Technology, Innovation, Policy and Climate

Fossil Energy: R&D Challenges and Opportunities

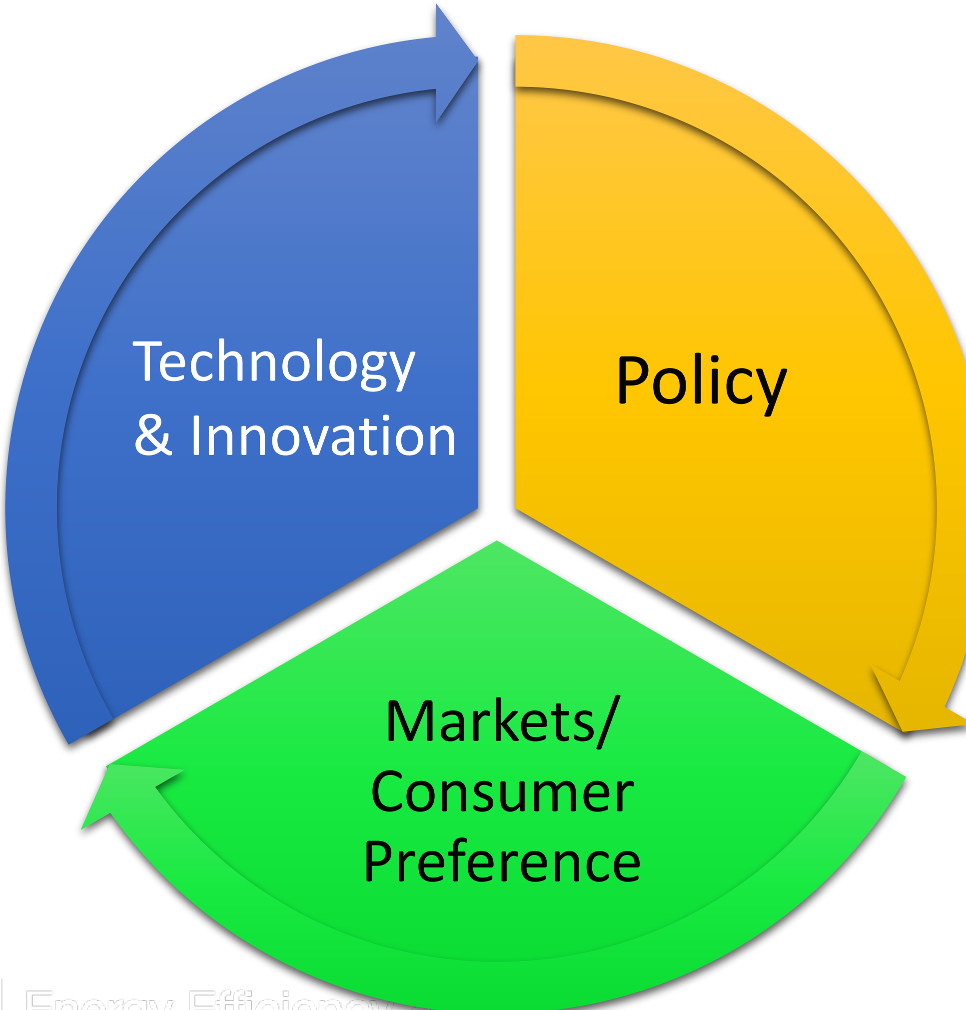
David Mohler

Deputy Assistant Secretary of Clean Coal and Carbon Management, DOE

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

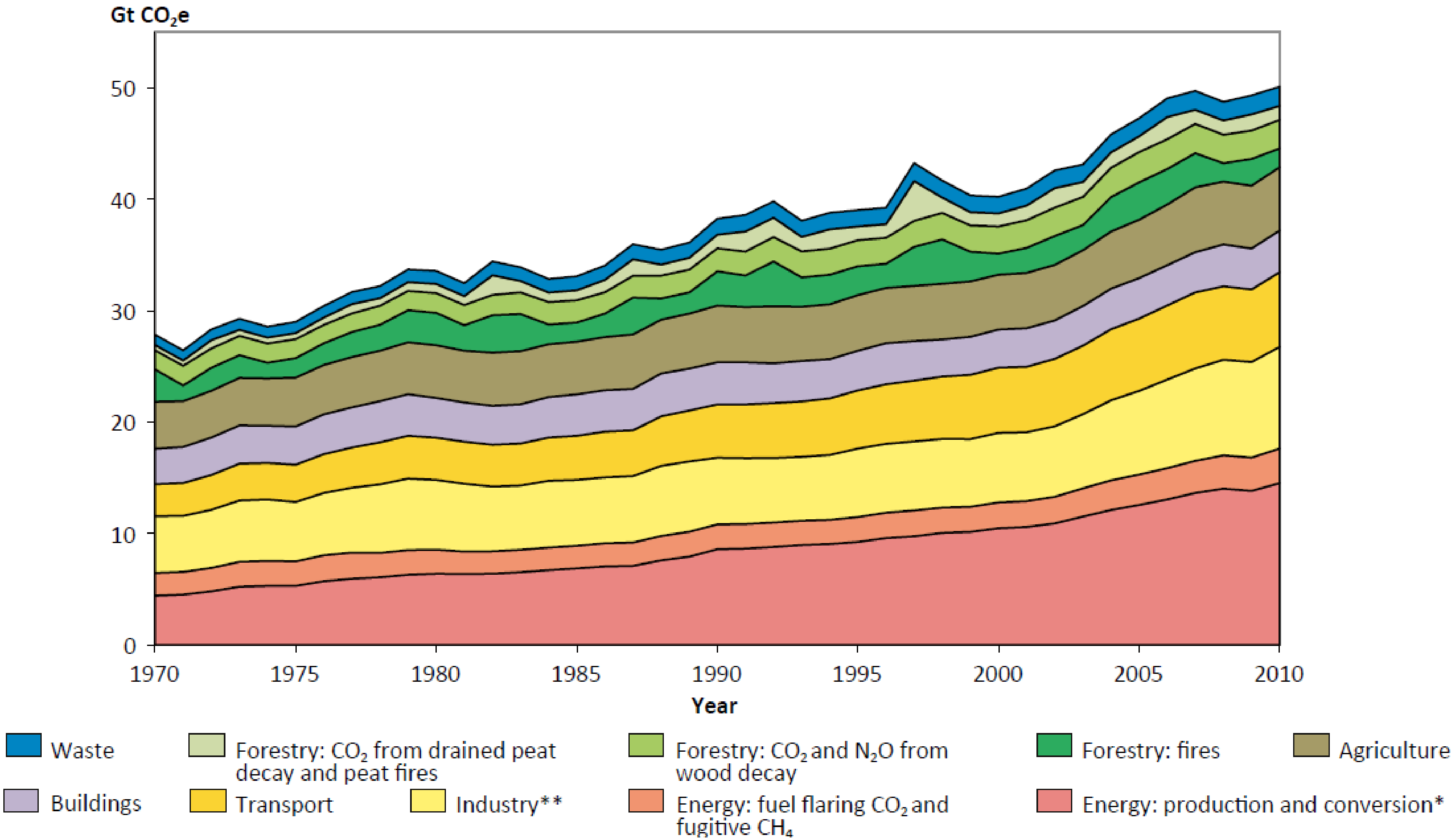
Purdue University | April 28, 2016

Clean Energy & Climate is the Defining Challenge of Our Time



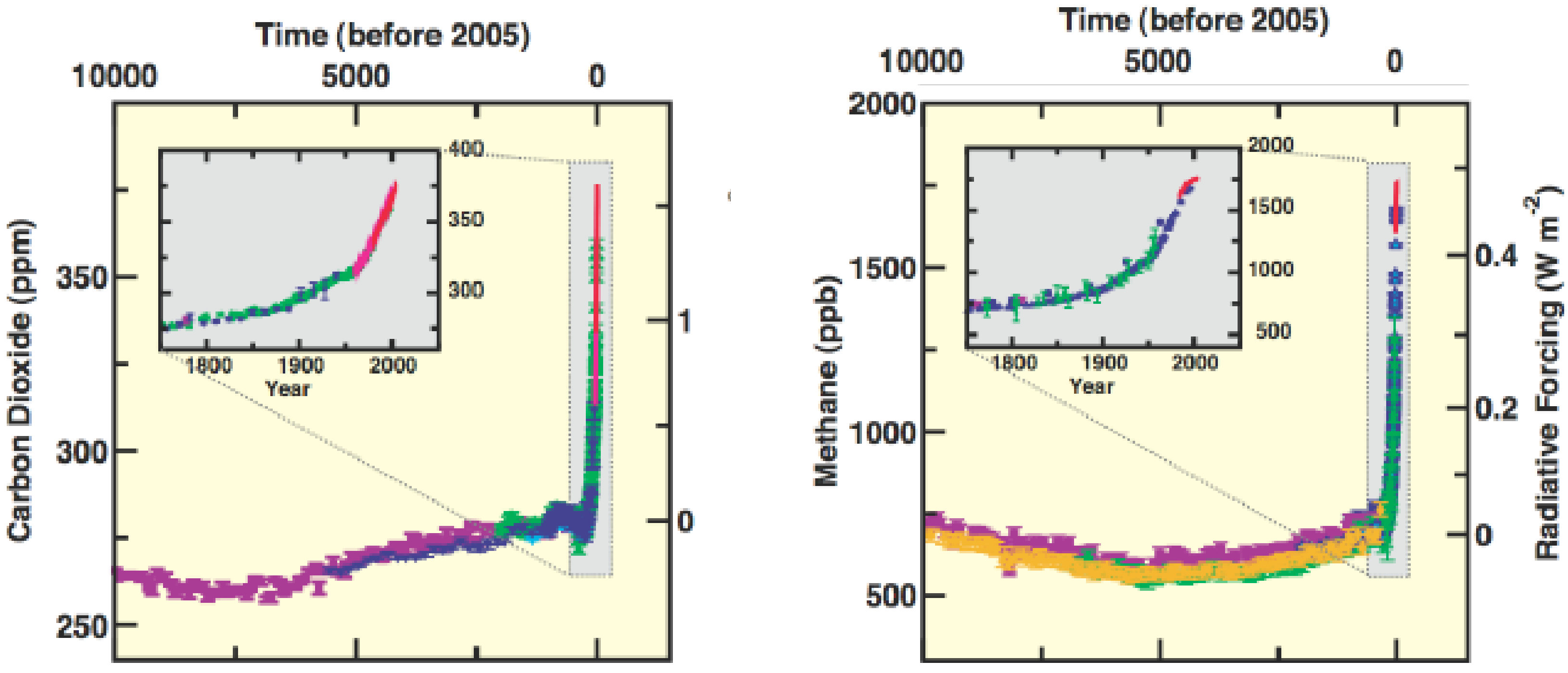
How do we address it?

Trend in global greenhouse gas emissions 1970-2010 by sector



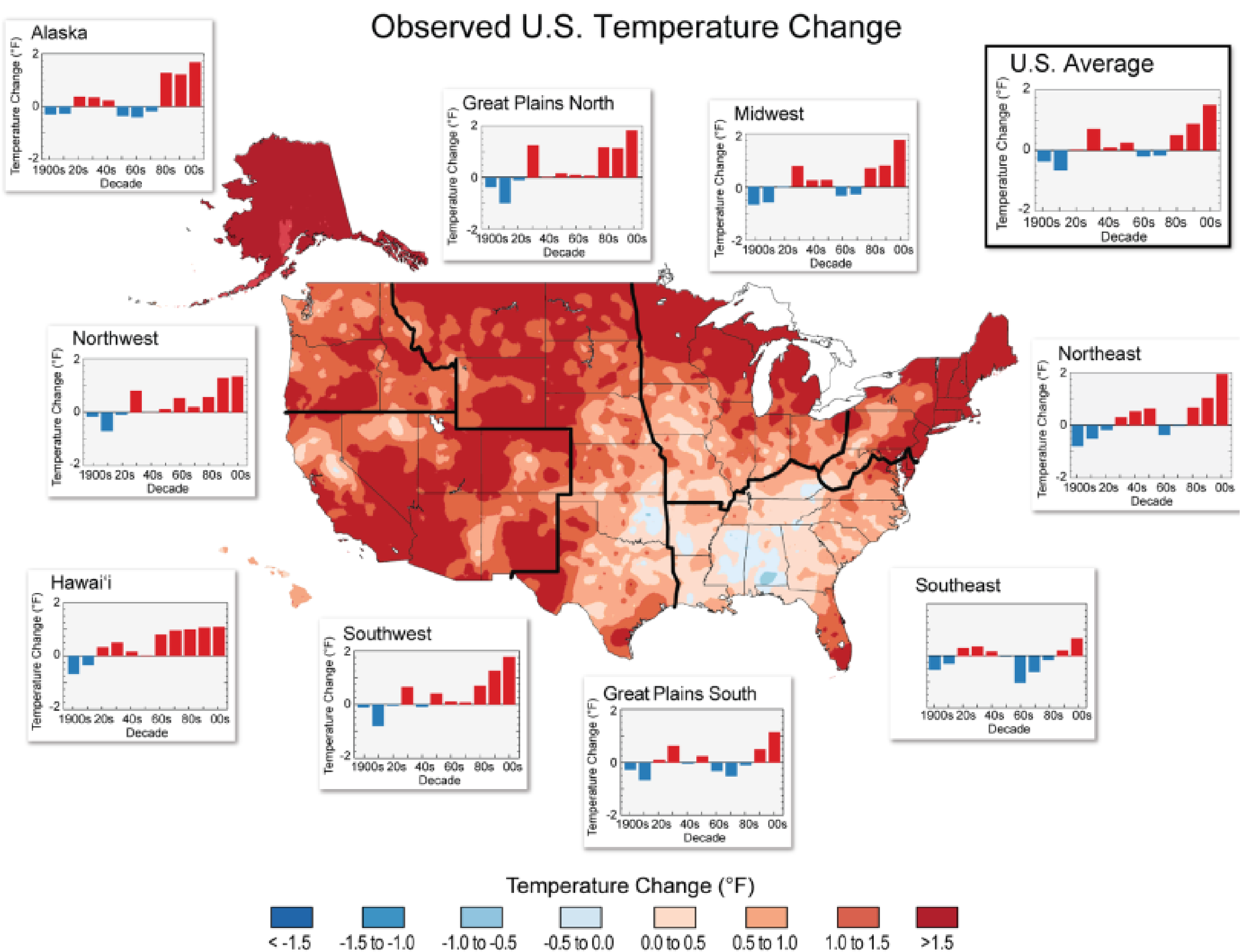
Source: UNEP, Emissions gap report, 2012

