JOINT CENTER FOR ENERGY STORAGE RESEARCH

Becoming Energy Efficient

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Argonne National Laboratory
University of Illinois at Chicago

Outline

Energy Sources and Uses

Transportation and Electricity Grid

Big Energy Changes

Shale, Conventional, Electric and Hydrogen Cars, Wind and Solar Electricity

What Can One Person Do?

Next Generation Batteries

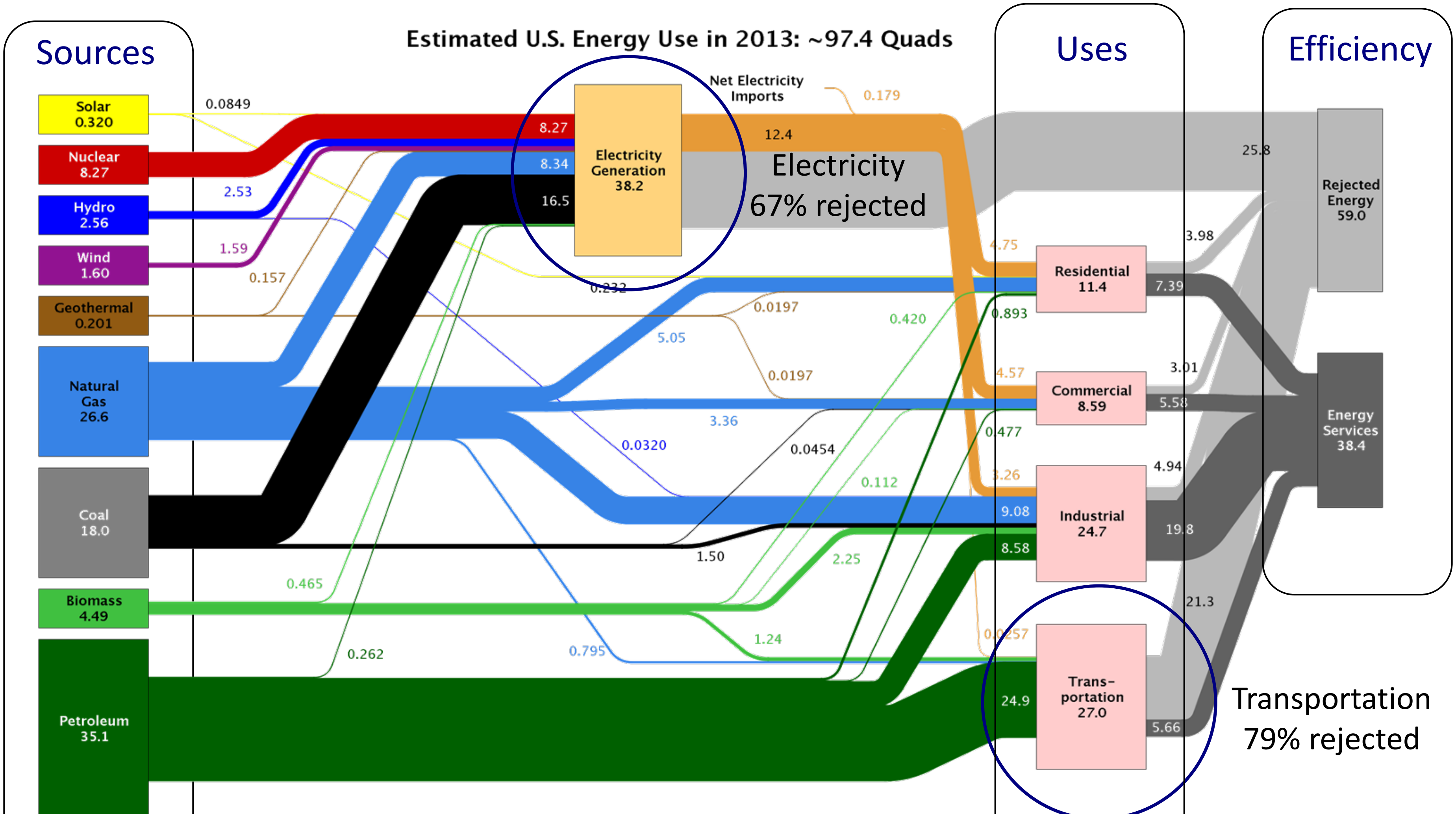
Holland's Energy Future
Holland MI
April 28, 2015

Energy Determines Aspirations and Limitations of Life

Energy

the prime mover of society

US Energy Flow 2013

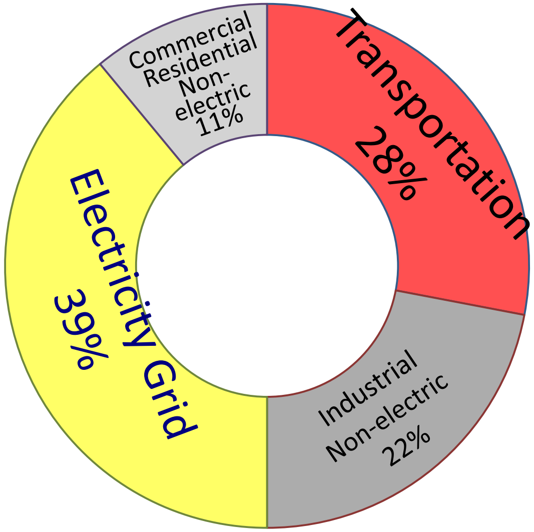


Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-

Energy Use and GHG Emissions

Energy Use 2013

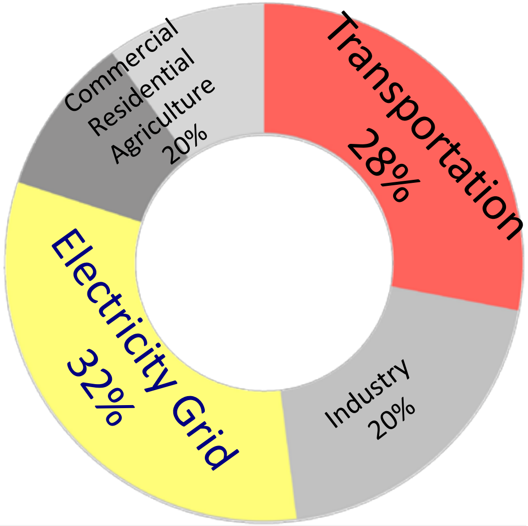
EIA Monthly Energy Review Table 2.1 (May 2014)



GHG Emissions 2012

EPA

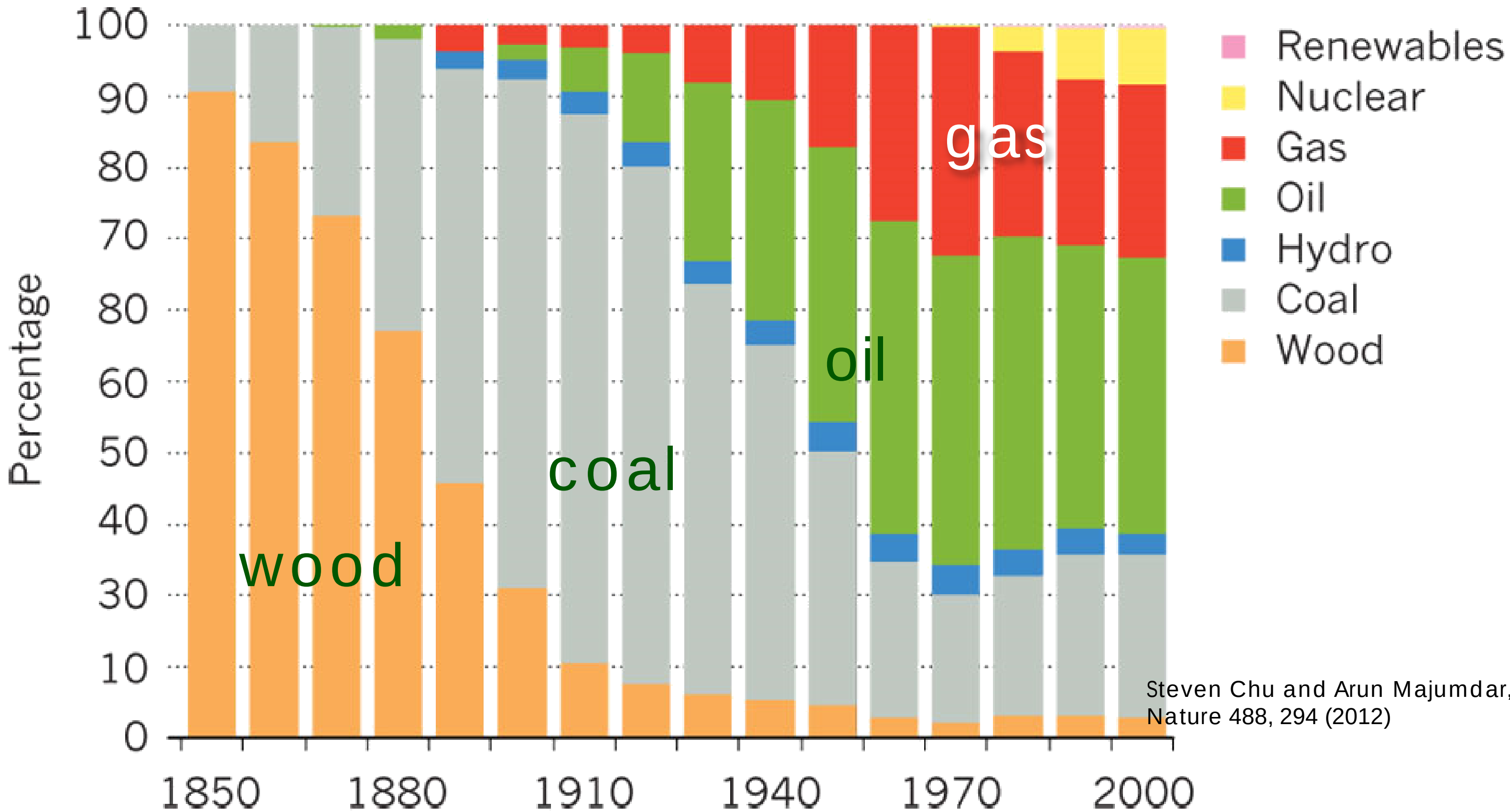
http://www.epa.gov/climatechange/ghgemissions/sources/electricity.html



