Carbon Dioxide Capture, Utilization and Storage

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Outline of the Presentation

I. Introduction – Defining terms. Understanding where CCUS might contribute to solutions in resolving climate concerns?

II. Brief background on climate change to set the stage for considering CCUS as a mitigation technology.

III. Introduction to carbon capture processes for large stationary power systems.

IV. Utilization options

V. Carbon dioxide storage –setting the stage for subsequent speakers

VI. Considering risk/reward trade-off amongst options.

VII. Comments and questions.

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Introducing the concepts behind CCUS

- Carbon dioxide capture, utilization and storage technologies are a family of processes involved in reducing carbon dioxide emissions to the atmosphere.
- Climate policies focused on resolving concerns over anthropogenic emissions (and other impacts) to the climate system generally consider three responses:
  - Mitigation of emissions
  - Adaptation to minimize impacts of climatic change
  - Geoengineering to reduce or offset atmospheric forcing caused by human activities.
- We'll spend a few minutes discussing these concepts, highlighting differences amongst them and how they differ from other elements of climate strategies.

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Key terms to keep in mind…

- **Mitigation(1):** Technological change and substitution that reduce resource inputs and emissions per unit of output. Several social, economic and technological policies would produce an emission reduction, with respect to climate change, but mitigation means implementing policies to reduce GHG emissions and enhance sinks.
- **Adaptation (1):** Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature shock resistant plants for sensitive ones, etc.
- **Geoengineering (1):** Technological efforts to stabilize the climate system by direct intervention in the energy balance of the Earth for reducing global warming

(1) http://www.ipcc.ch/pdf/glossary/ar4-wg3.pdf

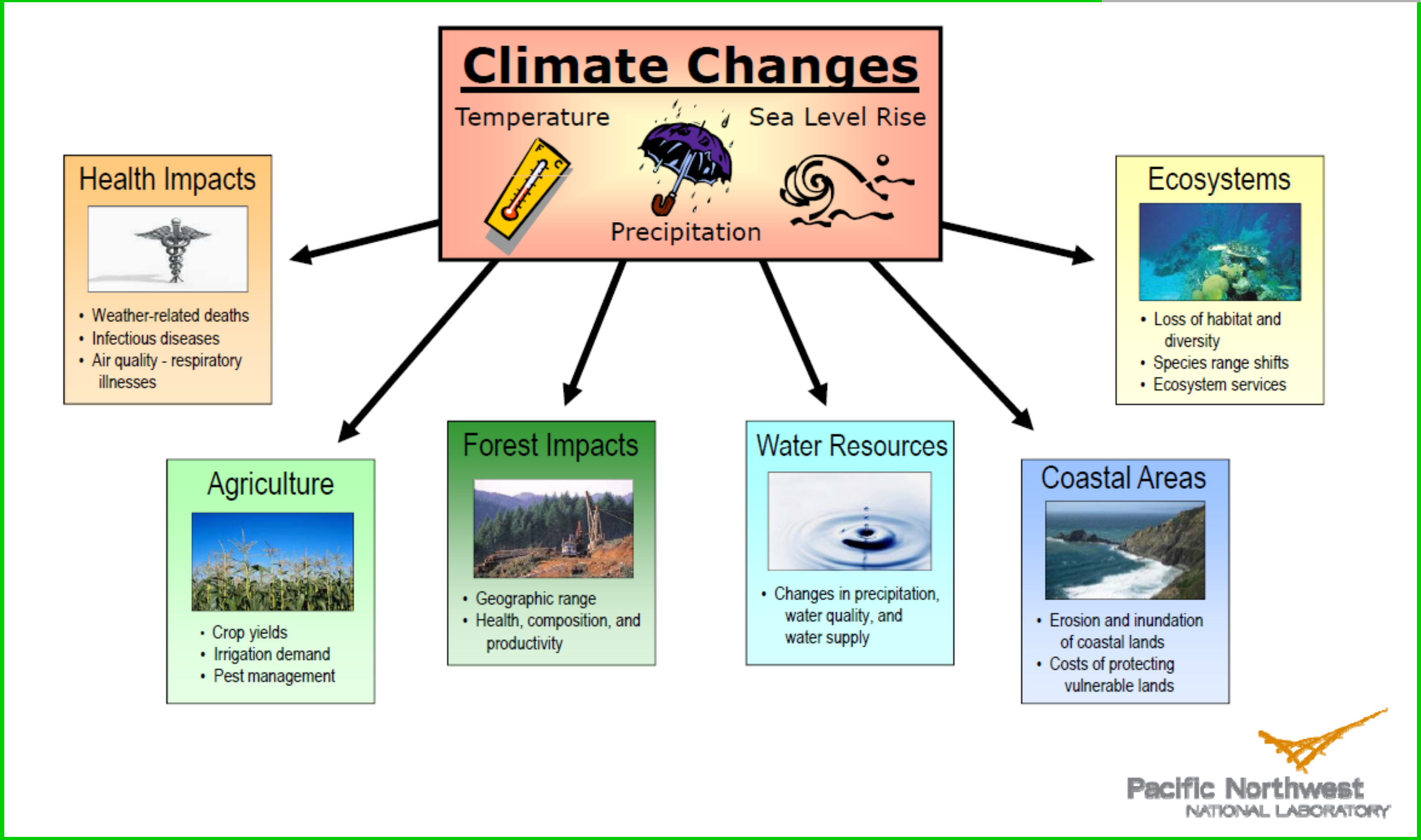
- **Carbon Capture and Storage (1):** A process consisting of separation of CO2 from industrial and energy-related sources, transport to a storage location, and long-term isolation from the atmosphere – often in geologic reservoirs
- **Biologic mitigation (1):** Biological options for mitigation of climate change involve one or more of the three strategies: conservation - conserving an existing carbon pool, thereby preventing CO2 emissions to the atmosphere; *sequestration - increasing the size of existing carbon pools, thereby extracting CO2 from the atmosphere*; substitution – substituting biomass for fossil fuels or energy-intensive products, thereby reducing CO2 emissions.
- **Carbon dioxide utilization (2):** Nature utilizes CO2 to produce myriad substances that are consumed by humans and animals. Some industrial processes aim to accelerate the utilization of CO2. Three pathways are recognized for utilizing CO2: conversion of CO2 into fuel, utilization of CO2 as a feedstock for chemicals , and non-conversion use of CO2.

(2)DNV Research and Innovation, Position Paper 07 – 2011, Carbon Dioxide Utilization

Technologies and Strategies

Technology Option / Climate Strategy	Terrestrial and other sinks for carbon dioxide	Geologic storage of captured carbon dioxide	Consumption of captured carbon dioxide	Beneficial reuse of captured carbon dioxide
Mitigate emissions of GHG’s and black carbon	●	●	●	●
Adapt to climatic change	●			●
Modify atmospheric and terrestrial processes that drive climate	●	●		

Brief background on climate change

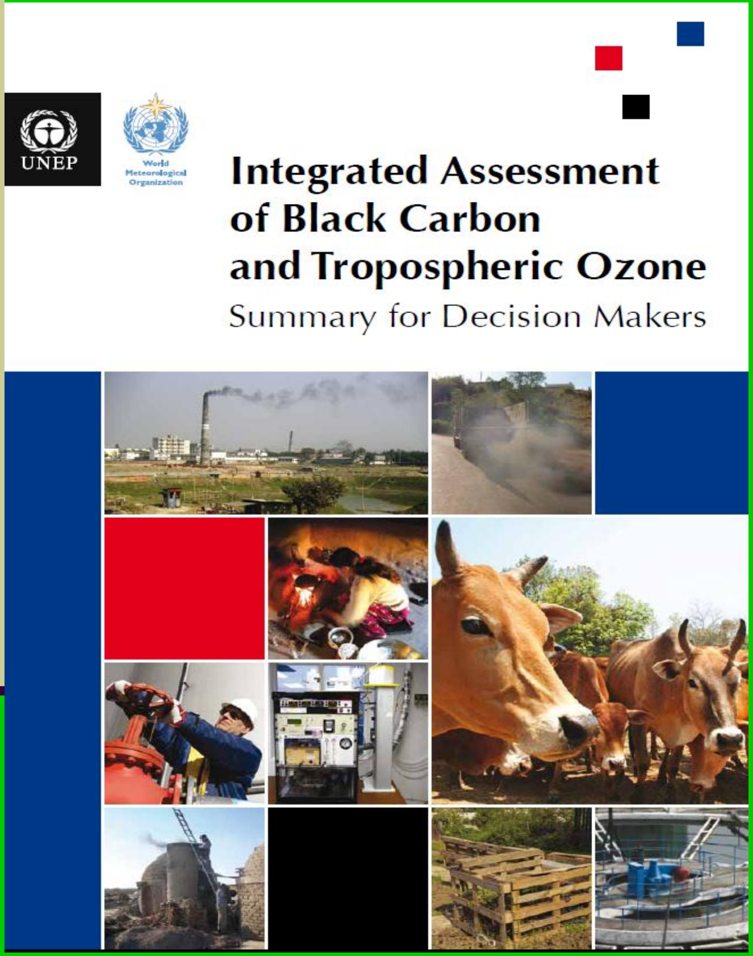


Taken from presentation by James Dooley, PNNL, USCSC Capacity Building Workshop, Columbus, Ohio (2009)