Change in GHG Concentrations



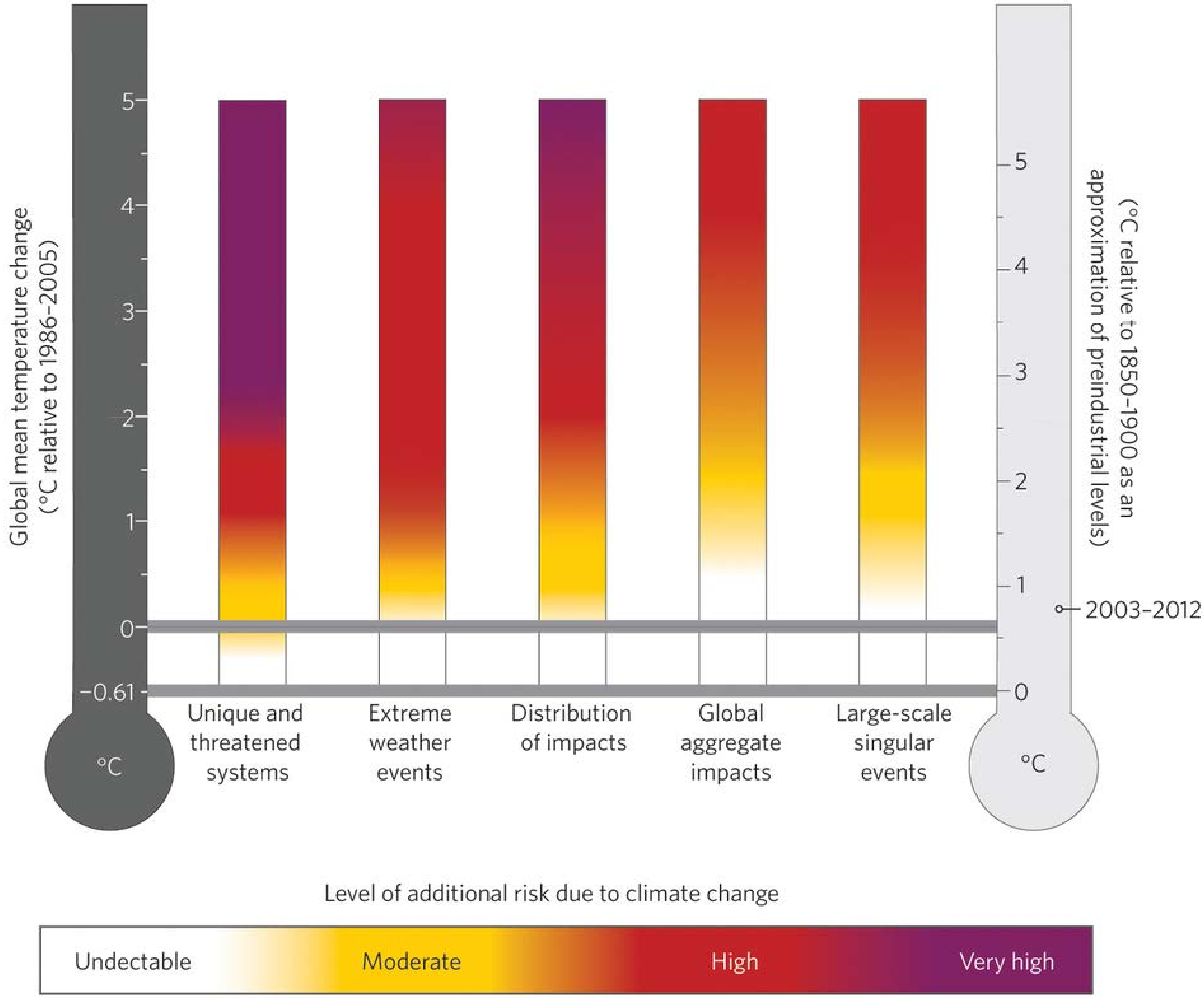
Source: IPCC, 2007

Temperature



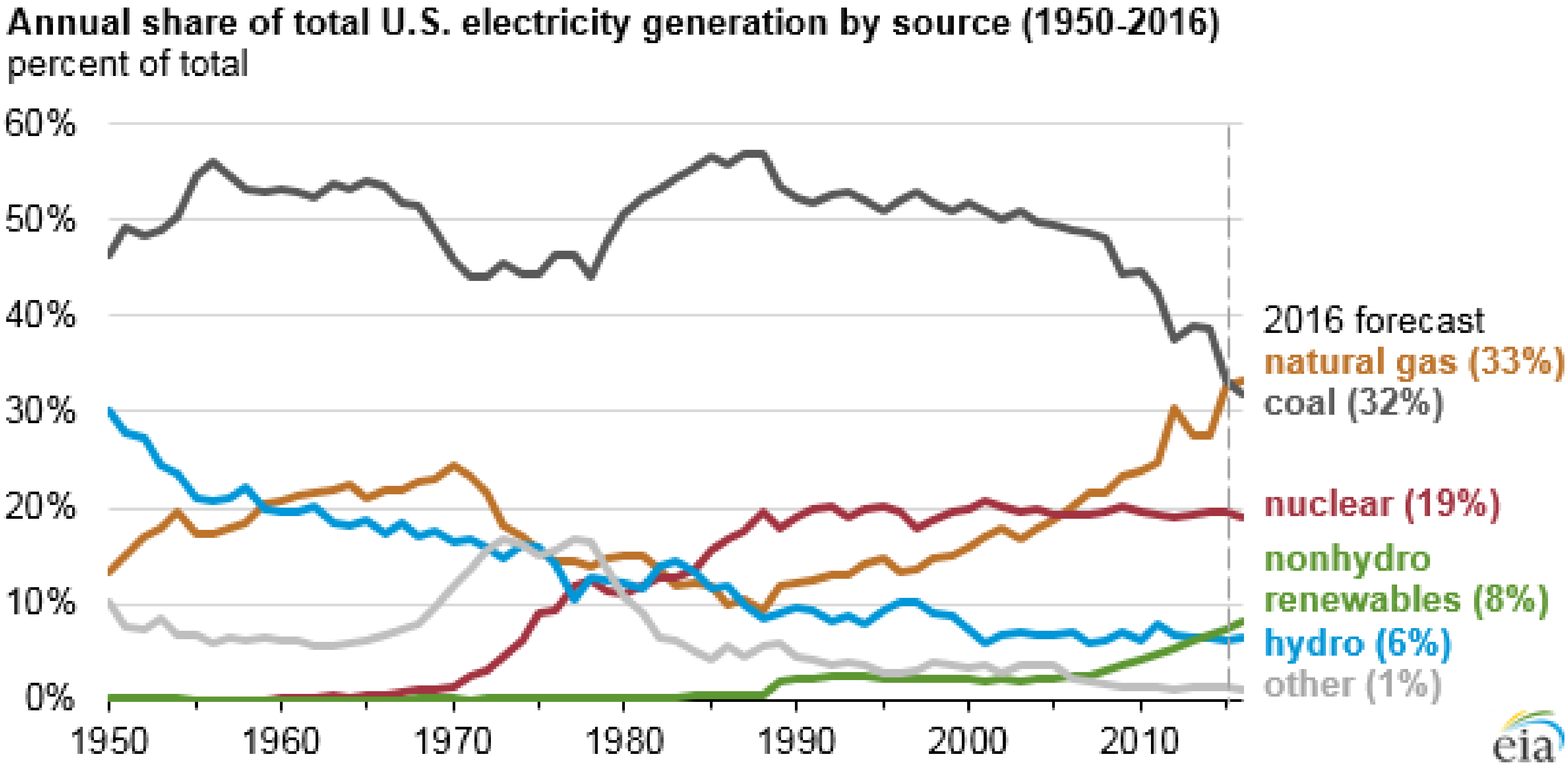
Source: USGCRP; http://data.globalchange.gov/file/e6e3a237-48f6-425d-bd31-bf941822180c

Impacts of Warming



Source: Warren, Nature Climate Change, v4, 534–535 (2014)

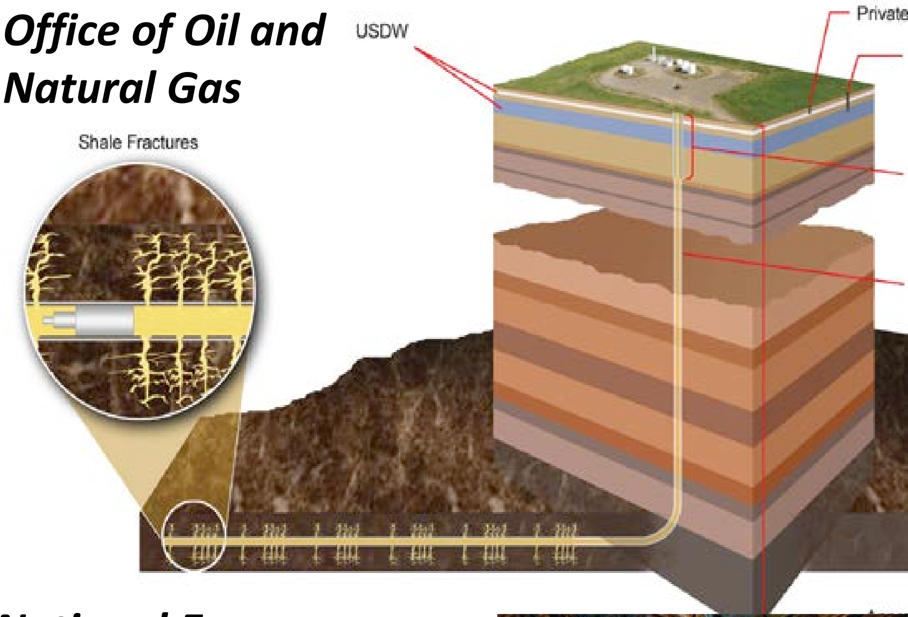
Natural gas is expected to overtake coal in fuel used for power generation in 2016



Office of Fossil Energy

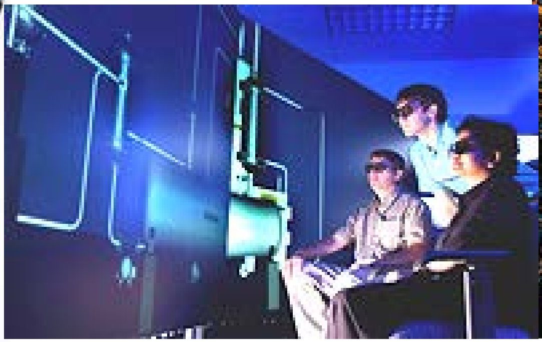
Office of Clean Coal and Carbon Management

