U.S. DEPARTMENT OF ENERGY | Office of Science

Energy Independence with Sustainability

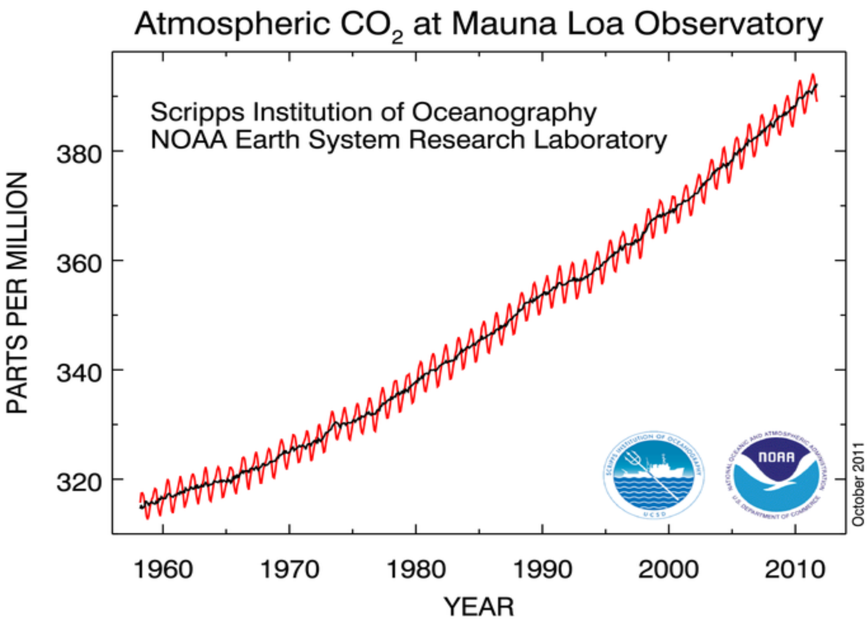
American Geophysical Union Fall Meeting

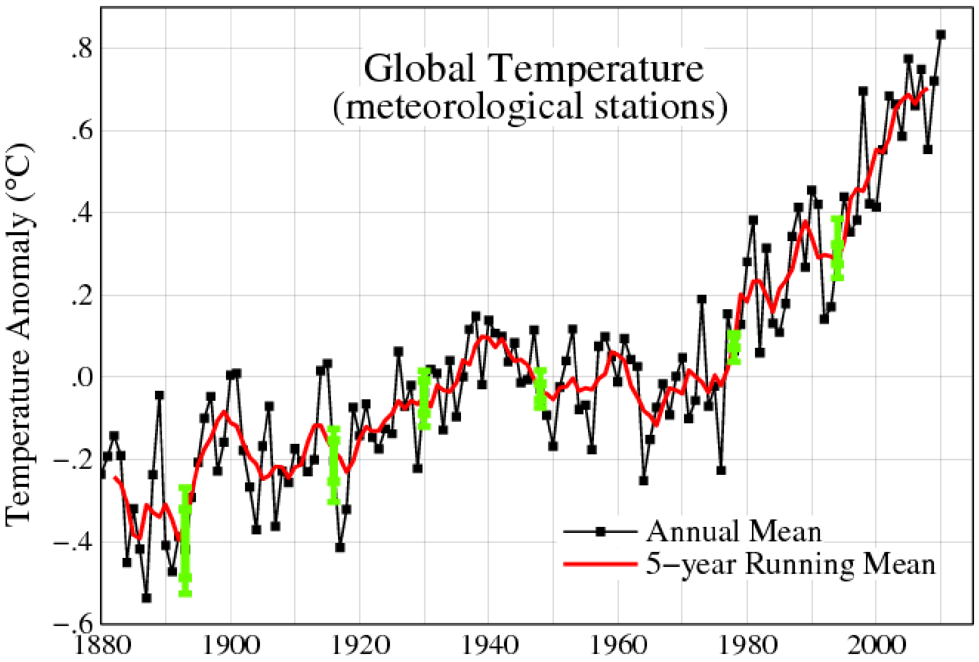
December 4, 2012

Dr. W. F. Brinkman
Director, Office of Science
U.S. Department of Energy

science.energy.gov

Innovations in Energy Technology must address CO_2 Issue

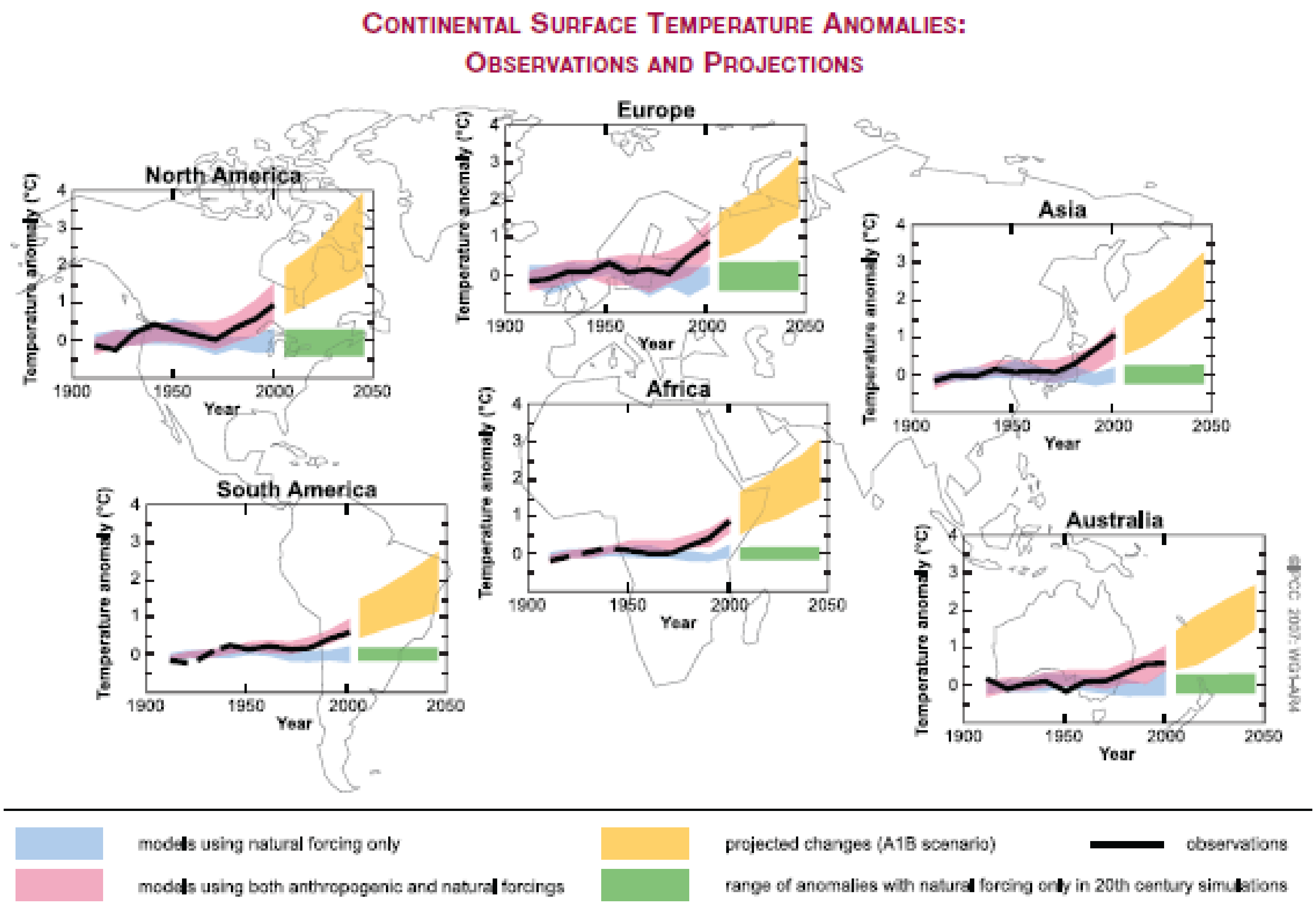




Anomaly is deviation from 1951-1980 mean

NASA GISS, update of Hansen et al., *J. Geophys. Res.*, 106, 23947-23963, 2001

Models capture observed regional temperature warming

