Document 2

Energy Innovations for a Secure, Affordable and Clean Energy System

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Stanford University

Industrial Revolution: Horse Power to Horsepower

Steven Chu & Arun Majumdar, "Opportunities and challenges for a sustainable energy future," *Nature* 488, 294 (2012)

250 yrs

300 Horsepower

10,000 Horsepower

100,000 Horsepower

The greatest engineering achievement of the 20th century

US National Academy of Engineering

Which innovations will shape the next 100 years of energy?

We seek technologies that have the potential to produce fundamentally new learning curves

Stanford University

arpa·e

300 Horsepower

10,000 Horsepower

100,000 Horsepower

250 yrs

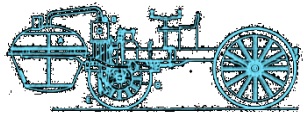
Which innovations will shape the next 100 years of energy?

Cost / Performance

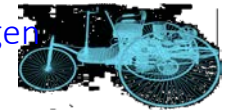
Scale

TRANSFORMATIONAL

Steam-powered Cugnot (1769)



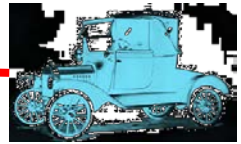
Benz Motorwagen (1885)



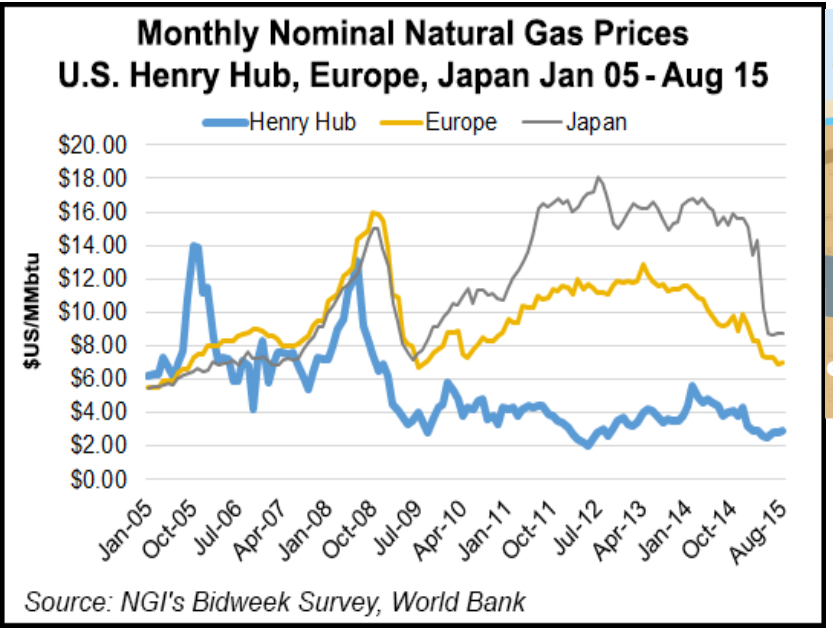
Incremental improvements in existing technology

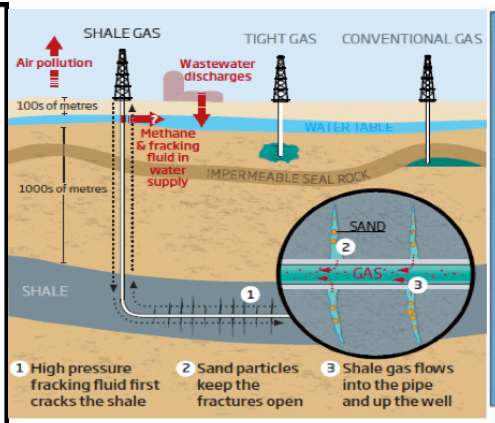
DISRUPTIVE

Ford Model T (1914)