Setting the stage…

- Substantial body of data exists to support claims that “climate” is changing at unprecedented rate consistent with the theoretical basis developed to explain anthropogenic climate change.
  - 2011 Neutral assessment of temperature and other terrestrial climate data supports arguments of significant change (See: http://www.berkeleyearth.org/)
- Studies that attempt to project impacts of continued elevated levels of greenhouses gases in atmosphere suggest either:
  - Long, slow rise in key indicators tied to GHG emissions and corresponding sea level rise, changes in rainfall patterns, changes in average regional temperatures, loss of sea ice, etc.
  - Rapid changes may occur once tipping points are reached.
- Controversies remain some focused on “denial” of the phenomena others focused on lack of key data, faulty models, etc.
  - Some anomalies may exist in “data” (for example glacier retreat).
- This talk not focused on science of climate change but rather on a particular technological options that could be deployed to reduce carbon dioxide emissions to the atmosphere.

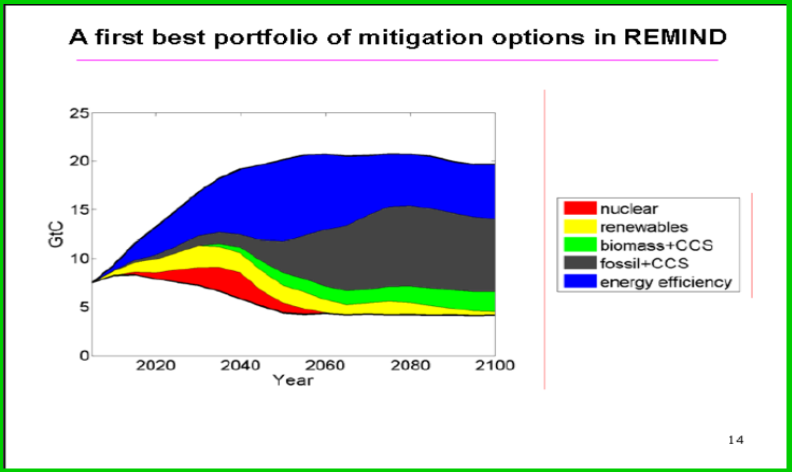
New Strategy – offering near-term mitigation

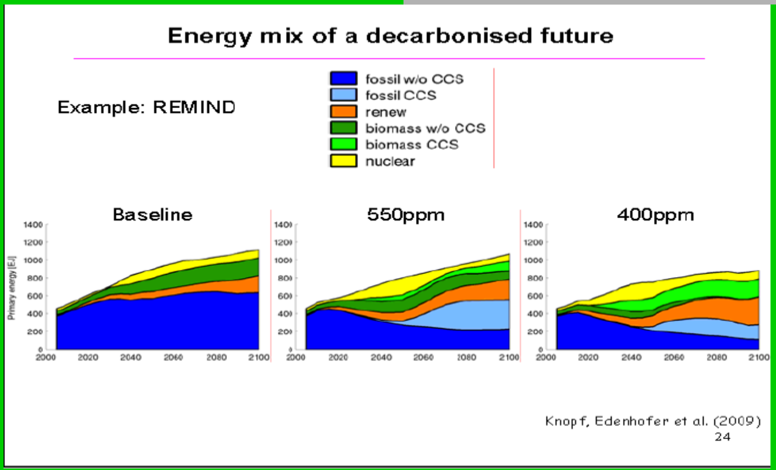


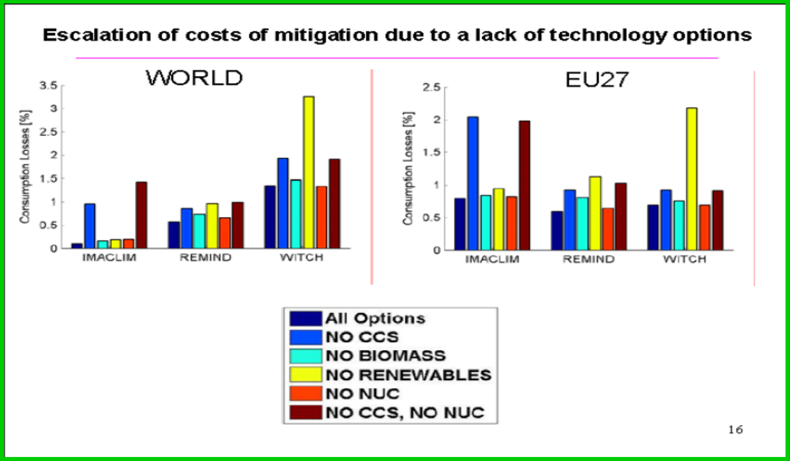
Last year, the United Nations Intergovernmental Panel on Climate Change ended up with a bit of mud on its face when it had to retract an alarming claim in its landmark 2007 assessment: that the probability of Himalayan glaciers "disappearing by the year 2035 and perhaps sooner is very high." ...In fact, there is still a paucity of scientific information about the Himalayan glaciers, whose melt supplies water to hundreds of millions of mostly poor people in Asia. ..A paper published recently in Nature Geoscience sets out to systematically and scientifically answer these questions. The study found that different parts of the Himalayas were reacting differently...The researchers reported that about half of the glaciers in the Karakoram region of the northwestern Himalayas were actually stable or even advancing, while two-thirds of the glaciers in the rest of the Himalayas were shrinking. Factors that scientists say hasten glacial retreat include rising temperatures and the presence of deposits of soot emanating from polluting factories and primitive cook stoves in the region. The thin layer of this black substance absorbs the sun's heat and promotes melting.

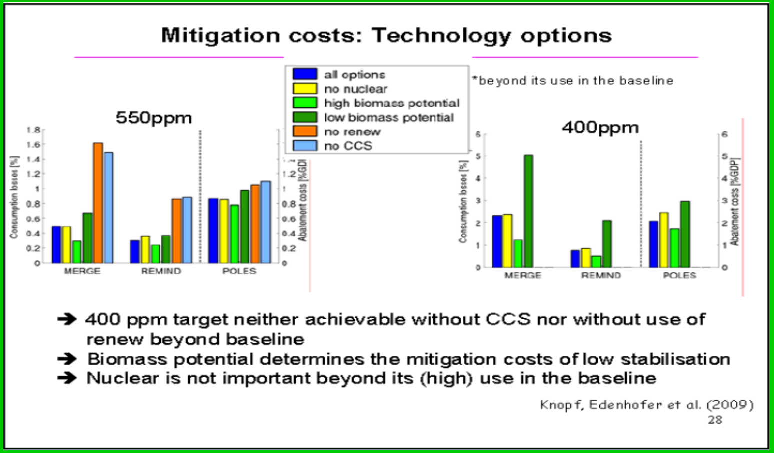
http://green.blogs.nytimes.com/2011/02/01/filling-in-the-blanks-on-himalayan-glaciers/

