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SLIDES: Getting onto a Path for Stabilizing Atmospheric CO2 at 450 ppmv with "Near-at-Hand" Energy Technologies

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Robert H. Williams, *Getting onto a Path for Stabilizing Atmospheric CO_2 at 450 ppmv with "Near-at-Hand" Energy Technologies*, *in* CLIMATE CHANGE AND THE FUTURE OF THE AMERICAN WEST: EXPLORING THE LEGAL AND POLICY DIMENSIONS (Natural Res. Law Ctr., Univ. of Colo. Sch. of Law 2006).

Climate Change and the Future of the American West: Exploring the Law and Policy Dimensions

Getting onto a Path for Stabilizing Atmospheric CO_2 at 450 ppmv with "Near-at-Hand" Energy Technologies

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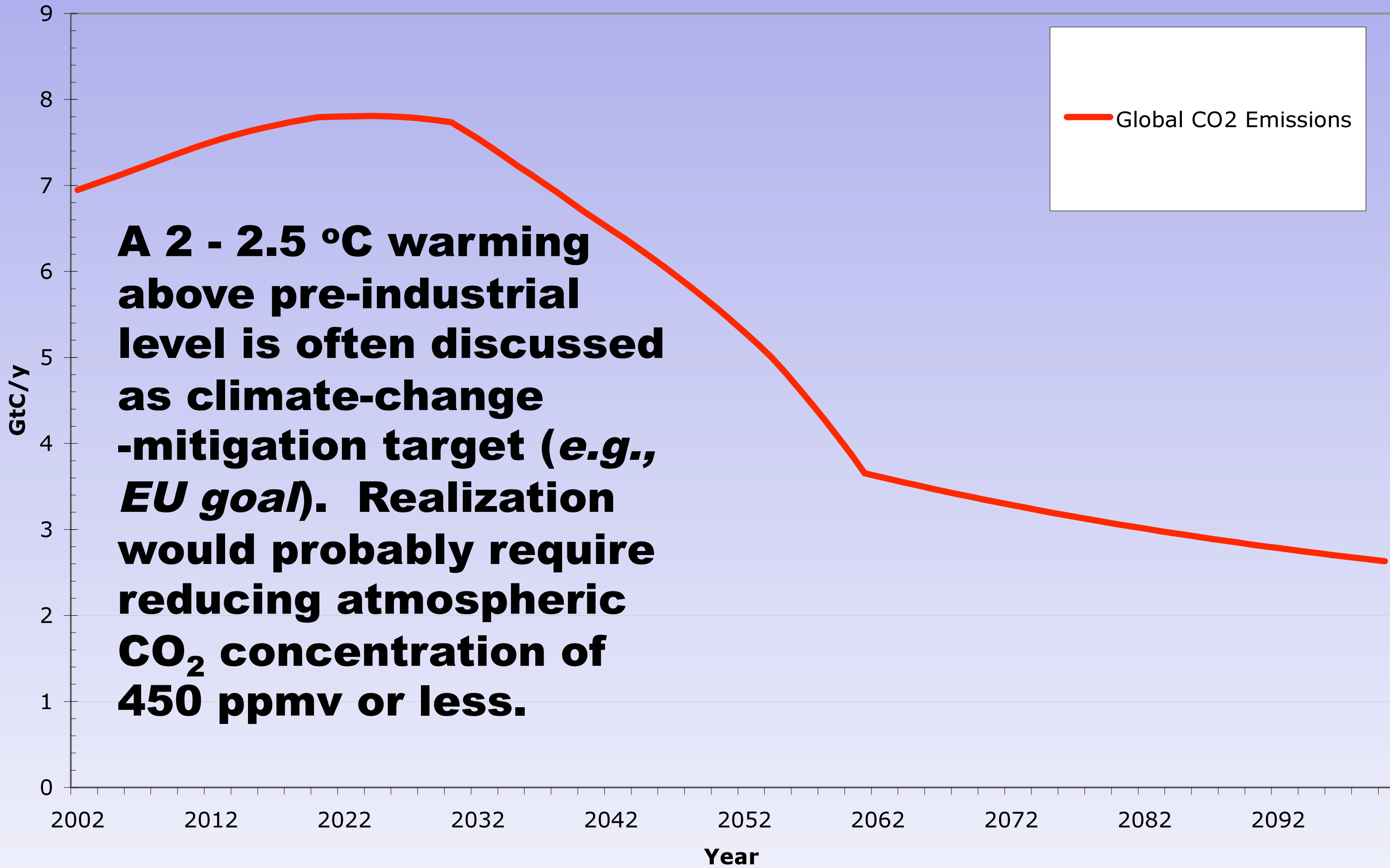
OUTLINE

- **Rationale for early action in mitigating climate change**
- **Introduction to Thought Experiment designed to explore feasibility of getting onto a 450 ppmv atmospheric CO_2 stabilization path using "near-at-hand" energy technologies**
- **Technologies considered for Thought Experiment**
- **Discussion of electricity and fuels used directly (*FUD*) components of total energy in Thought Experiment**
- **Estimation of incremental costs for low carbon energy supplies in Thought Experiment**
- **Lessons learned from Thought Experiment**

RATIONALE FOR EARLY ACTION

- **"Lock-in" carbon commitment from delay—e.g., lifetime C for ~ 1400 GW_e coal electric capacity expected to be built 2003-2030 is comparable to:**
  - **historical global emissions from coal burning**
  - **0.3 X 21st century C budget for 450 ppmv stabilization path**
- **For a given stabilization target, the alternative to early action is a more economically challenging steeper rate of decline in C emissions later**
- **Many low C technologies are "near-at-hand"**
- **Cost reductions via accumulating experience (*"learning by doing"*)**
- **Ancillary benefits: mitigation of air pollution/oil insecurity risks; first-mover technological leadership; manufacturing/construction employment opportunities via domestic clean energy production/infrastructure development**

GLOBAL EMISSIONS PROFILE CONSISTENT WITH ATMOSPHERIC CO_2 STABILIZATION @ 450 PPMV



A 2 - 2.5 °C warming above pre-industrial level is often discussed as climate-change -mitigation target (*e.g., EU goal*). Realization would probably require reducing atmospheric CO_2 concentration of 450 ppmv or less.

Is it feasible to mitigate climate change to this extent?

INTRODUCTION TO THOUGHT EXPERIMENT

- **Is it technically and economically feasible to stabilize atmospheric CO_2 at 450 ppmv?**
- **What would be the major challenges?**
- **A Thought Experiment is developed to explore these questions**
- **It will be shown that such a stabilization goal is daunting but plausibly achievable…at least technically and economically**
- **Moreover, it is suggested that "near-at-hand" technologies (*energy end-use efficiency + small # of energy supply technologies*) could get us through the first ½ century on this path**

ASSUMPTIONS FOR GLOBAL ENERGY THOUGHT EXPERIMENT, 2002-2061

- **Emphasis on efficient energy use—extrapolate to 2061 energy demands of WEO 2004 Alternative Scenario (*International Energy Agency*):**
  - GWP up 4.6 X by 2061 relative to 2002
  - Electricity generation up 2.6 X
  - Fuels used directly (*FUD*) up 1.8 X
  - Coal power generation fixed beyond 2030 at 2030 level
- **New energy supply technologies emphasized:**
  - Coal IGCC with CO_2 capture and storage (*CCS*)
  - Bioenergy with CCS (*"negative CO_2 emissions"*)
    - Biomass IGCC with CCS
    - F-T liquids from coal and biomass with CCS
  - Baseload electricity from wind + natural gas CAES (*compressed air energy storage*)
- **Coal and biomass are completely "decarbonized" over 50 years (*by 2061*)…thereby "making room in atmosphere" for substantial fossil fuel expansion**

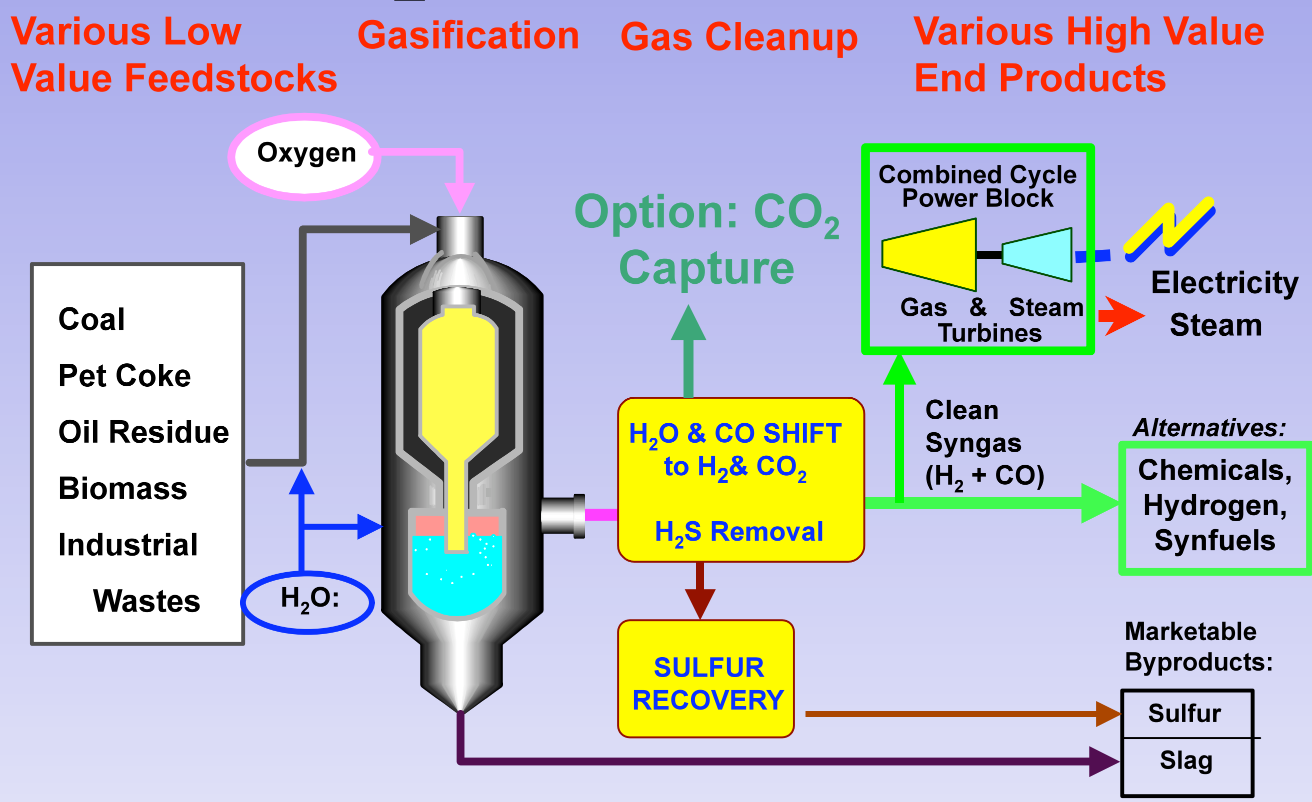
OPTIONS FOR CO_2 STORAGE

- **Goal**: store 100s/1000s Gt CO_2 for 100s/1000s years
- Major options:
  - Deep ocean (*concerns about storage effectiveness, environmental impacts, legal issues, difficult access*)
  - Carbonate rocks (*safe, costly, embryonic)*
  - Geological media (*focus of current interest*)
    - Enhanced oil recovery (*likely to be major initial focus*)
    - Depleted oil and gas fields (*geographically limited*)
    - Beds of unminable coal (*CO_2 adsorbed in coal pore spaces*)
    - Deep saline aquifers—huge potential, ubiquitous
- Most large anthropogenic CO_2 sources are within 0-200 km of geological disposal sites (*800 km = longest US CO_2 pipeline for EOR*)
- Experience:
  - EOR (*30 million tonnes CO_2/y—4% of US oil production*)
  - Sleipner, North Sea—storage in aquifer under seabed
  - In Salah, Algeria—storage in natural gas field
  - Other projects being planned

MAIN MESSAGES ON CO_2 STORAGE FROM IPCC SPECIAL REPORT ON CCS (*2005*)

- **IPCC is:**
  - **positive on geological storage,**
  - **not so positive on ocean storage/mineralization**
- **66-90% probability that worldwide geo-storage capacity is <u>at least</u> 2000 Gt CO_2**
  (*fossil fuel emissions = 24 Gt CO_2 in 2002*)
- **IPCC estimates of fraction retained if geological storage reservoirs are carefully selected:**
  - **90-99% probability that retained fraction will exceed 99% over 100 y**
  - **66-90% probability that retained fraction will exceed 99% over 1000 y**