Major Global Energy Trends

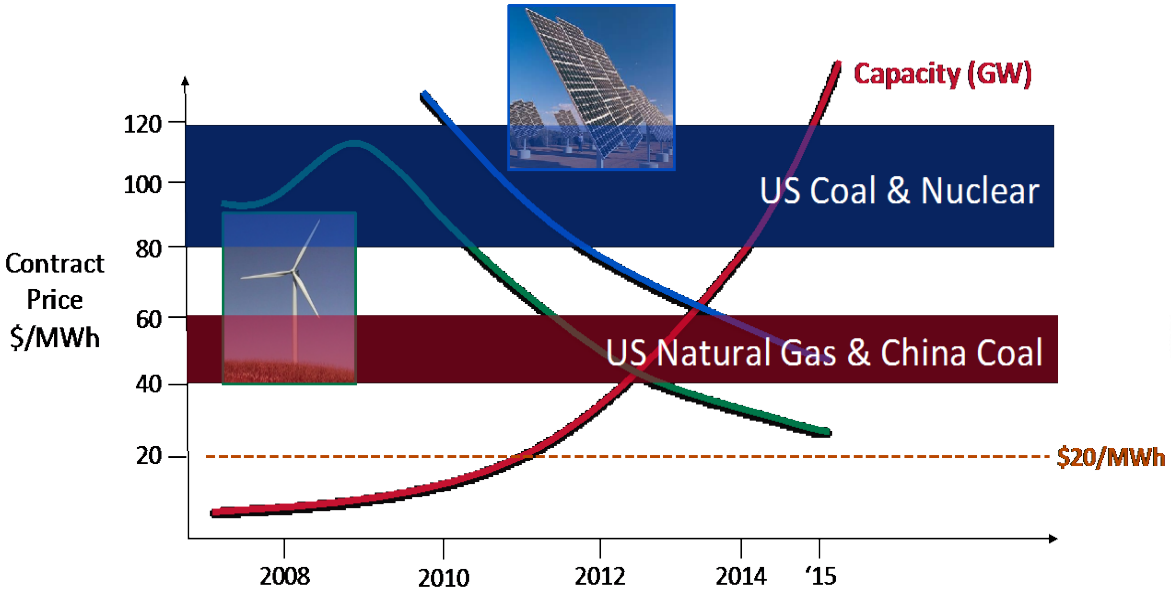




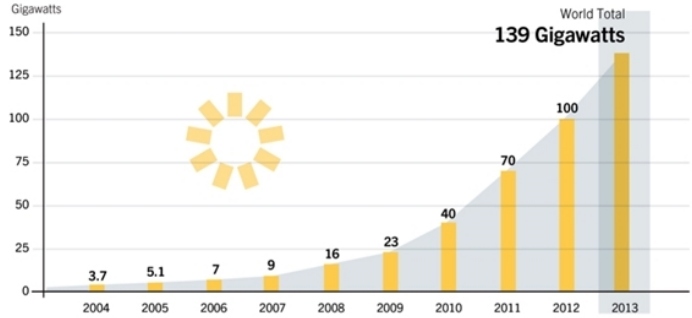
Stanford Natural Gas Initiative

Major Global Energy Trends – Renewables

Carbon-Free Renewable Electricity

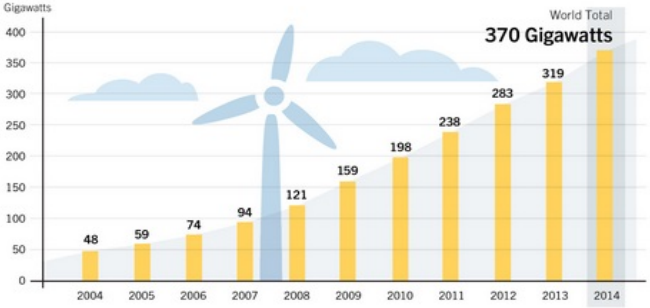


Solar PV Total Global Capacity, 2004–2013



REN21. 2014. *Renewables 2014 Global Status Report* (Paris: REN21 Secretariat).

