CCS IN OIL AND GAS RESERVOIR WITH ENVIRONMENTAL HEALTH & SAFETY ANALYSIS

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INTRODUCTION

- Problem Statement:
  - ***Examining the implementation of retrofitting and sequestration technologies on a 572MW coal plant in Shawville, PA for Carbon Capture and Storage (CCS) and Enhanced Oil Recovery (EOR) to make the project viable while reducing associated costs.***
  - Motivations/Focus:
    - Investigate the practicality of the stated problem statement
    - We want to see if retrofitting an existing plant is more practical and whether it provides greater incentives?
    - Shorter implementation time – retrofitting vs. new plant
    - Regional power plant/sequestration/utilization sites
    - Legislations/policies
    - Moving beyond conceptualization towards local application
    - A comprehensive economic analysis – will this work?

The Beginning of Regulations

- In 2007, the Supreme Court ruled that EPA must regulate greenhouse gas emissions, including CO_2
- Case was decided 5-4
- EPA claimed that it lacked authority under the Clean Air Act to regulate carbon dioxide and other greenhouse gases (GHGs) for climate change purposes

Massachusetts v. Environmental Protection Agency

Supreme Court of the United States

Argued November 29, 2006
Decided April 2, 2007

Full case name	*Massachusetts, et al., Petitioners v. Environmental Protection Agency, et al.*
Docket nos.	05-1120
Citations	549 U.S. 497; 127 S. Ct. 1438
Prior history	On writ of certiorari to the United States Court of Appeals for the District of Columbia Circuit

Holding

Greenhouse gases are air pollutants, and the United States Environmental Protection Agency may regulate their emission

http://www.supremecourt.gov/opinions/06pdf/05-1120.pdf

The American Clean Energy and Security Act

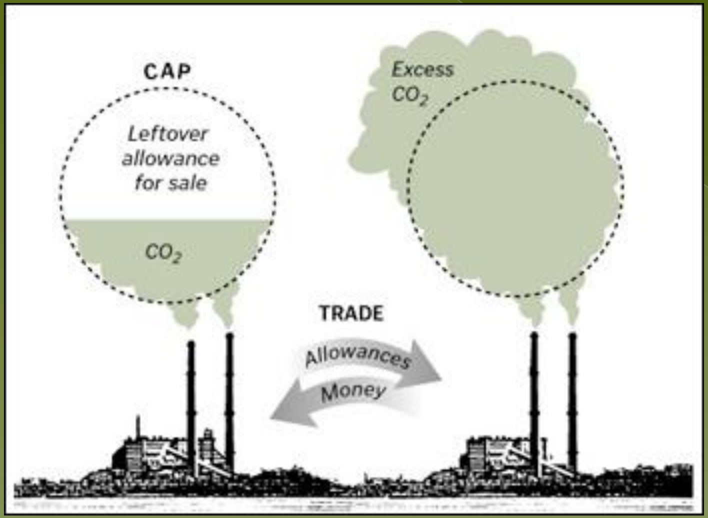
- The American Clean Energy and Security Act(H.R. 2454) , a cap-and-trade bill, was passed on June 26, 2009, in the House of Representatives by a vote of 219-212. The bill originated in the House Energy and Commerce Committee and was introduced by Rep. Henry A. Waxman and Rep. Edward J. Markey
- Bill currently under review in the Senate

Year	Required GHG Emission Reduction
2012	3.0%
2020	17.0%
2030	42.0%
2050	83.0%

http://en.wikipedia.org/wiki/American_Clean_Energy_and_Security_Act#cite_note-0

Cap and Trade

- Cap and Trade, also known as Emissions Trading is:
  - ***an administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants.***
- Government sets a national limit (**CAP**) for emission amounts then distributes to companies the rights (allowances) to emit gases (mainly CO2). Companies are then free to buy and sell (**TRADE**) these allowances. Entities that emit more will have to pay more, thus providing them financial incentive to reduce emission**.**



http://en.wikipedia.org/wiki/Emissions_trading#cite_note-0

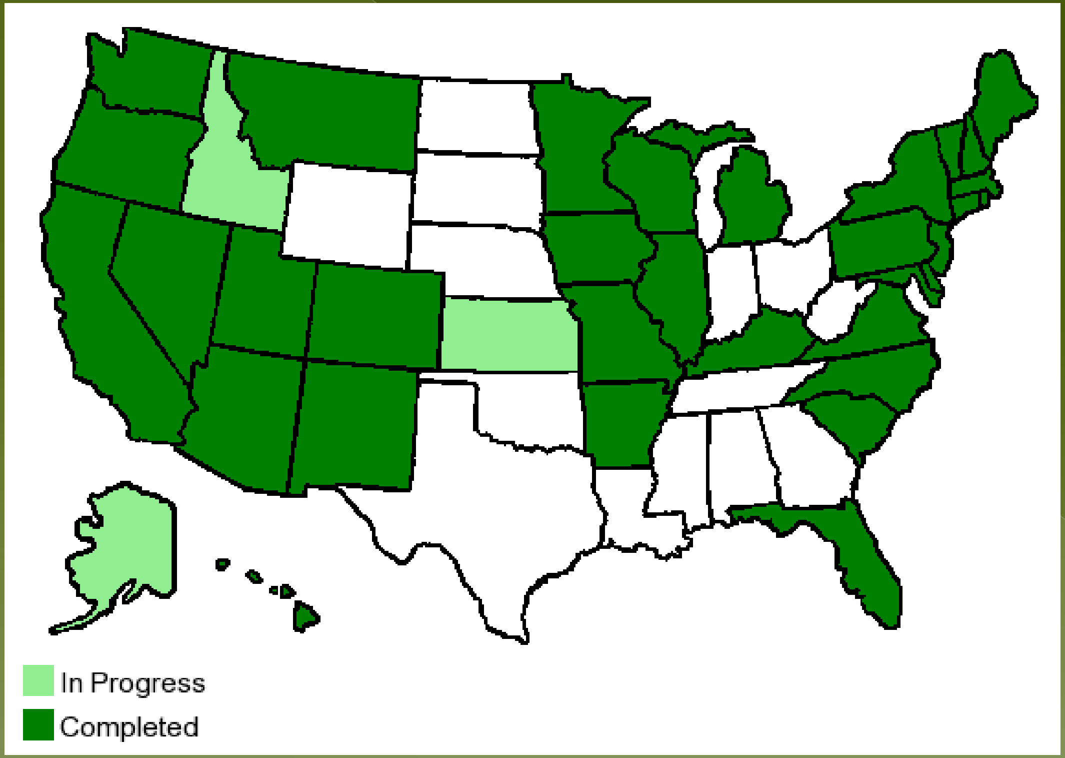
Energy Sector in PA

- Why bother with CCS?
  - Largest source of GHG in PA
  - In the year 2000, this sector produced 116.2 MMtCO2 (equivalent), which is 37% of the state's emission

Climate Change Action Plan, Chapter 4 – Electricity Generation, Transmission & Distribution

Climate Change Action Plan

- States where Climate Change Action Plan are initiated
- Pennsylvania contributes 1% of the world's CO_2 emission and 4% of the USA's



Climate Change Action Plan, Chapter 4 – Electricity Generation, Transmission & Distribution

Pennsylvania Legislation on CCS

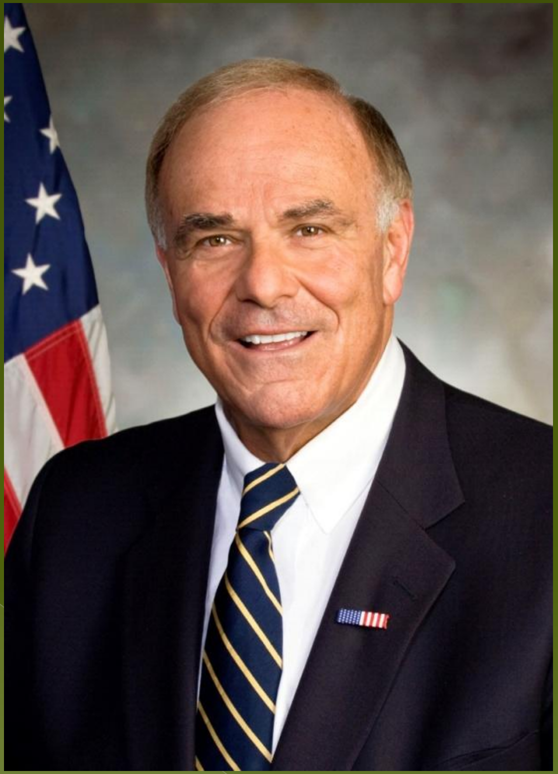
On July 9, 2008, Governor Rendell signed the Pennsylvania Climate Change Act (Act 70). This act requires the Department of Environmental Protection (DEP) to prepare a Climate Change Action Plan

On October 15, 2008, House Bill 2200 was signed into law by Governor Rendell. It requires the Department of Conservation and Natural Resources (DCNR) to conduct studies of carbon capture and sequestration, and present its findings to the Governor and the General Assembly by mid-to-late 2009.

House Bill 80

Climate Change Action Plan states that implementation of the Carbon Capture and Sequestration (CCS) would be supported via passage of House Bill 80.

HB 80 is currently under consideration and will involve CO2 indemnification funds, providing sequestration and transport pipeline facilities amongst

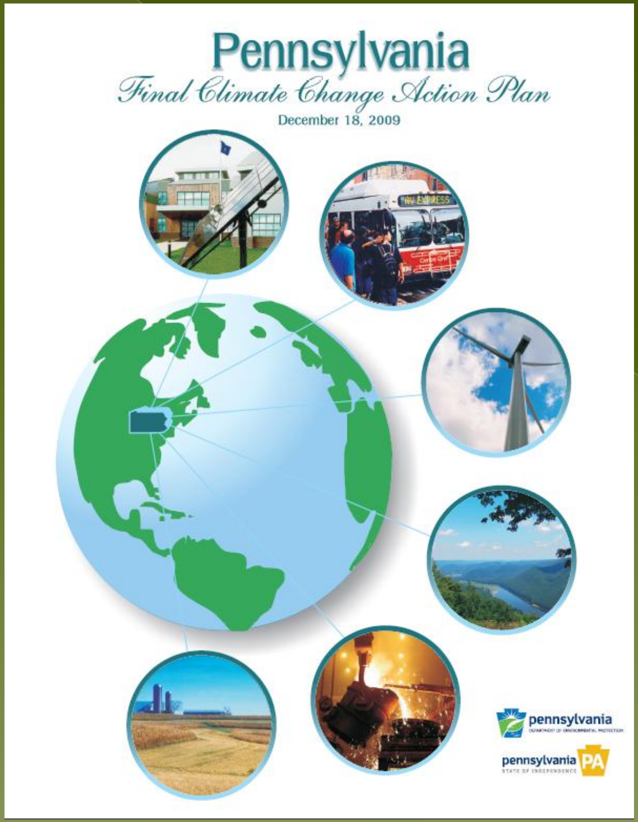


Governor Edward G. Rendell

http://www.legis.state.pa.us/cfdocs/billinfo/bill_history.cfm?syear=2009&sind=0&body=H&type=B&bn=80

PA's Climate Change Action Plan

- 52 recommendations to mitigate GHGs



Climate Change Action Plan, Chapter 4 – Electricity Generation, Transmission & Distribution

PA's Climate Change Action Plan

- **Electricity 5. Carbon Capture and Sequestration in 2014**
  - Retrofitting existing coal plants using entail anime scrubbing
  - Stimulus funds for CCS amounting to $3.5 billion
  - Combining with federal funds results in at least $8 billion
  - Loan guarantees for early-stage developments of CCS facilities and infrastructures
  - Funding for technical assessments of CCS potential in the state
  - Investment tax credits to cover up-front capital costs
  - Production tax credits over a specified period of generation
  - Direct cost sharing of project development costs through appropriations
  - Streamlined permitting for generation and associated transmission

Climate Change Action Plan, Chapter 4 – Electricity Generation, Transmission & Distribution

Dilemma of the Cap-and-Trade

- Looking at both sides of the situation:

Pros	Cons
Reduce CO_2 emissions	Higher electricity bills
Viewed as "greener"	Higher gas prices
Cleaner Air and Environment	Little impact on climate change
Create jobs	Damage to economy
	India/China might not follow through

POLICIES

- Dingell-Boucher – discussion draft
  - Promising cap-and-trade program
    - CCS Projects are responsible for leakages
    - Certified projects allocated bonus allowances from 2012 to 2025
    - Equation goes like this:

$$\frac{(\text{Tonnes of } CO_2 \text{ emissions avoided}^{23})\ (\text{bonus allowance value})}{(\text{Average value of an emission allowance during the preceding year.})}$$

    - $90 per ton for early projects, eventually dropping to $50 per ton
    - Available for the first 10 yrs of operation

http://www.ccsreg.org/working_papers.html

POLICIES

- **Stake Holders:**

U.S. Department of Energy
Office of Fossil Energy

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

NETL
National Energy Technology Laboratory

CO_2 Capture Project®

bp Chevron ConocoPhillips eni BR PETROBRAS StatoilHydro SUNCOR ENERGY U.S. D.o.E. Norges forskningsråd EU EPRI REPSOL YPF

Shawville Power Plant Specs.

	mass flow rate	
	kg/hr	ton/yr
IN		
Coal	154,131	1,414,000
Air	2,210,698	21,302,290
Total:	2,364,829	22,716,290
OUT		
Ash	19,125	166,000
Flue Gas	2,345,704	22,550,290
Total:	2,364,829	22,716,290

- 2 – 125 MW PC Boilers
- 2 – 188 MW PC Boilers

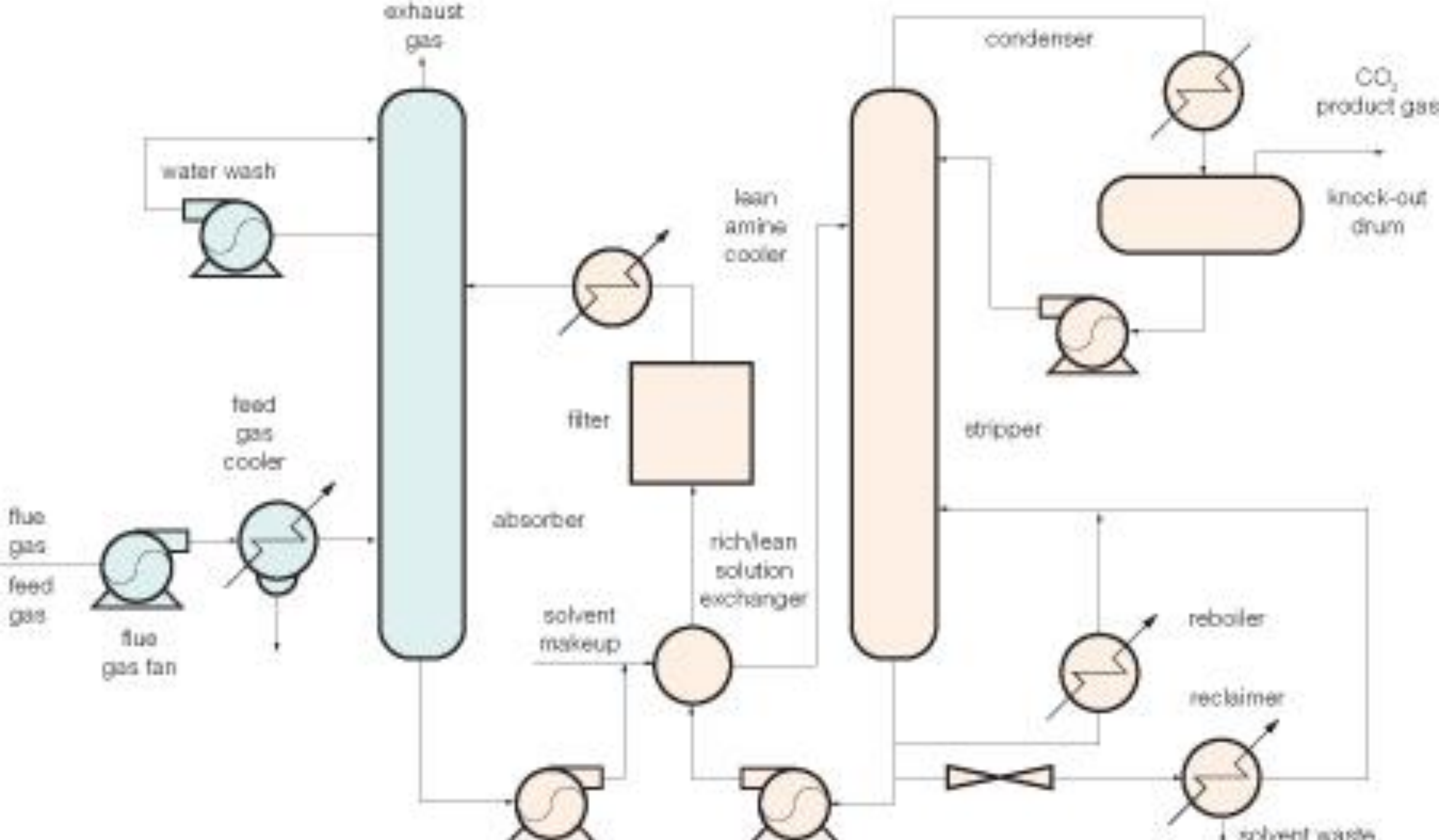
- Input: 33.9E12 Btu/yr
- Output: 3.2E6 MWh
- η = 32.2%

By assuming a steady state system, the flue gas composition is determined

Flue Gas Composition

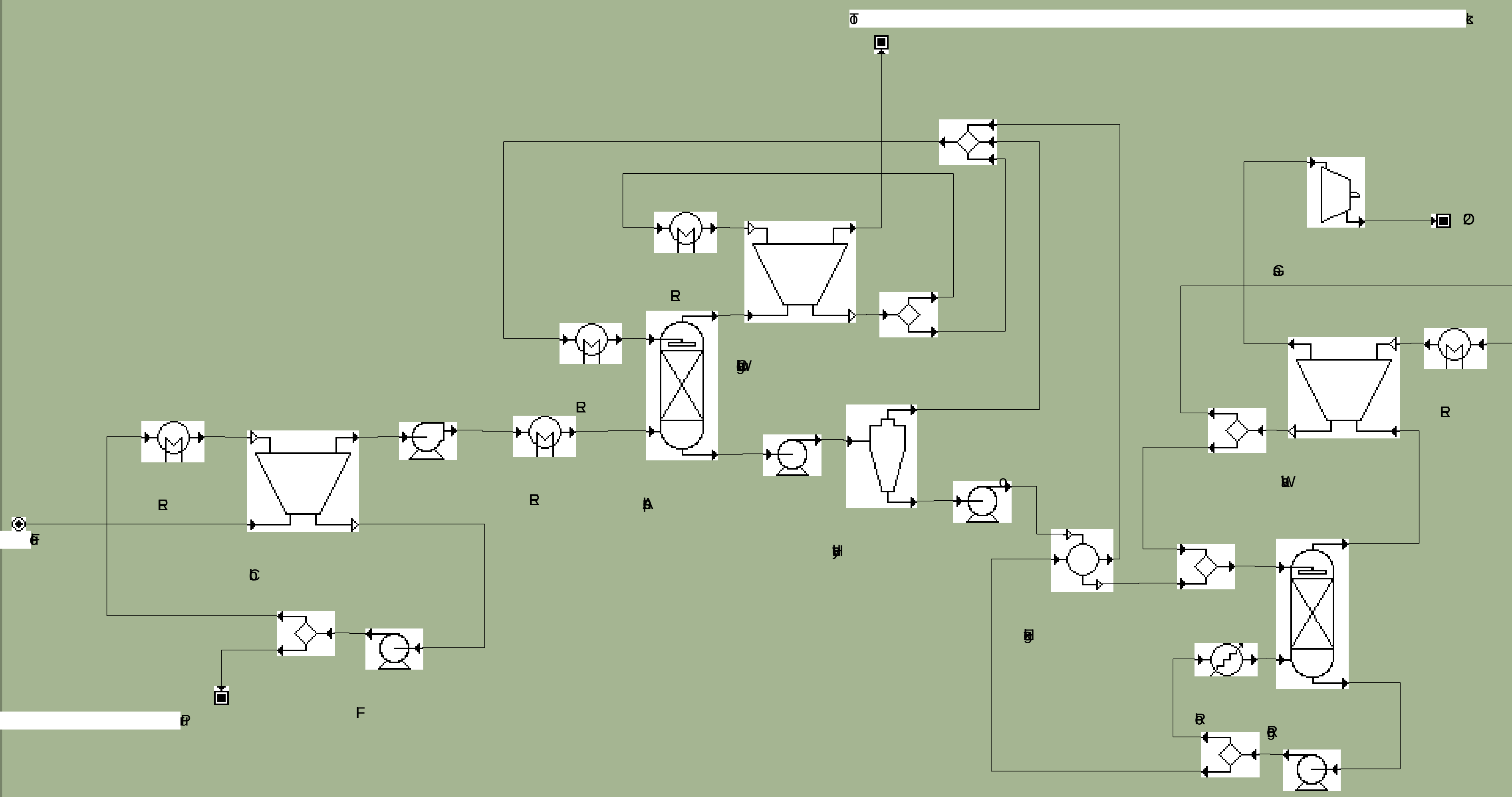
	mass flow rate		mass percentage
	kg/hr	ton/yr	
CO_2	392,132	3,403,902	15.1%
SO_x	5,413	46,976	0.2%
NO_x	793	6,885	0.0%
H_2O	222,000	2,176,548	9.7%
N_2	1,581,262	15,503,132	68.7%
O_2	144,105	1,412,847	6.3%

MEA: Monoethanolamine



Source: IEA-Clean Coal Centre

CAP: Chilled Ammonia Process



Carbon Capture Comparison

	Base Plant	MEA w/ FGD	CAP
Energy Input (MW)	1259	1259	1259
Energy Output (MW)	405	258	335
Energy Penalty	-	11.7%	5.6%
η_{th} (% HHV)	32.2%	20.5%	26.6%
Capital Costs (MM $)	-	446.6	65.1
O & M Cost (MM $)	-	96.7	227.5
Avoided Cost, $/ton CO_2	-	57.06	77.97
Price (¢/kWh)	6.5	14.99	15.44
Price Increase		57.3%	58.5%

Assumptions:

- 90% CO2 capture rate (by weight) = 3.06 mm ton/yr
- Capital charge factor = 0.175 (DOE/NETL)
- Annual Operating Time is 7888 hr/yr (90% capacity factor)

Storage and Transportation with cost estimation

- Geological CO_2 Sequestration Opportunities in the MRCSP
- Carbon Storage Site Selection---Rose Run
- Transportation---Pipeline
- Models of CO2 Transportation and Storage Cost
- Future Work

2.Carbon Storage Site Selection ---Rose Run

➢Hydraulic Parameters

- ➢The Rose Run Sandstone has a low seismic hazard risk rating, and injection is unlikely to cause seismic activity unless injection occurs in a faulted interval. No extensive faulting or fracturing **i**s present in the study area.
- ➢The containment unit of the Rose Run is approximately 1,200 ft thick and primarily shale with very low permeability and porosity. Also, containment layers are diverse and extensive. This suggests an excellent setting for long-term storage of CO2.

