CLEAN COAL

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by

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Presentation Overview

Quick background of SFA Pacific specific to CO_2 capture

"Clean coal" means different things to different people

- Assuming the interest of this group is clean coal for CO_2 mitigation in addition to traditional coal emission (SO_2, NO_x, $PM_{2.5}$ & Hg) controls

Clean coal technologies: status, costs and challenges

- Focused on CO_2 capture + overview of CO_2 geologic storage issues

Busy slides used as "story boards" to be read & studied later, as this presentation will only address key issues in yellow

SFA Pacific Background

Founded in 1980

Performs technical, economic & market assessments for the major international energy & engineering companies

- **Over 50% of our work is consistently outside the United States**

Principal work involves heavy oil upgrading, syngas (H_2 & CO), electric power generation & emission controls

Niche is objective outside opinion & comparative analysis before companies make major decisions or investments

Unique perspective with no vested interest in engineering, resources, technologies, R&D or project development

Background of SFA Pacific CO_2 Capture & Storage (CCS) Related Projects

- 1989: CO_2 Capture analysis for EPRI
- 1994: Consultant for China's National Response Strategy on Global Climate Change
- 2001: Private Multiclient Analysis of CO_2 Mitigation Options
- 2002-2008: Advisory Board to the CO_2 Capture Project - CCP
- 2003-2005: Lead author of the UN IPCC Special Report on CO_2 Capture & Geologic Storage – part of 2007 Nobel Peace Prize
- 2007: CCS economics for Canada's Government & Industry Expert Economic and Policy Working Group
- 2008: CCS economics for the CEO Business Roundtable analysis of CO_2 mitigation costs

What We Have Is a Failure to Communicate and Work Together for the Common Good

National Resources Defense Council (NRDC):

"There is no such thing as clean coal"

When asked how China would ever meet the growing demand for electricity, liquid fuel and natural gas (NG), Du Minghua, Director of the Beijing Research Institute replied:

"Coal is the solution to all three"

The facts: clean coal (technology) is real, used today and likely essential for the long-term good of the world & USA

- The challenge is getting everyone to stop promoting their vested interest agendas & start working together for the common good of all the people who already use & are going to continue using coal

Basic Problem: Coal is a "Four Letter Word"

Everyone loves to hate coal as long as their lights & computer stay on, they can recharge their iPod & Blackberry and their monthly electric bill is reasonable

Without coal we cannot live the lifestyle we are accustomed to

- **Coal supplies >40% of the world's electricity & 50% in the USA**
- **Coal enables USA electric prices to be some of the world's lowest**
  - **Industrial/residential power prices in U.S. cents/kWh as per EIA 2008:**

    USA: 6/11, France: 6/16, Japan: 12/18, Germany: 10/22, UK: 12/22
- **Coal is nearly two-thirds of the world's remaining fossil fuel energy + much high extraction rates & much lower energy cost than oil & NG**
  - **USA has the world's largest coal supply: 250 years at current rate of use**
  - **U.S. EIA International Outlook 2008 business as usually (BAU) projects world coal use growing faster than oil, NG, nuclear and renewables**

To Replace the Current 50% USA Coal-Power

NUCLEAR now 20% : 300 new 1,000 MW nuclear reactors

- At only $4,000/kW = $1,200 billion
- Still have to effectively resolve nuclear waste storage & reprocessing