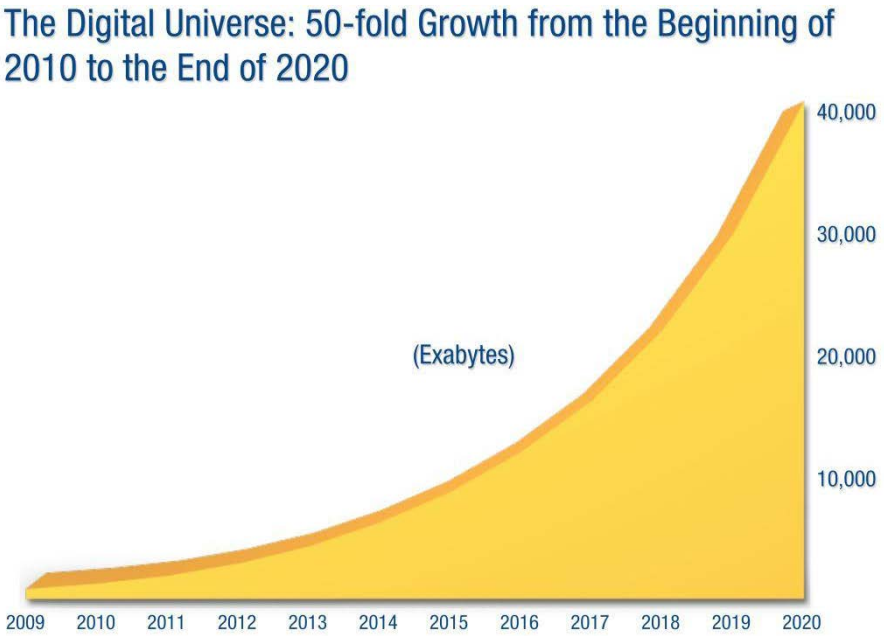
Wind Power Global Capacity, 2004–2014



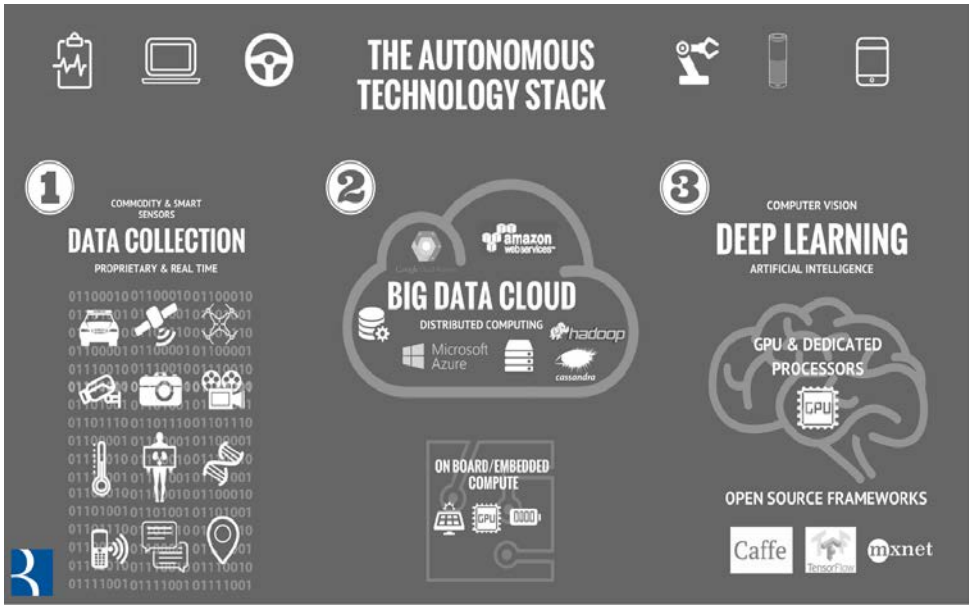
REN21 *Renewables 2015 Global Status Report*

Stanford Bits and Watts Initiative for Grid Innovations

Digital Automation



J. Gantz & D. Reinsel, "The Digital Universe in 2020: Big Data, Bigger Digital Shadows, and Biggest Growth in the Far East," EMC Corp. (2012)



Stanford Data Science Initiative

Stanford Bits and Watts Initiative

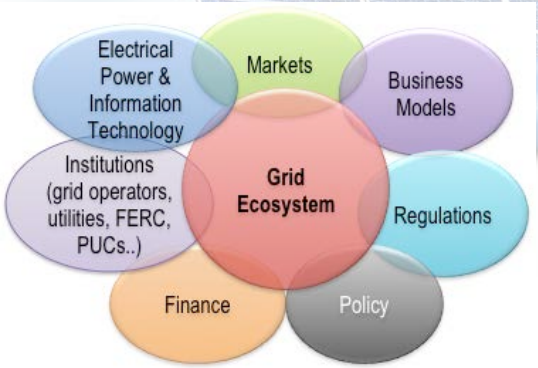
Innovation for the 21st Century Electric Grid

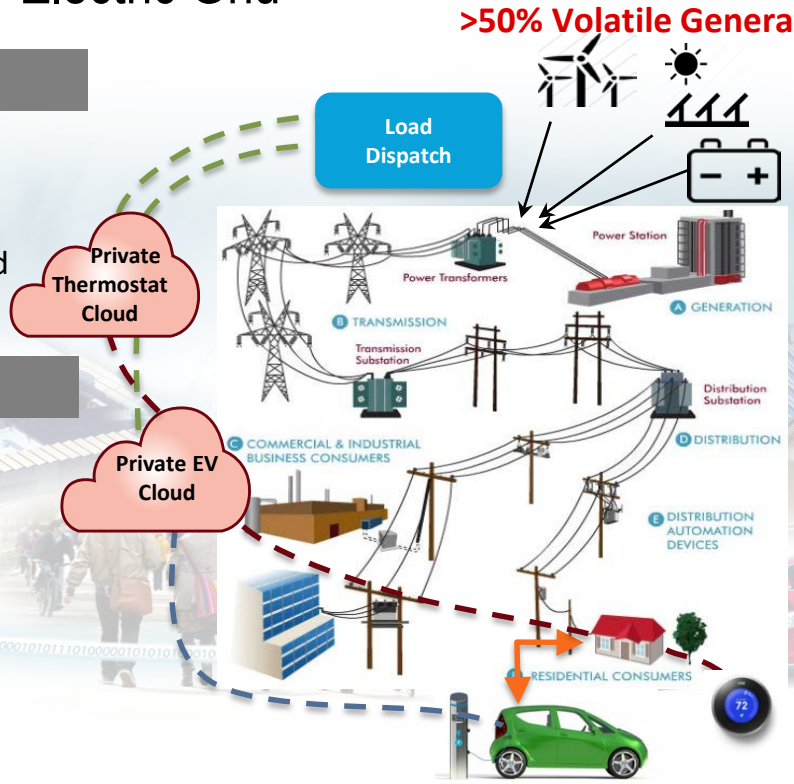
20th Century

- Large centralized generation
- One way power flow
- Continuous generation follows uncontrolled load