Office of Oil and Natural Gas

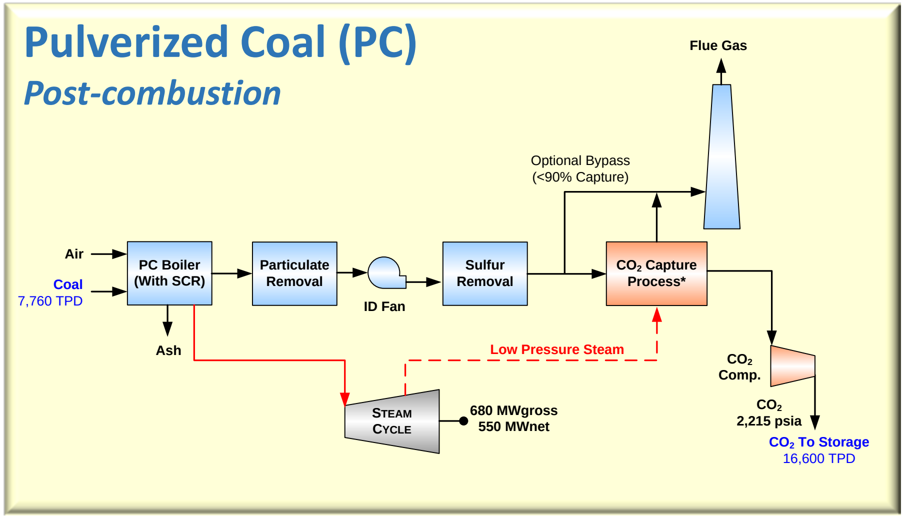


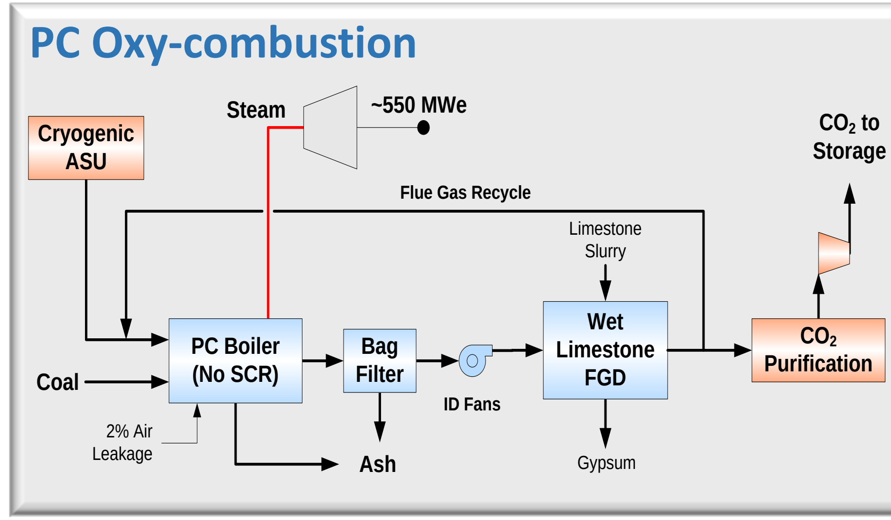
Strategic Petroleum Reserves

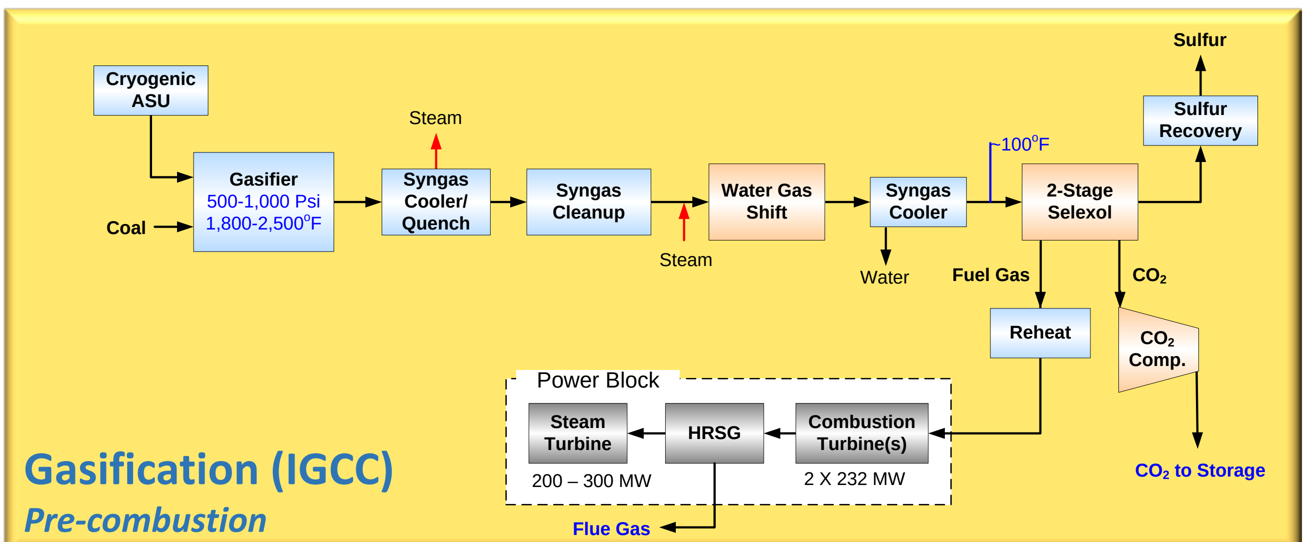
National Energy Technology Laboratory



CO_2 Capture Options for Fossil Energy Generators





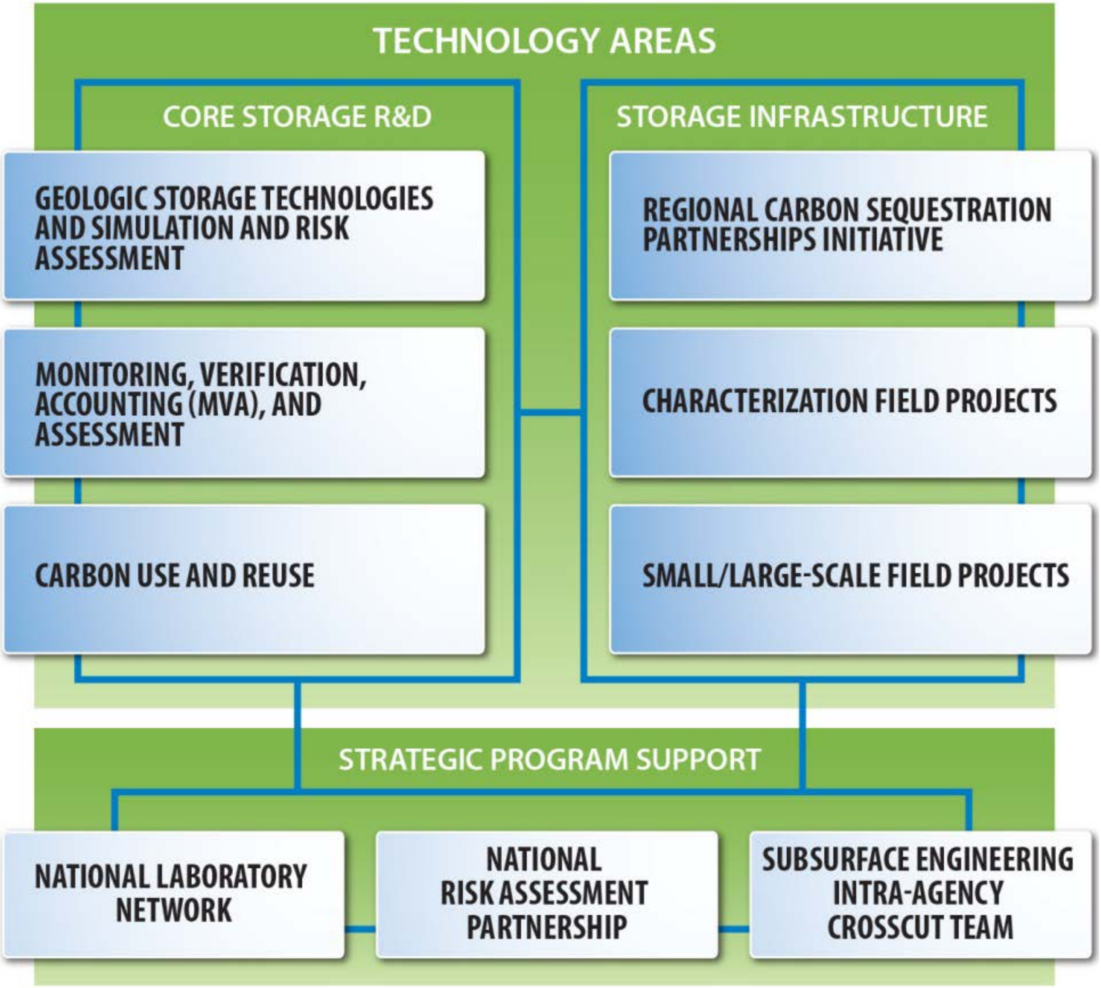


Technologies also applicable to:

- Industrial sources (cement, refinery, chemical…)
- NGCC power plants

Source: Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity; NETL, May 2007.

Carbon Storage Program Overview



- Predicting and monitoring CO_2 plume and brine pressure front movement, stabilization, and impacts
- Developing and validating risk assessment strategies
- Mitigating risks such as the risk of leakage from old wells and induced seismicity
- Carrying out field tests for different storage types and depositional environments

Core R&D Research Areas

Key Technology Areas Research Pathways

Geologic Storage Technology Area

(Storage Technologies and Simulation and Risk Assessment)

- Wellbore construction and materials
- Mitigation technologies for wells and natural pathways
- Fluid flow, reservoir pressure, and water management
- Geochemical effects on formation, brine, and microbial communities
- Geomechanical impacts on reservoirs- seals and basin-scale coupled models; microseismic monitoring
- Risk Assessment databases and integration into operational design and monitoring

Monitoring, Verification, Accounting & Assessment (MVAA) Technology Area

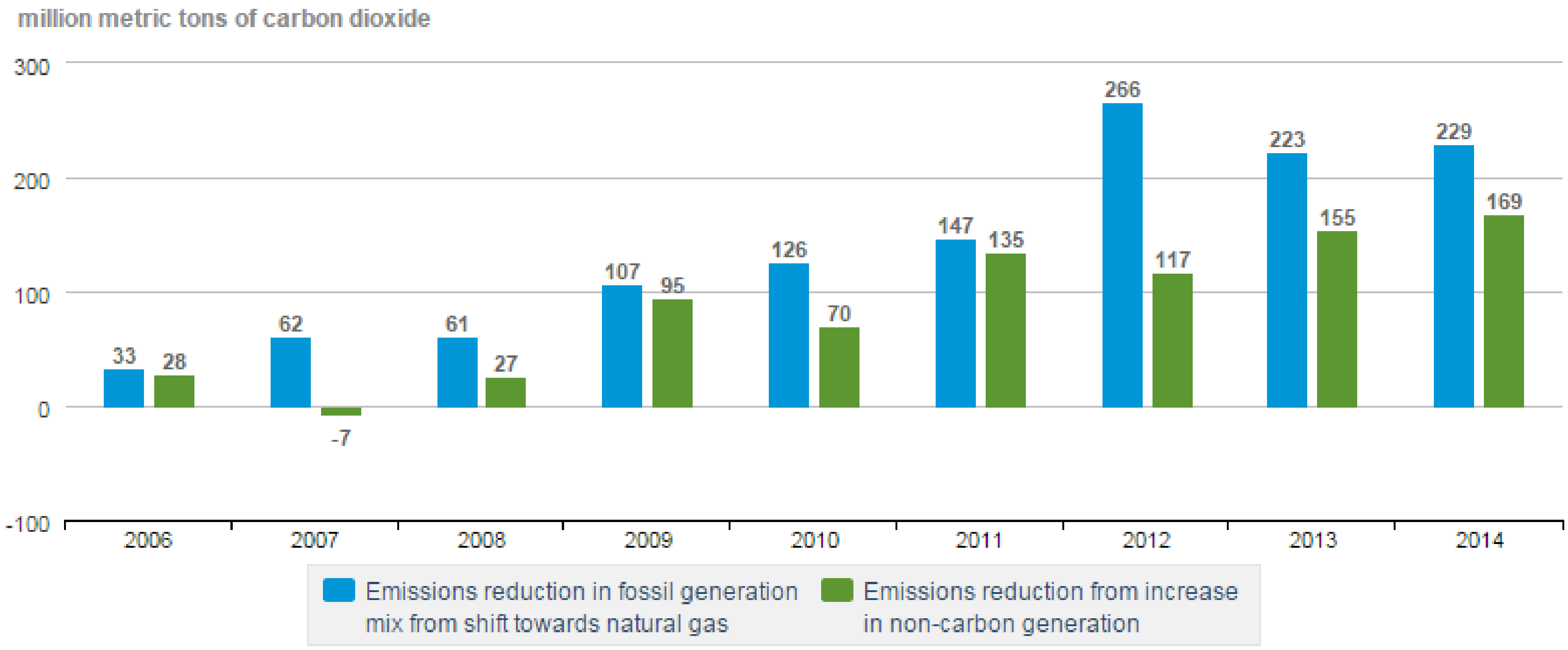
- Atmospheric Monitoring and remote sensing technologies
- Near-Surface Monitoring of soils and vadose zone
- Subsurface Monitoring in and near injection zone

CO_2 Use/Reuse Technology Area

- Chemicals, plastics, minerals and cements (building products)
- Algae and other possible uses

Reducing emissions – the role of gas

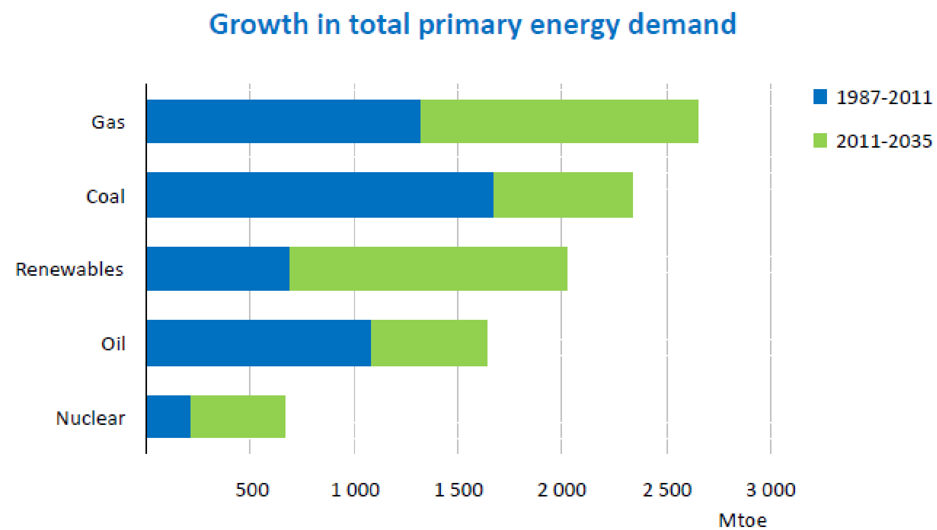
Electric power sector CO_2 emissions reduction from shifting to natural gas and non-carbon generation in years 2006 through 2014 relative to 2005 generation and fuel mix and efficiency



Source: U.S. Energy Information Administration, *October 2015 Monthly Energy Review*, Table 12.6 Carbon dioxide emissions from energy consumption: electric power sector
Table 7.2b Electricity net generation: electric power sector
From 2004 to 2014, includes an estimate of distributed solar generation from the National Energy Modeling System,
Table 16. Renewable Energy Generating Capacity and Generation,

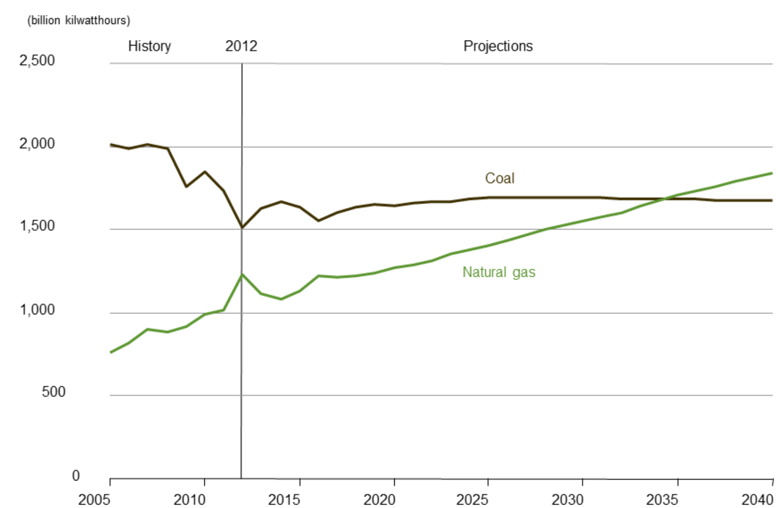
Future of Fossil Energy Demand and Generation

- Fossil energy reduces its world share of demand from 82% to 75% by 2035, offset by a surge in renewable energy (IEA 2013)
- Natural gas and renewables outpace growth and demand of all other sources world wide
- Fossil Energy remains dominant share (68%) of United States electricity generation in 2040