NATURAL GAS now 20%: 17 more Trillion Cubic Feet/yr NG use

- Not enough domestic supply, would be from mostly imported LNG

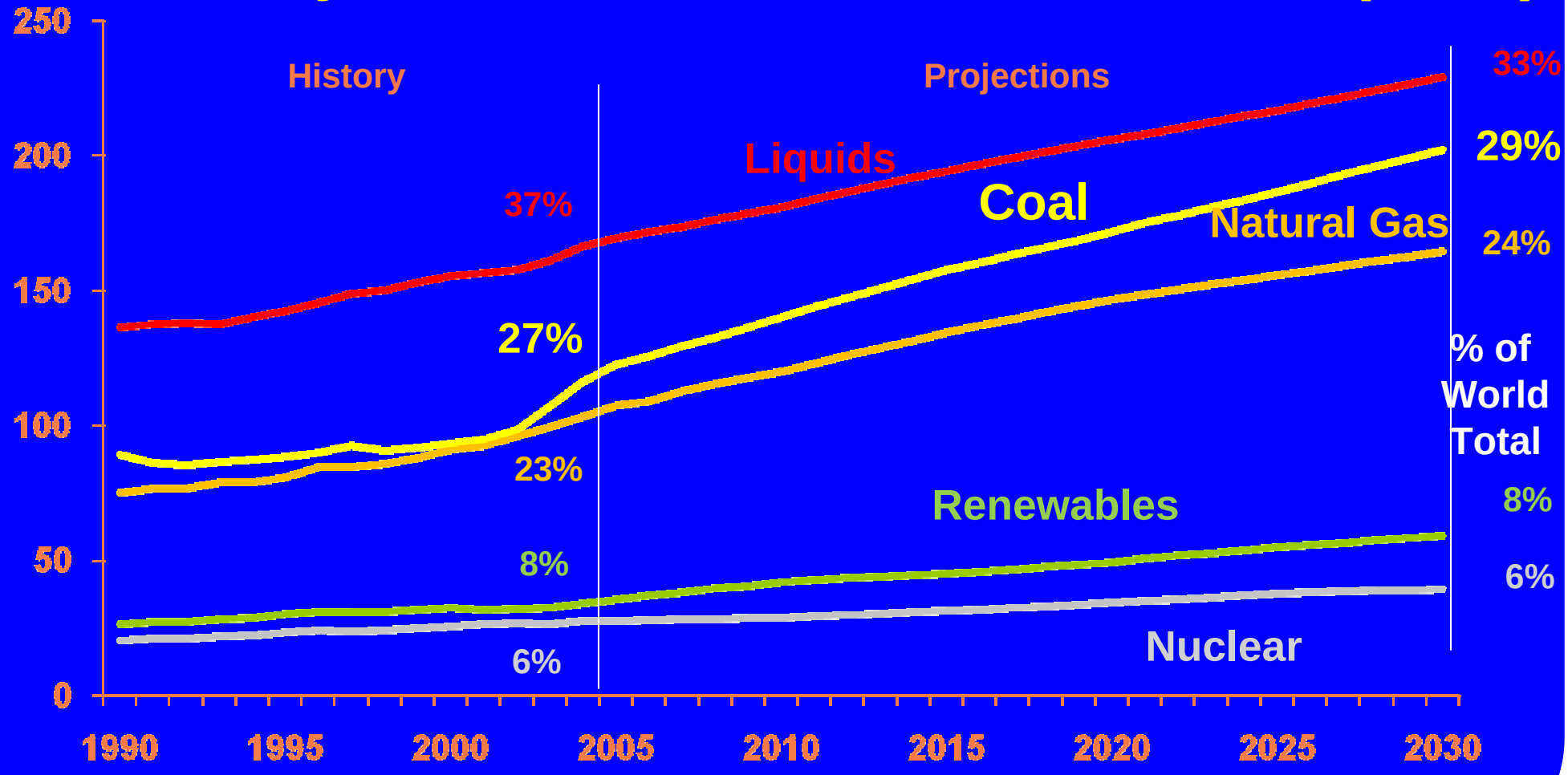
HYDRO now 7%: 500 facilities size of Hoover Dam

- No effective sites remain, in addition to the severe environmental issues

Wind turbines now 2%: 5,000 more 200 MW wind farms

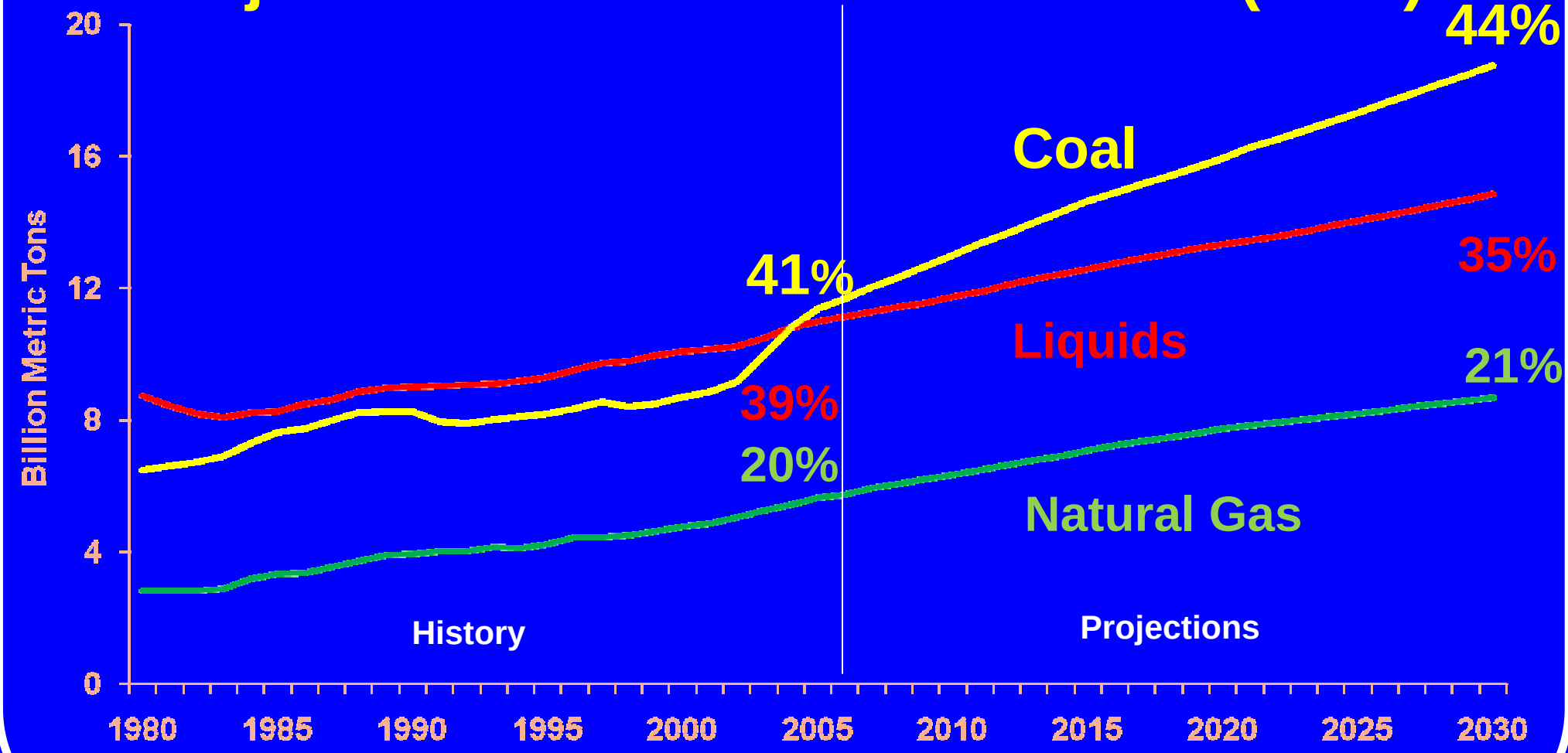
- Need much larger capacity due to intermittent (only ~ 30% annual load) & uncontrollable timing vs. demand requiring big fossil fuel back-up
- At only $2,000/kW = $2,000 billion + major grid upgrades & NG-GTs