~ 60% of energy use and GHG emissions from electricity and transportation

The World in Fifty Years . . .

. . . depends on the energy choices we develop now



Steven Chu and Arun Majumdar,
Nature 488, 294 (2012)

fifty years

JCESR

Shale and Hydraulic Fracturing

Abundant world wide sources

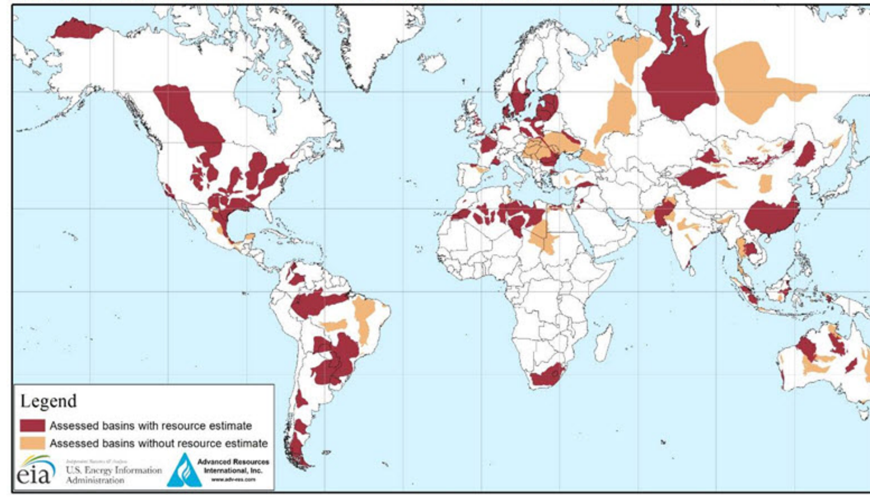
Inexpensive

Lower carbon emissions than coal or oil

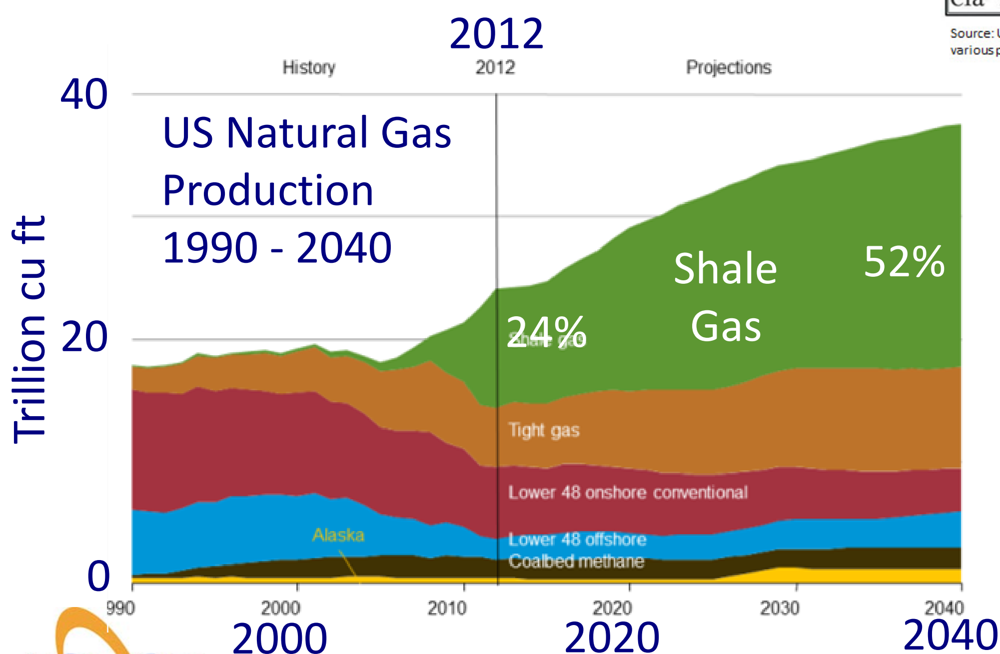
	$/MBTU
peak 05-08:	$12
non-peak 05-08:	$8
Since Jan 2012:	$2 - $4

Source: EIA

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.



