

A satellite image of Earth showing the continent of Africa in the foreground and Europe in the background. The Earth's curvature is visible on the left side. The text is overlaid on a semi-transparent dark band across the middle of the image.

Climate Solutions: What Do We Know?

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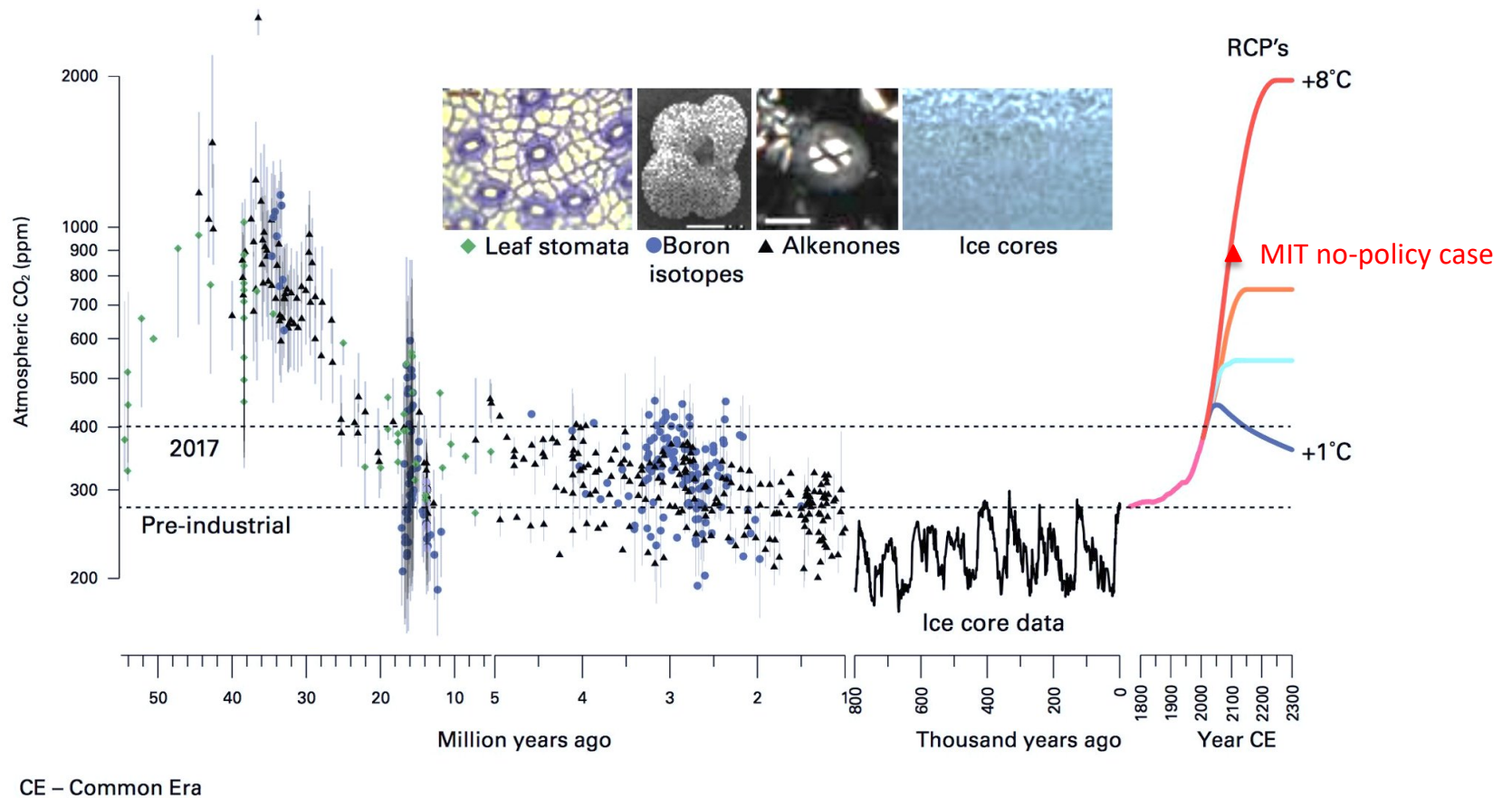
What we know about climate