These analyses, by PIK, make a case for global deployment of CCS

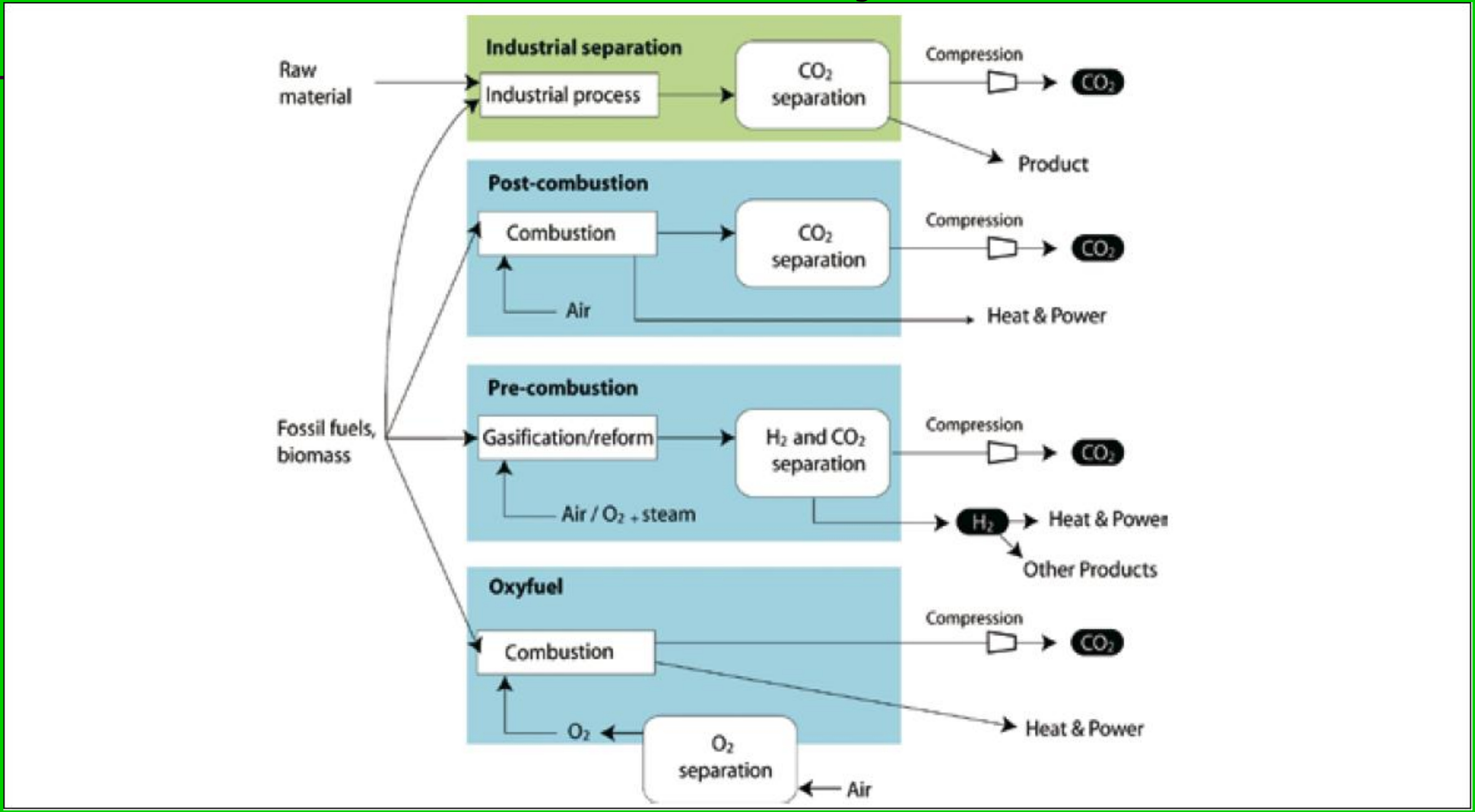








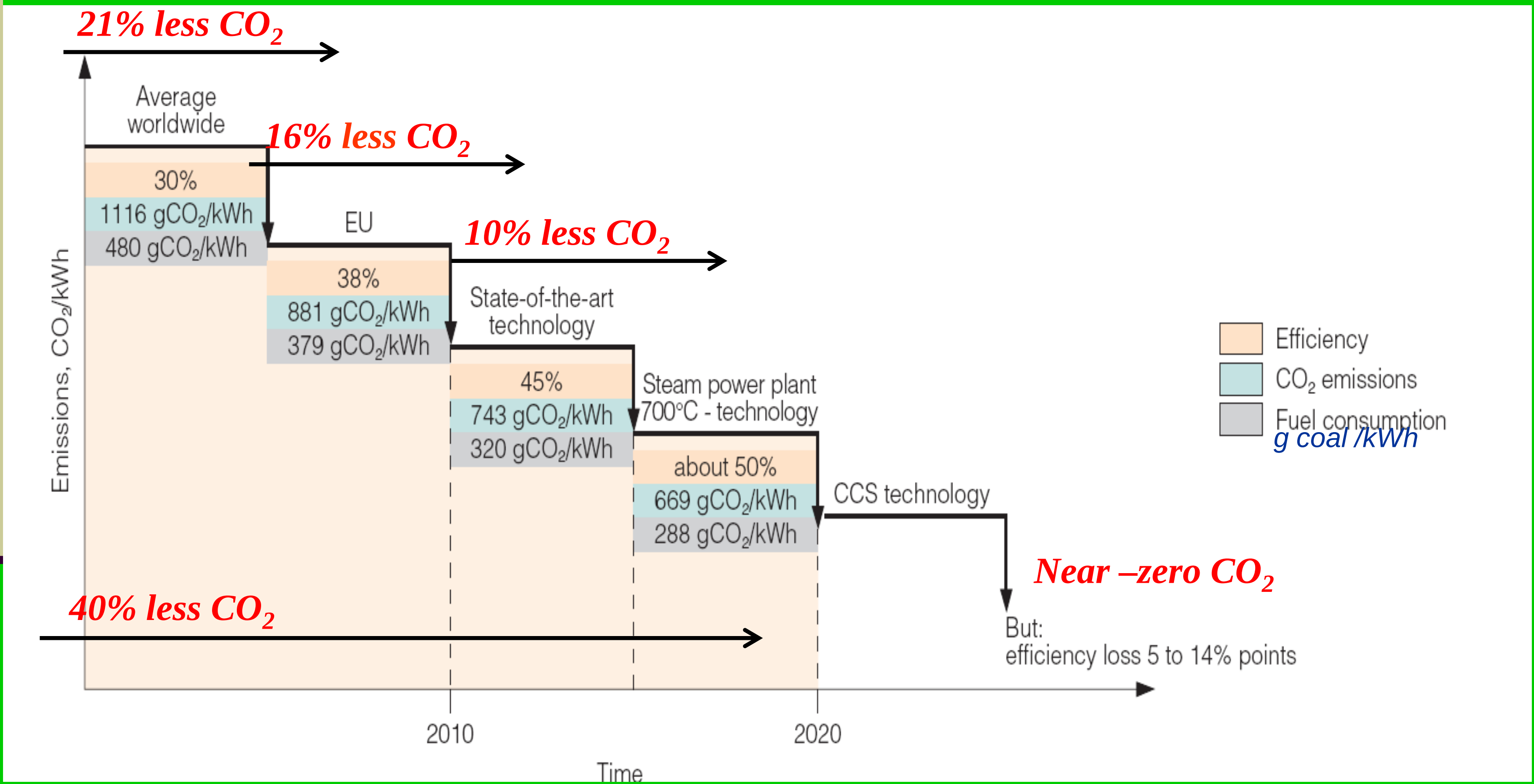
Carbon capture processes for large stationary sources.



Schematic representation of capture systems. Fuels and products are indicated for oxy-fuel combustion, pre-combustion (including hydrogen and fertilizer production), post-combustion and industrial sources of CO2 (including natural gas processing facilities and steel and cement production) (based on Figure 3.1) (Courtesy CO2CRC).