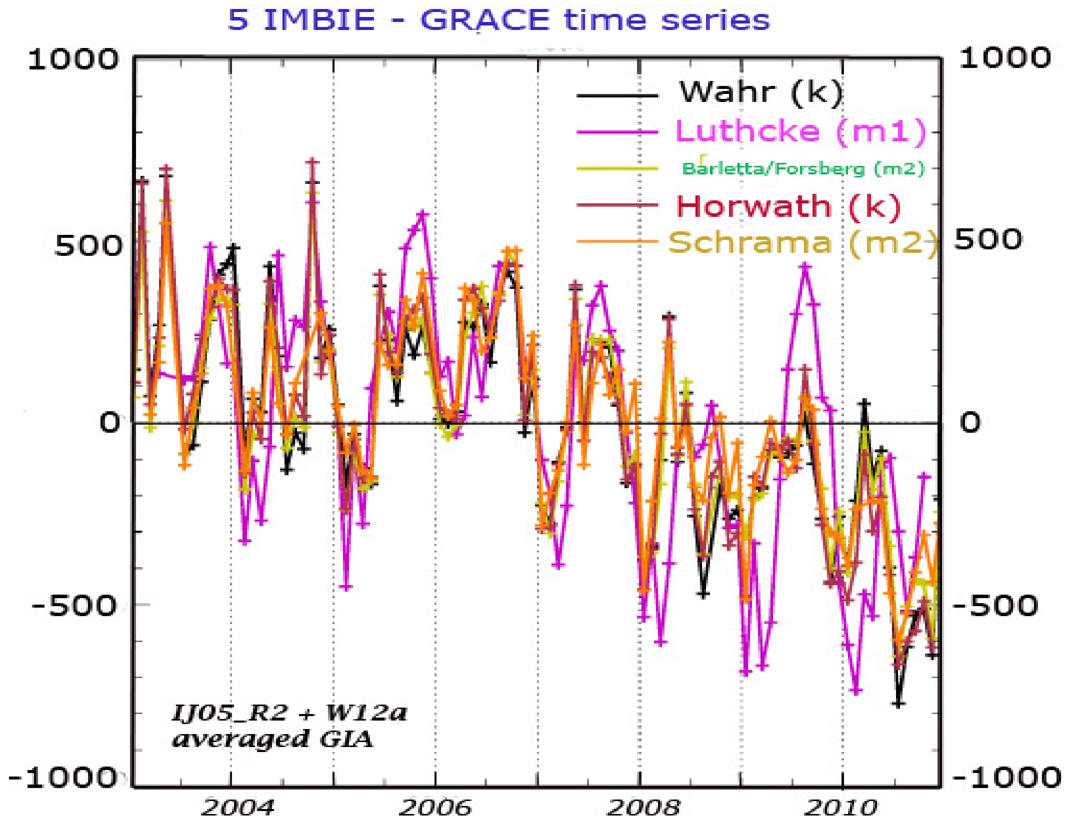


Anthropogenic forcings needed to simulate obs

IPCC 4th Assessment

Ice Sheet Mass Loss – 2003 to 2011

Ice Sheet Mass Balance Inter-comparison Exercise (IMBIE)



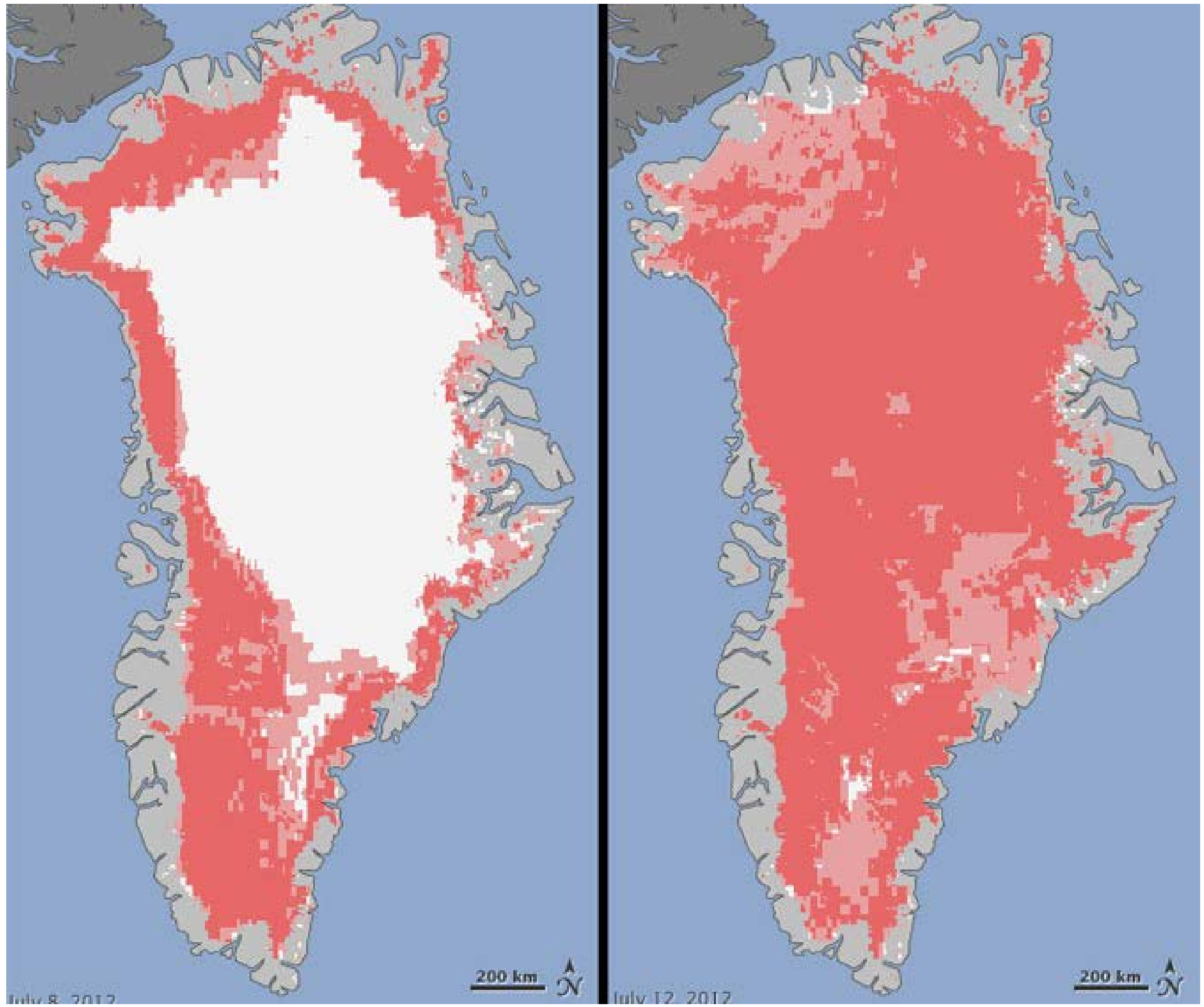
Monthly changes in Antarctic ice mass, in gigatons, as measured by NASA's Gravity Recovery and Climate Experiment (GRACE) satellites from 2003 to 2011.

Satellites See Unprecedented Greenland Ice Sheet Surface Melt in July

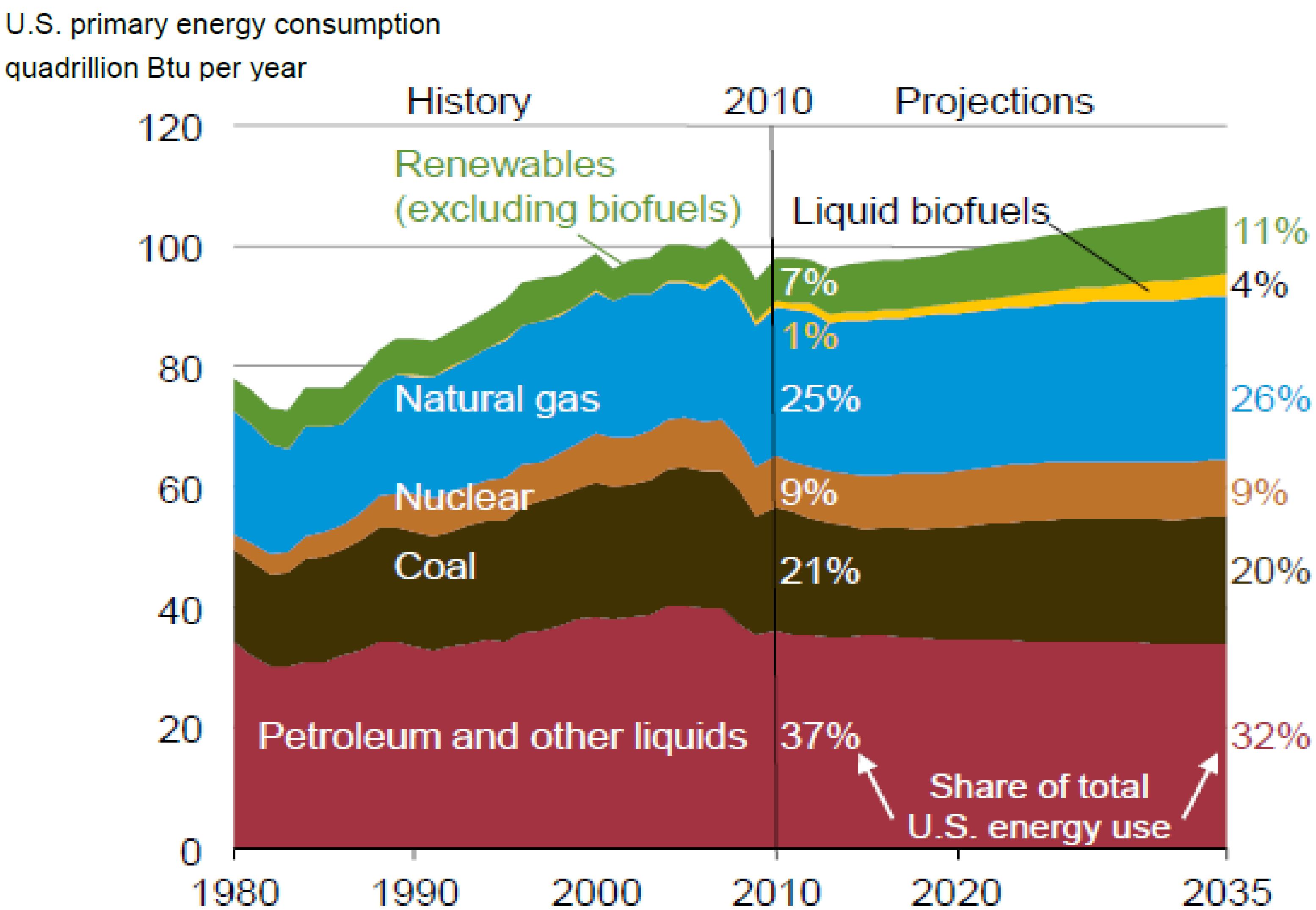
White – no melt
Light pink – probable melt
Pink - melt