- It's real
- It's us
- Experts agree
- It's bad
- There's hope, BUT
- we need to move REALLY fast

All but last point from Ed Maibach at George Mason University:

http://assets.climatecentral.org/presents/AMS-ShortCourse2017/AMS2017_Maibach.pdf

Historical CO₂ concentrations

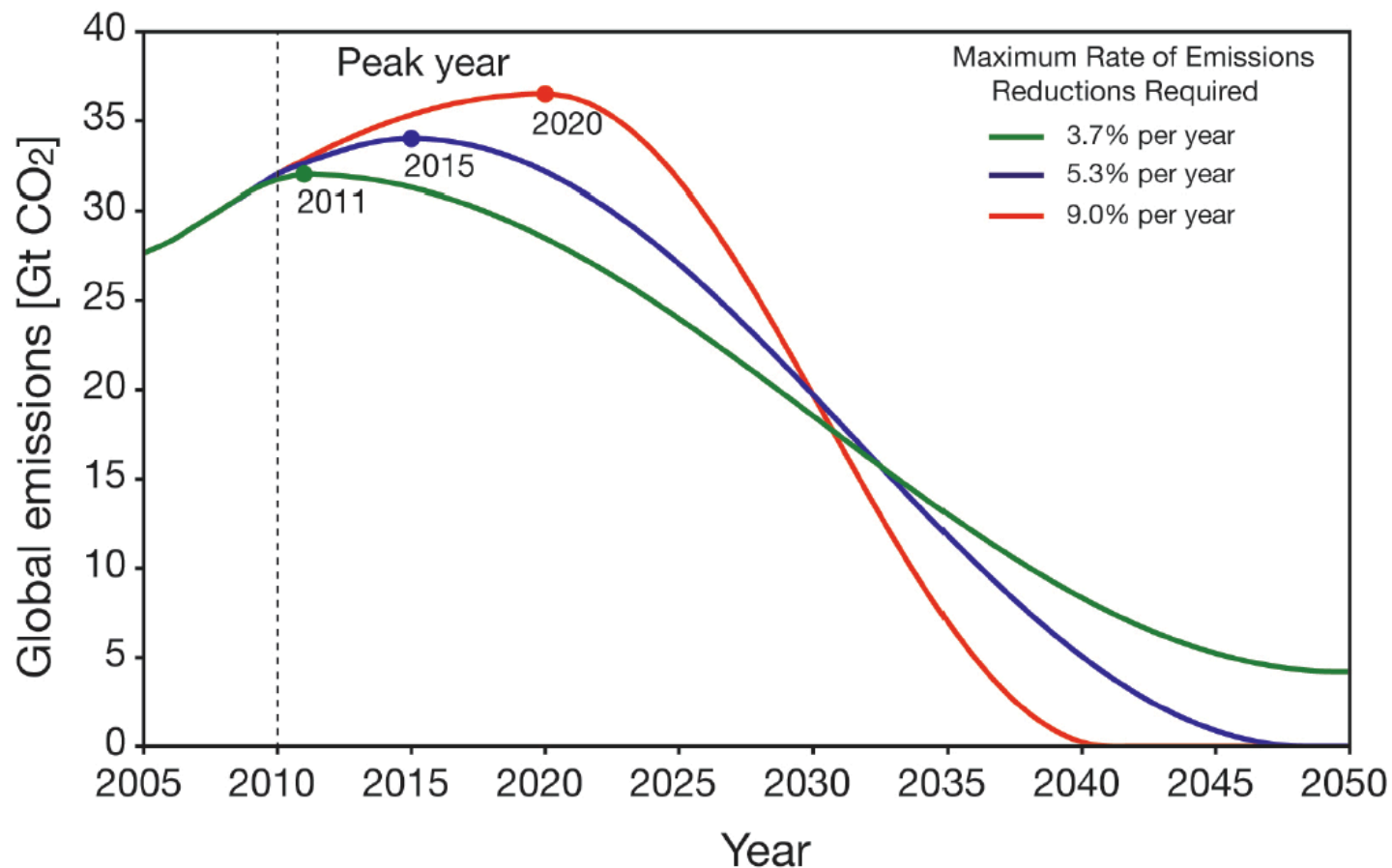


WMO. 2018. *WMO Statement on the State of the Global Climate in 2017*.
Geneva, Switzerland: World Meteorological Organization. WMO-No. 1212.
[https://library.wmo.int/opac/doc_num.php?explnum_id=4453]

We need to reduce emissions as
much as possible, as fast as
possible, starting as soon as
possible.