(From: IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

Decoupling: Efficiency improvements offer immediate reductions

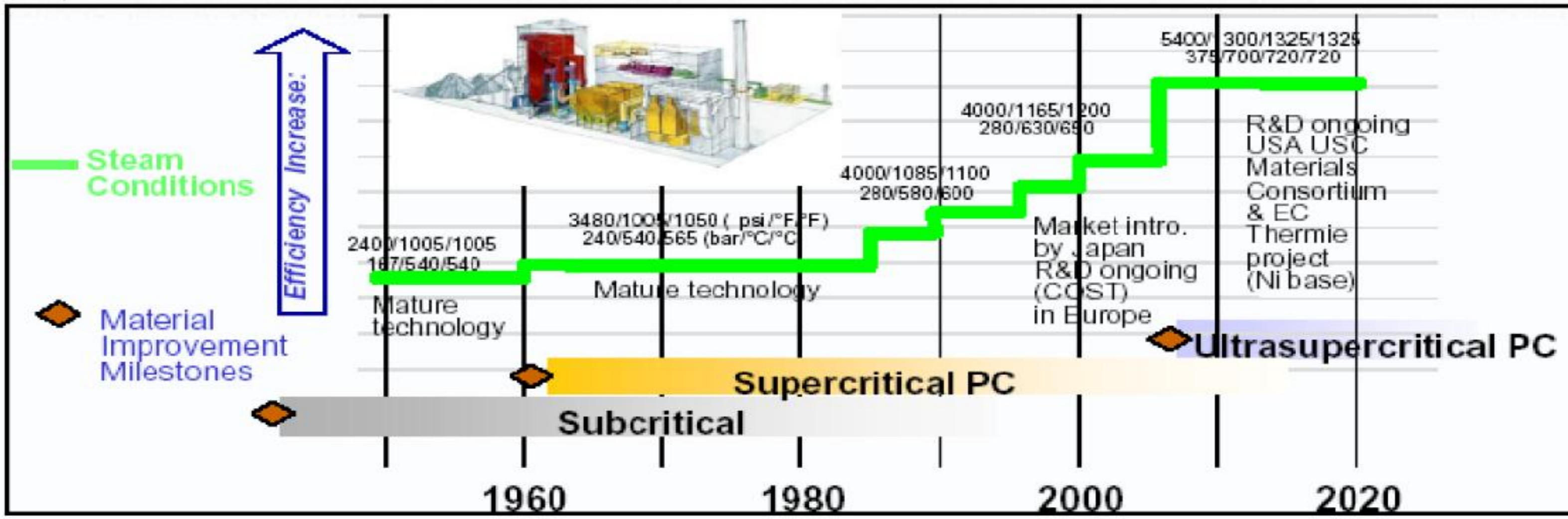


Coal plant efficiency and CO_2 emissions

Source: IEA Clean Coal Centre

Developmental trends in advanced coal combustion

Advanced Coal Combustion Efficiency



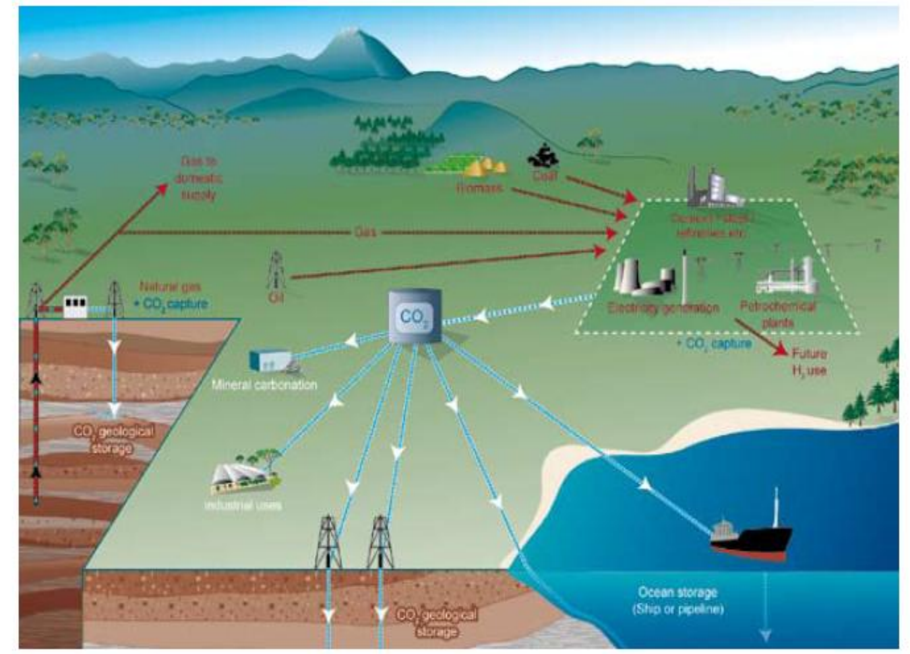
Advanced cycles - A proven path to reliable, high efficiency power generation

Current Operation		Potential	
Supercritical:	38% - 40%	UltraSupercritical:	43% - 45%
IGCC:	35% - 38%	Future IGCC:	38% - 45%

Source: Alstom

System view that includes "U" alongside "CCS"

- Conceptually, CCS could include:
  - Additional power generation with a CO2-based cycle
  - Providing CO2 to a consumptive end-use commercial venture such as growing algae or producing high-value chemicals (regionally distributed)
  - Using CO2 for enhanced oil recovery
- Compared to geologic CCS, the quantities of CO2 used in various beneficial use applications may be small. However, using CO2 for beneficial purposes may be perceived as being more valuable, or as having a lower risk (e.g., applications where carbon dioxide is consumed) compared to geologic storage. The perception of lower risk and higher value may facilitate rapid development of the required CO2 infrastructure (such as pipeline networks) and the deployment of novel technologies, in turn, enhancing prospects for geologic CCS.



Schematic diagram of possible CCS systems showing the sources for which CCS might be relevant, transport of CO2 and use or storage options (Courtesy of CO2CRC). (As used in the IPCC Special report on Carbon Capture and Storage)