	Depth [a](ft)	Thickness[a]	Permeability(mD)		Porosity(%)		Pressure Gradient (psia/ft)	Formation Fluid Temperature (1°F/100ft)
			Regional [b]	Site [c]	Regional[b]	Site [c]		
Rose Run Sandstone	2,500-11,000	50-200	0.01-198	N/A	2-25	N/A	0.41-0.46	1-1.2
Underlying Shawville,Clearfield,PA	7,550	75-150	N/A	13-86	N/A	8-14	0.43-0.46	1

(a)---Approximation values based on nearby deep well.
(b)---Approximation values based on regional summary data
(c)---Approximation values based on nearby deep wells or gas fields

Source: Ohio River Valley CO2 Storage Project Preliminary Geologic Assessment Report

2.Carbon Storage Site Selection---Rose Run

Rose Run Formation

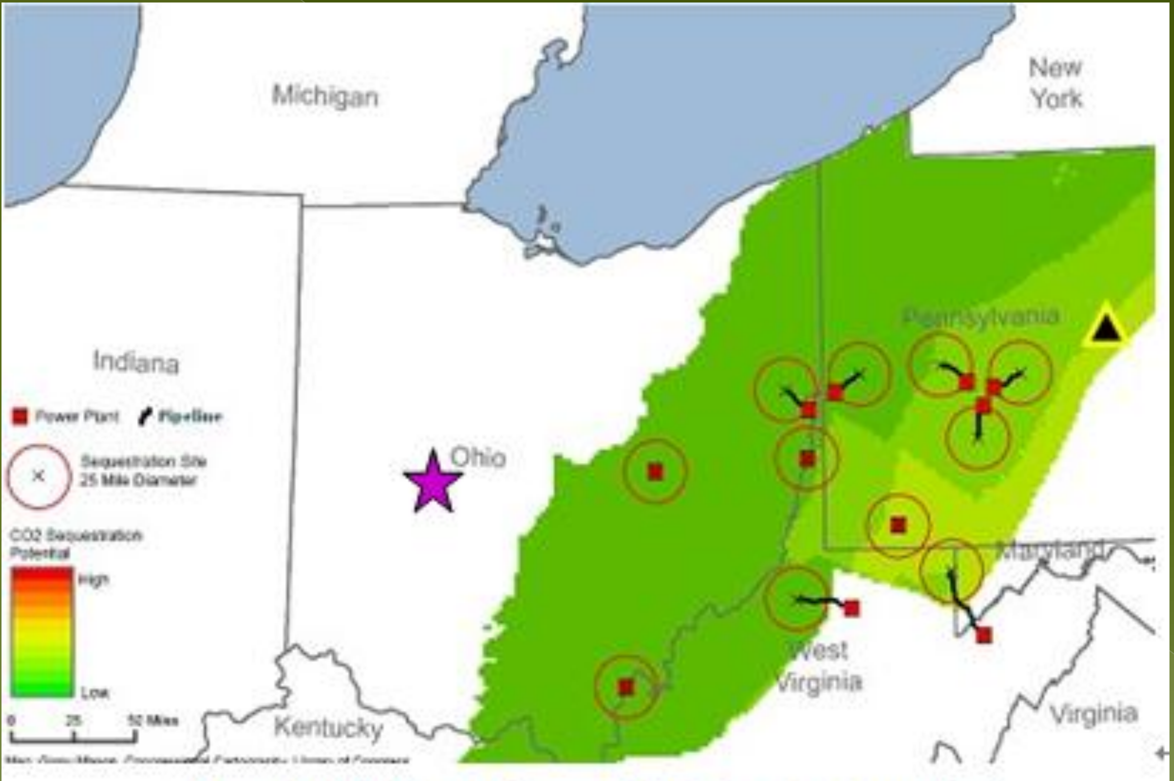


Figure 4: Major Power Plant and the Rose Run Formation

Shawville, PA

2.Carbon Storage Site Selection---Rose Run

- Estimates on reservoir capacity were calculated to provide some guidance on the amount of fluid that may be injected in the target formations. These capacities are approximate involving many assumptions, and more detailed modeling is required to assess injection capacities. However, the methods are suitable for initial investigations.

  - $$Q = V_p \, h_{st} \, \rho_{CO2}$$

- $V_p = V_b(\text{Net:Gross})\varphi$,
- V_b = bulk aquifer volume (km3),
- Net:Gross = percentage of porous, permeable rock,
- φ = formation porosity (%),
- h_{st} = storage efficiency (i.e., fraction of pore volume that can be filled with CO2 [%]),
- ρ_{CO2} = density of CO2 (700 kg/m3) and,
- Q = storage capacity (Mt).

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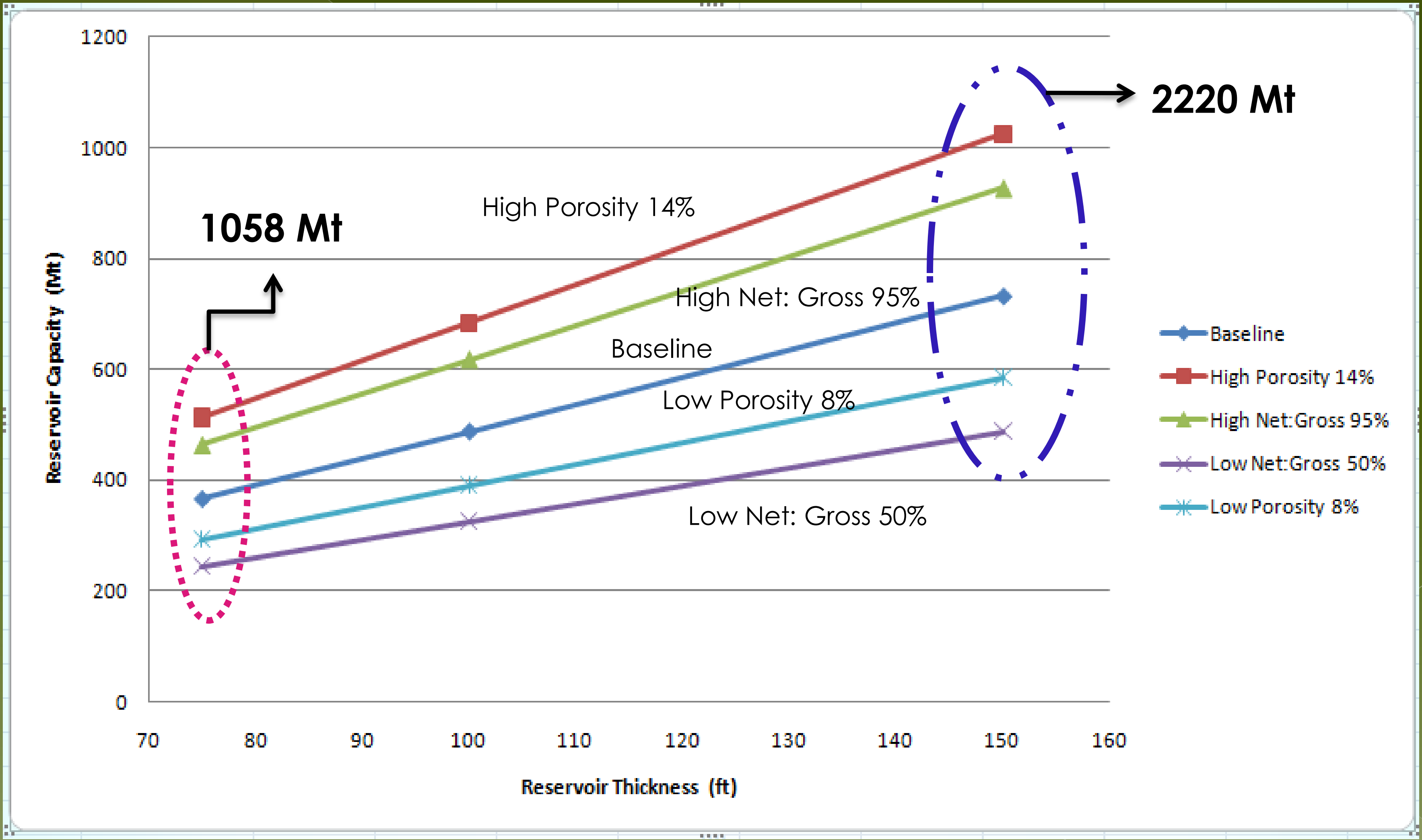

3 Transportation---Pipeline

1. Pipeline:
   1. Scenarios for CO_2 pipeline
   2. Special design consideration for CO_2 transmission system
   3. Pipeline Transmission Cost Factors
   4. Operating Experience with CO_2 Pipelines
   5. Pipeline Rights of Way Considerations

2. Basic Assumption

At this stage, we consider one-to-one source-sink matching only, that is , we look at transportation CO_2 from one emission source or node to exactly one injection site.

4 Models of CO2 Transportation and Storage Cost

Calculation of Compressor &Pump Power requirements

Pinitial	Pcut-off	Pfinal
3MPa (After Capture)	7.38MPa (After Compressor)	15.2MPa

CR

- Compression ratio(CR)
- CR=(Pcut-off/Pinitial)^(1/Nstage)

Kinder Morgan

$$W_{s,i} = \left(\frac{1000}{24*3600}\right)\left(\frac{m Z_s R T_{in}}{M \eta_{is}}\right)\left(\frac{k_s}{k_s - 1}\right)\left[(CR)^{\frac{k_s - 1}{k_s}} - 1\right]$$

Ws-total

- Total combined compression power requirement for all stages(kW)

Ntrain=ROUND_UP(Ws-total/40000)

Ws-total=3.24E+03

Source: Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage &Correlations for Estimating Carbon Dioxide Density and Viscosity

Calculation of Compressor &Pump Power requirements

To calculate the pumping power requirement for boosting the CO_2 pressure from $P_{cut\text{-}off}$ (7.38 MPa) to P_{final} (15 MPa), the following equation has been adapted from [1]:

$$W_p = \left(\frac{1000 * 10}{24 * 36}\right)\left[\frac{m\left(P_{final} - P_{cut-off}\right)}{\rho \eta_p}\right]$$

Wp=1.63E+03 (KW)

Source: Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage &Correlations for Estimating Carbon Dioxide Density and Viscosity

Capital,O&M,Levelized---Compression & Pump

- **Scenario One-40km**
  - Ccomp=$**8.39E+06** /comp
  - Cpump =$1.88E+06
  - Cannual=(Ccomp+Cpump) *0.15=1.54E+06 --- CRF=0.15/year
  - Clev=**0.5034**
- **Scenario Two-400km**
  - Ccomp=$**2.52E+07**
  - Cpump =$1.88E+06
  - Cannual=(Ccomp+Cpump) *0.15=1.54E+06 --- CRF=0.15/year
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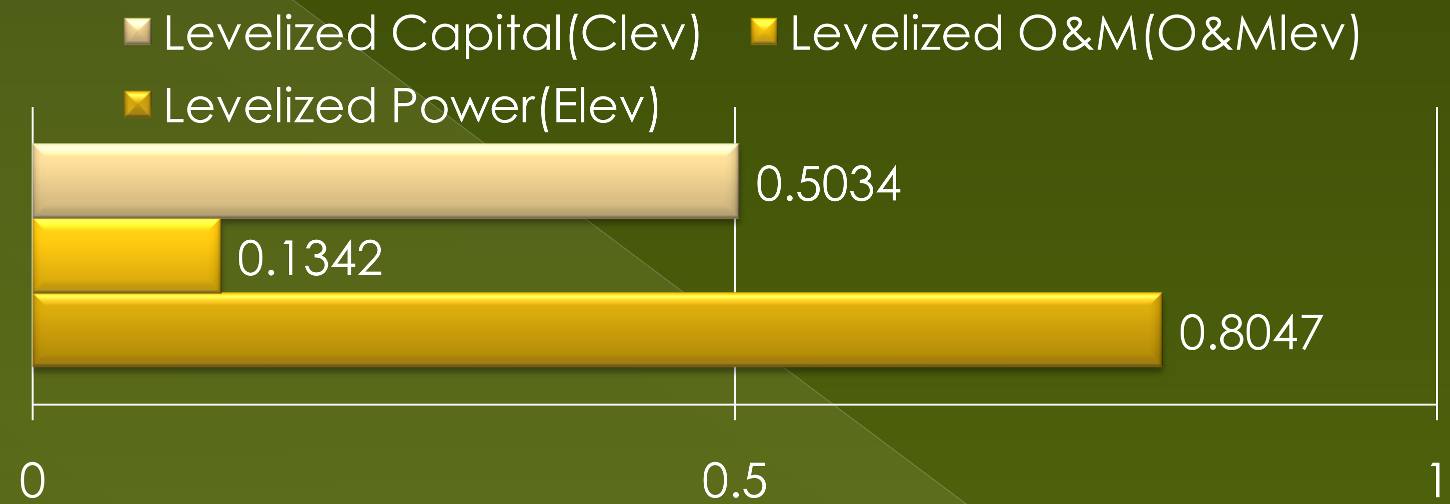
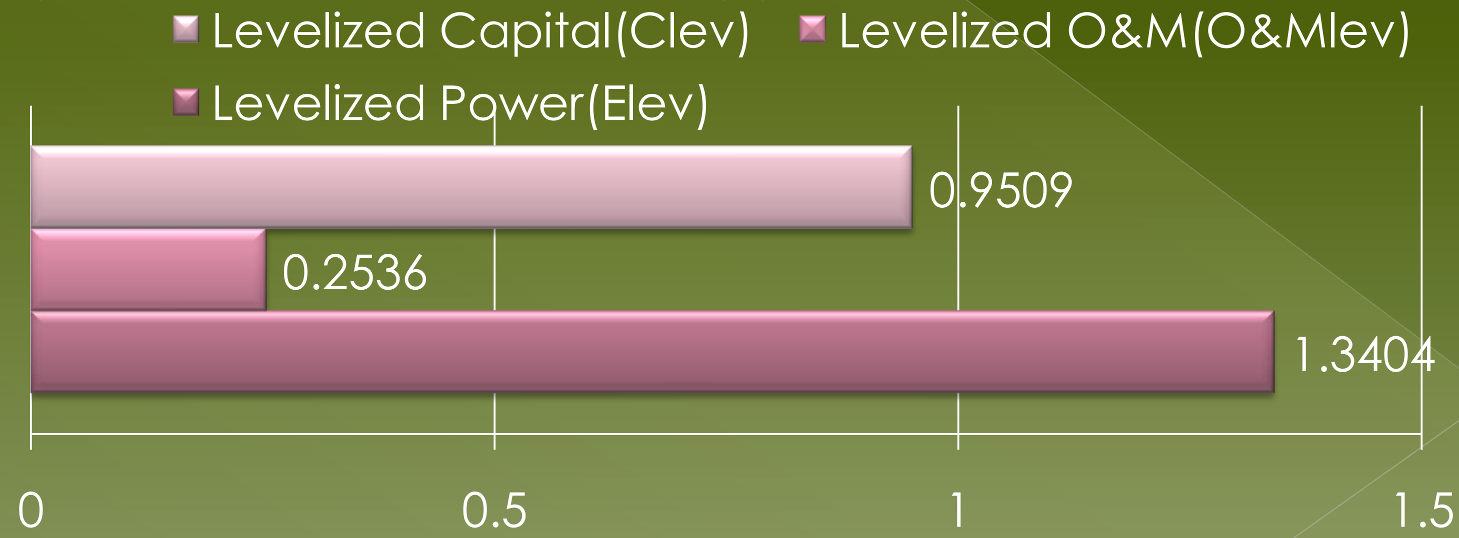
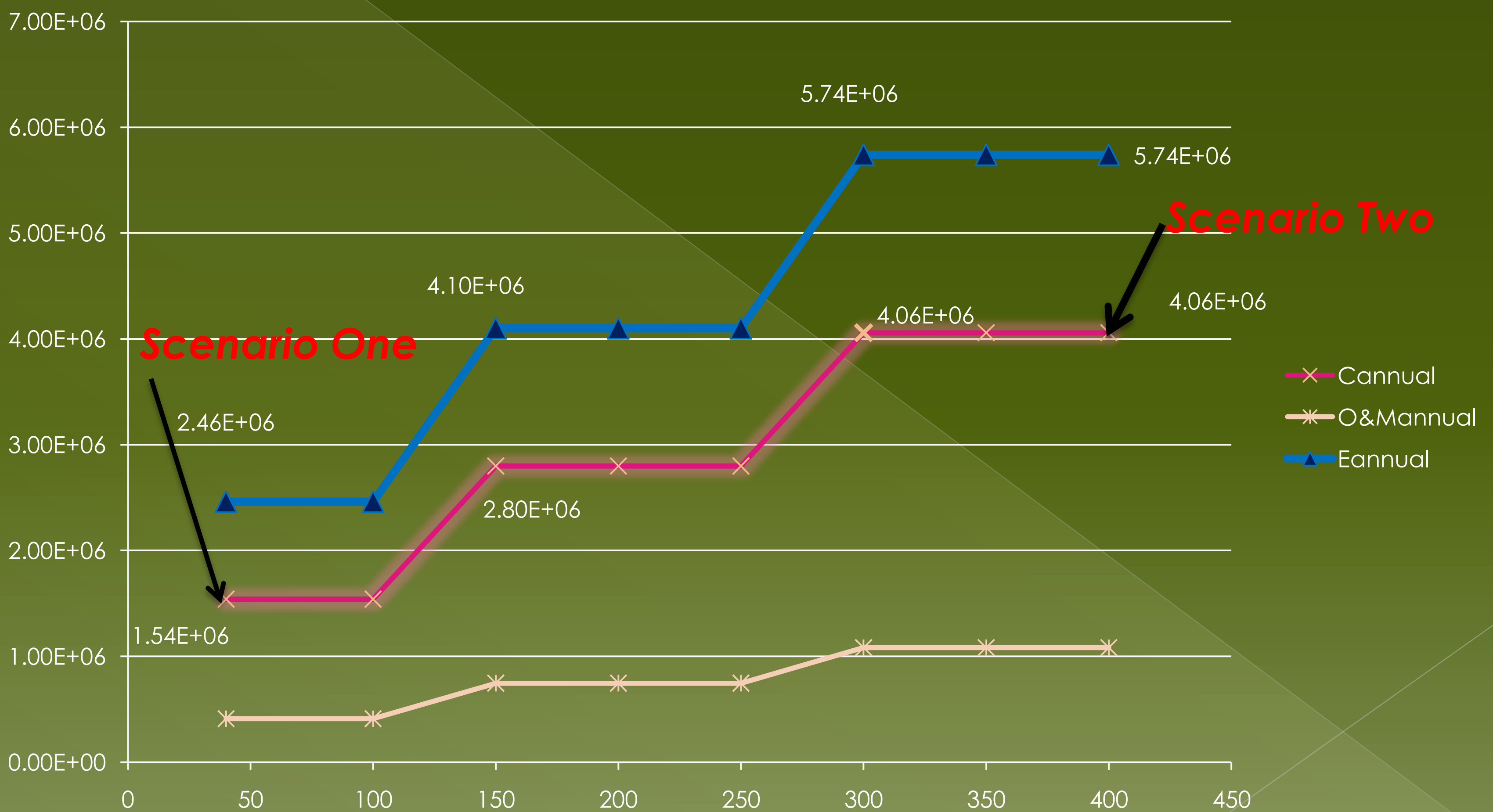




Recompression is often needed for pipelines over 150 km (90 miles) in length.

