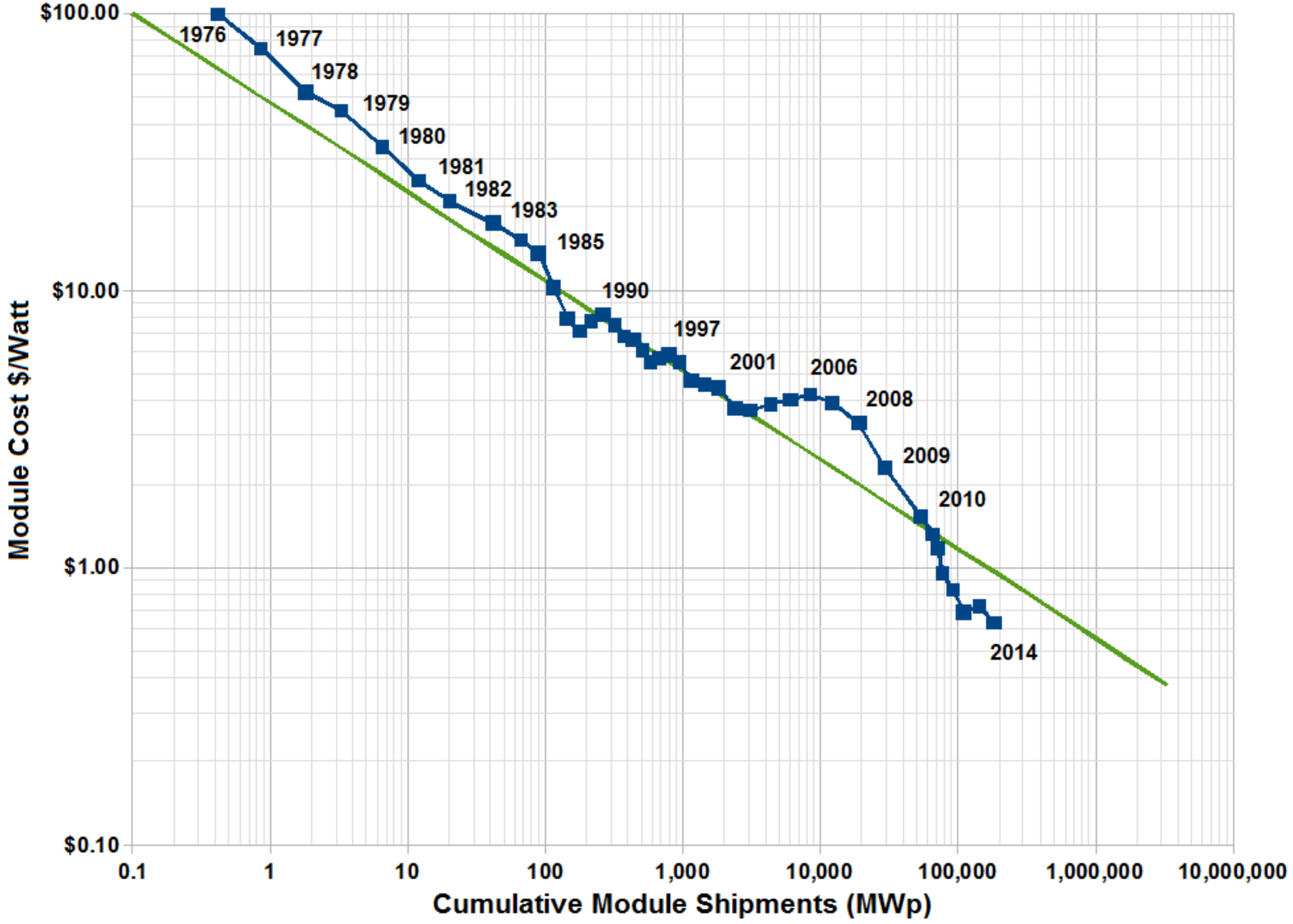

© Nearmap.com

Solar PV is growing as fast as cell phones

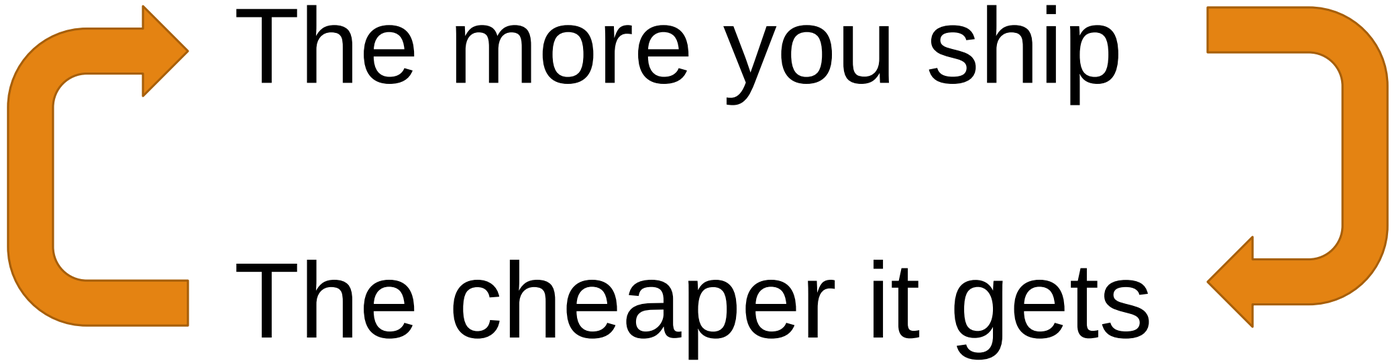


http://www.epia.org/fileadmin/user_upload/Publications/EPIA_Global_Market_Outlook_for_Photovoltaics_2014-2018_-_Medium_Res.pdf
http://stats.areppim.com/stats/stats_mobile.htm

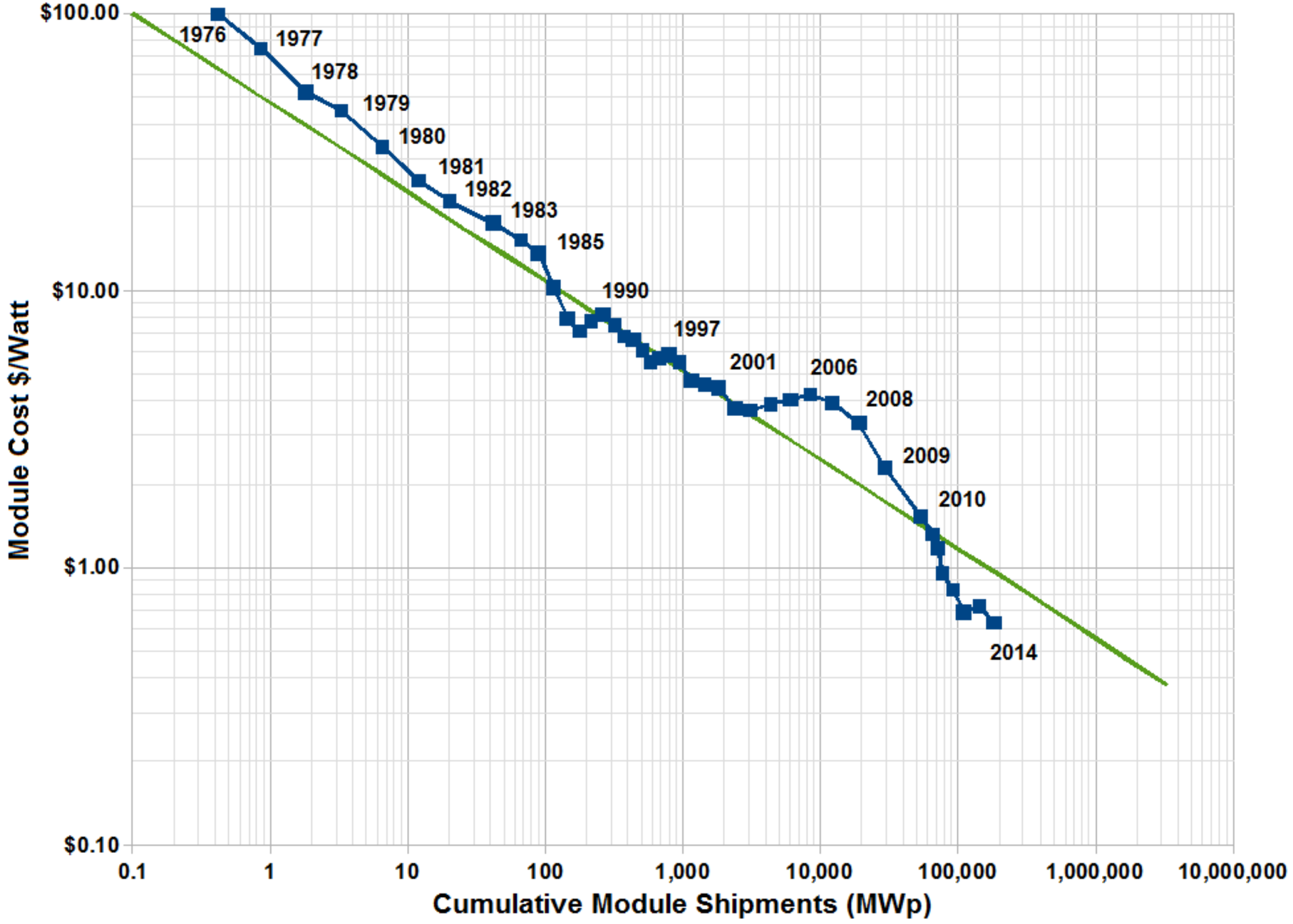
Swanson's Law

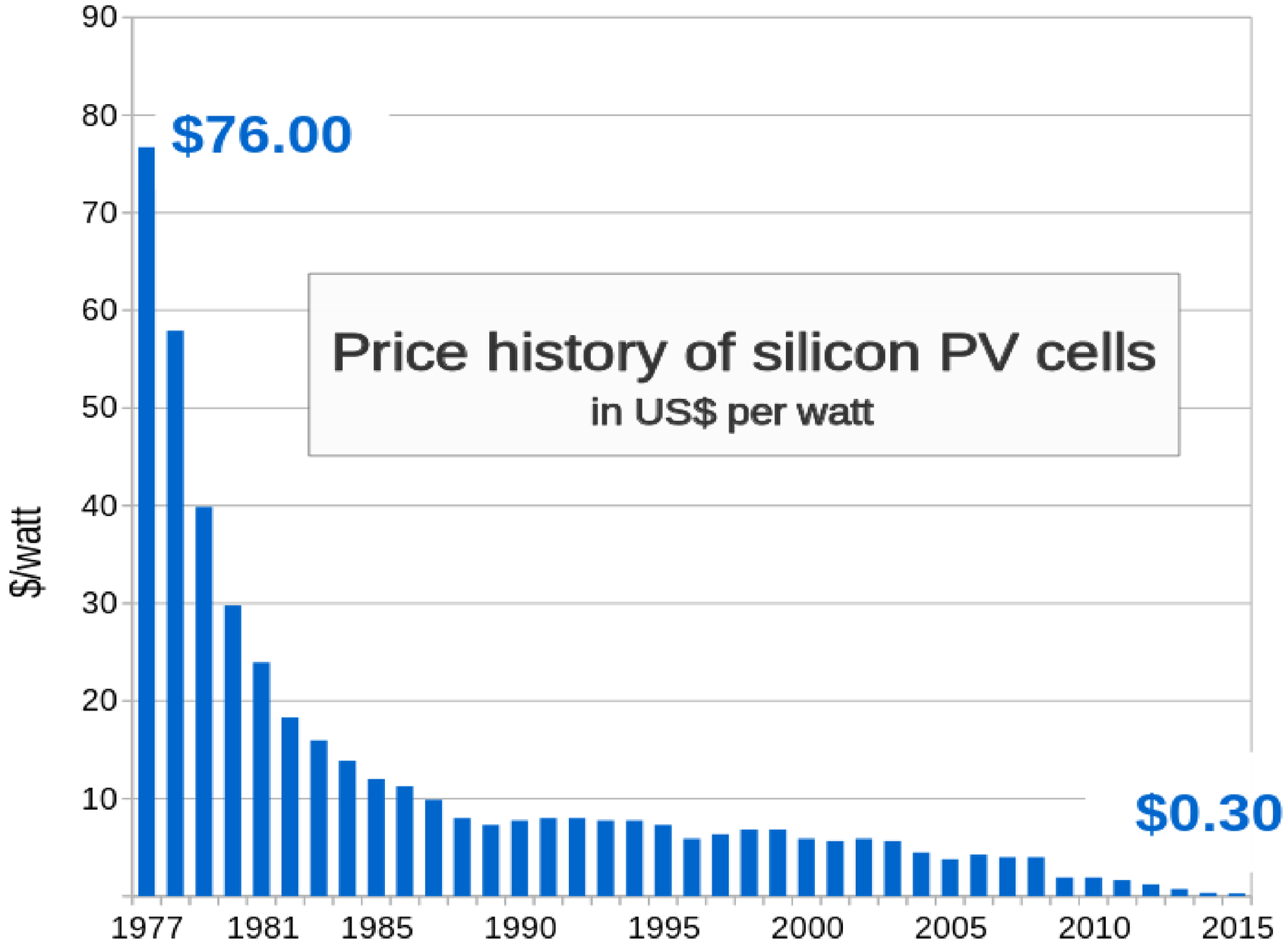


Positive feedback loop



Swanson's Law





Source: Bloomberg New Energy Finance & pv.energytrend.com

3 characteristics of solar generation

1. Sunlight is free!
   - Near-zero OPEX, all cost is CAPEX

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2. 20-25 year nearly maintenance-free lifetime

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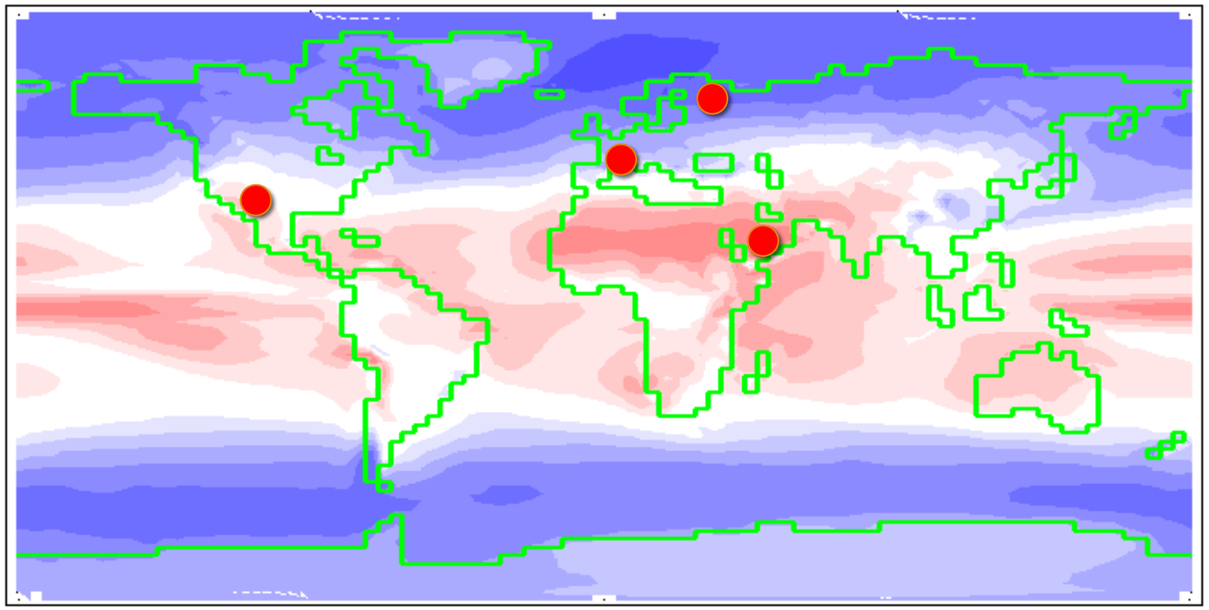
2. 20-25 year nearly maintenance-free lifetime
3. Amount of generation over lifetime depends on geography



Levelized Cost of Energy

Levelized Cost of Energy

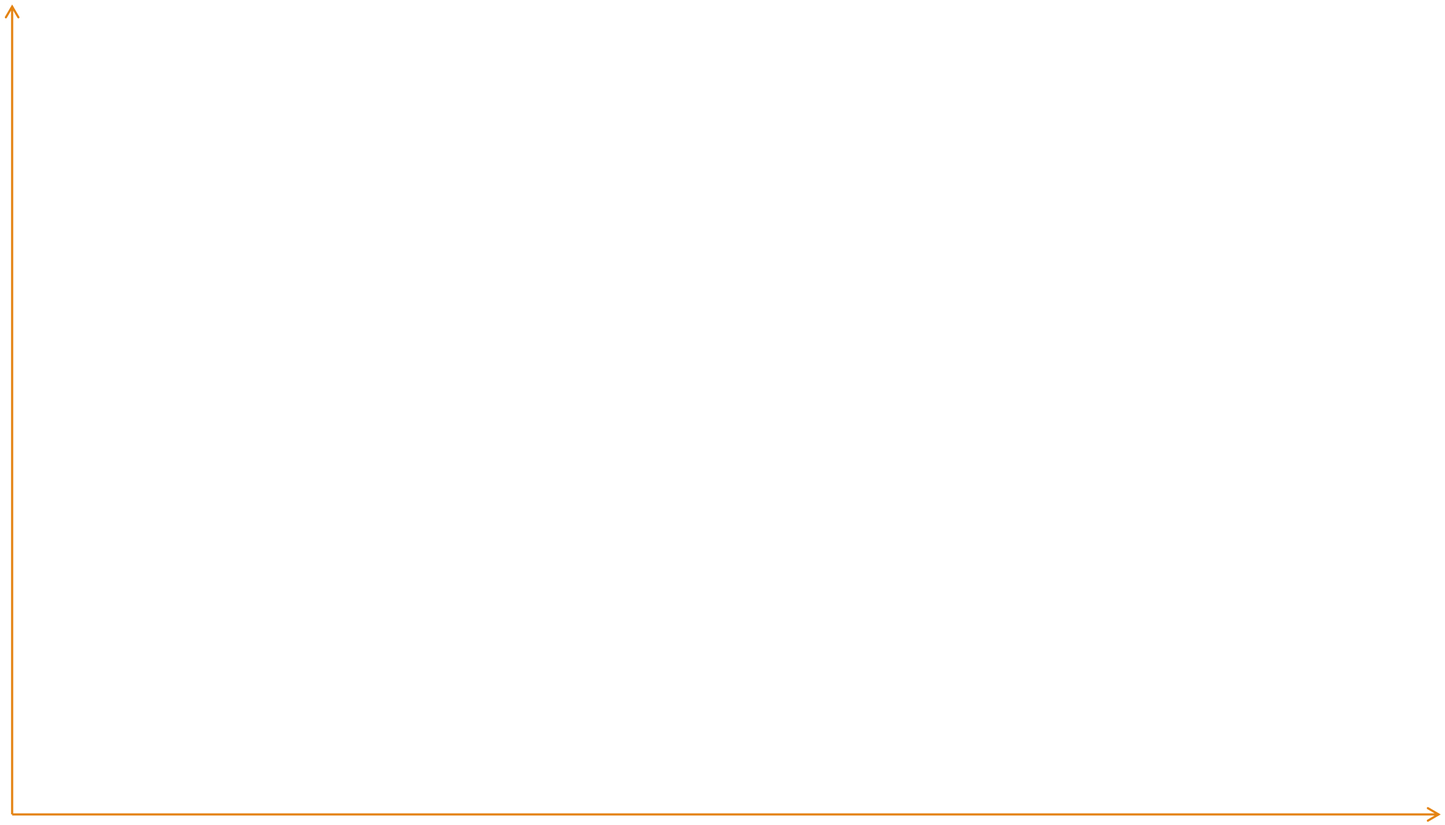
Effective cost per kWh (units of energy)