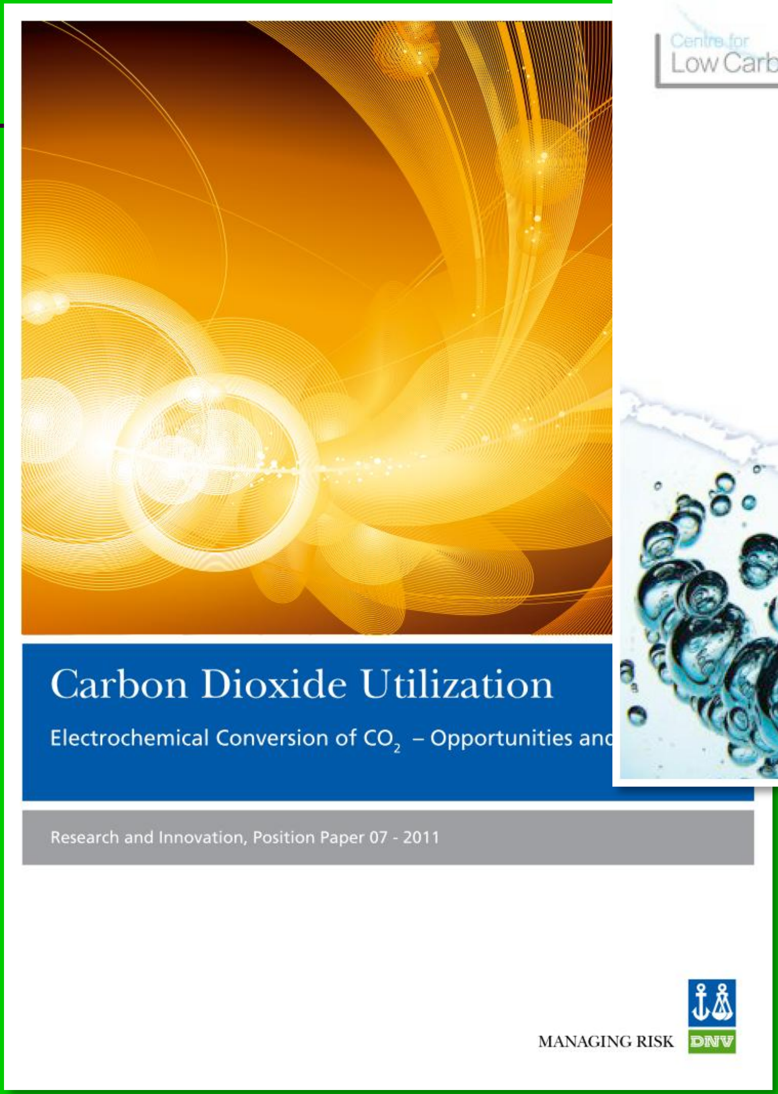
Utilization options

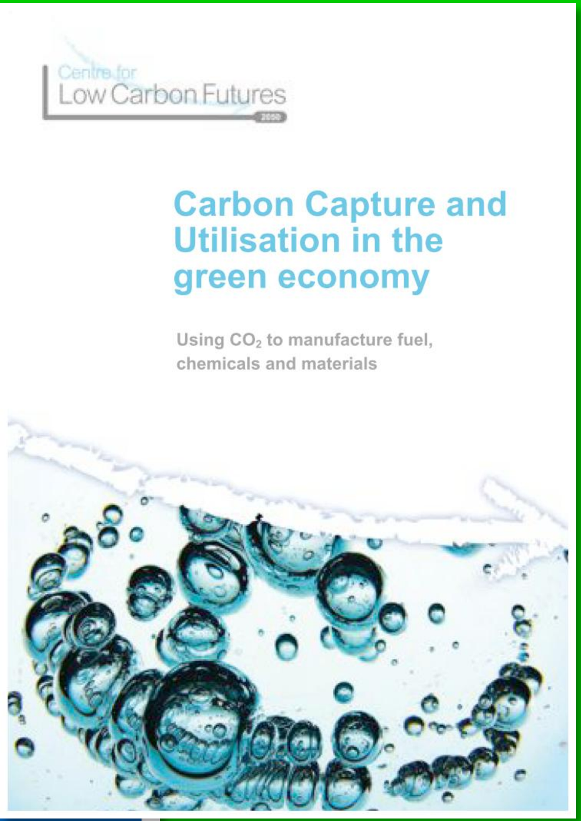
Hydrocarbon Recovery	Non-consumptive	Consumptive
• CO_2-EOR • CO_2-EGR • CO_2-ECBM • CO_2-EGHR • Oil sands • CO_2-fracturing	• Fuels & chemicals • Desalination • Slurry transport • Beneficiation • Working/HT fluid • Solvent extraction	• Soil amendment/fertilizer • Synthetic cementitious materials, building materials • Fuels & chemicals

Beneficial Use: Value to end-user, markets for CO2 producers.

A large number of specific processes could be developed focusing on the routes identified in these categories.

Recent publications evaluating CO_2 Utilization…



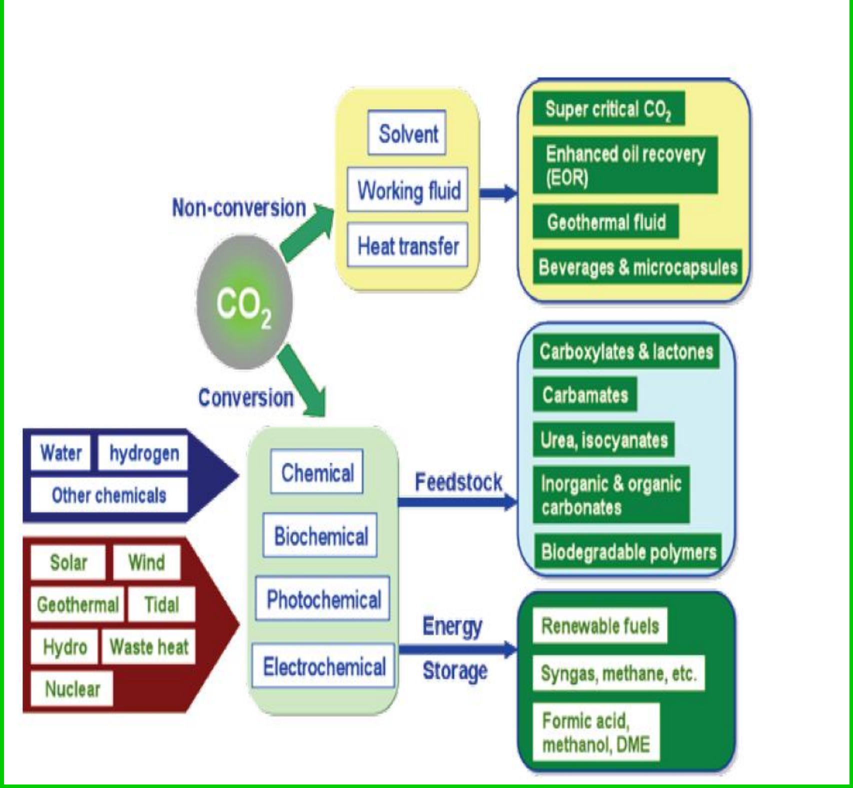


Metrics

Quantity of CO_2 Mitigation *(direct+indirect)*	• Captured CO_2 utilized (direct) • CO_2 consumed • Is capture intrinsic to CO_2-use process?
Benefits *(unit cost of reduction), system basis*	• Cost of capture & processing (\$/T CO_2) • By-product value (\$/T CO_2)
Energy Consumption /Penalty *(total system)*	• Capture, disposal • By-product process • Energy avoided
Market Size & Potential	• Capture & storage [=T/y] • CO_2 consumed [=T/y] • By-products' market sizes [=T/y] • Net-nominal benefit (\$/y) = Market size * Unit cost /benefits

How much could reuse contribute?

- DNV report: "The various utilization technologies together have the potential to reduce CO2 emissions by at least 3.7 gigatons/year (Gt/y) (approximately 10 % of total current annual CO2 emissions), both directly and by reducing use of fossil fuels. However, much greater reductions are possible through wider adoption of these technologies.
- ARI/USDOE estimates that CO2 –EOR in the U.S. could use 246 to 343 Mt CO2/yr for 30 years.
- Appalachian Basin(1): Evaluation of 84 reservoirs suitable for miscible EOR and 19 suitable for near-miscible EOR showed 48 could be economically feasible candidates for miscible-CO2-EOR. Application of this technology could produce ~1.3 billion barrels total while utilizing ~290 Mt of CO2.



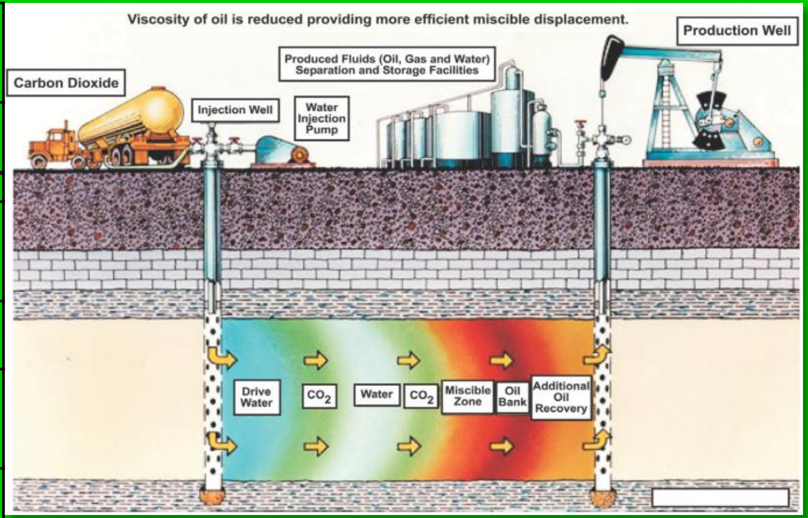
(1) NETL-ESPA/ARI (2011) Improving Domestic Energy Security and Lowering CO2 Emissions with Next-Generation CO2-Enhanced Oil Recovery

Current and Projected U.S. CO_2-EOR Production & CO_2 Supply/Demand

- 2010 OG&J EOR Survey
  - CO_2-EOR 42% of U.S. EOR production
  - Miscible-CO_2-EOR: 272109 bbl oil/d
  - 109 miscible, 9 immiscible-CO_2 EOR projects
  - Major players: Oxy, Denbury, KM, Chevron
- Current U.S. CO_2-EOR CO_2 Demand
  - ~60 MT/y (~3.1 billion scf/d)
  - 26% of this is anthropogenic. CO_2-EOR is currently supply-limited
- Proposed CO_2-EOR projects/ Projected CO_2 Demand
  - 1.7 billion T CO_2 in 30 yrs, ~64 MT/y additional demand
  - NETL/ESPA-ARI Report: 320 to 446 MT CO_2/y