LOW-COST CO_2 CAPTURE VIA GASIFICATION

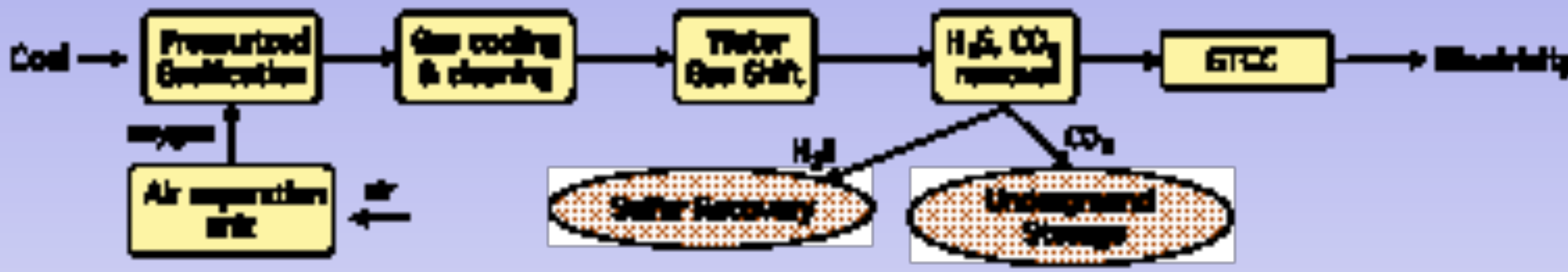


Gasification in O_2/steam converts carbonaceous feedstock into syngas (mostly CO, H_2)

Water-gas-shift reaction ($CO + H_20 \rightarrow H_2 + CO_2$) converts all or some CO

CO_2 is captured at high pressure/concentration

COAL IGCC
WITH CO_2 CAPTURE/STORAGE (CCS)



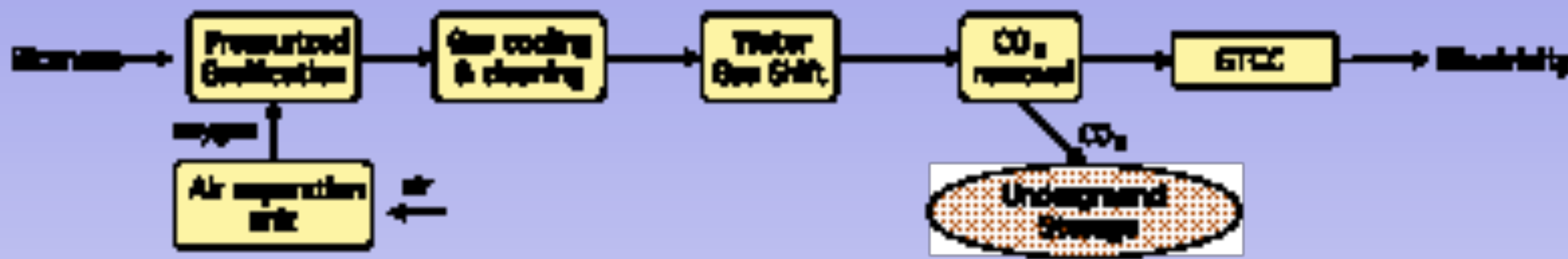
~ 90% of coal C is captured/stored as CO_2

All components proven, commercially ready …though no integrated system has been built

Impacts of shifting from CO_2 venting to CCS:

- **Coal input up ~ 1/6 with capture,**
- **Generation cost up ~ ¼ with capture,**
- **Generation cost up ~ 2/5 with capture/storage**

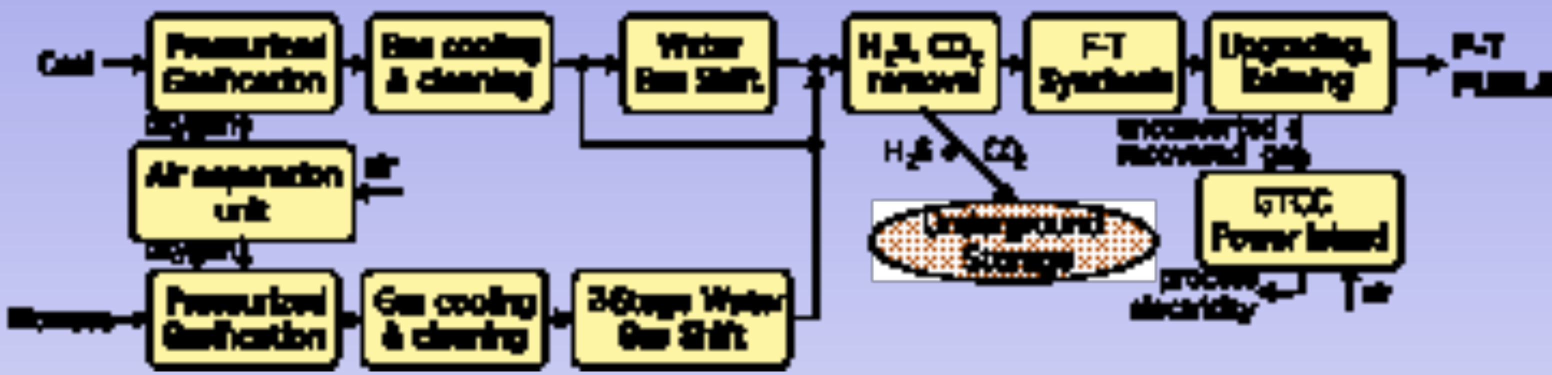
BIOMASS IGCC WITH CCS



Similar to coal IGCC except that:

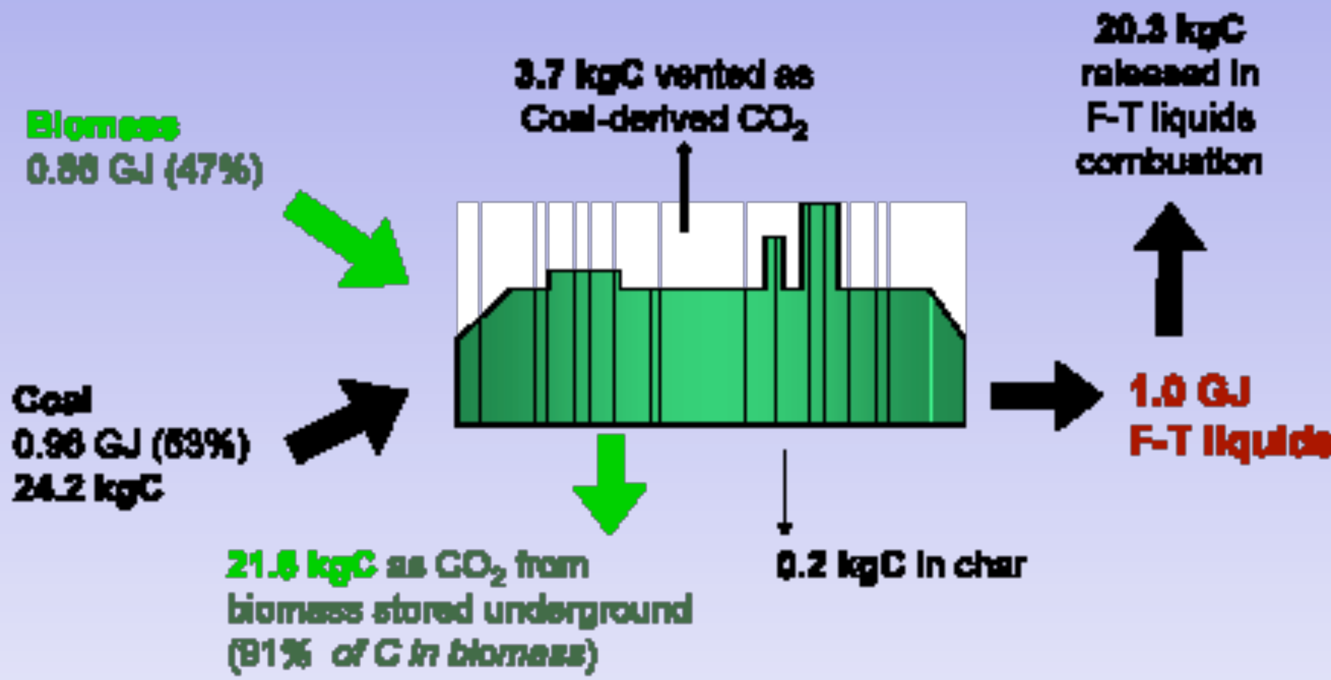
- **S cleanup not needed**
- **Less O_2 needed to gasify biomass than coal**
- **No commercial biomass gasifier…but could be commercial by ~ 2015**
- **With ~ 90% of biomass C stored underground, these systems are characterized by strong negative CO_2 emissions that can offset emissions from difficult-to-decarbonize fuels (*e.g., crude oil-derived transport fuels*)**

FISCHER-TROPSCH LIQUIDS FROM COAL + BIOMASS WITH CCS



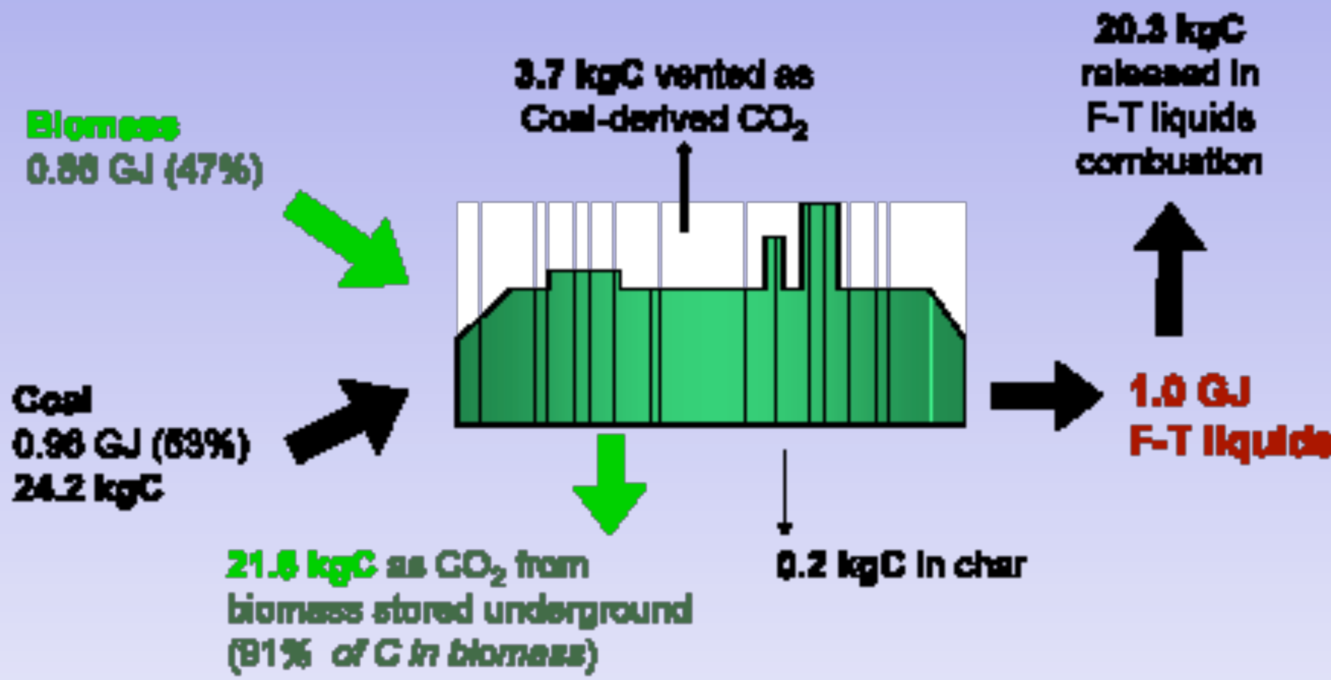
- Same gasifiers as for coal/biomass IGCC
- Synthesis gas partially shifted to get H_2/CO ratio needed for synthesis in catalytic reactor
- Final products are synthetic diesel and gasoline
- Ultra-low net CO_2 emission rate exploiting negative emissions potential of photosynthetic CO_2 storage
- All components proven/commercial except biomass gasifier...which could become commercial ~ 2015

CARBON/ENERGY BALANCES FOR MAKING FISCHER-TROPSCH LIQUIDS FROM COAL + BIOMASS WITH CCS



Net CO_2 emissions = 3.7 + 20.3 – 21.6 = 2.4 kgC/GJ of F-T liquids *(~ 10% of rate for crude oil products*)