O&M Factor=0.04

Same trend for E_lev,O&M_lev and C_lev



Calculation for Pipeline Cost --- Diameter for Transportation

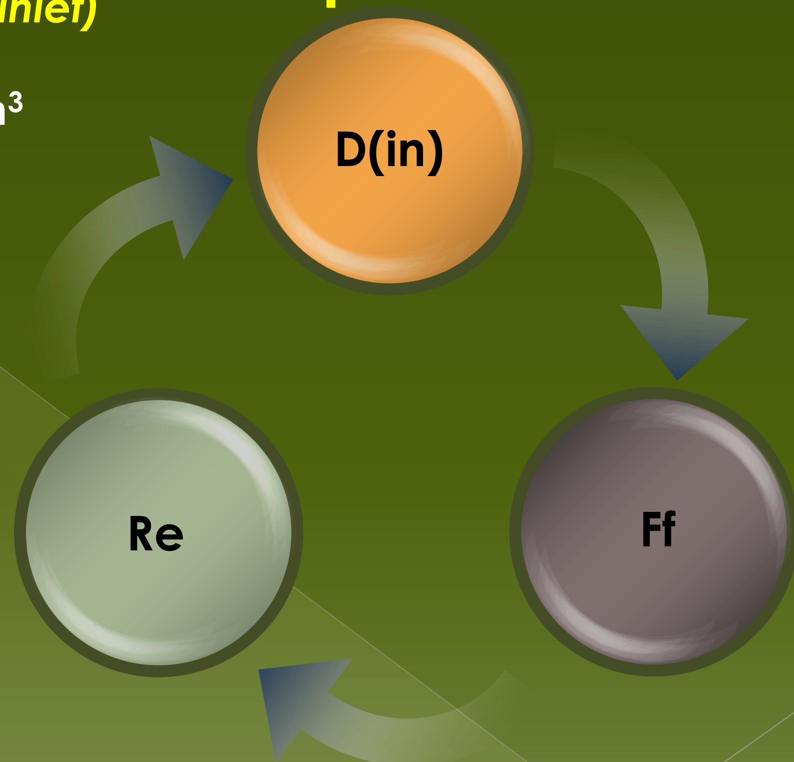
T=12 °C; Pinlet=10.3MPa; Poutlet=15.2MPa

*Pave=2/3(Poutlet+Pinlet-Poutlet*Pinlet/(Poutlet+Pinlet)*

Viscosity=1.06E-4=0.106cp; Density=930.56 km/m^3

"Using actual values form Kinder Morgan"

Find Pipeline Diameter



Diameter	D=10 Initial guess of pipeline diameter
Reynold's Number	Re=(4*1000/24/3600/0.0254)*m/(pi*v*D)
Fanning Friction factor	$F_f = \dfrac{1}{4\left[-1.8\log_{10}\left\{\dfrac{6.91}{\mathrm{Re}} + \left(\dfrac{12(\varepsilon/D)}{3.7}\right)^{1.11}\right\}\right]^2}$

Diameter for 40km is 10in.

Diameter for 400km is 16in.

Source: Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage &Correlations for Estimating Carbon Dioxide Density and Viscosity

Capital,O&M,Levelized Costs for CO2 Transportation ------CMU Correlation

- LCC and O&M
  - $LCC = \beta * D^{1.035} * L^{0.853} * z$
  - B=$42404
  - D=Diameter in inch
  - L=Length in miles
  - z=regional weights (Midwest=1.516)
  - O&M =5000/miles
  - CRF=0.15/year
  - Annualized=LCC*CRF+O&Mcost;
  - Levelized=Annualized/myear;

Source: 1.McCoy,Sean.2006. Pipeline Transportation of CO2 –Model Documentation and Illustrative Results, Carnegie Mellon University Manuscript . 2. Heddle, Gemma,Howard Herzog & Michael Kleet.2003. The Economics of CO2 Storage

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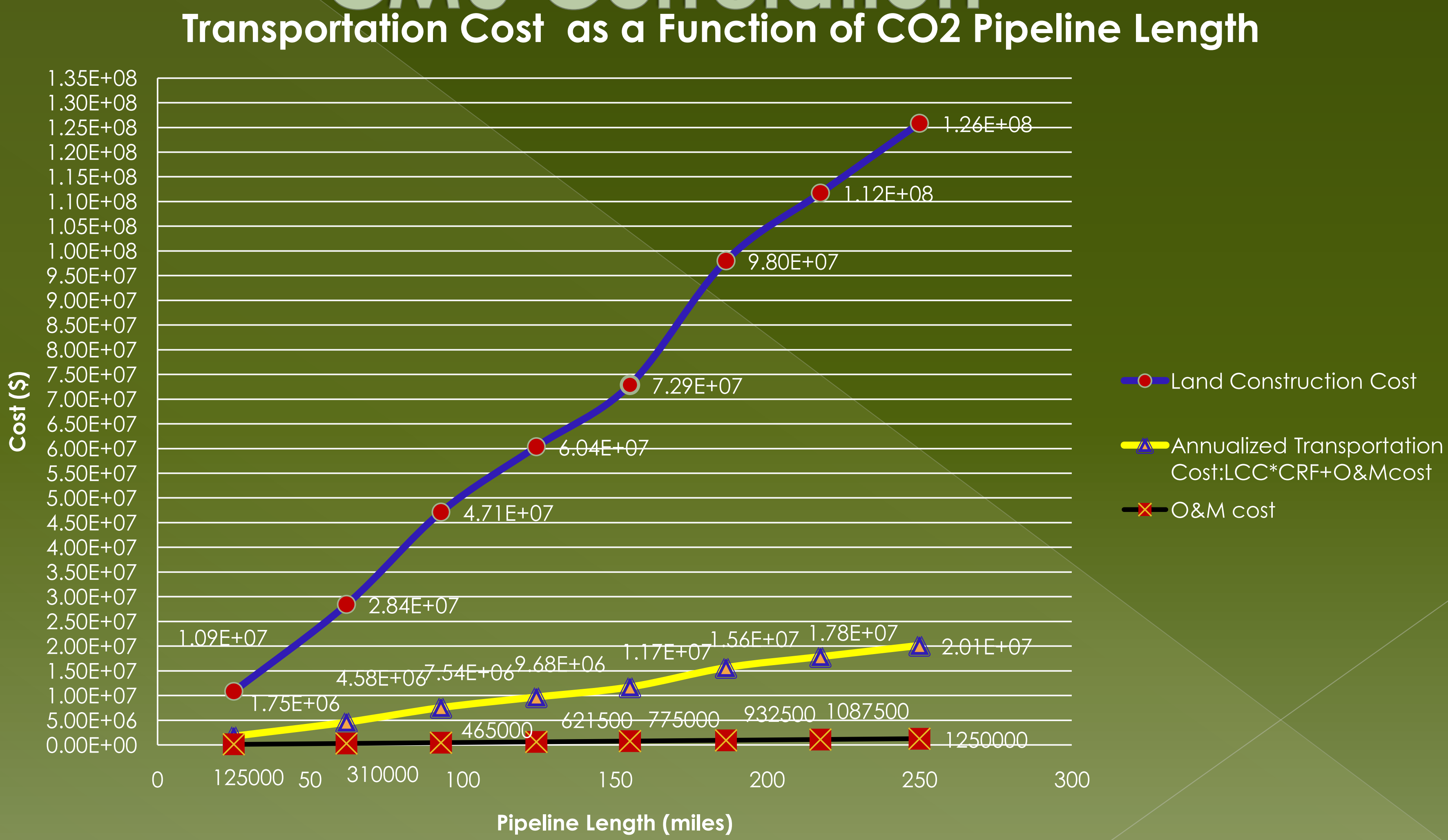

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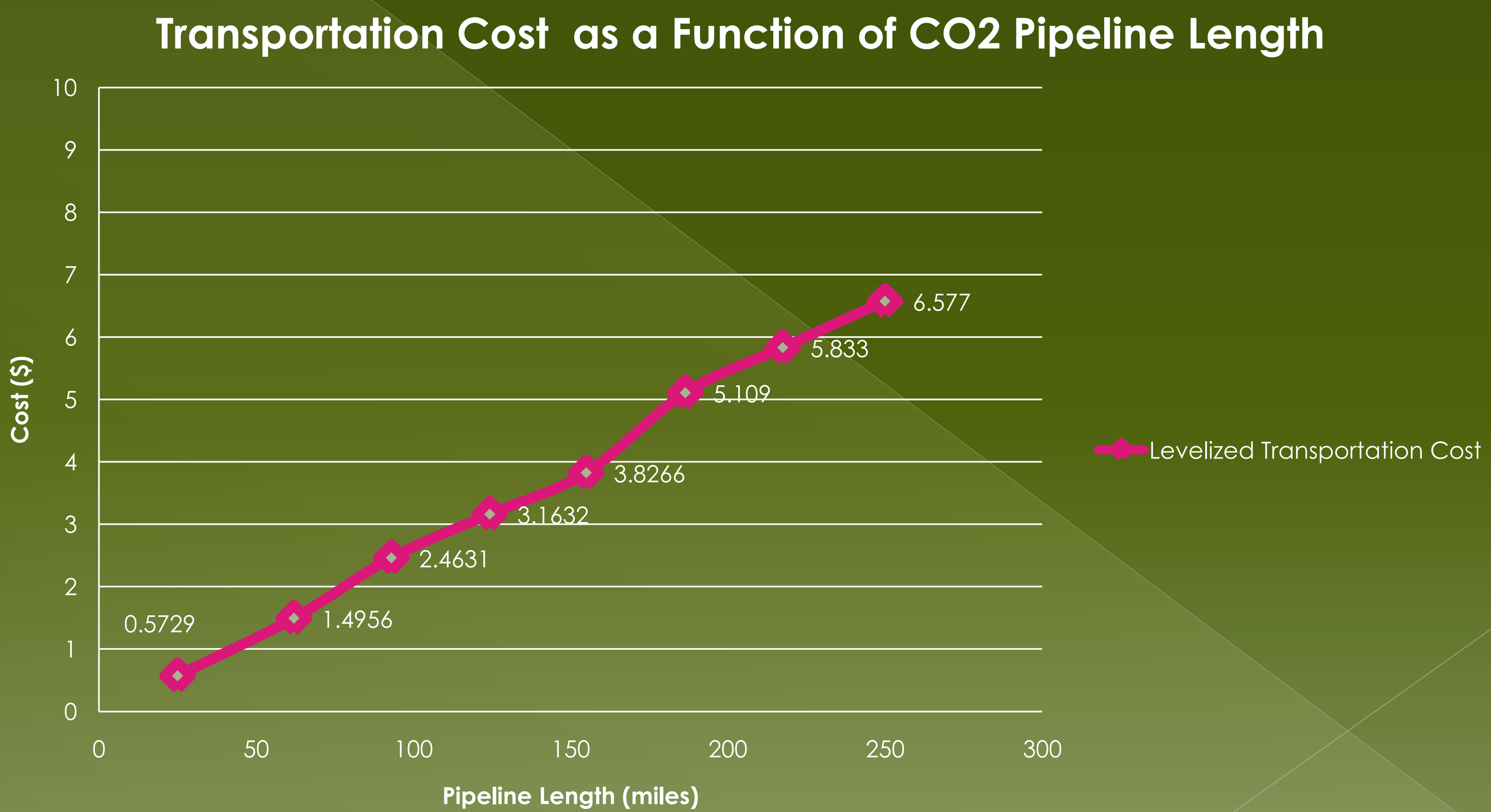
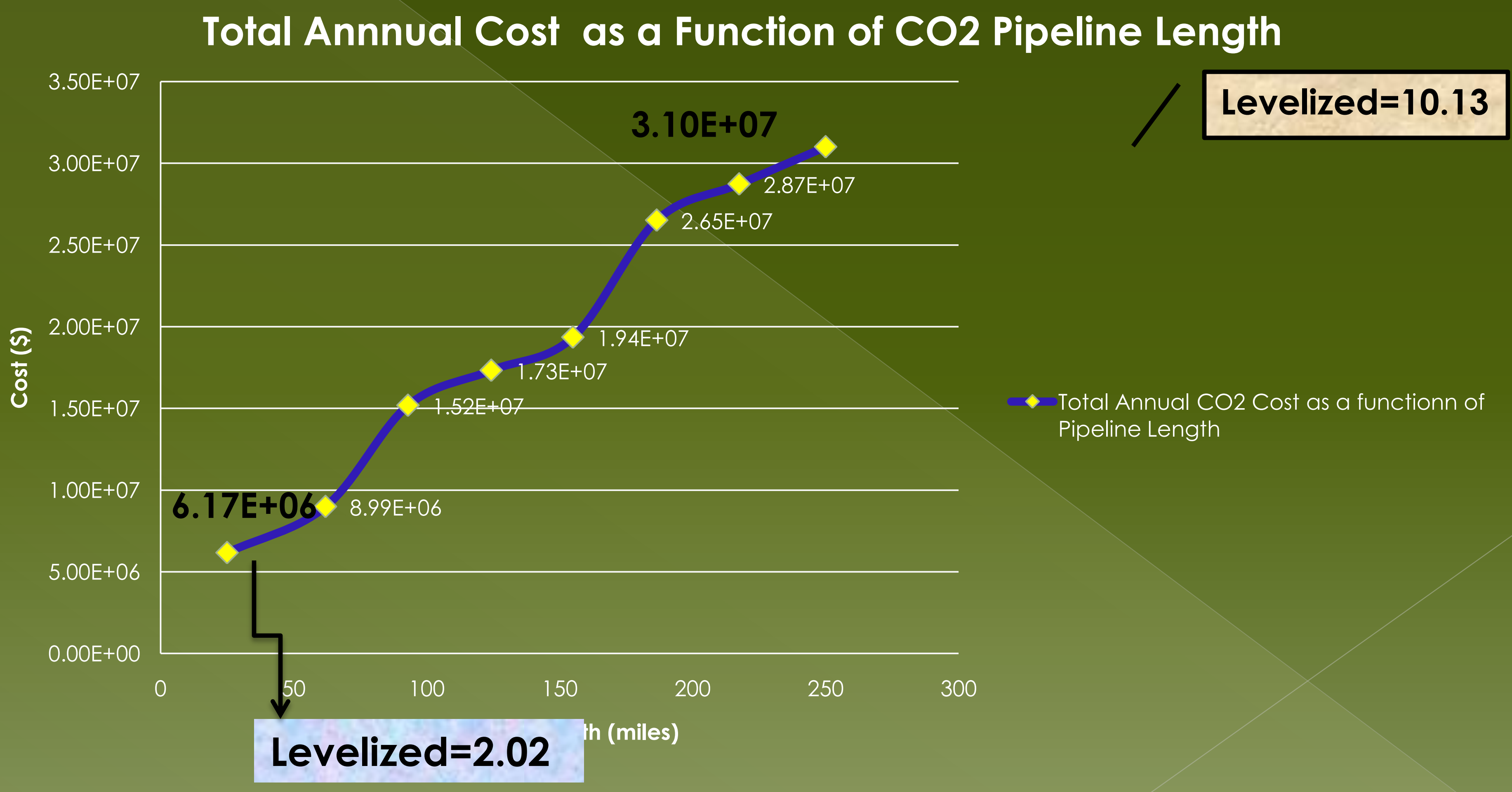


Total Annual CO2 Cost---Power Consumption+Transporatation



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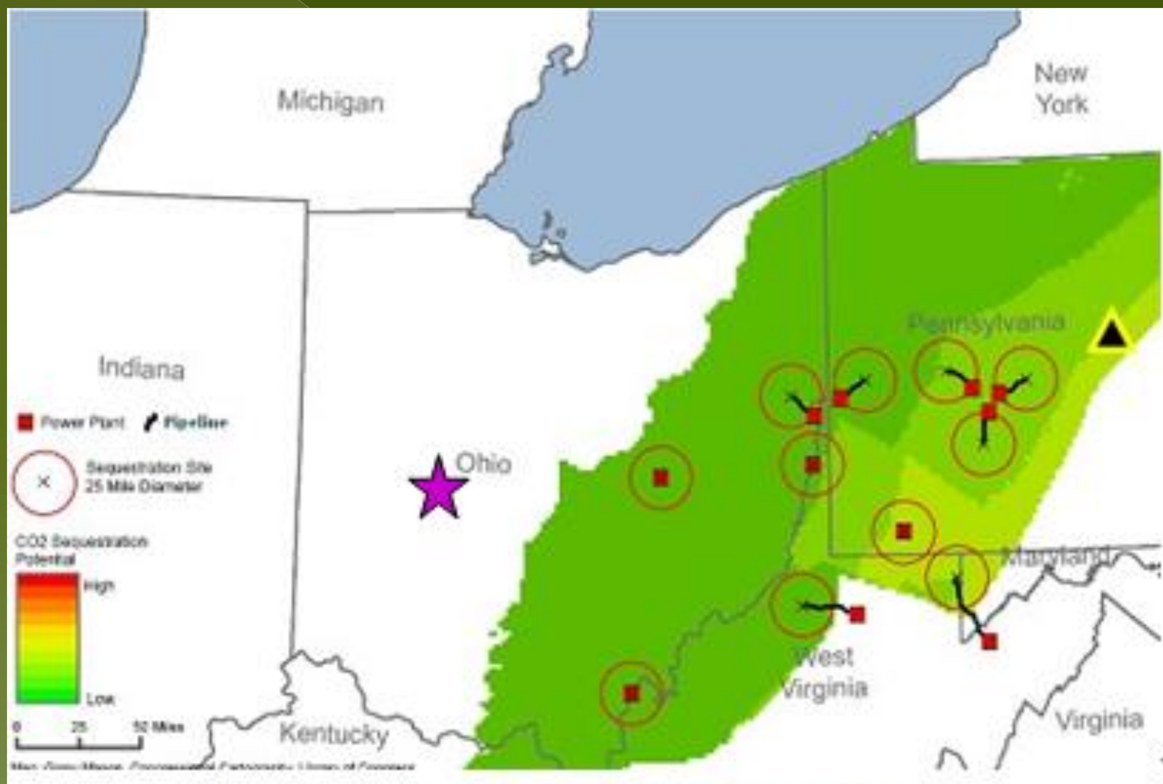