Levelized Cost of Energy

Levelized Cost of Energy

Average cost per unit of energy over 20y lifetime

$/kWh

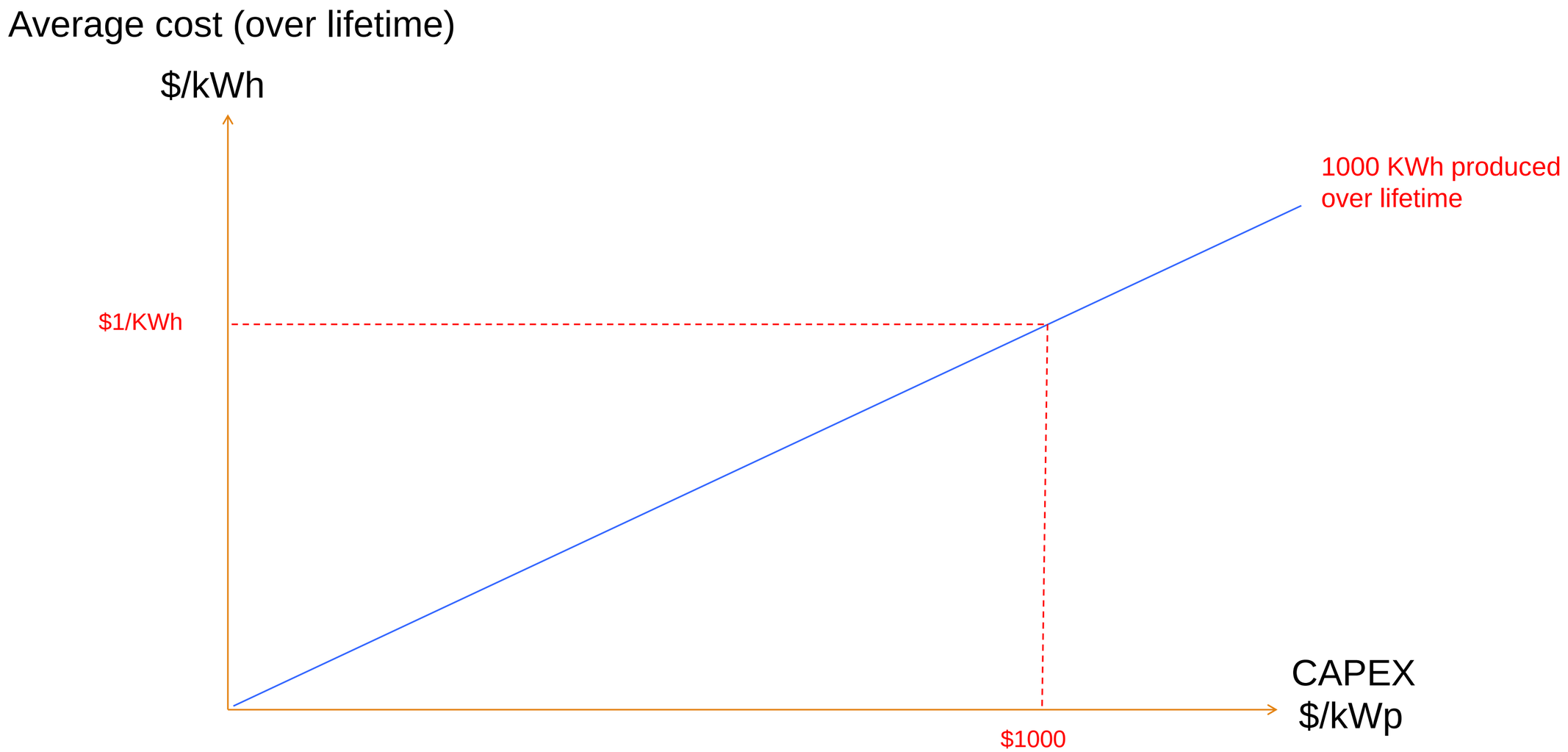


CAPEX
$/kWp

$1000

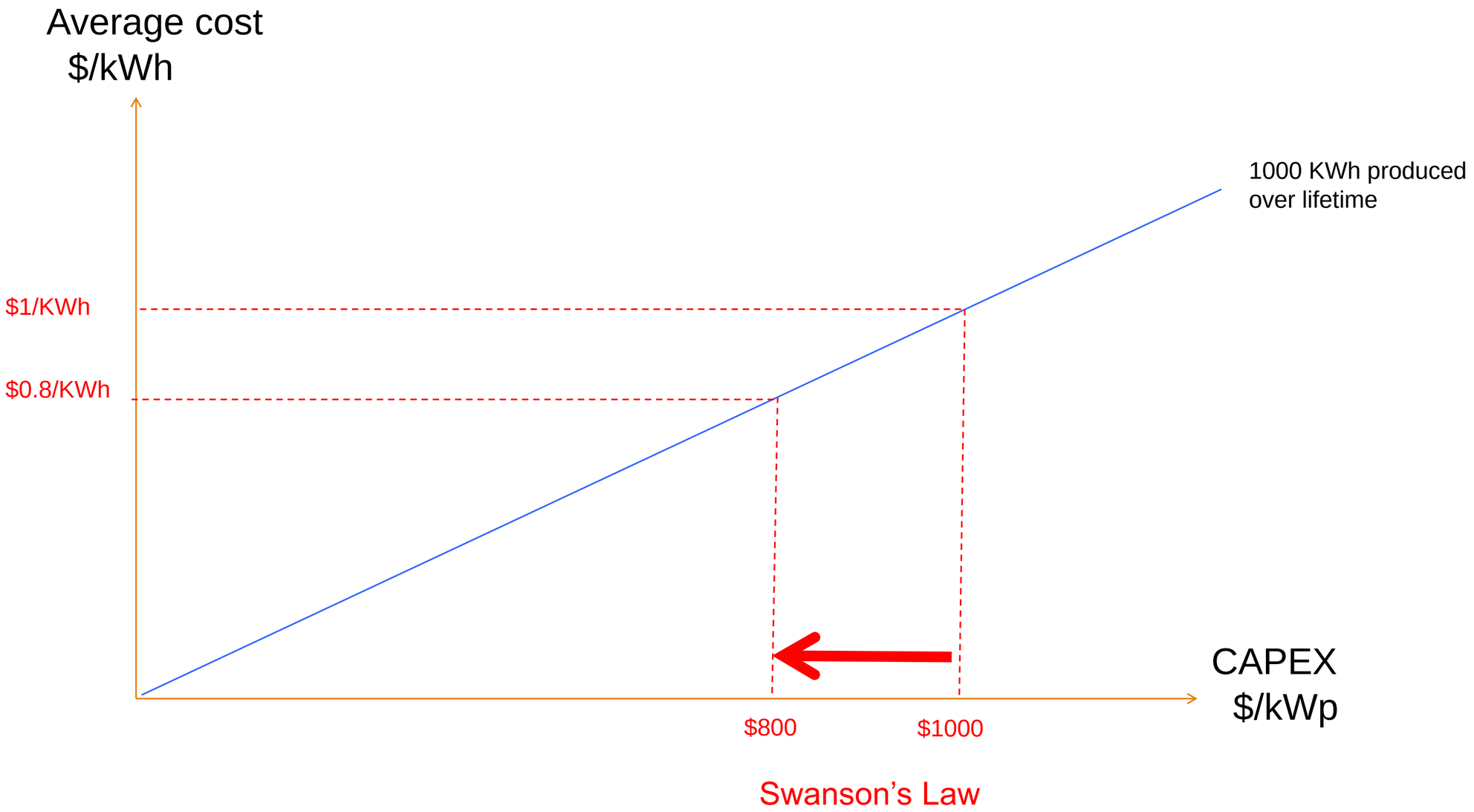
*Assumes a fixed equipment lifetime

Levelized Cost of Energy

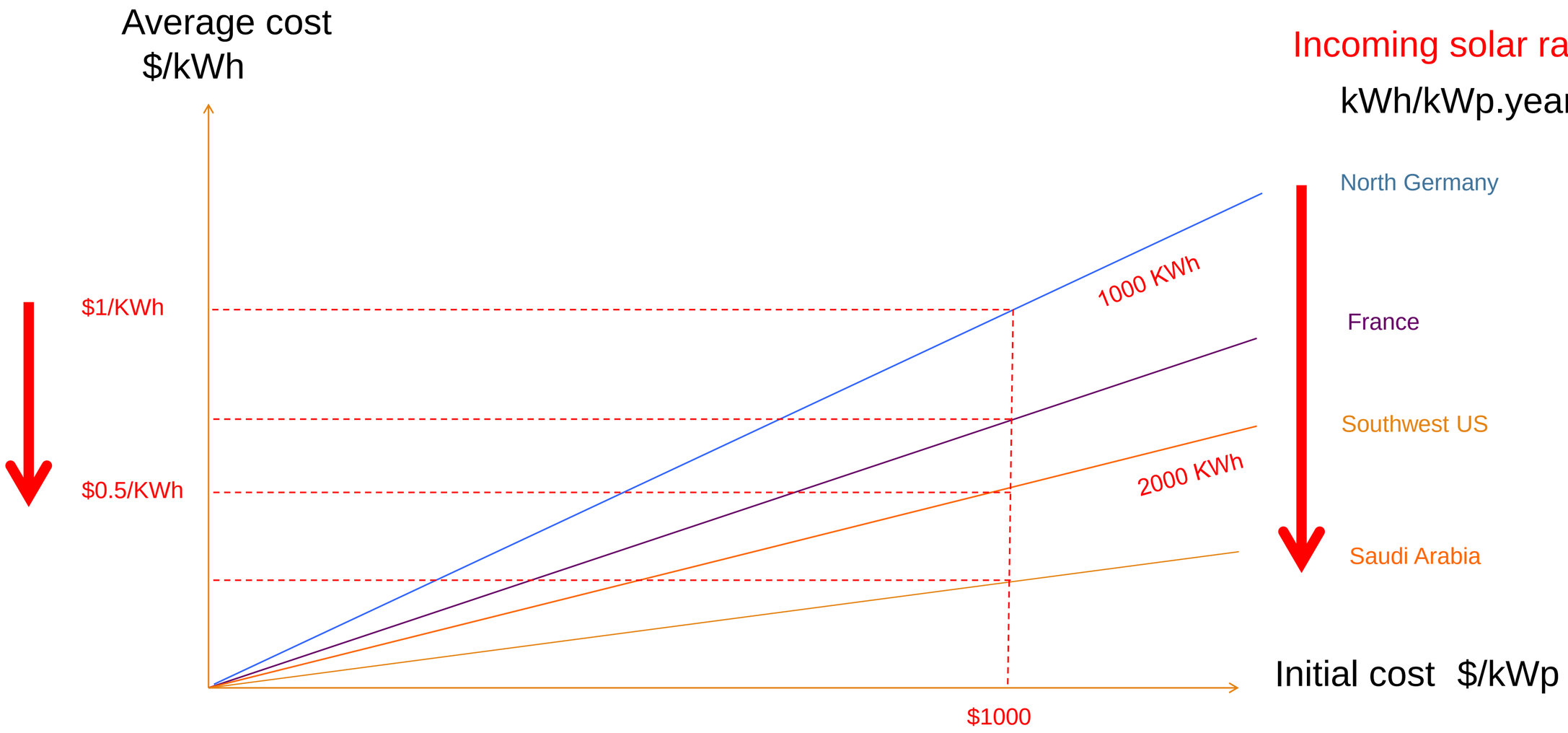


*Assumes a fixed equipment lifetime

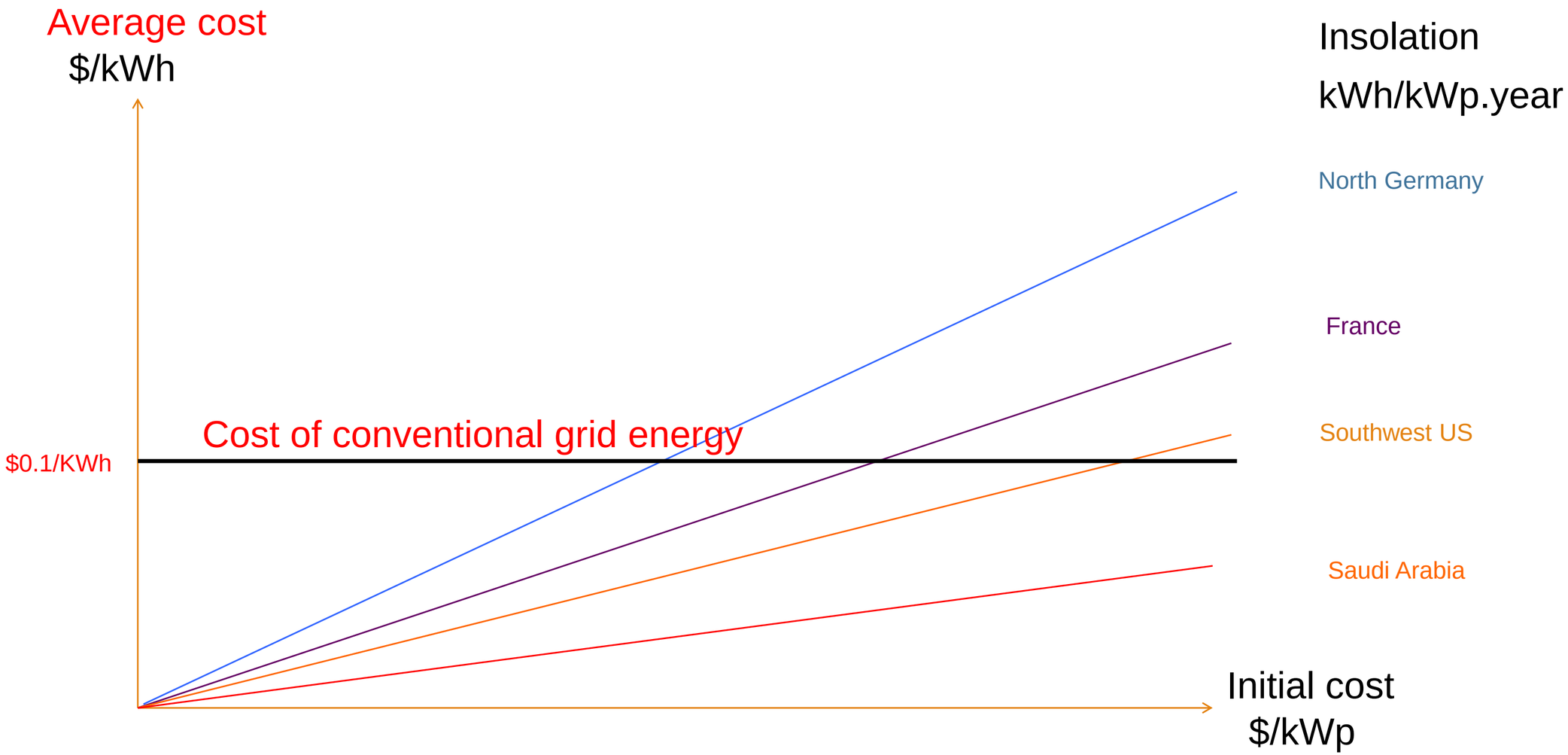
Impact of CAPEX reduction



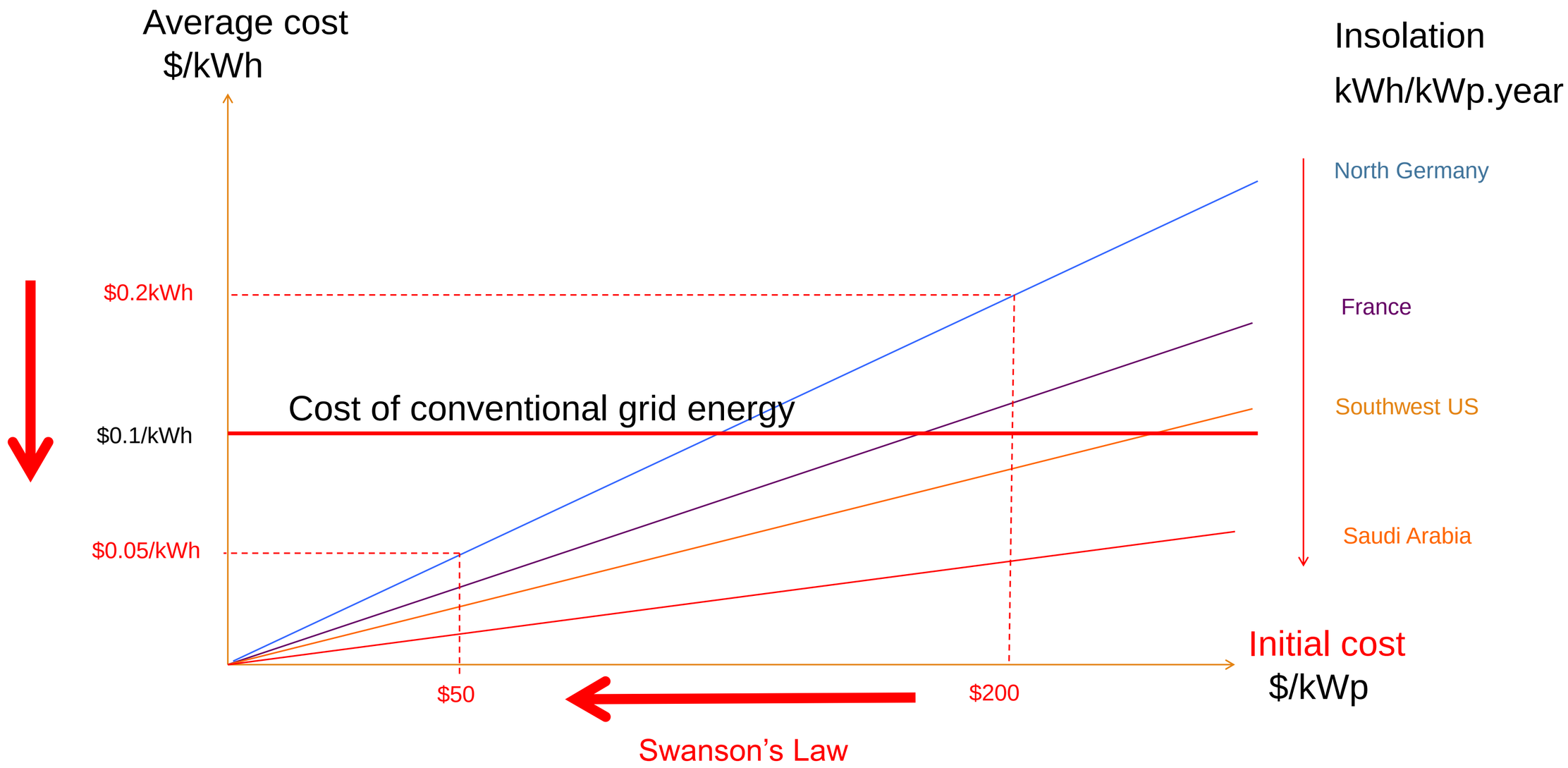
Impact of geography



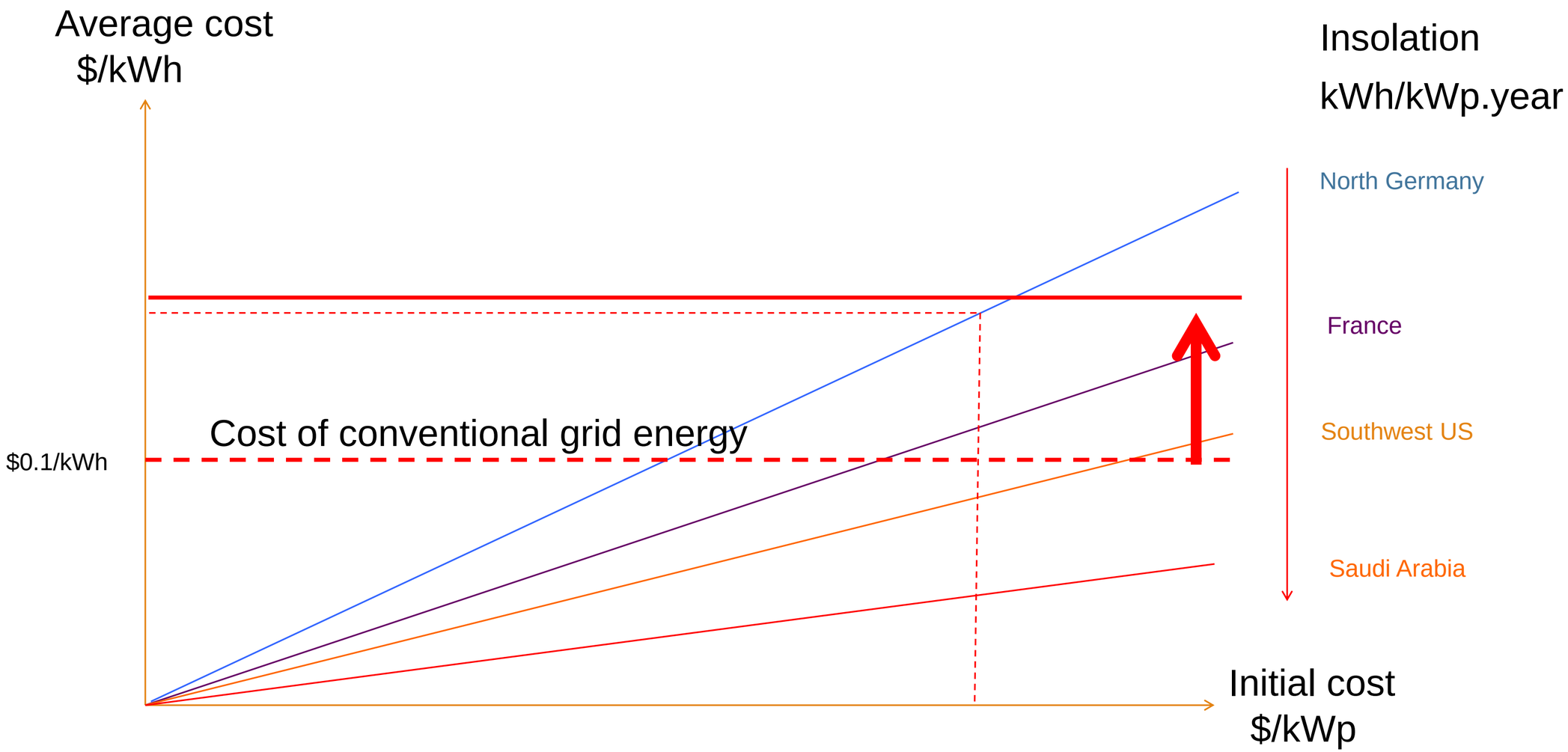
Compare to conventional



CAPEX trend


Average cost
$/kWh
Insolation
kWh/kWp.year
North Germany
France
Southwest US
Saudi Arabia
$0.2kWh
$0.1/kWh
$0.05/kWh
Cost of conventional grid energy
$50
$200
Initial cost
$/kWp
Swanson's Law

Conventional energy trend



Solar wins! Everywhere!