Game Changer

lower carbon emissions

energy security

diversity of sources and uses

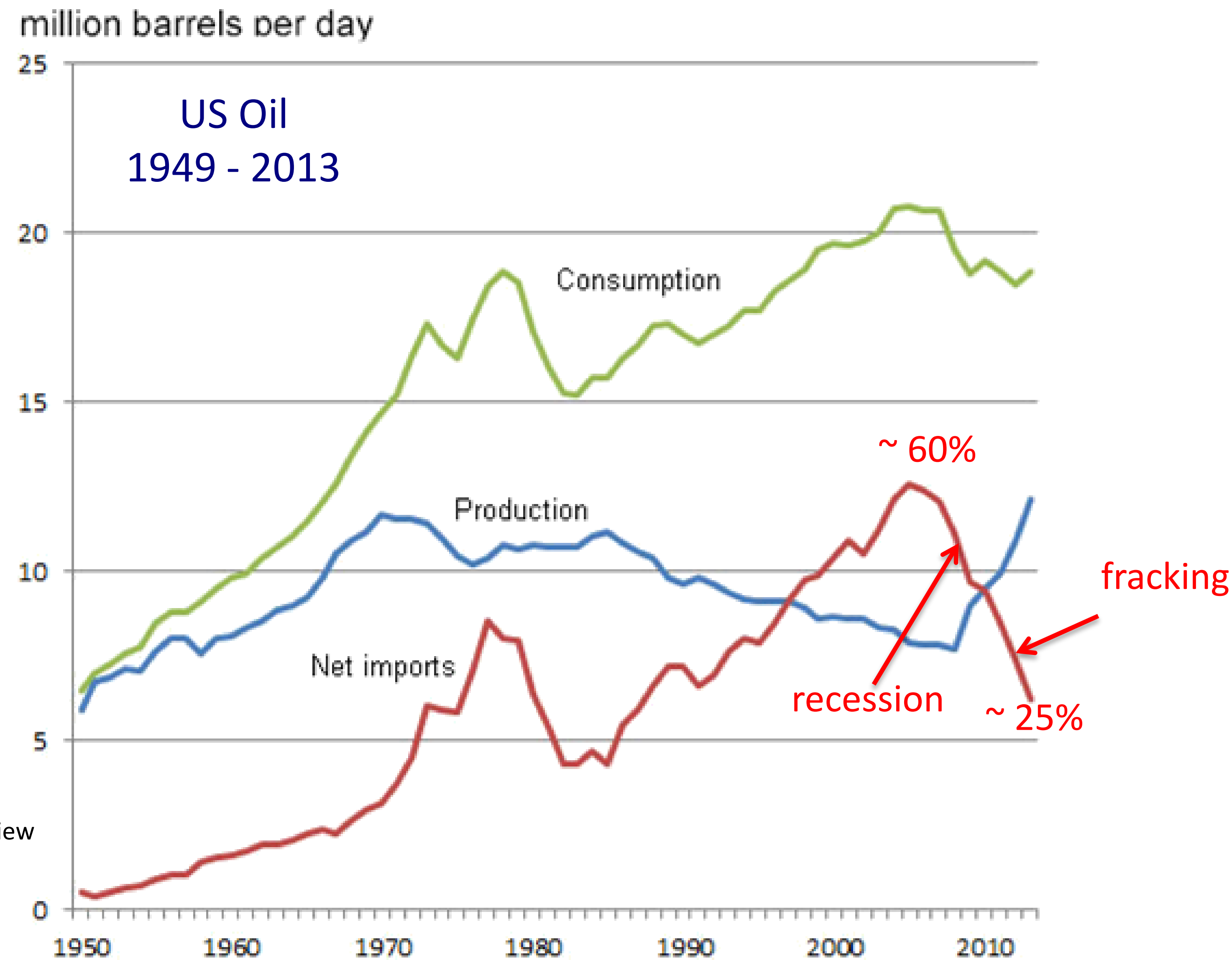
replace coal for power production

oil for transportation

Shale Dramatically Reduces US Oil Imports

Reduces foreign oil imports

Little effect on efficiency



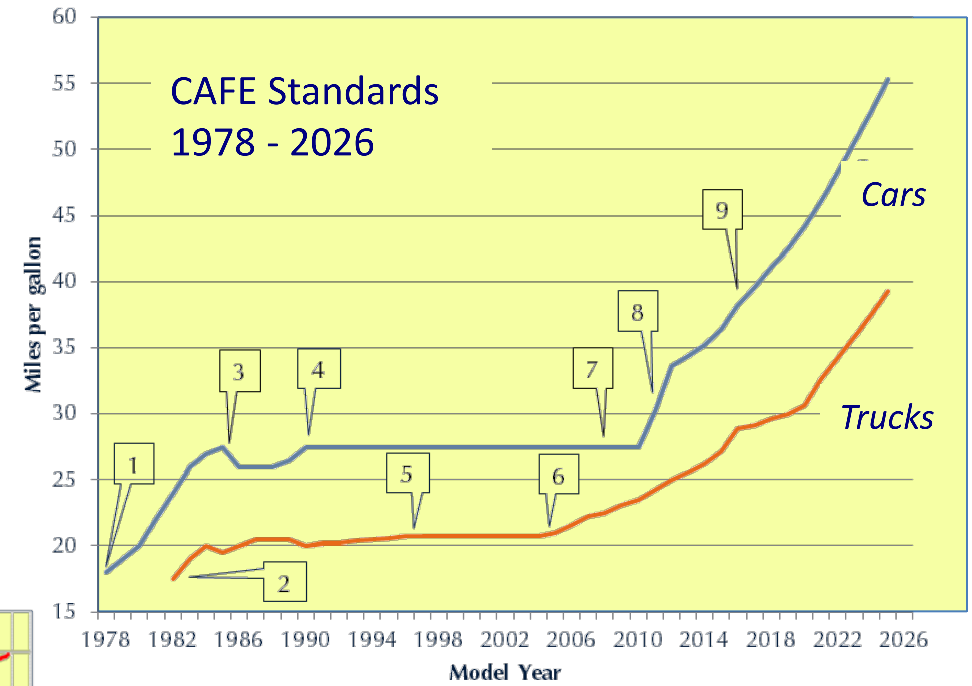
EIA :Monthly Energy Review
Table 3.1 Sep 2014

Conventional Transportation

Trends are positive

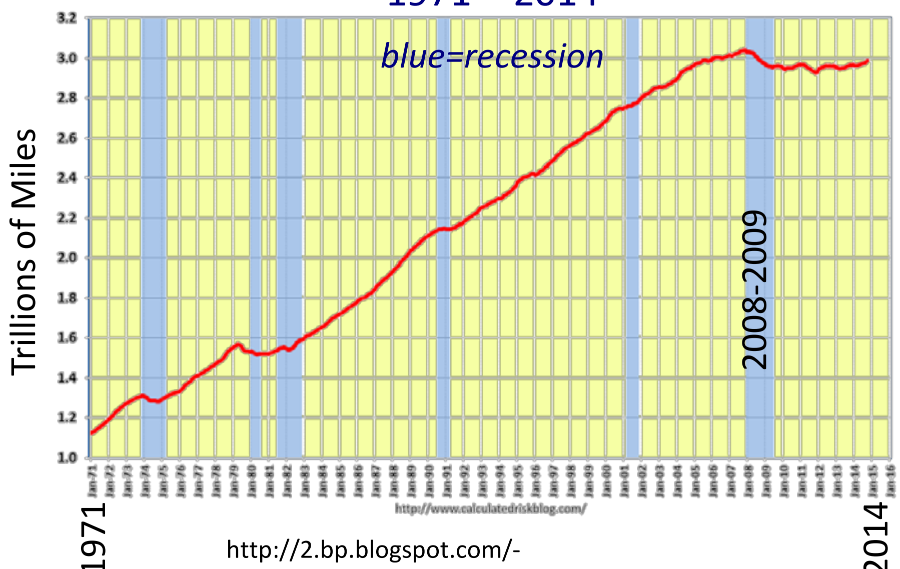
Cars are becoming more efficient

We drive less



http://www.c2es.org/federal/executive/vehicle-standardsAgreement 2ith 13 automakers, Aug 28, 2012

Vehicle Miles Driven
1971 – 2014



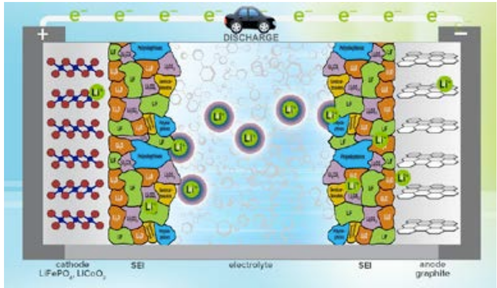
http://2.bp.blogspot.com/-wGRACDgtnC0/U6rny_IFHGI/AAAAAAAAfhI/ybr8m_o1oog/s1600/VehicleMilesApr2014.jpg

Electrified Transportation

Tesla Model S

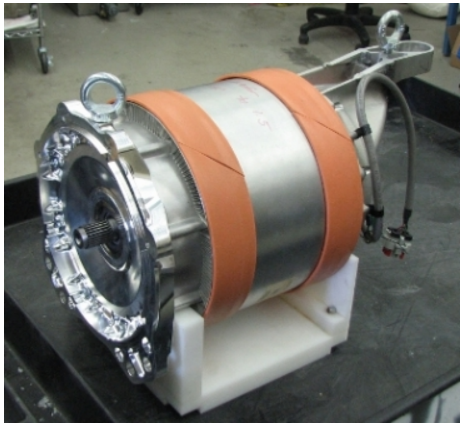
coal, gas electricity production

renewable, nuclear electricity production



battery

electric motor replaces gasoline engine

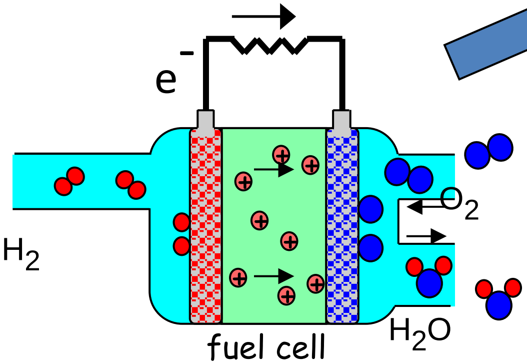


tesla motors

reforming methane CH_4 (todaay)

renewable hydrogen production (tomorrow)