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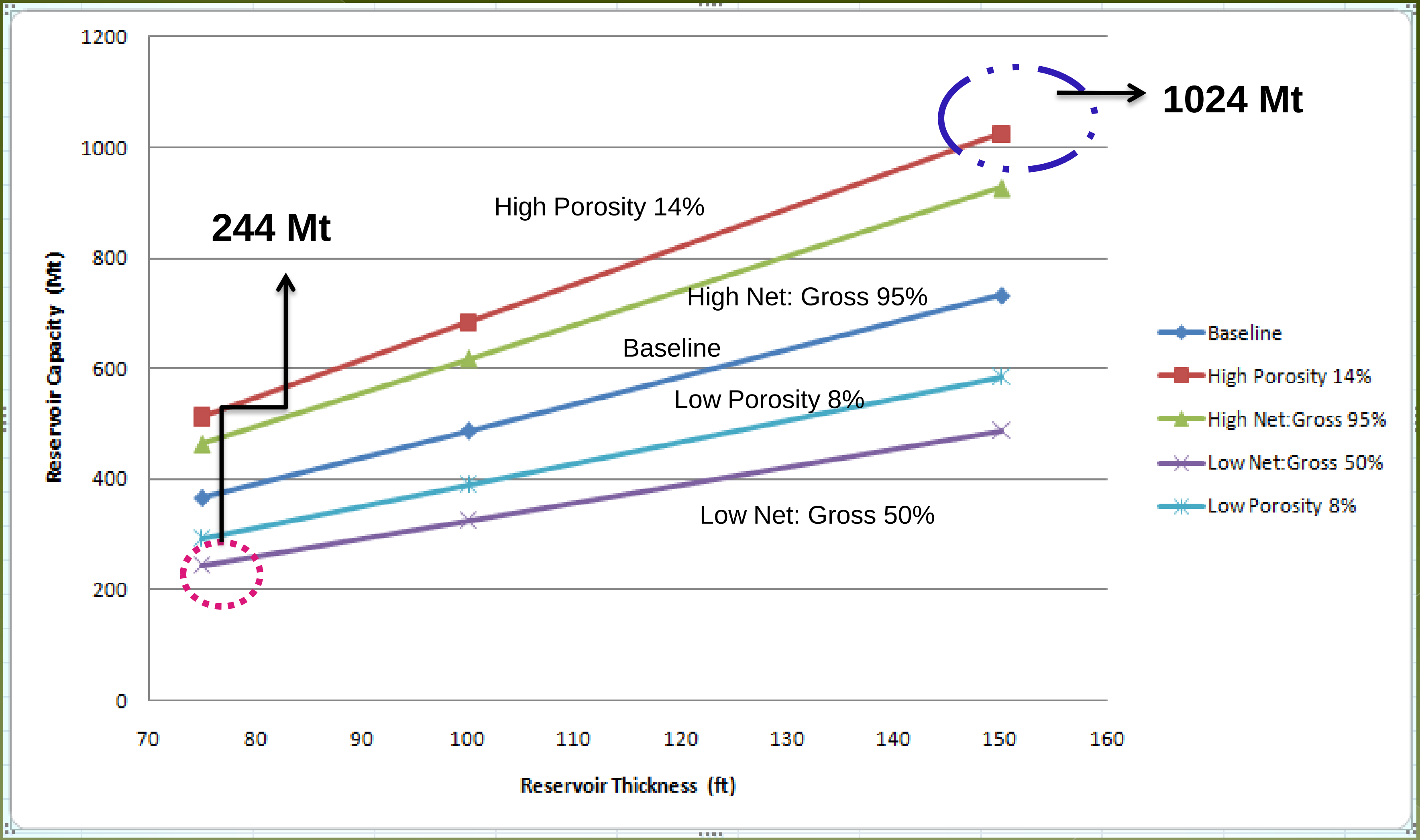

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435 psi (After Capture)	1070 psi (After Compressor)	2200 psi

CR

- Compression ratio(CR)
- CR=(Pcut-off/Pinitial)^(1/Nstage)

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Ws-total

- Total combined compression power requirement for all stages(kW)

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- **Scenario Two-1320000ft**
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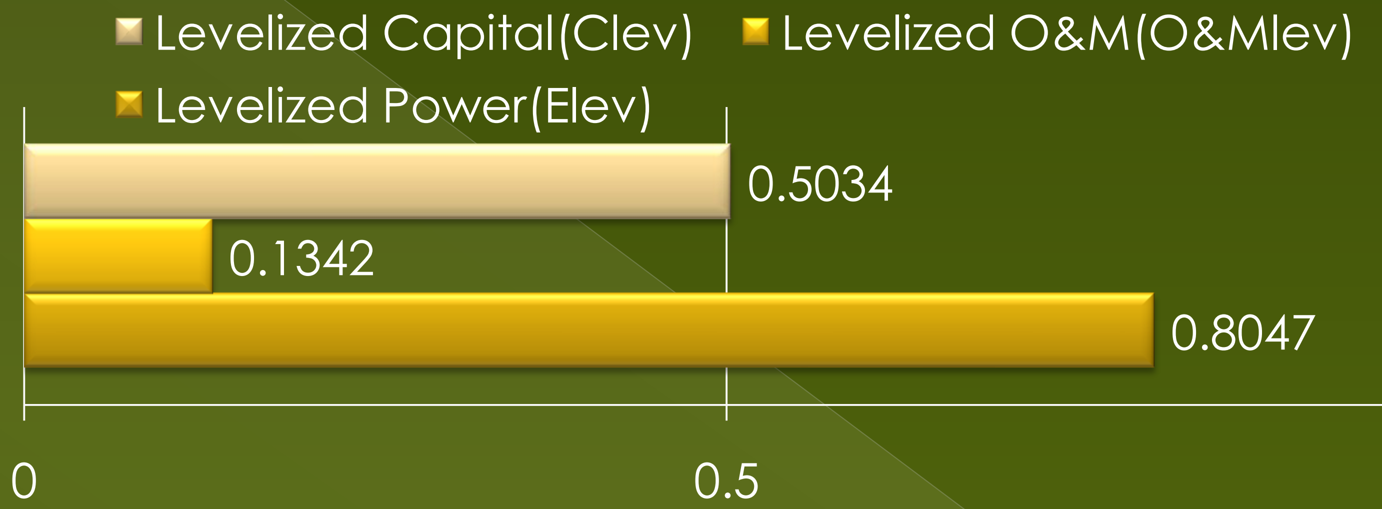

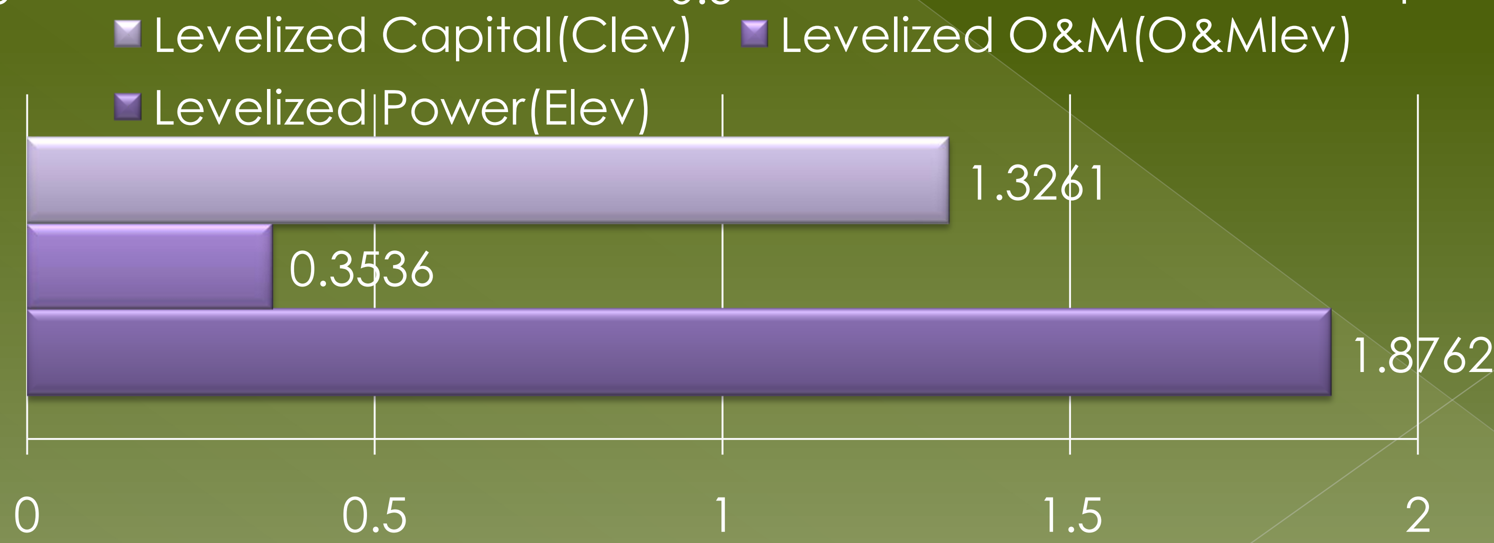

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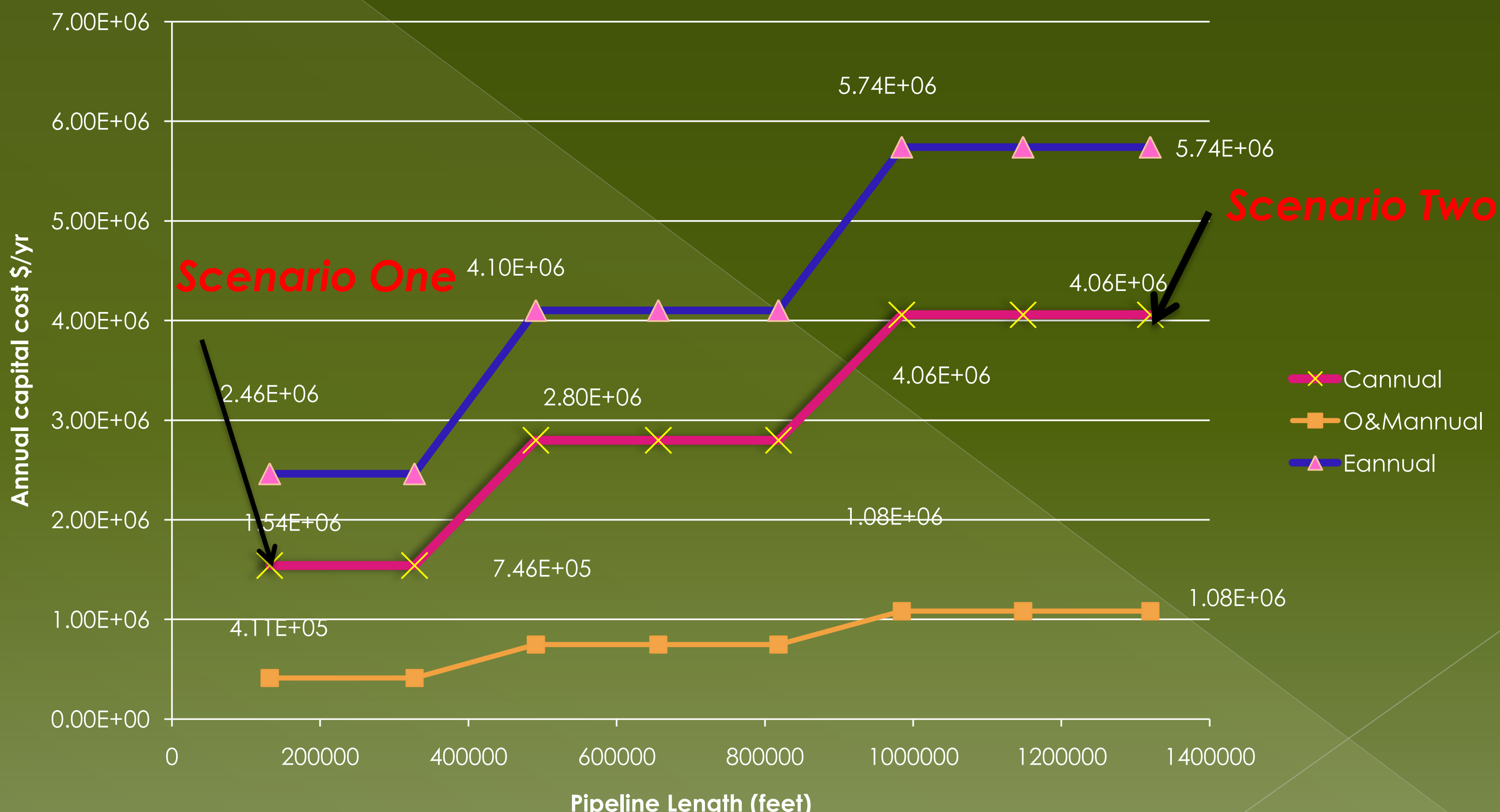

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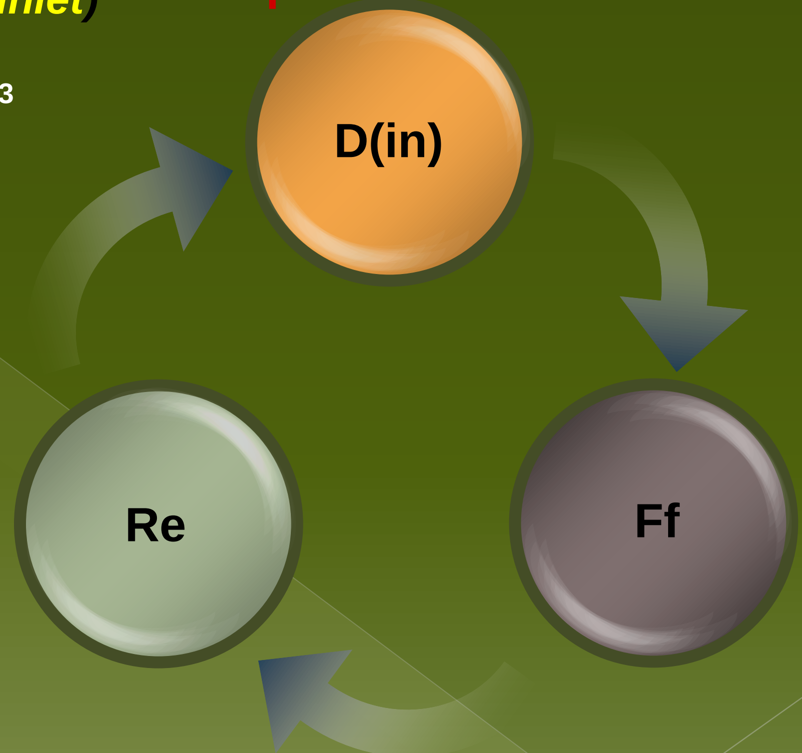
"Using actual values form Kinder Morgan"

Find Pipeline Diameter



Diameter	D=10 Initial guess of pipeline diameter
Reynold's Number	Re=(4*1000/24/3600/0.0254)*m/(pi*v*D)
Fanning Friction factor	$F_f = \frac{1}{4\left[-1.8\log_{10}\left\{\frac{6.91}{Re}+\left(\frac{12(\varepsilon/D)}{3.7}\right)^{1.11}\right\}\right]^2}$

Diameter for 132000 ft is 10in.

Diameter for 1320000 is 16in.

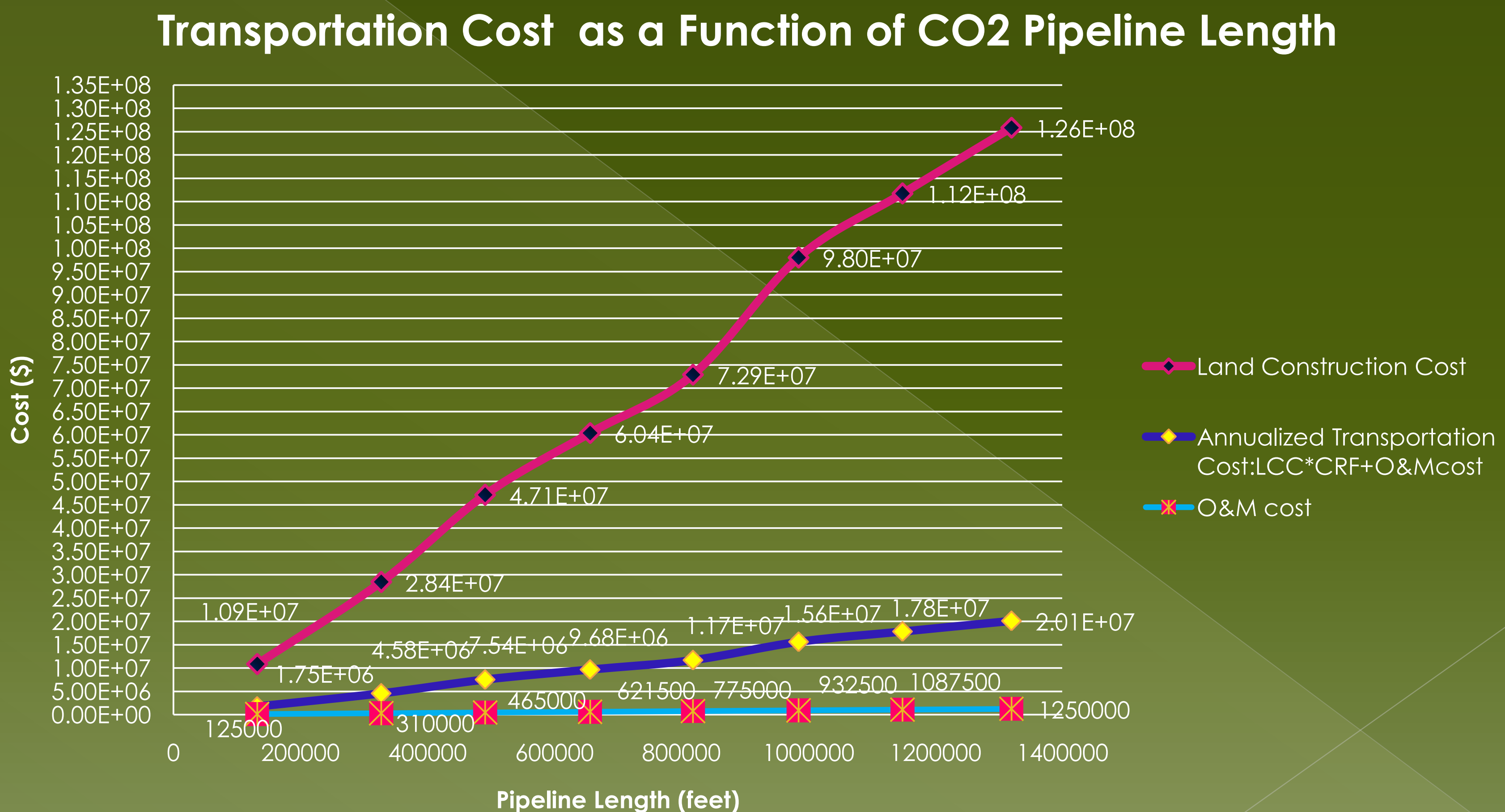
Source: Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage &Correlations for Estimating Carbon Dioxide Density and Viscosity

Capital, O&M, Levelized Costs for CO2 Transportation ------CMU Correlation

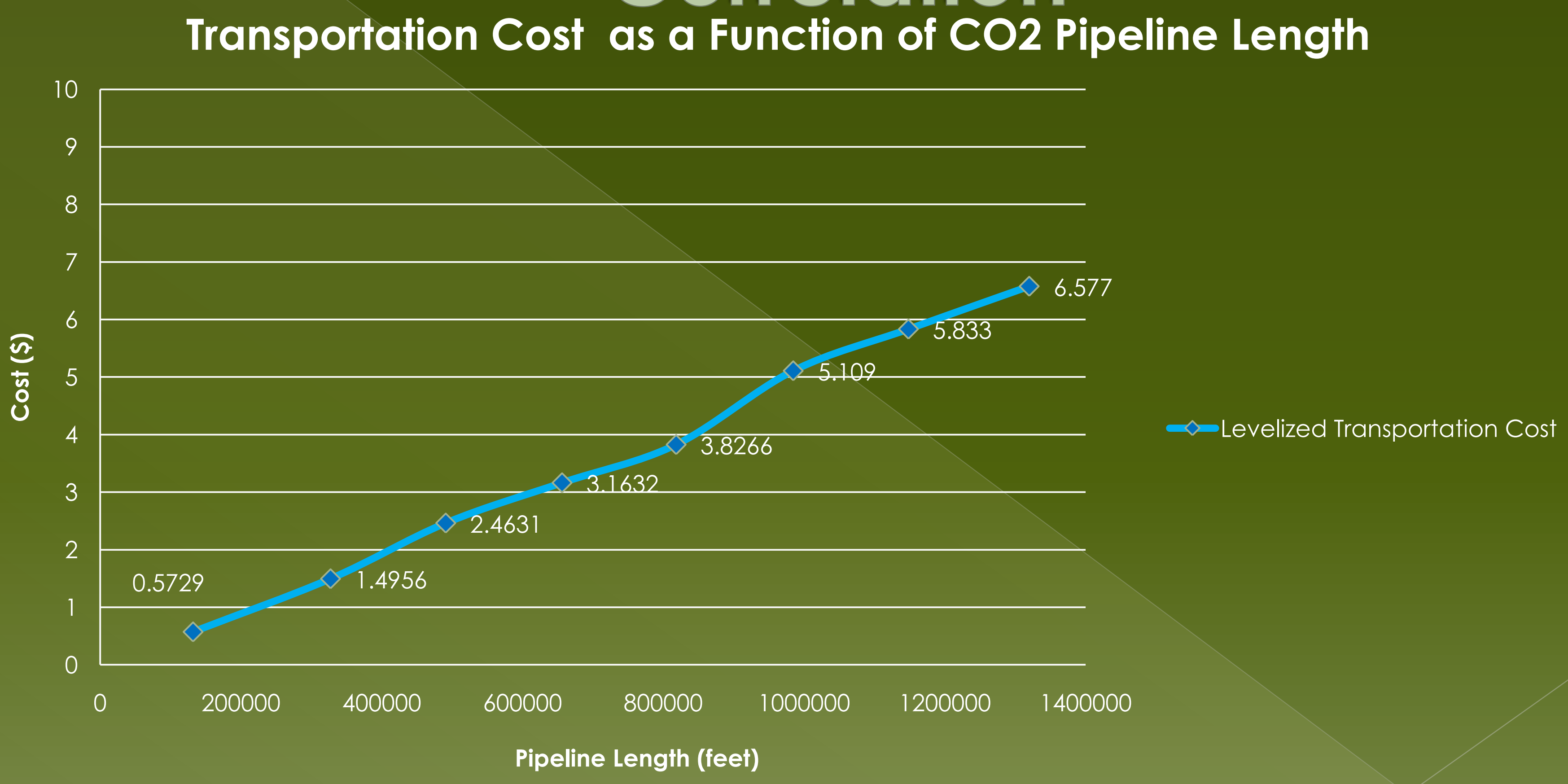
- LCC and O&M
  - $LCC=\beta * D^{1.035} * L^{0.853} * z$
  - B=$42404
  - D=Diameter in inch
  - L=Length in miles
  - z=regional weights (Midwest=1.516)
  - O&M =5000/miles
  - CRF=0.15/year
  - Annualized=LCC*CRF+O&Mcost;
  - Levelized=Annualized/myear;