July 8 – 40 percent of ice sheet surface thawed

July 12 - 97 percent of ice sheet surface thawed



US energy consumption by source



EIA Annual Energy Outlook 2012, Fig. 73

Growth in Wind Drives Growth in Renewables

Figure 100. Nonhydropower renewable electricity generation capacity by energy source, including end-use capacity, 2010-2035 (gigawatts)

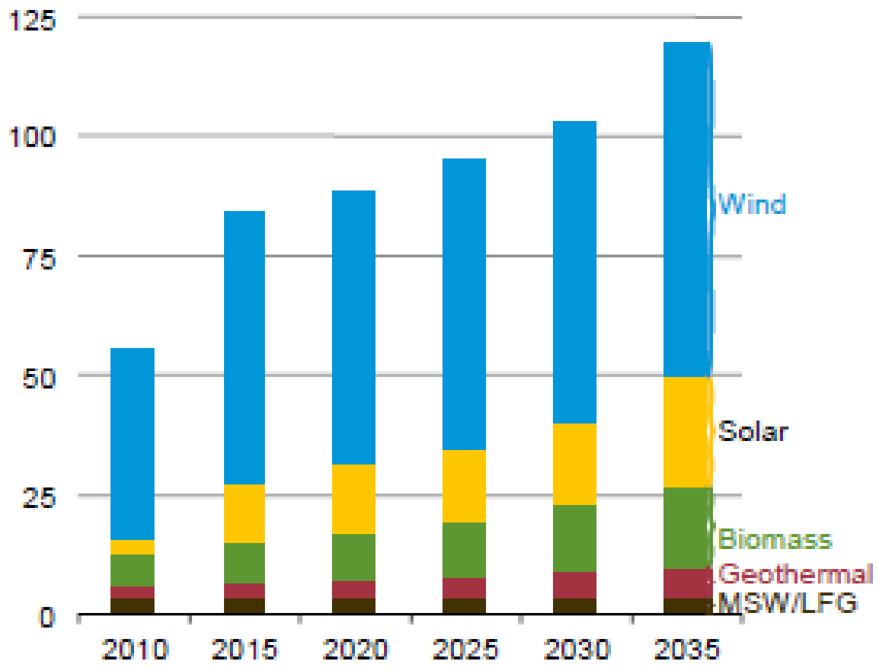
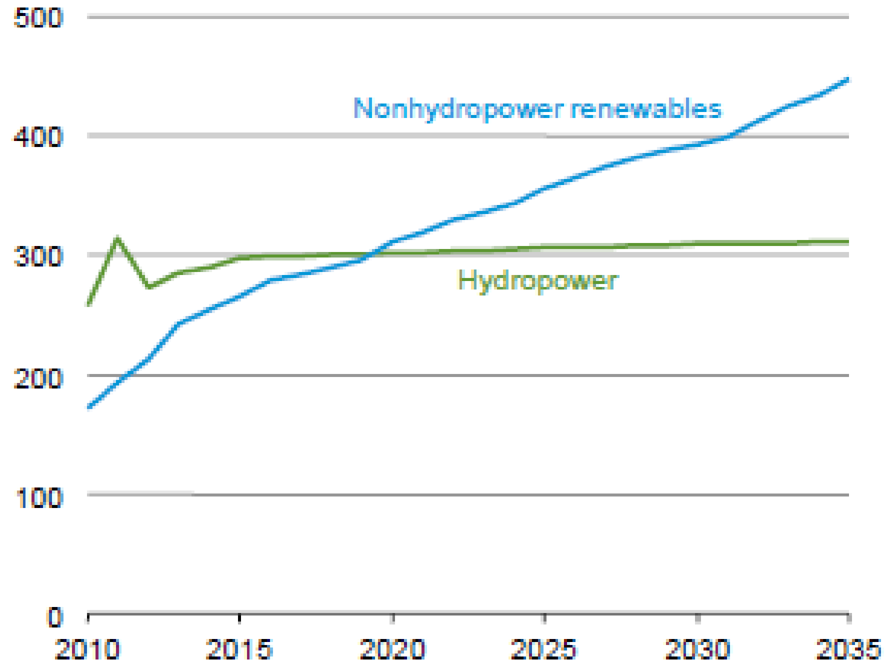


Figure 101. Hydropower and other renewable electricity generation, including end-use generation, 2010-2035 (billion kilowatthours)



So what can we do?

Lots of solutions but
the real issue is competitive costs
and economic viability

Driving toward more coordinated approach across the department in several important areas:

Solar: Sunshot*

Small Reactors*

CCUS*

Fuel Cells

Biofuels

Geothermal*

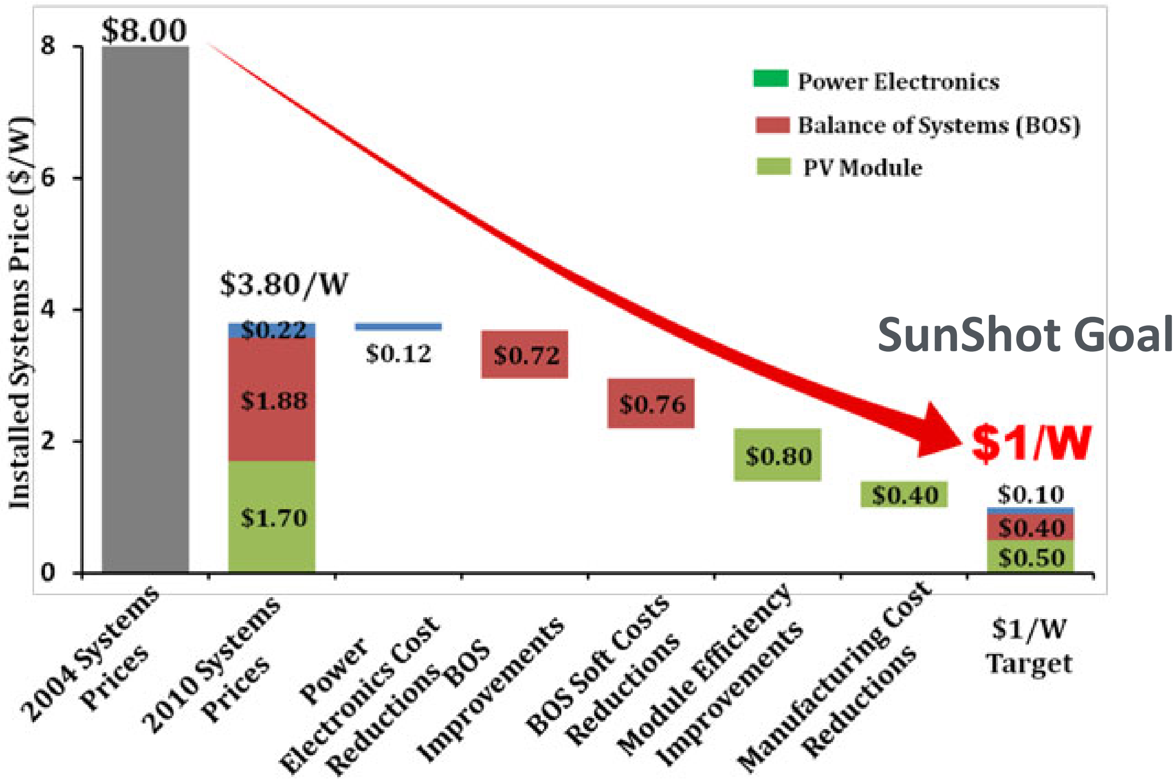
GRID

Fusion*

Wind

Batteries*

• The DOE-EERE SunShot Initiative is a collaborative national initiative to make solar energy cost competitive with other forms of energy by the end of the decade and restore U.S. leadership in the global clean energy race



Agua Caliente Solar Project (First Solar)

Yuma, AZ

290 MW
(550 MW
in 2014)

When completed, It will
- power ~ 100,000 homes per year
- displace ~ 220,000 metric tons of CO_2 annually
  (equivalent of taking ~40,000 cars off the road).

http://www.cleanenergyactionproject.com/CleanEnergyActionProject/CS.Agua_Caliente_Solar_Project___Thin_Film_Photovoltaic_Solar_Power_Case_Studies.html

Geothermal

How can we further tap the Earth as an energy source?