World Energy Use by Fuel Type: History & Future Projections for Business-As-Usual (BAU)



Source: U.S. EIA International Energy Outlook 2008

CO_2 Emissions by Fossil Fuel: History & Future Projections for Business-As-Usual (BAU)

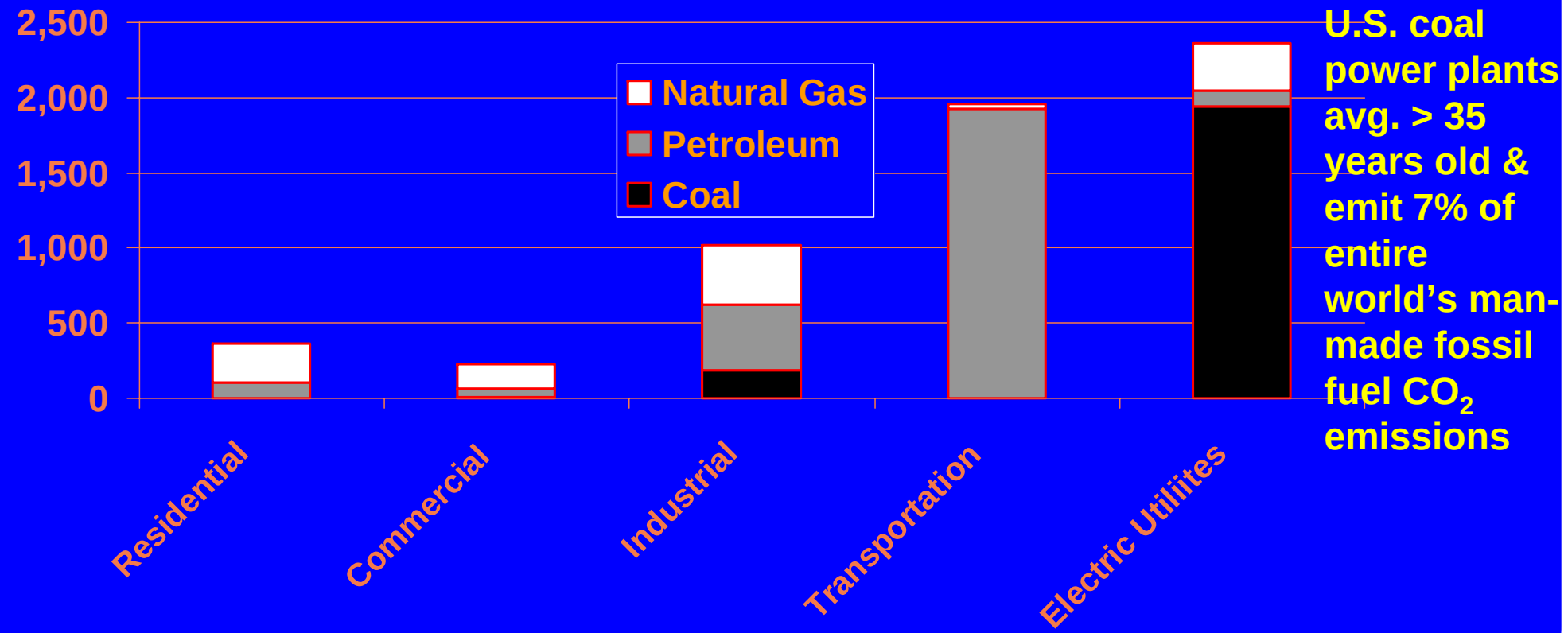


Source: U.S. EIA International Energy Outlook 2008

USA 2005 CO_2 Emissions By Sector & Fuel

About 6 Gt/yr of 30 Gt/yr World Total fossil fuel CO_2 in 2007

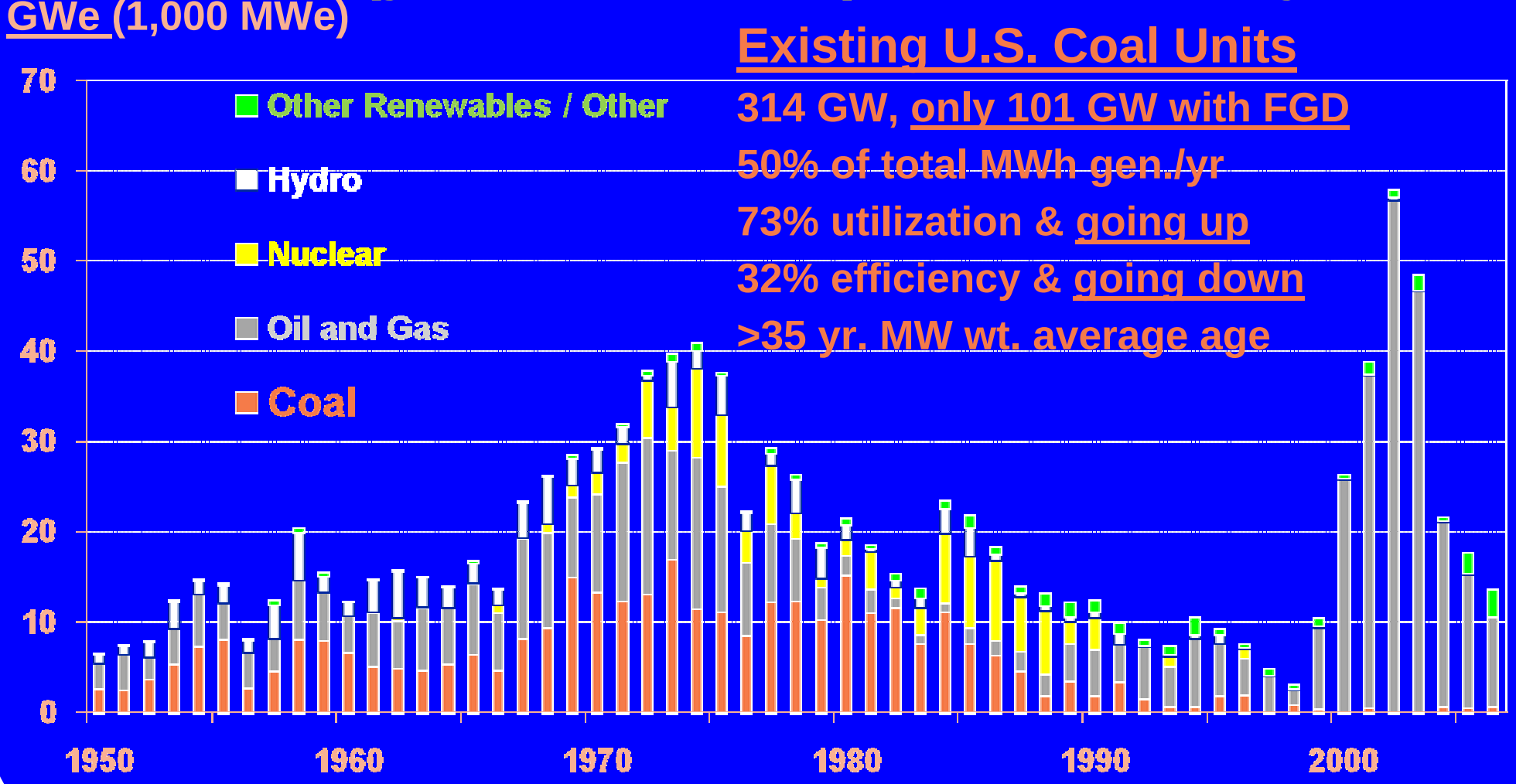
Millions of metric tons per year CO_2 (divide by 3.67 for carbon equivalents)



U.S. coal power plants avg. > 35 years old & emit 7% of entire world's man-made fossil fuel CO_2 emissions

Source: SFA Pacific plot from U.S. DOE/EIA-0383 February 2007 data

United States Electric Generating Capacity Installed (year in-service): 1950-2006 by Fuel



Existing U.S. Coal Units

- 314 GW, only 101 GW with FGD
- 50% of total MWh gen./yr
- 73% utilization & going up
- 32% efficiency & going down
- >35 yr. MW wt. average age

Source: SFA Pacific from U.S. EIA data

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CO_2 Mitigation Options

Current fossil fuel CO_2 emissions of 30 Gt/yr - most effective to analyze via the famous *Kaya Identity* where CO_2 emissions =

people x GDP/person x energy/unit GDP x CO_2/unit energy

Thereby only four basic options to impact our CO_2 emissions:

- **Population** (number of people)
- **Standard of living** (GDP/person)
- **Energy intensity** (energy/unit of GDP)
- **Carbon intensity** (CO_2 /unit energy)

Any meaningful worldwide CO_2 reduction requires focus on carbon intensity & energy intensity in the USA & China

- **USA - 20% of world man-made CO_2, however, also 20% of world GDP**
- **China - appears to have passed the USA in CO_2 emissions in 2007**

Classic Ugly American: Confuses "US" with U.S.