Everything else is noise

To stabilize climate at $<2^{\circ}\text{C}$, net emissions must go 0 or negative ASAP



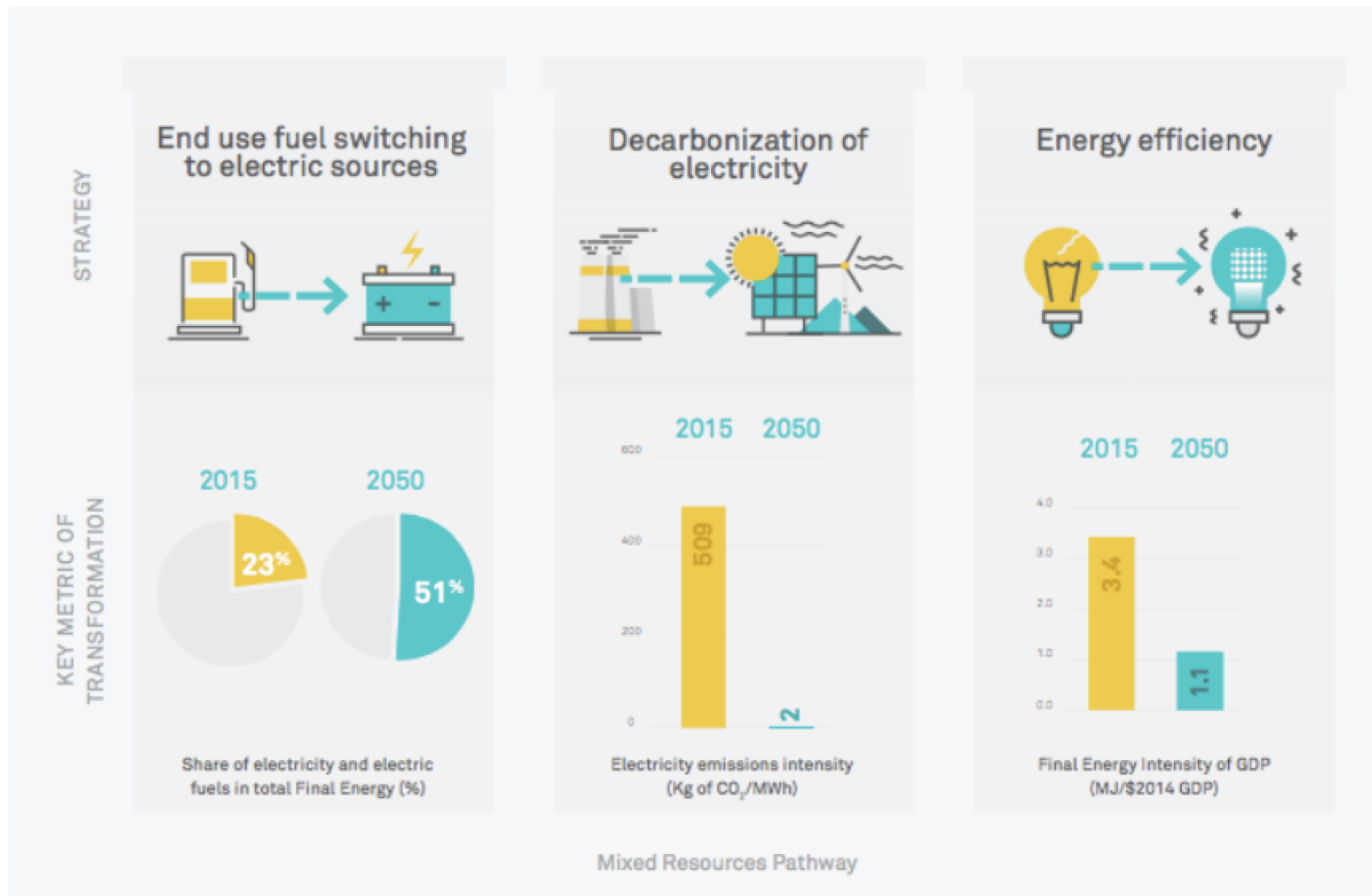
More recently: Rockstrom “Carbon Law” of halving emissions every decade