High pressure hydrogen storage

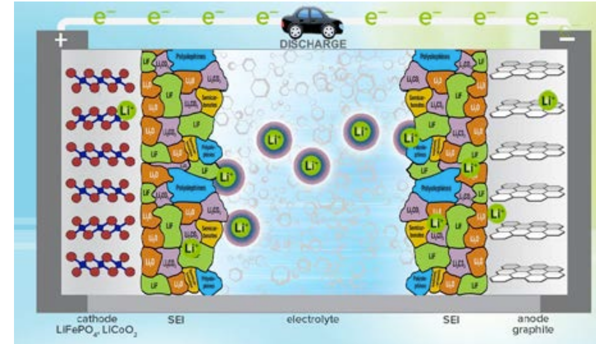


fuel cell

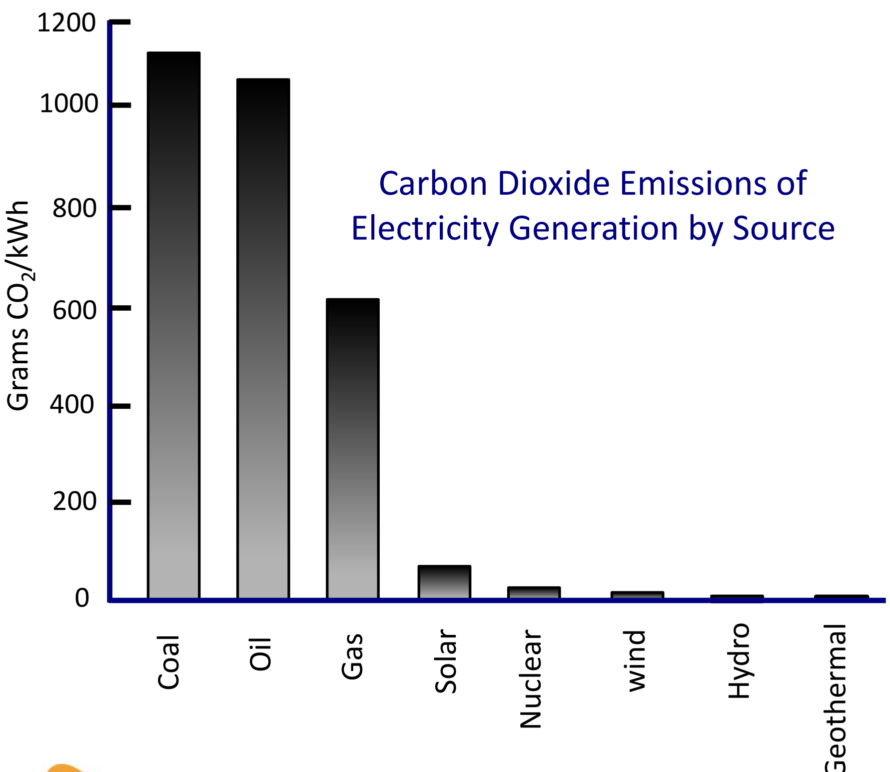
2015 Toyota Mirai Fuel Cell

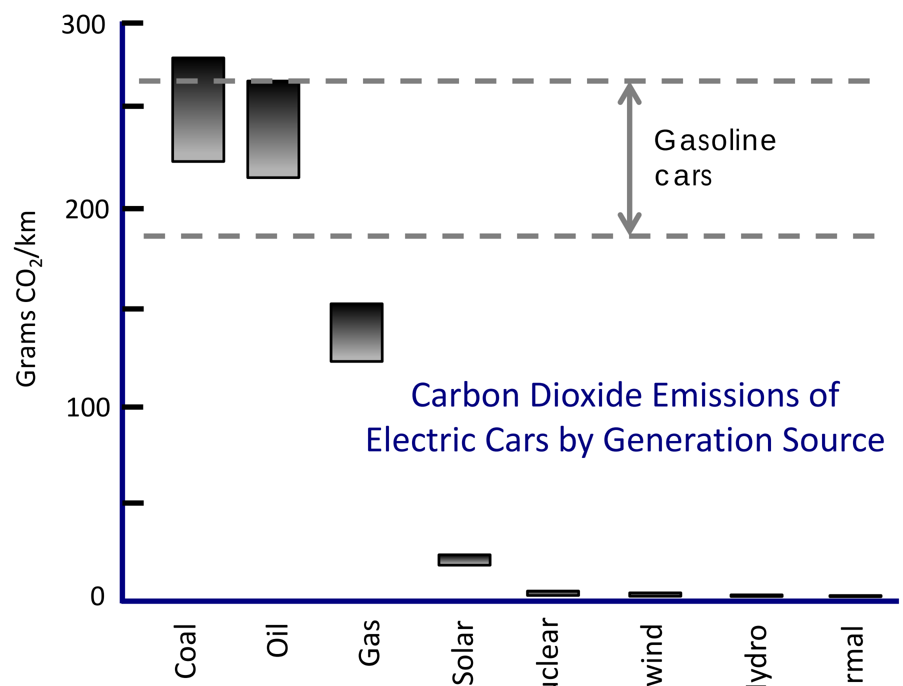
http://www.nytimes.com/2015/04/17/automobiles/hydrogen-fuel-cell-cars-return-for-another-run.html?hp&action=click&pgtype=Homepage&module=mini-moth&region=top-stories-below&WT.nav=top-stories-below

How Much Better are Electric Cars?



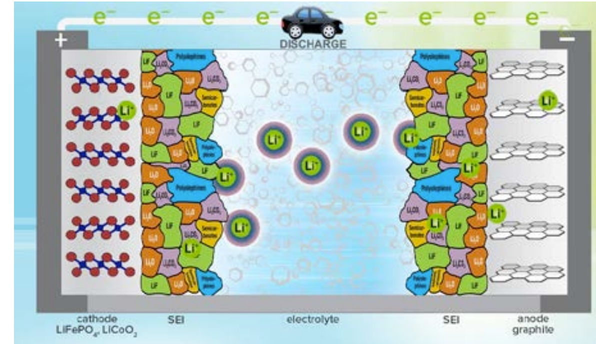
Carbon Dioxide Emissions
Electric vs Gasoline Cars





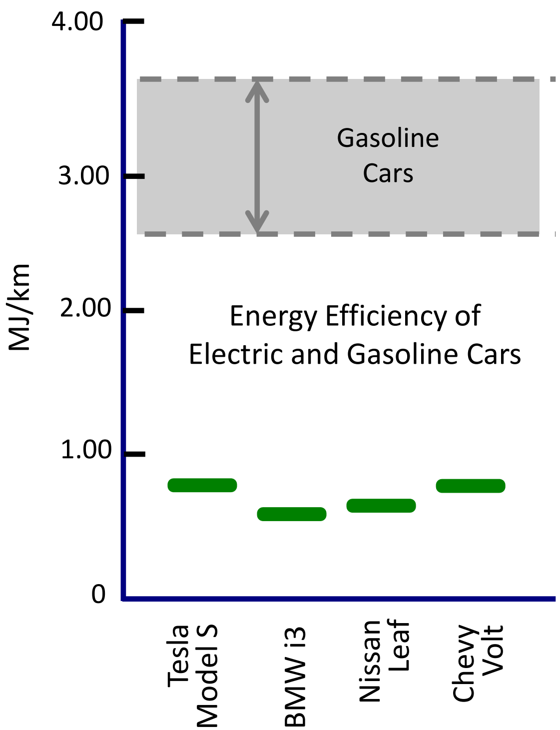
UCS State of Charge (2012)
http://www.ucsusa.org/assets/documents/clean_vehicles/electric-car-global-warming-emissions-report.pdf

How Much Better are Electric Cars?

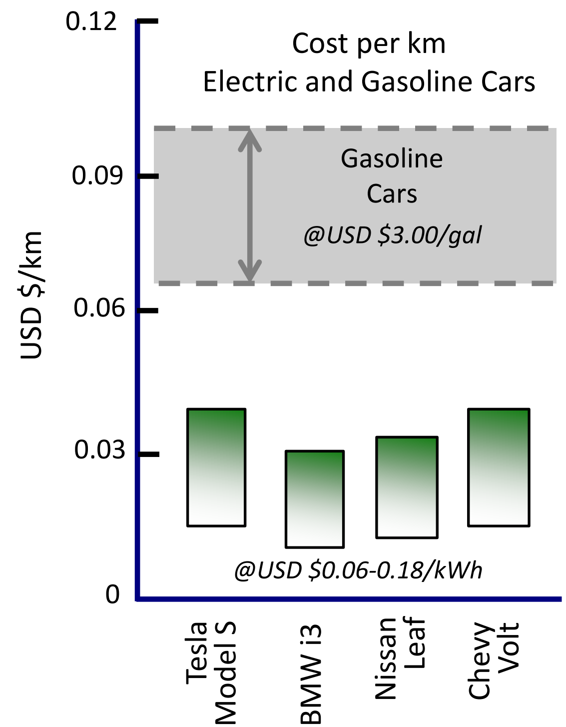


Energy Use and Operating Cost
Electric vs Gasoline Cars

Energy Use



Operating Cost



http://www.fueleconomy.gov/feg/findacar.shtml

Electric Car Challenges

Range

Chevy Volt: 38 miles on single charge
Nissan Leaf: 84 miles on single charge
BMW i3 81 miles on single charge
Tesla Model S: 208 miles on single charge