CO_2-EOR Example

Gross/net CO_2 reduction per tonne of primary CO_2	Net reduction: 0.77 T/T CO_2 stored
Indirect carbon dioxide impacts (tonnes per tonne)	71 to 95 kg CO_{2eq}/bbl oil [15] , or 0.23 T CO_2 emitted/T CO_2 stored
Estimated scale of single project (i.e. plant or field size)	0.3 to 0.5 million MT CO_2/reservoir/year
No. deployments at maturity	~1,000 reservoirs in the USA
Estimated time to full deployment/ market saturation	~15 years
Estimated duration of significant impact	50 years
Cumulative reduction through 2050	9,840 to 113,720 MT CO_2
Special requirements on CO_2 (purity, etc.)	N_2, CH_4 increase minimum miscibility pressure, H_2S, SO_x, NO_2 promote miscibility of CO_2 with oil at lower pressures compared to pure CO_2. (See notes page)
Process/Technology Input Raw Materials and/or Energy	CO_2 steam, water for WAG, electrical energy required for recycle compression, separation and any artificial lift
Process/Technology Outputs	Crude, breakthrough gas, brine
Any concomitant advantages?	Domestic crude production may reduce foreign imports. CO_2-EOR may lower market barriers for geologic sequestration in saline formations
Typical costs to deploy (state basis)	NA
Value of carbon dioxide in this activity	NETL/ESPA (ARI) estimates an economic margin of 15 \$/bbl, or 90 to 115 \$/T CO_2. Without accounting for taxes, quality of crude oil, royalties, leases or capital costs, the value is 305 to 705 \$/T CO_2
Legal/regulatory framework	Currently, CO_2-EOR wells are designated as Class II wells in the Underground Injection Control (UIC)



Estimated impact /Net CO_2 considered permanently sequestered (US, MT CO_2/yr)	Gross: 320 to 446
Gross current *(equivalent)* CO_2 consumption in this use (US), million MT/year	60 (injected amount, 26% anthropogenic CO_2)
Projected growth in future CO_2 demand for this application	TBD
Game-changing events/scenarios favorable for this process	Higher volume CO_2 injection, better monitoring of CO_2, novel flood designs, improving injected-CO_2/oil mobility ratio, extending oil miscibility with CO_2)

Potential contribution of Reuse and Consumptive use options

- No single major annual/cumulative use application
  - CO_2-EOR stands out
  - Chemicals: High impacts (\$/T CO_{2eq})
- CO_2-EOR
  - [NETL/ESPA-ARI next-generation CO_2-EOR report, 2011]
  - 16-22 billion T CO_2, ~100 \$/T CO_2 economic margin (167 to 243 \$/T net-benefit)
- Consumptive uses: Carbonation approaches need to be demonstrated at larger scales
- Indirect processes: desalination, beneficiation, gasifier feed, slurry, HT fluids, freight pipelines, solvents: increased efficiencies, benefits TBD

EUROPEAN COMMISSION
DIRECTORATES-GENERAL
ENVIRONMENT AND CLIMATE ACTION
SRD - Shared Resources Directorate
SRD.2 - Finance

EN

Brussels, 14-07-2011
CLIMA.C.1/SER/2011/0033
FC/ajs Ares(2011) 768743

Dear Sir/Madam,

Contract: *Implications of the Reuse of Captured Carbon Dioxide for European Climate Action Policy*
Reference: CLIMA.C.1/SER/2011/0033
Official Journal reference : 2011/S 133-220436

CCR Industry Overview Report

Prize Capital's Report Profiles 136 Different "Carbon Capture and Recycling" (CCR) Entities:

AN INDUSTRY IS EMERGING WITH A NEW OPTION TO MITIGATE INDUSTRIAL CARBON DIOXIDE (CO2) EMISSIONS WHILE GENERATING ADDITIONAL REVENUE

Dubbed "Carbon Capture and Recycling" (CCR), this new industry dispels the notion that CO2 is a liability that needs to be buried – as is the case with carbon capture and sequestration (CCS) – and instead views the gas as a resource to be capitalized upon, using it as a feedstock in the production of valuable products such as fuel, building materials, animal feed, specialty chemicals, and plastics, among other things.

Improving the Regulatory Framework, optimizing organization of the CCS value chain and financial incentives for CO2-EOR in Europe, L. Birkeland, et al.

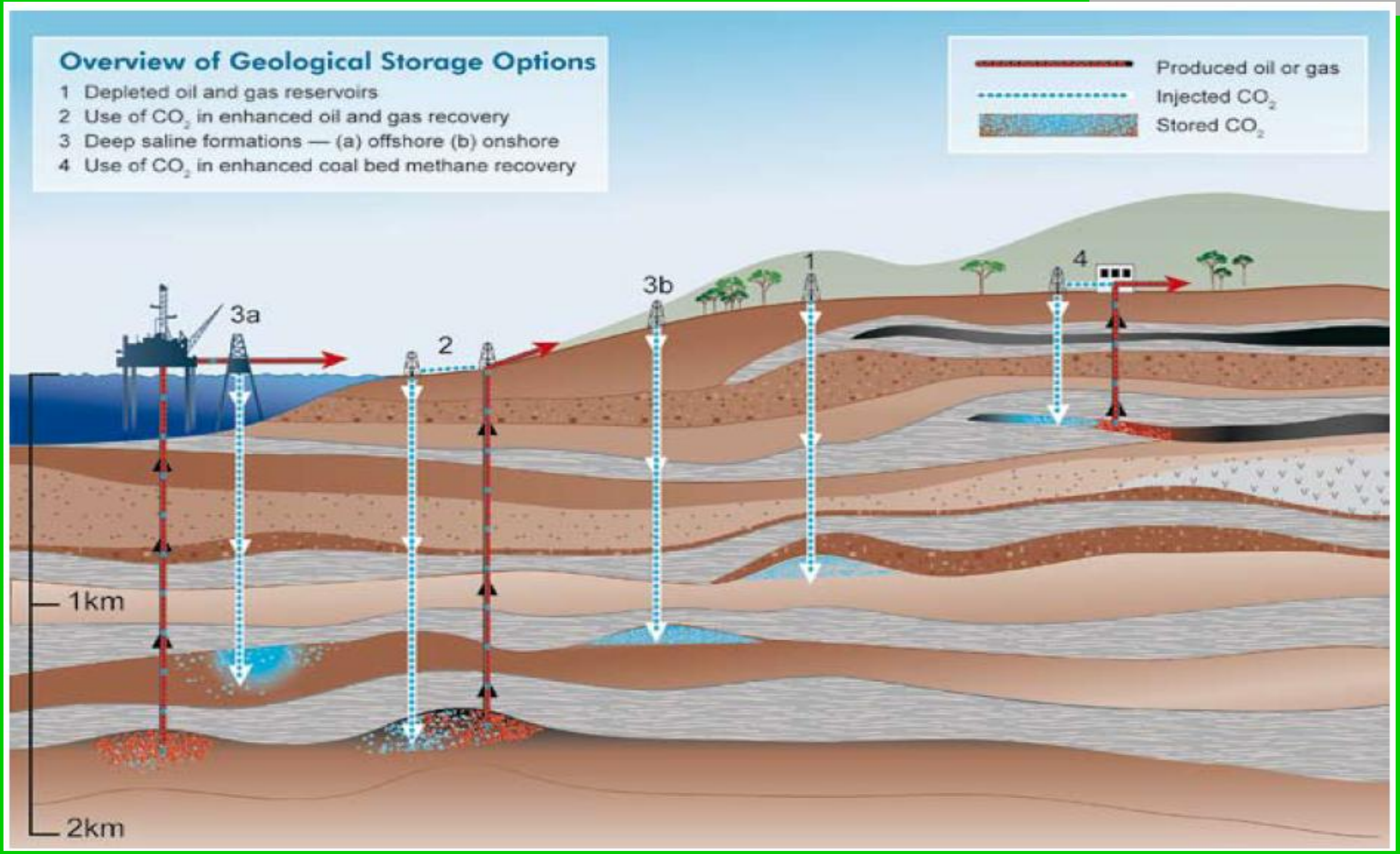
Abstract

The authors provide recommendations for improvements of the regulatory framework that is deemed necessary to facilitate the establishment of CO2 value chains in the near term. The recommendations address liability issues, cross border regulations and emission trading schemes (like EU ETS).

Recommendations for an overall organization of the value chain in terms of access rights, trans-boundary transport and storage of CO2 and rules for utilization/capacity allocation are also made. A range of financial incentives for CCS and CO2 for EOR are reviewed…Additional revenues to the State arising from the increase of oil produced through CO2 for EOR could be earmarked to future investments in CCS.