Source: The Copenhagen Diagnosis, 2009
Rockstrom et al 2017, Science (Carbon Law)

Key Lessons

- Three pillars: Efficiency, electrification, zero emissions electricity
- Rapid learning opens new possibilities
- Focus on the whole system
- Information technology: our ace-in-the-hole
- Address capital stock turnover/replacement

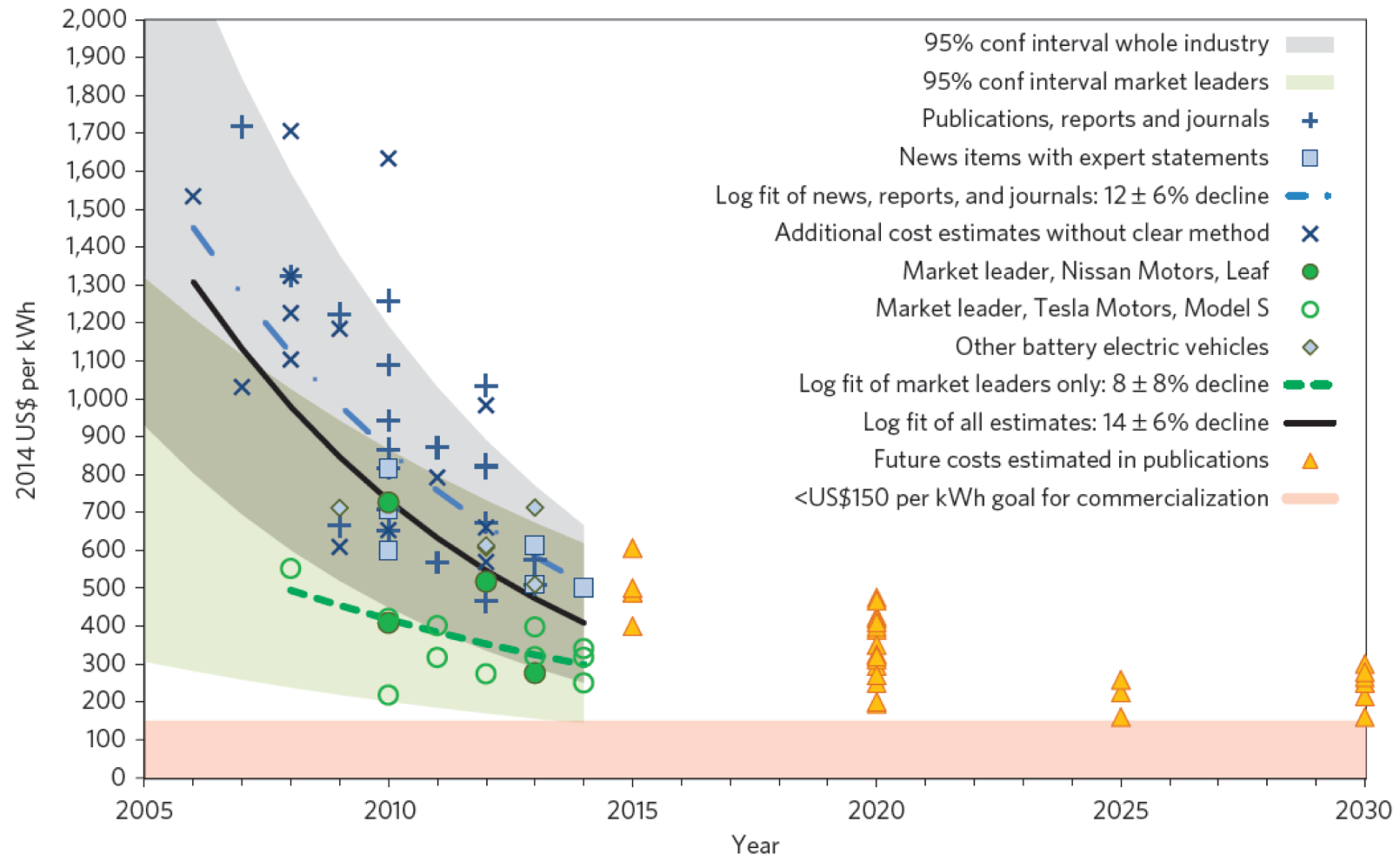
Three Pillars of Deep Decarbonization



<https://riskybusiness.org>