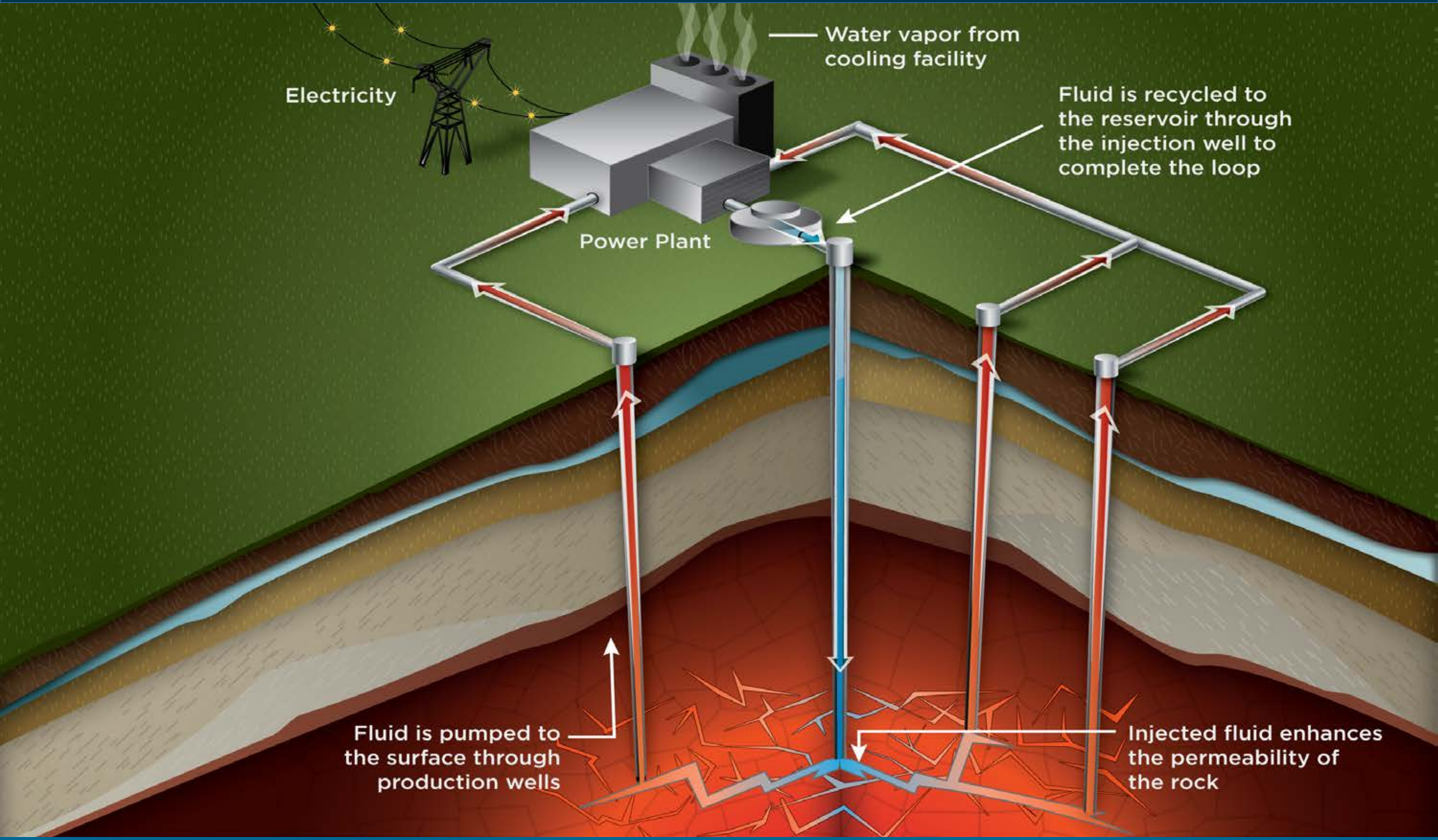
Enhanced geothermal systems?

Enhanced Geothermal Systems

The Future: Creating power from hot, tight rocks

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

EGS uses advanced technologies to access the heat of the earth and produce electricity.

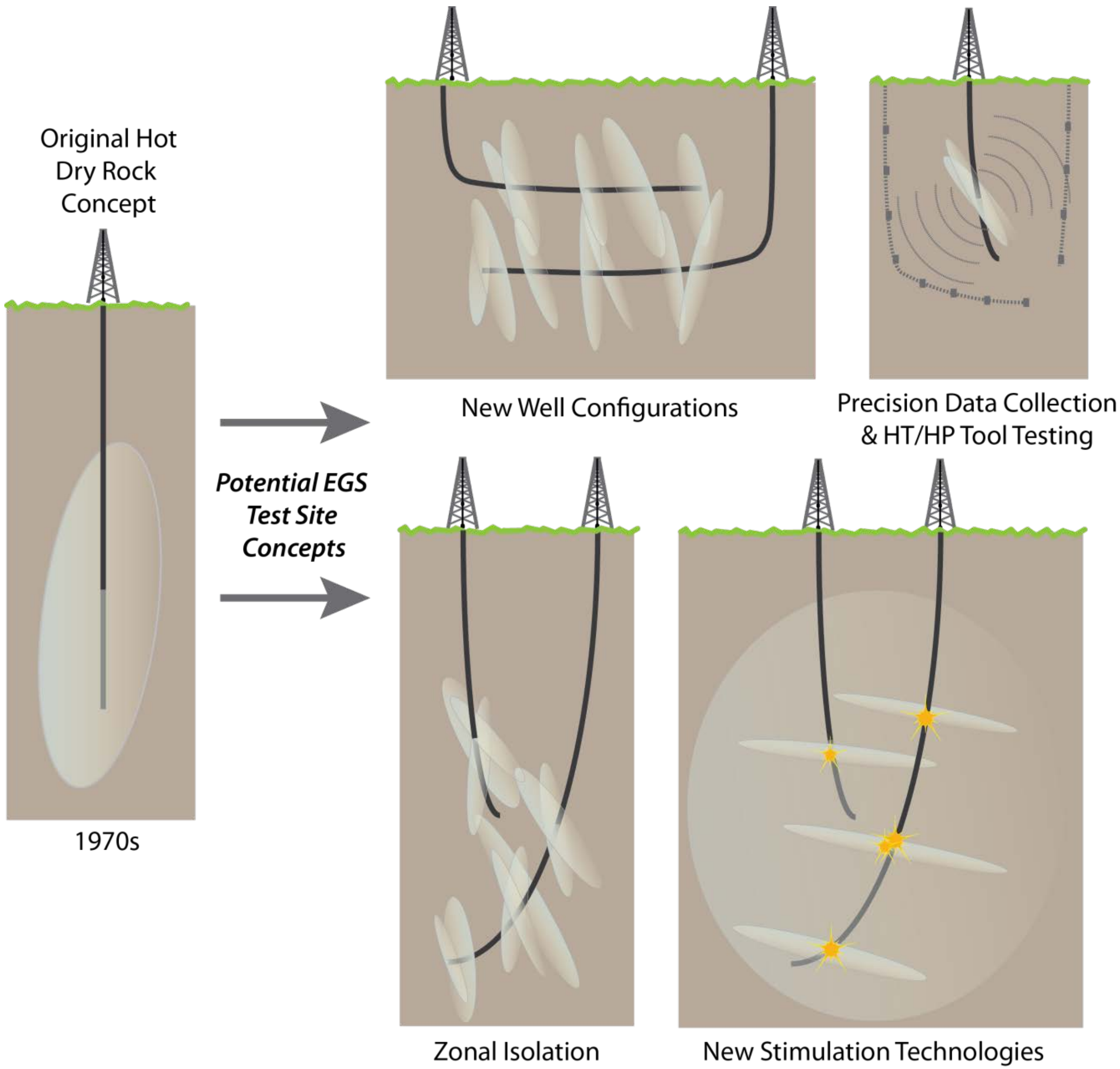


Targeting 1st-ever:

- Horizontal geothermal wells
- Multi-stage stimulations
- Long term Hi-T/Hi-P tool and technique testing
- Highly controlled modern R&D and data collection

Initial activity planned FY14-FY15

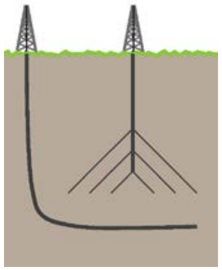
- Private sector cannot / will not take on risk or costs alone
- Pathway to achieving 100+ GWe potential



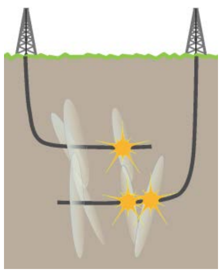
Key Barriers to EGS Development

Technology and Engineering Needs

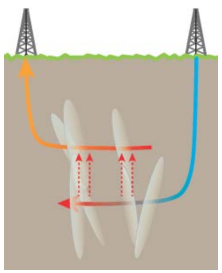
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



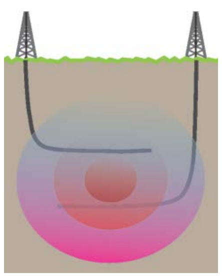
Reservoir Access
New well geometries and concepts, optimized drilling



Reservoir Creation
Characterize local stress, zonal isolation, novel fracturing methods, increase fractured volume per well



Productivity
Increase flow rates without excessive pressure needs or flow localization



Sustainability
Maintain productivity with minimal thermal drawdown and water losses

- Hard/Hot-rock drilling, completion technologies
- Horizontal wells – a first for geothermal
- Rotary steering
- Stress-field diagnostics
- Smart tracers
- Modeling
- High-T sensors
- Cross-well monitoring
- Diverter technologies

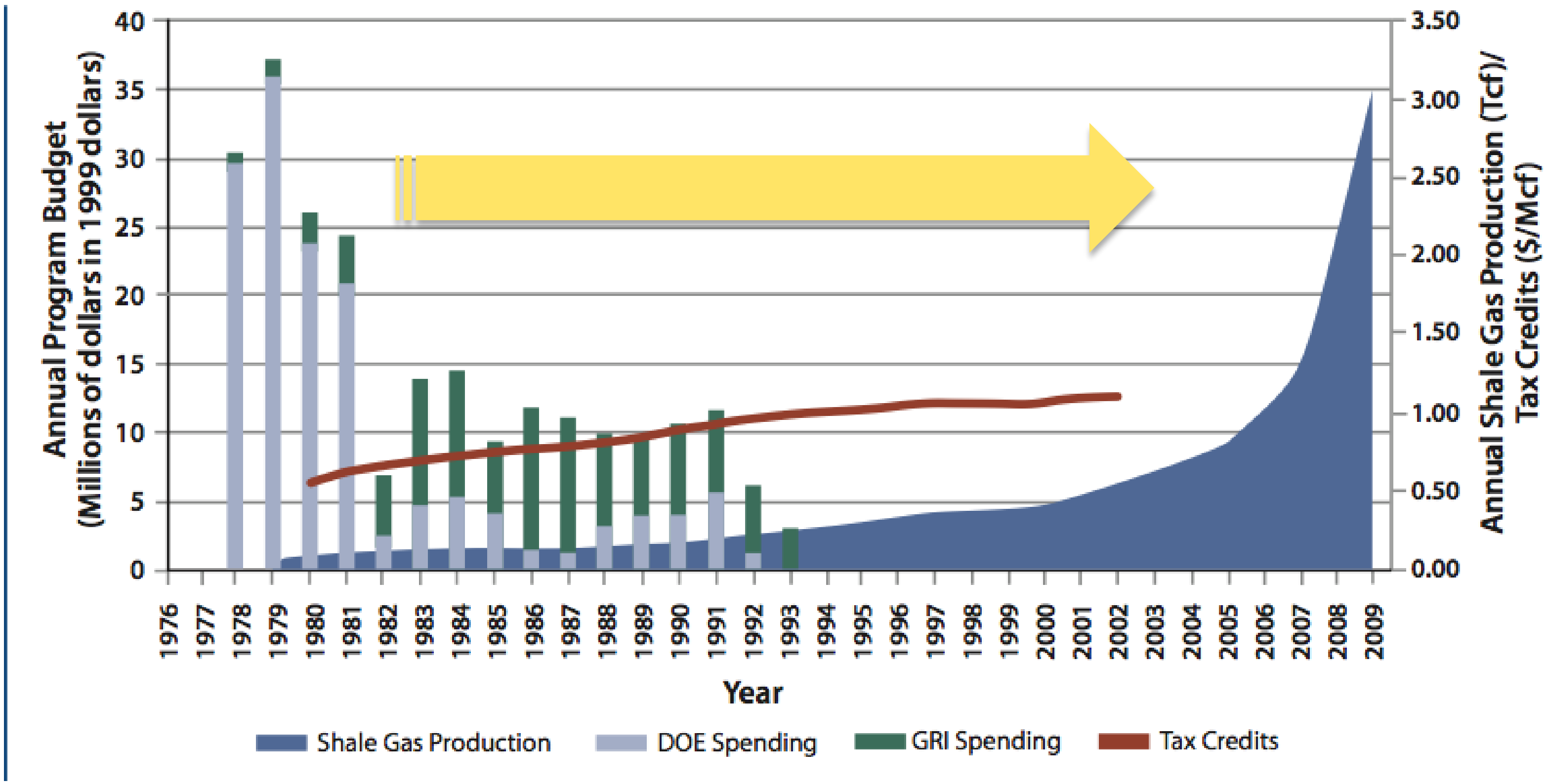
Optimized Reservoirs

Shale Gas and EGS: *Impact of RD&D and Policy*

*Over 25 years of government and private investment in shale gas RD&D and supporting policy mechanisms were necessary to have a "material impact"**

Will similar investment in enhanced geothermal techniques have a similar impact?

Figure 8.2 Shale Gas RD&D Spending and Supporting Policy Mechanisms



* from the MIT report titled, *The Future of Natural Gas,* available at http://web.mit.edu/mitei/research/studies/natural-gas-2011.shtml c

Where are we going in batteries

Nickel Metal Hydrides and Li ion batteries are the mainstream.

What about--

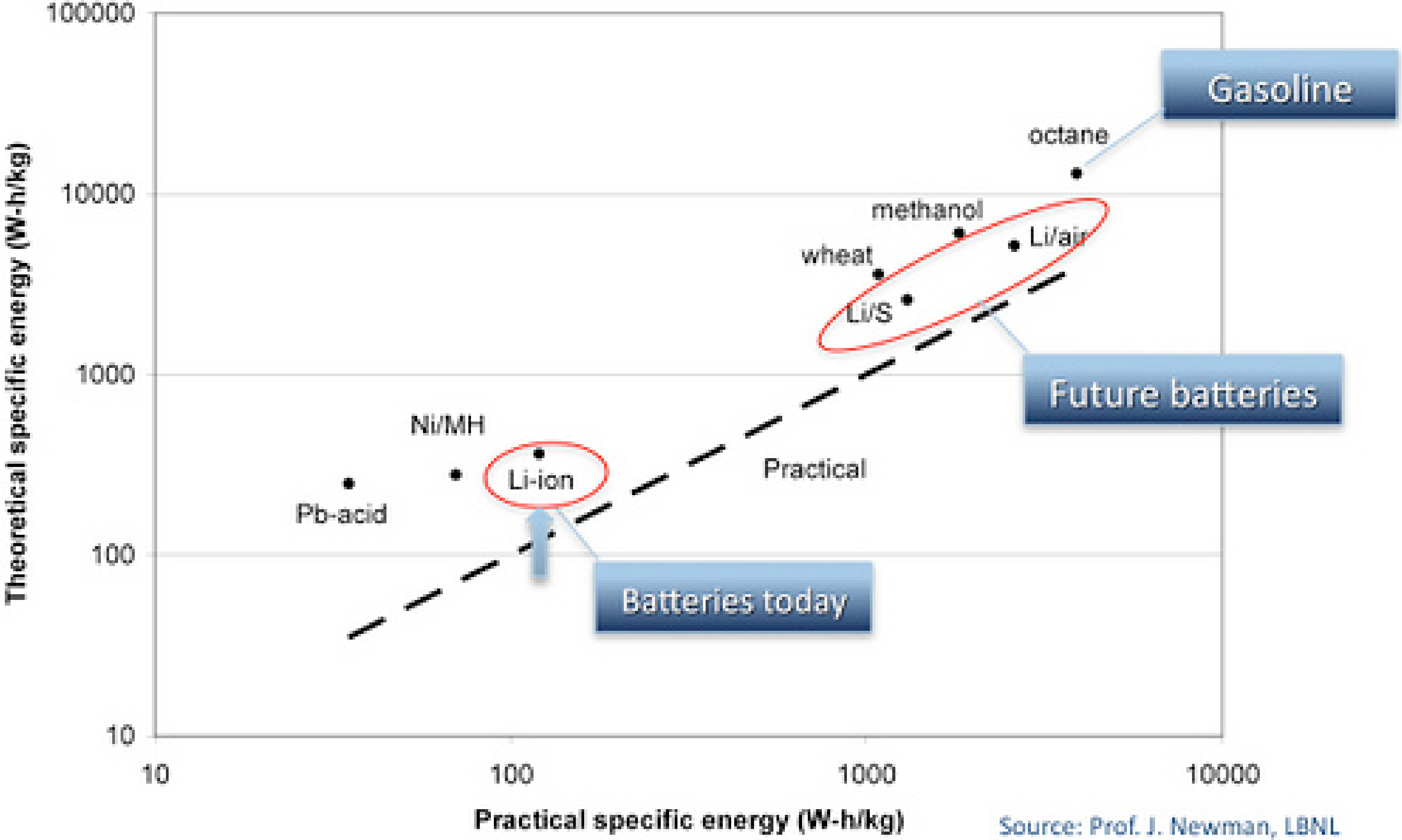
Graphite-silicon or tin?