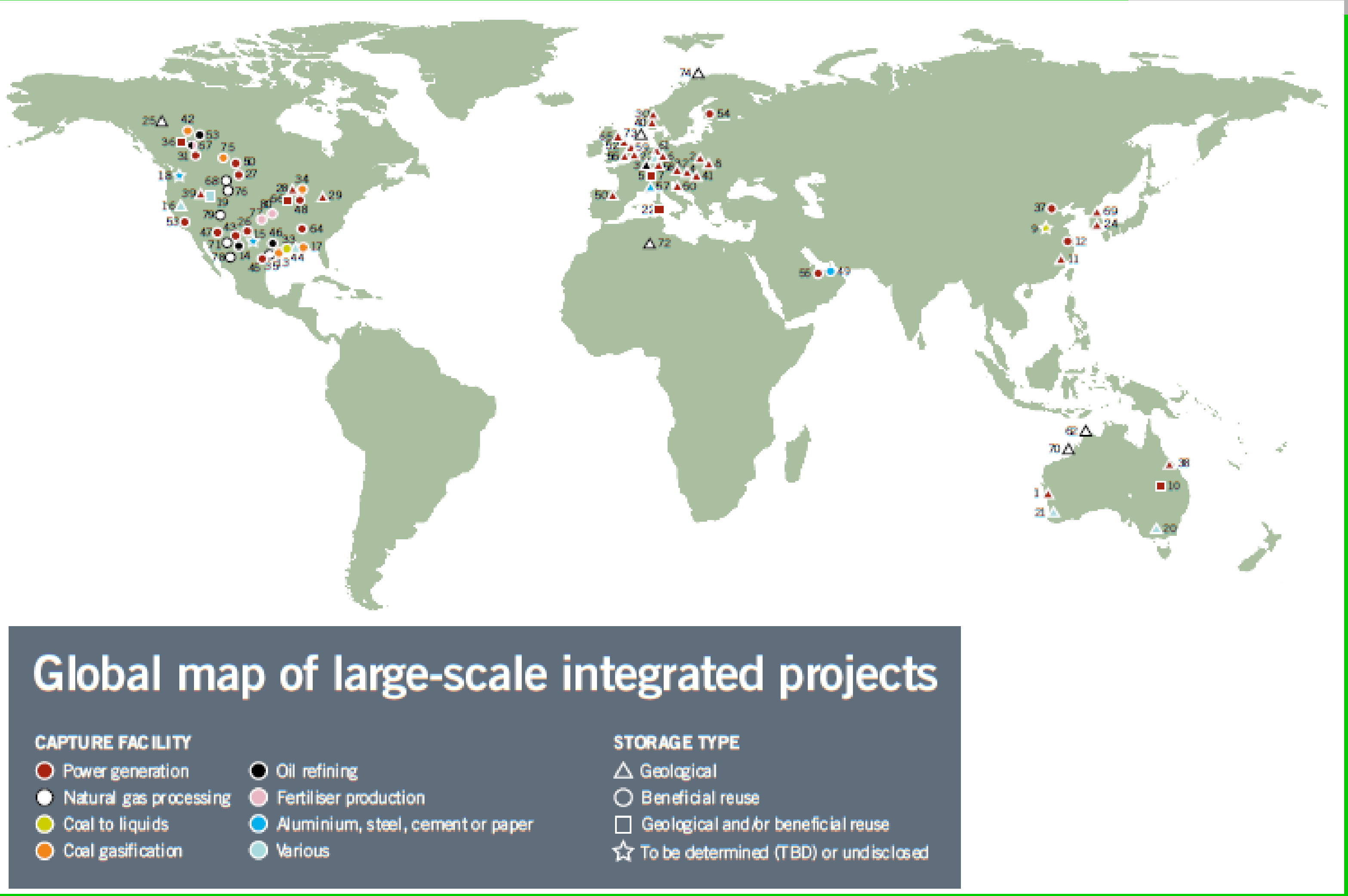
To encourage a wide portfolio of CCS projects, it is preferable to establish an incentive scheme common to all CCS projects. However specific time-limited incentives for CO2 for EOR projects could be considered as a fall-back.

Carbon dioxide storage



Overview of geological storage options (based on Figure 5.3) (Courtesy CO2CRC).
(As used in the IPCC Special report on Carbon Capture and Storage)

GCCSI Identified 80 (Mostly Planned) Large Scale CCS Projects



Source: GCCSI, 2010

GCCSI Identified 31 (Mostly Planned) Large Scale CCS Projects in the United States

Source: GCCSI, 2010

Considering risk/reward trade-off amongst options.

- Legal and Regulatory Issues – considerable basis in law to support deployment of key pieces of CCUS system.
- There exists substantial, relevant experience with important aspects of the CCUS system.
  - Weyburn, Sleipner, In Salah for example
- There is time to allow for a careful deployment of the required infrastructure for CCUS.
- Certain key issues remain to be resolved. But projects involving CCUS are receiving permits and moving forward.
  - Chamber of Commerce Project/No Project study highlights difficulties encountered by any energy project
- CCUS will deploy across U.S. economy driven by mix of economics and policy.
  - Some 3900 miles of dedicated CO2 pipelines that cross state and international boundaries have been built and operated on public and private lands for over 35 years *without the need for sweeping new eminent domain powers*.
  - Studies suggest that ~70,000 miles of CO2 pipeline could be needed by 2030

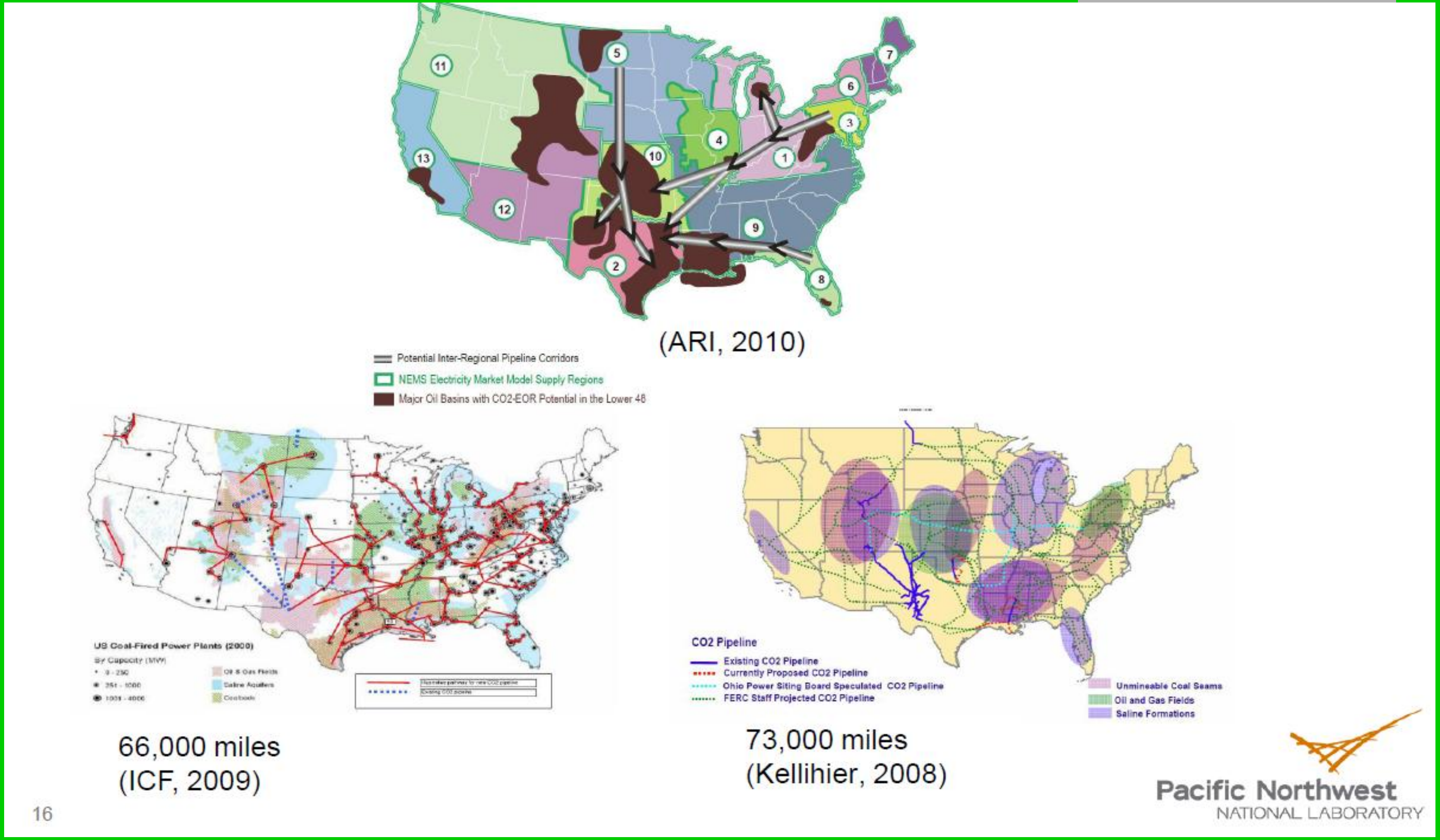
What is the international picture?