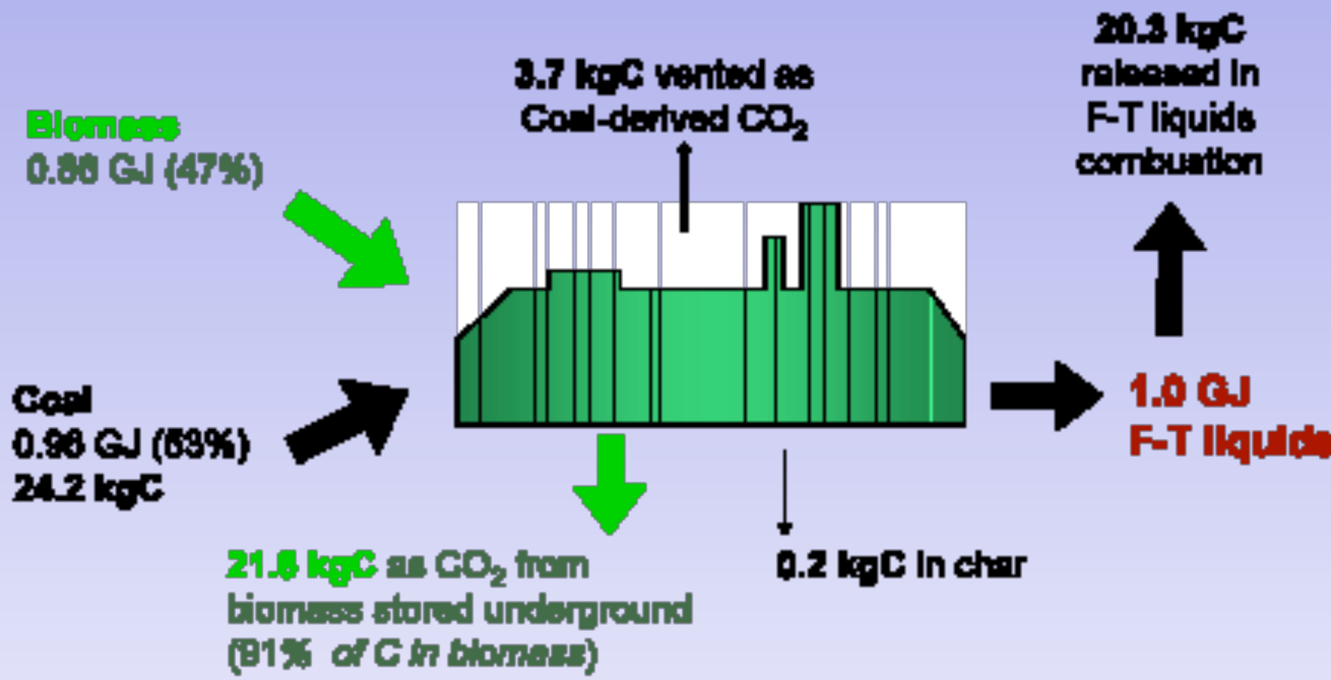
CARBON/ENERGY BALANCES FOR MAKING FISCHER-TROPSCH LIQUIDS FROM COAL + BIOMASS WITH CCS



Net CO_2 emissions = 3.7 + 20.3 – 21.6 = 2.4 kgC/GJ of F-T liquids *(~ 10% of rate for crude oil products)*

For comparison, the emission and storage rates per GJ of H_2 derived from coal with CCS are 1.3 and 1.7 times as large as for this F-T liquids option

CARBON/ENERGY BALANCES FOR MAKING FISCHER-TROPSCH LIQUIDS FROM COAL + BIOMASS WITH CCS

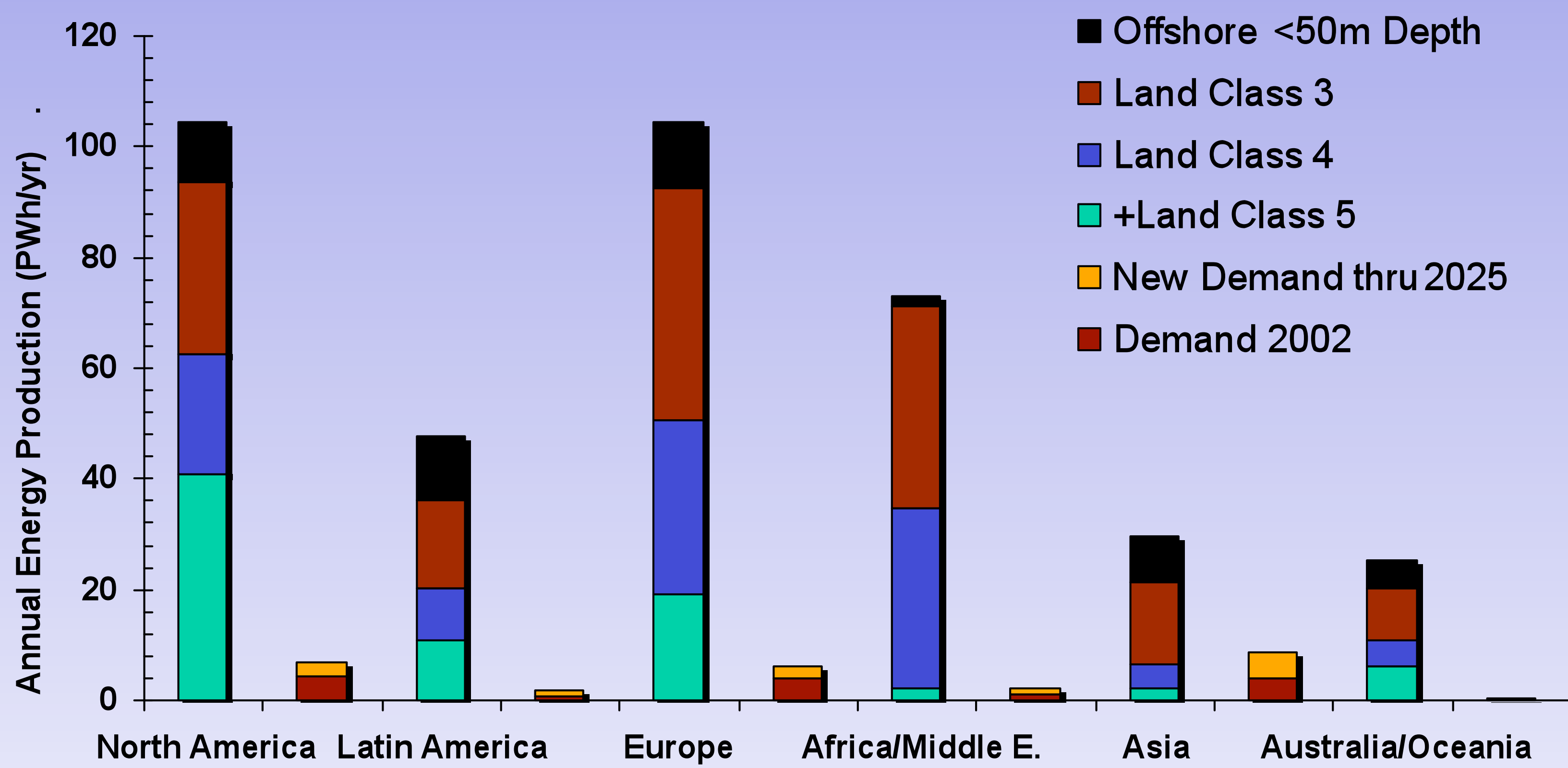


Net CO_2 emissions = 3.7 + 20.3 – 21.6 = 2.4 kgC/GJ of F-T liquids (~ 10% of rate for crude oil products)

For comparison, the amount of biomass input required per GJ of conventional biofuels such as cellulosic ethanol is ~ 2X as much

WIND RESOURCES VS ELECTRICITY DEMAND

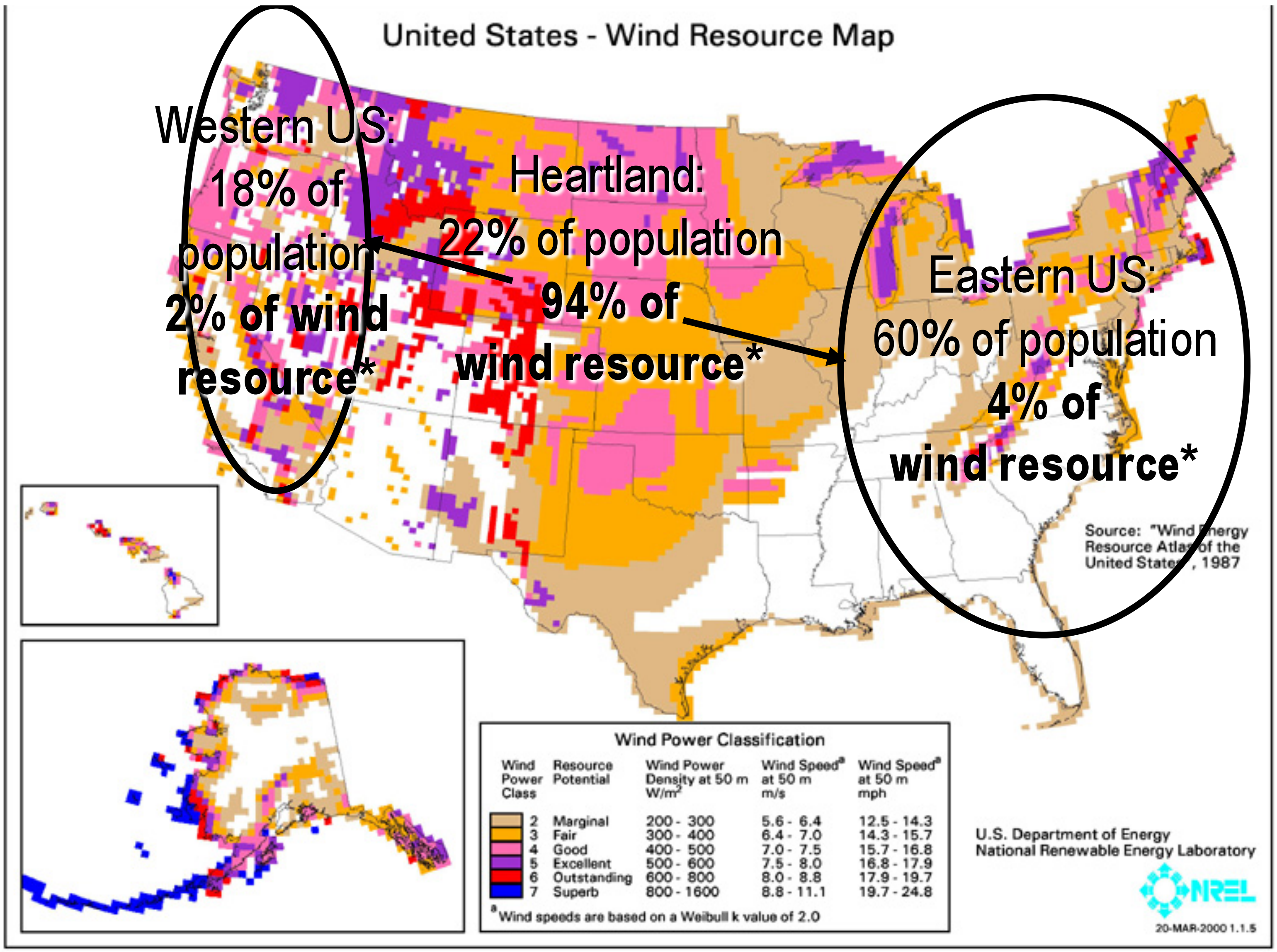
(*assuming 50% land exclusion*)



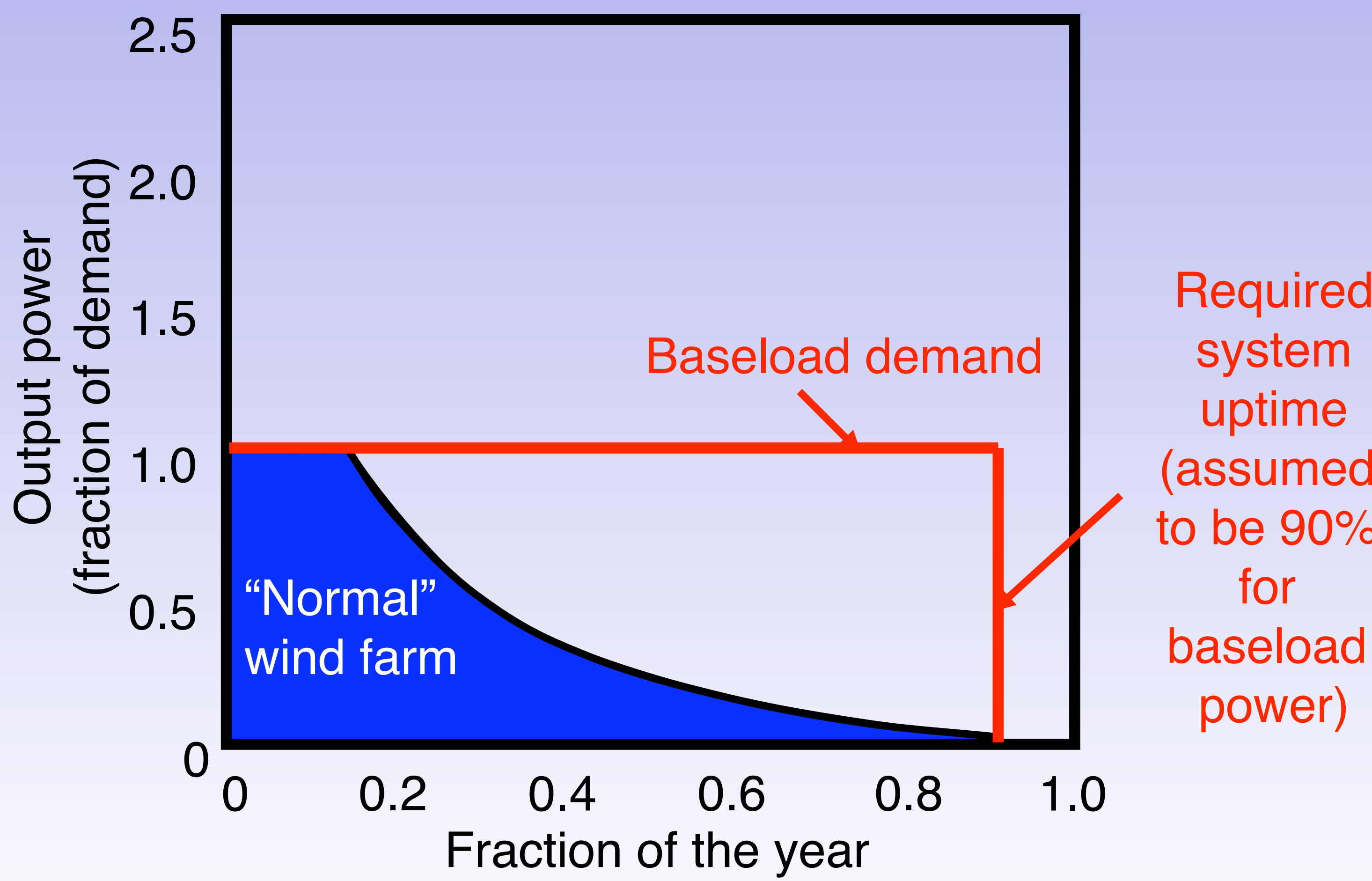
Huge potential relative to electricity demand, but