Li –S?

Li-Air?

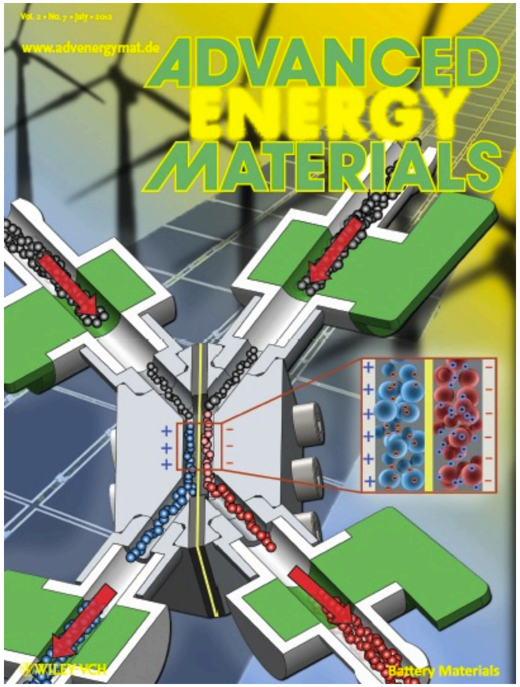
Na batteries?

Energy Density Goals



Source: Prof. J. Newman, LBNL

Scalable, High Power Charge Storage with Carbon Slurries



Scientific Achievement

Discovered that carbon slurries can store electrical energy in electric double layers just like supercapacitors.

Significance and Impact

Capacitive carbon slurries can flow, enabling a new type of electrochemical storage device called the electrochemical flow capacitor (EFC), which combines the high power of supercapacitors with the scalable energy capacity of flow batteries.

a: Schematic showing charged and discharged slurries stored in separate containers which are scalable to the energy requirements of the system.

b: A charge/discharge EFC cell used for charging flowing slurry.

Presser, V. et al. *Advanced Energy Materials* 2012, **2**, 895-902.

Batteries and Energy Storage Innovation Hub

Joint Center for Energy Storage Research
Argonne National lab lead
selection announced on Nov. 30

JCESR

- JCESR aggressive "5/5/5" goal: 5 times the energy density, 1/5 the cost, in 5 years.

4 National Labs: Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, SLAC National : Accelerator Laboratory.

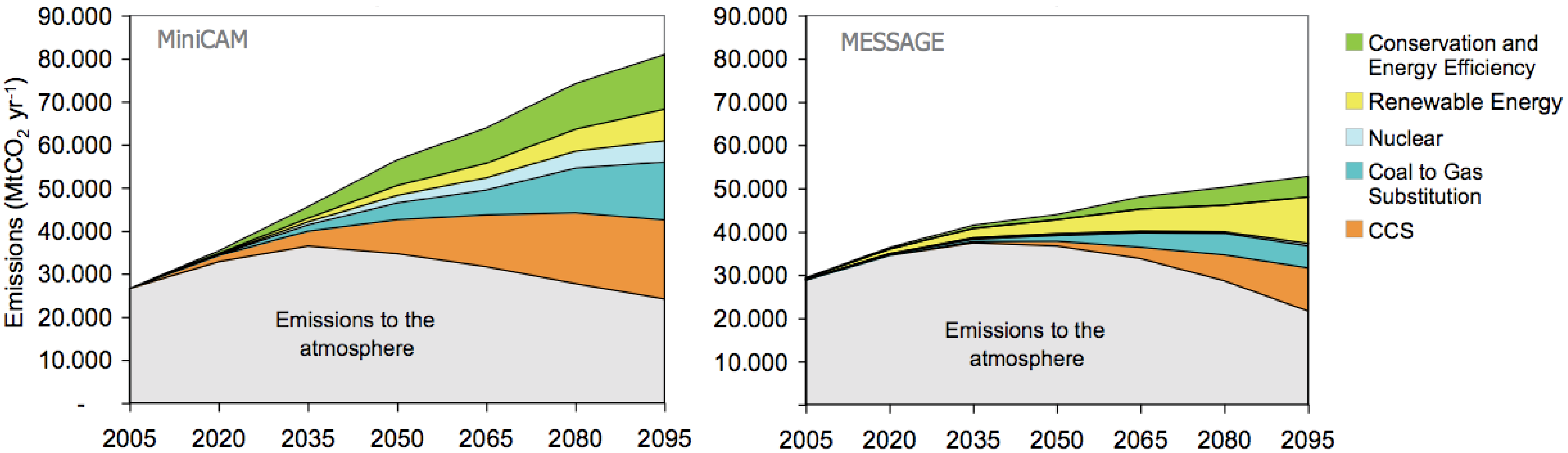
5 Universities: Northwestern University, University of Chicago, University of Illinois-Chicago & Urbana-Champaign University of Michigan.

Four Industrial Partners: Dow Chemical Company, Applied Materials, Inc., Johnson Controls, Inc., Clean Energy Trust.

Where to go with Carbon Capture and Storage?

How can we capture and reuse carbon dioxide at an affordable cost?

Carbon Capture and Sequestration



Two scenarios for reducing carbon dioxide emissions to keep atmospheric concentrations at 450-750 ppmv. Left: high-emission scenario, where nuclear plays an important role. Right low-emission scenario. In both cases, carbon capture and storage (CCS) – the orange wedge - plays a critical role. (IPCC report, 2007)

- Continued use of fossil fuel while capping the atmospheric concentration of carbon dioxide to about double the pre-industrial level requires the sequestration of ~10 GT of CO_2 per year.
- Current technologies for the post-combustion capture of CO_2 are too expensive.

DOE Fossil Energy Program Carbon Capture Goals

Capture 90% of fossil-fuel generated CO_2 from a power plant, increasing cost of electricity by no more than 35%

(comparing to an identical plant without carbon capture)

Big Bend Coal Power Station, Apollo Beach, FL

Research and Development Goals for CO2 Capture Technology, National Energy Technology Laboratory, DOE, December 2011

Promising Membrane Technology for Carbon Capture

DOE National Carbon Capture Center (NCCC)

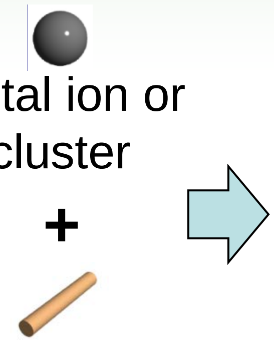
Membrane Technology and Research Inc. (MTR) Polaris^{TM} membrane system

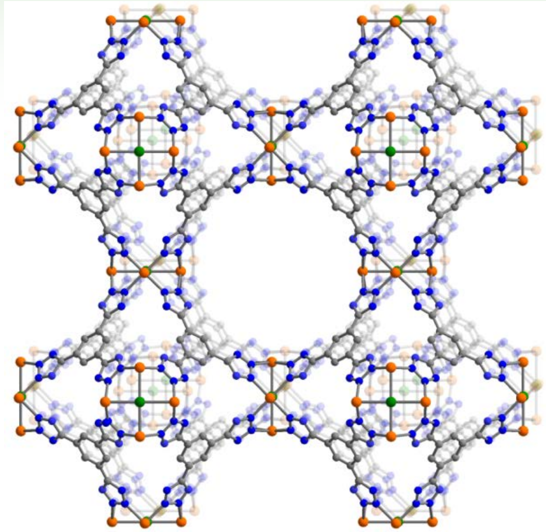
a MTR membrane system will be tested at the NCCC in early 2013, processing 20 tons of flue gas per day

http://www.fossil.energy.gov/news/techlines/2012/12057-DOE_Approves_Carbon_Capture_Field_.html and http://www.mtrinc.com