Honda Accord: 533 miles on single tank

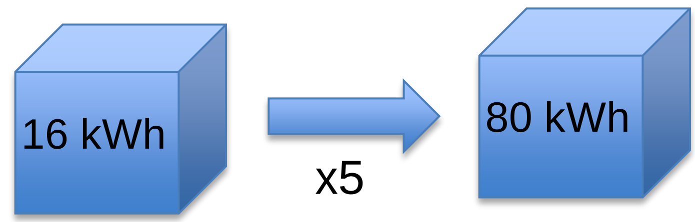
Purchase Price (2015)

Chevy Volt: $34 170 – $36 700
Nissan Leaf: $29 010 - $35 120
BMW i3: $42 400 - $46 250
Tesla Model S: $69 900

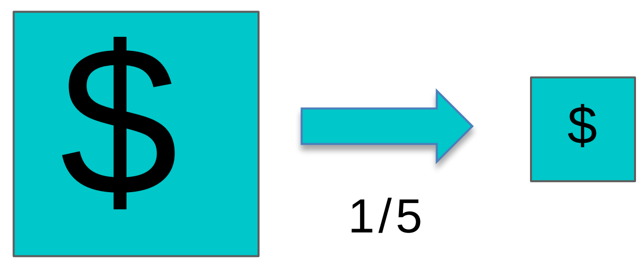
Honda Accord: $22 105 - $33 630

Added cost driven by large batteries

5x higher battery energy density



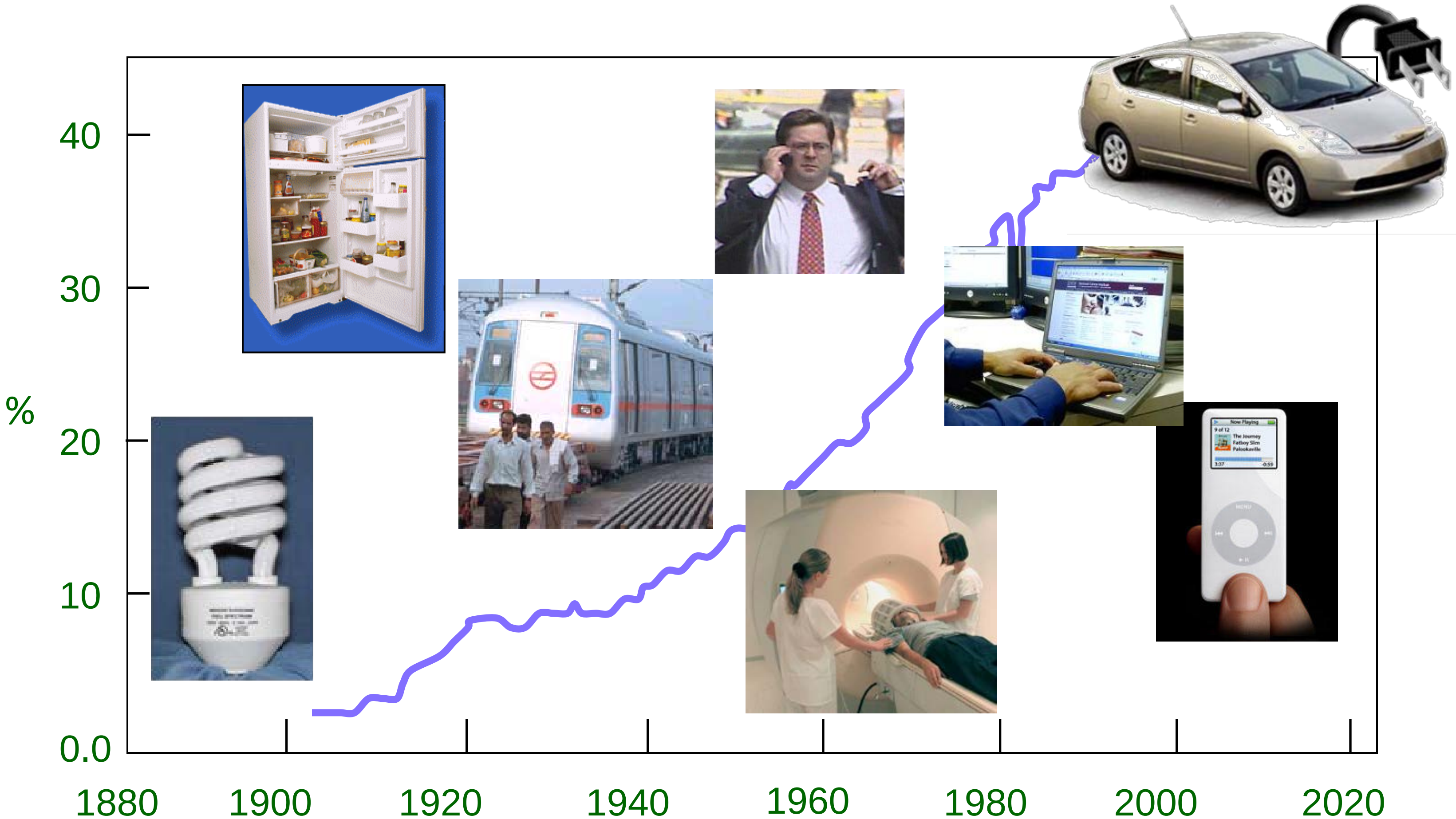
5x lower battery cost



http://www.fueleconomy.gov/feg/findacar.shtml
http://www.cars.com/

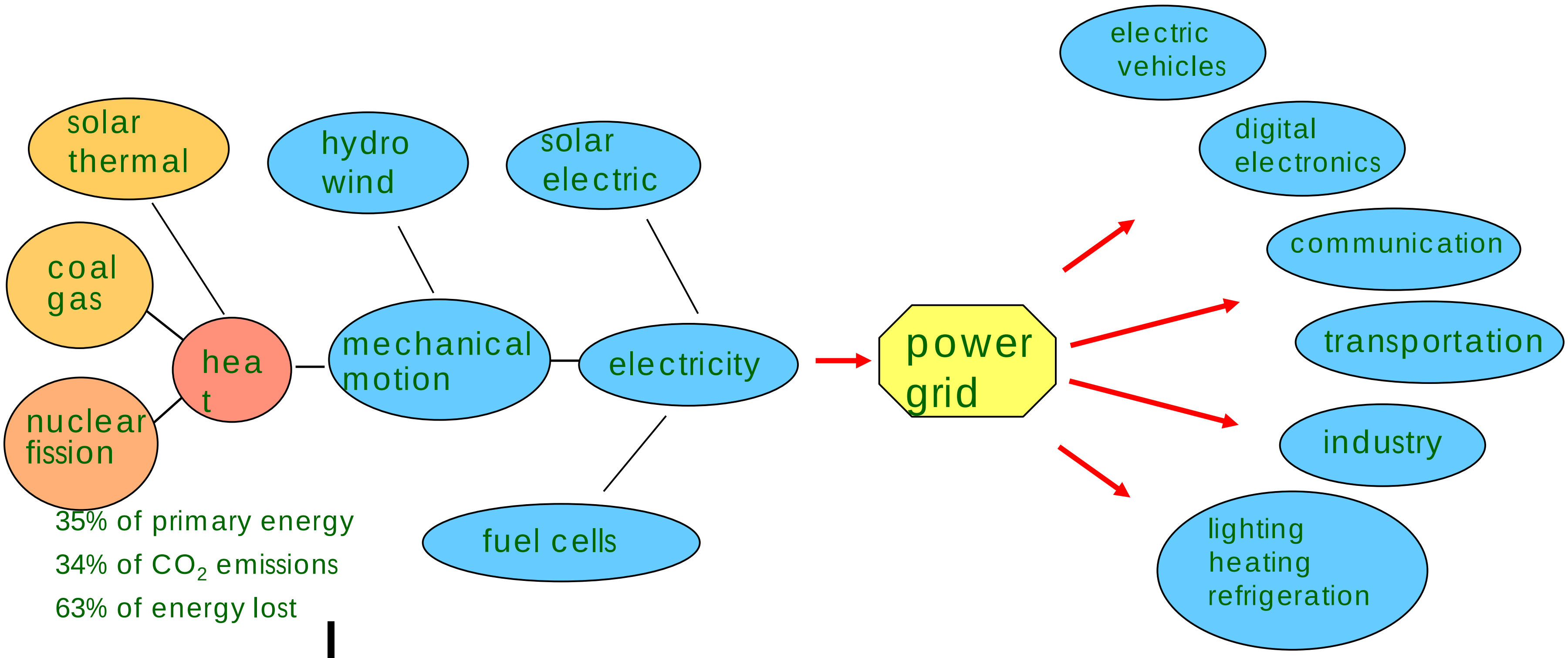
Electricity - the Great Enabler

40% of US primary energy devoted to electricity production



source: EPRI