- **Wind intermittency → declining economic value with increasing grid penetration**
- **Best resources often remote from markets**

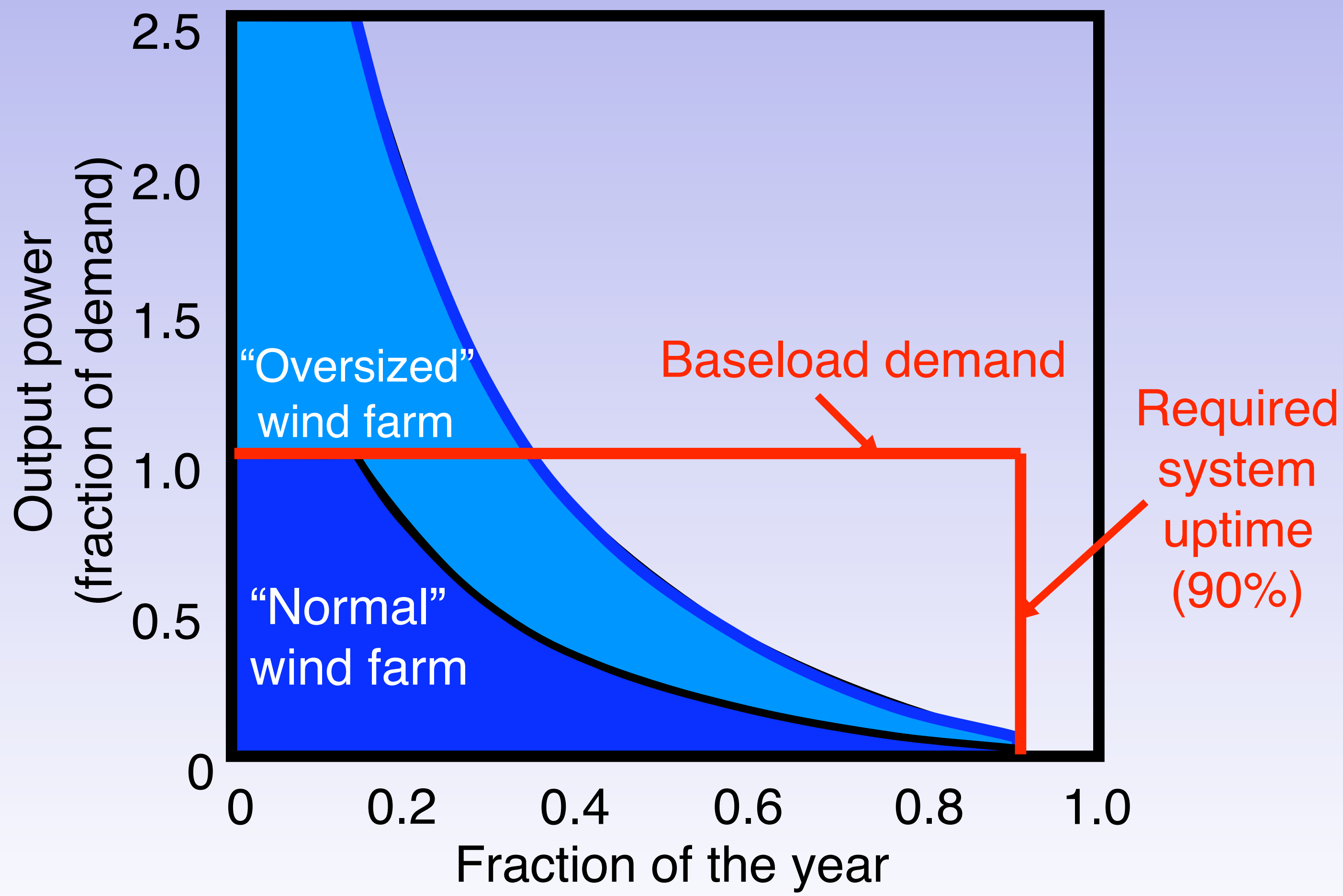
US SITUATION



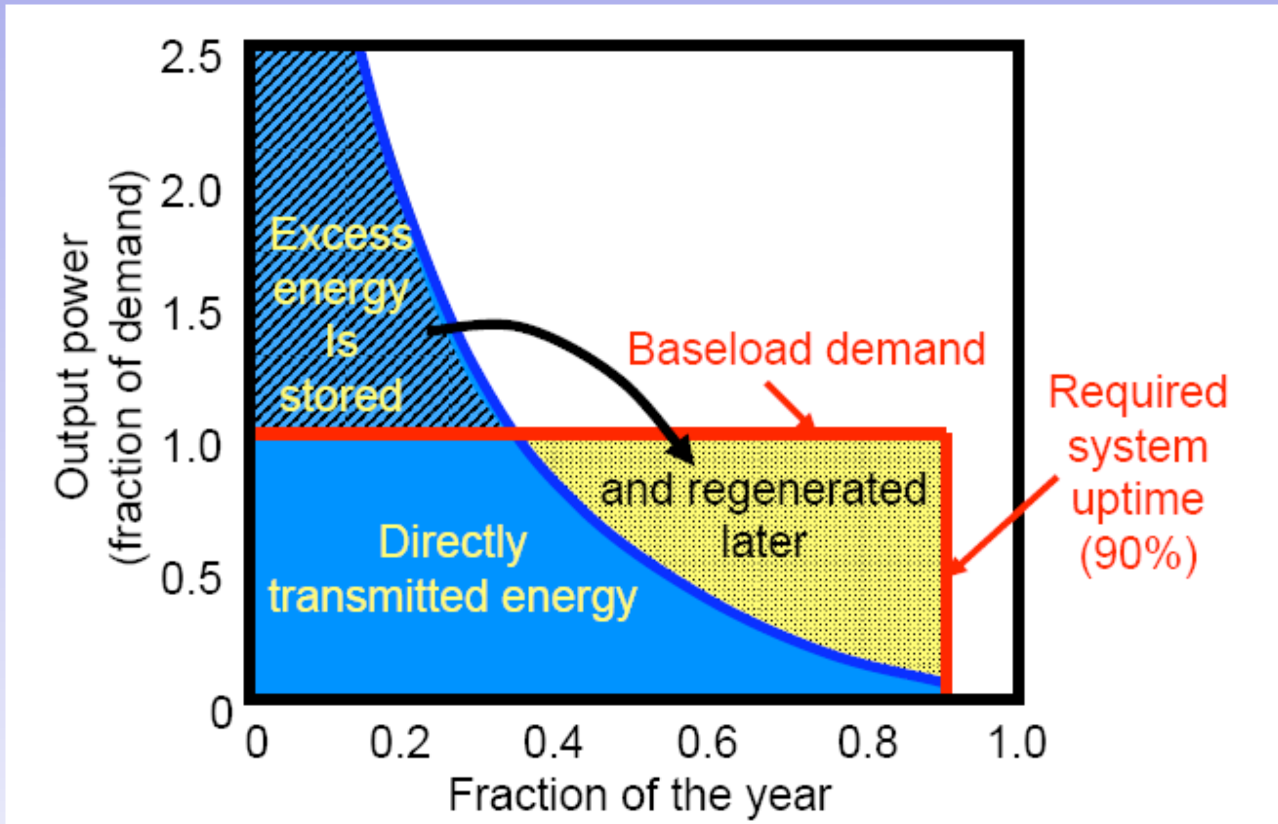
CAN WIND PROVIDE BASELOAD POWER & COMPETE WITH FOSSIL ELECTRICITY AT HIGH GRID PENETRATION LEVELS?



STEP 1 : OVERSIZE WIND FARM

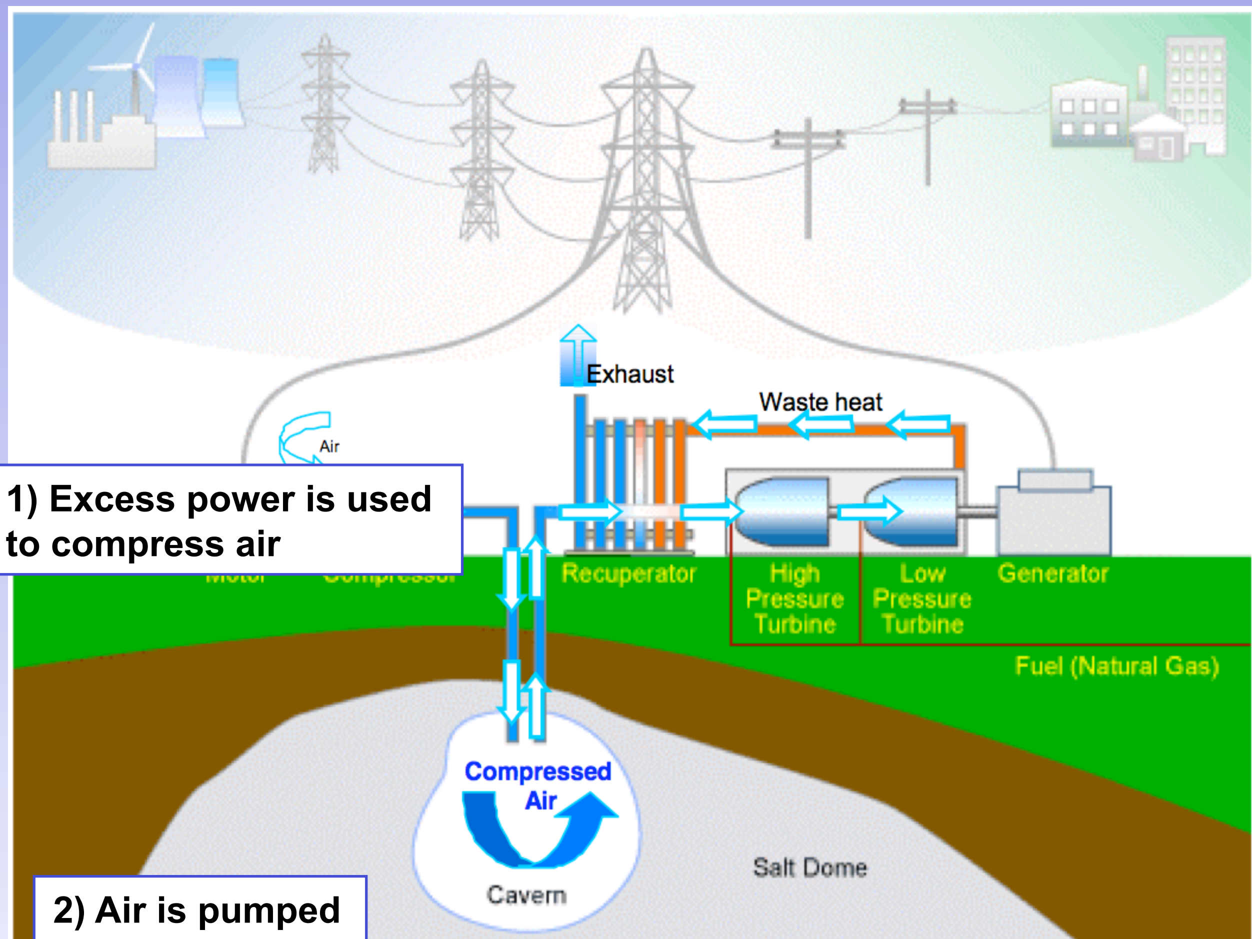


STEP 2: STORE EXCESS WIND ENERGY FOR LATER USE



Among storage options, compressed air energy storage (*CAES*) is especially attractive…offering good prospects that wind/CAES baseload units could compete with coal IGCC systems with CCS