Coordination example: gas separations EFRC at UC Berkeley / LBL

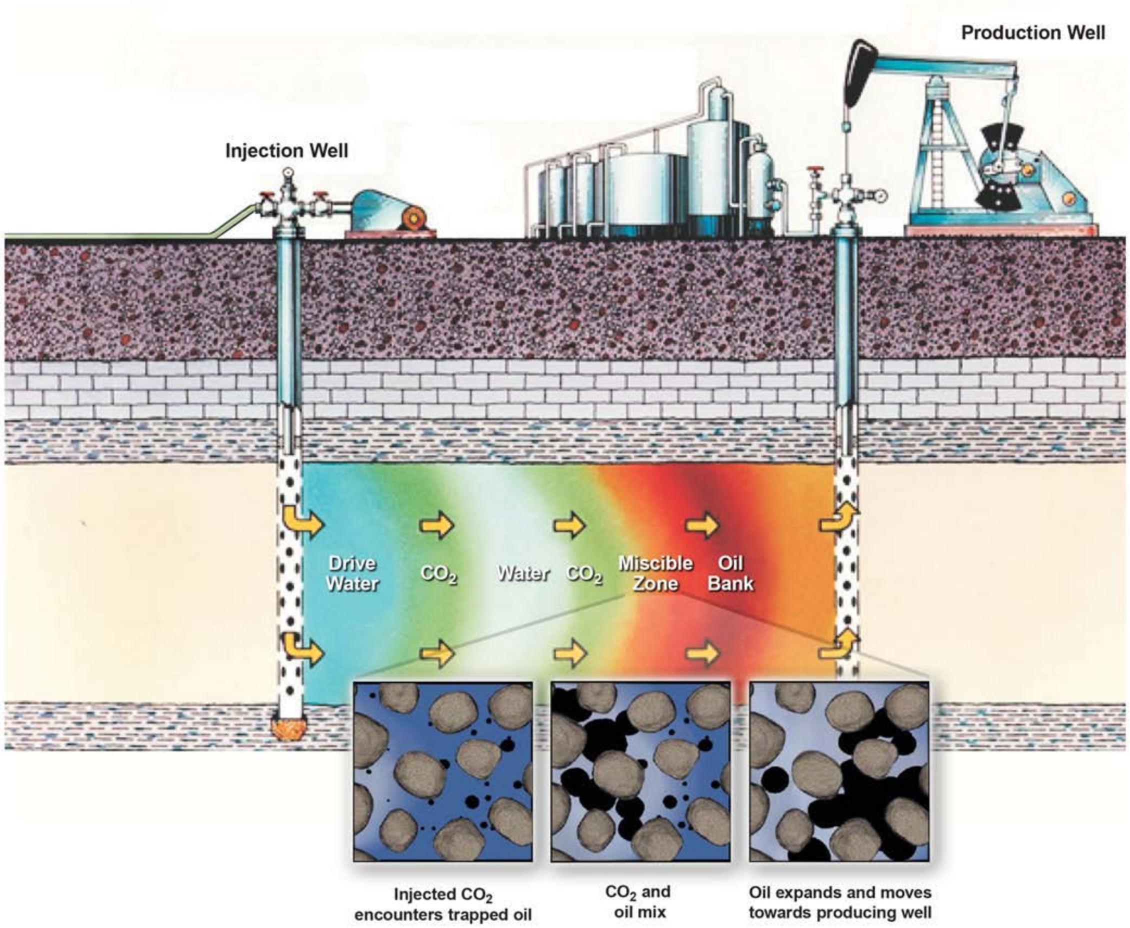
New materials such as metal organic frameworks (MOFs, right) and ionic liquids are the focus of intense basic & applied research





BES / EFRC Basic Science Advances	ARPA-E High Throughput Methodology	FE / NETL Advanced Development
• New MOF chemistry and functionalization of ligands • Computational modeling of new structures and prediction of separation properties • Improved cross-cutting characterization techniques	• High throughput (HT) MOF fabrication • HT NMR as a pore size screening technique • HT gas sorption measurements • MOF life-cycle analysis • Industrial process simulations	• MOF testing under realistic flue gas conditions • Fabrication of mixed-matrix membranes based on MOFs • MOFs for oxygen separation • Application of chemical informatic models to prediction of ionic liquid properties

Use of CO_2 for Enhanced Oil Recovery



Using CO_2 from power plant effluents to recover more oil could partially offset the cost of carbon capture.

CO_2 could be stored in reservoir after enhanced oil recovery is completed.

Carbon Dioxide Enhanced Oil Recovery: Untapped Domestic Energy Supply and Long Term Carbon Storage Solution
National Energy Technology Laboratory, DOE, 2010

Major CO_2 Pipelines Exist in West Texas

Over 3,000 miles of large diameter CO_2 pipelines have been installed in the Permian Basin of West Texas linking CO_2 supplies with oil fields.

The large volume (30-inch), long distance (502-mile) Cortez Pipeline from McElmo Dome to Denver City was constructed by Shell Oil in the early 1980s. It has a throughput capacity of 1.3 Bcfd (25 MMmt/yr.)

Advanced Resources International, Inc.

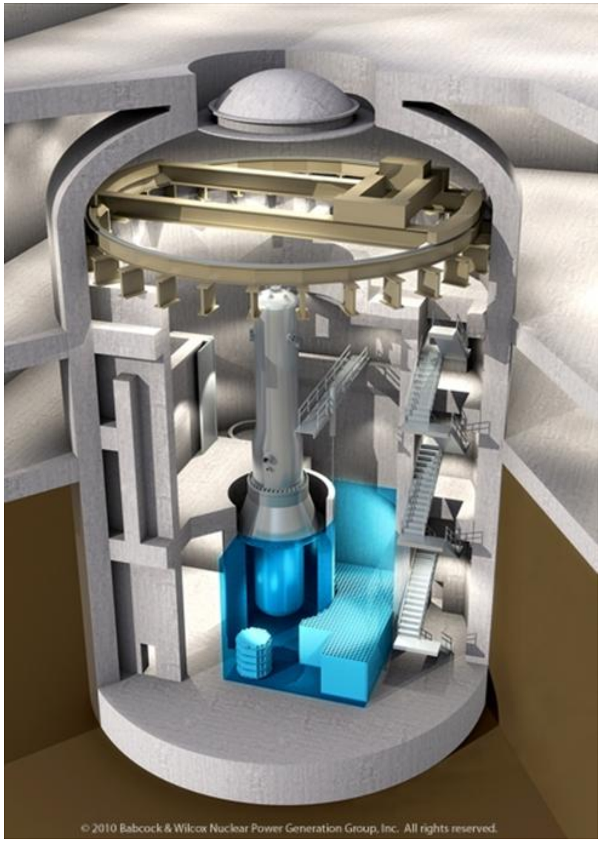
Nuclear Power
Can we depend on it?

Maybe a new approach??
Small modular reactors?

The Case for Small Modular Reactors

Small Modular Reactors (SMRs): < 300 megawatts have several potential advantages:

- **Low technical risk** with designs based on the conventional low-enriched uranium LWR fuel cycle
- **Established licensing process**
- **More robust decay heat removal via passive cooling:**
- **Integration of "primary system" (steam generator, pumps, etc.)** within reactor vessel limits failure modes
- **Below-grade construction** hardens reactor to external hazards
- **Lower financial resources –economy of scale**
- **Intended to meet existing domestic and international (IAEA) norms for nuclear material safeguards, spent nuclear fuel standards, and proliferation concerns**



Babcock & Wilcox mPower reactor

Ultimate goal is construction in a factory setting to achieve economies of scale

DOE is funding licensing R&D

DD?