21st Century

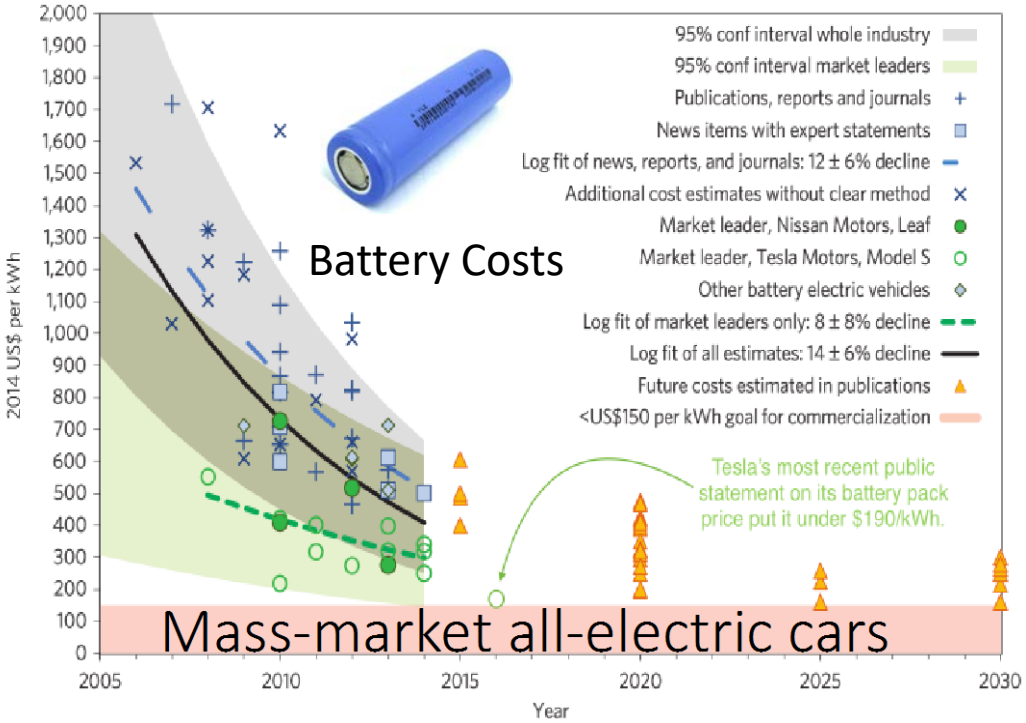
- Deep Decarbonization via Renewables
- Distributed Energy Resources





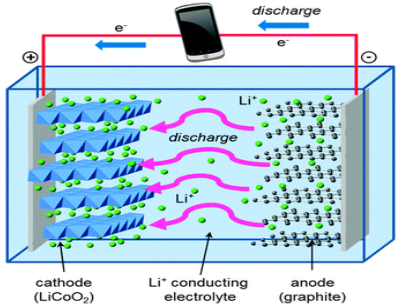
origin · EPRI Electric Power Research Institute · Rte · Schneider Electric · State Grid Corporation of China · Google · ENGIE · innogy · SMUD Sacramento Municipal Utility District · PG&E · Terna · SIEMENS Ingenuity for life · HITACHI Inspire the Next

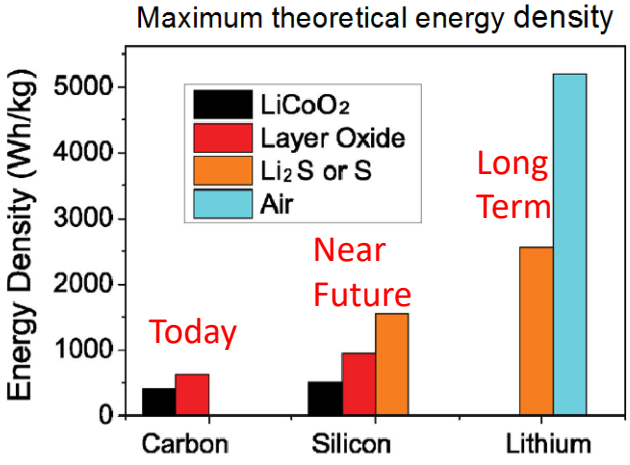
Noteworthy Global Trends – Energy Storage & Use