Electricity as a Sustainable Energy Carrier



35% of primary energy

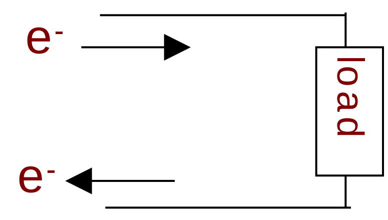
34% of CO_2 emissions

63% of energy lost

clean, efficient, versatile

accommodates many sources and uses

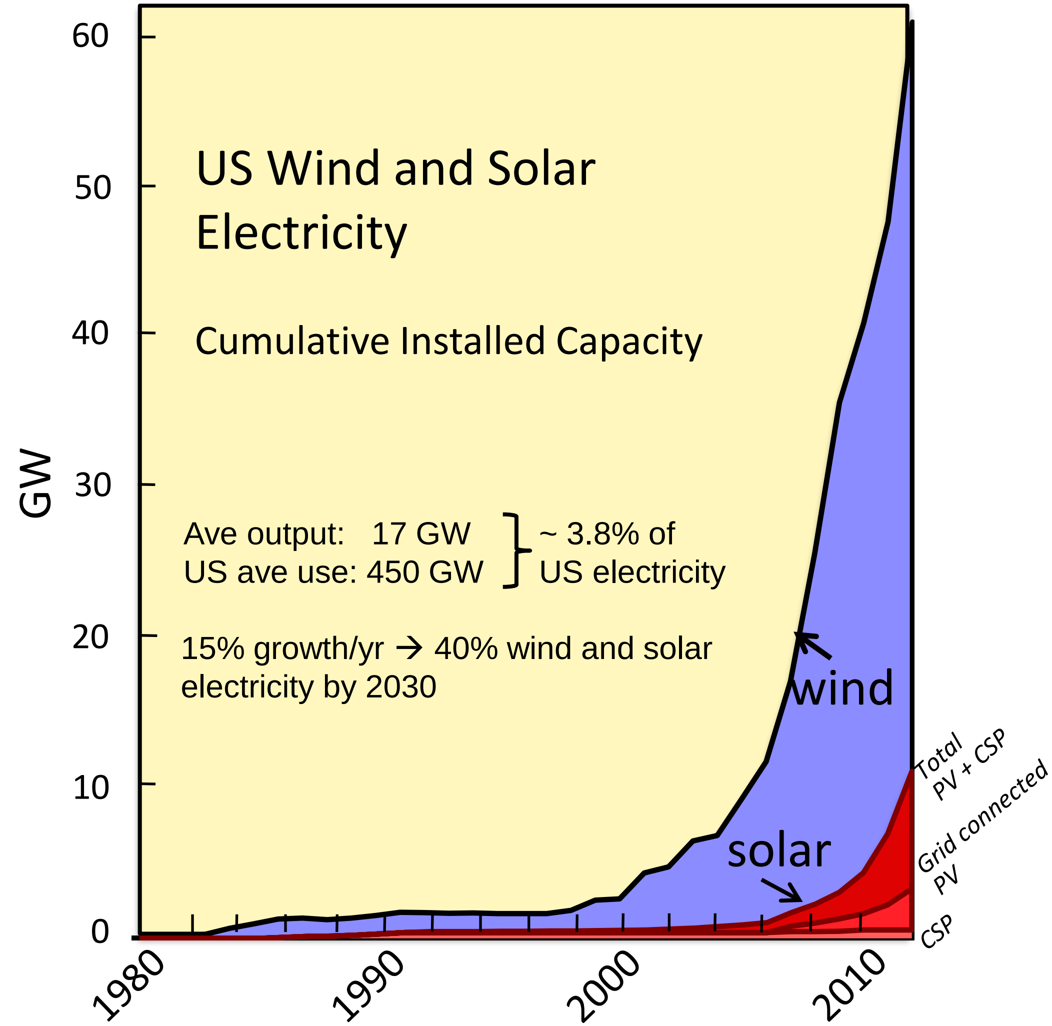
fossil and renewable



Wind and Solar Electricity

✓ Stable climate

✓ Energy security



Viable technologies

on deployment path

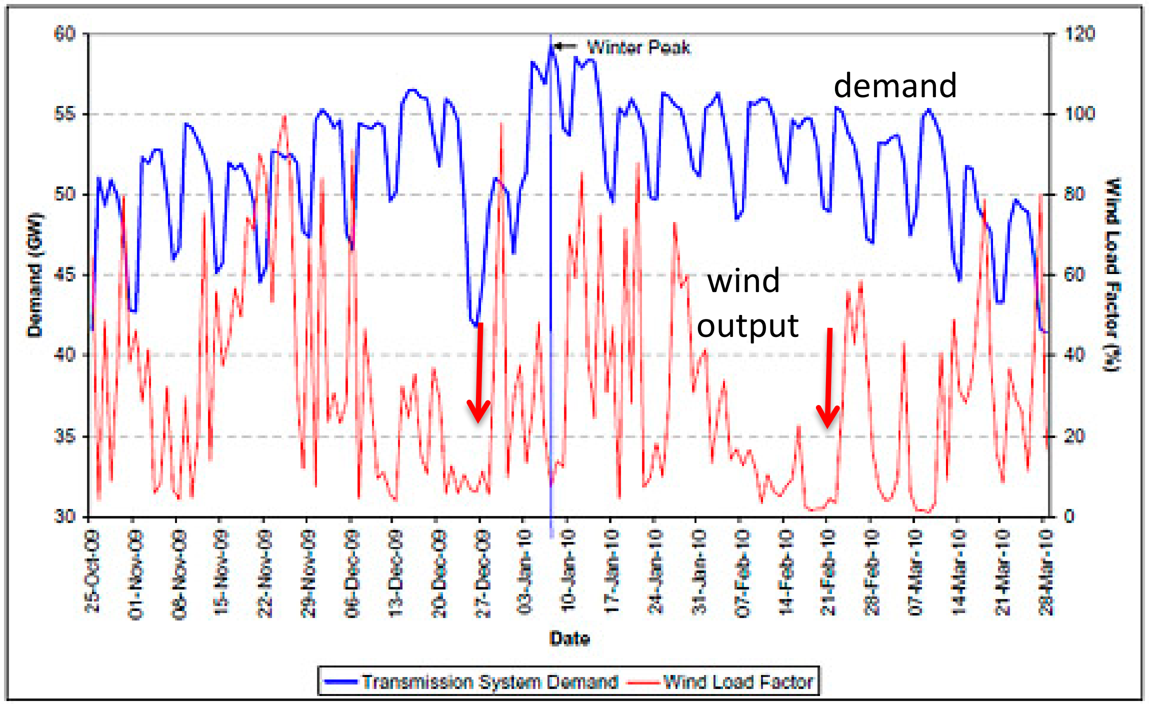
Remaining science challenges

improve efficiency

lower cost

Energy Storage Enables Variable Wind and Solar Generation

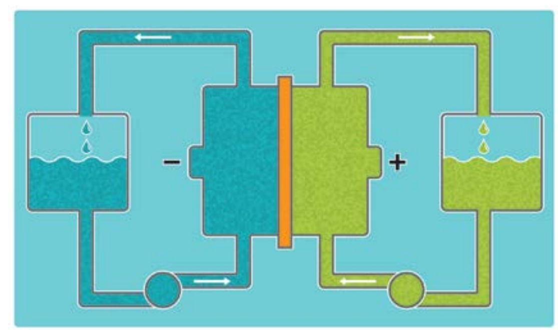
Figure A.30 – 2009/10 Daily Peak and Wind Generation