Nuclear Fusion

- **Can the promise of fusion be realized as an energy source?**
- **How soon and at what cost can we achieve net energy production?**

Fusion Overview

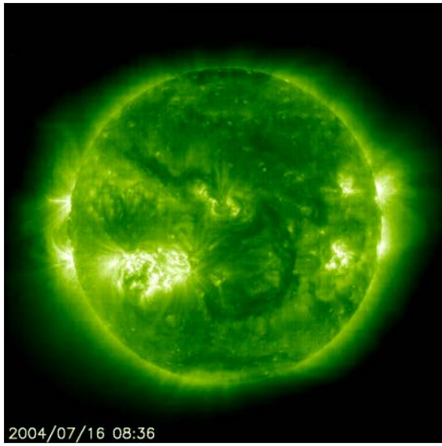
- **Fuel**
  - Plentiful and inexpensive

    Deuterium: plentiful in the oceans

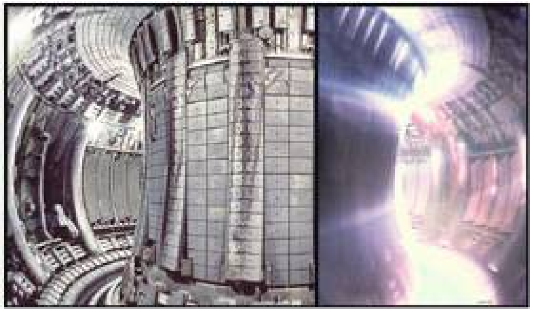
    Tritium: produced from Lithium
- **Safety**
  - No possible runaway scenario or meltdown
  - No proliferation issues
- **No long lived waste products**
  - Neutron induced activation

    (low radio toxicity < 100 years)

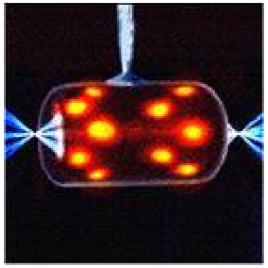
Gravitational confinement



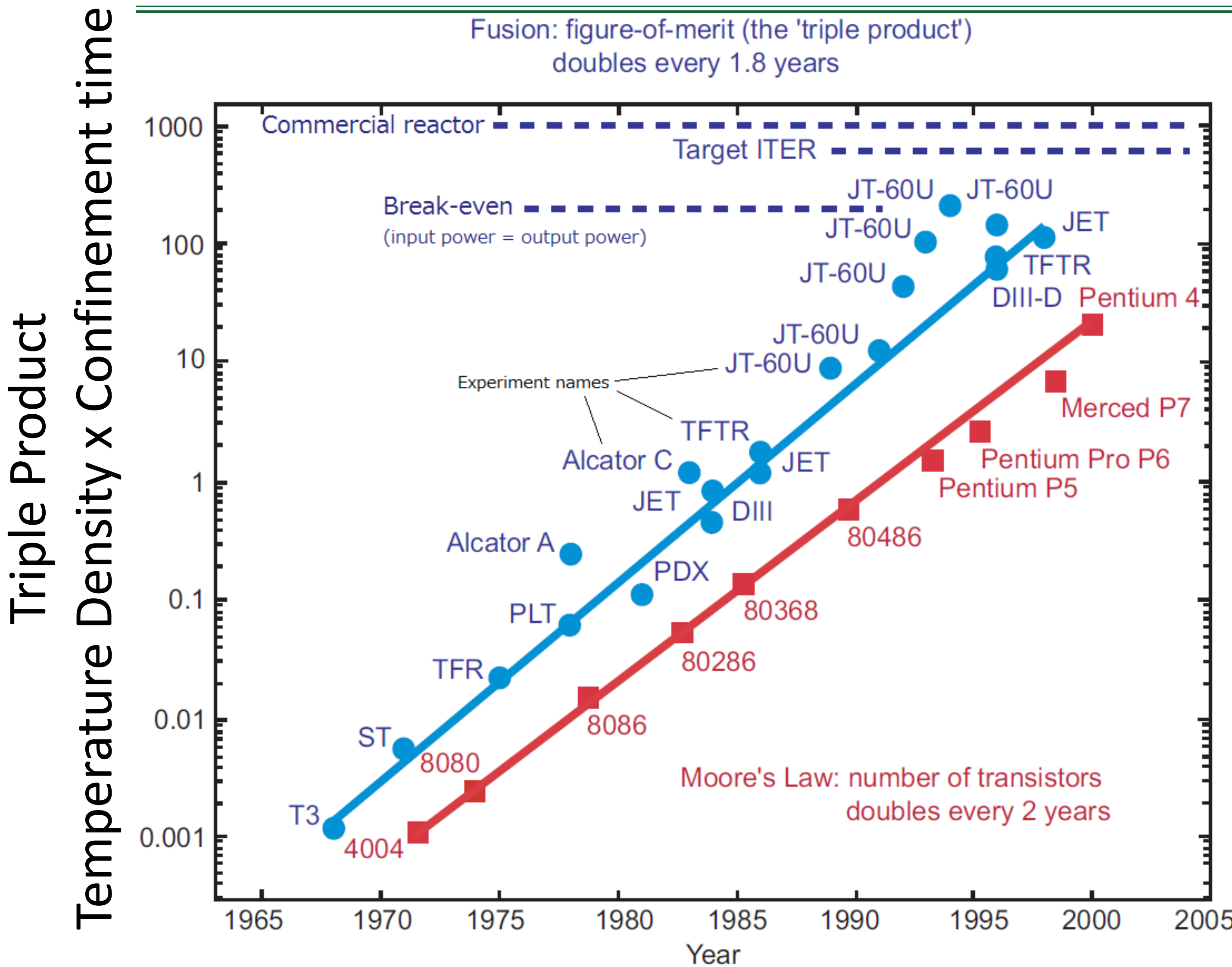
Magnetic Confinement



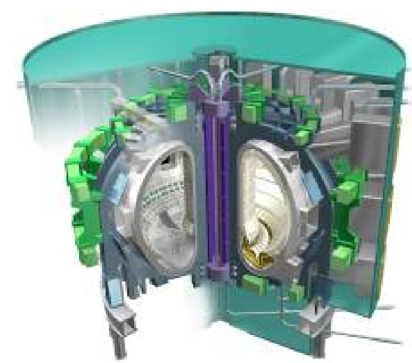
Intertial Confinement



Progress Toward ITER



Source: A.J. Webster, 2003 Phys. Educ. 38 135



ITER

800 m³

~ 500 MW$_{th}$

~2020

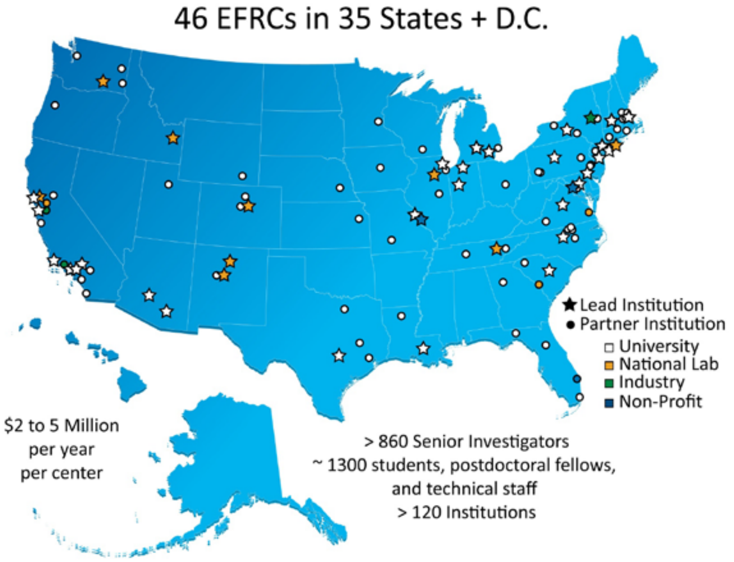
Basic and Applied Energy Research

3 Biofuel Research Centers

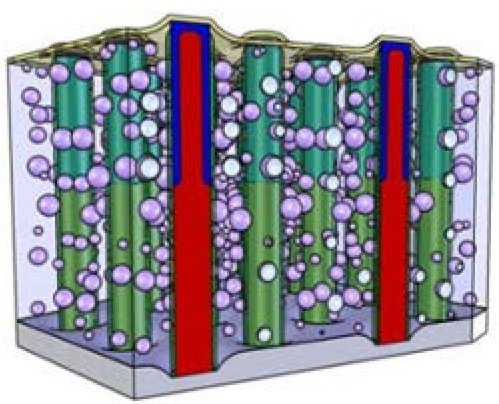
BESC
BioEnergy Science Center

jbei
Joint BioEnergy Institute

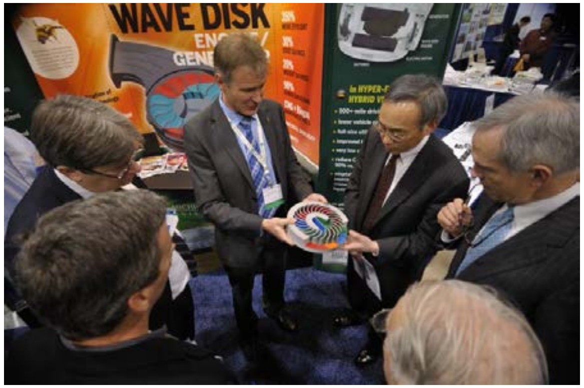
GREAT LAKES BIOENERGY RESEARCH CENTER



5 Energy Innovation Hubs



ARPA-E



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