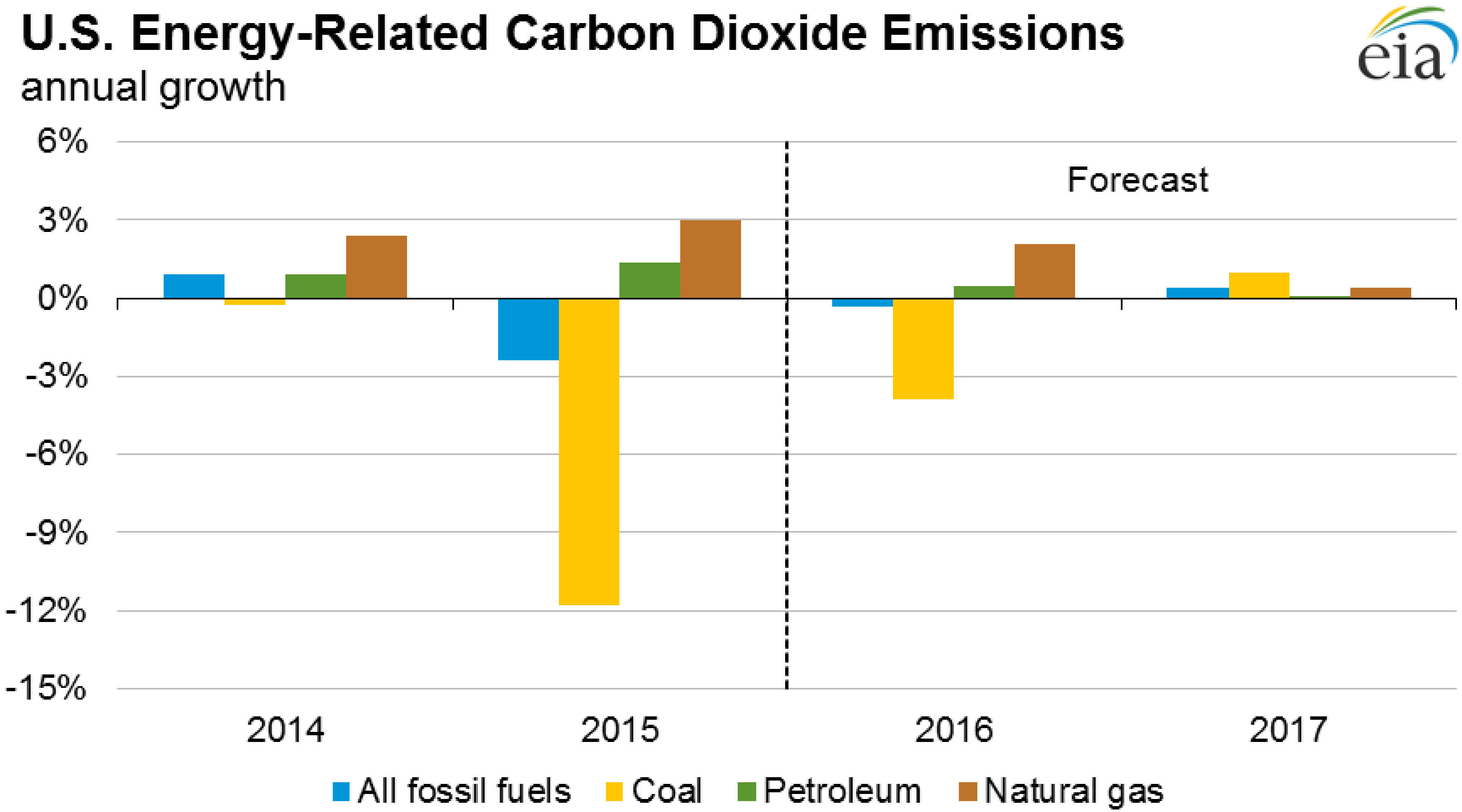
Source: IEA 2013 World Energy Outlook

Figure 3. Electricity generation from natural gas and coal, 2005-2040



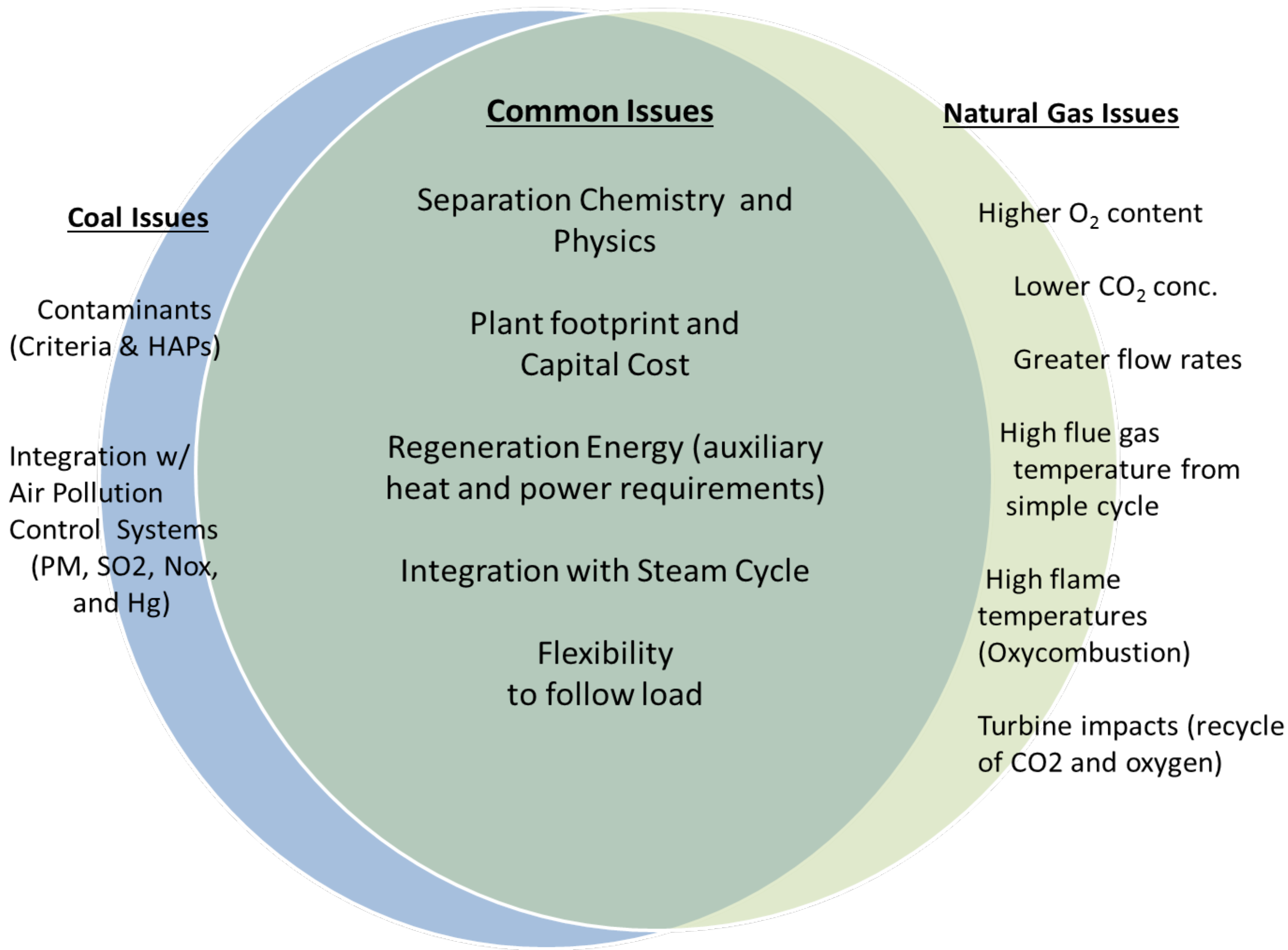
Source: EIA 2014 Annual Energy Outlook

Projected growth in CO_2 emissions comes from gas, not coal



Source: Short-Term Energy Outlook, March 2016.

CCS for Coal and Natural Gas
Integration of R&D Efforts



Coal continues to play important role in electricity generation

US Power Gen: Mixed Scenario

US Power Gen: Low-Demand Scenario

Electricity Production

[Billion kWh/yr]

0

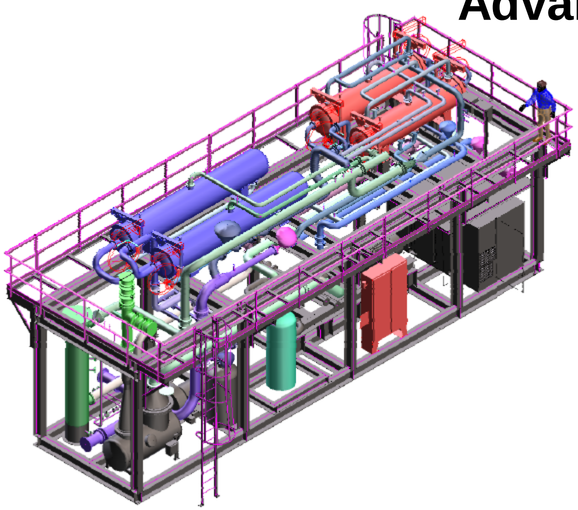
50

<u>CCUS needed to decarbonize</u>

We need CCUS

Advanced CO_2 capture technologies: Many pathways to success

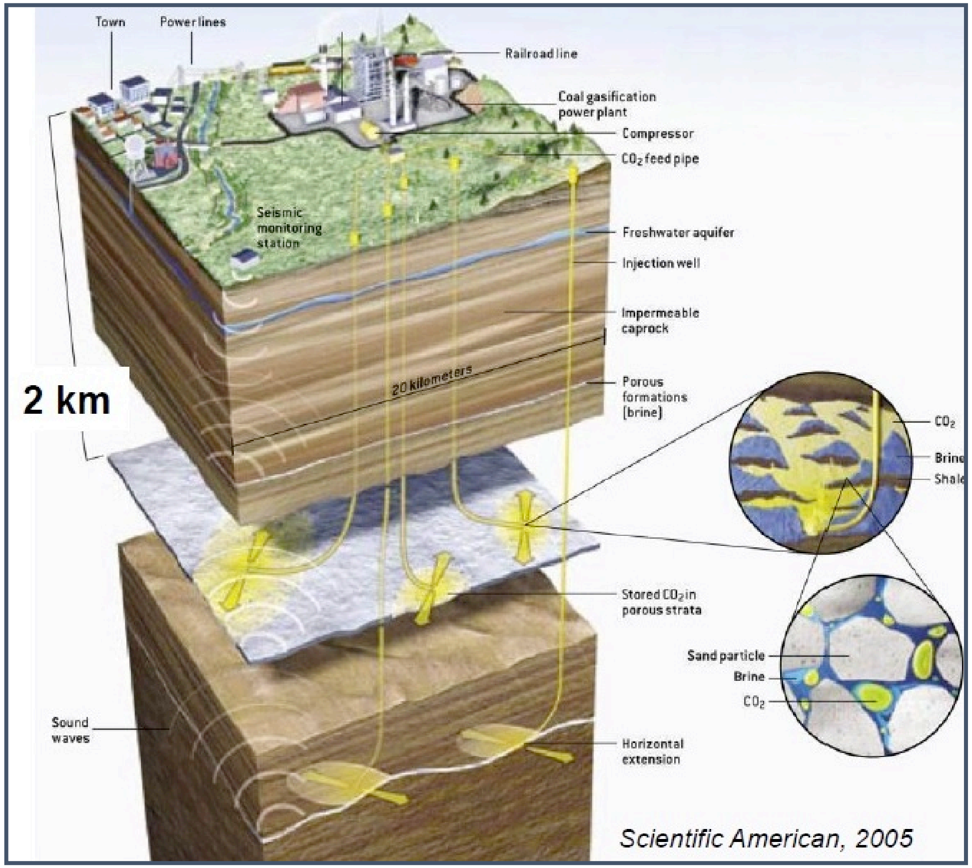
Advanced membranes



Solid sorbents

Carbon Capture and Sequestration

CO_2 is captured and concentrated from large sources; then injected deep underground



Scientific American, 2005

Capture: Power plants and industrial sources

- Pre-combustion
- Post-combustion
- Oxyfired combustion
- High conc. streams

Storage: > 1km depth

- Porous & permeable units
- Large capacity
- Good seals and cap rock

Two main targets

- Saline formations (~2200 Gtons capacity in N. Am.)
- Enhanced oil recovery (100’s Gt capacity; ~100’s B bbls addl. recovery)

CO_2 Utilization

Fossil Energy R&D Program supporting projects coupling CO_2 storage with Enhanced Oil Recovery (EOR)

- Majority of large-scale demonstration projects have an EOR component

Small R&D program focused on CO_2 conversion

- Mineralization, Chemicals Production, Biological capture (algae)

Lab- and Bench-Scale Applications for R&D of Transformational CO_2 Capture Technologies for Coal-Fired Power Plants

- Includes funding opportunity for CO_2 utilization
- Biological CO_2 use/conversion to value-added products

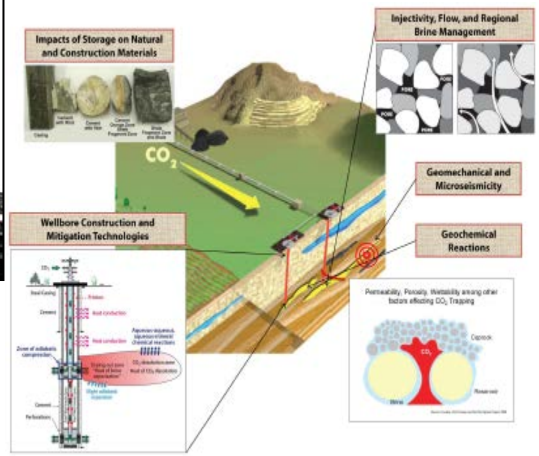
Project Highlight: Skyonic

- Operational as of October 2014
- Capturing 75,000 metric tons per year
- Converting CO_2 into useful, saleable products

Skyonic Carbon Capture Unit

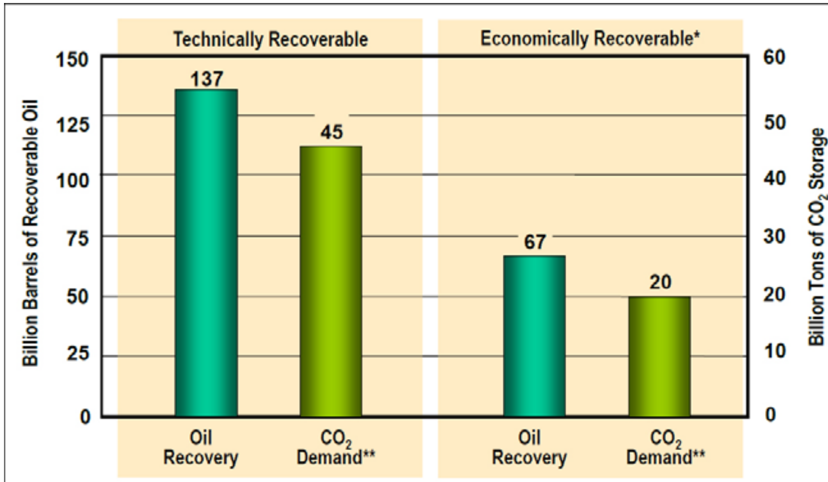
CCUS technology development and market mechanisms

Technology Push



Market Pull

Domestic Oil Supplies and CO_2 Demand (Storage) Volumes from "Next Generation" CO_2-EOR Technology**



*At an oil price of $85/B, a CO_2 market price of $40/mt and a 20% ROR, before tax.
**Includes 2,300 million metric tons of CO_2 provided from natural sources and 2.6 billion barrels already produced or being developed with miscible CO_2-EOR.
Source: Advanced Resources Int'l (2011).