Compressed Air Energy Storage (CAES)



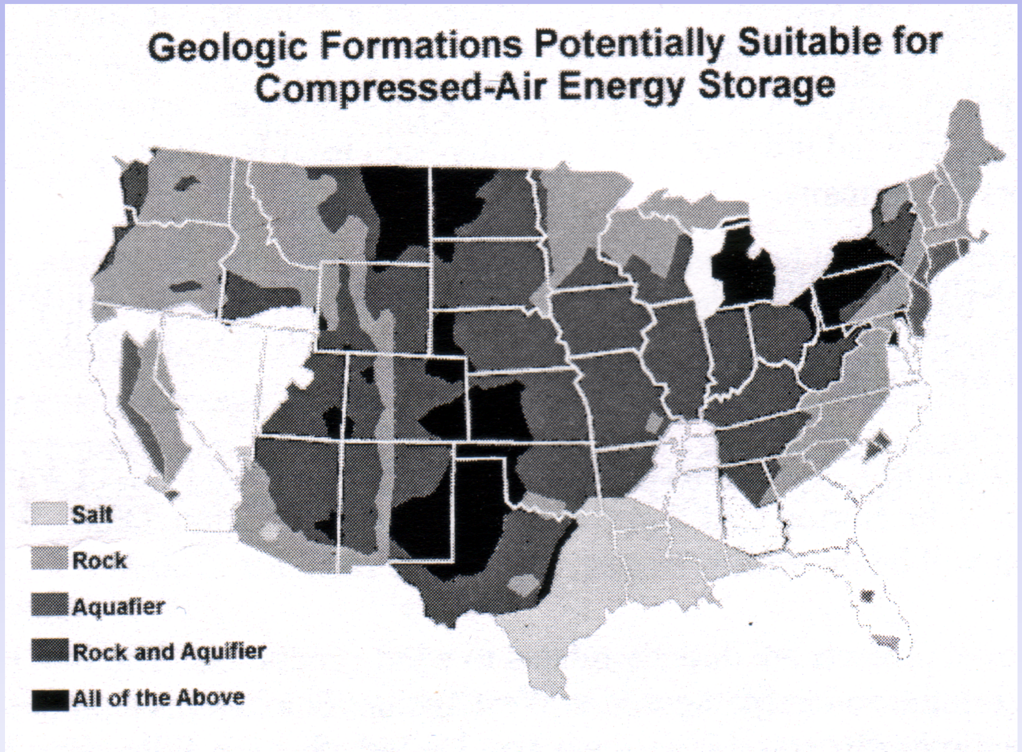
1) Excess power is used to compress air

2) Air is pumped underground and stored

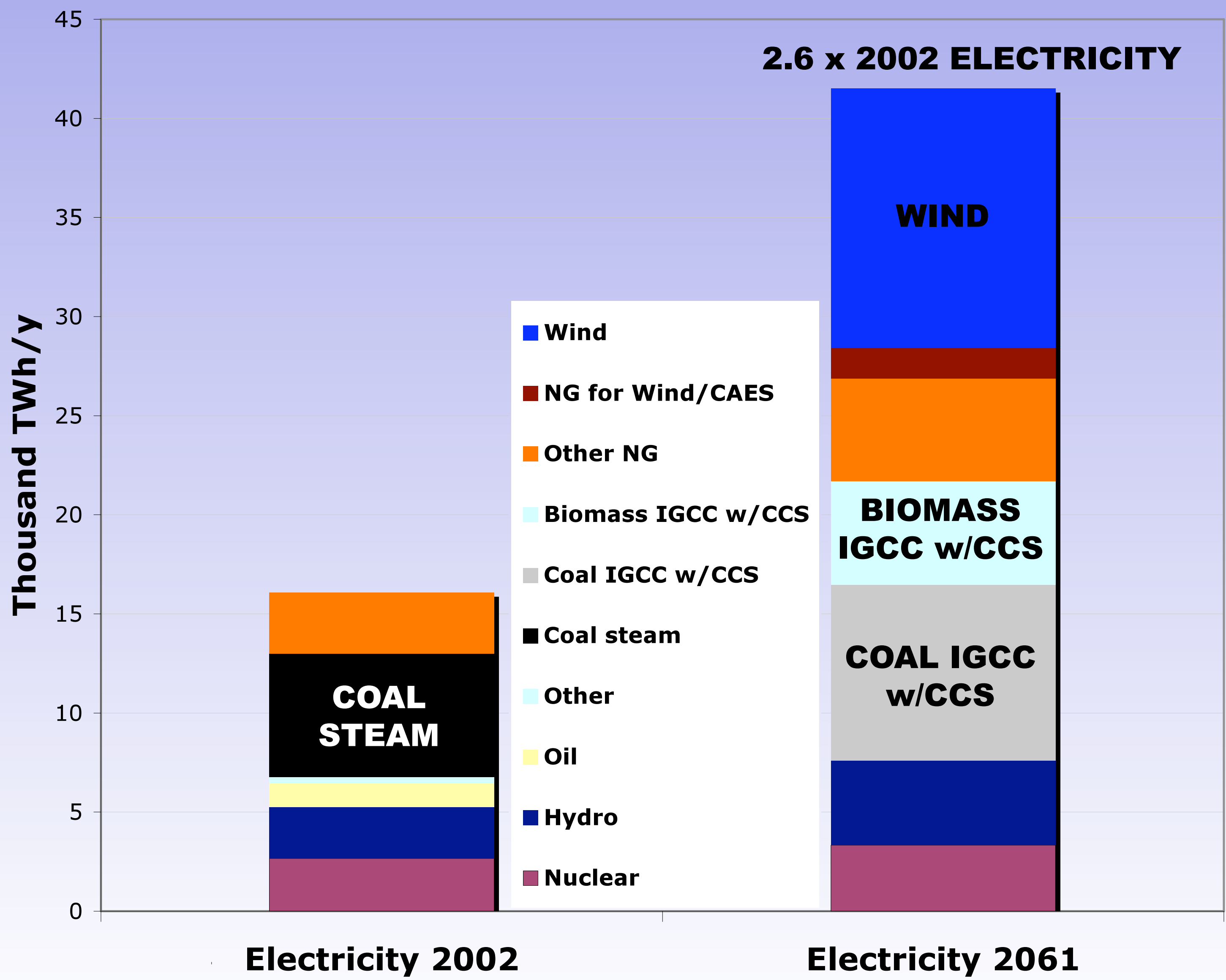
3) When electricity is needed, stored air is utilized to run a gas turbine expander (*fueled, e.g., with natural gas*)

WHAT IS GEOGRAPHICAL AVAILABILITY OF GEOLOGIES SUITABLE FOR CAES?

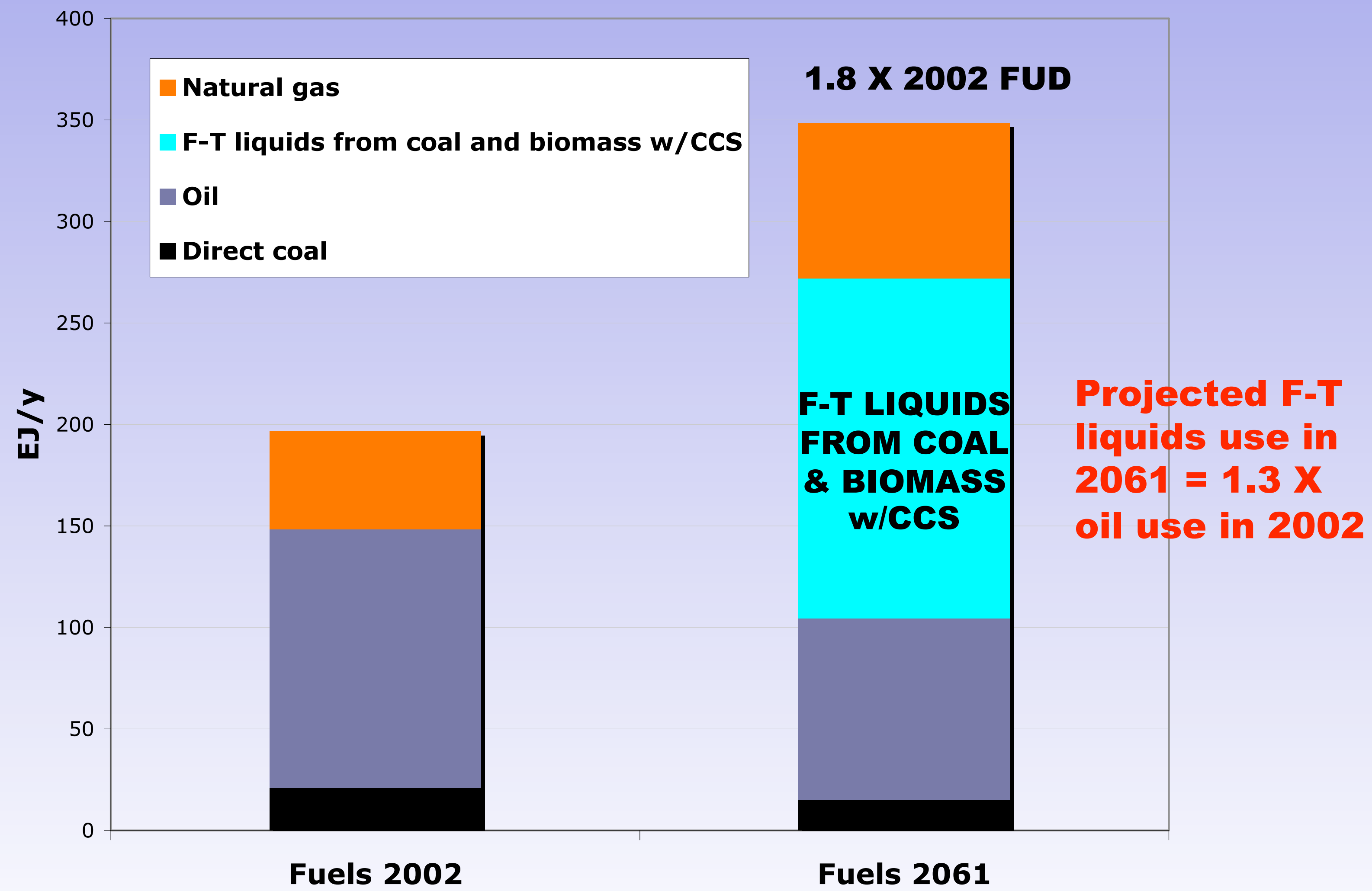
- Suitable geology for compressed air storage found over 80% of the area of the USA
- Locations coincident with high quality wind resources
- Also suitable CAES fuel (*e.g., natural gas*) must be available for wind/ CAES systems deployment