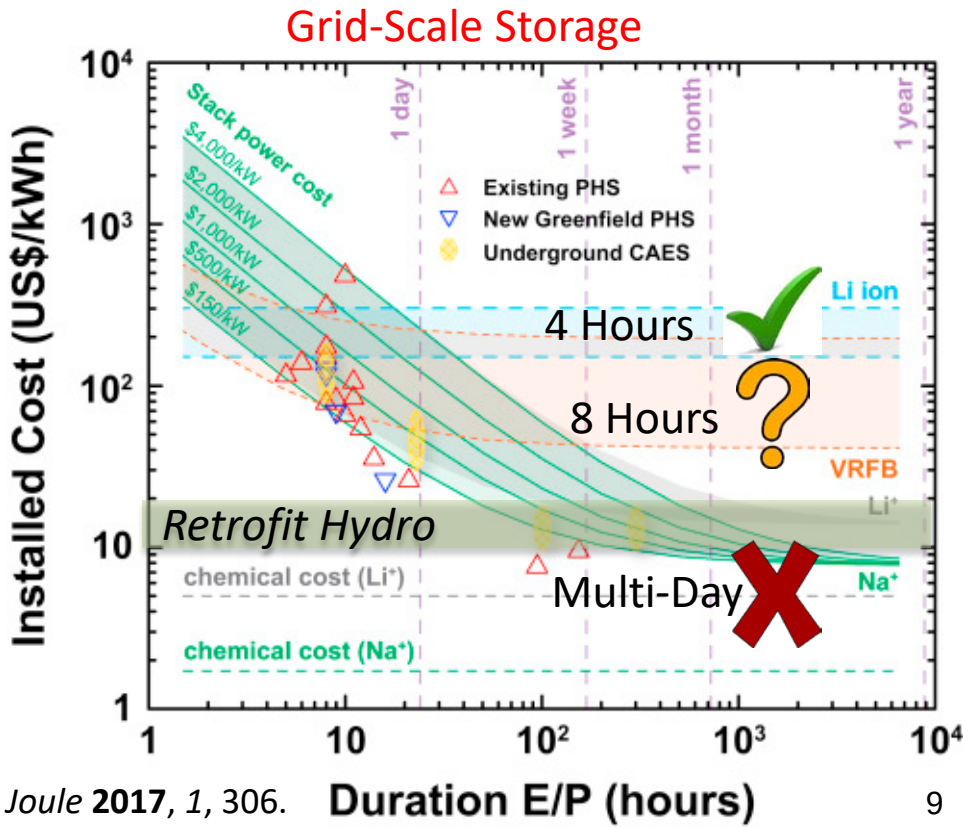


Stanford StorageX Initiative

How much more cost reduction in batteries?



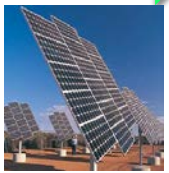




Li et al., *Joule* **2017**, *1*, 306.

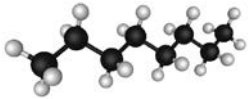
Low-Carbon Fuels & Chemicals

Carbon-Neutral Energy < $30/MWh



CO_2

Chemicals & Fuels



Electrochemical

Photochemical

Biochemical

Thermochemical

H_2: Need < $2/kg

Today @ $5/kg

O_2

2 ¢ /gallon of gasoline

Oil tankers are transcontinental energy "transmission lines"

DIRECT CONVERSION

O_2

Methane, CH_4

Electrochemical

Photochemical

Biochemical

Thermochemical

Methanol CH_3OH

How to decarbonize cost-effectively?

Fuel switch from coal to natural gas, with global access to cheap natural gas or low-carbon fuel (e.g., methanol)

Decarbonize grid by integrating renewables; reduce cost of nuclear energy; carbon capture utilization/seq

Decarbonize transportation via electrification and low-carbon fuels (H_2, CH_4, CH_3OH, zero-net carbon fuels)

Find alternatives materials and decarbonize industrial heating for steel, concrete, petrochemicals, food.