R&D

Demos (integration and learning)

Existing Market Mechanisms: Enhanced Oil Recovery (EOR)

65 million tons per year of CO_2 to produce nearly 300,000 barrels of oil per day.

Regulatory Framework (Evolving)

Financing (Tax Credits and Loan Guarantees)

Major CCS 1st Gen Demonstration Projects

Clean Coal Power Initiative

ICCS Area 1

Archer Daniels Midland

CO_2 Capture from Ethanol Plant

CO_2 Stored in Saline Reservoir

$208M – Total, $141M – DOE

SALINE – ~0.9M MTPY 2015 start

Summit TX Clean Energy

Commercial Demo of Advanced IGCC w/ Full Carbon Capture

~$1.7B – Total, $450M – DOE

EOR – ~2.2M MTPY 2018 start

HECA

Commercial Demo of Advanced IGCC w/ Full Carbon Capture

~$4B – Total, $408M – DOE

EOR – ~2.6M MTPY 2019 start

Southern Company

Kemper County IGCC Project

Transport Gasifier w/ Carbon Capture

~$4.12B – Total, $270M – -DOE

EOR – ~3.0M MTPY 2015/2016 start

Petra Nova (formerly NRG)

W.A. Parish Generating Station

Post Combustion CO_2 Capture

$775 M – Total

$167M – DOE

EOR – ~1.4M MTPY 2017 start

Air Products and Chemicals, Inc.

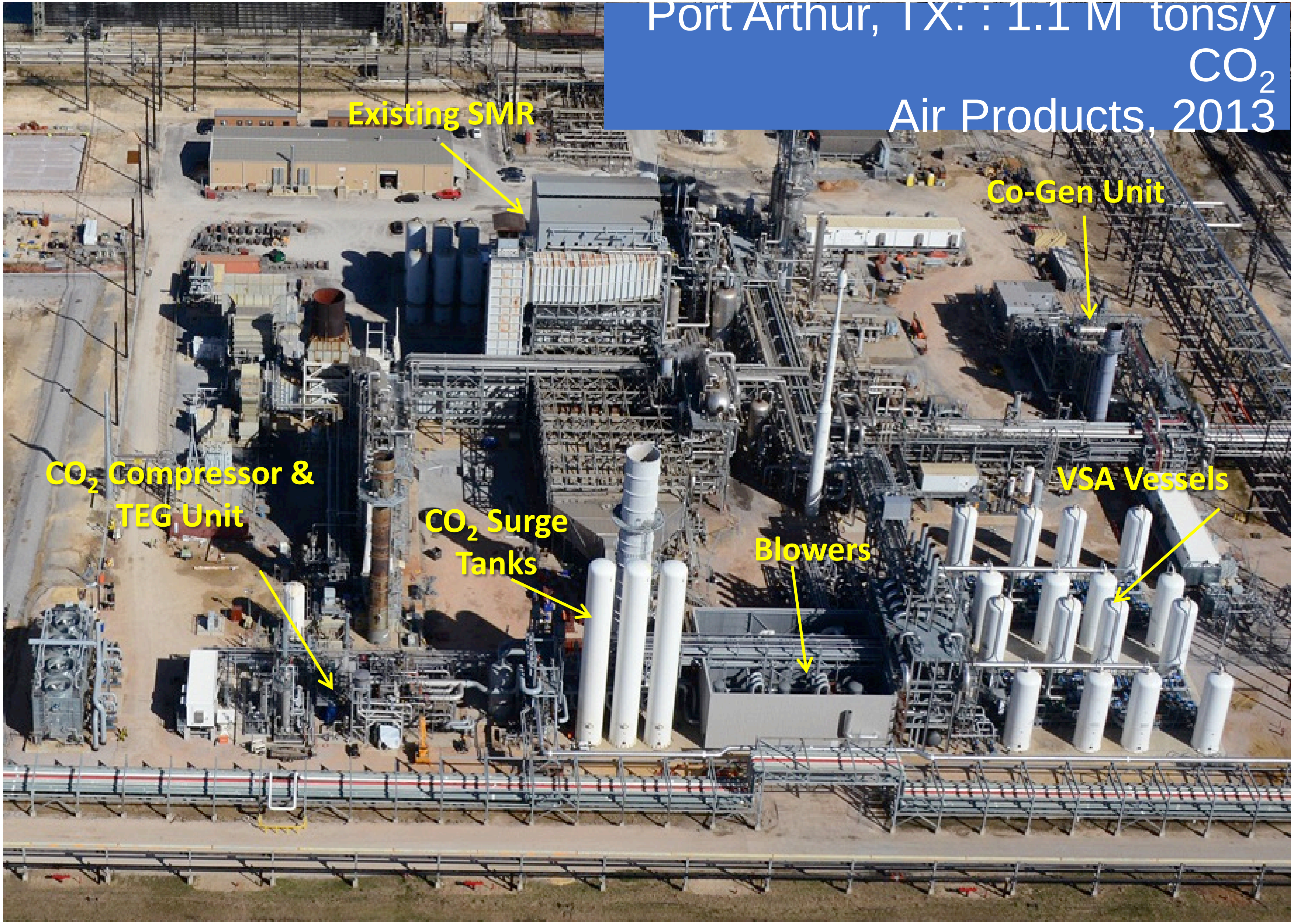
CO_2 Capture from Steam Methane Reformers

EOR in Eastern TX Oilfields

$431M – Total, $284M – DOE

EOR – ~0.93M MTPY 2012 start

Port Arthur, TX: : 1.1 M tons/y CO_2
Air Products, 2013



Operational! 1.6M tons stored so far

Boundary Dam, Saskpower Saskatchewan

Operational! 1.1M tons stored /yr

PetraNova Project, W.A. Parrish, TX

Broke Ground Sept. 2014; On time & budget for 2016
$100/ton CO_2 costs; next plant 30% less

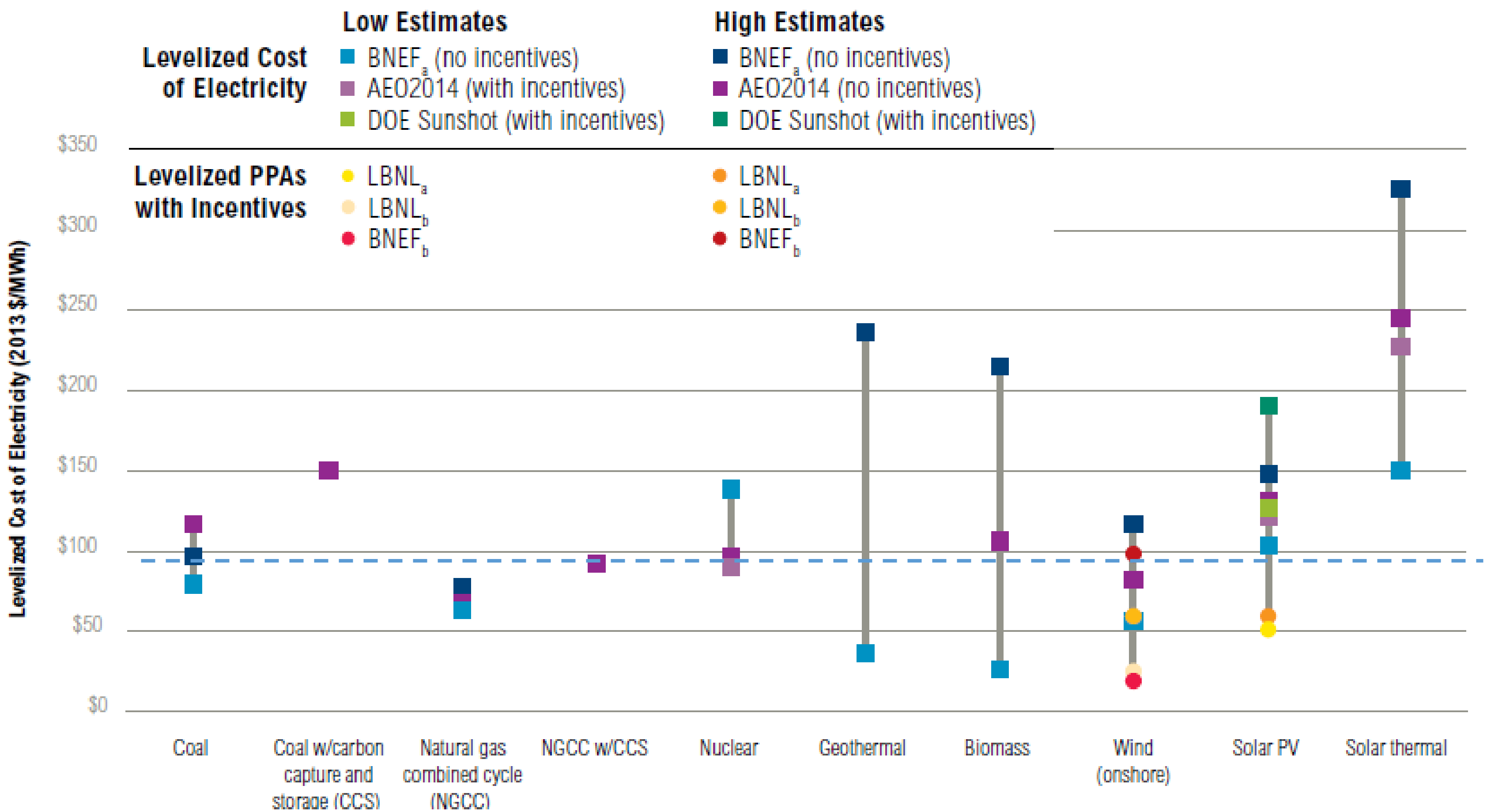
Kemper County, MS – Southern Company

Anticipated start August 2016

CCUS – Cost, policy and parity

LCOE and PPAs

Figure 1.2 | **Levelized Cost of Electricity ($/MWh) for New Generation Sources and Levelized Power Purchase Agreement Prices for Recent Wind and Solar Projects**



CCUS – Commercial Deployment Incentives

Federal Income Tax Benefits – Emerging Proposals

NEORI & CURC Welcome Bipartisan Bill to Improve 45Q Tax Credit

Issued February 25, 2016; Updated March 17, 2016

- $13 billion invested in CCS since 2007 vs. ~$1.8 trillion for renewables*
- Only 15 large-scale CCS projects in operation globally
- Carbon Capture and Enhanced Oil Recovery Act
  - Rep. Mike Conaway (R-Texas)
  - 23 bi-partisan co-sponsors
  - Makes permanent the IRC Section 45Q tax credit
  - Developers need such assurances to obtain project financing
- Evidences more aggressive effort in policy and investment
- High-efficiency low emissions (HELE) coal plants deliver major environmental improvement
- Current 45Q credit levels increase ratably to $30 per tonne in 2025
- Owner-taxpayer may elect to transfer the credits to the taker of the CO_2
- 150,000 tonne annual minimum
- Placed in service after 12/31/2015, and before 1/1/2025

LEARN MORE

* http://thehill.com/blogs/congress-blog/energy-environment/273314-yes-coal-can-power-clean-energy#

Financing: US policies and proposals

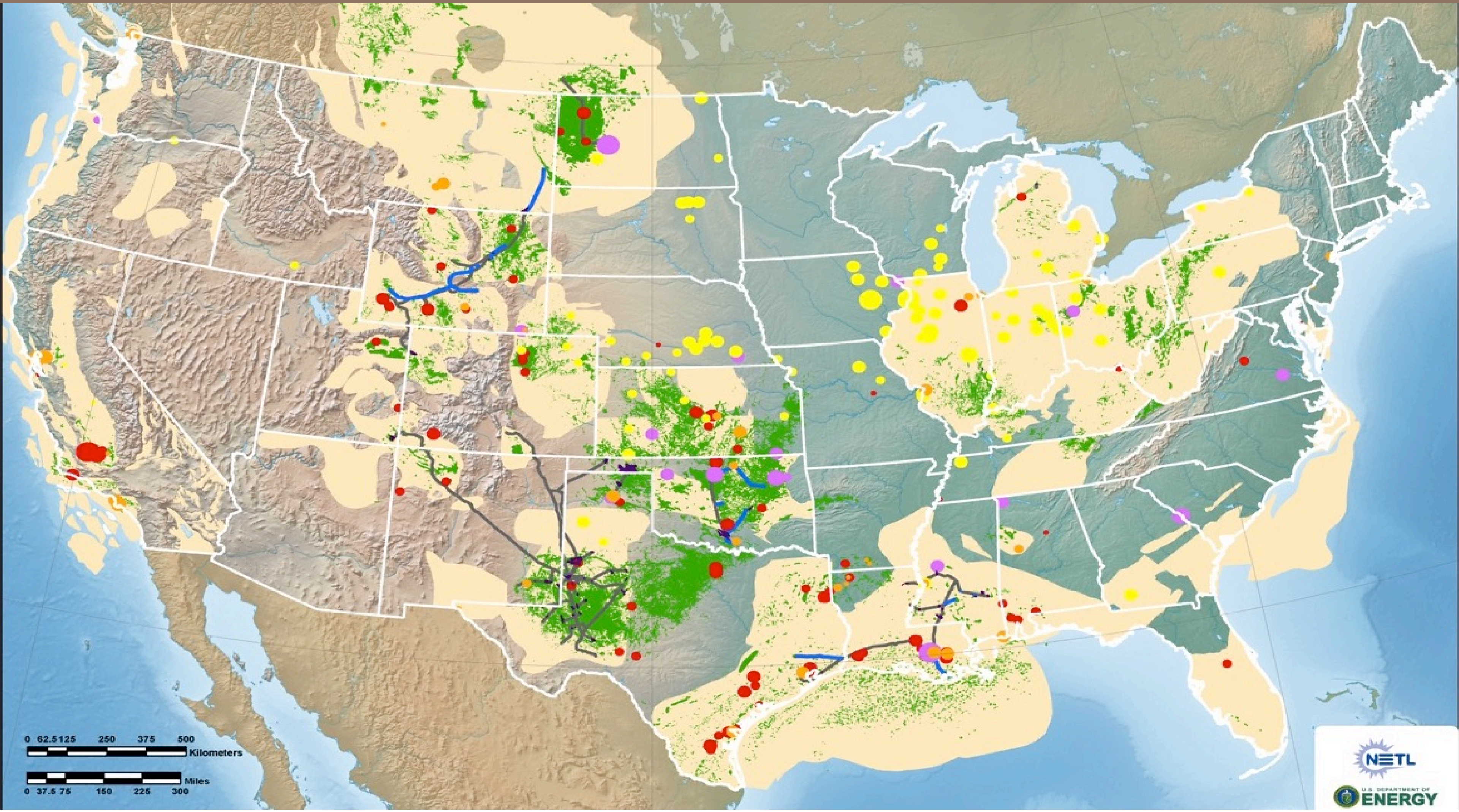
Cost recovery is the main issue

Administration
- 48a, 48b, and 45q tax credits
- ITC and STC tax credit proposals (2016)
- CPP (new source) – CCUS as BSER for coal (1400 lbs/MW-hr)
- CCP (existing source) – CCUS as compliance option; tradable crediting