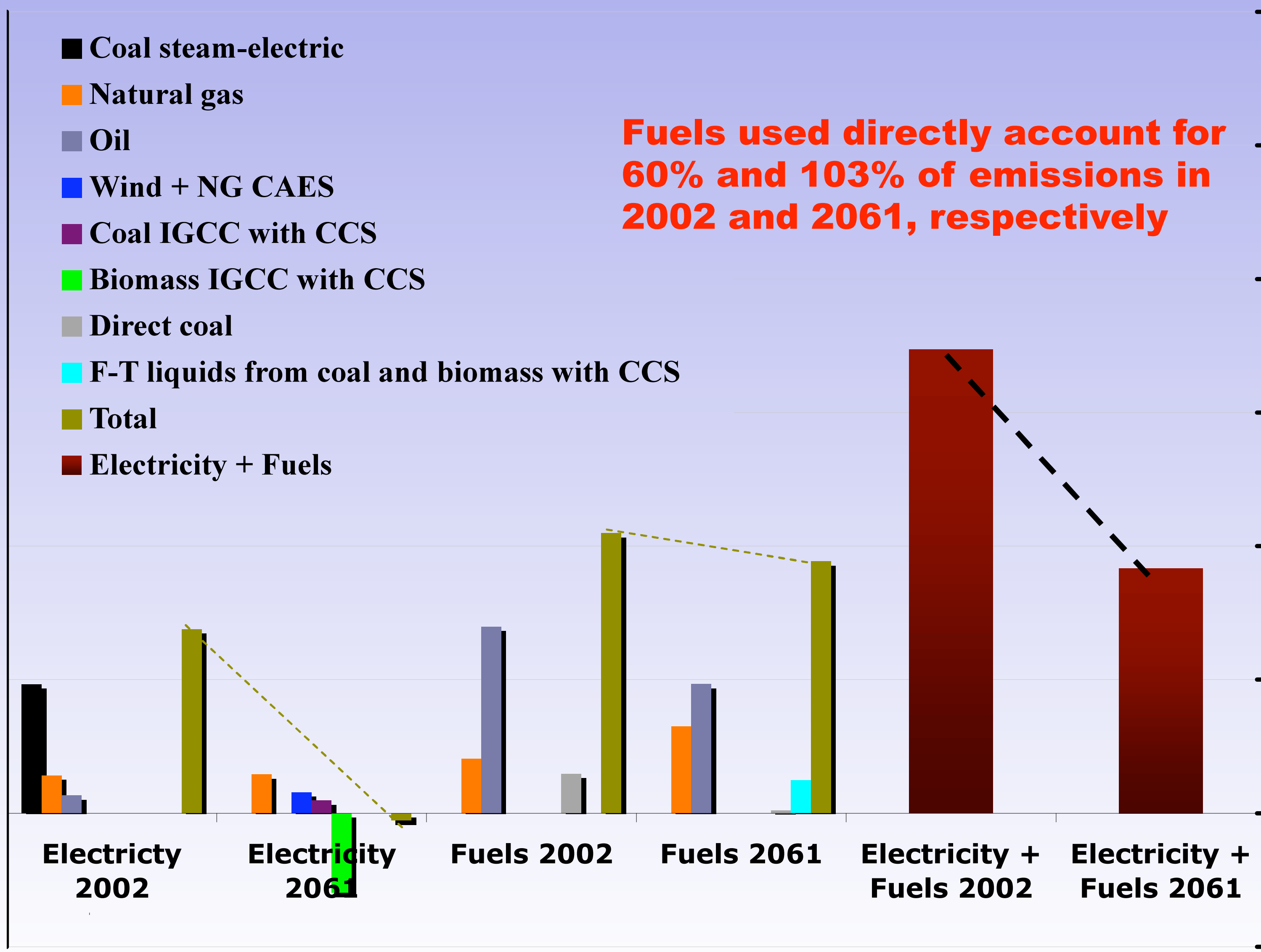
ELECTRICITY IN THOUGHT EXPERIMENT



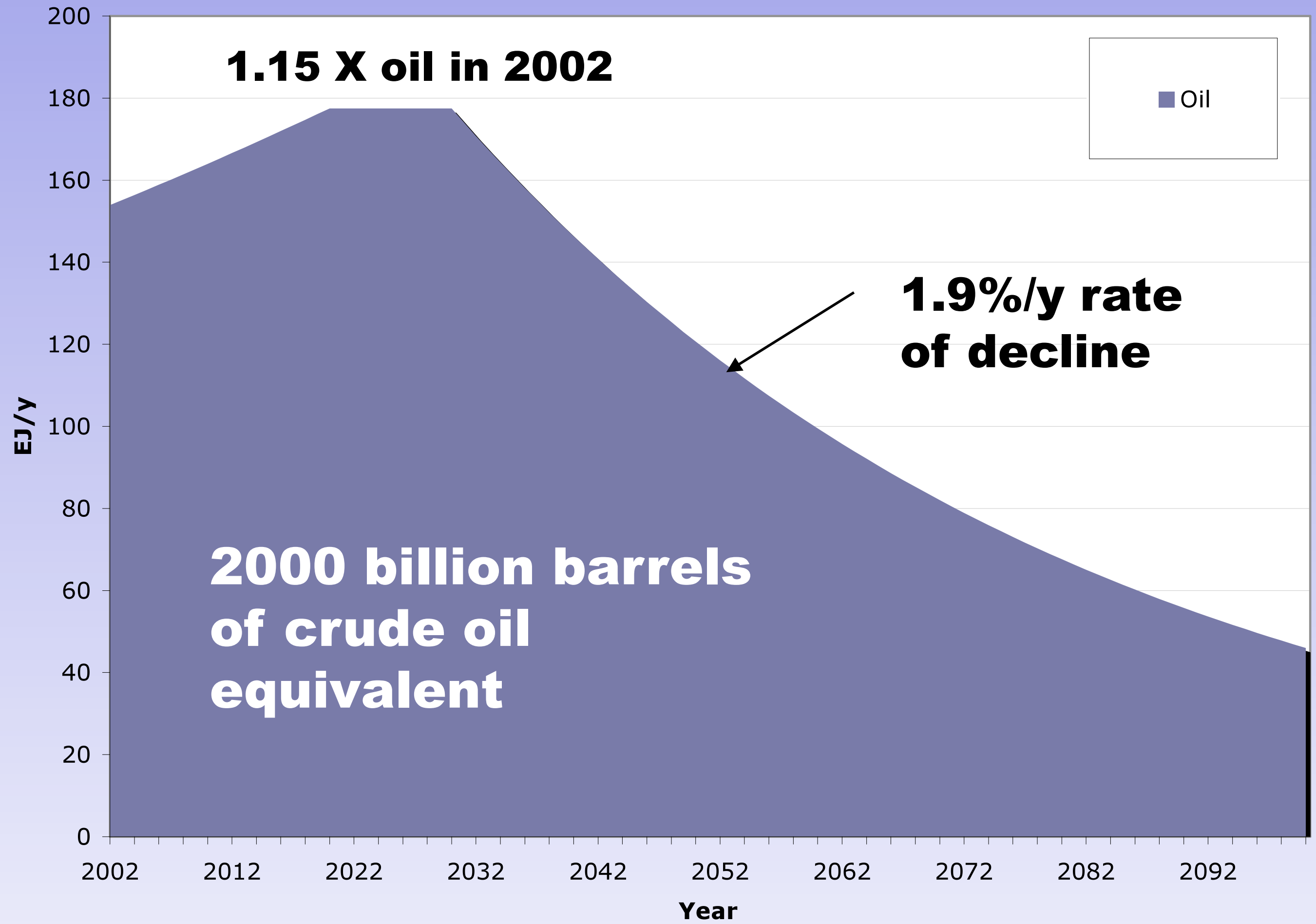
FUELS USED DIRECTLY IN THOUGHT EXPERIMENT



EMISSIONS FROM ELECTRICITY AND FROM FUELS USED DIRECTLY—BY COMPONENT, 2002 AND 2061

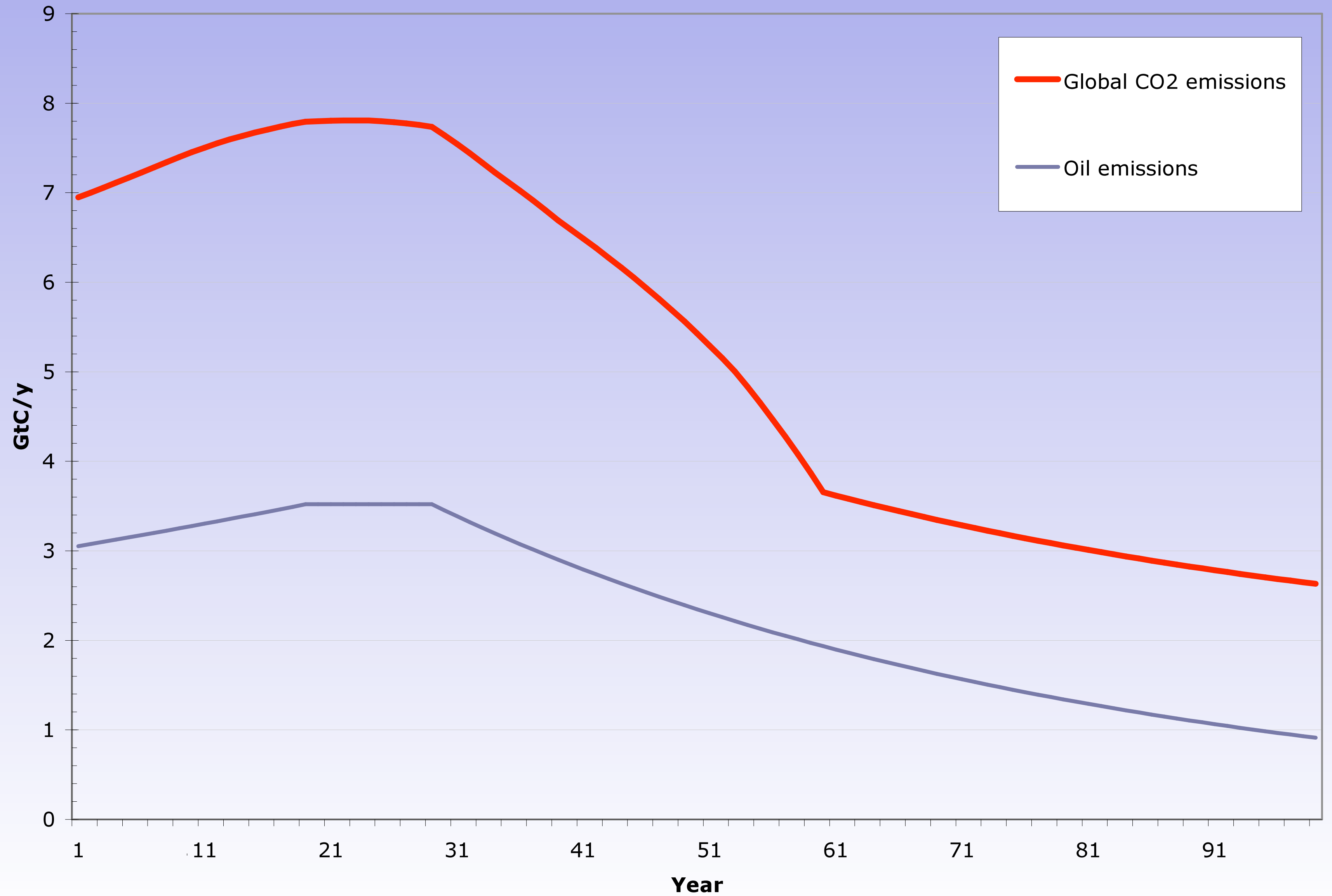


OIL ROLE IN THOUGHT EXPERIMENT

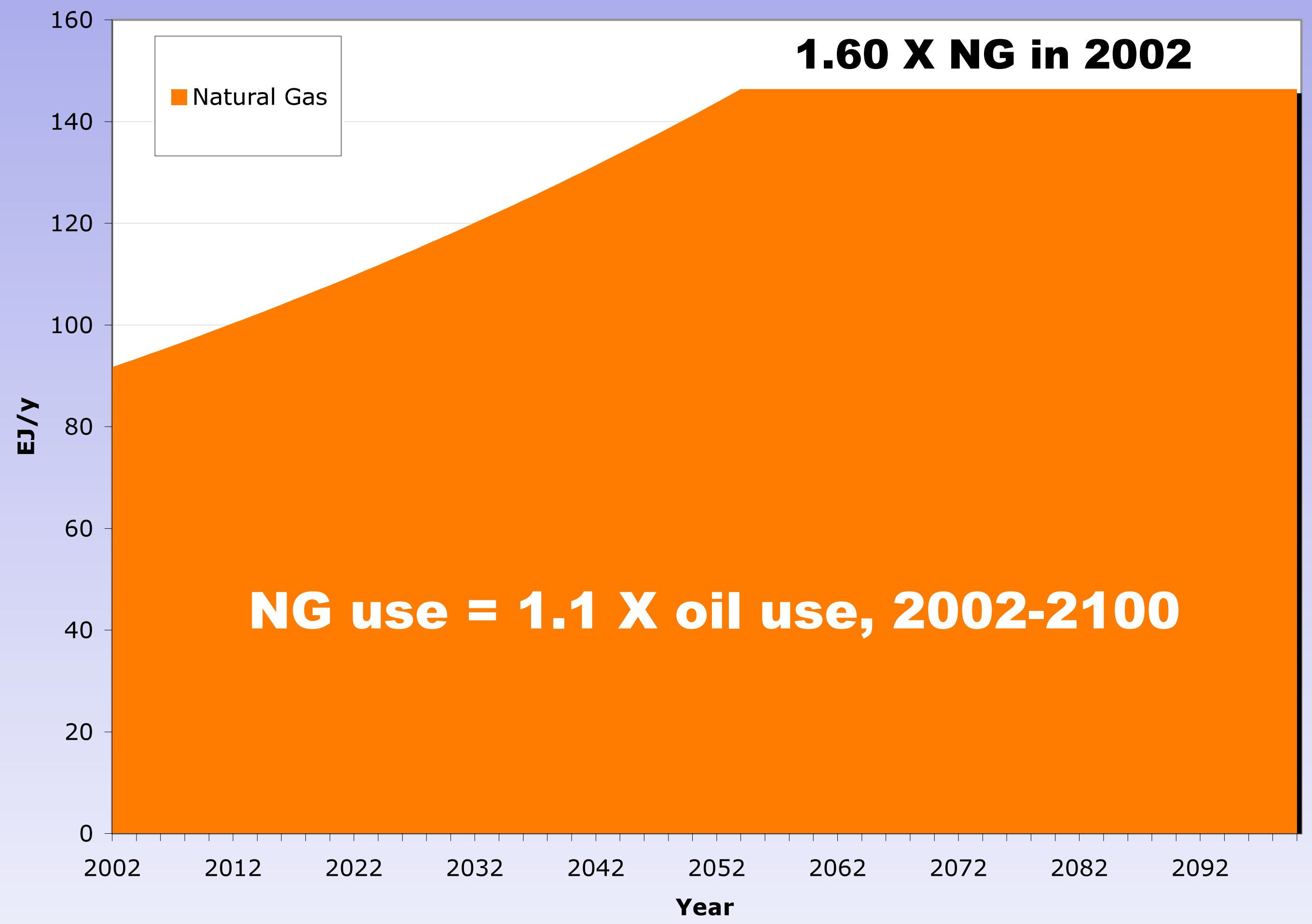


44% of CO_2 emissions from oil in 2002 → less dependence on oil via end-use efficiency + fuel switching to realize deep reduction of CO_2 emissions