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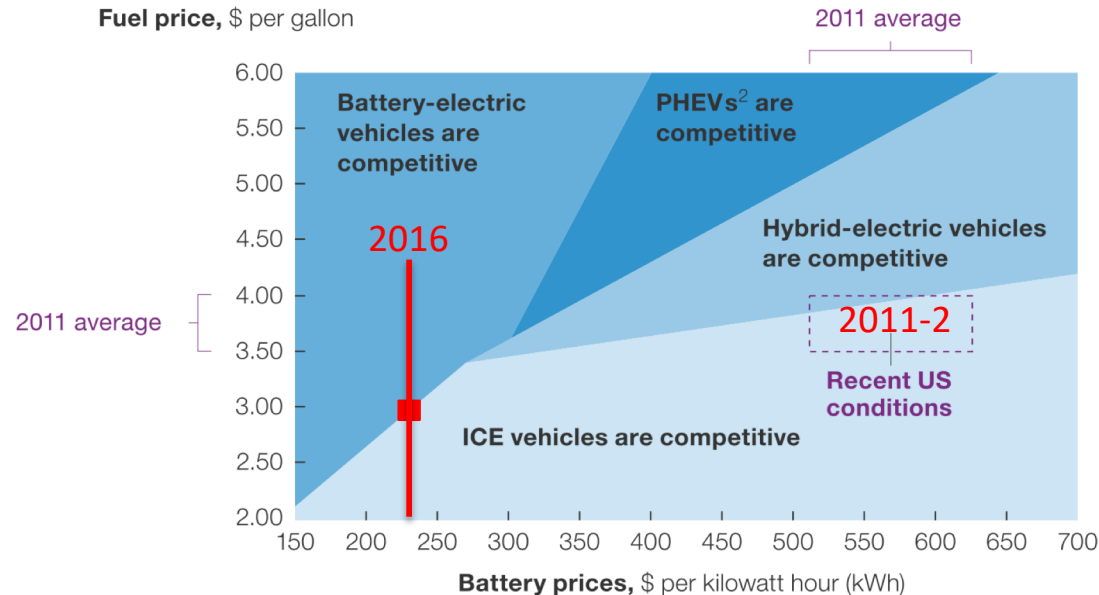
Learning Fast: Battery Costs



Source: Nykvist and Nilsson 2015.

Learning fast: EVs more competitive

Electrified vehicles' projected competitiveness with internal-combustion-engine (ICE) vehicles, based on total cost of ownership¹ (US example)



¹Assumes 240 watt hours per mile (as may be achieved with lightweight, efficient air conditioning) compared with today's 305–322 watt hours per mile.