Draft legislation: Bipartisan and bicameral
- Hoeven/Conaway & Jenkins: 45Q expansion ($20/$30/$40 uncapped)
- Heitkamp & Manchin: Price support (contract for differences)
- Whitehouse-Booker: 45T: New proposal for ITC/STC mix

Proposed policies
- Clean energy portfolio standards; feed-in tariffs; CO_2 utilities
- Tax-free debt financing; bonus depreciation

Low-cost, rapid deployment options for CCUS could help US and others achieve INDC's



High Purity CO_2 sources within 100 miles of a CCUS target site

Saline Formations: ~43 Mt/y (4 Mt/y)

EOR fields: ~32 Mt/y; (2 Mt/y)

Mission Innovation

- 20 heads of state
- Countries represent 85-90 % of global R&D investment
- Each country supporting a doubling of its R&D investment over the next five years
- Complemented by a private sector initiative

Breakthrough Energy Coalition


Mukesh Ambani


John Arnold


Mark Benioff


Jeff Bezos


Alwaleed bin Ttalal


Richard Branson


Ray Delio


Aliko Dangote


John Doerr


Bill Gates


Reid Hoffman


Chris Hohn

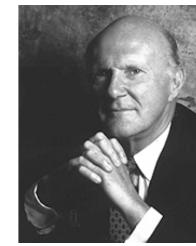

Vinod Khosla


Jack Ma


Patrice Motsepe


Xavier Niel


Hasso Plattner


Julian Robertson


Neil Shen


Simmons & Baxter-Simmons


Masayoshi Son


George Soros


Tom Steyer


Ratan Tata


Meg Whitman


Zhang Xin Pan Shiyi


Mark Zuckerberg, Priscilla Chan

- 27 investors & University of California; Collective net worth: $300+ billion
- Commitment to invest in innovation emerging from Mission Innovation pipeline
- Long term, patient and risk tolerant capital

iNNOVATION CCS

Consistent with Mission Innovation, utilize a regional approach to accelerate the development and deployment of a full spectrum of CCS technologies

Broad deployment requires:

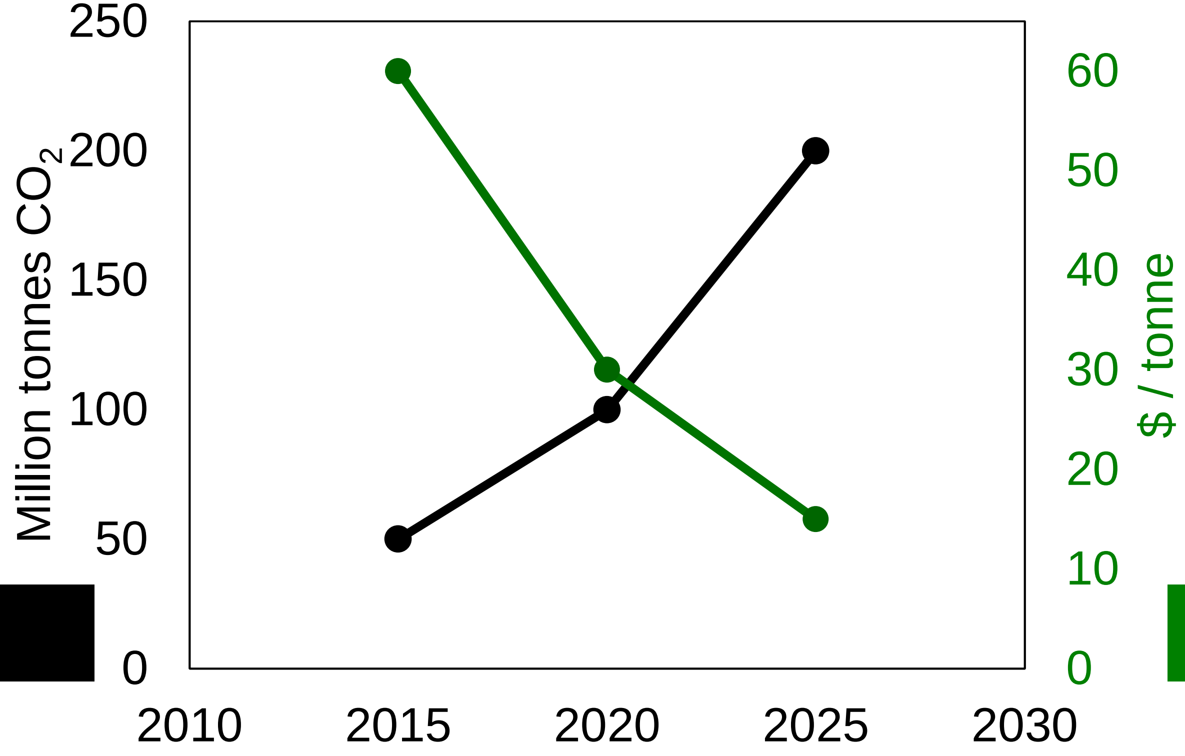
(1) Enabling CCS projects with infrastructure

(2) Reducing costs through RD^3

(3) Driving deployment with incentives

iNNOVATION CCS
Cost and storage goals

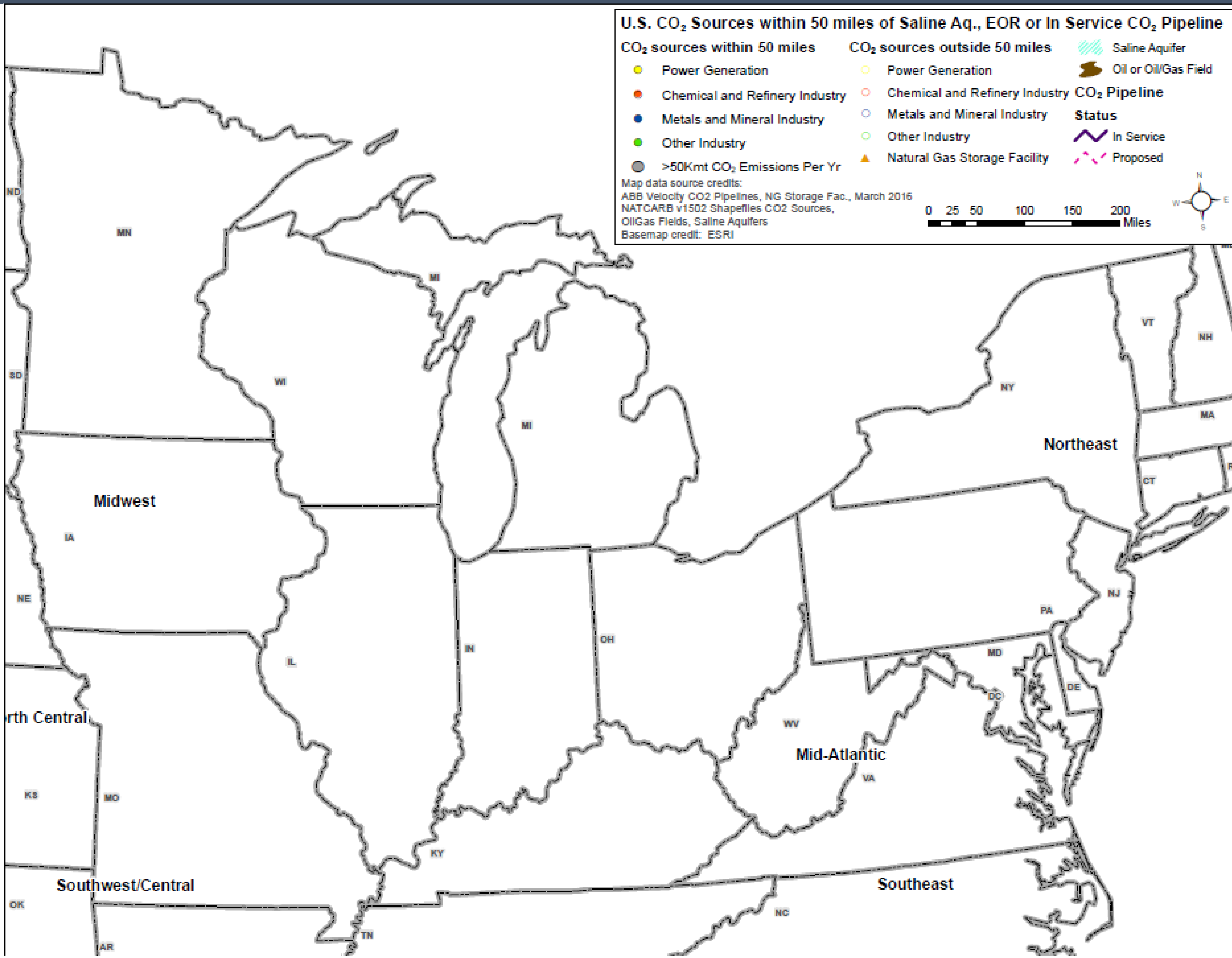
Every 5 years:



2x storage

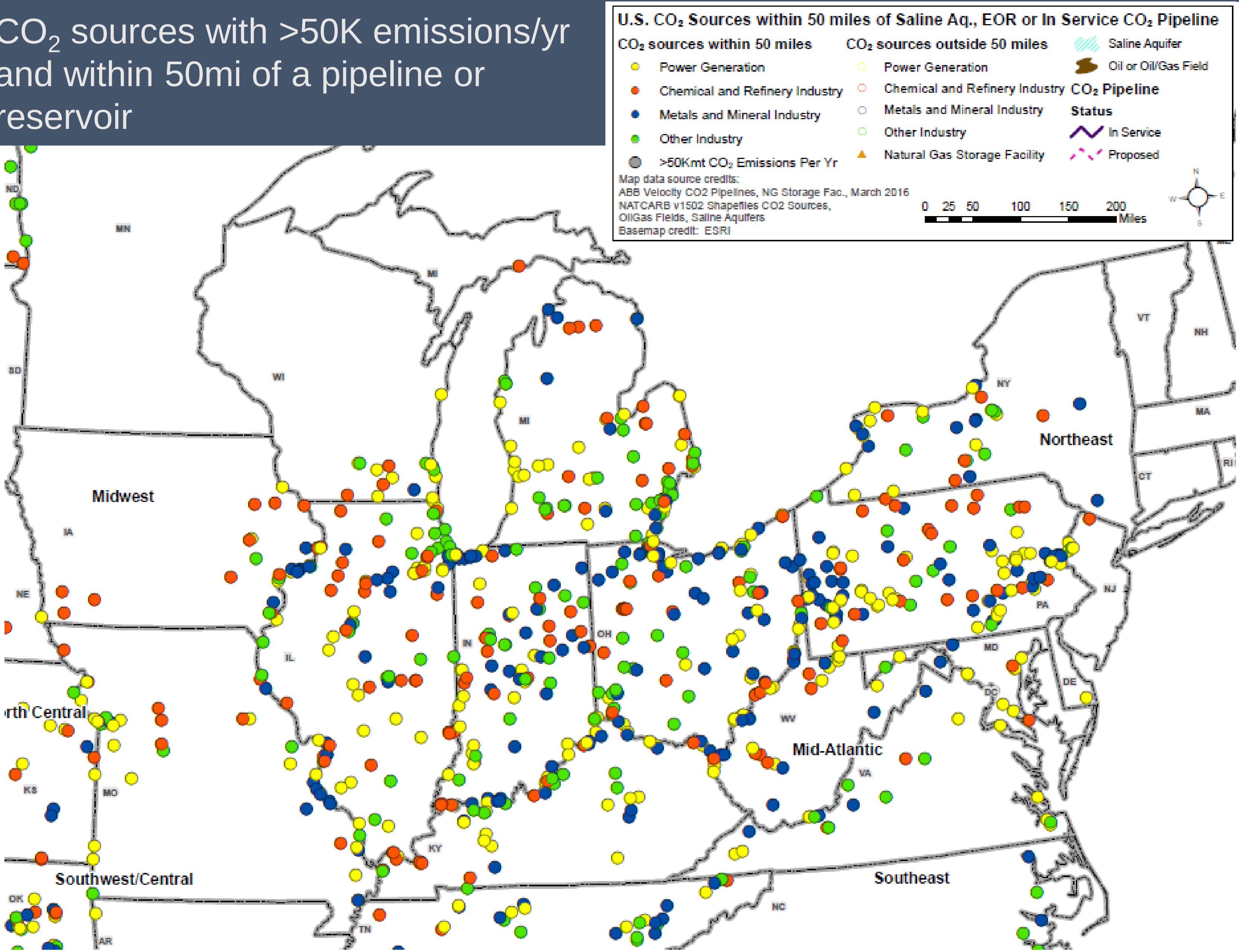
½ cost

Mid Atlantic



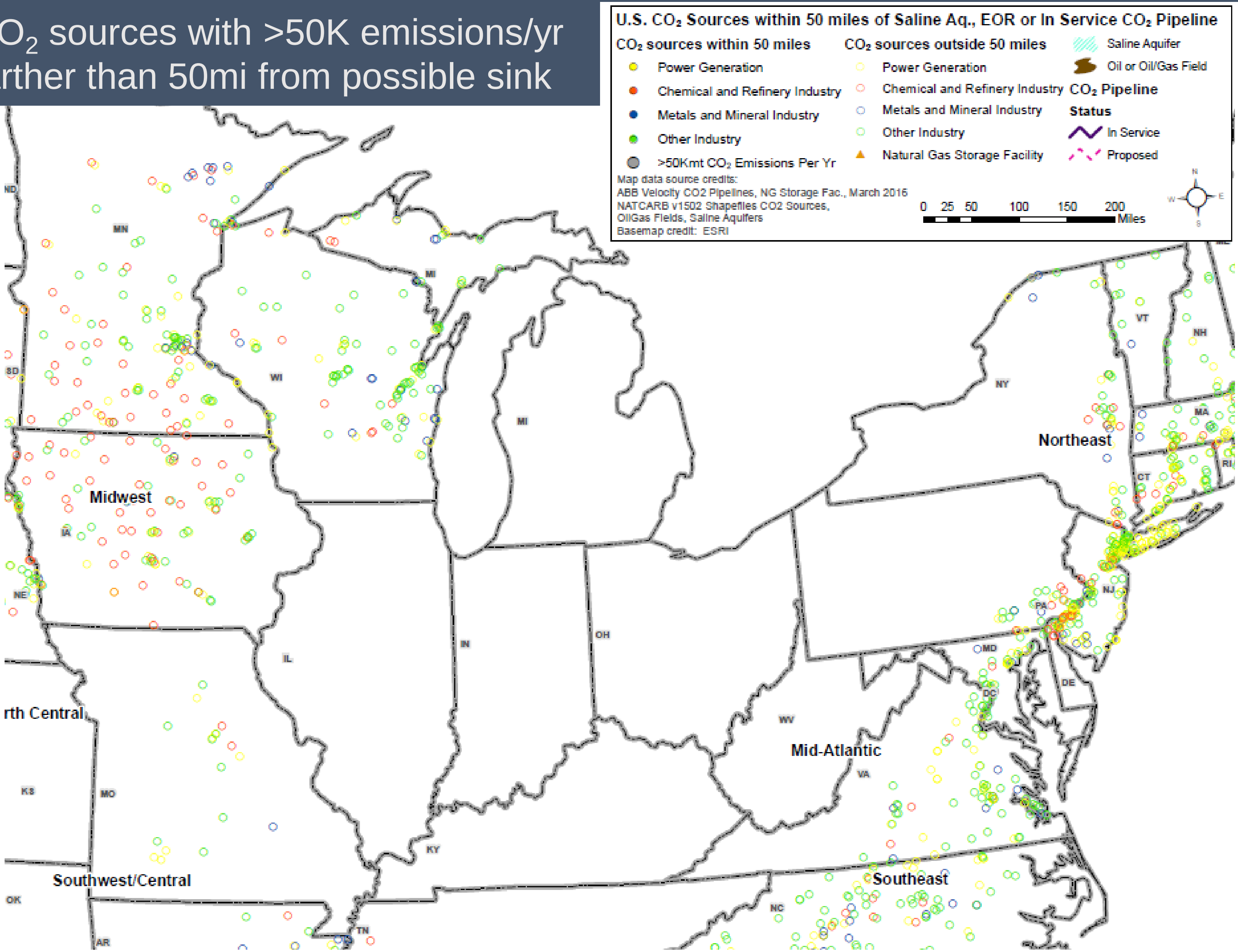
Mid Atlantic

CO_2 sources with >50K emissions/yr and within 50mi of a pipeline or reservoir



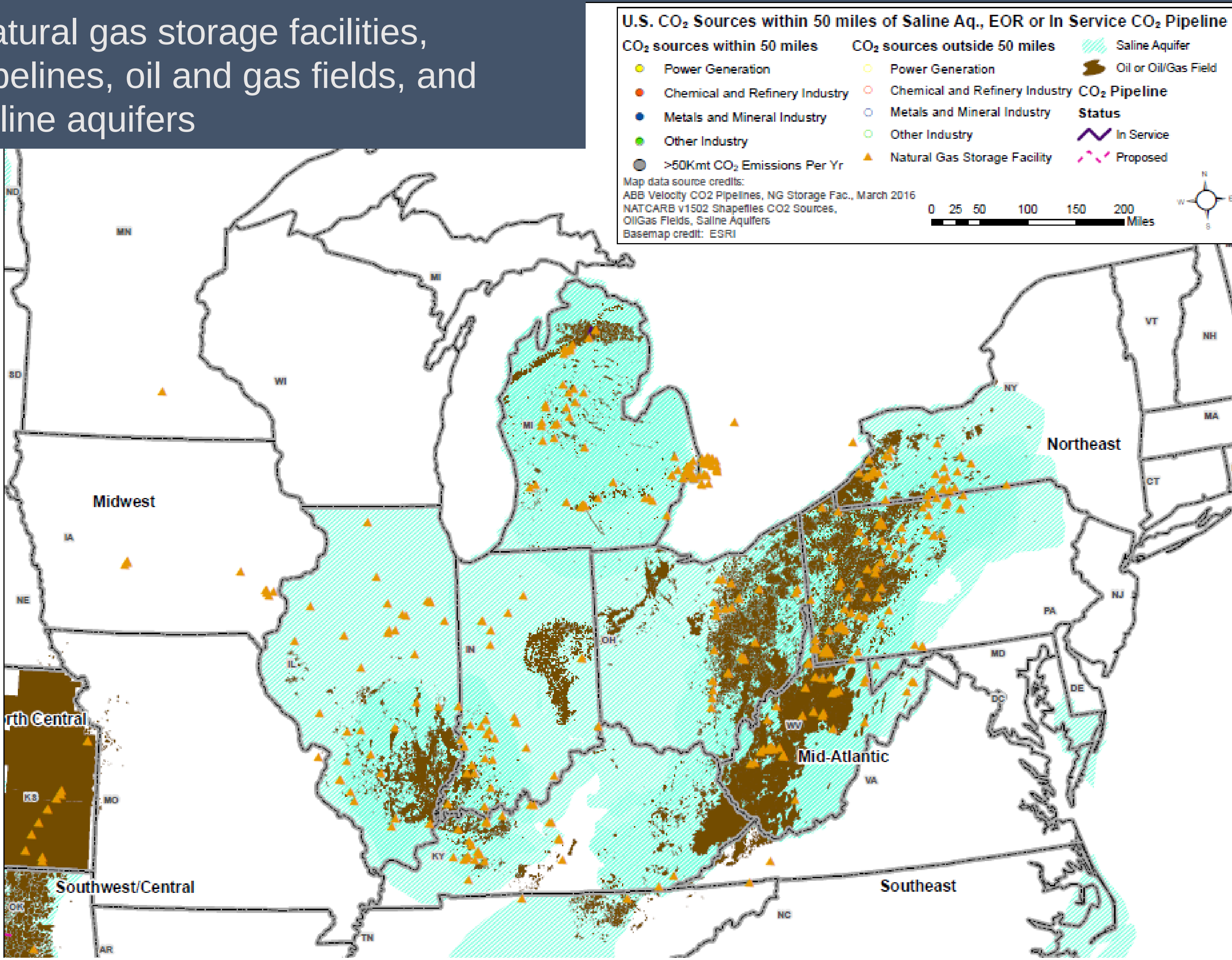
Mid Atlantic

CO_2 sources with >50K emissions/yr farther than 50mi from possible sink

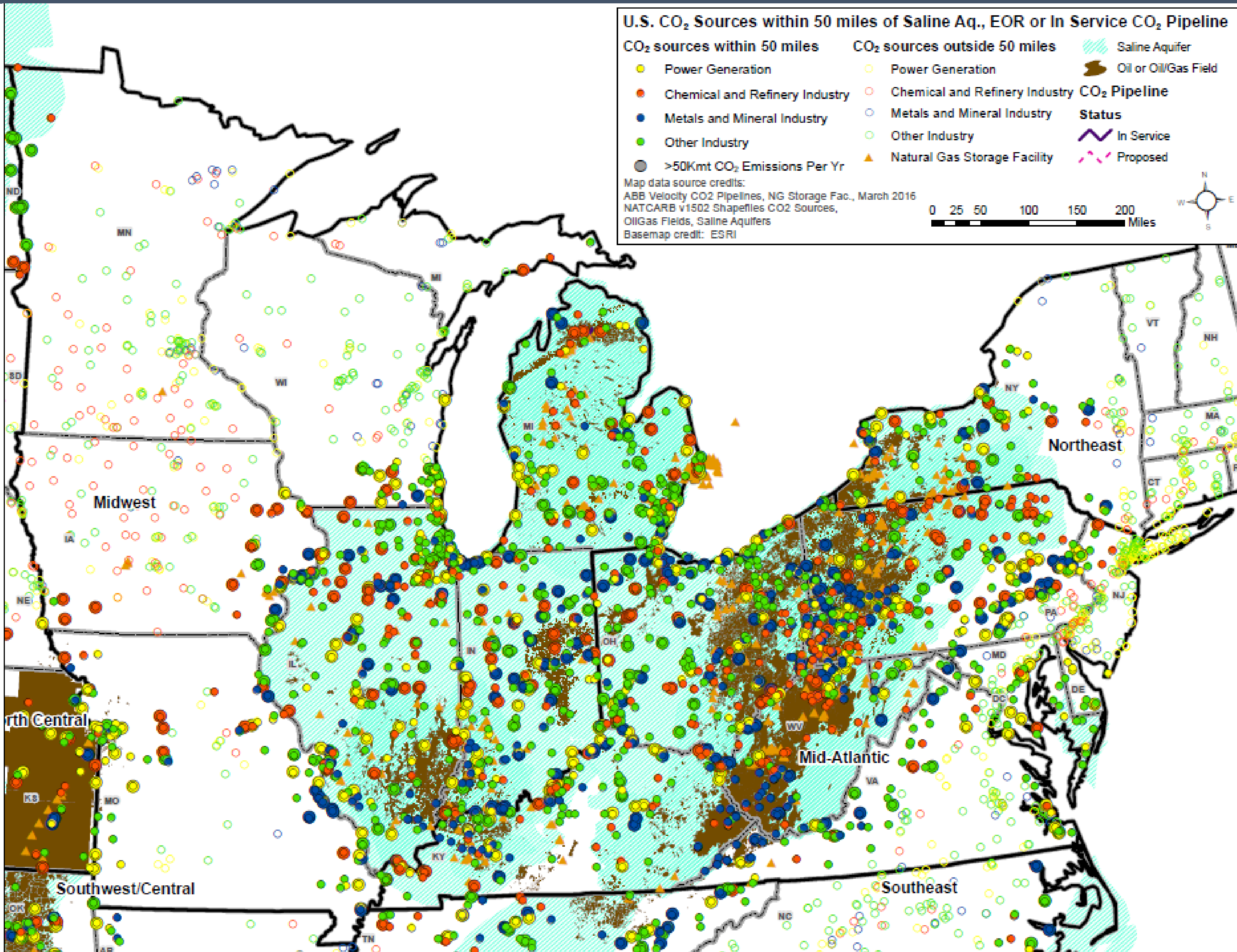


Mid Atlantic

Natural gas storage facilities, pipelines, oil and gas fields, and saline aquifers

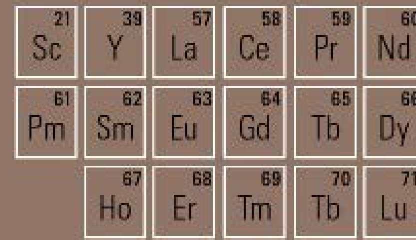


Mid Atlantic



RARE EARTHS

THE HIGH-DEMAND METALS



WHAT ARE RARE EARTH MINERALS?

Rare earths refer to 17 elements that are abundant in the Earth's crust, but whose minable concentrations are less common than many other minerals. Rare earths are in high demand because they are critical to U.S. high-tech innovation, advanced energy and national security.

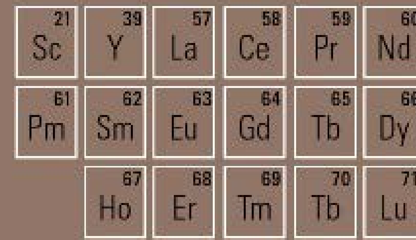
HEAVY Rare Earth Elements
LIGHT Rare Earth Elemetns

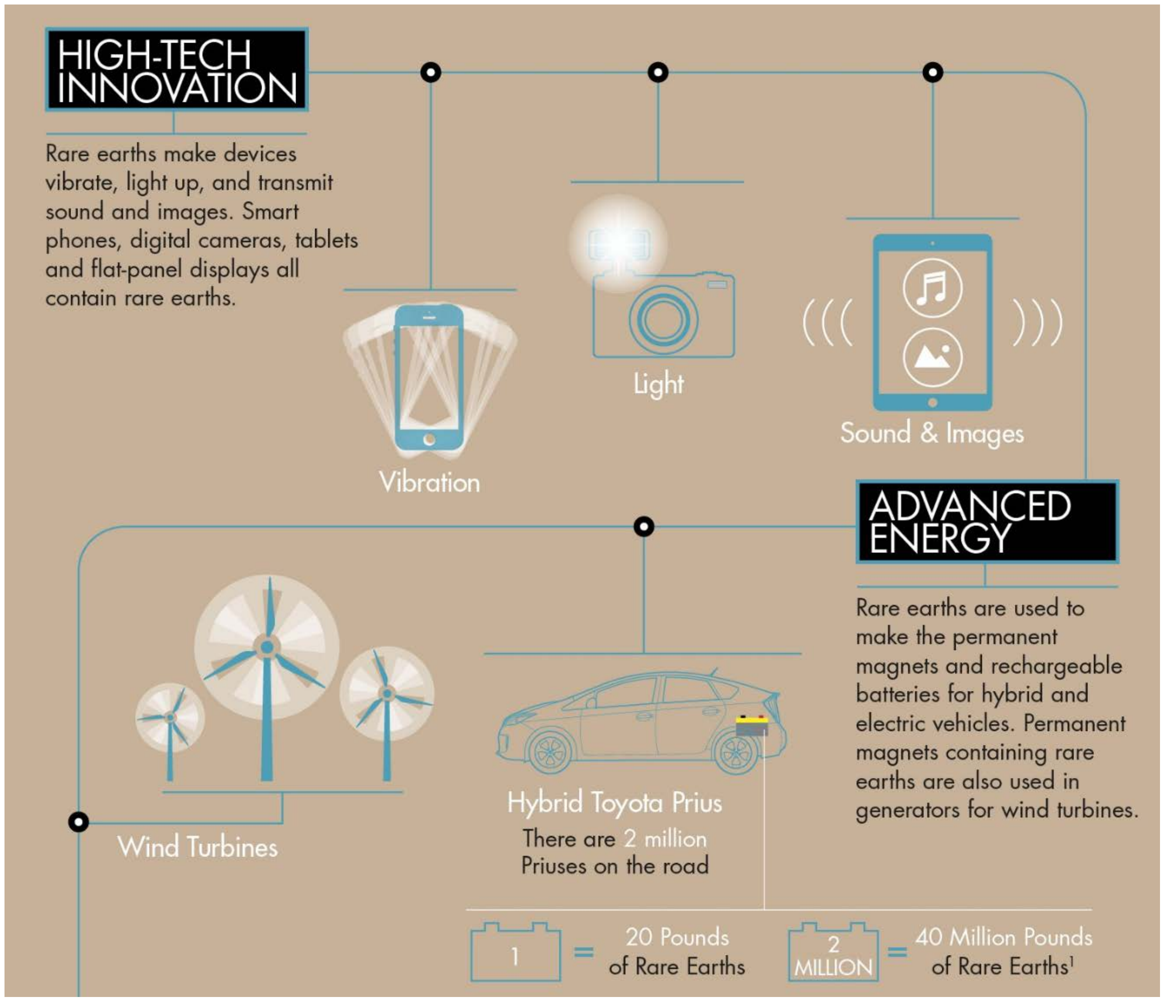
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	A
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt									