OIL EMISSIONS RELATIVE TO TOTAL EMISSIONS IN THOUGHT EXPERIMENT

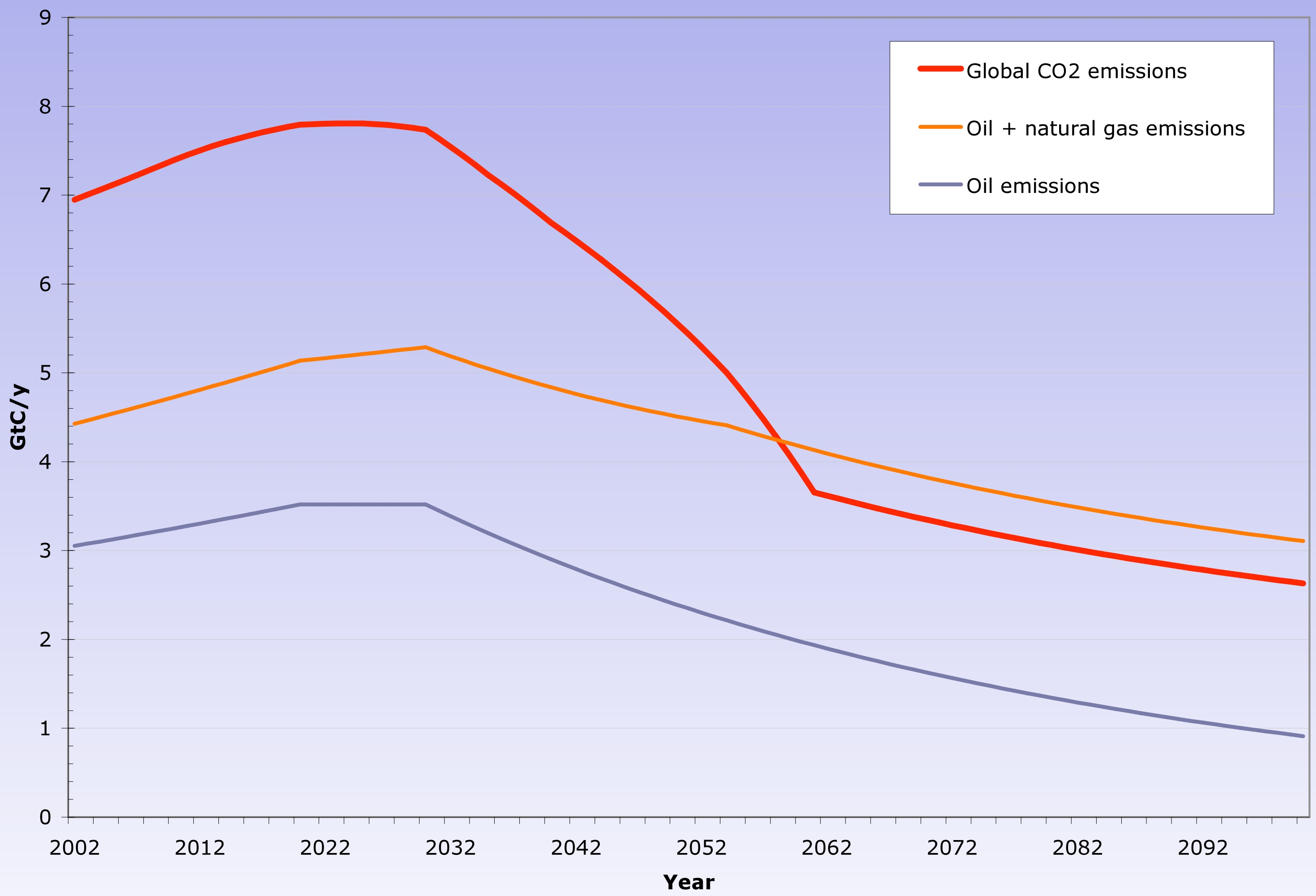


NATURAL GAS ROLE IN THOUGHT EXPERIMENT



NG is least C-intensive fossil fuel that can typically be used at higher efficiency than other fossil fuels → large role for NG in thought experiment

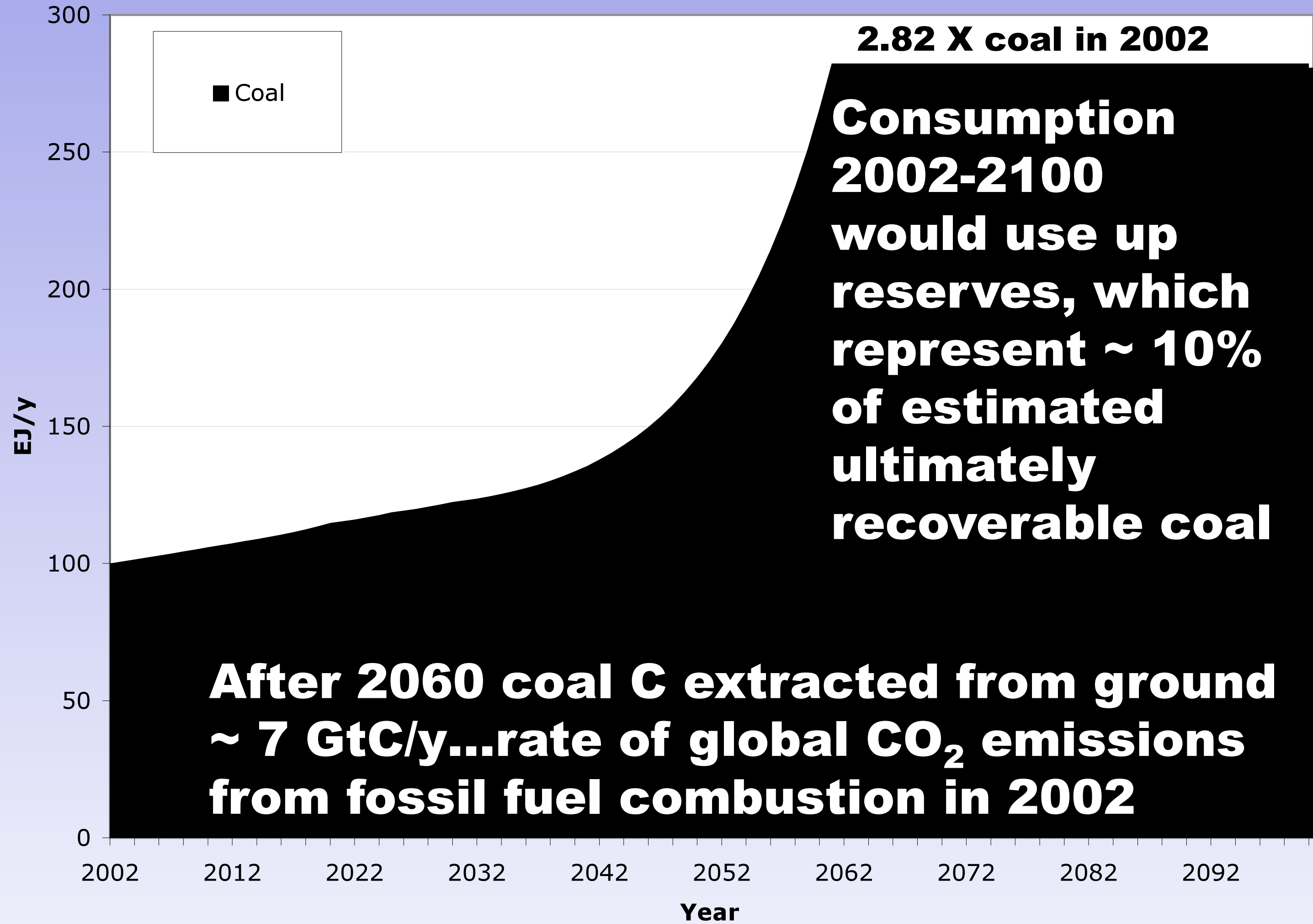
OIL + NG EMISSIONS RELATIVE TO GLOBAL EMISSIONS IN THOUGHT EXPERIMENT



Oil + NG emissions exceed total emissions after 2060

...and coal emissions have not even been considered!

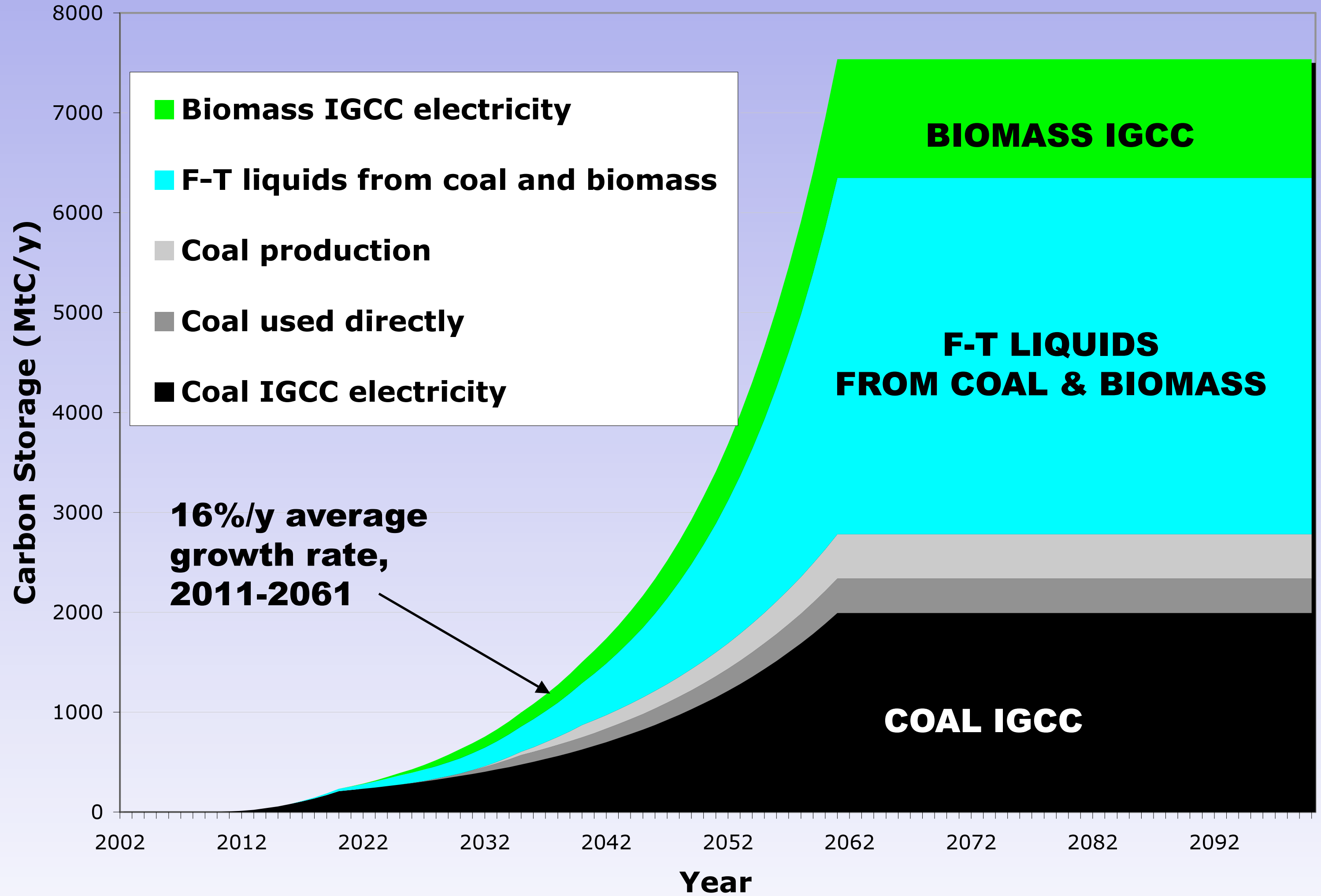
COAL ROLE IN THOUGHT EXPERIMENT



Coal is most C-intensive fossil fuel…but also most abundant, least costly, most secure