The solar revolution …

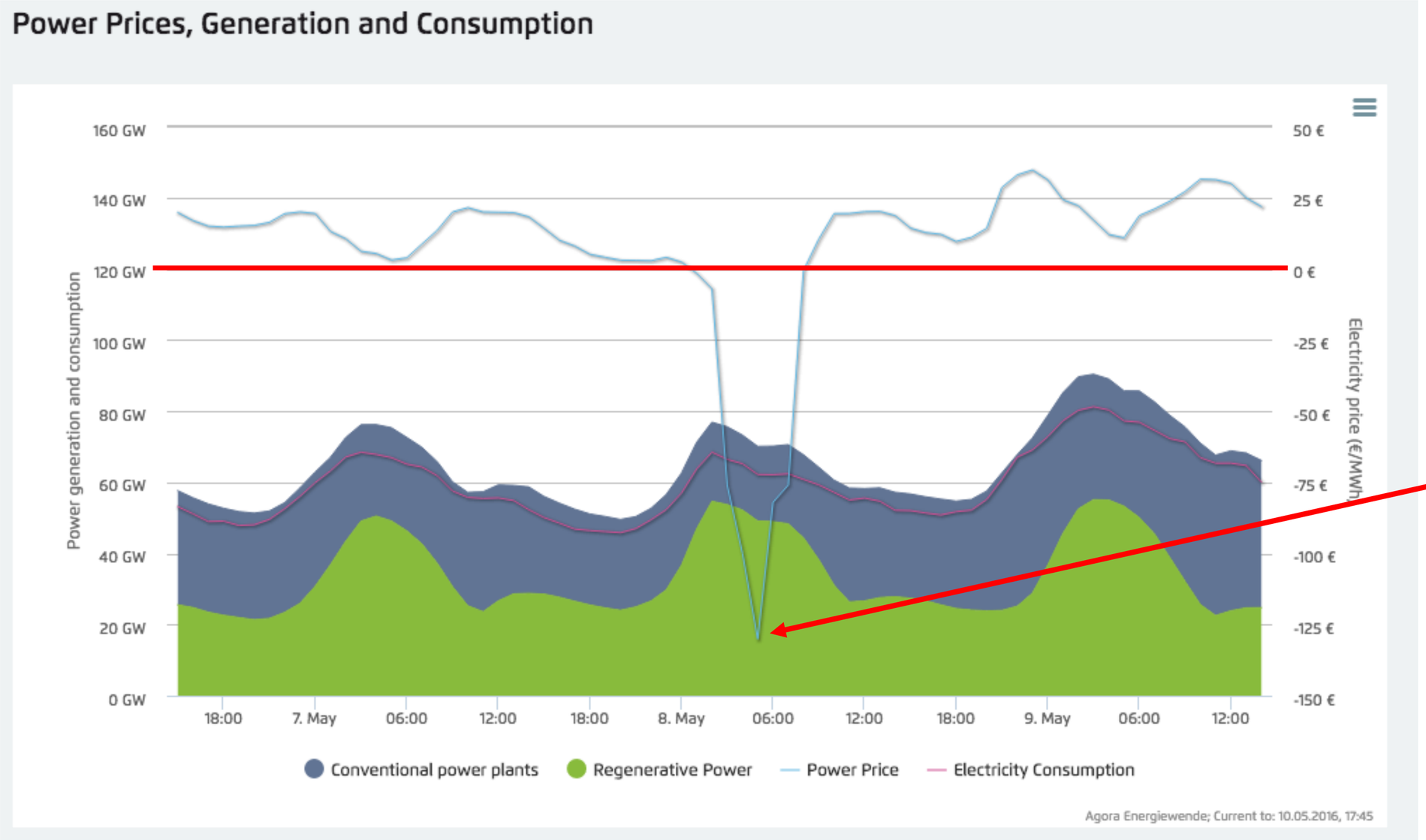
… will be led by the accountants

Unfortunately…

Problem 1: No sun at night…

Solution: use solar by day and grid by night

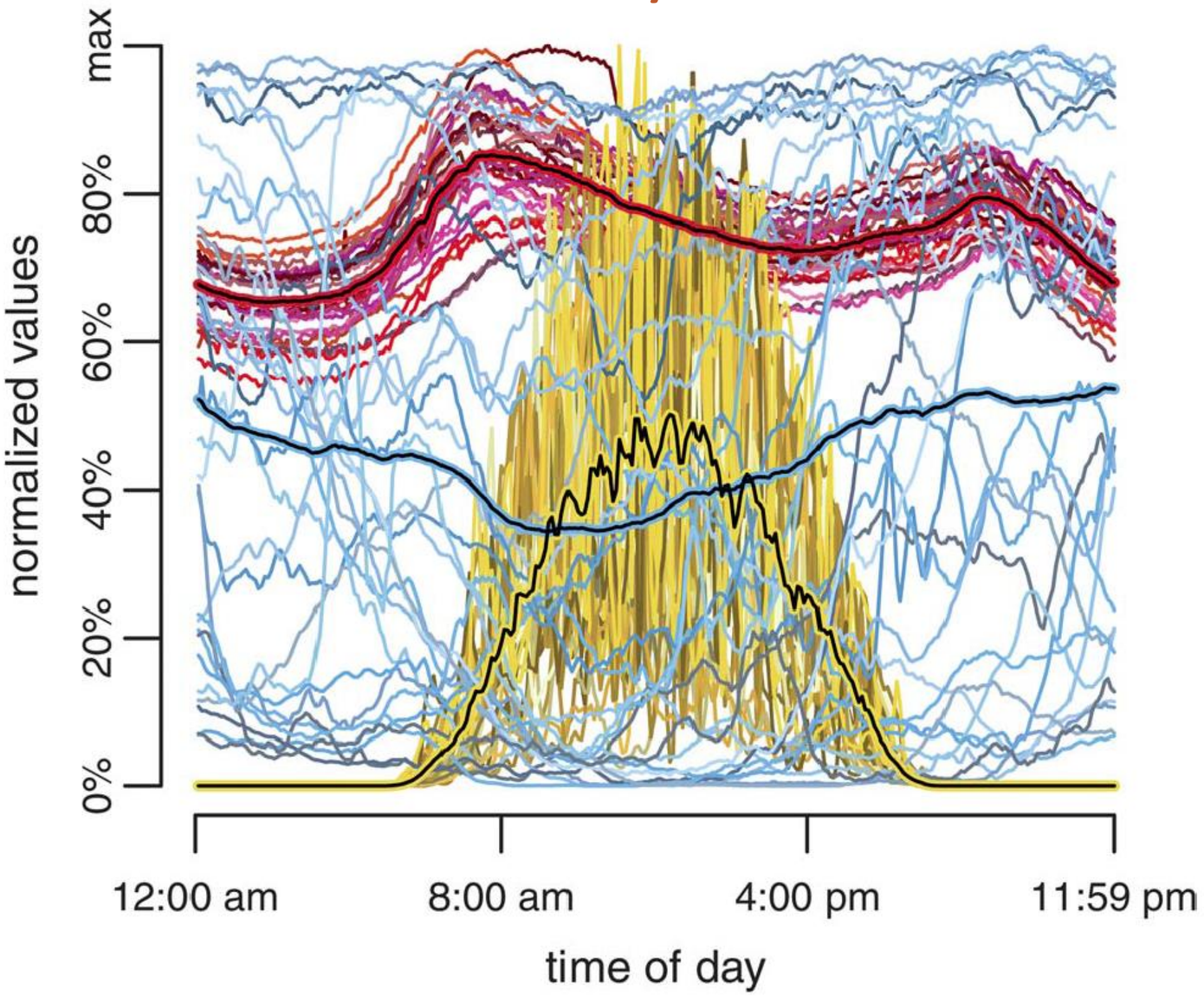
Problem 2: excess solar generation



8 May 2016, Germany (from Agora Energiewende)

Solution: use ‘free energy’ for something

Problem 3: Variability



Barnhart *et al*, Proc. Energy and Environment, 6:2804, 2013

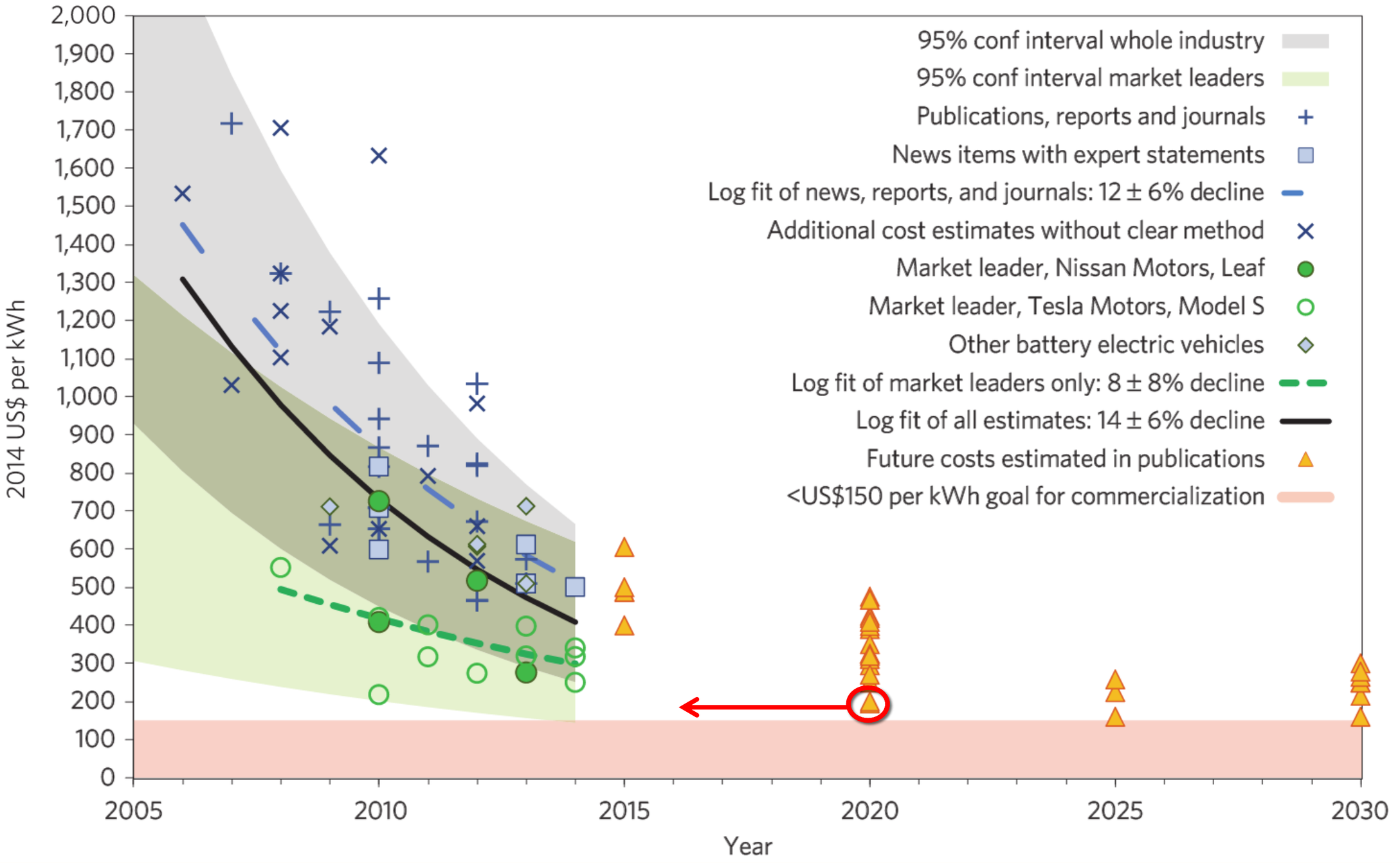
Solution: storage

Storage decouples supply and demand

Storage is hot…

Global investment in energy storage technologies to reach $122 Billion by 2021

Source: Pike Research

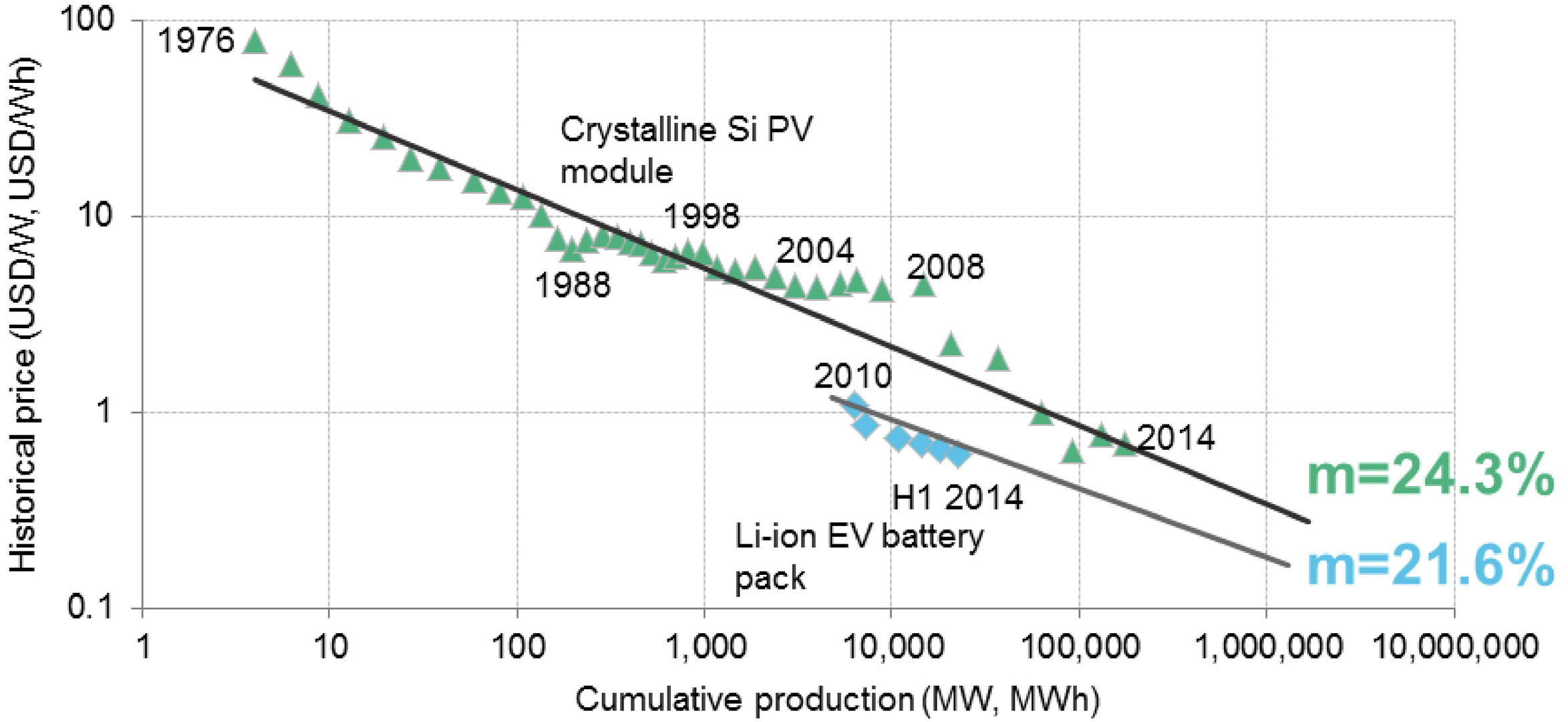


Tesla/Panasonic and GM/LG Chem battery costs are already (in 2016) down to the lowest projections for 2020!

Nature Climate Change: 2014

LITHIUM-ION EV BATTERY EXPERIENCE CURVE COMPARED WITH SOLAR PV EXPERIENCE CURVE

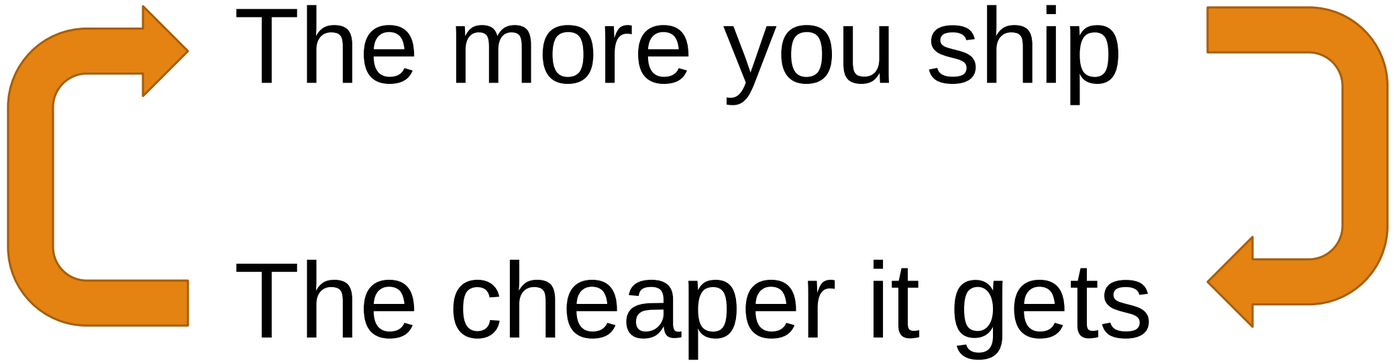
Bloomberg NEW ENERGY FINANCE



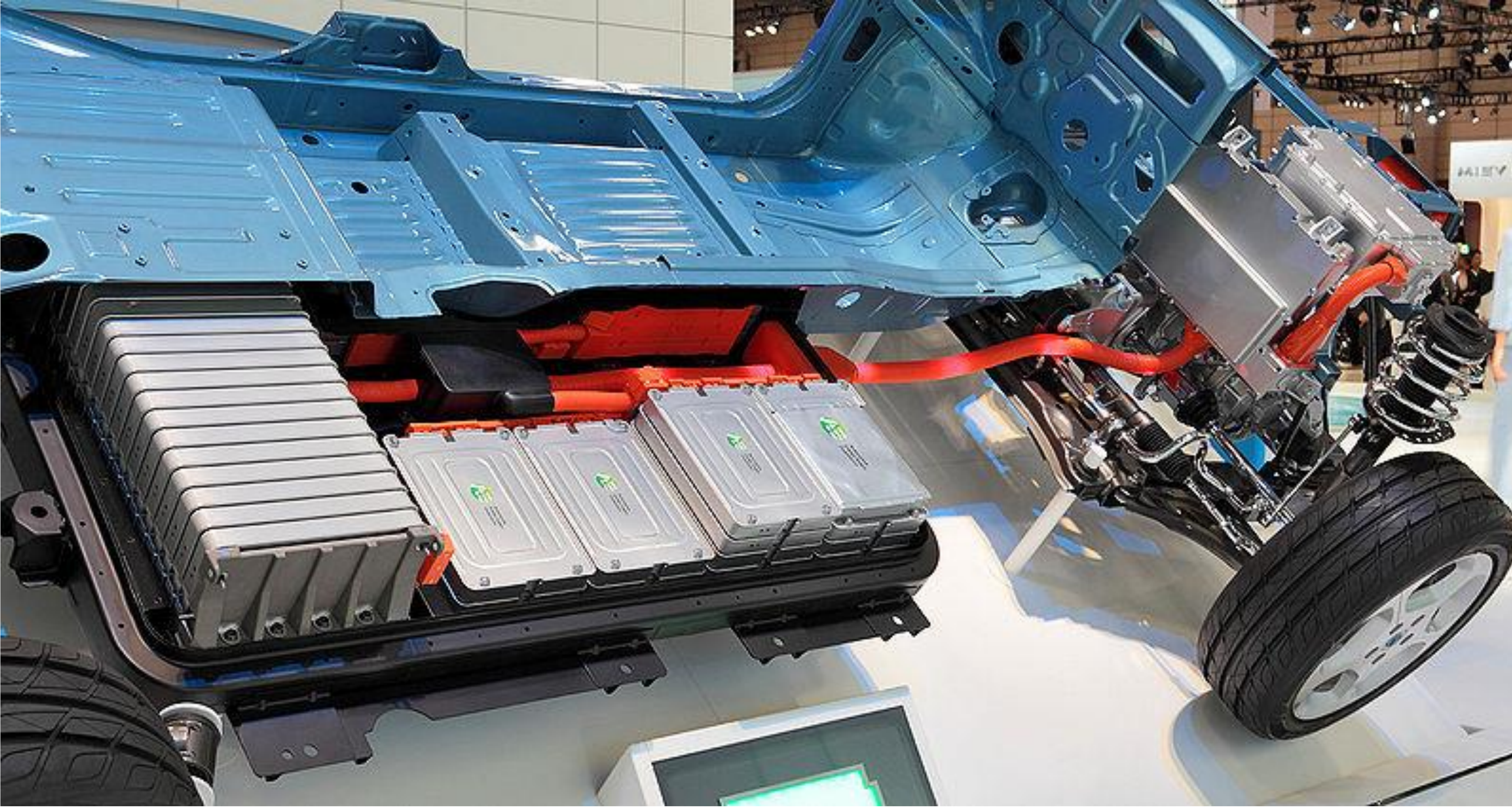
Note: Prices are in real (2014) USD.

Source: Bloomberg New Energy Finance, Maycock, Battery University, MIT

Positive feedback loop



Why?