Source: 1.McCoy,Sean.2006. Pipeline Transportation of CO2 –Model Documentation and Illustrative Results, Carnegie Mellon University Manuscript . 2. Heddle, Gemma,Howard Herzog & Michael Kleet.2003. The Economics of CO2 Storage

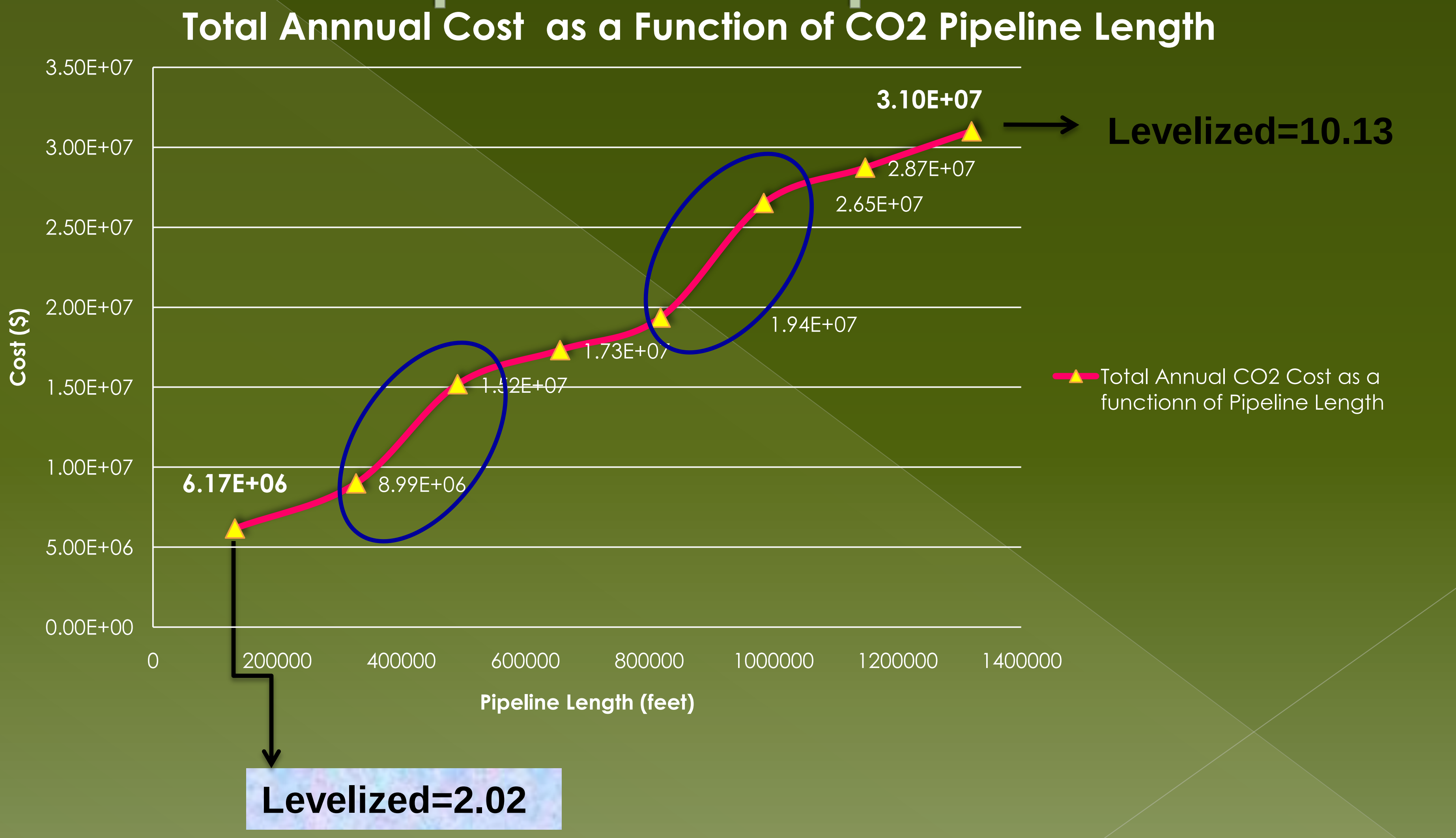
Capital,O&M,Levelized Costs for CO2 Transportation ------CMU Correlation



Capital,O&M,Levelized Costs for CO2 Transportation---CMU Correlation



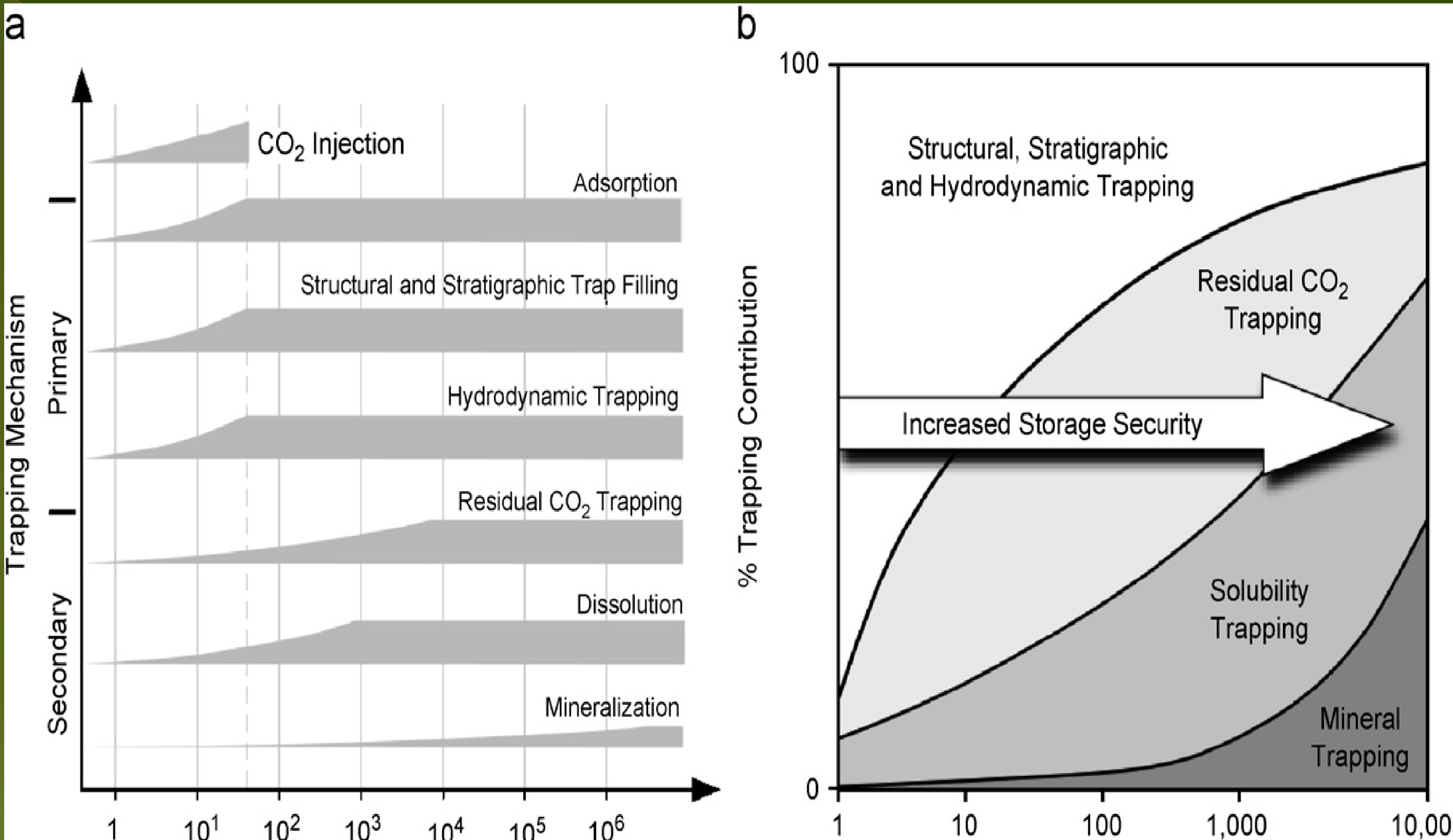
Total Annual CO2 Cost---Power Consumption+Transporatation



CCS IN ROSE RUN(with EOR IN COALFEX FIELD)

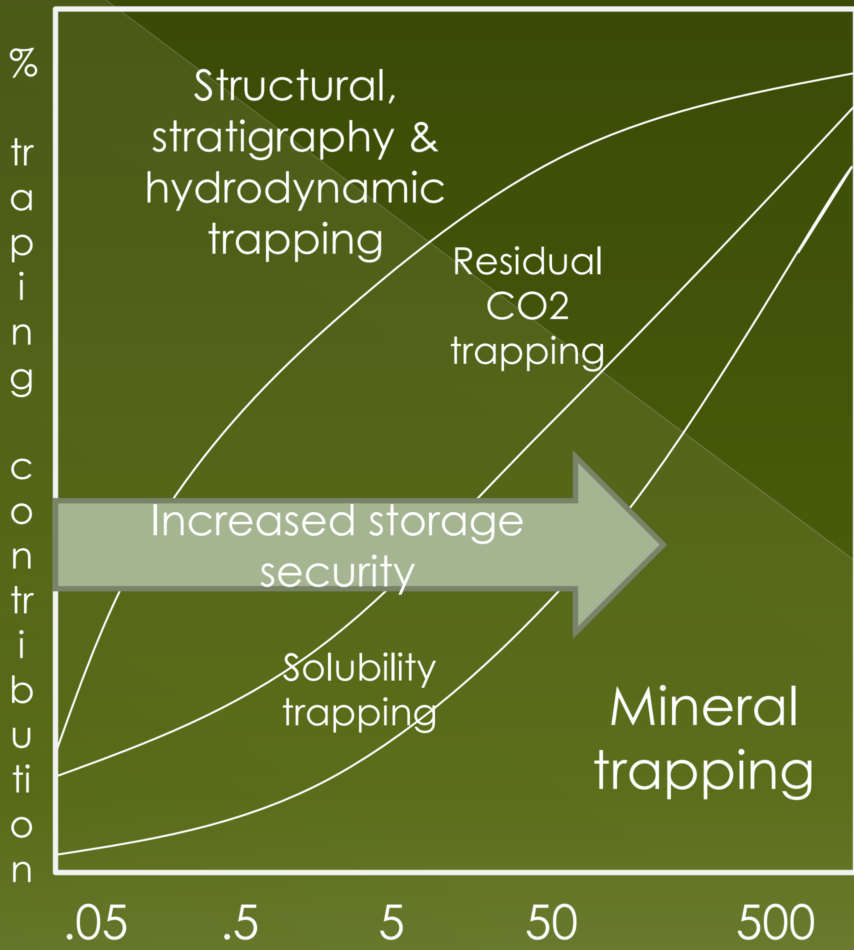
- TRAPPING MECHANISM
  - Hydrodynamic Trappling
  - Residual CO2 Trapping
  - Solubility Trapping
  - Mineral Trapping

- REACTIONS INVOLVED IN MINERAL TRAPPING:
  - CO_2(gaseous) $\Rightarrow$ CO_2(aqueous)
  - CO_2(aqueous) + H_2O $\Rightarrow$ H_2CO_3(aqueous)
- SOLUBILITY TRAPPING
  - H_2CO_3(aqueous) + OH^- $\Rightarrow$ HCO_3^- (aqueous) + H_2O
- IONIC TRAPPING
  - HCO_3^- (aqueous) +OH^- $\Rightarrow$ $CO_3 2^-$ (aqueous) + H_2O;
  - CO_3^{2-} (aqueous) + Ca^{2+} $\Rightarrow$ $CaCO_3$(solid)
  - CO_3^{2-}(aqueous)+Mg^{2+} $\Rightarrow$ $MgCO_3$(solid)
- MINERAL TRAPPING

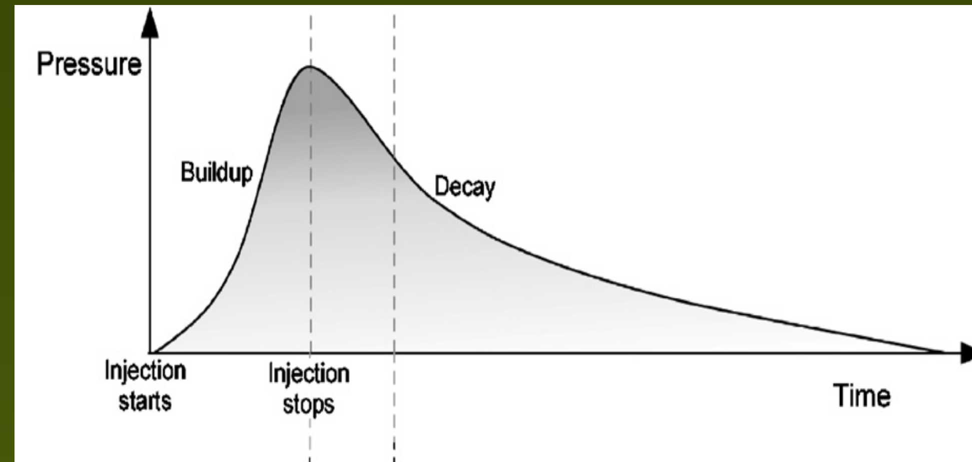


Differences between various CO2 trapping mechanisms in geological media: (a) operating timeframe, and (b) contribution to storage security

SOURCE: CO2 storage in geological media: Role, means, status and barriers to deployment, Stefan Bachu



FORCED MINERAL TRAPPING



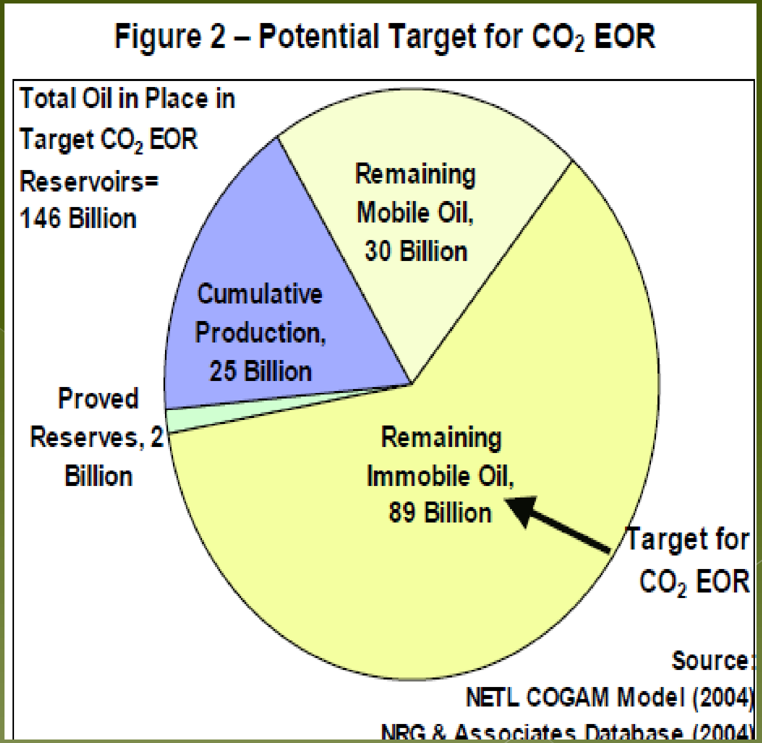
Operational Period	Active	Closure	Post-Closure
Trapping Mechanism Dominance	Primary	Increasingly Secondary	
Risk	Increasing	Decreasing	
Monitoring Frequency & Resolution	High	Targeted	Decreasing
Liability	Operator and/or Emitter		State Agency

Relation between pressure behavior and operational phases, dominance of CO2 Trapping Mechanisms, monitoring frequency and resolution, and liability at a CO2 storage site.

SOURCE: CO2 storage in geological media: Role, means, status and barriers to deployment, Stefan Bachu

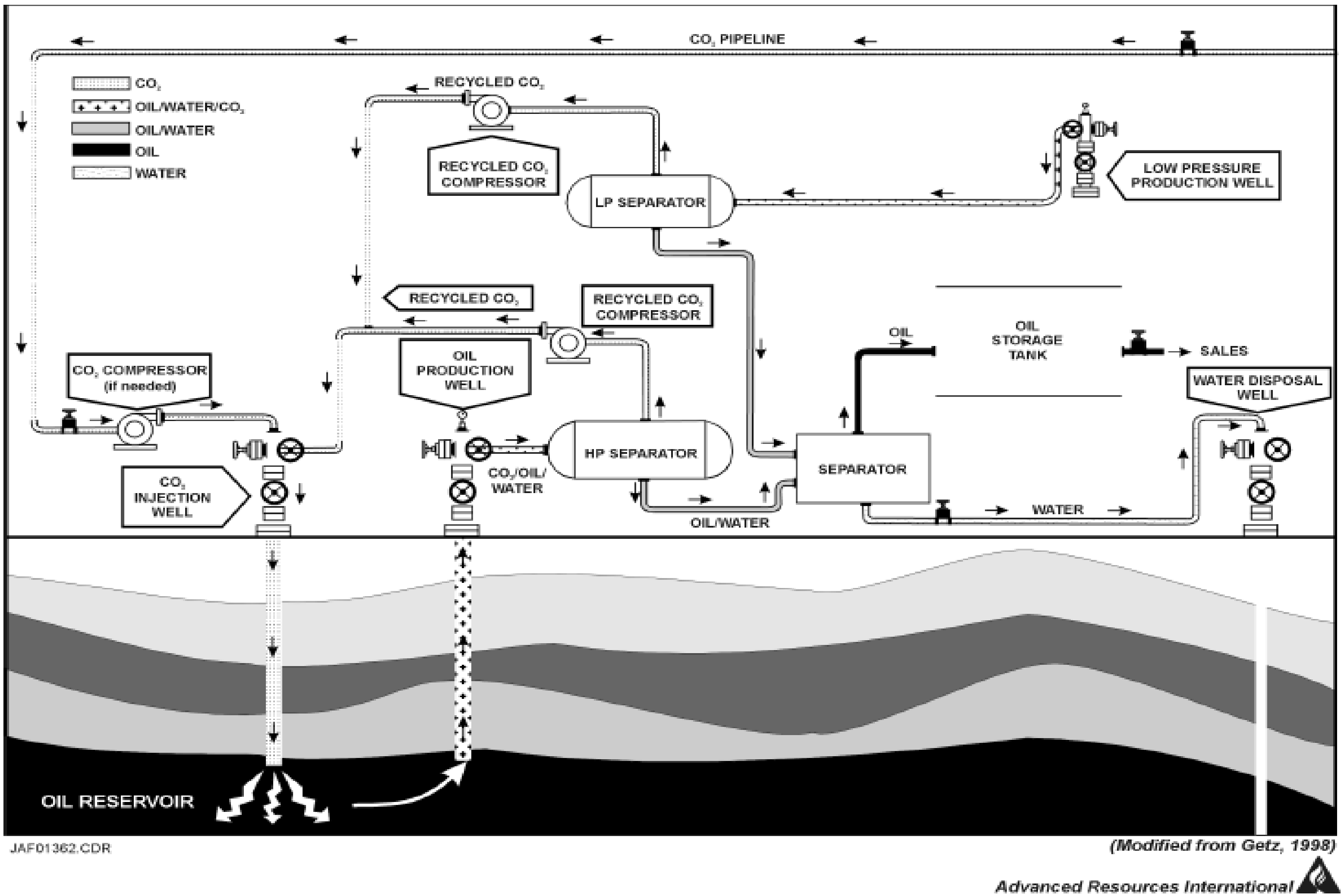
CO_2 - EOR

- Why EOR:
  - Only 30-40% recovery is done by primary recovery (recovery due to reservoir pressure), 15-25 % more oil can be recovered by EOR
- POTENTIAL OF EOR IN USA:
  - CO2-EOR projects accounted for 3.1% of total crude oil produced in USA in 1998
  - In 2005, oil production from CO2 -EOR was approximately 237,000 bbls/day.