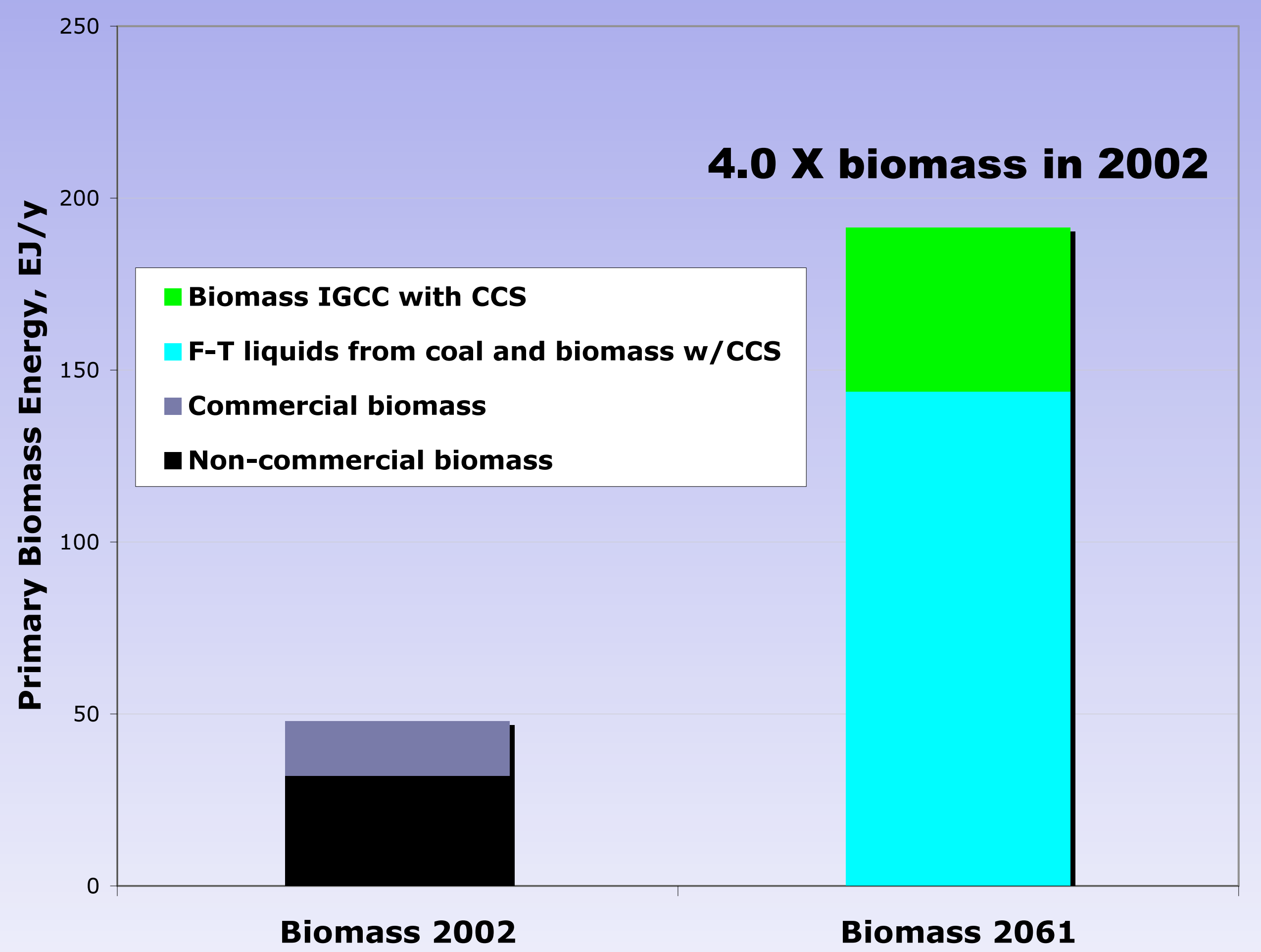
…and it is the fossil fuel for which CCS is least costly

GEOLOGICAL CO_2 STORAGE IN THOUGHT EXPERIMENT



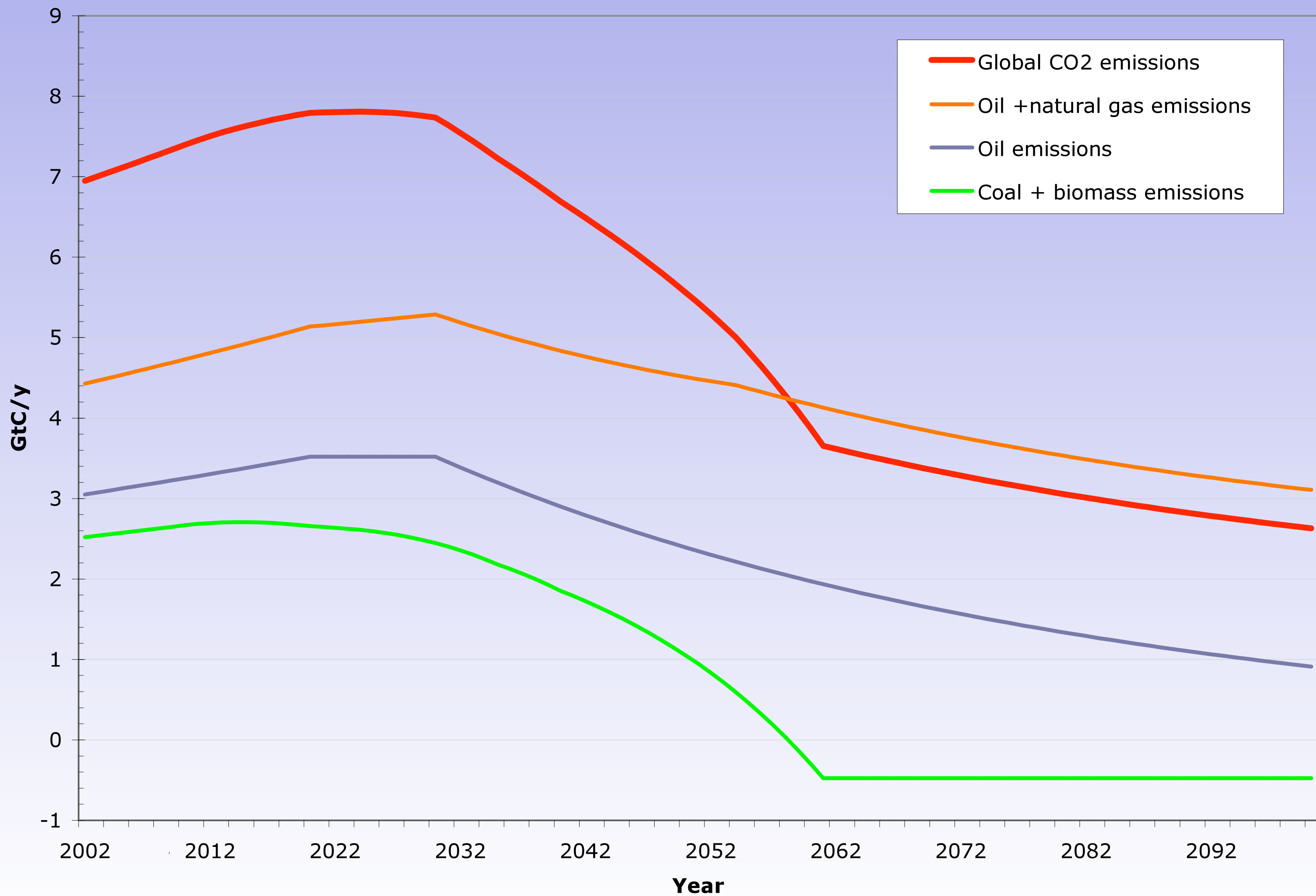
Coal + biomass are completely decarbonized by 2061, when CO_2 storage rate exceeds 2002 emission rate

BIOMASS ROLE IN THOUGHT EXPERIMENT

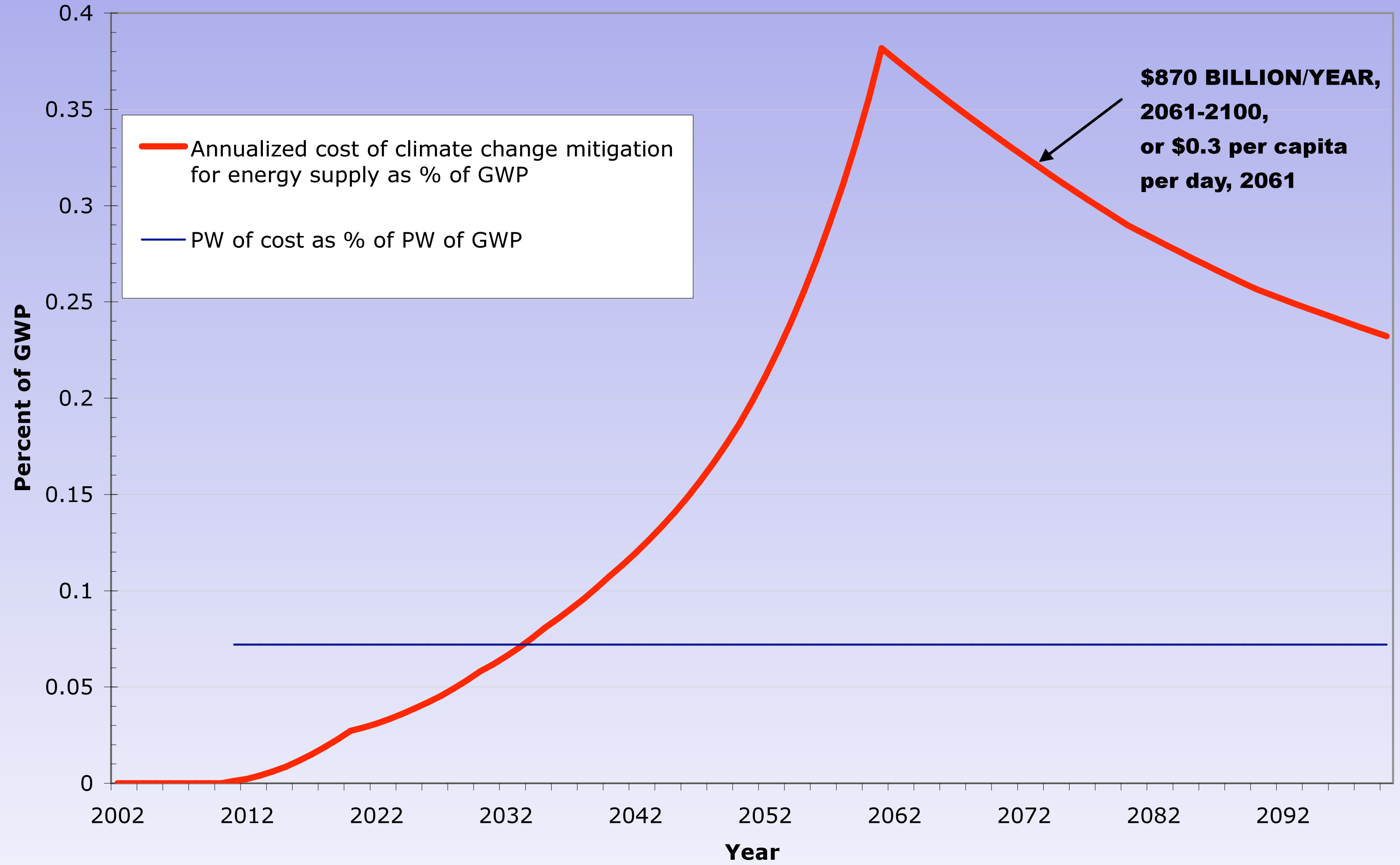


Global bioenergy potential (*long-term*):
~ 100-300 EJ/y (*World Energy Assessment*, 2000)

NET NEGATIVE EMISSIONS FROM COAL + BIOMASS WITH CCS AFTER 2060 BRINGS TOTAL EMISSIONS IN LINE WITH 450 PPMV TRAJECTORY



COST OF MITIGATING CLIMATE CHANGE FOR ENERGY SUPPLY IN THOUGHT EXPERIMENT



PW of future cost (*8% discount rate*) ~ $1 trillion (*1/2 cost of Iraq War*) = 0.07% of PW of future GWP

LESSONS LEARNED

- **With technologies "near at hand" can plausibly move along 450 ppmv stabilization path for ~ ½ century…at modest cost**
- **Electricity is far easier to decarbonize than FUD**
- **Fossil CCS and renewable energy/energy efficiency are complementary—not competitive strategies**
- **More nuclear electricity would not change emissions outlook**
- **Huge CCS effort is required to decarbonize FUD**
- **Can we reduce future FUD demand via more energy efficient energy use and/or find ways to shift more FUD to electricity?**
- **Radical new technologies needed for second ½ of century….liquid fuels via artificial photosynthesis?**