Standard of Living & Fossil Fuels Consumption

The fundamental greenhouse gas (GHG) issue of fairness via GHG per person

Source: Scott Willis of the San Jose Mercury News (California)

For a "Carbon Constrained World" to Ever "Really" Develop Requires All of the Following

More conservation & energy efficiency via higher energy prices & CO_2 taxes

Natural gas demand/prices go up while coal demand/prices go down as CO_2 avoidance & emission liabilities gain "real" market value

Nuclear makes a big comeback, however, starts slow: first life-extensions & upgrades & eventual decommissioning of current fleet while the industry demonstrates effective waste disposal & competitive costs of new units

Renewables become increasingly important in spite of inherent limitations

- Intermittent solar PV & wind turbines need back-up fossil power & **can only marginally replace baseload coal supplying >40% of total world electricity**
- Beyond waste biomass, limited by yield per ha/y, fertilizer & water needs, impact on food & deforestation + basic economics of land & labor costs

CO_2 capture & storage becomes strategic for technical, economic, energy supply & most importantly, overall CO_2 reduction perspectives

- **Once developed for big coal units, increasing CO_2 taxes enables more co-processing of waste biomass whenever available for "double reductions"**

Coal-Based Power Gen. Will Be Forced to Meet a Disproportionate Share of Any CO_2 Mitigation

Vehicle owners have voting power over CO_2 intensive industries

- Politicians believe they cannot get re-elected if they increase transportation fuel taxes via adding a CO_2 tax on gasoline or diesel

Power plants cannot move to China, as other CO_2 intensive industries in Annex 1 nations will, if faced with CO_2 taxes

Big CO_2 reduction potential from coal-based power generation

- Reduce coal CO_2 emissions via conservation & efficiency
- Replace coal with NG, nuclear, biomass and wind/solar
- CO_2 capture & storage (CCS) with coal due to the large CO_2 point sources, power generation pricing & utilization by everyone plus potential to co-process waste biomass for "negative CO_2 emissions"