http://www.windbyte.co.uk/windpower.html

gas plant

Back up the wind farm with



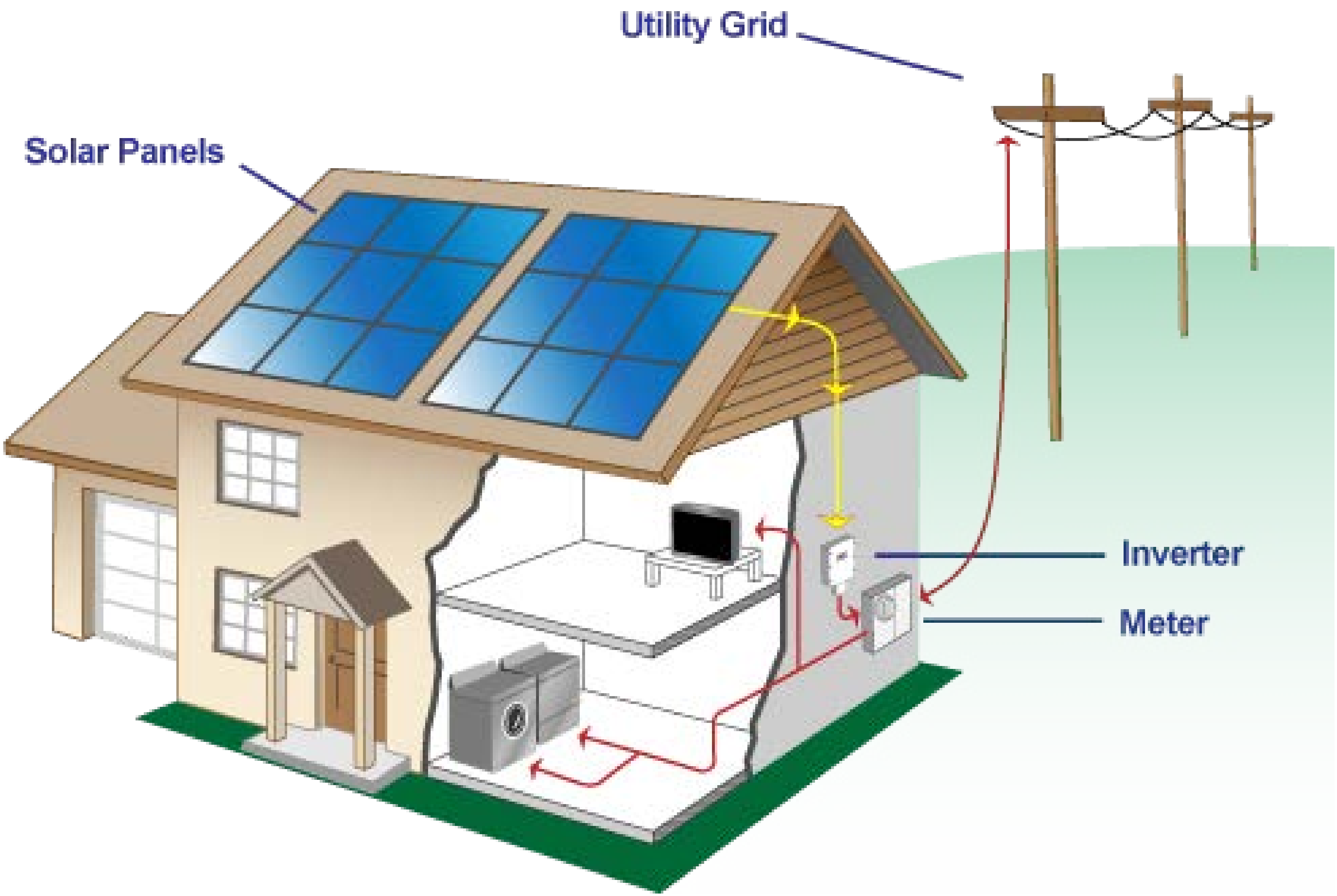
battery $ = 5x gas plant $

One or two calm days per month

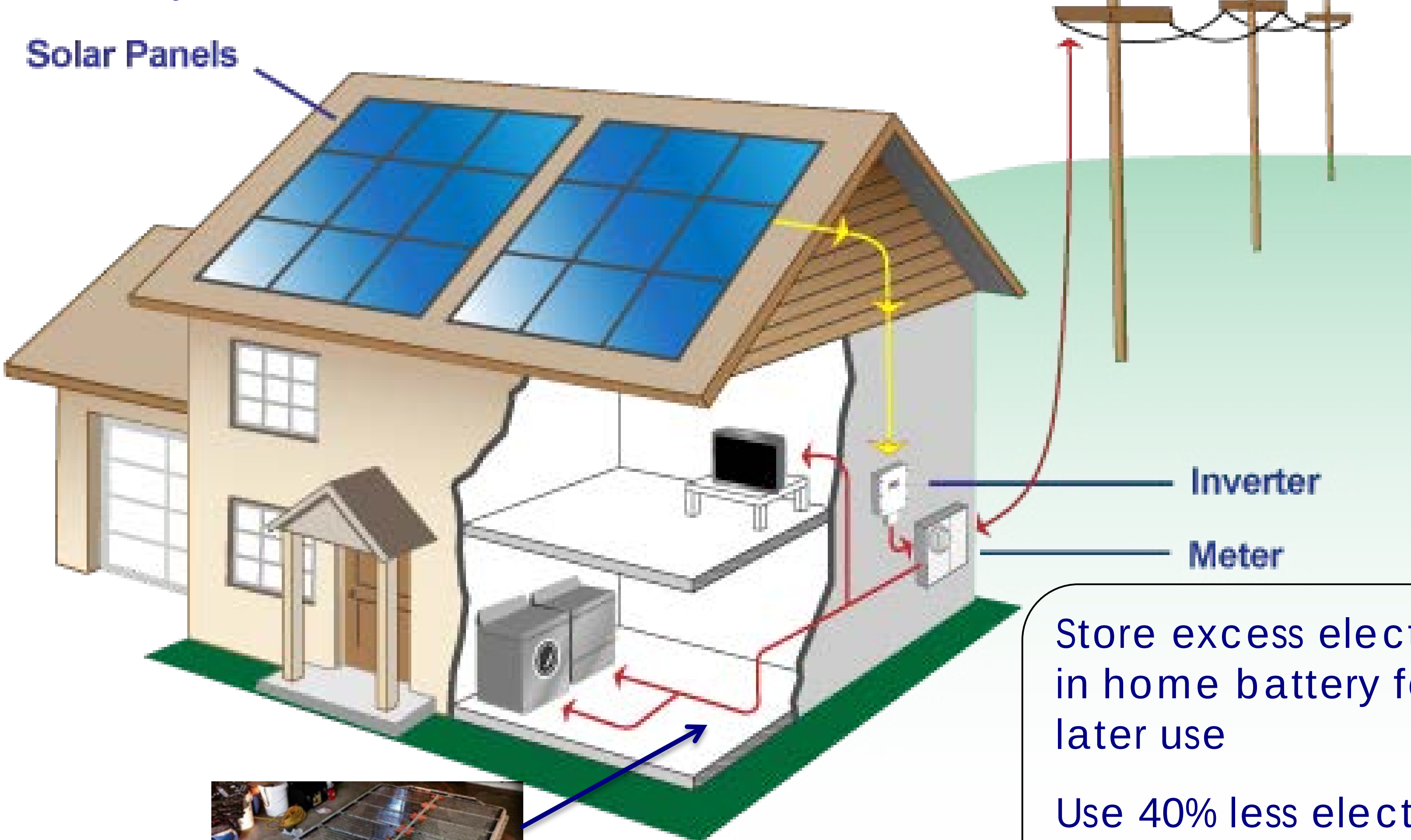
Wind stronger at night

Wind does not follow diurnal pattern

Conventional Solar House



Solar Panel on Roof
Battery in Basement



Store excess electricity in home battery for later use

Use 40% less electricity from grid

Home Battery

http://www.autoevolution.com/news/first-images-with-teslas-home-battery-leaked-could-be-rated-at-more-than-400-kwh-94019.html

JCESR

What Can One Person Do?


Solar panels


Geothermal heating and cooling

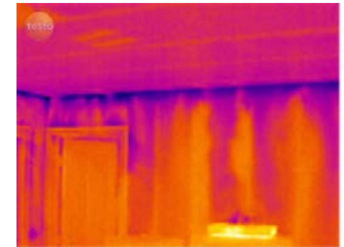


1929 Colonial house

Scorecard 2014:
coldest winter in history
of Chicago

From the grid: 3883 kWh
To the grid: 5760 kWh

Net zero energy house and car?