Nissan Leaf chassis

Tesla gigafactory

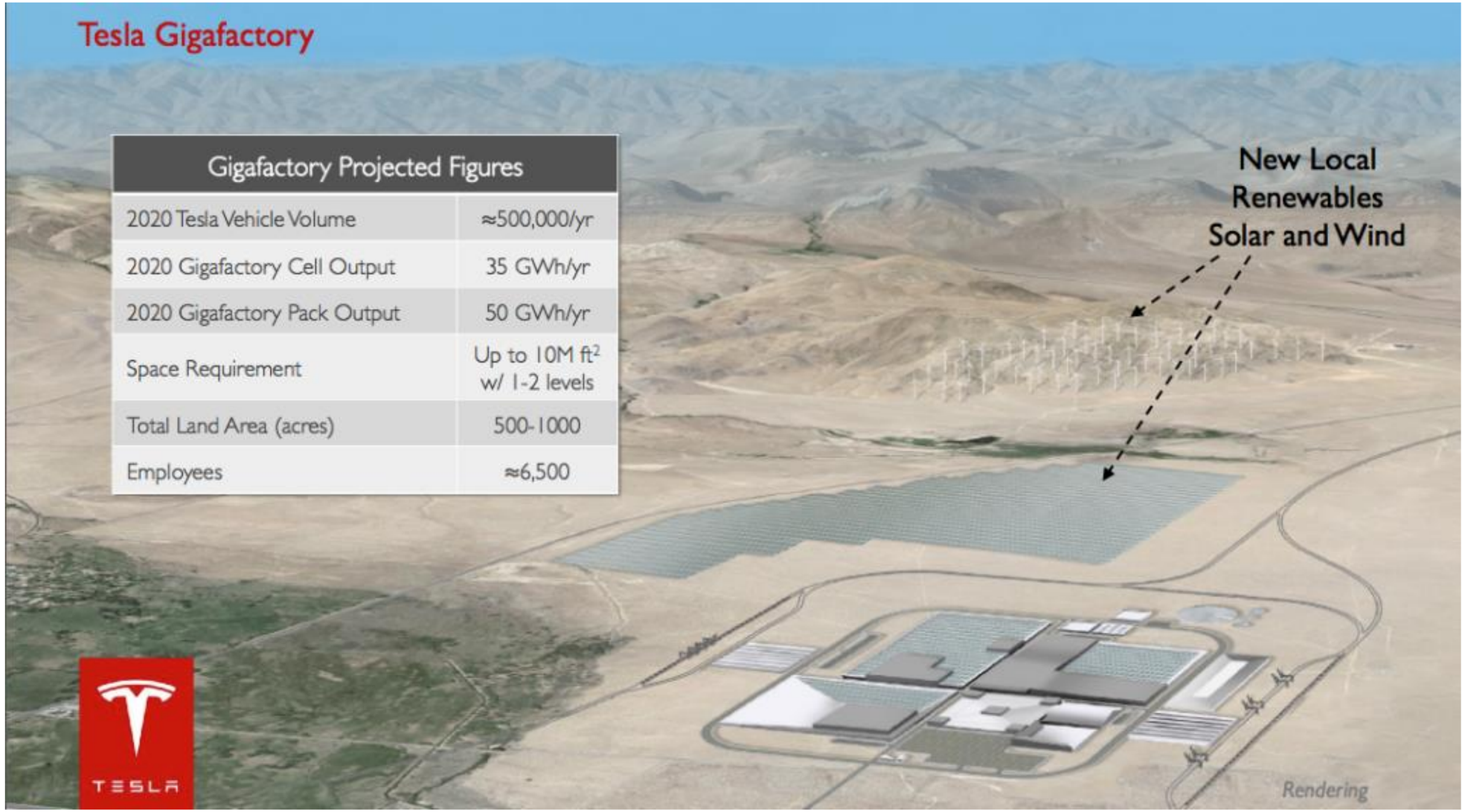
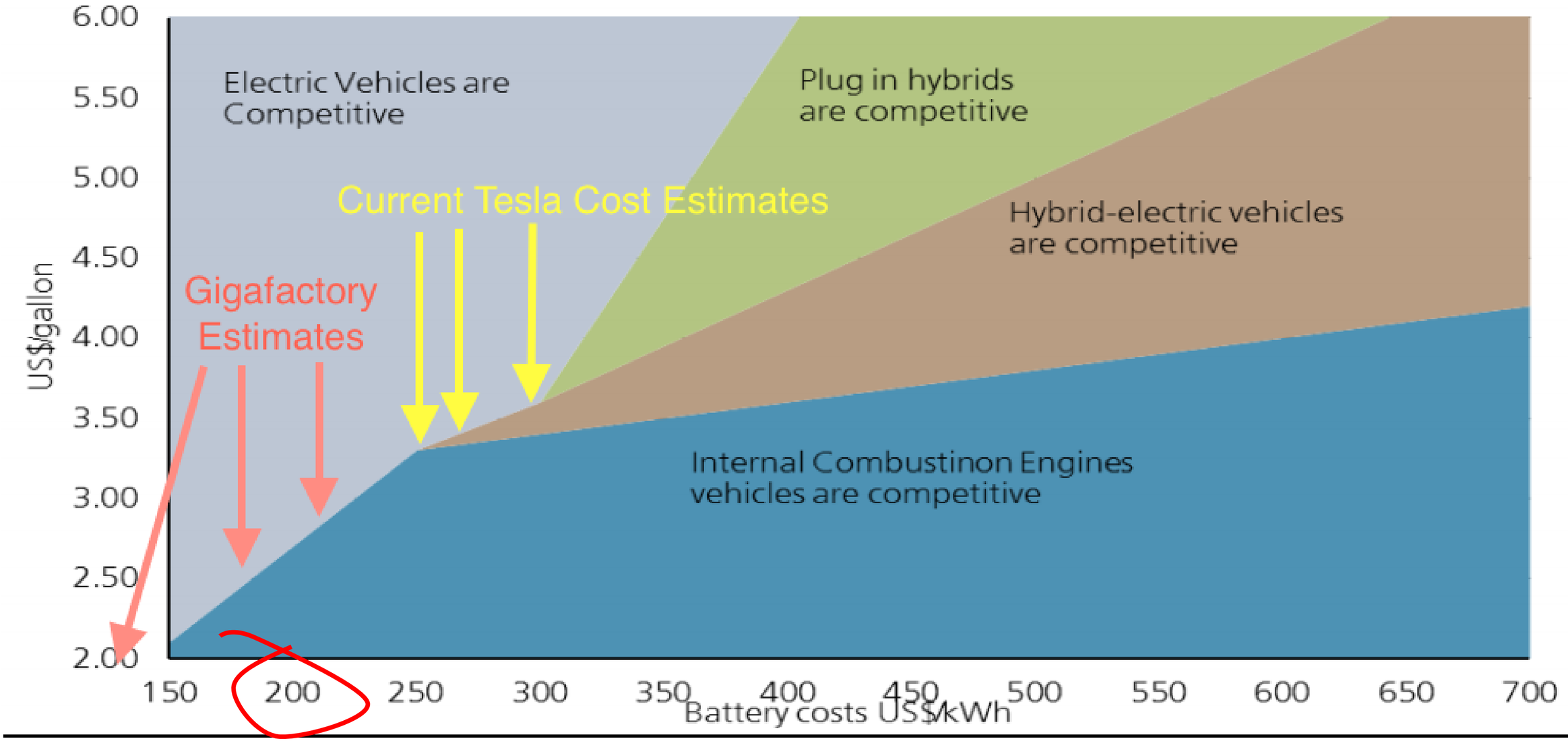
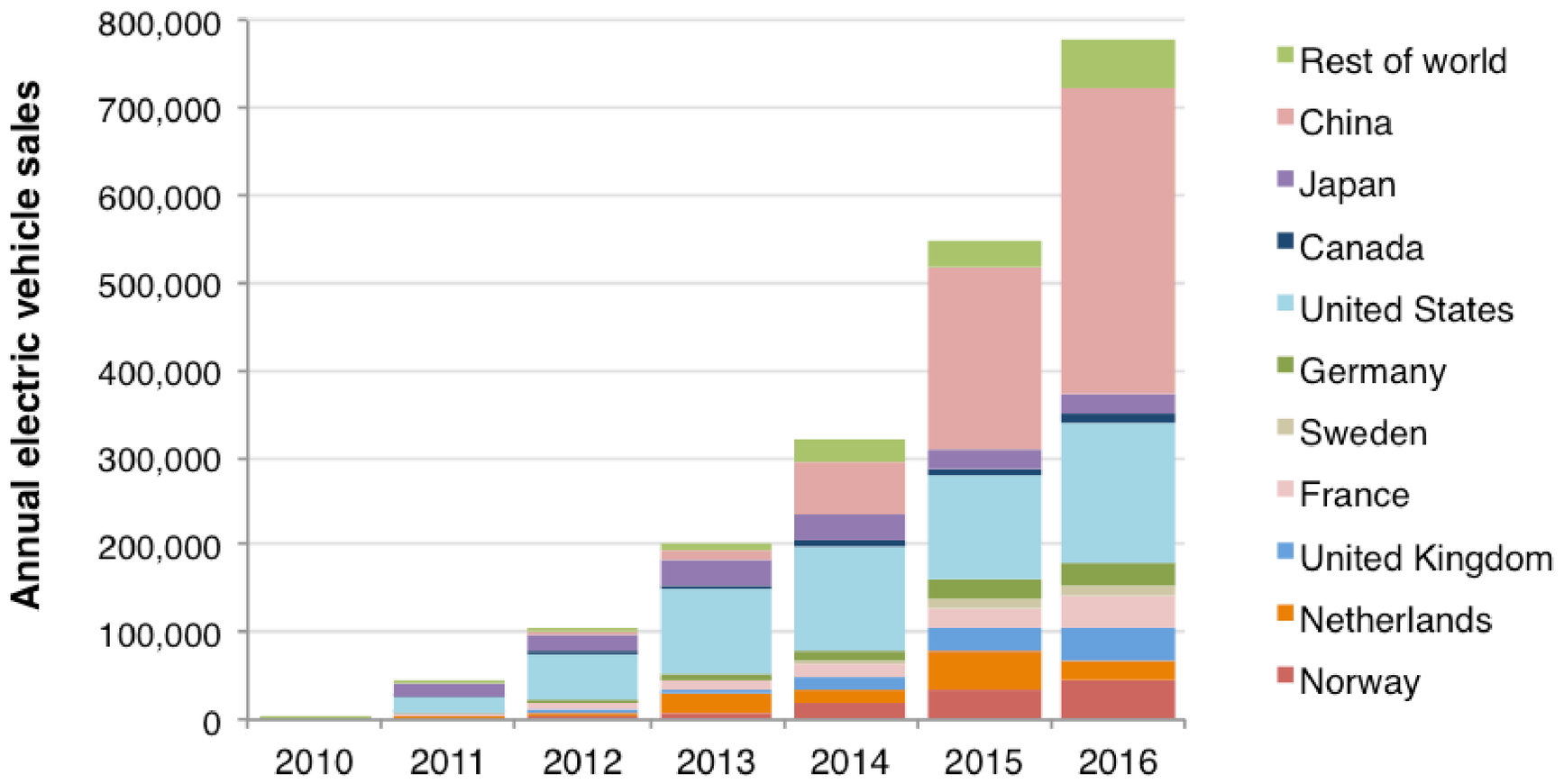


Figure 22: EV, H/EV and PHEV competitiveness versus ICE



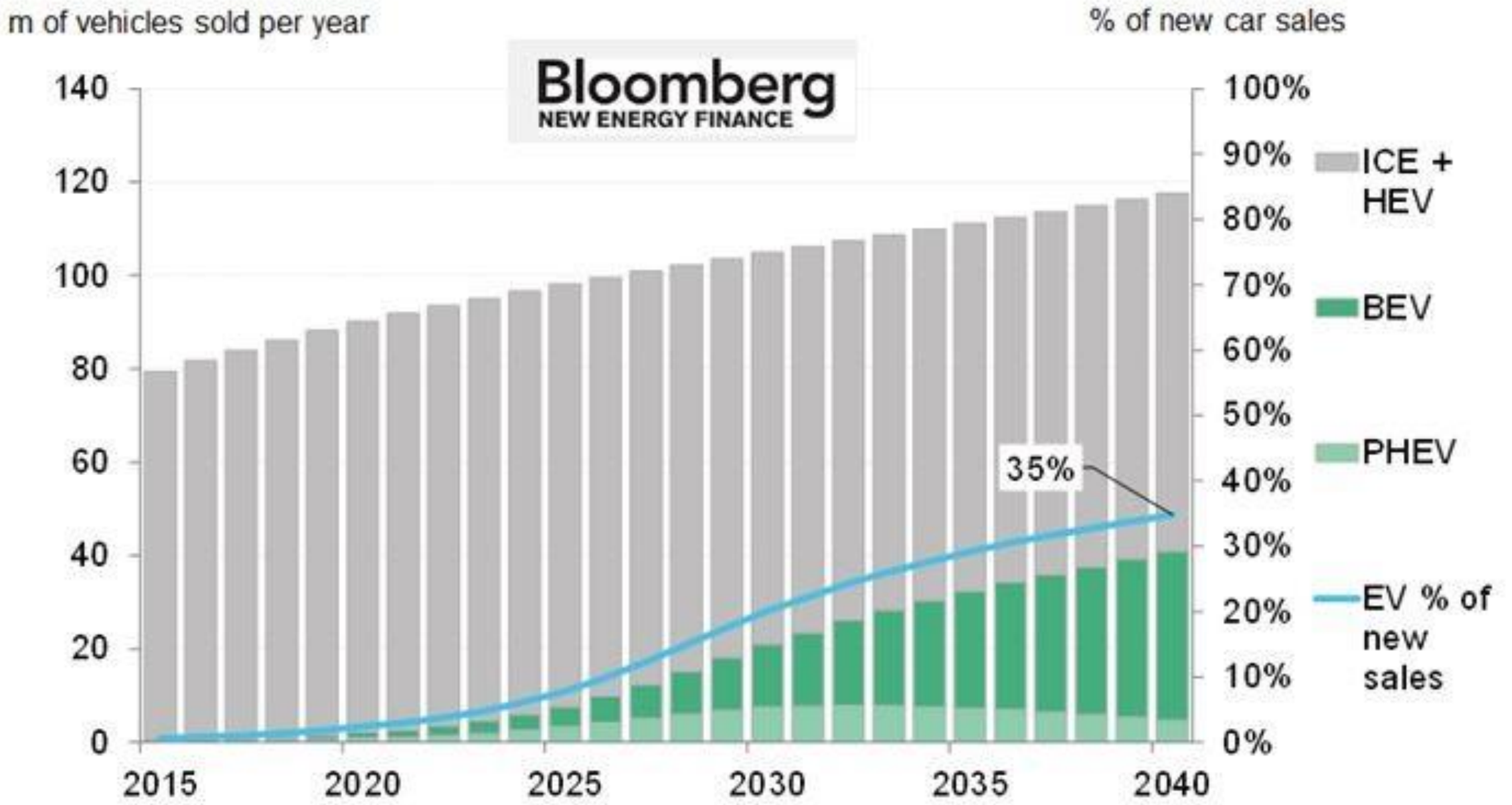
Source: McKinsey, EIA

Annual EV sales

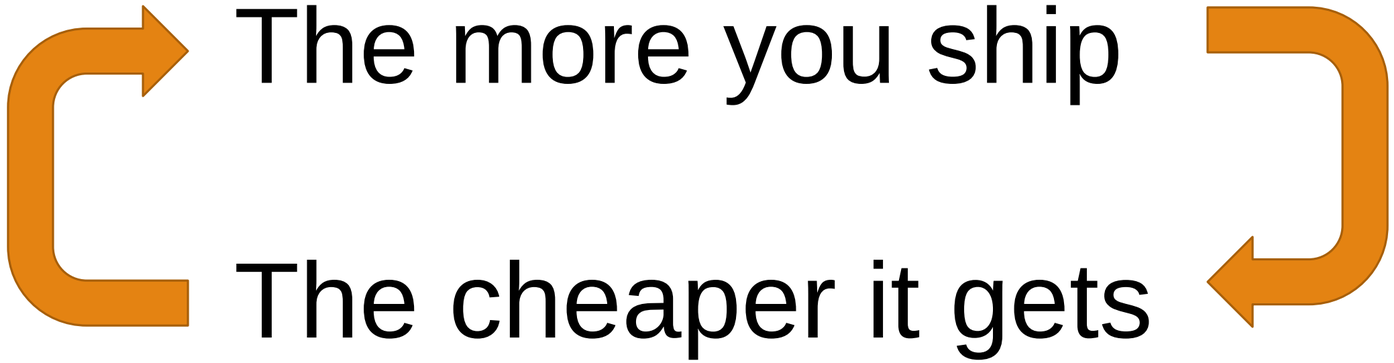


*Includes Battery as well as Hybrid Electric Vehicles

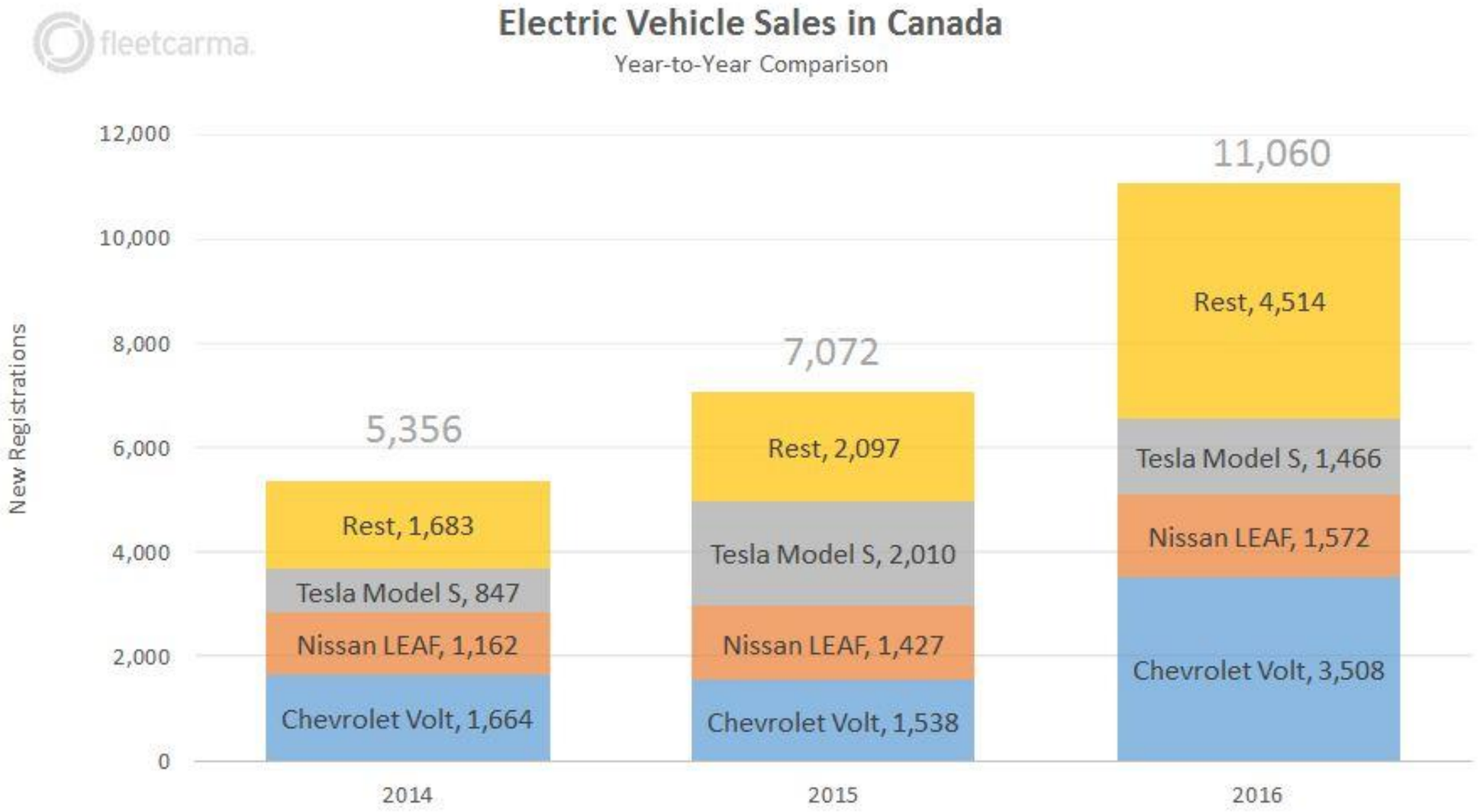
Source: EvSales.blogspot.com


m of vehicles sold per year
% of new car sales
Bloomberg
NEW ENERGY FINANCE
140
120
100
80
60
40
20
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2015
2020
2025
2030
2035
2040
35%
ICE + HEV
BEV
PHEV
EV % of new sales