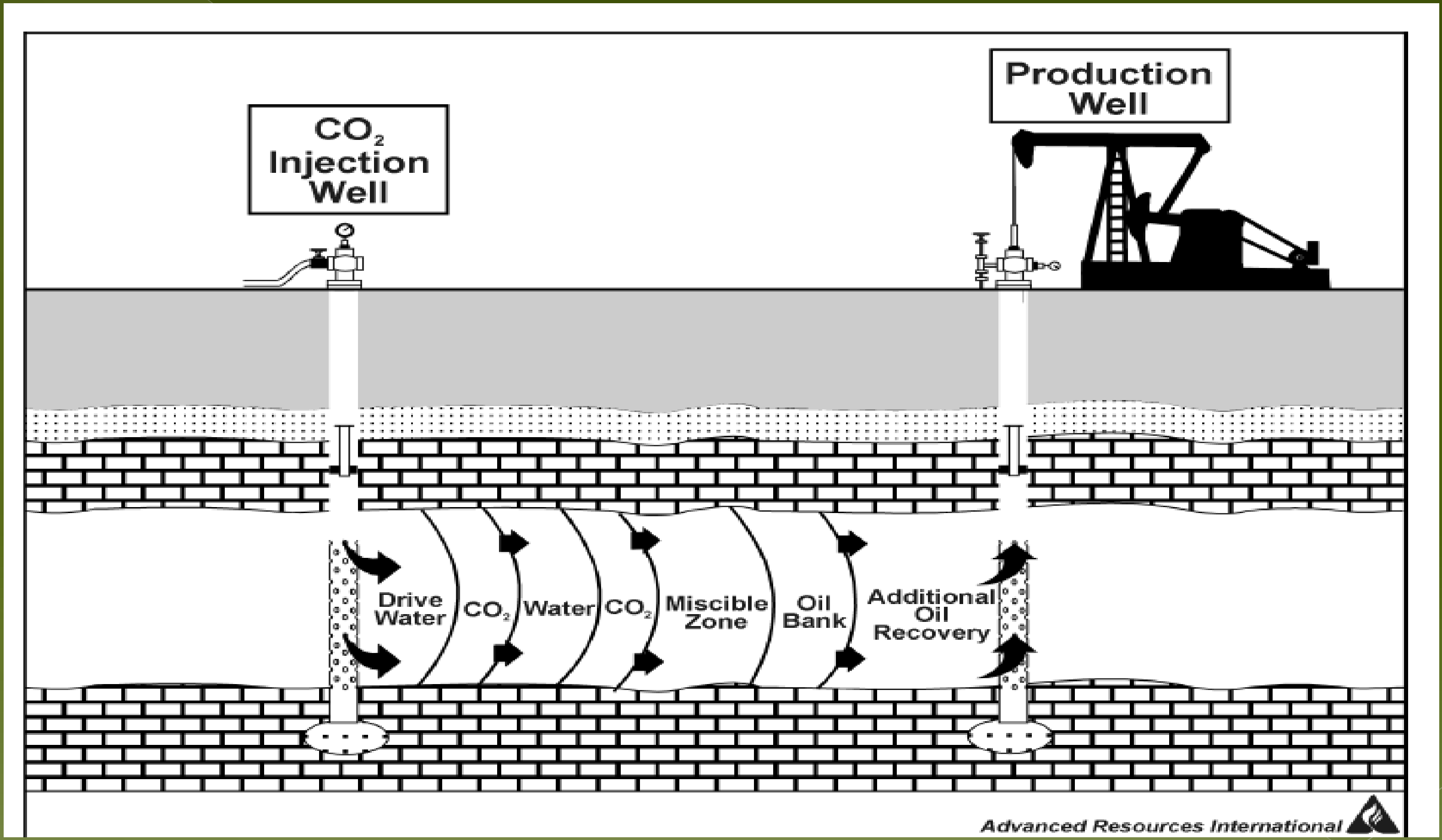
- MAKING CCS VIABLE:
  - CCS with in EOR makes Carbon sequestration economically feasible.

TYPICAL CO2 EOR FIELD OPERATION



SOURCE: ENHANCED OIL RECOVERY SCOPING STUDY, TR 113836, FINAL REPORT

Wag(water alternating gas)

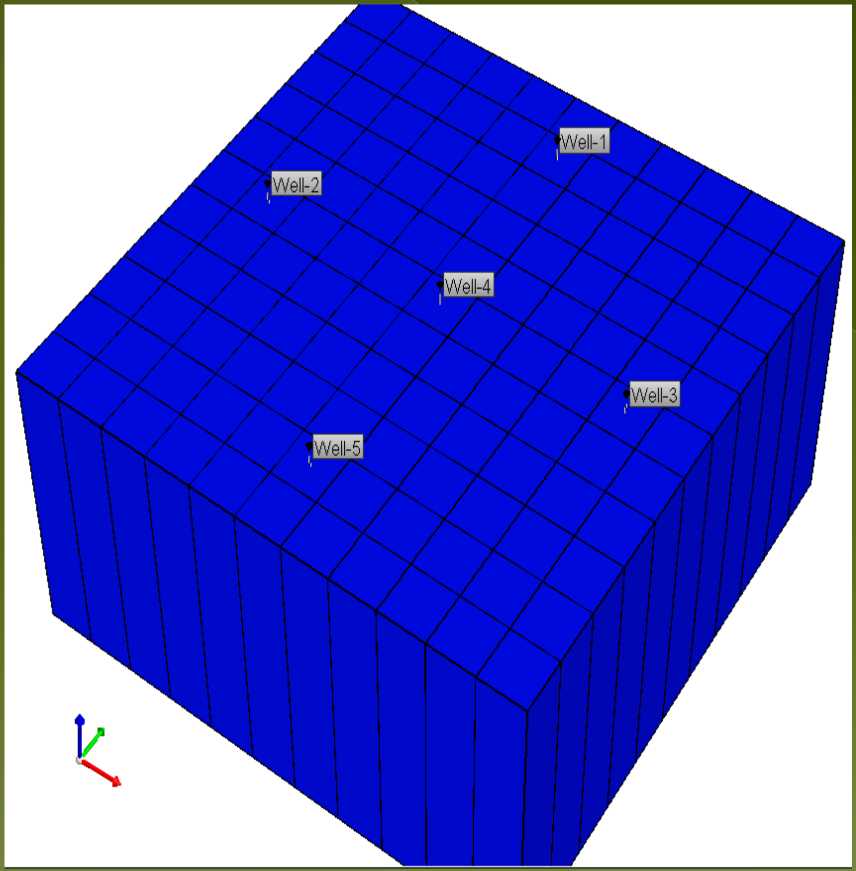


CARBON DIOXIDE FLOODING

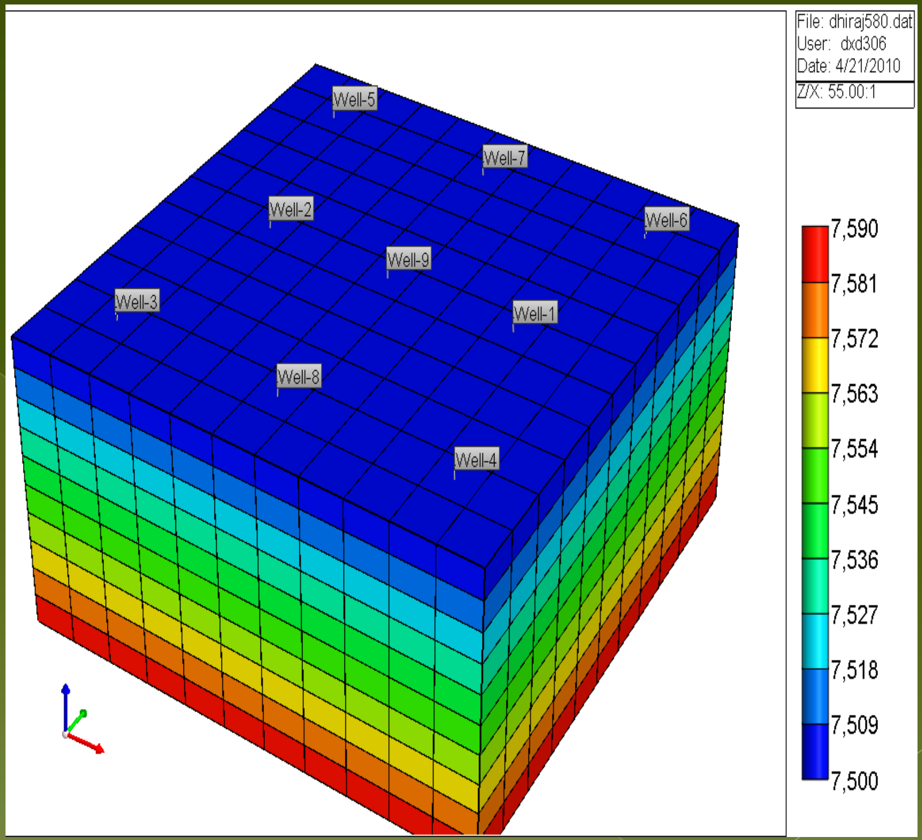
Coalfex Field(ROSE RUN SANDSTONE) Reservoir Model

- Assumptions
  - Black oil reservoir
  - Uniform & homogeneous
  - No new wells are drilled(wells previously drilled are reworked).
  - Miscible displacement of oil by CO2 takes place
  - Field is considered as abandoned(so no lease cost is included)