- Kyoto Protocol expires in 2012
- UN process nearly collapsed at Copenhagen COP/MOP
- Cancun meeting may have rejuvenated UN action but redirected it toward less comprehensive agenda.
- The next meeting (COP 17) will be held in Durban, South Africa in November of 2011.
- A number of Annex I signatories to Kyoto have continued efforts to comply – notably within the EU.
- Other Annex I signatories have taken steps but are concerned about absence of restrictions on non-Annex I countries (including China, India, Brazil, etc.) and allocations of reductions to others.
- Japan, Canada, and Russia have said they won’t sign up for another round of carbon emission reductions under the Kyoto Protocol.

Where does the U.S. stand at present?

- **Current regulatory action at national level on greenhouse gases proceeding based on authority granted under the Clean Air Act (CAA) to control air pollutants that endanger health or public safety.**
  - **New Source Review/ Permitting**
  - **Prevention of Significant Deterioration**
  - **Greenhouse Gas reporting**
- Attempts in prior Congress failed to enact national legislation to deal with greenhouse gases in the context of global climate change. The major proposals all included some form of cap-and-trade. CCS viewed as potential mitigation strategy but that needed to be demonstrated.
- **Regional GHG programs RGGI and Western Climate Initiative**
  - **In May, 2011 New Jersey announced plans to withdraw from RGGI**
  - **Allowance prices in 2010 fell to approximately $1.87 per allowance**
  - **Western Climate Initiative includes 6 U.S. and 4 Canadian Provinces**
- **California adopts carbon cap and trade rules** - California is first US state to adopt carbon cap and trade regulations in a move that could lead the way to stricter greenhouse gas regulations throughout the country. The California Air Resources Board unanimously passed the legislation late Thursday, allowing low-polluting businesses to gain credits that they can trade for cash to businesses with high pollution levels.

Three alternative views of the need for a large national CO2pipeline network by 2030



Taken from presentation by James Dooley, PNNL, USCSC Capacity Building Workshop, Columbus, Ohio (2009)

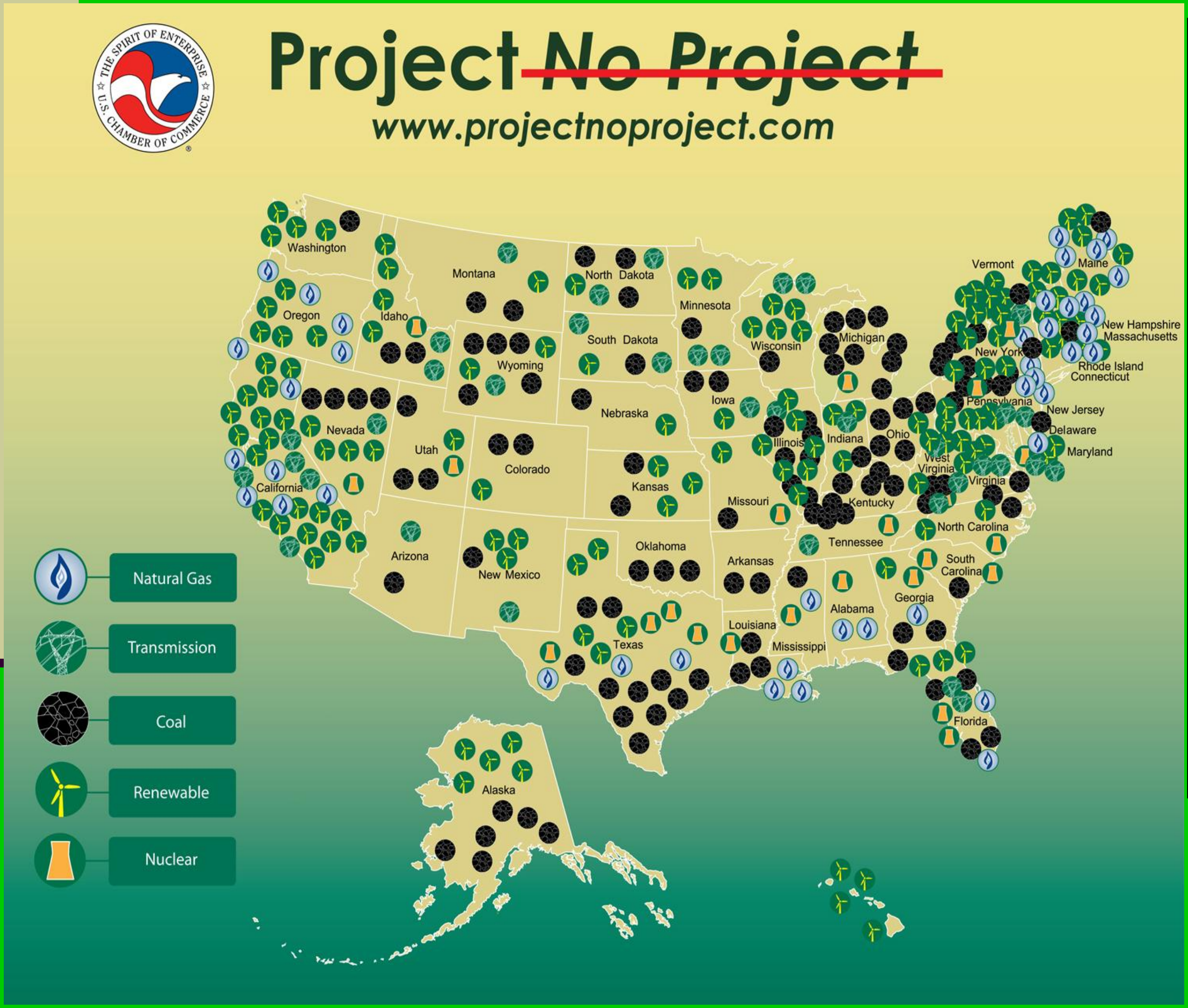
Legal basis for Regulatory Actions – Supreme Court decisions

Court decisions that caused EPA to act

In *Massachusetts* v. *EPA*, 549 U. S. 497, this Court held that the Clean Air Act authorizes federal regulation of emissions of carbon dioxide and other greenhouse gases, and that the Environmental Protection Agency (EPA) had misread that Act when it denied a rulemaking petition seeking controls on greenhouse gas emissions from new motor vehicles. In response, EPA commenced a rulemaking under §111 of the Act, 42 U. S. C. §7411, to set limits on greenhouse gas emissions from new, modified, and existing fossil-fuel fired power plants. Pursuant to a settlement finalized in March 2011, EPA has committed to issuing a final rule by May 2012. The nuisance matter appears to be heading for the Supreme Court.

In Connecticut, et al. v. American Electric Power, et al., two groups of plaintiffs filed separate complaints in a Federal District Court against five major electric power companies at a date prior to the decision cited above. The District Court dismissed both suits as presenting non-justiciable political questions, but on appeal, the Second Circuit reversed. In June of 2011, the Supreme Court found that the common law basis for the original complaint was no longer applicable stating that “The critical point is that Congress delegated to EPA the decision whether and how to regulate carbon dioxide emissions from power plants; the delegation displaces federal common law.”

Project No Project: Economic Impacts of Permitting Challenges



•Study estimates the potential loss in economic value of 351 proposed solar, wind, wave, bio-fuel, coal, gas, nuclear and energy transmission projects that have been delayed or cancelled due to significant impediments

•It is just as difficult to build a wind farm in the U.S. as it is to build a coal-fired power plant. In fact, roughly 45 percent of the challenged projects that were identified are renewable energy projects

*•Successful construction of the 351 projects identified in the **Project No Project** inventory could produce a **$1.1 trillion** short-term boost to the economy and create **1.9 million jobs** annually*

Source: Project No Project, www.projectnoproject.com

Thank you!

LTI