Positive feedback loop



EVs in Canada

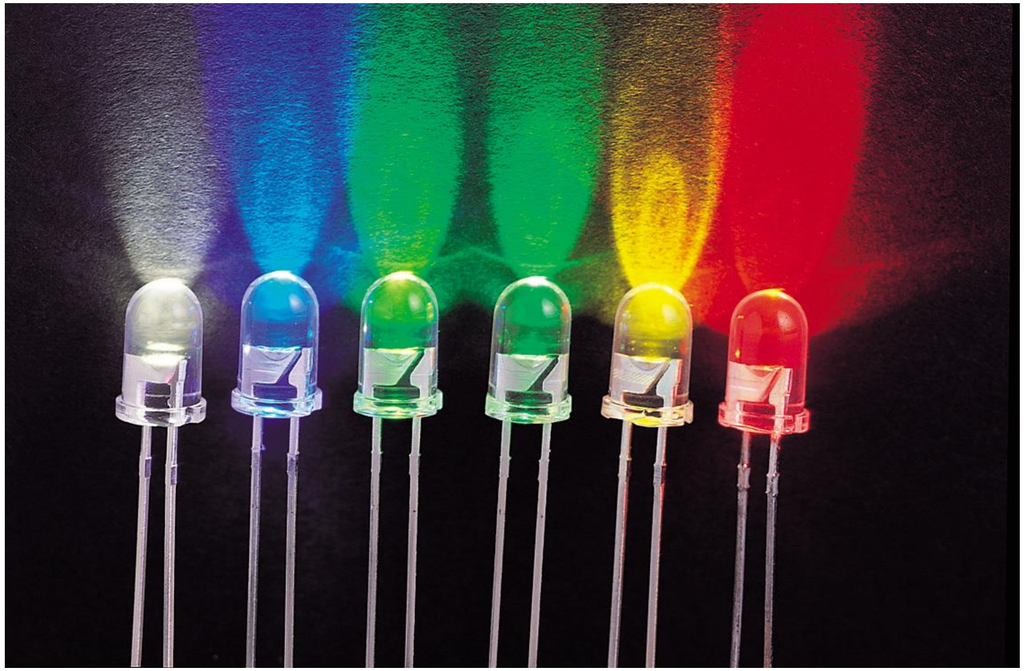


From Fleetcarma.com, Feb 2017

In other news…

Building lighting accounts for 30% of building electricity use

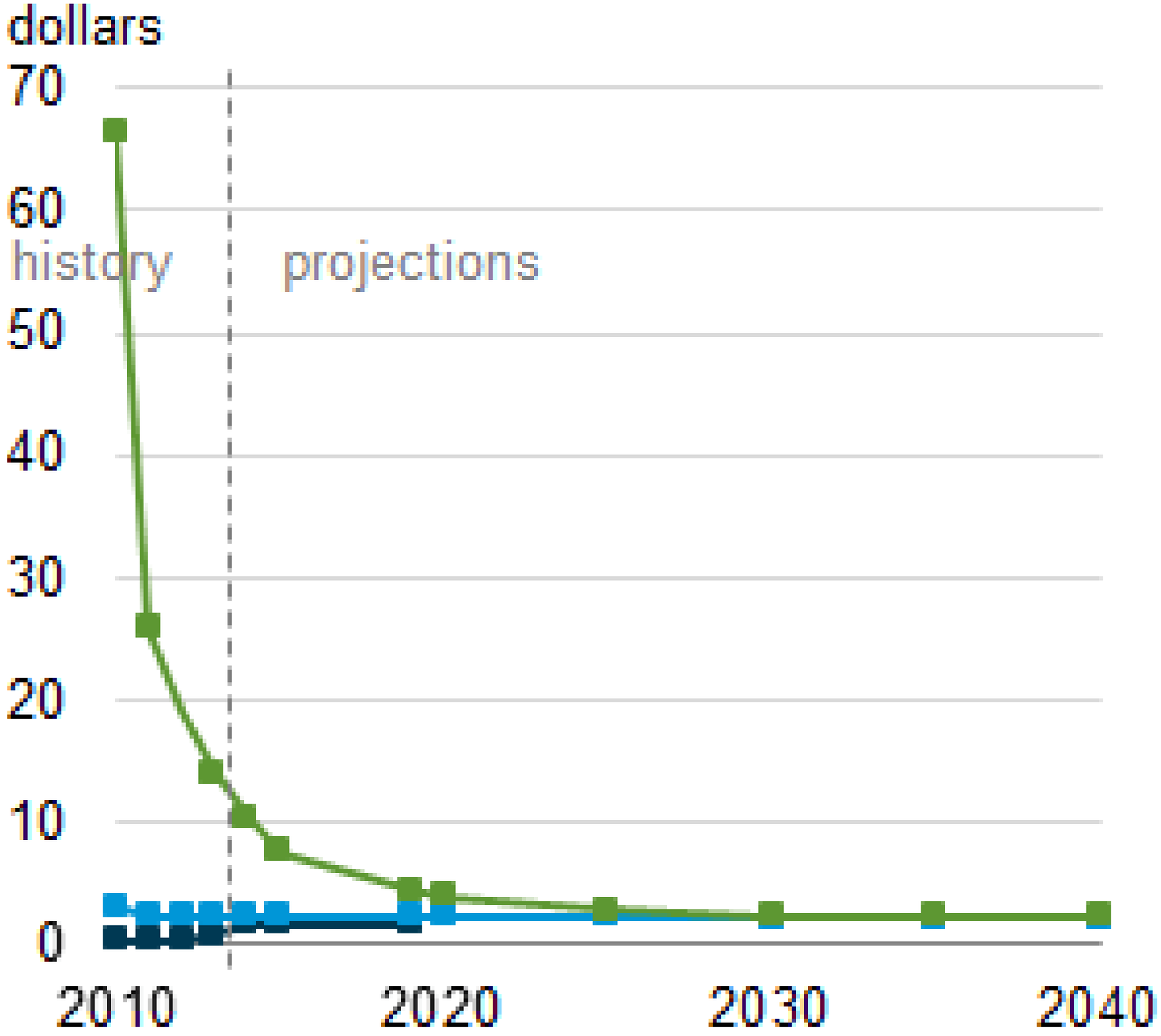
Cost: $230 Billion/year



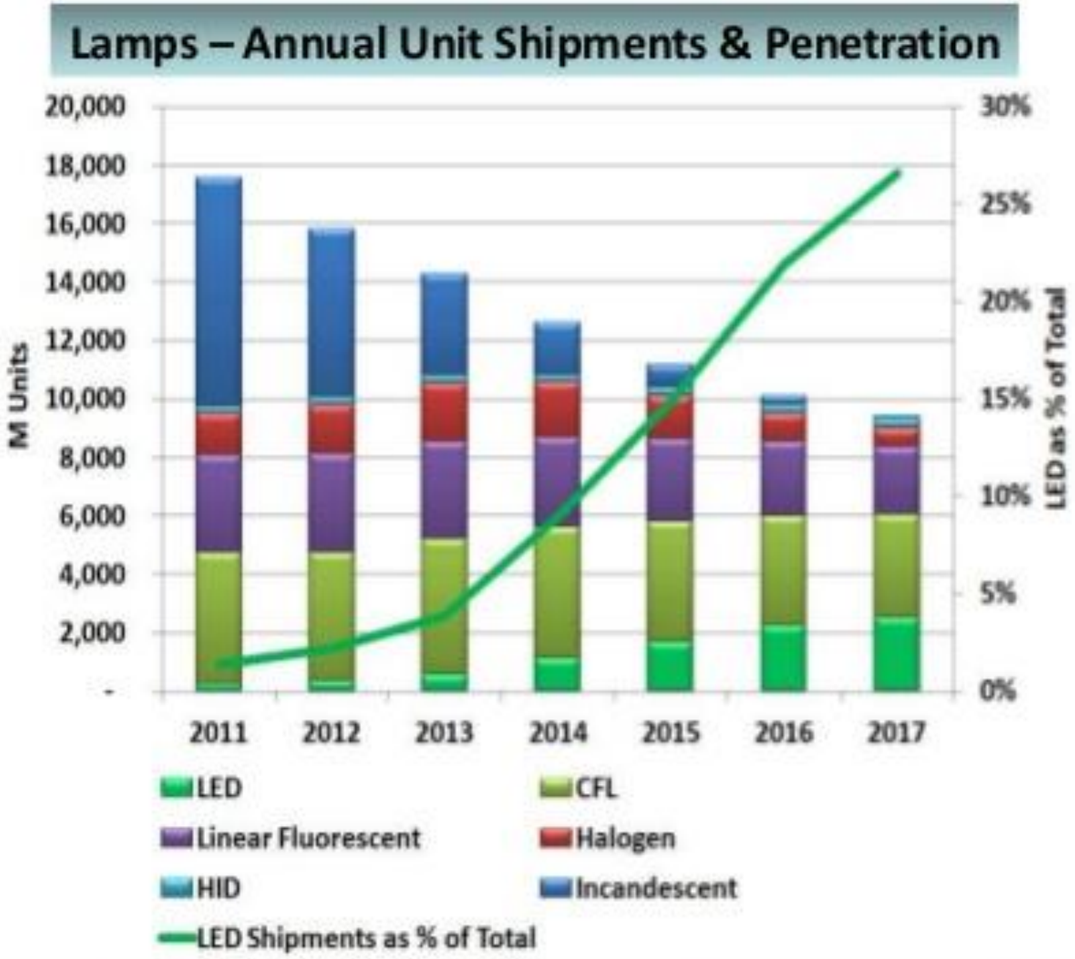
Incandescent : CFL : LED

10 : 2 : 1

LED cost projection



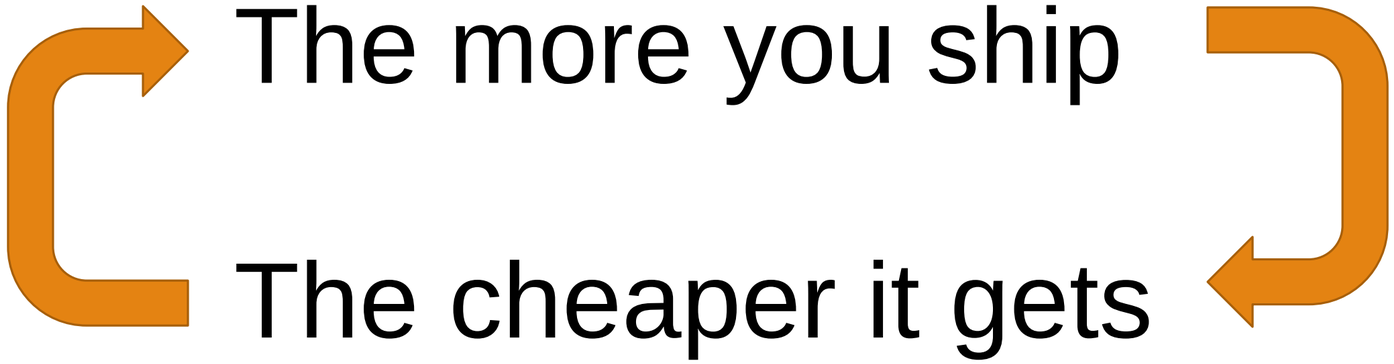
Global Lighting Market



- Annual shipments of 14B units – declining to 10B due to longer lifetime of LED Bulbs
- All lighting technologies flat, except incandescents that will decline
- LED experiencing explosive growth and capture 25% share by 2017

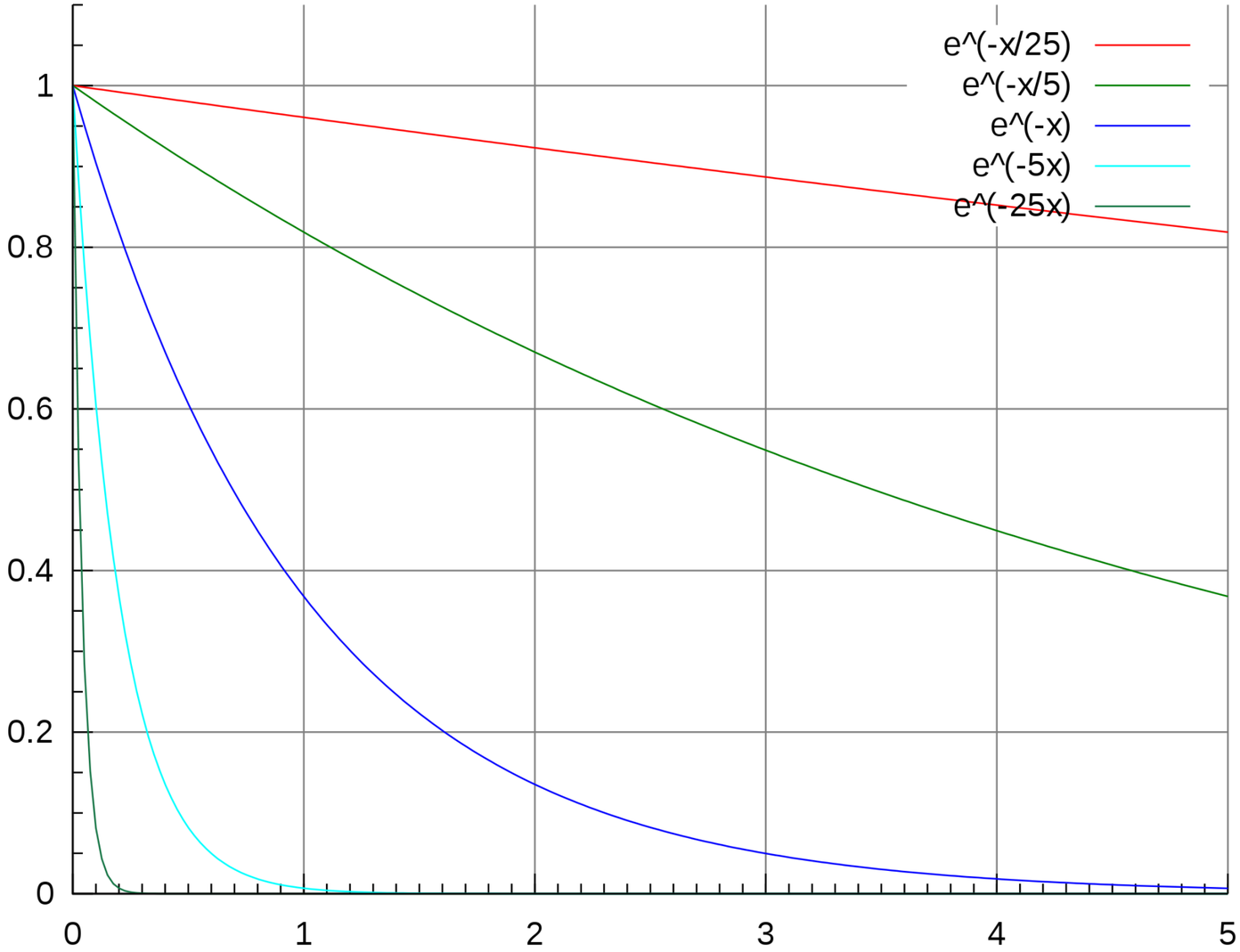
Source: Datapoint, Corporate Marketing

Positive feedback loop



To sum up...

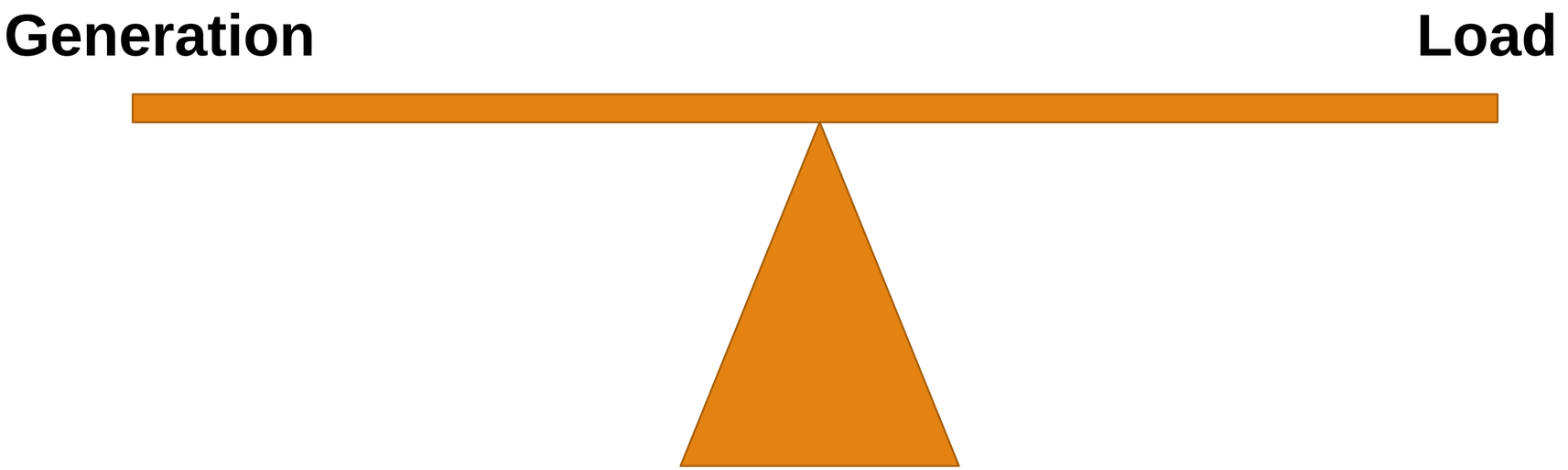
Solar, storage, and LEDs are all declining exponentially in price



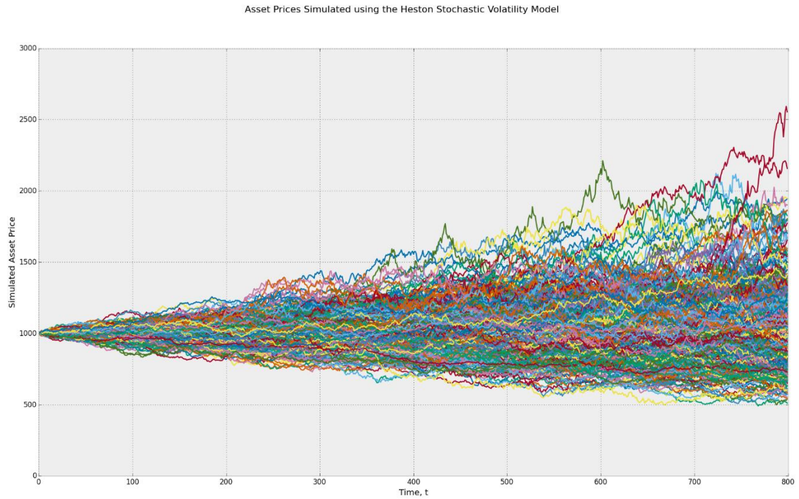
But something is missing…

Sensing and control

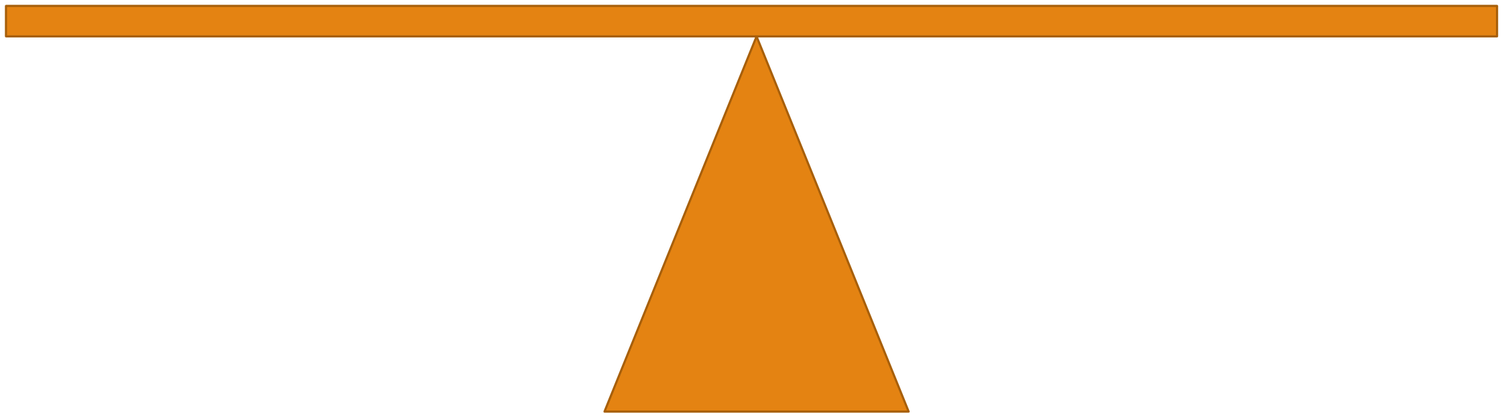
Why?