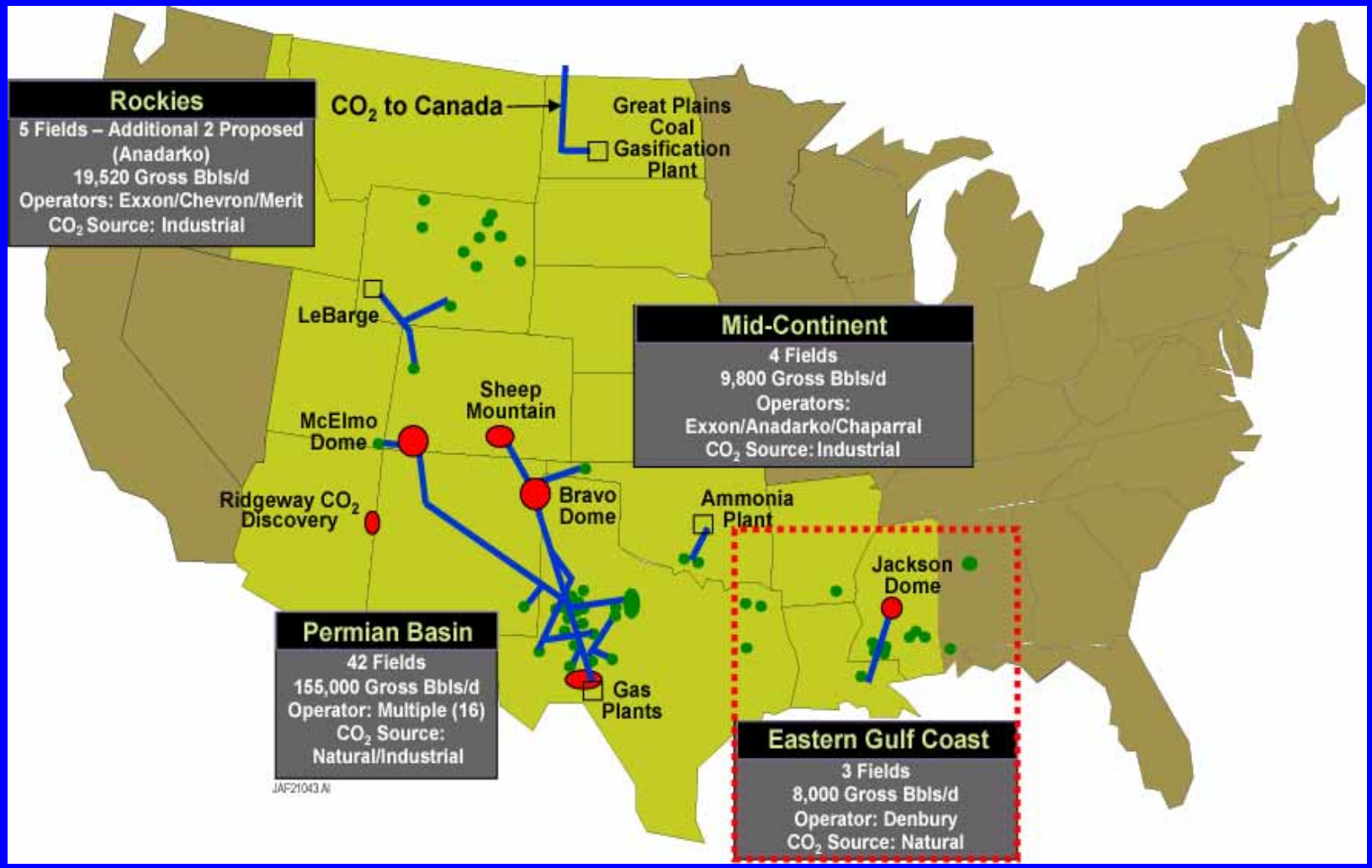
CO_2 Capture & Storage (CCS) Overview

Simple concept: recover CO_2 from fossil fuel or waste biomass utilization then geologically store CO_2 deep underground

However, the "devil is in the details", requires the following:

- **Locations with specific geologic formations of sedimentation & cap rock - typically oil & NG and/or deep saline aquifers geology**
- **Large "point sources" of CO_2 for essential economy-of-scale**
  - **Typically coal power plants, cement kilns & other big "smoke stack" industrial complexes: oil refineries, bulk chemicals & iron/steel making**
- **Concentrate & compress to high pressure for geologic CO_2 injection**
  - **Some pure CO_2 vents but usually only 15% CO_2 in coal boiler flue gas thus large costs & energy use to recover or capture CO_2 as pure stream**
  - **Compress the recovered or captured CO_2 to high pressure supercritical conditions for pipeline transport & injection into geologic storage**

25 Years of CO_2 Experience – about 35 million t/y CO_2 storage with 25% man-made CO_2 sources (squares below) used in producing 250,000 bbl/d of Enhanced Oil Recovery (EOR)



Large CO_2 EOR Opportunity While Also Reducing CO_2

Currently 0.25 million bbl/d EOR while storing 35 million t/y CO_2 with total USA domestic oil production at only 5 million bbl/d and total USA proven reserves of only 21.9 billion bbl

Feb. 2006 DOE Report by ARI estimate of U.S. EOR potential:

- **582 billion barrels OOIP & 389 billion barrels ROIP (67% of original IP)**
- **47 billion barrels (*economic potential, current technology*)**
- **89 billion barrels (*technical potential, current technology*)**
- **129 billion barrels (*technical potential, advanced technology*)**
- **Exploitable U.S. CO_2-EOR potential up to ~ 3 million bbl/d by 2020**
  - **CO_2 requirements - about 0.5 billion t/yr CO_2 or 9% of U.S. total**

EOR is currently limited by CO_2 supplies - must develop cost effective man-made CO_2 supplies as this is a big "win-win"

The CCS Liability Challenge

CCS in the USA is limited to "CO_2 enhanced" (added value for CO_2 avoidance) EOR until there are fundamental changes in USA liability & mineral rights laws plus tort reform

- **USA tort litigation + mineral rights laws would turn "ambulance chasing lawyers" into "CO_2 injection chasing lawyers"**
  - **Classic "David vs. Goliath" easy to win, regardless of the facts**
- **States like Texas are trying to address this key CCS limitation for EOR**
- **EPA and IOGCC heading toward a power struggle over control of CCS**

Beyond "enhanced" EOR, CCS likely to develop in areas of world where the government owns the mineral rights & pore space underground plus litigation is rational & fair

- **Like: Australia, Canada, China and Europe**

The CCS Magnitude & Acceptance Challenge

Magnitude required for 0.5 ppm/yr CO_2 or 50 ppm in 100 years reduction from BAU - 4 Gt/yr or total 400 Gt CO_2 reduction

- **500 GWe of zero CO_2 emissions baseload nuclear (as solar & wind are only cycling load) replacements of existing coal power plants**
- **500 GWe of replacement new for old coal power units with 100% CCS = 4 Gt/y CO_2 which at 100°F & 150 atm. pressure = 80 million bbl/d CO_2**
- **Only 333 GWe of replacement coal power plants with 100% CCS when co-processing 50% biomass energy = 2.67 Gt or 53.3 million bbl/d CO_2**