Energy efficiency & conservation

The global energy system at a tipping point for a major transformation

Decarbonization

- Global drive to reduce greenhouse gas emissions

Digitization

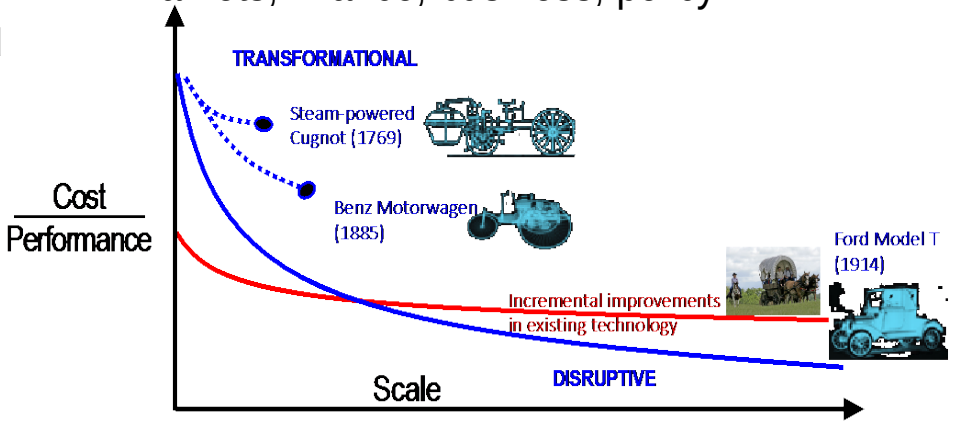
- Digital automation increasing efficiency and reducing cost

Diversification

- More fuel options; more consumer choice; hybrid centralized-decentralized system

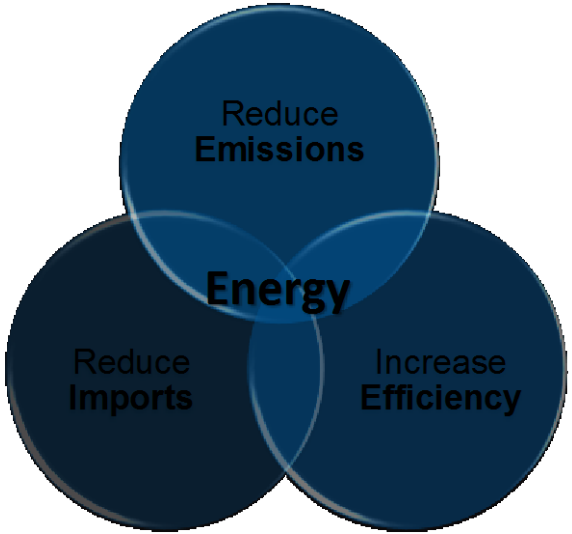
For one of the largest industry in the world ($10T/year), the fundamentals are rapidly changing for the first time in 100+ years

Energy innovations needed in technology, markets, finance, business, policy



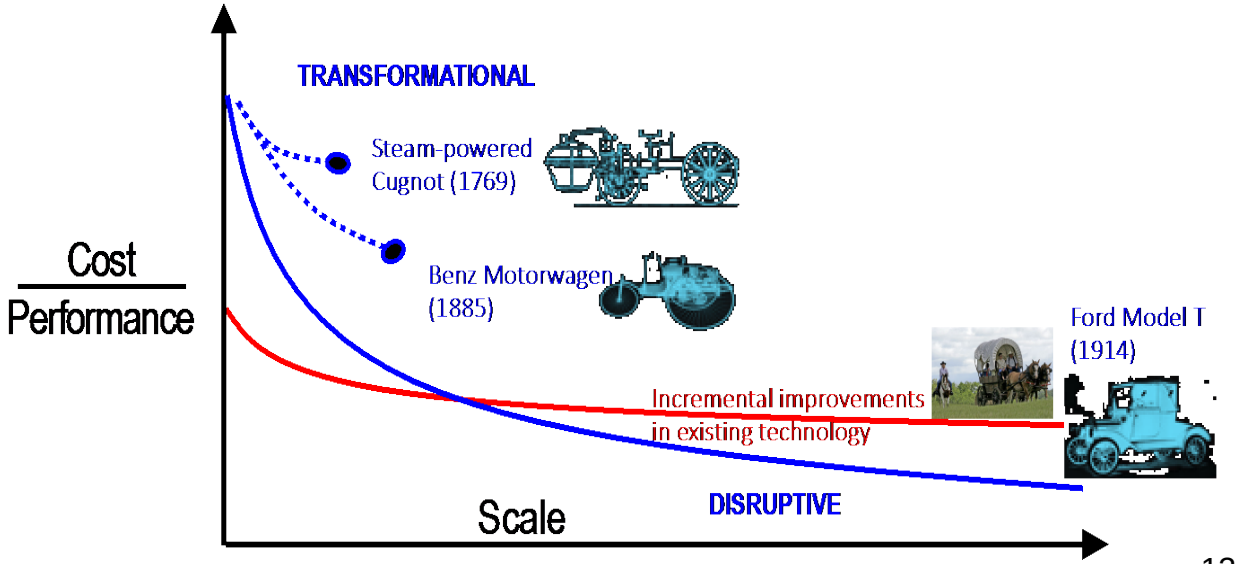
Advanced Research Projects Agency-Energy