Lanthanides	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Actinides	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

RARE EARTHS

THE HIGH-DEMAND METALS

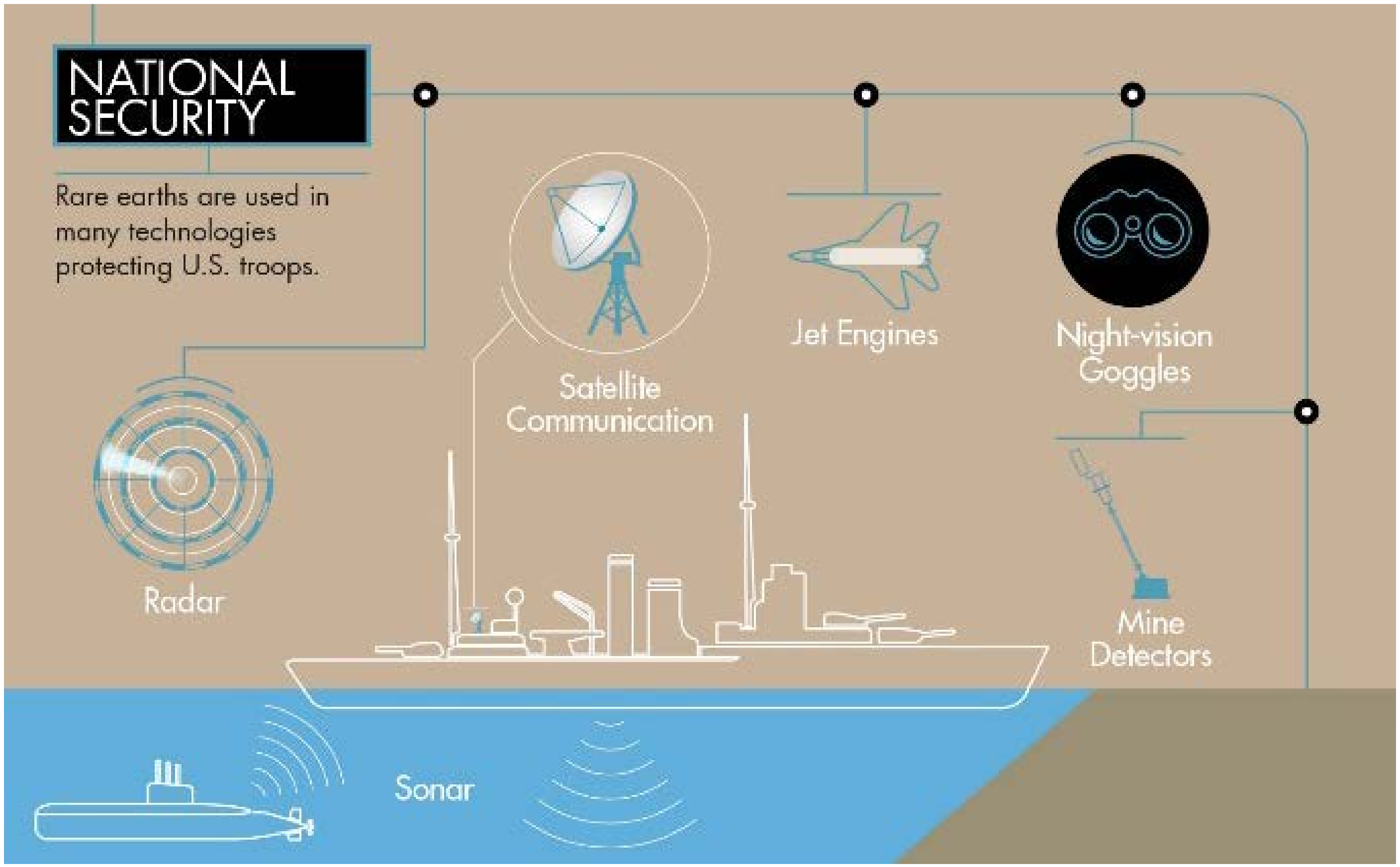




RARE EARTHS

THE HIGH-DEMAND METALS

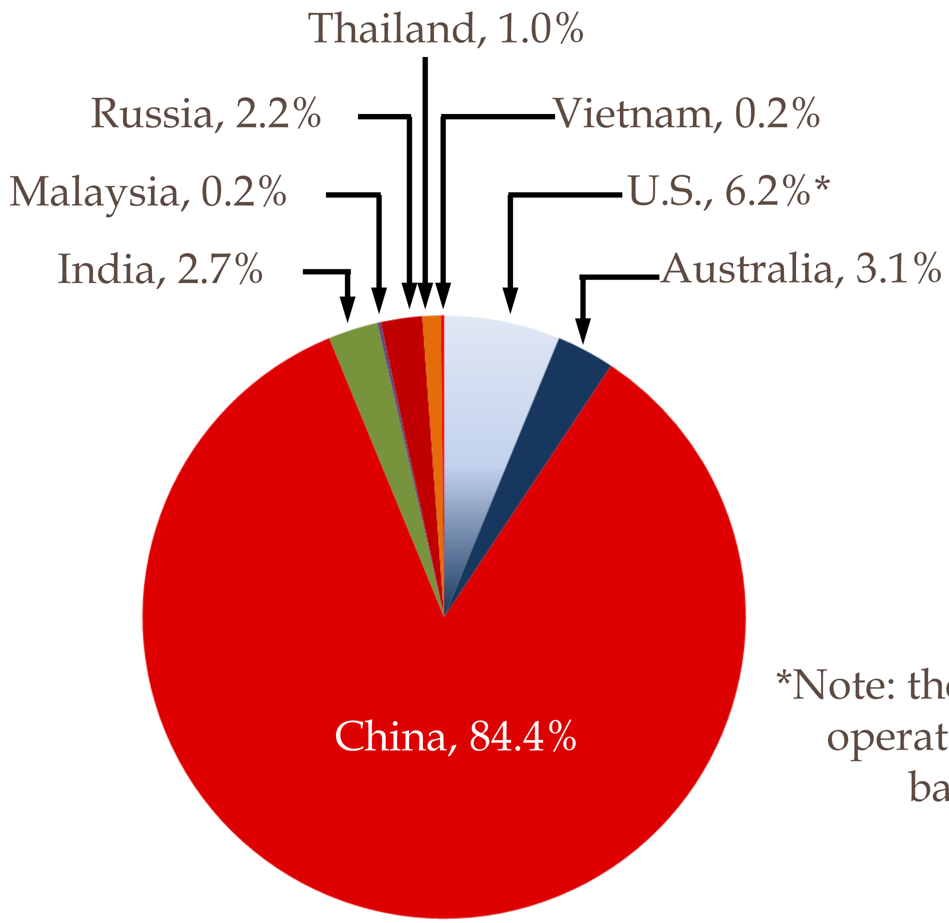
21 Sc	39 Y	57 La	58 Ce	59 Pr	60 Nd
61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy
	67 Ho	68 Er	69 Tm	70 Tb	71 Lu



RARE EARTHS
THE HIGH-DEMAND METALS

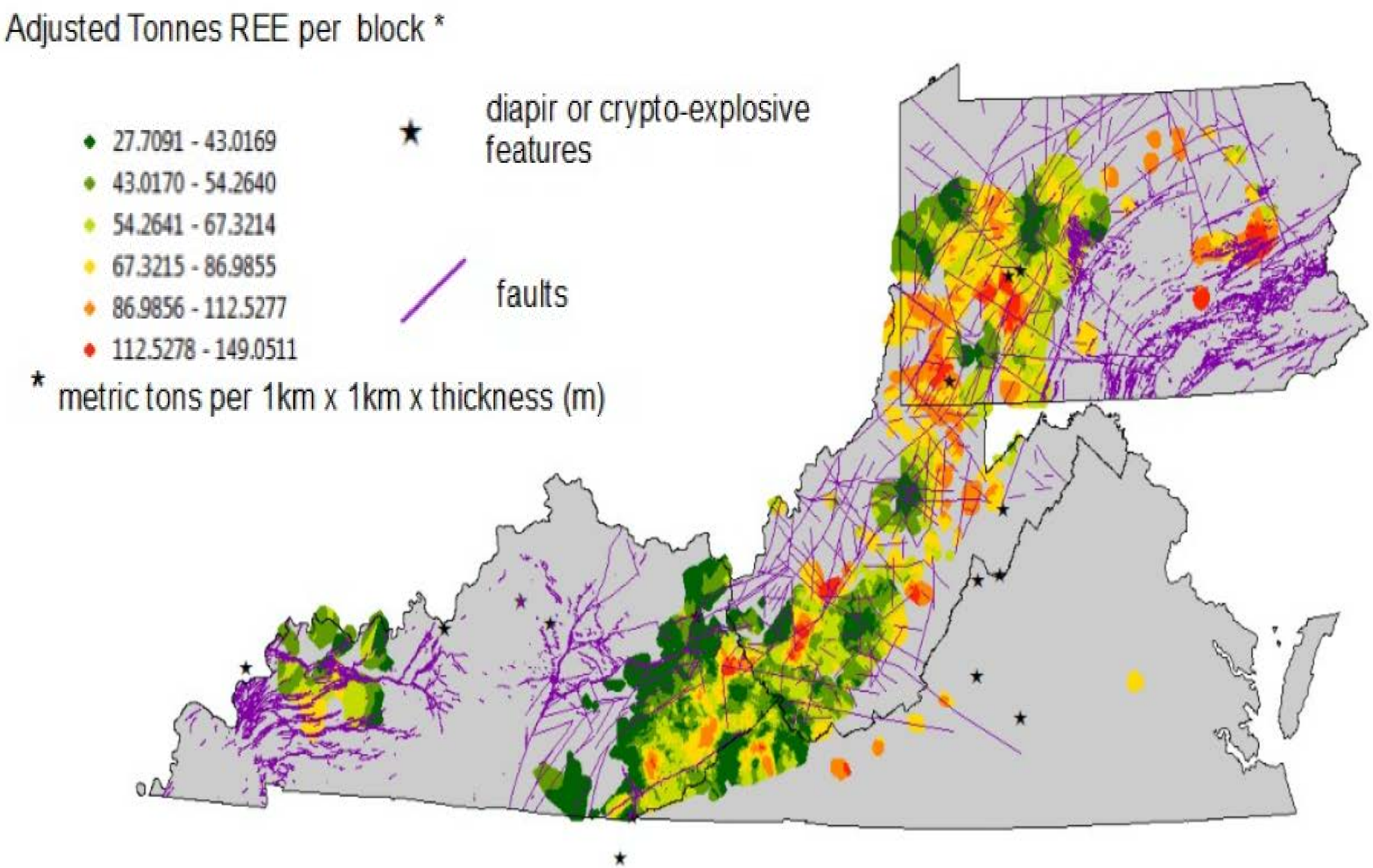
Sc Y La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Tb Lu

Share of global rare Earth mine production, 2014 (USGS data)



*Note: the sole U.S. production operation Molycorp went bankrupt in 2015

Resource assessment of rare earth elements in the Appalachia region



Coal country has advantages

- Trained Work Force
    - Mining and Reclamation
    - Mining Supply Chain
- Existing Mining Supply Chain
    - Mining/Processing Equipment
    - Fuels/Chemicals
    - Contracting/Service Firms
    - Transportation
- Academic Expertise

DOE R&D Projects in Indiana

Active Projects In Indiana	Performer	Project End	DOE Share
New Mechanistic Models of Creep-Fatigue Interactions for Gas Turbine Components	Purdue University	2017-11-30	$260,470.00
Effects of Exhaust Gas Recirculation (EGR) on Turbulent Combustion and Emissions in Advanced Gas Turbine Combustors with High-Hydrogen-Content (HHC) Fuels	Purdue University	2016-09-30	$277,999.00
Advancing Pressure Gain Combustion in Terrestrial Turbine Systems	Purdue University	2018-09-30	$797,181.00
Predicting Microstructure-Creep Resistance Correlation in High Temperature Alloys over Multiple Time Scales	Purdue University	2016-07-21	$156,500.00
Hybrid Encapsulated Ionic Liquids for Post-combustion CO2 Capture	University of Notre Dame	2018-09-30	$1,699,558.00
Novel Functionally Graded Thermal Barrier Coatings in Coal-Fired Power Plant Turbines	Trustees of Indiana University	2016-08-31	$293,519.00
An Assessment of Geological Carbon Sequestration Options in the Illinois Basin - Phase II and III	Indiana Geological Survey - Indiana University	2017-12-17	$1,302,911.00
Midwest Regional Carbon Sequestration Partnership (MRCSP) - Phase II/ Phase III	Indiana Geological Survey - Indiana University		$796,314.00

Questions