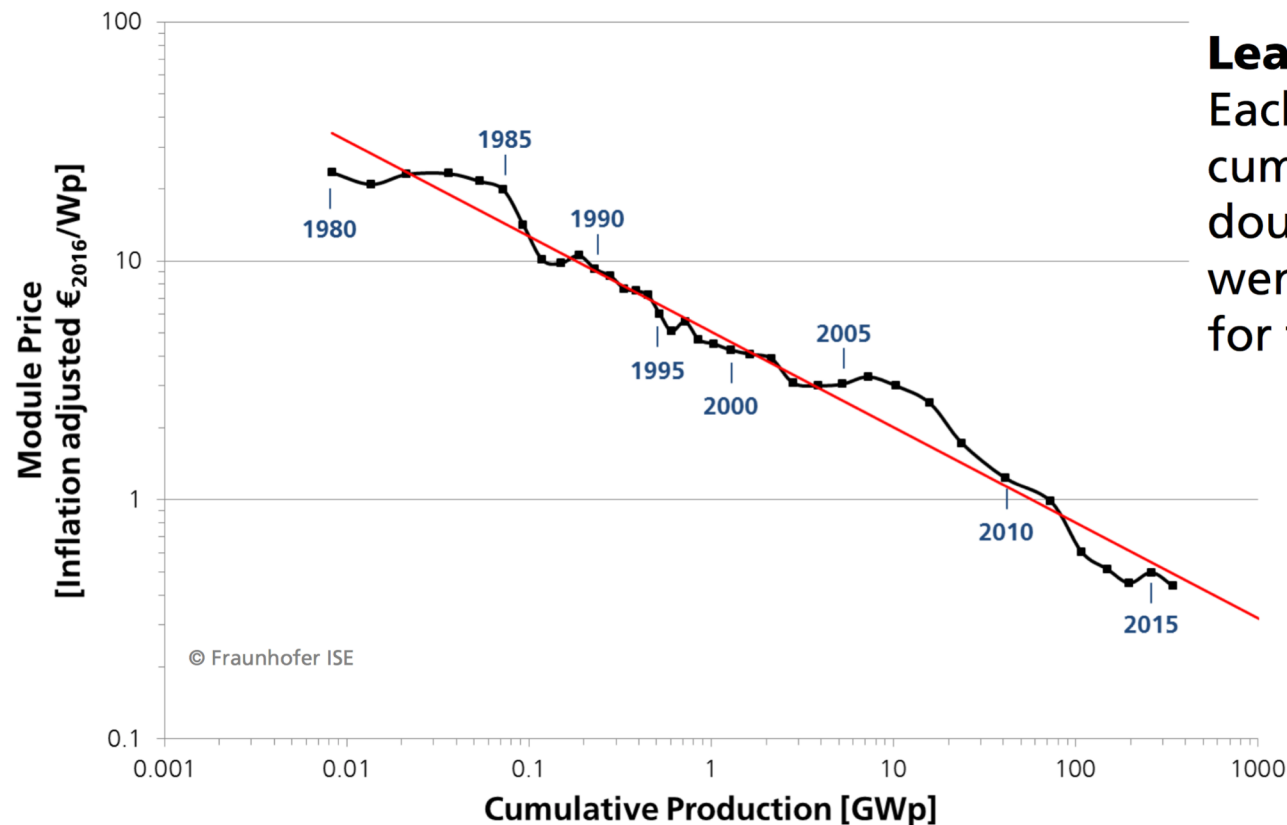
²Plug-in hybrid-electric vehicles.

Source: US Energy Information Administration; McKinsey analysis

Example: Honda will sell the 150 mile range Electric Fit for \$20k starting in 2020.

Sources: <https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/battery-technology-charges-ahead>
<https://electrek.co/2017/01/30/electric-vehicle-battery-cost-dropped-80-6-years-227kwh-tesla-190kwh/>
<https://insideevs.com/hondas-new-186-mile-electric-fit-will-be-priced-below-20000/>