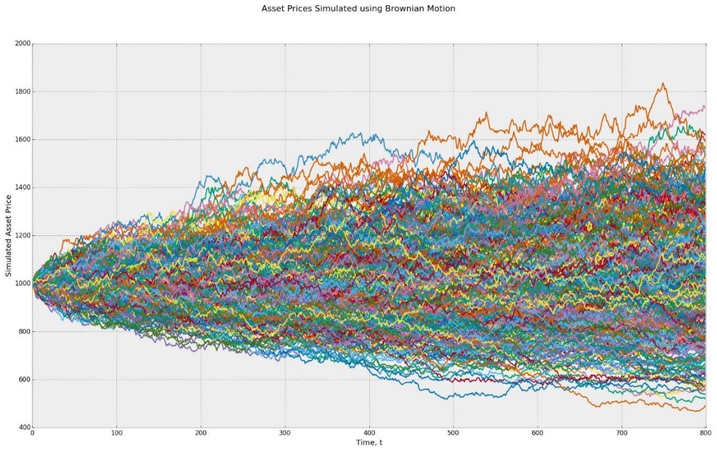
Conventional grid

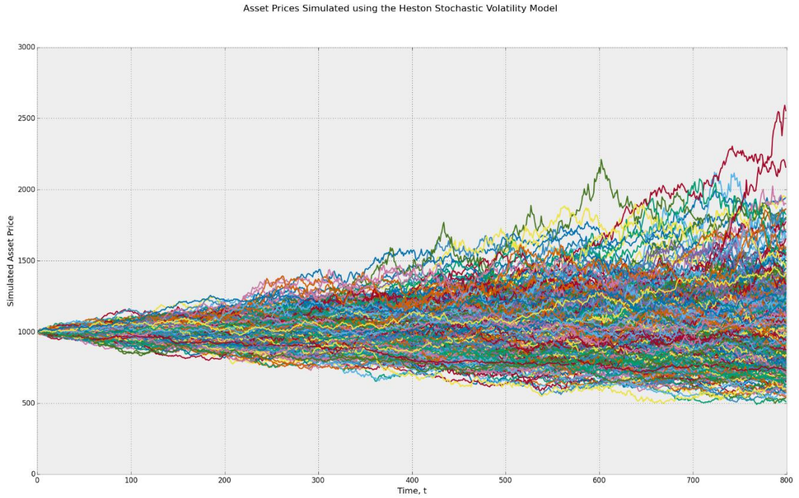


Generation **Load**

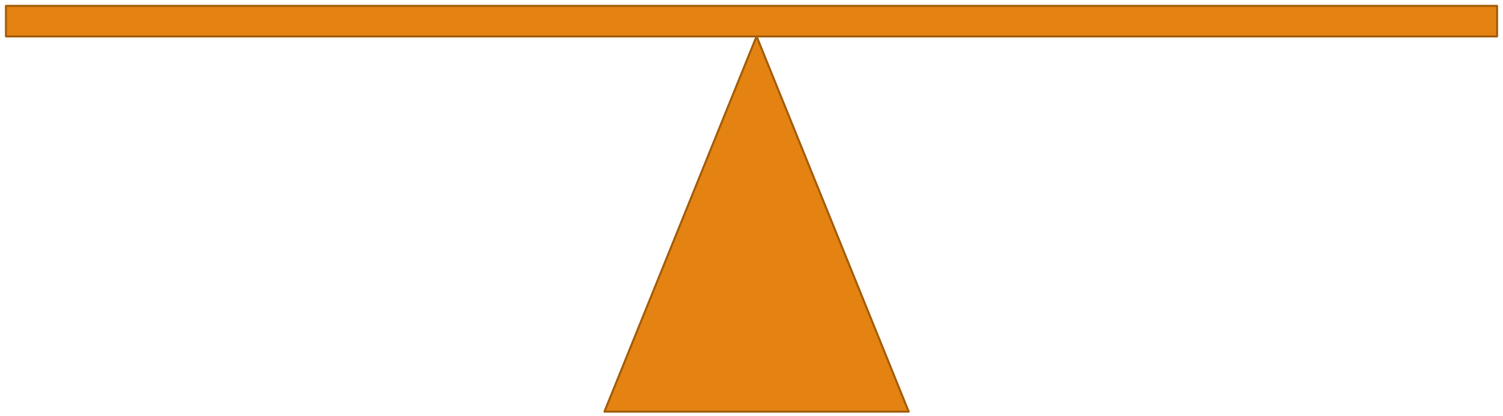


Future grid

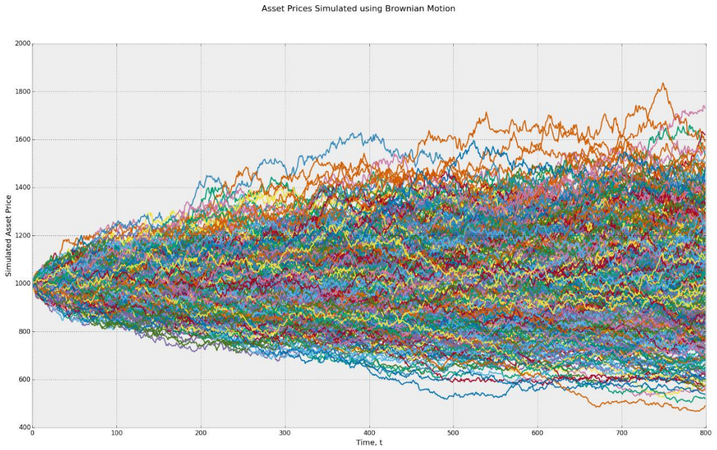


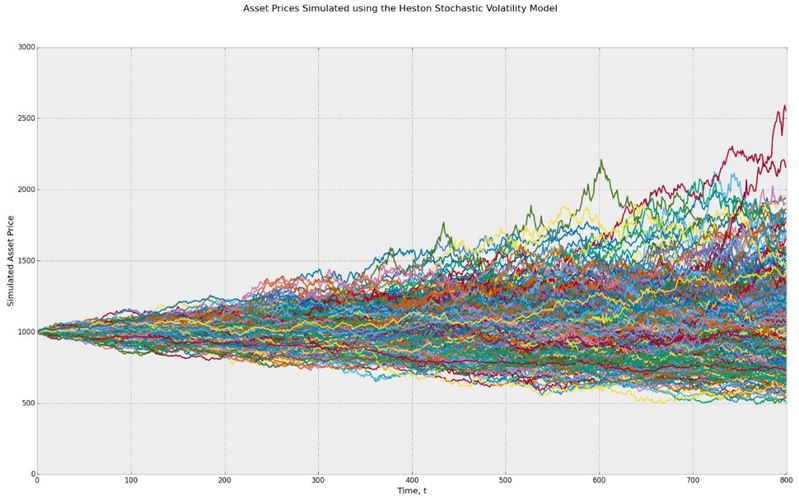


Generation **Load**



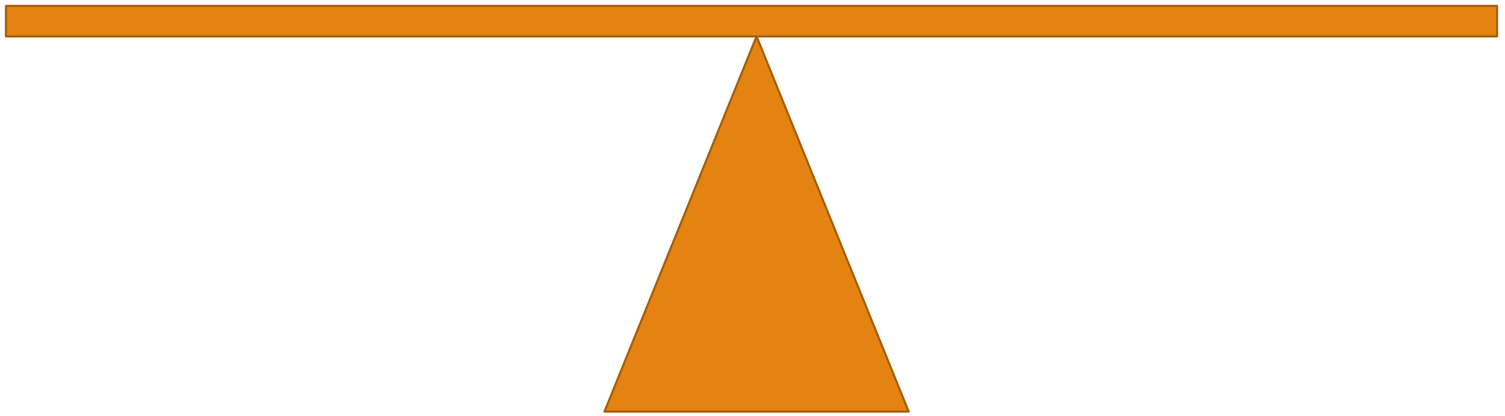
Future grid



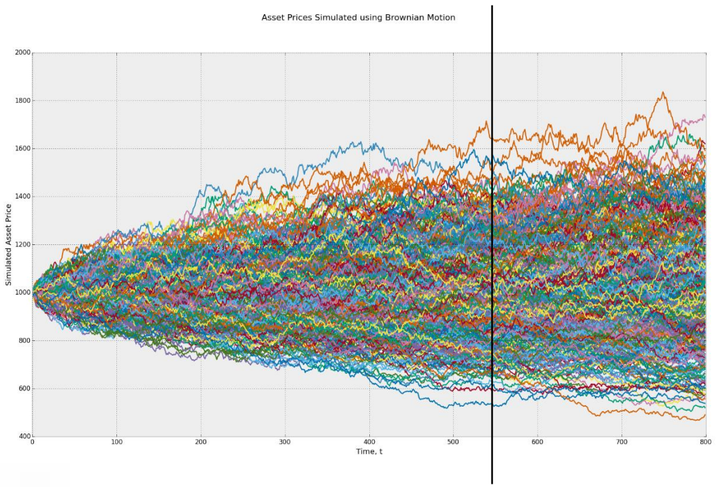


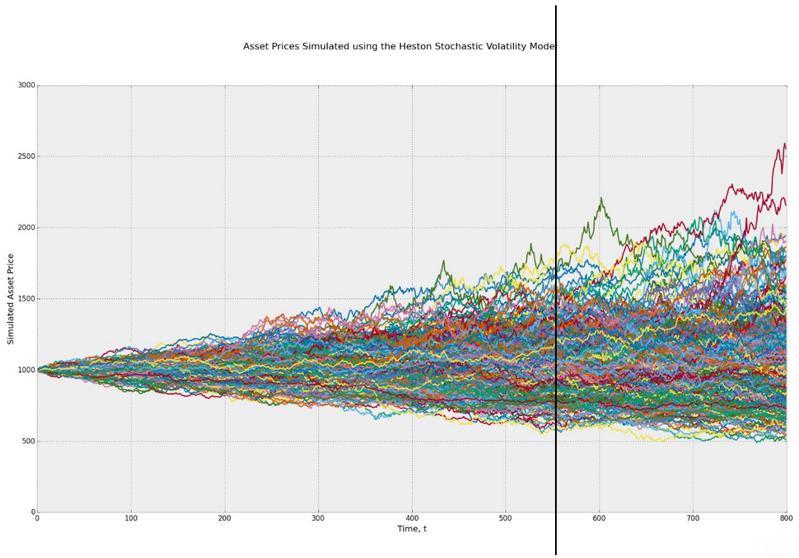
Generation

Load



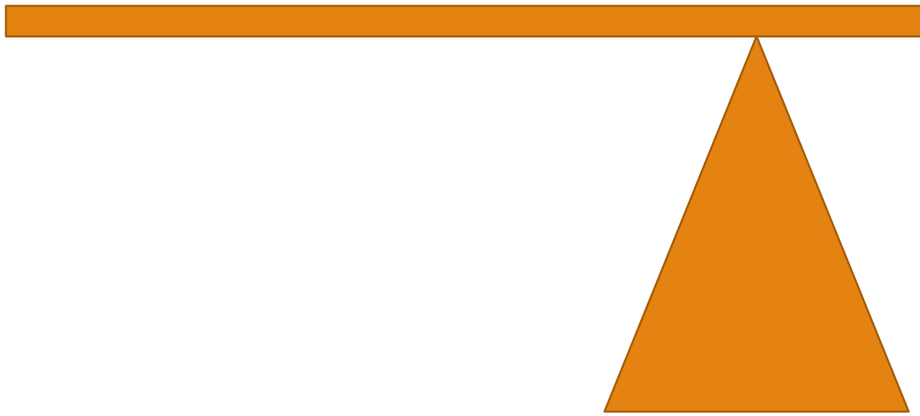
Need to forecast, monitor and control…





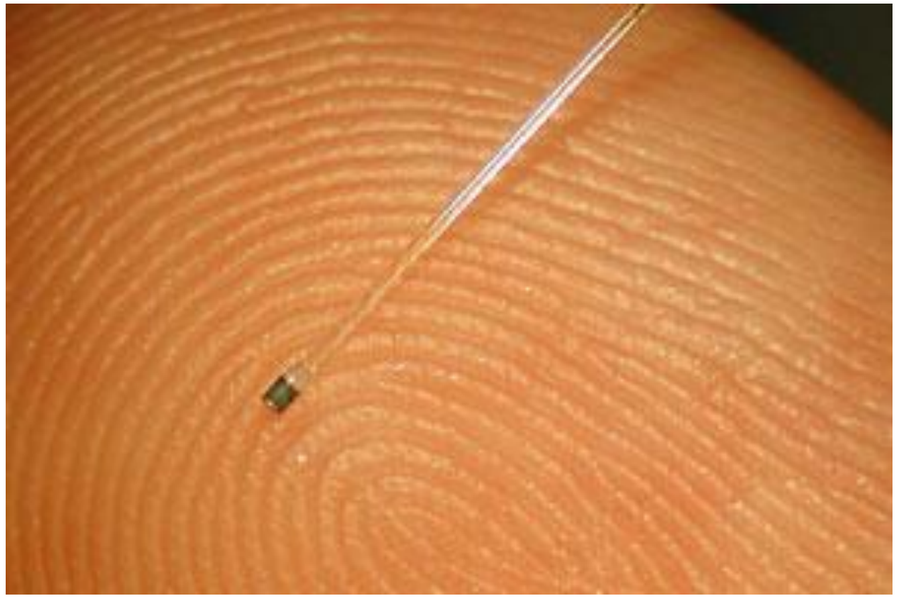
Generation

Load



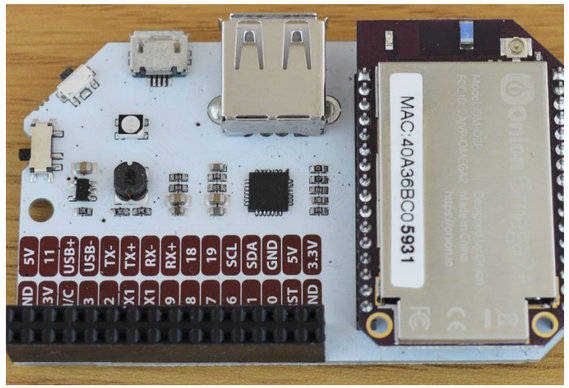
Internet of Things

Micro sensors



Pervasive communication

Pervasive control



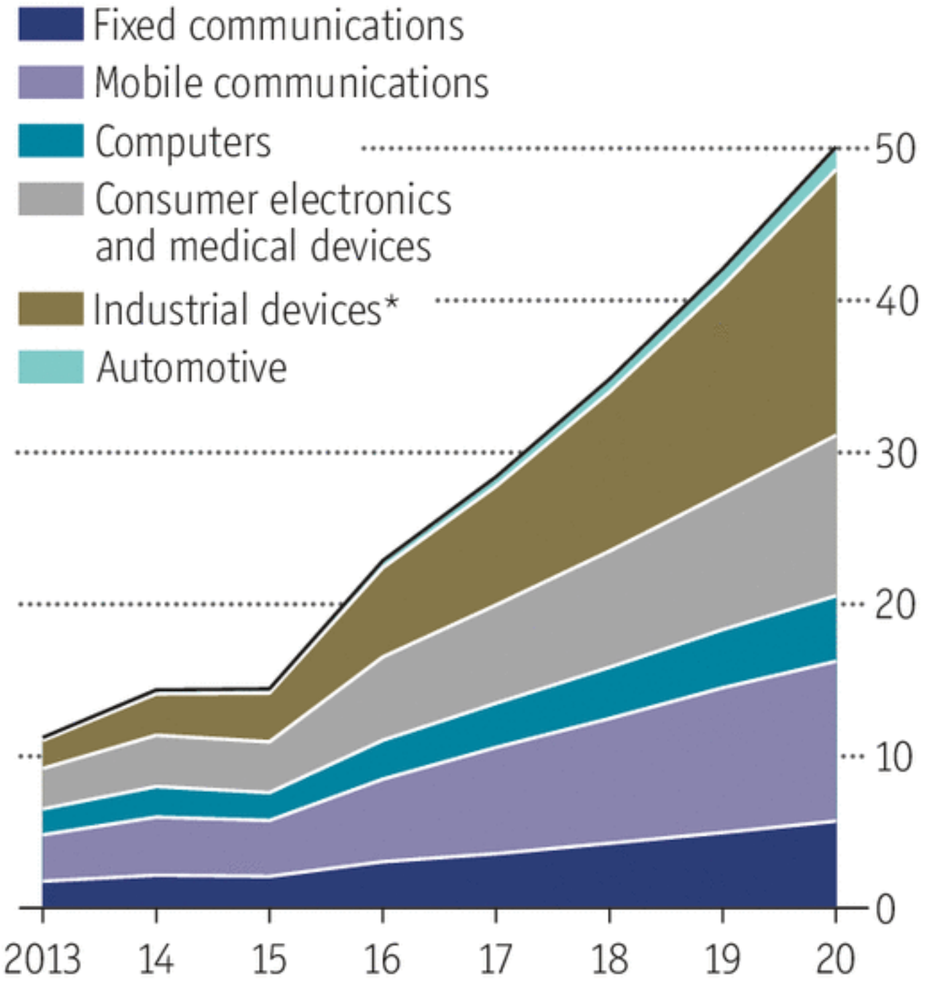
IoT allows pervasive communication, sensing, computation, control

Source: The Economist

The 50 billion question

5

Worldwide number of internet-connected devices, forecast, bn

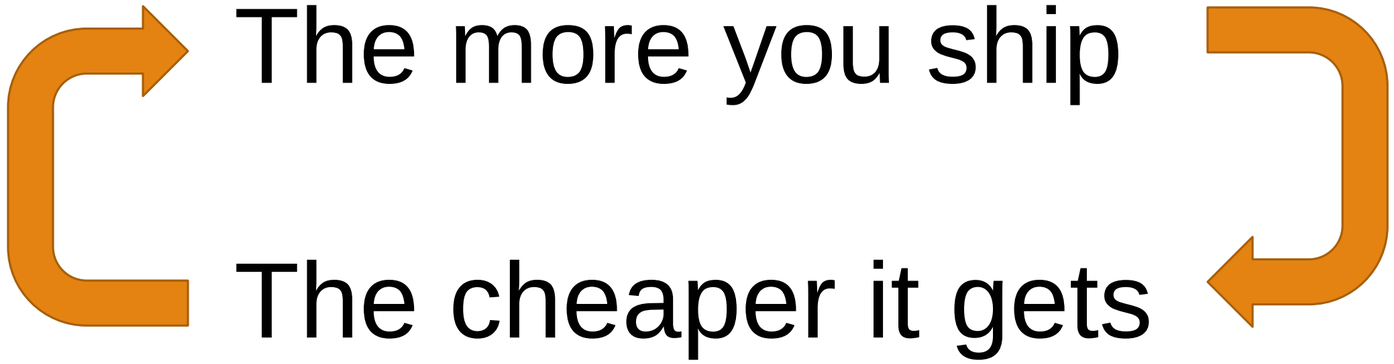


Source: Cisco

*Includes military and aerospace

Source: The Economist

Positive feedback loop

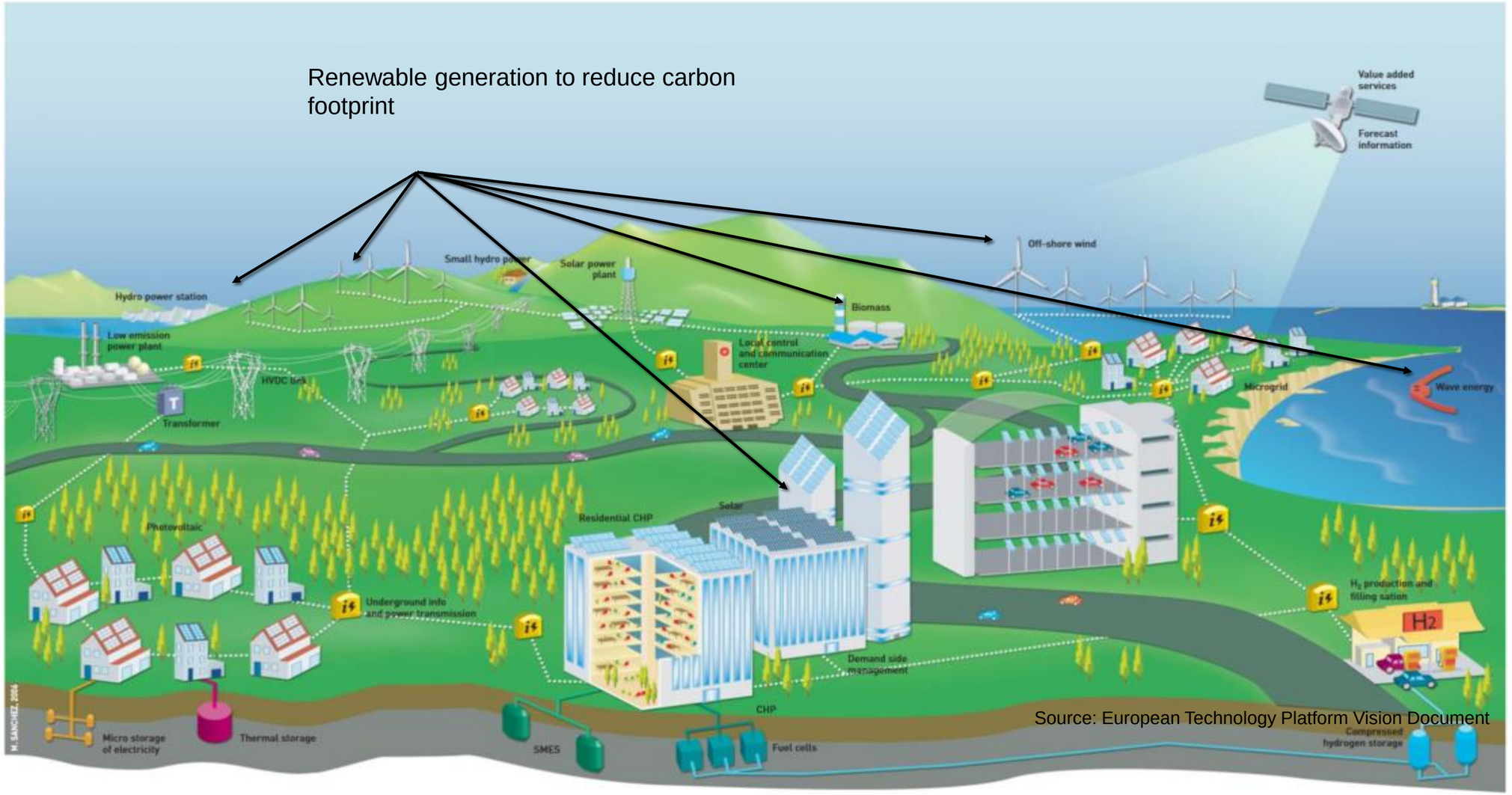


O wonder!
How many goodly creatures are there here!
How beauteous mankind is! O brave new world,
That has such people in't.