Reservoir well models for CCS & CO2-EOR

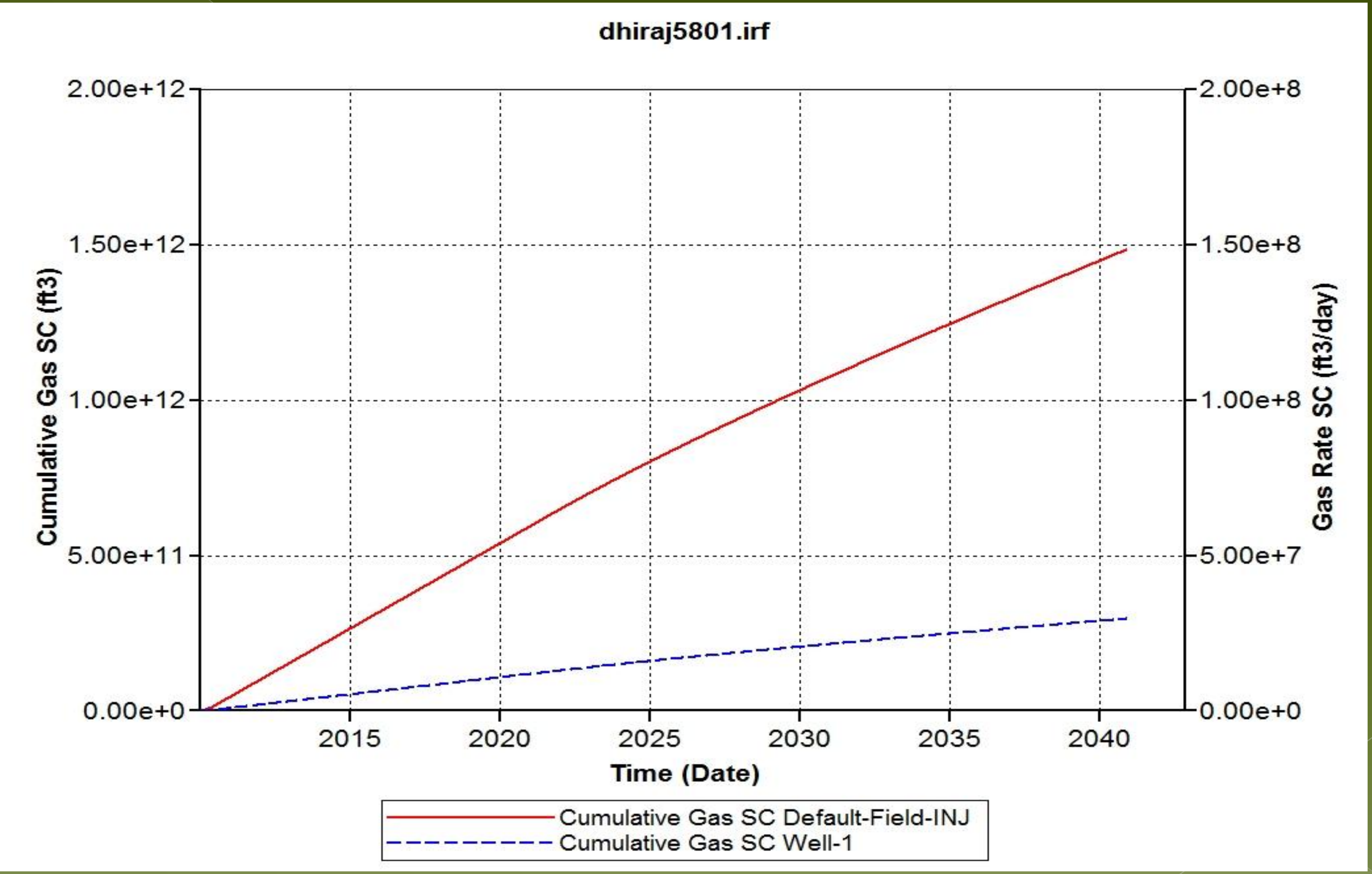


RESERVOIR WELL MODEL FOR CCS PROCESS W/O EOR

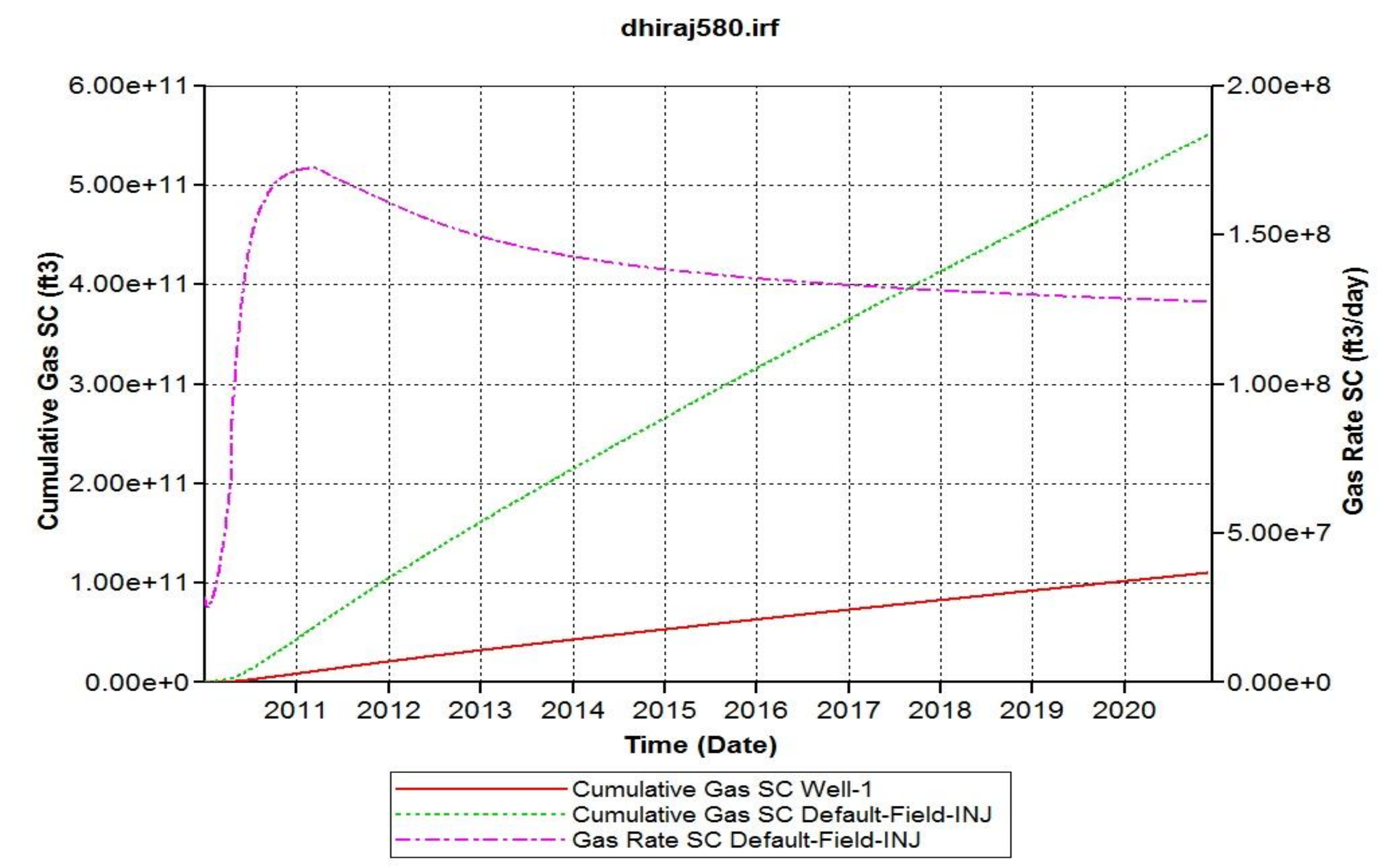


RESERVOIR WELL PROFILE FOR CO2-EOR PROCESS

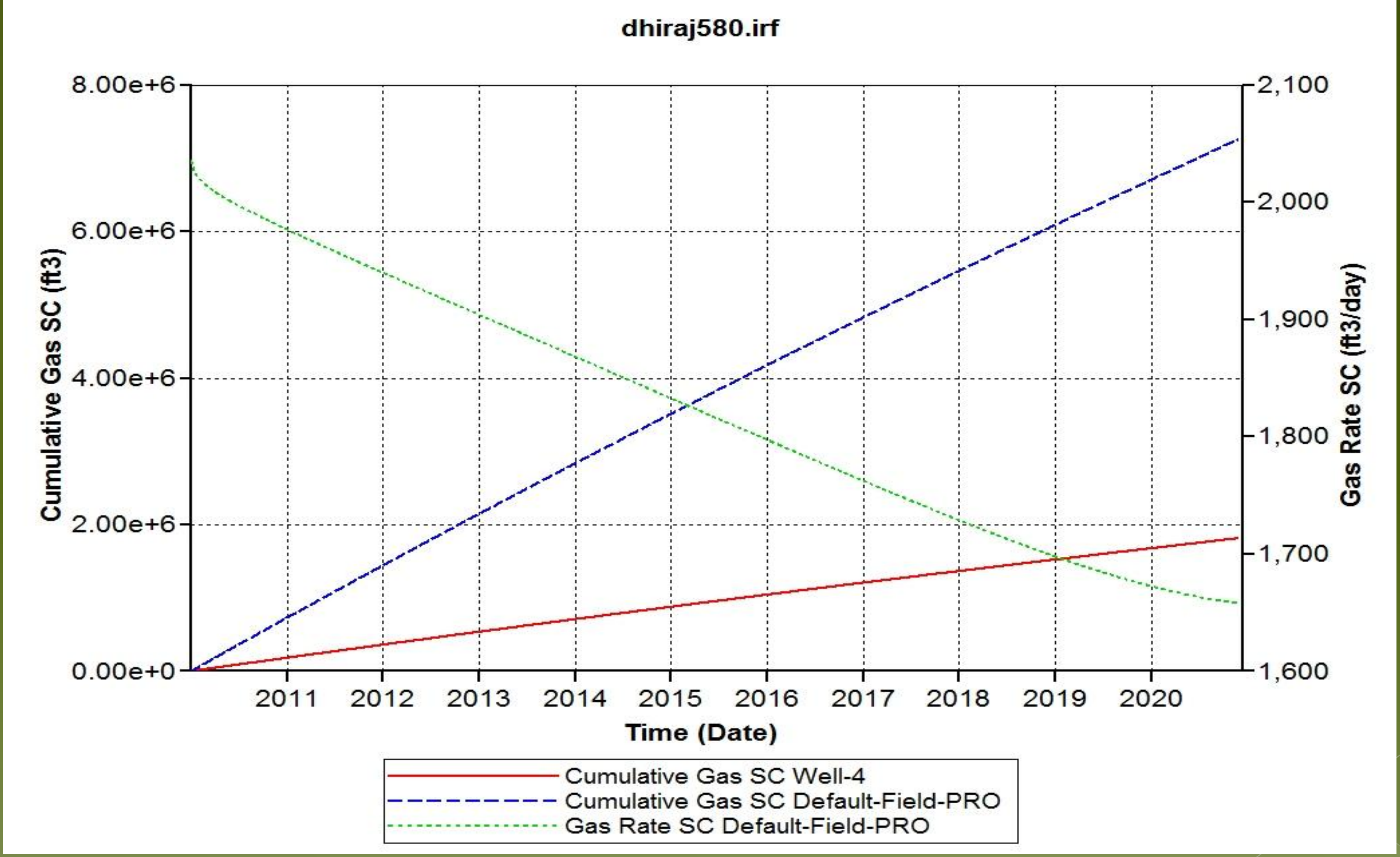
CO2 Injection in CCS



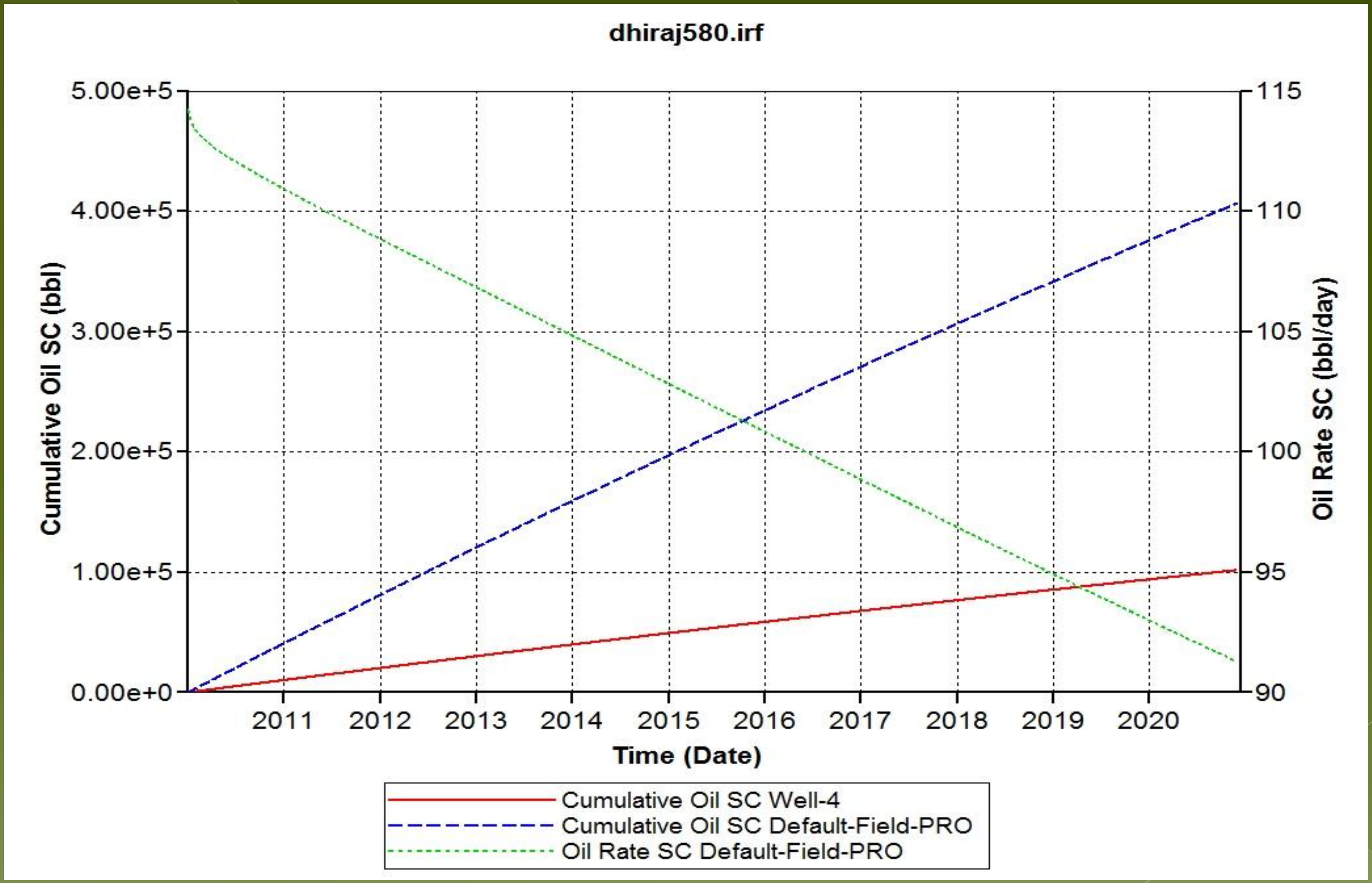
CO2 Injection profiles IN EOR



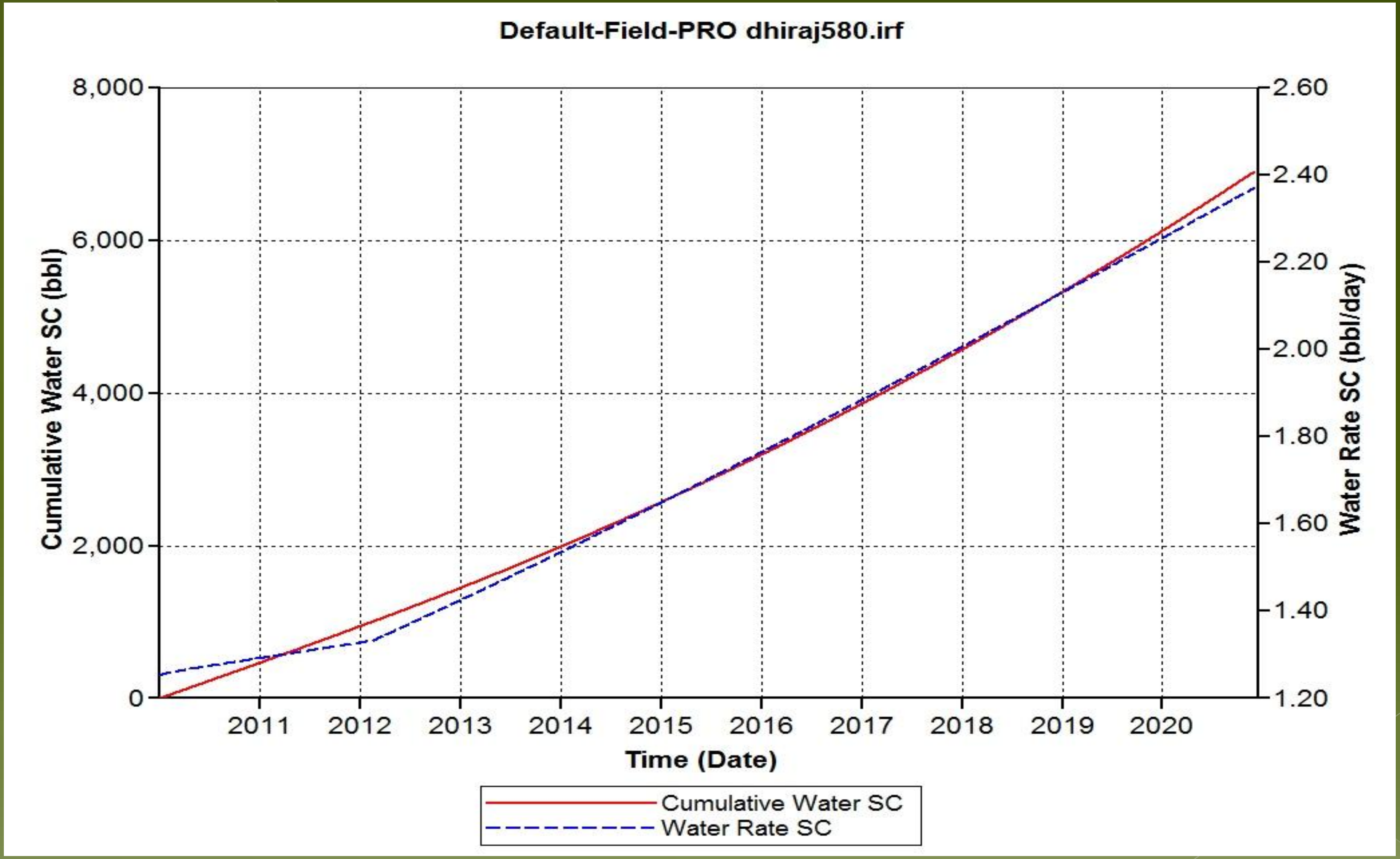
CO_2 PRODUCTION FROM PRODUCTION WELLS



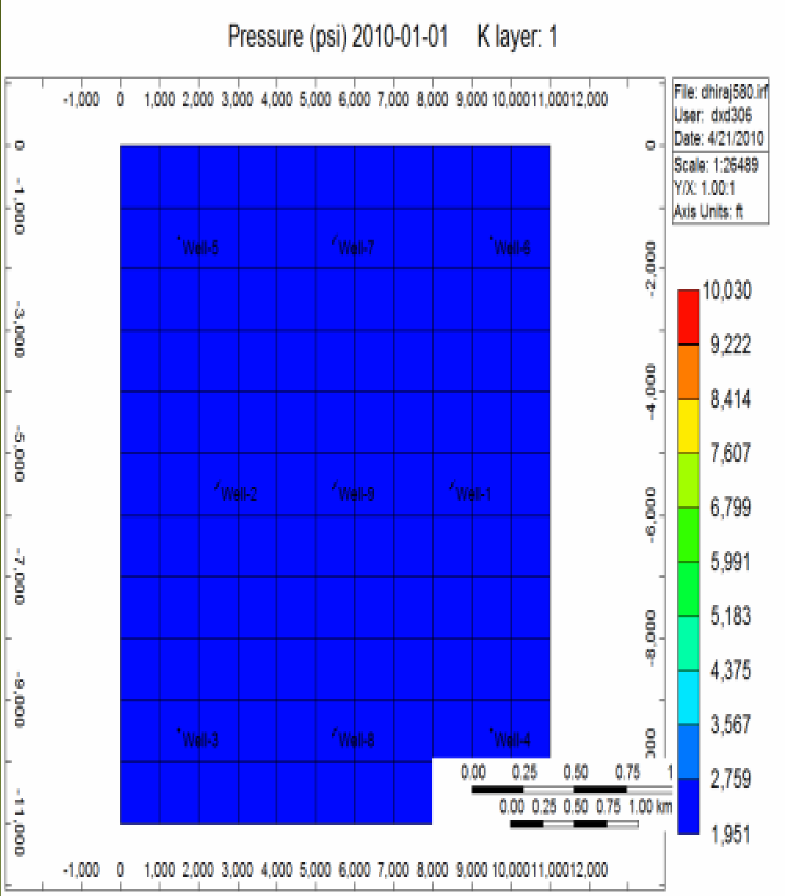
Production of Oil

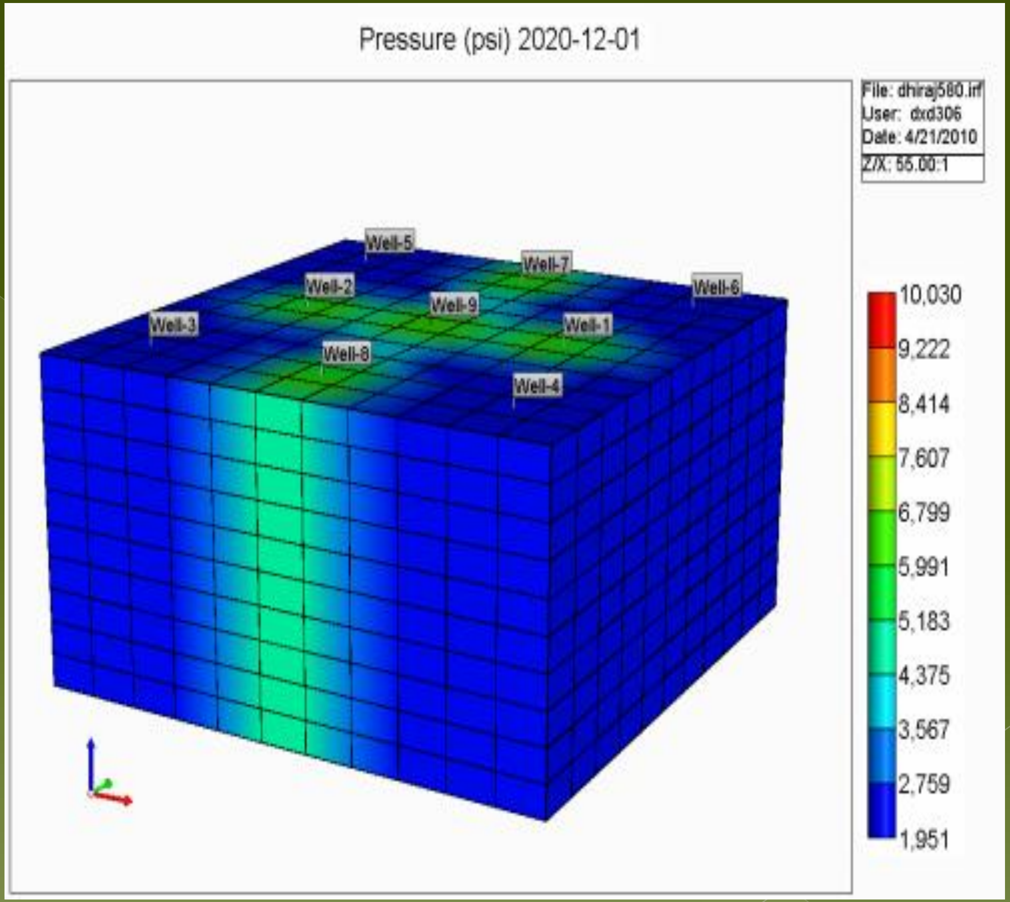


Water Production Profile

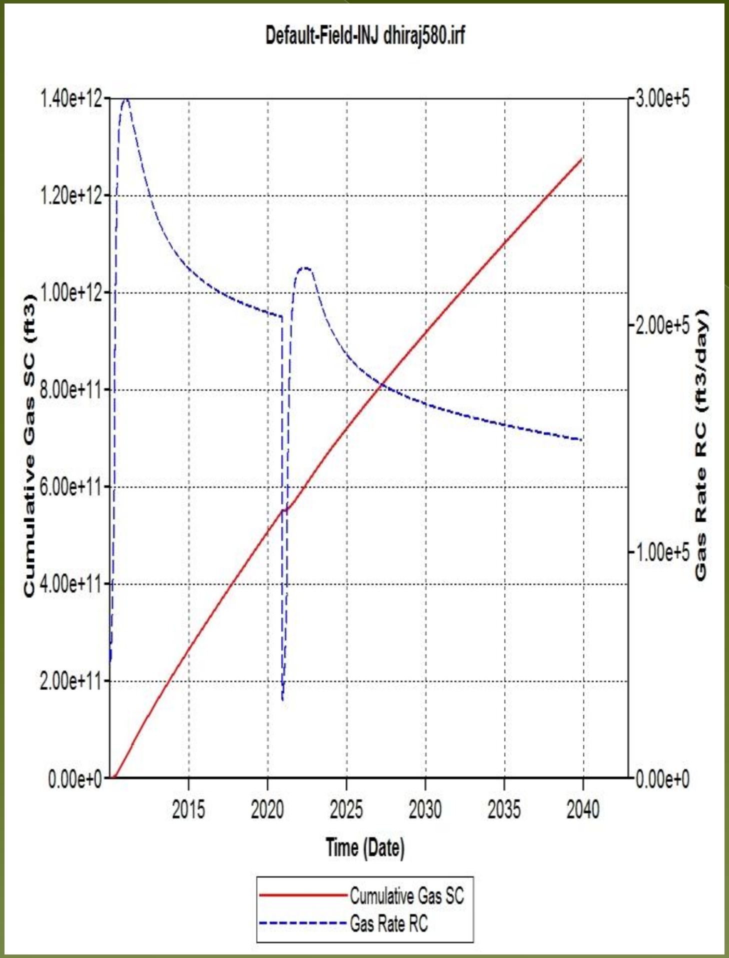


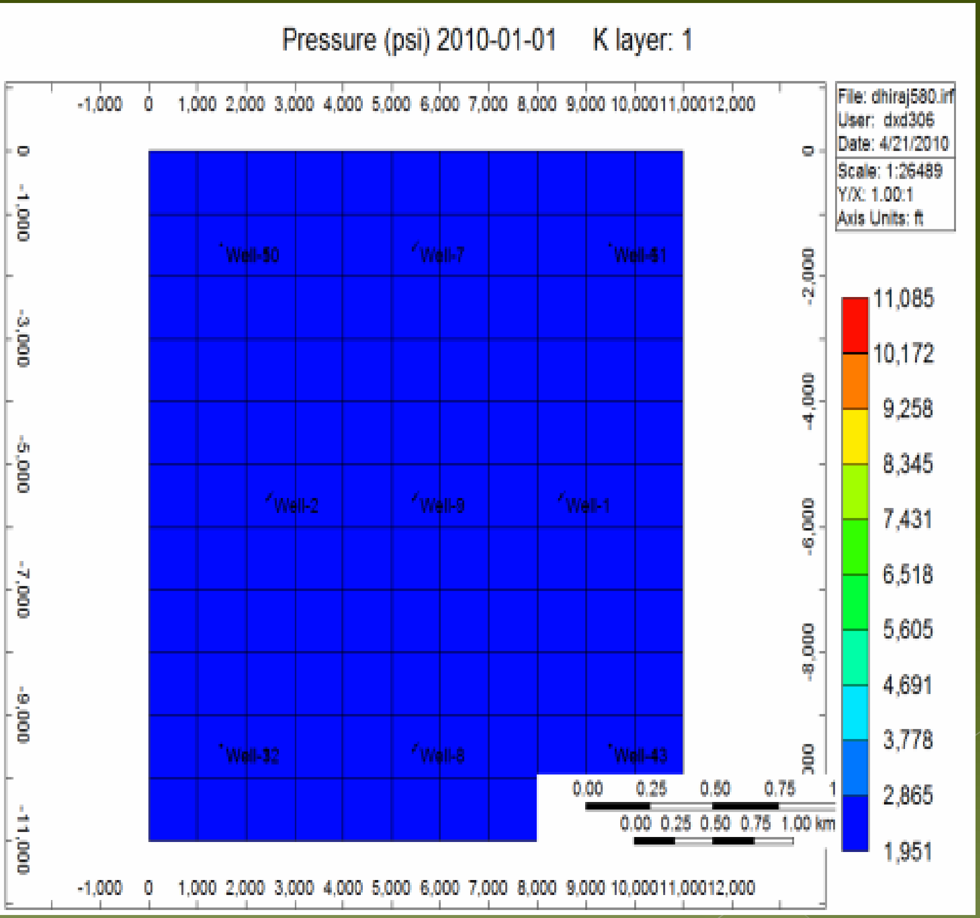
Pressure Changes in The Reservoir





CO2 injection over 30 years period





Results and ultimate recovery

- CO_2 emission from from the plant-
  - 3.34MMton= Total emission
  - Captured CO_2 -3.06MMton=54599.58MMscf/year
- OOIP = 2207-2282 MSTB(12% of which has been recovered by primary recovery)
- Cumulative Oil recovery after 10 years
  - 406.614MSTB(18% of OOIP)
- Amount of CO_2 injected per year
  - 43859MMcf
- Amount of CO_2 produced per year:
  - 733.35Mcf

Cost analysis FOR 10 YEARS period of CCS W/O EOR

VARIOUS COSTS	PER WELL PER YEAR($)		TOTAL(MM$)
reworking on existing wells	181968.75(constant for 1 well)		.9098
operating & maintenance costs	111863.75		5.593
CO2 recycle cost	-		-
CO2 recycle O&M cost	-		-
Lifting costs	-		-
G&A costs	-		-
MONITORING COST			
total			6.5028