Who needs CCS: coal & coal-based electric power industries

- **CO_2 capture is the easy part – moderate costs & available technology plus cost pass-through to everyone in electric power pricing**
- **The key issue is public acceptance of CO_2 storage plus the reality that the oil & gas industries have the essential geologic expertise required**

The CCS Cost Basics

CCS costs can be separated into its 3 distinct process steps: 50% for capture to pure CO_2 stream, 25% for compression & 25% for CO_2 pipeline, injection & geologic storage monitoring

- **If use CO_2 for EOR, can reduce the overall CCS costs in half**

CCS costs are mostly from added capital & internal energy use

- **Adding CCS to a new coal unit reduces capacity & efficiency**
- **However, existing coal unit CCS rebuilds can avoids this capacity & efficiency loss while reducing all emissions to near zero**

CCS bottom line costs: best matrix is electricity cost increase, as \$/t CO_2 avoidance cost vary greatly depending on baseline

- **Nevertheless, CO_2 avoidance cost is the minimal required CO_2 tax at which CCS starts to become an economic option for CO_2 mitigation**
- **\$/t CO_2 avoided = (\$/MWh_{CCS} - \$/MWh_B) / (to atm: t CO_2/MWh_B - t CO_2/MWh_{CCS})**

The CCS Cost Challenge

What is the minimum CO_2 tax at which coal-based power with or without CCS has the same power cost?

- **New coal plant: ~ $50/mt CO_2 & 11 cent/kWh plant gate or ~ 4 cent/kWh higher delivered baseload (industrial) power in constant 2008 dollars**
- **Existing paid-off coal plant: ~ $75/mt CO_2 for the same power price, thus need a "cap & trade" system or better: CO_2 tax with plant age inflator**

If faced with a ~ $50/mt CO_2 tax for a new power plant, what is the NG price where NGCC without CCS is the same power cost as coal-based power with or without CCS or "triple point"

- **$11-12/MM Btu NG vs. $2/MM Btu coal @ 11 cent/kWh & $50/t CO_2 tax**
- **In a carbon constrained world: NG demand & prices will increase due to lower risk & capital of lower carbon NG wo CCS vs. coal w/wo CCS**
  - **At high NG prices, NGCC with CCS is higher cost than coal with CCS**

Pre-Combustion CO_2 Capture

Overview

- Gasification at high pressure of any carbonaceous fuel with O_2 to make H_2 & CO "syngas" then CO reaction with H_2O to just H_2 & CO_2
  - Easy separation of CO_2 from H_2 due to high pressure (HP) & concentration via physical solvents with high CO_2 loading & low energy use flashing to LP

Status

- Many commercial gasification based hydrogen and ammonia plants are making pure H_2 & CO_2 - with units >5,000 t/d CO_2 capture operating
  - Of the >30 GWt large-scale coal gasification plants operating worldwide, all except the few coal-IGCC units (2 GWt or 1 GWe) have large CO_2 capture
  - Over 500,000 hours operation of commercial GTs firing H_2 rich fuel, however this experience is mostly in low firing temperature GTs for oil refinery cogen

Attributes

- H_2 or high H_2/CO ratio fuels have many strategic long-term utilization advantages over just making steam in a boiler - such as high power/heat ratio cogen, clean transportation fuels & perhaps "the H_2 economy"

Post-Combustion CO_2 Capture

Overview

- CO_2 capture from flue gas, after conventional combustion of any fuel
- Harder separation of CO_2 due to low pressure & concentration + O_2
  - Amine chemical solvent liquid absorber/stripper system requiring large amounts of steam for stripping (over 1.5 ton steam per ton CO_2)

Status

- Many big commercial amine chemical CO_2 capture systems usually for natural gas but at high pressure and without the presence of O_2
- However, only a few, relatively small units used for flue gas CO_2 capture - the biggest in operation is just 330 t/d CO_2 capture

Attributes

- Viewed as just another flue gas scrubber by traditional coal power plant people already familiar with flue gas desulphurization (FGD)
- Potential advantage to retrofit any existing flue gas with minimal impact of existing system beyond big additional steam & power needs

Oxygen-Combustion CO_2 Capture

Overview

- Replaces air with oxygen (O_2) combustion of <u>any fuel</u> plus mixed with a large CO_2 rich flue gas recycle or water injection to about the same properties, flows & heat flux rates as traditional air combustion
  - Requires over twice as much O_2 per net MWe as pre-combustion

Status

- Only small pilot plant testing, however, commercially done in large high sulfur nickel ore kilns to concentrate SO_2 for conversion to H_2SO_4

Attributes

- Avoids complex chemical processes like pre-combustion
- Can "theoretically" capture 100% of the CO_2 & avoid flue gas cleanup but technically unclean is that is possible
- Potential advantage to retrofit existing systems, especially when oxygen replacement of air combustion can increase existing capacity

Advanced CO_2 Capture Tech. Under Development

Pre-combustion

- Demonstrations of H_2-IGCC with CCS by traditional coal-based utilities
- Longer-term: solid oxide fuel cells to directly convert CO rich syngas to higher efficiency electricity & high-pressure CO_2 in one step