Learning super fast: Solar PVs



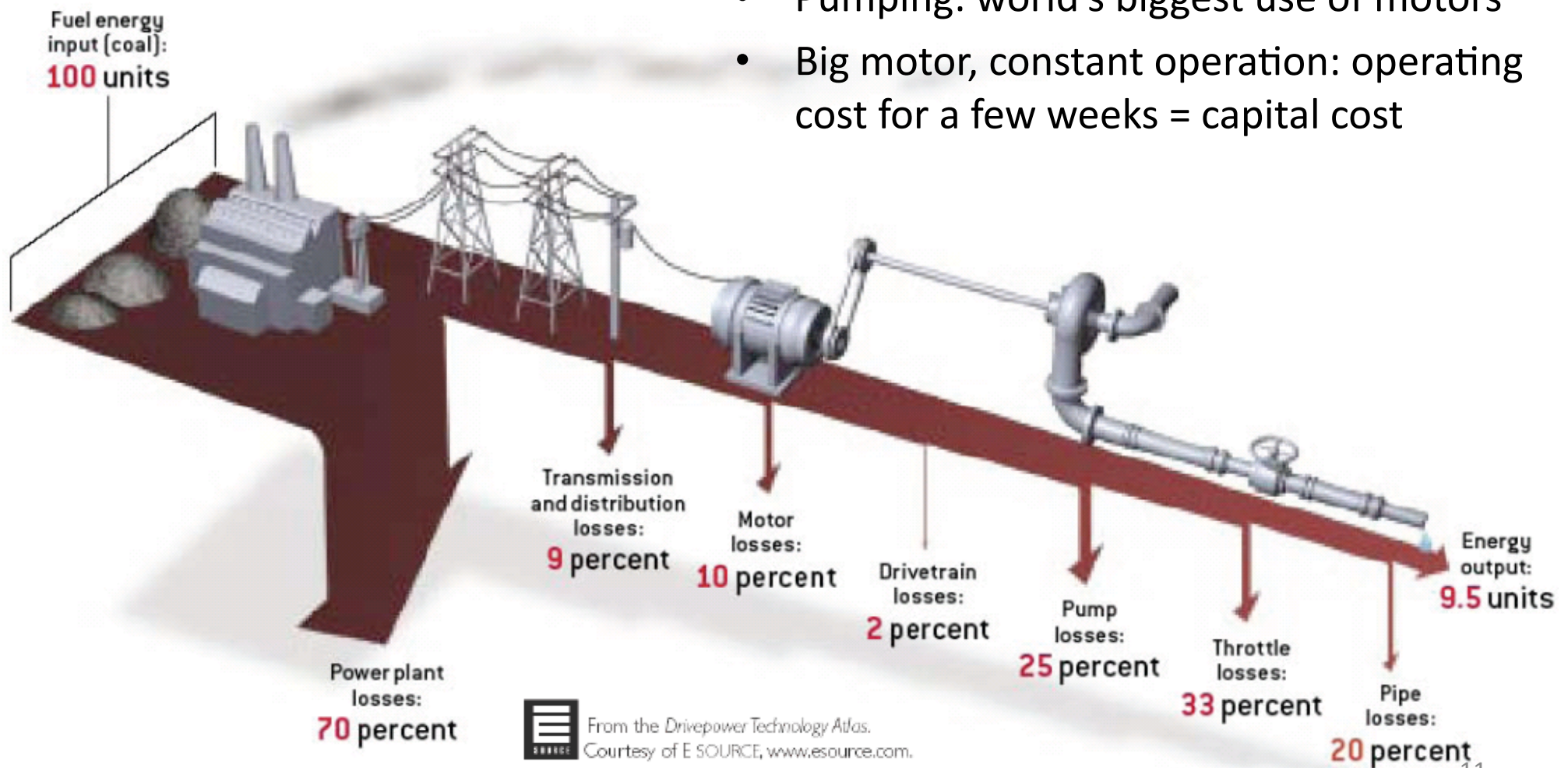
Learning Rate:
Each time the cumulative production doubled, the price went down by 24 % for the last 36 years.

Data: from 1980 to 2010 estimation from different sources : Strategies Unlimited, Navigant Consulting, EUPD, pvXchange; from 2011 to 2016: IHS. Graph: PSE 2017

<https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf>

Whole system design: Compounding losses...or savings...so start saving at the downstream end

- Pumping: world's biggest use of motors
- Big motor, constant operation: operating cost for a few weeks = capital cost



IT is our “ace-in-the-hole”

- Substituting smarts for parts (replacing parts with electronics)
- Moving bits not atoms (telecommuting, sending PDFs, control bigger systems)
- Real time data collection, optimization, and control.
- More rapid, accurate, and sophisticated prototyping & design