CLARITY IN HIGH-LEVEL MISSION

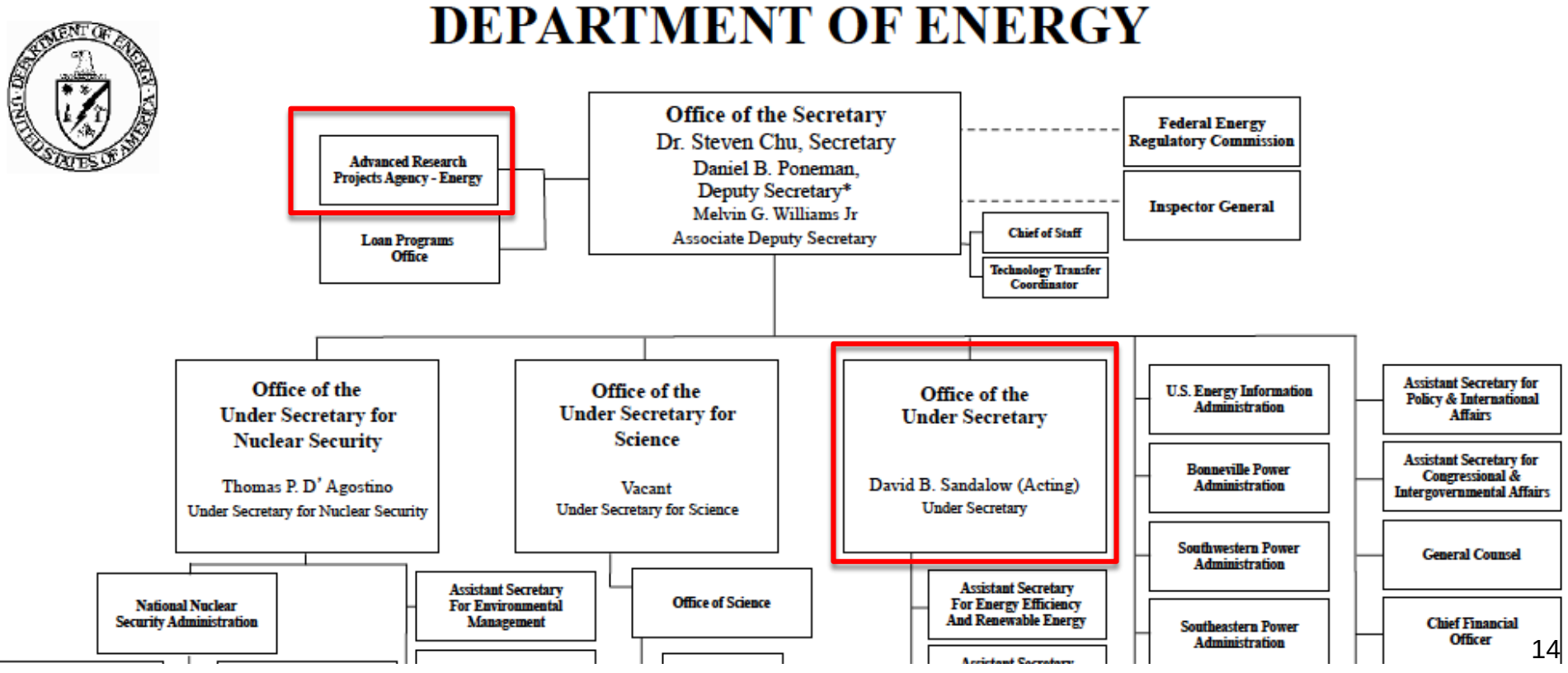


Ensure U.S. lead in advanced energy technologies

ARPA-E invests in research in science and engineering to produce breakthrough energy technologies that have the potential to produce fundamentally new learning curves