Post-combustion

- Demonstrations of large coal boiler power plants with CCS
- Longer-term: Alstom chilled ammonia system may greatly reduce both the stripping steam & CO_2 compression power needs

Oxygen-combustion

- Demonstrations of large coal boiler power plants with CCS
- Longer-term: pressurized oxy-coal boilers & oxy-syngas GT: smaller size & ultra high heat flux & reduced CO_2 compression power needs

Needs both "learning-by-doing" & improved technology R&D

Brief Geologic CO_2 Storage Overview

USA CO_2 geologic estimates range from 1.16 – 3.55 billion tons

- **Or > 200 times the USA total annual CO_2 emissions**

Potential CO_2 geologic storage sites by capacity

- **Deep saline aquifers >> un-mineable coal beds > oil & NG reservoirs**

Reliability of estimates

- **Oil & NG >> Deep saline aquifers > un-mineable coal bed**

Highly un-even distribution of geologic storage capacity

- **Generally the best are in oil & NG production areas**

Requires better cooperation between the coal power industry that needs CCS and the oil & NG industries with the geologic knowledge & expertise required to most effectively do CCS

Why Some NGO Dislike CO_2 Capture & Storage

Besides keeping coal alive, a new coal plant of 600 MWe at 40% effic. Adding CCS can drop to as low as 450 MWe at 32% effic.

- **Adding CCS drops the CO_2 per net MWh electricity by 80-90%, however coal use increases ~ 25% more per net MWh electricity generated plus requires additional 150 MWe of low-CO_2 capacity for same net capacity**
- **Thus more coal mining, coal transport & storage emissions means less clear overall SO_2, NO_x, PM $_{2.5}$ and CO_2 reductions than at the CCS unit**

Even worse, CCS retrofit of older subcritical PC of 2x300 MWe at 33% efficiency drops to only 2x200 MWe at 25% efficiency

- **Over 30% more coal per net electricity**
- **Requires additional 200 MWe of low-CO_2 capacity for same net capacity**
- **Big new CCS investment on a >40 year old PC power plant is dubious**

Why Clean Coal CO_2 Capture Should Focus on Old Existing Coal Power Plant Rebuilds First

Unless new coal plants with CCS replace old coal plants, CCS only reduces the growth rate of CO_2 emissions in power gen

Existing coal power plant replacements are the big CO_2 reduction

- The USA has the big existing capacity of old, long paid-off, low efficiency (high CO_2/MWh) & relatively dirty coal power plants

CCS retrofits can reduce CO_2 as well as SO_2 & NO_x depending on the existing coal plant emission controls – nevertheless, still suffers from efficiency & capacity losses of CCS retrofit

However, CCS rebuilds of older, less efficient, coal power plants can avoid net efficiency & capacity losses while at the same time greatly reducing all emissions

Way Forward for Clean Coal CO_2 Reductions

Must resolve ASAP the liability issues of geologic CO_2 storage

Demonstrations ASAP: pre, post & oxygen combustion CCS

- **Focus on gaining public acceptance of long-tem CO_2 storage in various geologic storage types, especially deep saline aquifers**
- **More emphasis on the low-risk CO_2 capture technologies that can built at large scale today with high probability of success**
- **Continued emphasis on advanced clean coal tech with more realistic assessments of time to commercial use, cost/performance & risks**

Commercial CCS emphasis on rebuilding oldest existing coal units with new supercritical PC boilers with post or oxygen CCS or IGCC pre CCS depending on space & water limitation and experience with chemical processes

Other Issues Needed to Drive Clean Coal

Simple and equitable long-term CO_2 policy – like a CO_2 tax

- Until, existing old coal plant owners are encouraged to maximize CO_2/MWh in case of EU style CO_2 cap and "charade" (trade) system
  - Best way to protect old coal power plants is to focus most CCS development on just high advanced technologies

If no CO_2 tax, pricing for lower CO_2/MWh power regardless of source or producer to let the best & cheapest options develop

- Perhaps long-term power purchase agreements (PPA) based on power prices inversely proportional to CO_2/MWh
- This would allow the commercially proven industrial gasification industry with lower CO_2 capture costs to quickly help add CCS capacity

Summary

Clean coal is real, in large commercial use for industrial gasification & essential due the growing worldwide coal use

- **Example: Dakota coal to SNG with big CO_2 capture & storage via EOR**

Issue: developing clean coal for traditional electric power gen.

- **This requires many large demonstrations ASAP of all options (pre, post & oxy combustion CCS) + public acceptance of geologic CO_2 storage**

Challenge: need sound & equitable long-term CO_2 policy – until encourages life extensions of old, high CO_2/MWh coal units

Best path forward: CCS rebuilds of our oldest, highest CO_2/MWh & dirtiest existing coal power plants as this avoids capacity & efficiency CO_2 losses of CCS while reducing all emissions

- **How – CO_2 tax or open market power pricing based on CO_2 /MWh**