IT: Moving bits not atoms: Big Belly trash compactor avoids truck trips

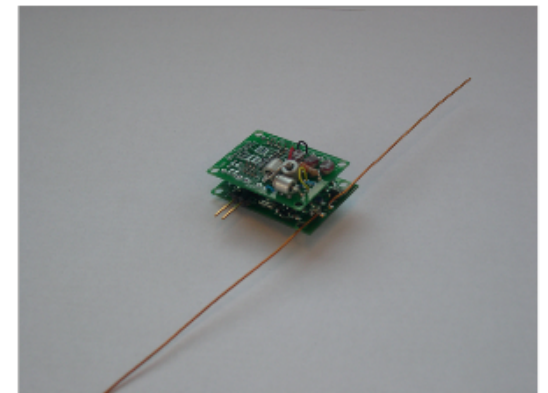
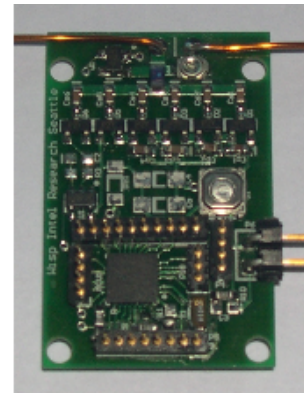
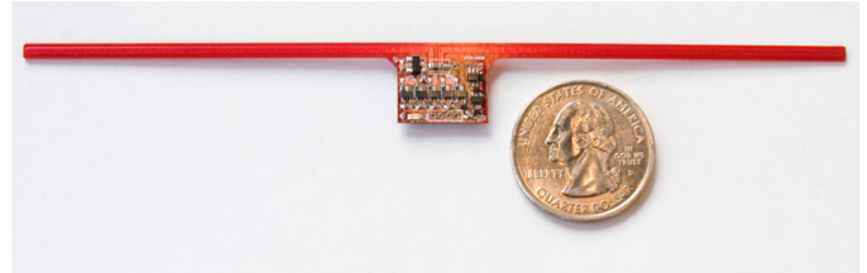


- Compacts trash 5 x
- Sends text message when full
- PV panel generates power from sunlight
- An economic and environmental home run

<http://www.bigbellysolar.com>

IT: Real-Time Data Collection

- Consider the wireless no-battery sensors created by Joshua R. Smith of the University of Washington
<http://www.nytimes.com/2010/07/18/business/18novel.html>, <http://www.economist.com/node/16295708>
 - sensors use 60 microwatts on average (60×10^{-6} watts)
 - scavenge power from radio and TV signals
- Other possible power sources for similar devices: light, heat, motion, blood sugar, digestive fluids



Images courtesy of Josh Smith, U of WA

IT: Real-Time Controls: Makani Power

- Wind turbines on a tether (<https://x.company/makani/>)
- Capacity factors over 50%
- Current prototype = 600 kW
- Couldn't work without controls as sophisticated as missile guidance systems

Makani kites:
airborne wind energy



IT: Speed up prototyping & design

- IT is a “general purpose technology”
- All industrial products are now designed on computers to avoid errors
 - e.g., pipes reversed for Diablo Canyon nuclear plant circa early 1980s
- 3D printing allows rapid & cheap prototyping
- Artificial intelligence allows computers to create designs that solve old problems in new ways (See McAfee and Brynjolfsson 2017)

Address capital stock turnover

- Push new installs because they're much cheaper
 - Efficiency standards
 - CEC mandate for PV on new homes
- Retire existing fossil capital early
 - Accelerate retirements of existing coal and oil plants
- Stop building new fossil capital
 - Easier to stop new builds than to shut them off after operation
 - Start by blocking new coal and heavy oil infrastructure
 - Evaluate new gas infrastructure on a case-by-case basis

Summary

- Science points to 2 deg C limit but ultimate choice is a value judgment. Implies
 - rapid emissions reductions
 - keeping most fossil fuels in the ground
 - rapid innovations in technologies AND behavior/institutions
- Immediate implementation is essential. Learning by doing only happens if we *do*!
- Existing low carbon resources are plentiful but we'll need new innovations in later decades to keep reductions on track

We need to reduce emissions as
much as possible, as fast as
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