ACT V SCENE II, THE TEMPEST, W. SHAKESPEARE

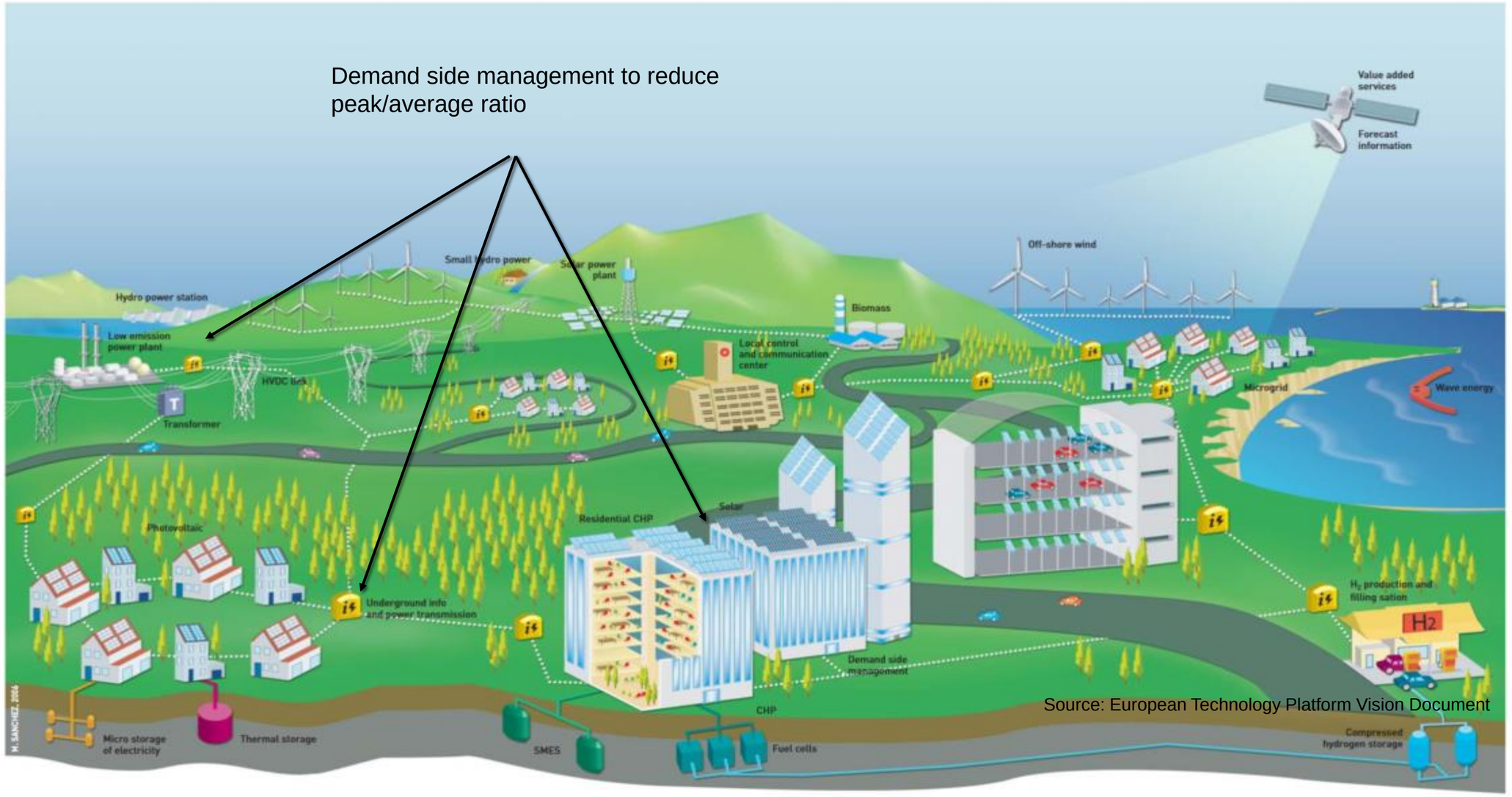
Source: European Technology Platform Vision Document

Renewable generation



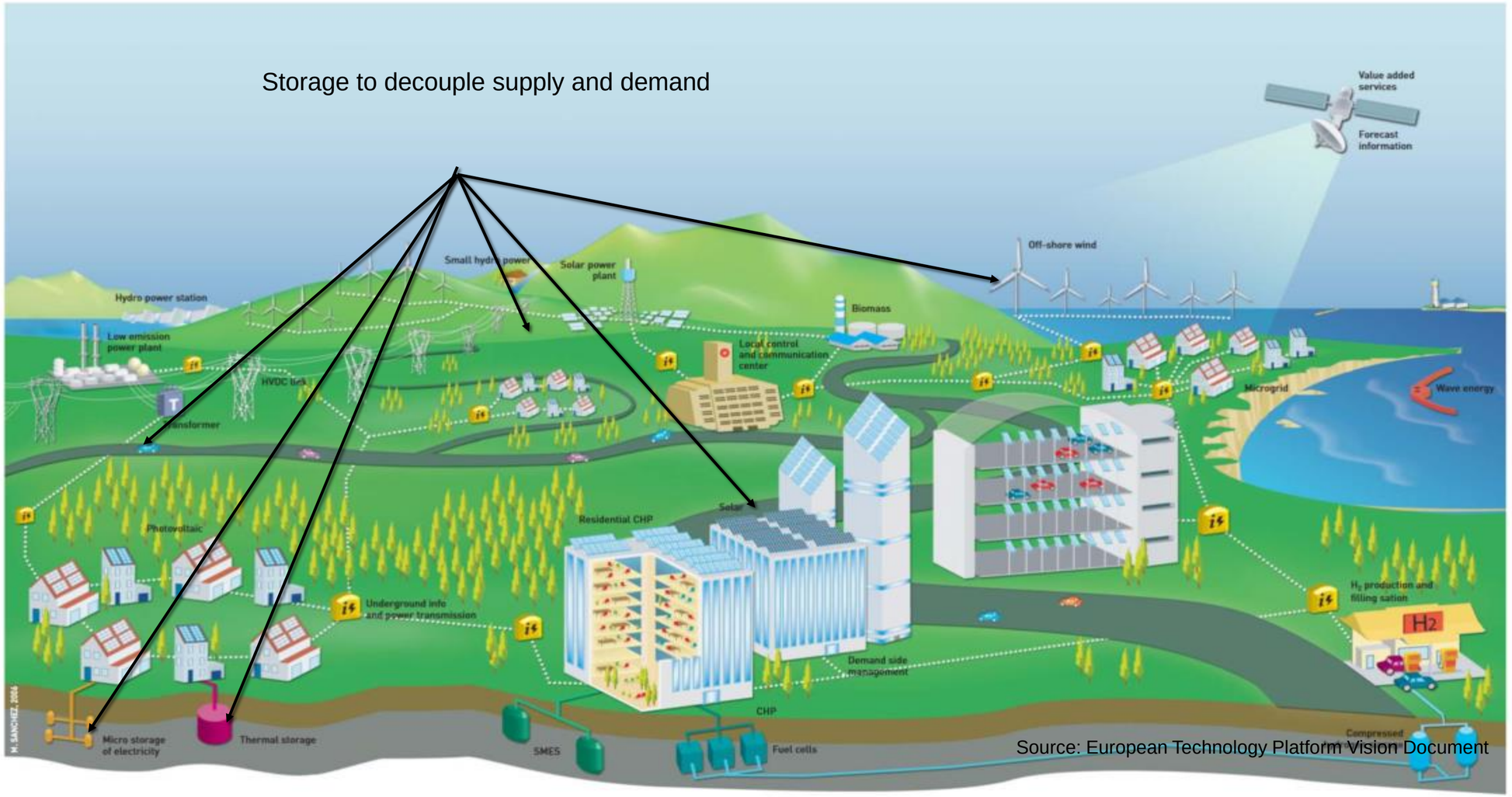
Source: European Technology Platform Vision Document

Demand-side management



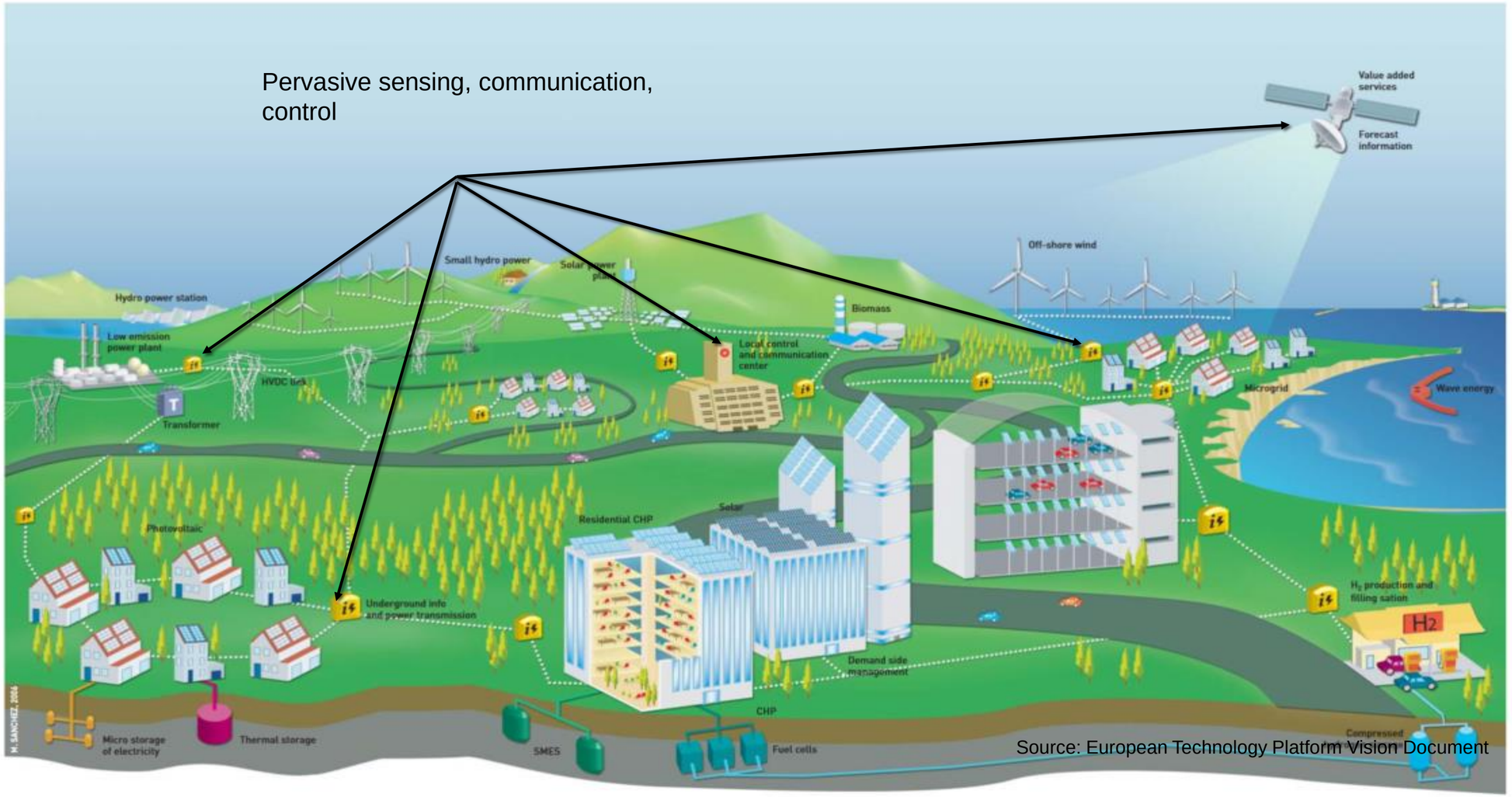
Source: European Technology Platform Vision Document

Storage management

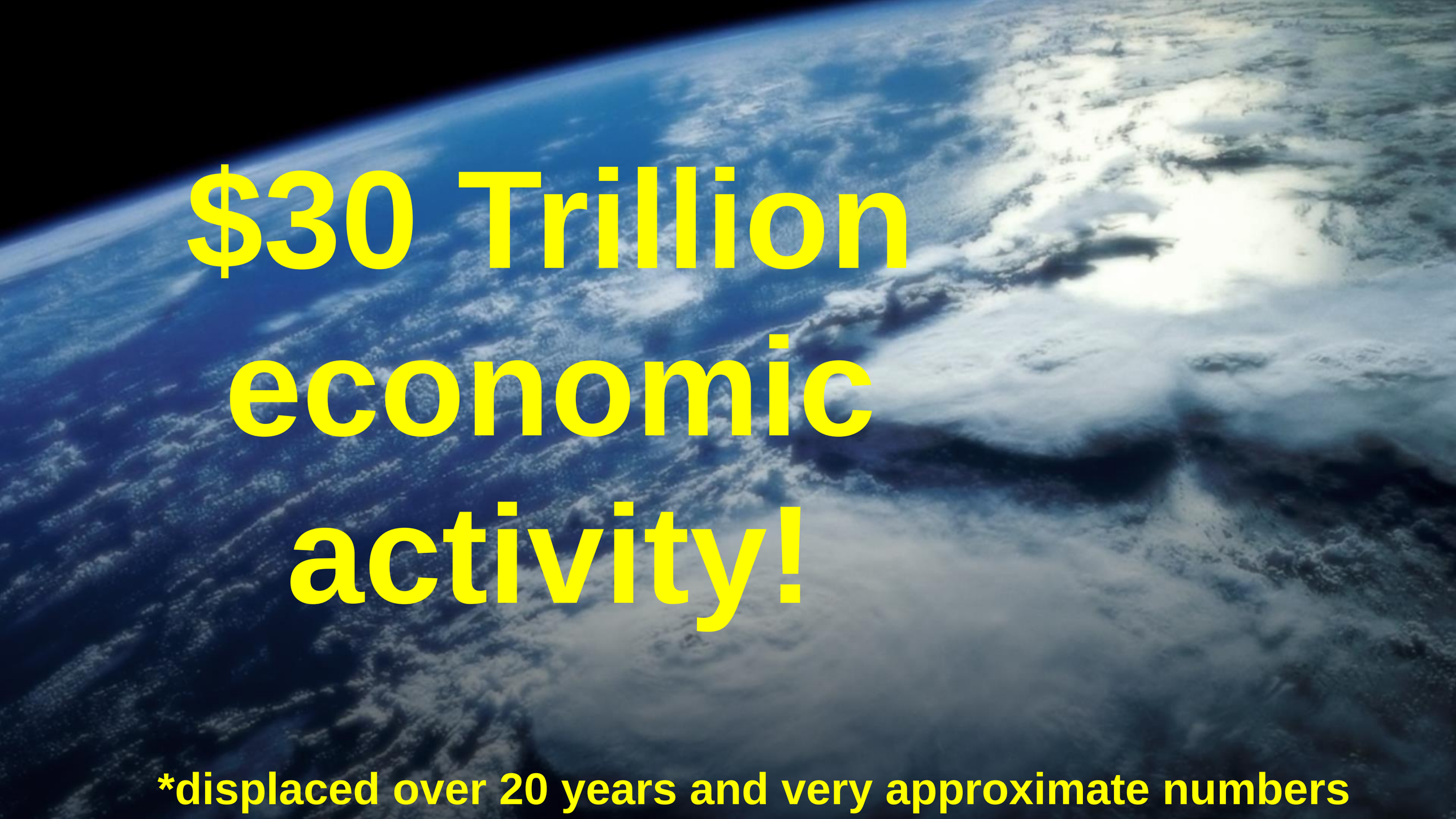


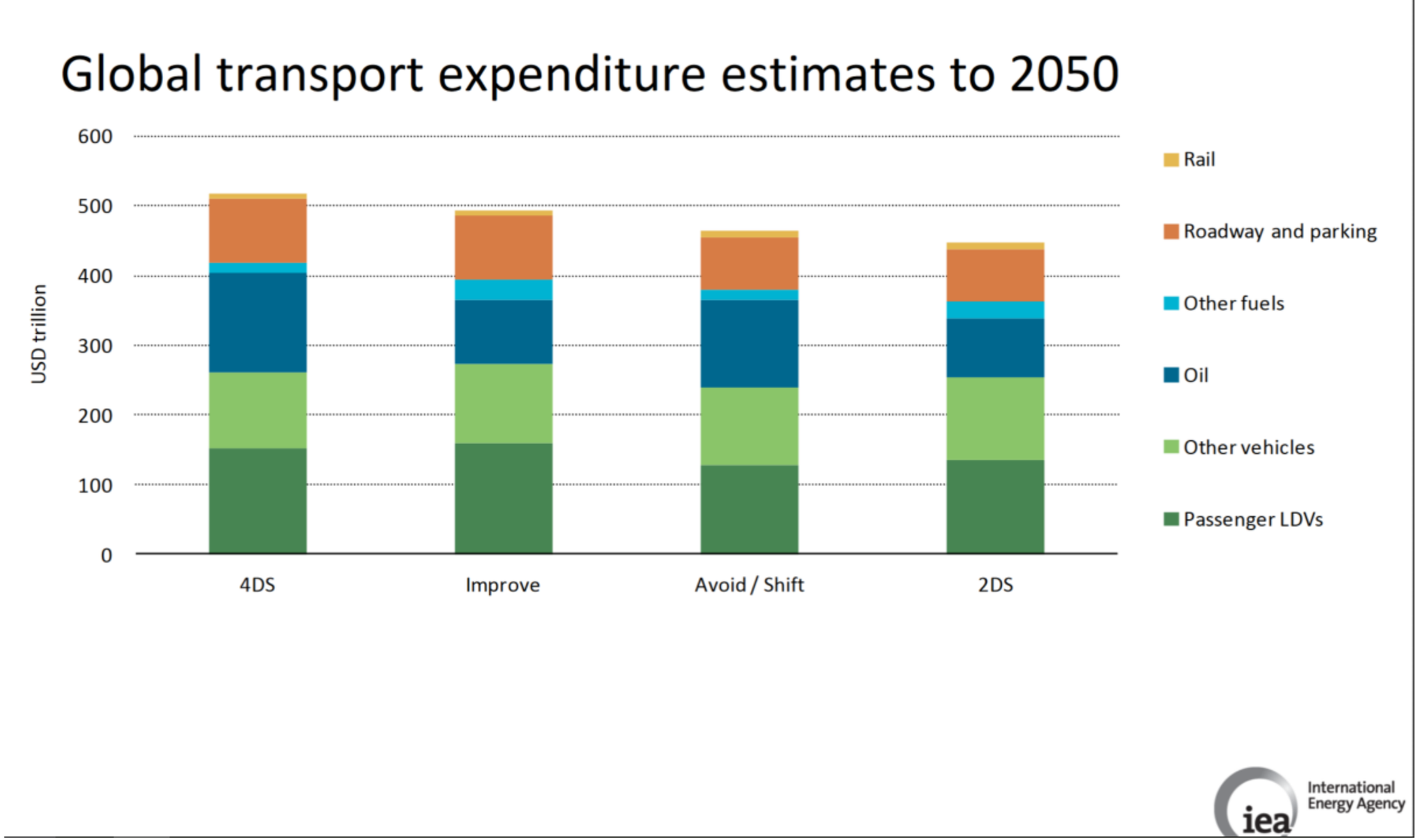
Source: European Technology Platform Vision Document

Sensing, communication, and control



Source: European Technology Platform Vision Document


$30 Trillion
economic
activity!
*displaced over 20 years and very approximate numbers



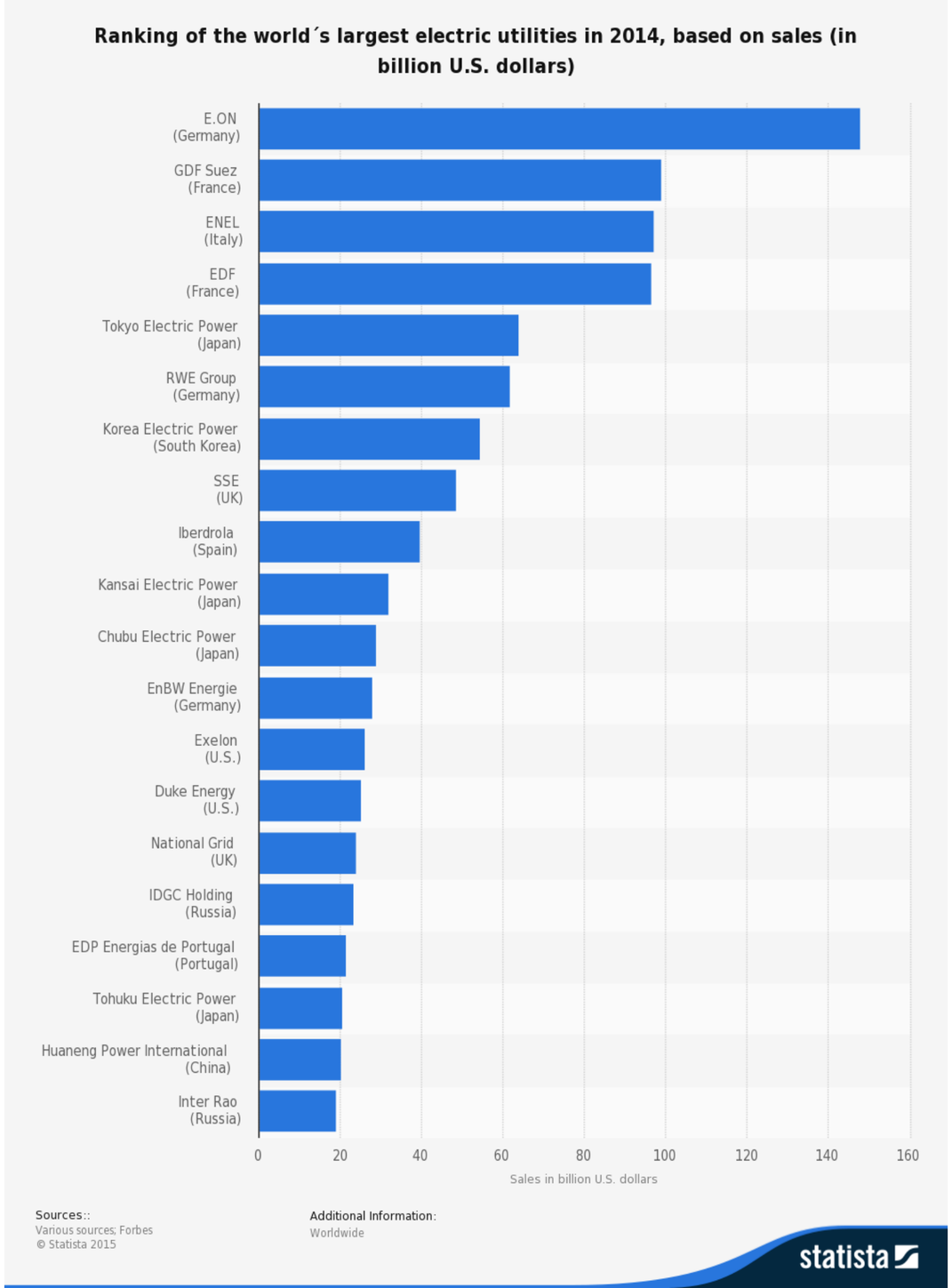
Fuel cost of transportation: $3.5 Trillion/year