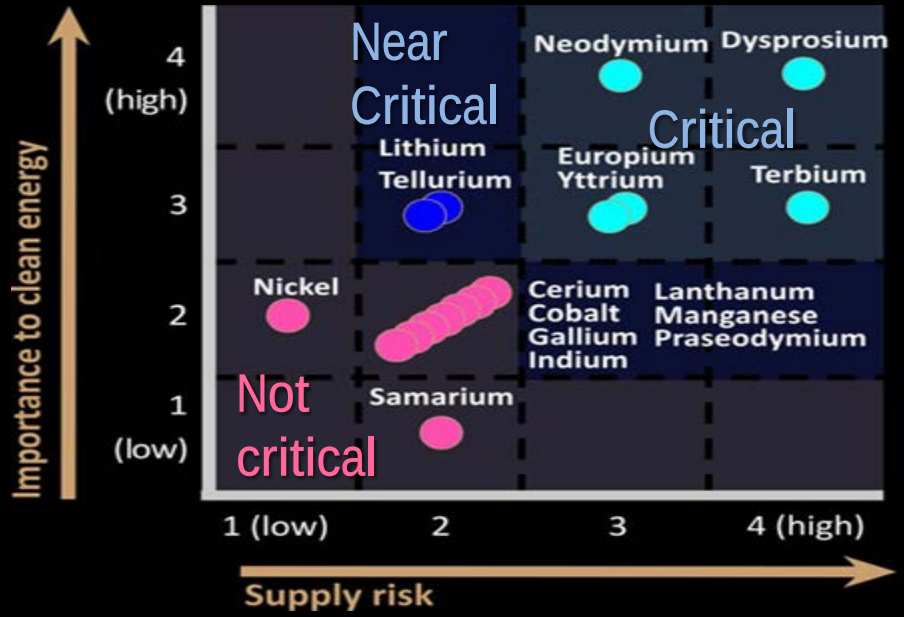
DOE Organization

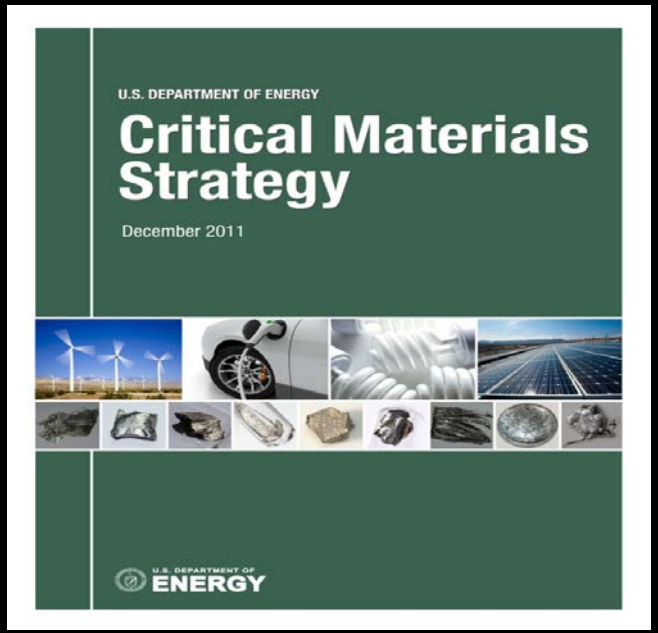


Critical Materials

Rare Earth Elements

Medium Term

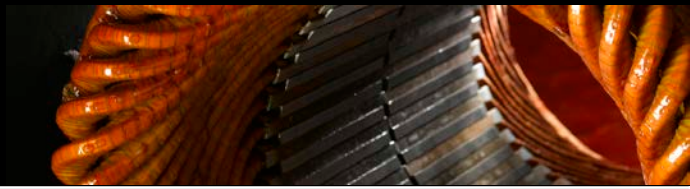




Source: US DOE 2011, Critical Materials Strategy

REACT

RARE EARTH ALTERNATIVES TO CRITICAL TECHNOLOGIES



Mission

Identify low-cost, abundant replacement materials for rare earths and technologies that use them more efficiently.

Program Director	Projects	Total Invested
Mark Johnson	14	$22M

Goals

- Eliminate most or all rare earth magnets in electric vehicle motors and wind generators
- Enable widespread use of electric vehicles and wind power

Approaches

- Rare earth free magnetic materials
- Low rare earth content, high Jc superconductors
- Low rare earth content electric machines

Focused Programs

2009-2012: $430M, 14 programs

Each program has about 15 projects

Transportation

Stationary

Electrofuels

BEEST

HEATS

REACT

IMPACCT

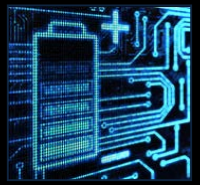
BEETIT

GRIDS

PETRO

MOVE

AMPED



SBIR/STTR

ADEPT

GENI

Solar ADEPT

Success of any organization lies in its people & culture

ARPA-E Director must be recognized scientist/engineer and leader

ARPA-E Director has authority to hire/fire any Program Director "A's hire A's… B's hire C's"

Grueling interview process; Highly selective recruiting Limited Time of 3–5 years in ARPA–E

How would you like to spend $30-60M on solving the nation's most important energy problems?

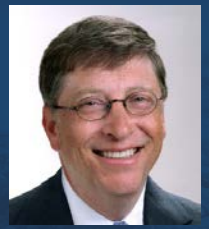
External Strategy

1. Define yourself before others define you – mission, people, culture, operational efficiency, financial integrity, metrics of success
2. ARPA-E Brain Trust: Recruit technology business leaders to have a stake in your success. Create a larger community of stakeholders
3. Partnership with Congress & White House and focus on non-partisan topic – Innovation.
4. Convene the community & enable networking

arpa·e

2012feb27-29
washingtondc

energy innovation summit



Bill Gates
Founder and Chairman
Microsoft

Ursula Burns
Chairman & CEO
Xerox Corp.

Susan Hockfield
President & Professor
Of Neuroscience, MIT

Bill Clinton
Former President of USA

Lee Scott
Former CEO
Walmart

Fred Smith
Chairman, President, and CEO
FedEx Corp.

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