Weatherizing



Efficient appliances


Chevy Volt


Tesla Model S

JCESR Has Transformative Goals

TRANSPORTATION

$100/kWh

400 Wh/kg 400 Wh/L

800 W/kg 800 W/L

1000 cycles

80% DoD C/5

15 yr calendar life

EUCAR

GRID

$100/kWh

95% round-trip efficiency at C/5 rate

7000 cycles C/5

20 yr calendar life

Safety equivalent to a natural gas turbine

Vision

Transform transportation and the electricity grid with high performance, low cost energy storage

Mission

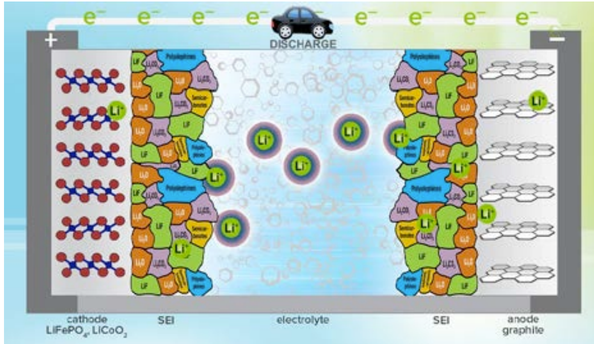
Deliver electrical energy storage with five times the energy density and one-fifth the cost of today's commercial batteries within five years

Legacies

- **A library of the fundamental science** of the materials and phenomena of energy storage at atomic and molecular levels
- **Two prototypes, one for transportation and one for the electricity grid**, that, when scaled up to manufacturing, have the potential to meet JCESR's transformative goals
- **A new paradigm for battery R&D** that integrates discovery science, battery design, research prototyping and manufacturing collaboration in a single highly interactive organization

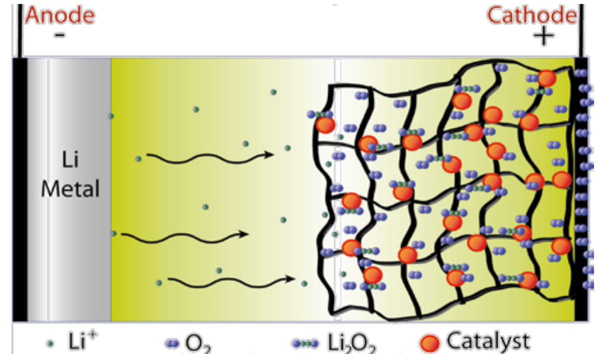
JCESR: Focus exclusively on beyond lithium-ion batteries

JCESR's Beyond Lithium-ion Concepts



Lithium-ion "Rocking Chair"

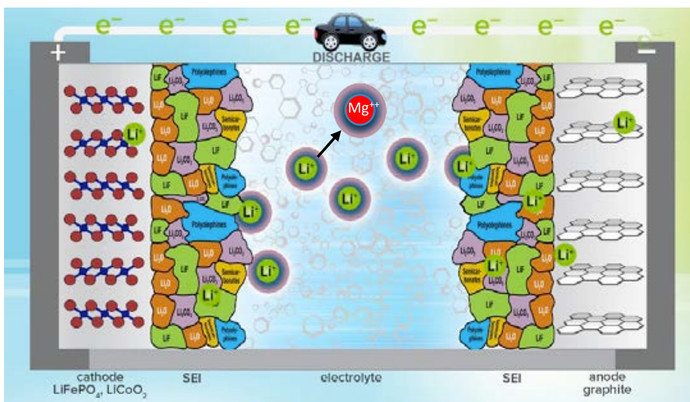
Li^+ cycles between anode and cathode, storing and releasing energy



Black, Adams, Nazar, Adv. Energy Mater 2, 801 (2012)

Chemical Transformation

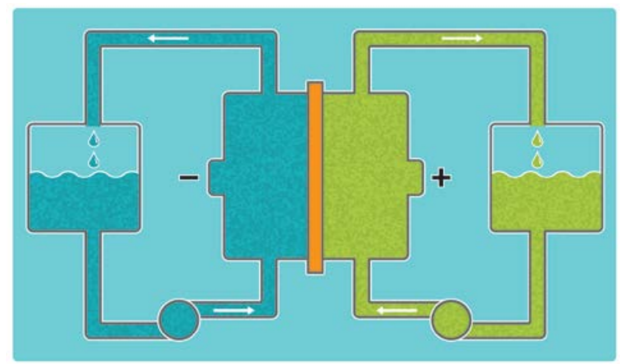
Replace intercalation with high energy chemical reaction: Li-S, Li-O, Na-S, . . .



Multivalent Intercalation

Replace monovalent Li^+ with di- or tri-valent ions: Mg^{++}, Al^{+++}, . . .

Double or triple capacity stored and released



Non-aqueous Redox

Replace solid electrodes with liquid solutions or suspensions: lower cost, higher capacity, greater flexibility

JCESR

Argonne NATIONAL LABORATORY

Further Reading

In Press: *Physics of Sustainable Energy III: Using Energy Efficiently and Producing It Renewably*, edited by R. H. Knapp et al, AIP Conference Proceedings (Number ***), Melville, New York, 2014.

The Joint Center for Energy Storage Research: A New Paradigm for Battery Research and Development

George Crabtree

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Abstract. The Joint Center for Energy Storage Research (JCESR) seeks transformational change in transportation and the electricity grid driven by next generation high performance, low cost electricity storage. To pursue this transformative vision JCESR introduces a new paradigm for battery research: integrating discovery science, battery design, research prototyping and manufacturing collaboration in a single highly interactive organization. This new paradigm will accelerate the pace of discovery and innovation and reduce the time from conceptualization to commercialization. JCESR applies its new paradigm exclusively to beyond-lithium-ion batteries, a vast, rich and largely unexplored frontier. This review presents JCESR's motivation, vision, mission, intended outcomes or legacies and first year accomplishments.

Keywords: energy storage, batteries, materials science, electrochemistry, solvation
PACS: 61, 66, 68, 71, 72, 73, 81, 82, 88

OVERVIEW

Transportation and the electricity grid account for two-thirds of U.S. energy use [1]. Each of these sectors is poised for transformation driven by high performance, low cost electricity storage. The Joint Center for Energy Storage Research (JCESR) pursues discovery, design, prototyping and commercialization of next generation batteries that will realize these transformational changes. High performance, low cost electricity storage will transform transportation through widespread deployment of electric vehicles; it will transform the electricity grid through high penetration of renewable wind and solar electricity and a new era of grid operation free of the century-old constraint of matching instantaneous electricity generation to instantaneous demand. It is unusual to find transformational change in the two largest energy sectors driven by a single innovation: high performance, low cost energy storage.

These transformative outcomes for transportation and the electricity grid require electricity storage with five

Review Article

https://anl.app.box.com/s/wixxv7f3mg9ev3t926rc

http://arxiv.org/abs/1411.7042

Video: Employee Spotlight
Chemical Engineer and Postdoctoral Researcher Damla Eroglu seeks to create new breakthrough energy storage technology. Learn more »

JCESR Accomplishments
JCESR Director, George Crabtree, published a detailed description of JCESR accomplishments. Learn more »

Events
October 21 Event Wrap Up UIUC JCESR Symposium: Integrating Energy Storage on the Grid Learn more »
November 5 NY-BEST JCESR Technical Conference Buffalo, New York Learn more »

JCESR First Year Accomplishments

In its first year, the JCESR partnership has moved from launch to full operation and is now producing groundbreaking research.

MORE

Video: Employee Spotlight
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Webpage

http://www.jcesr.org/

Further Reading Fifty Year Energy

ELSEVIER

http://ei.phy.uic.edu/resources/energy_science_society.pdf

JCESR

Perspective

More on JCESR website
www.jcesr.org

Vision: Transform transportation and electricity grid with high performance, low cost energy storage

Mission: Deliver electrical energy storage with five times the energy density and one-fifth the cost

→ Beyond lithium ion

Legacies:

A library of the fundamental science of the materials and phenomena of energy storage at atomic and molecular levels

Two prototypes, one for transportation and one for the electricity grid, that, when scaled up to manufacturing, have the potential to meet JCESR's performance and cost goals

A new paradigm for battery R&D that integrates discovery science, battery design, research prototyping and manufacturing collaboration in a single highly interactive organization

- A bold new approach to battery R&D
- Accelerate the pace of discovery and innovation
- Bring the community to the beyond lithium-ion opportunity

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