1.05
Trillion/yr

30% solar-powered transportation

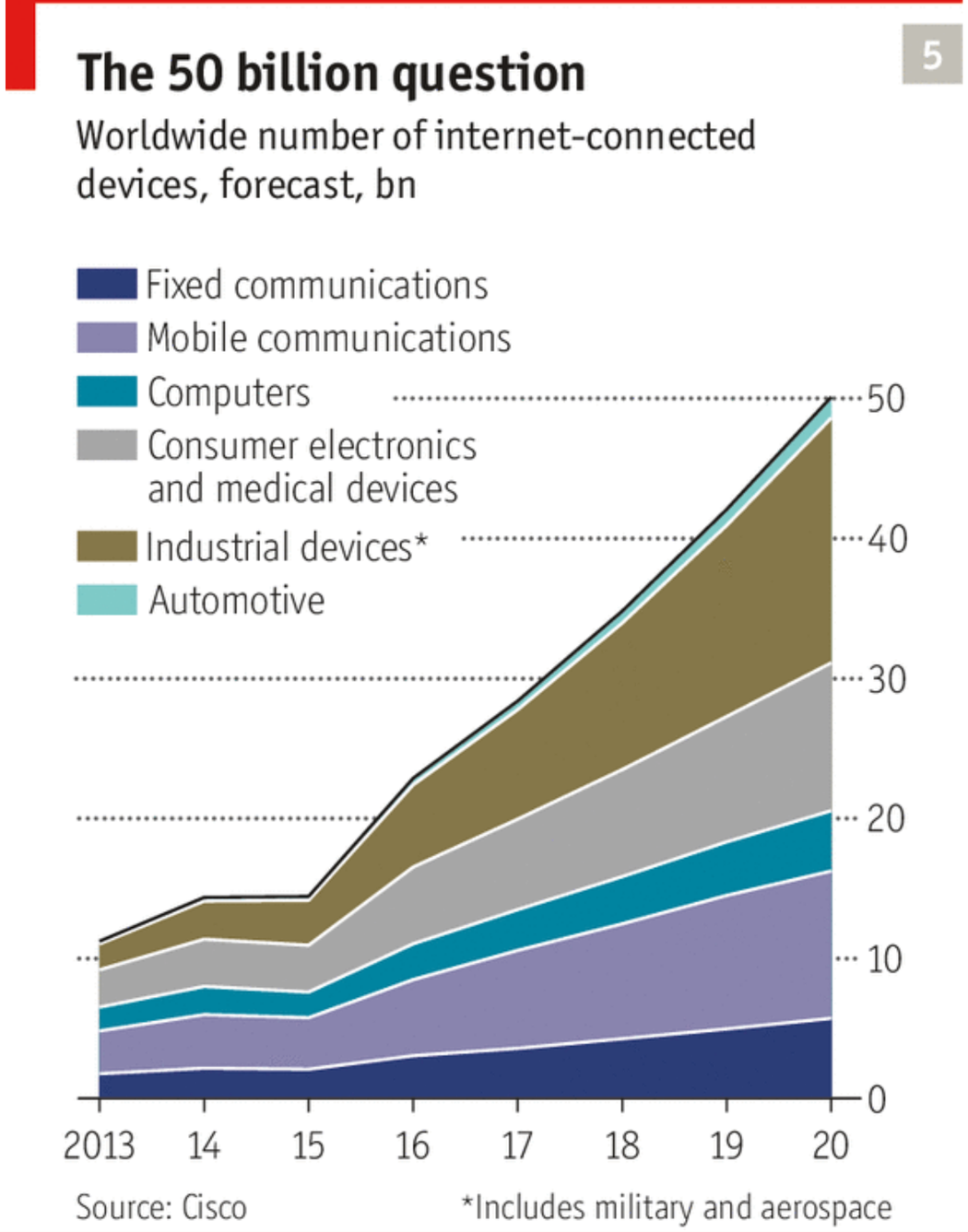
Electric Utility Annual Revenues:

1 Trillion/year



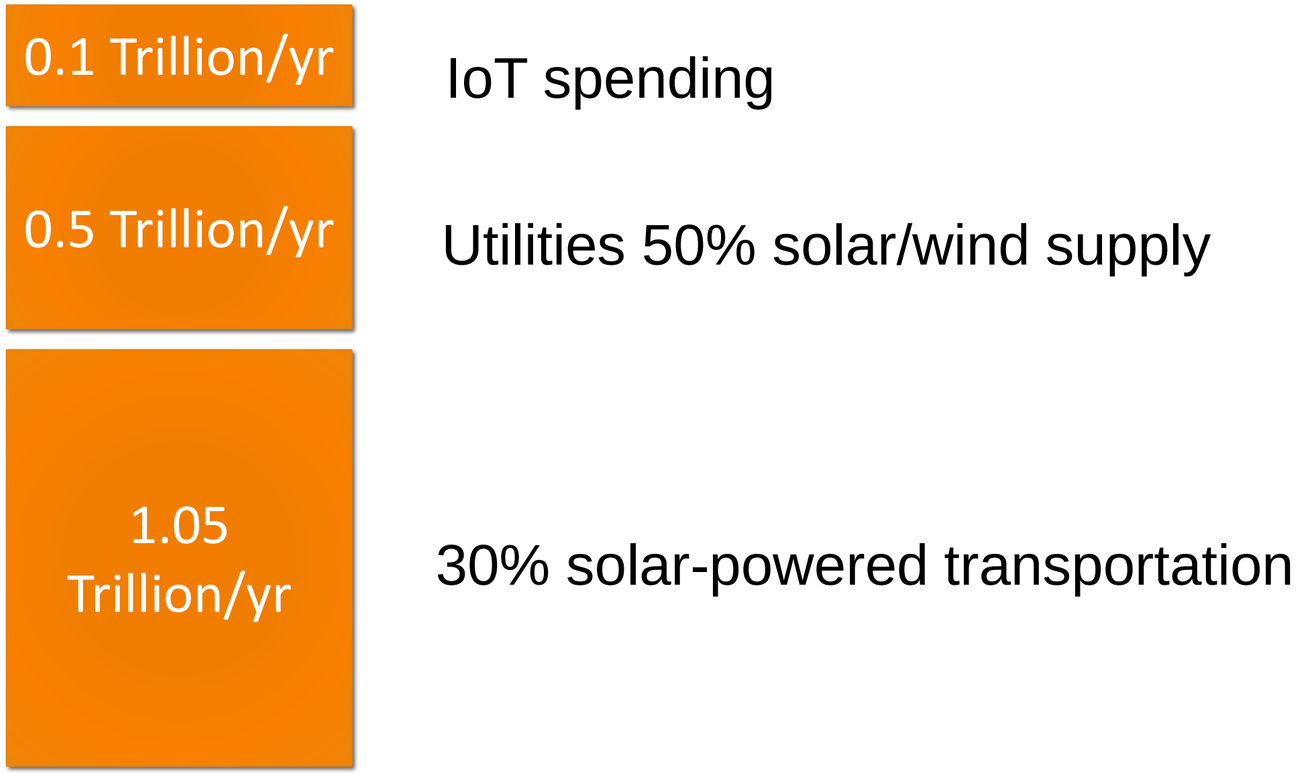
Utilities 50% solar/wind supply

30% solar-powered transportation



IoT spending
= 10% of revenue
= 0.1 Trillion/year

Source: The Economist


0.1 Trillion/yr
IoT spending
0.5 Trillion/yr
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1.05 Trillion/yr
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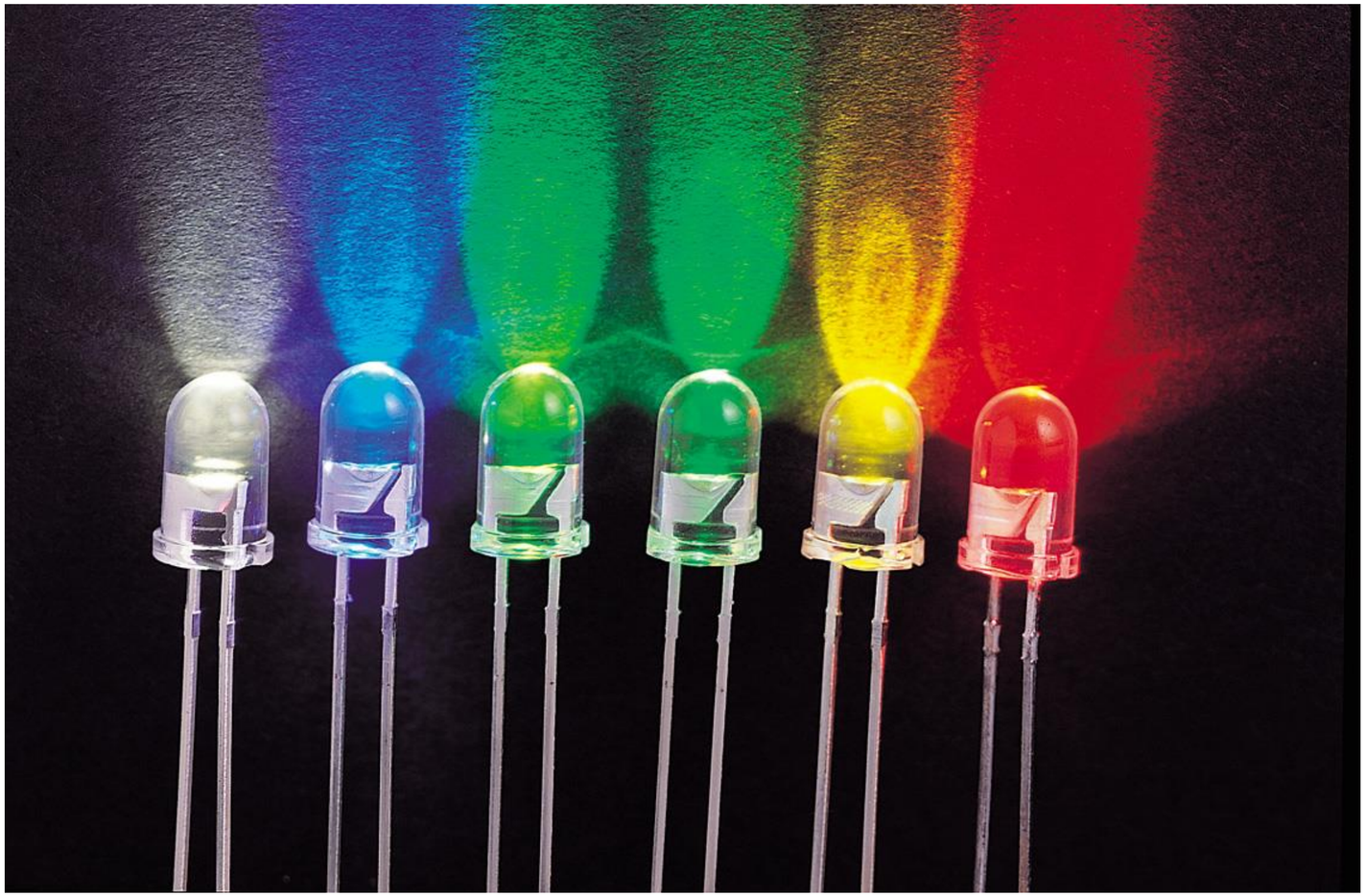


Cost reduction from LED lighting: $.2 Trillion/year

Demand-side savings from LED lighting

IoT spend

Utilities 50% solar/wind supply

30% solar-powered transportation

$1.85 Trillion/year of economic disruption

Demand-side savings from LED lighting

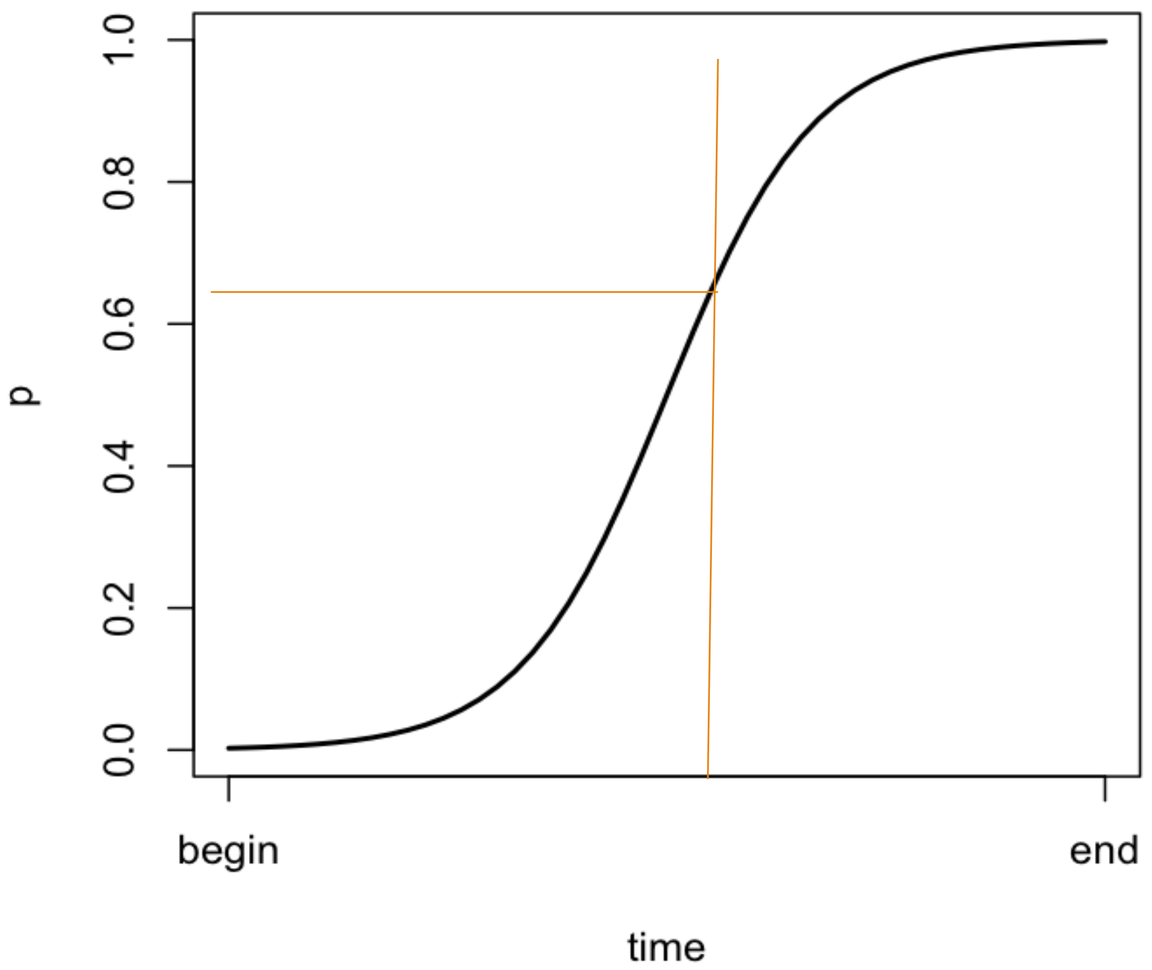
IoT spend

Utilities 50% solar/wind supply

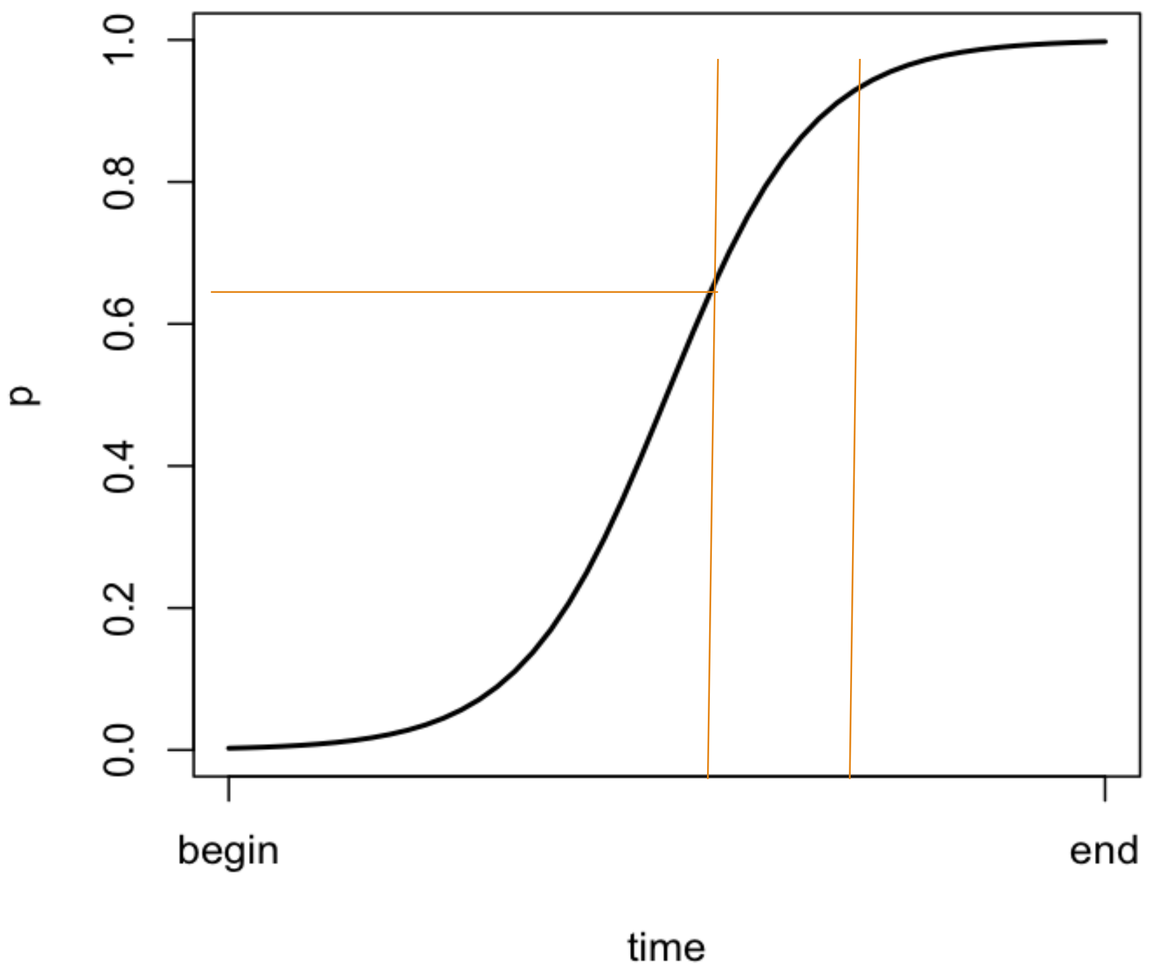
30% solar-powered transportation


$ 37 Trillion
economic
activity!
*over 20 years

I’m lying…



Well, perhaps not



Buffett Ready to Double $15 Billion Solar, Wind Bet

China Aims to Spend at Least $360 Billion on Renewable Energy by 2020

Apple Invests $3 Billion in Solar Energy

By Bill Gates: Why I'm investing $1 billion of my own money into clean energy research

Japan to Invest $20 Billion in Indian Solar Power

timesofindia

Power minister Piyush Goyal and French environment minister Segolene Royal announced the solar finance programme that aims to lower the cost of finance and facilitate the flow of more than $1 trillion investment to members of the International Solar Alliance (ISA).

Goal: 1TW by 2030

Times of India, April 23, 2016

Information Systems and Science for Energy Laboratory

Mission

To use information systems and science to

- increase the efficiency
- reduce the carbon footprint

of energy systems

Contexts

- Smart homes and buildings
- Distribution networks
- Distributed generation

New technologies

- Solar and wind
- Storage
- Electric vehicles
- LED lighting
- Pervasive computation and communication

Approaches

- Internet-inspired
- Energy system design
- Data-driven analysis
- Optimization

ISS4E

http://iss4e.ca

A pond fills with pond scum.
The scum doubles daily.
The pond fills on the 30^{th} day.

When is the pond half full?

Acknowledgments

NSERC
CRSNG

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