W/O TAKING TAX INCENTIVES, TRANSPORTATION AND CAPTURE COST INTO ACCOUNT

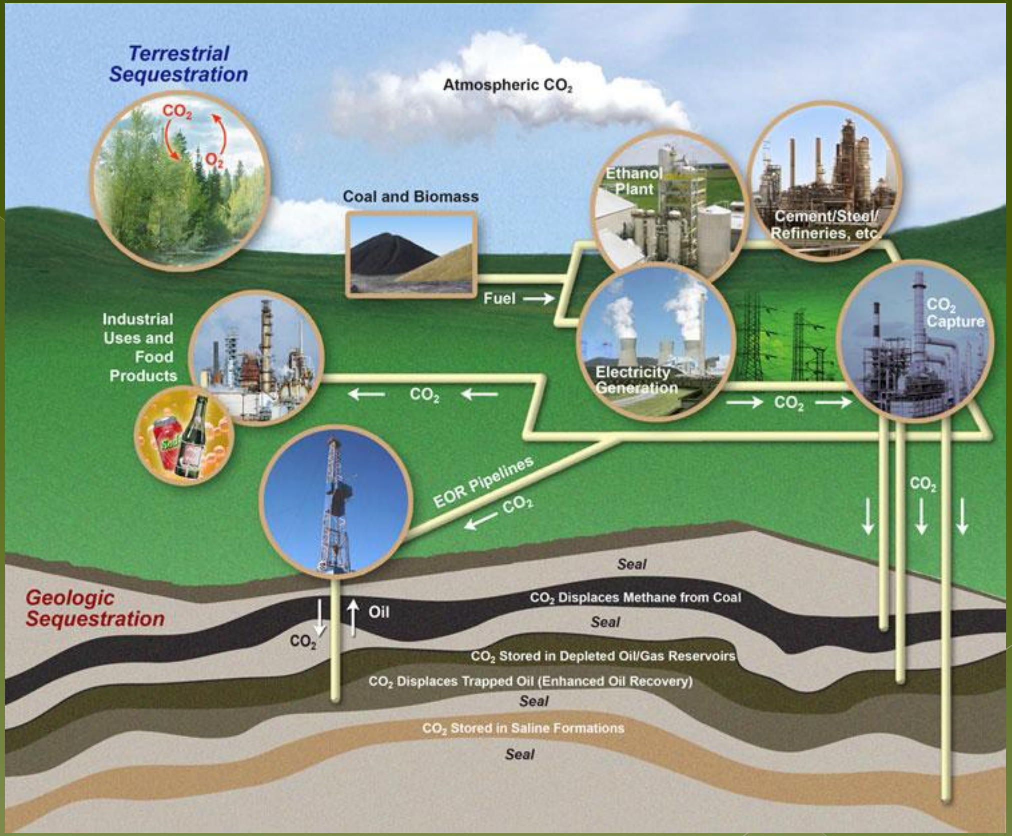
CCS with in CO2-EOR cost analysis for 1st 10 years

- **Oil price=90$ per bbl**
- Oil production=406.614 MSTB
- Total income from oil production=36.595MM$
- Total expenses over 10 years= 23.6396MM$
- Capture cost =.00305$/scf
  - Total for 10 years period=1664.946MM$
- transportation cost=
- Monitoring cost=

- Tax incentives: 90$ per ton for first 5 years and 50 $ per ton for next five years
  - Total tax incentives for 10 years period=2408.00MM$

Environmental Health and Safety

- Associated Hazards
  - Induced Seismicity
  - Ground Deformation
  - Aquifer Intrusion
  - Reservoir Changes
  - Leakage
- Monitoring
  - Pre-Injection
  - Post-Injection



Department of Energy

Monitoring Tools

- LiDAR
  - Monitor Ground Deformation
  - Monitor CO_2 Leakage
- Optical Borewell Sensors
  - Monitor in Reservoir Properties
- Water Monitoring
  - Monitor Reservoir Geochemical Reactions
- Biomonitoring
  - Leakage Detection

Monitoring Partnership

Western Pennsylvania Conservancy
water, land, life.

Pennsylvania Fish & Boat Commission

Pennsylvania Game Commission 1895

DCNR

NASA

JAXA
Japan Aerospace Exploration Agency

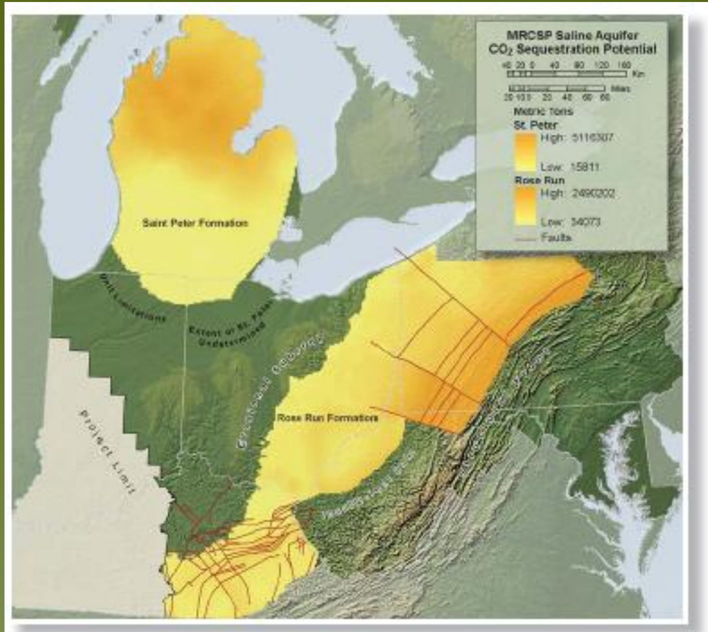
NETL

United States Environmental Protection Agency

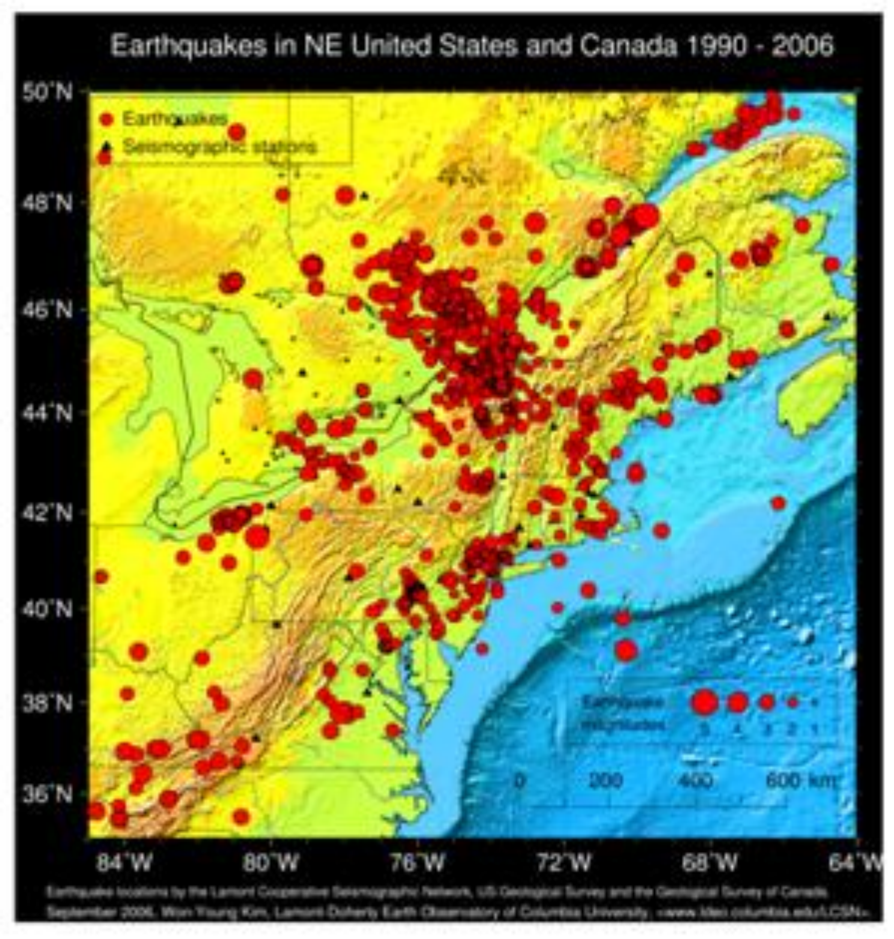
USGS
science for a changing world

Geologic Hazards

- Regional Faults and Fractures
  - Avenues for CO_2 migration
  - Changes in reservoir pressures may caused subsidence or activation of faults



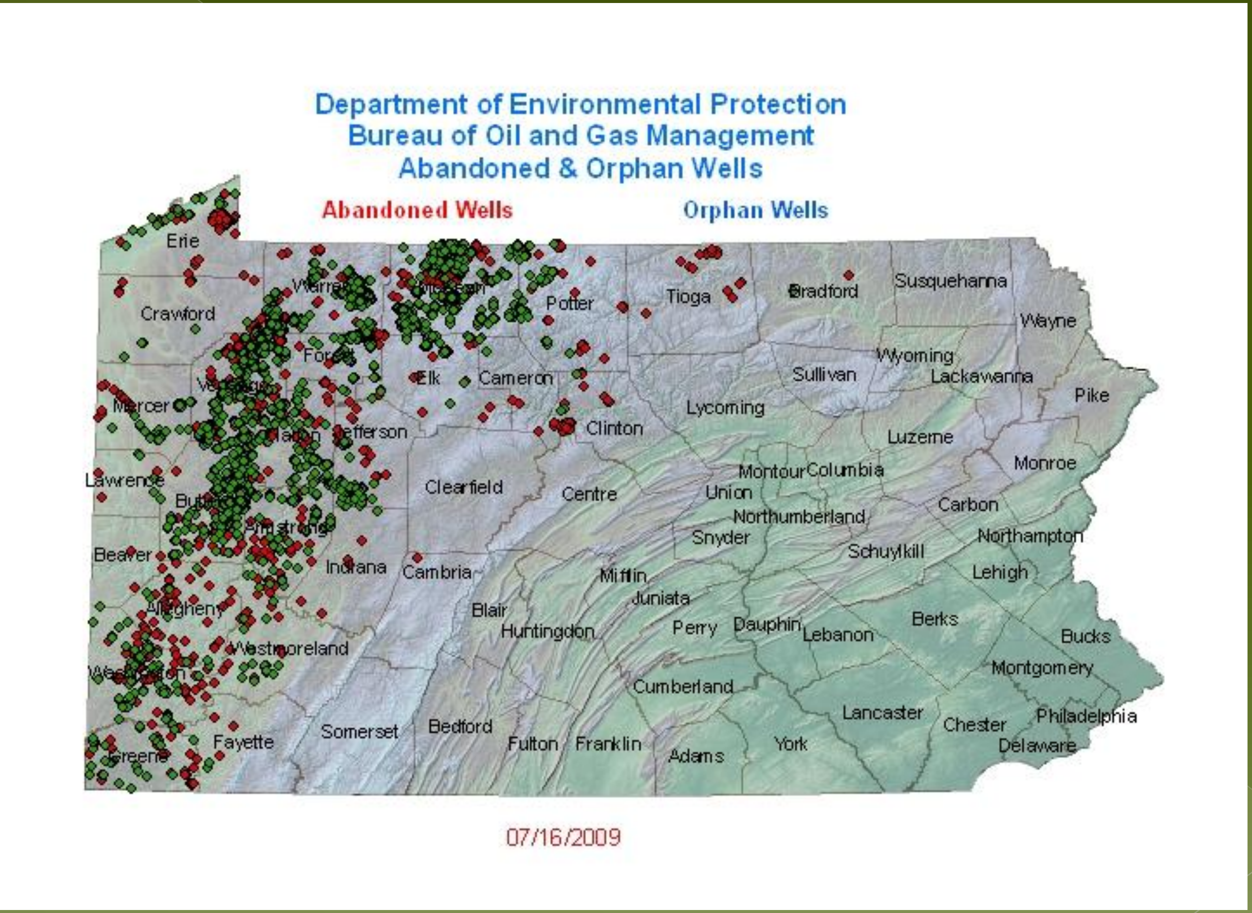
Saint Peter and Rose Run formations are other deep saline rock targets for carbon sequestration.



National Energy Technology Laboratory

United States Geological Survey

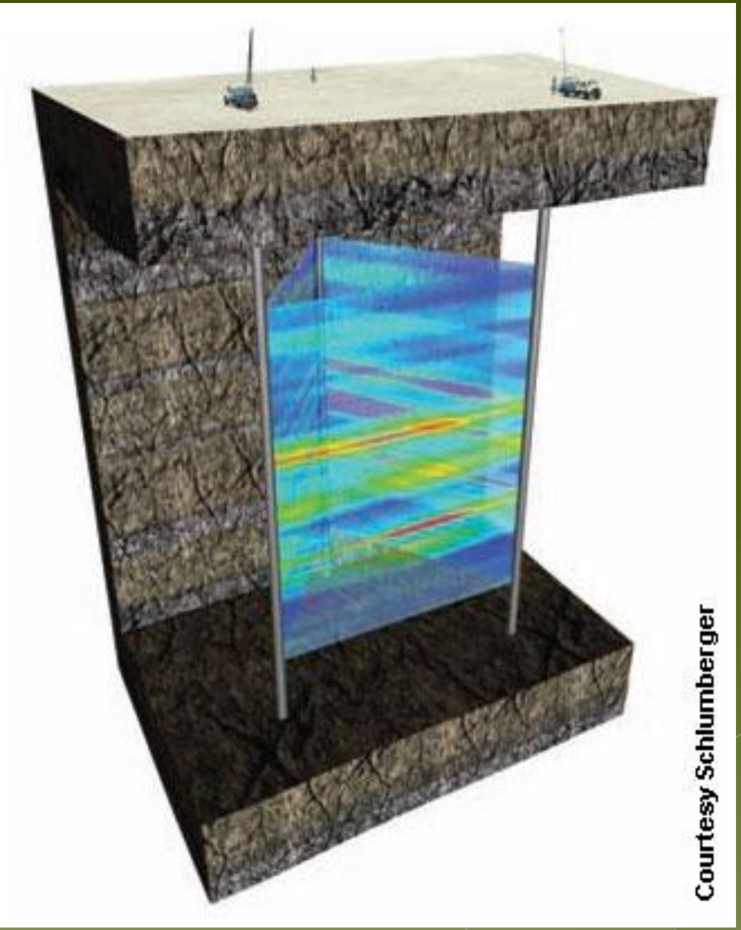
Abandoned Oil and Gas Wells



PA DCNR

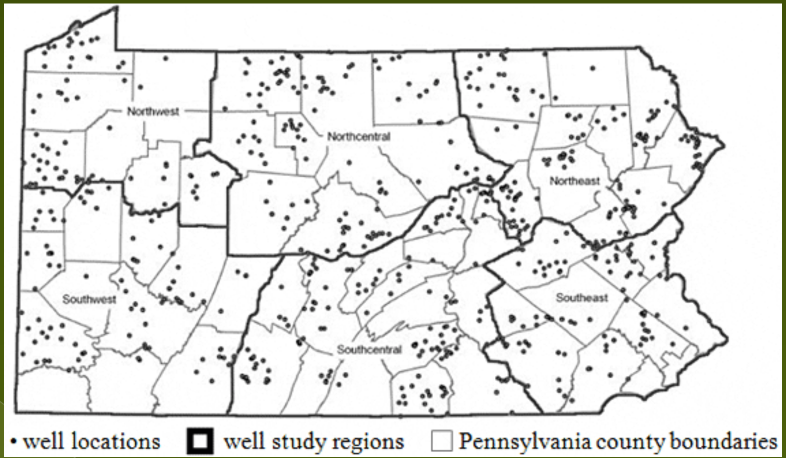
Reservoir Modeling

- Develop Monitoring Network
- Utilize abandoned wells (reduced cost)
- If necessary, drill our own monitoring wells (expensive)
- Insert borewell sensors
  - Sensors measure reservoir properties.

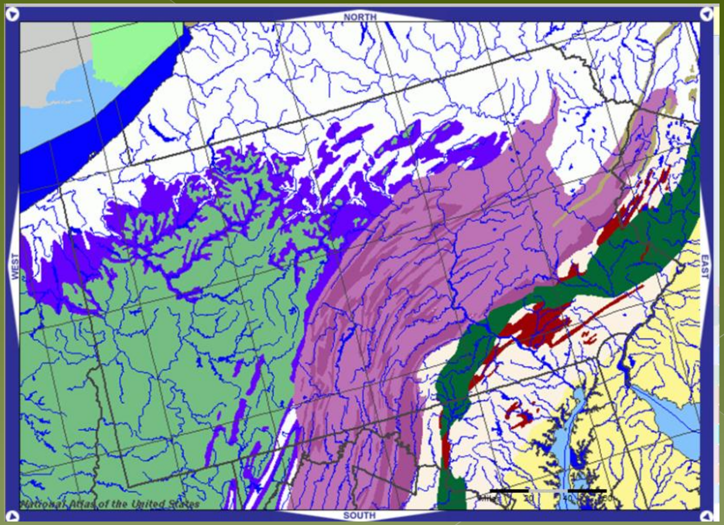


Water Quality Hazards

- Pennsylvania Department of Environmental Protection
- Leakage Hazard
  - Changes in pH can mobilize heavy metals
  - Impact regional aquifers



PA DCNR



Geochemical Changes

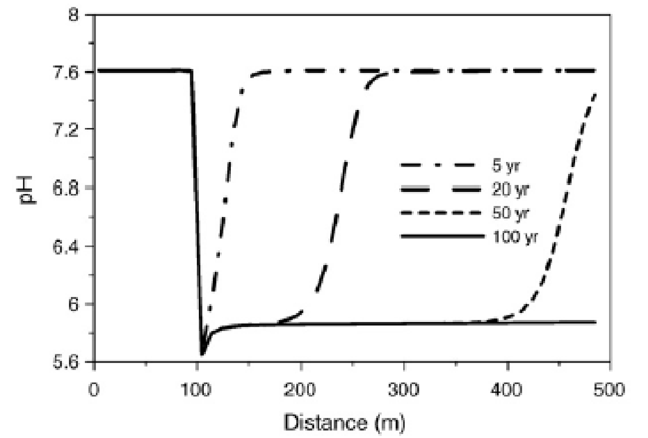


Fig. 3. pH profiles along the *x*-axis at $y = 0$ m at different times.

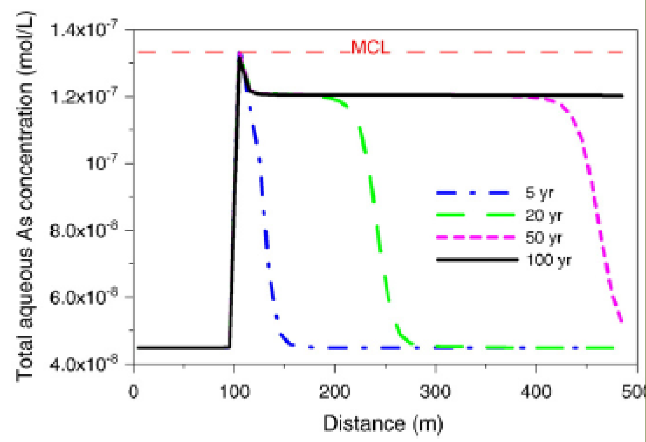


Fig. 10. Total aqueous arsenic concentration profile along *x*-axis at $y = 0$ m.

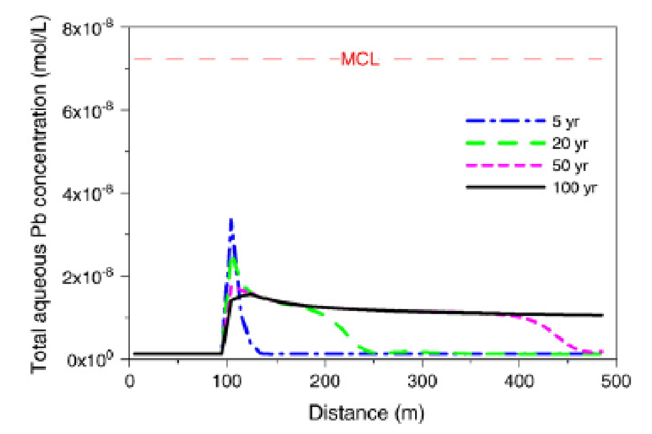


Fig. 7. Total aqueous lead concentration profile along *x*-axis at $y = 0$ m at different times.

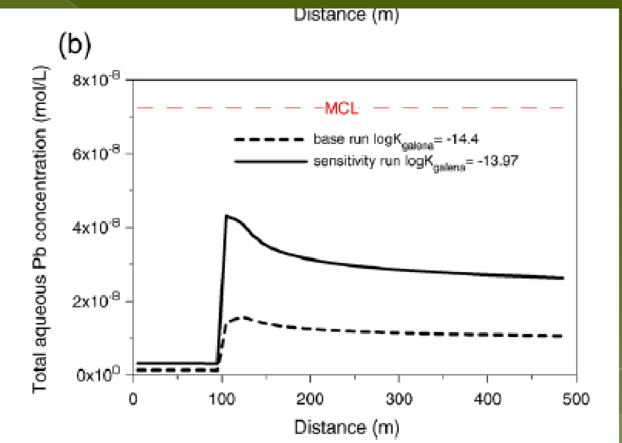
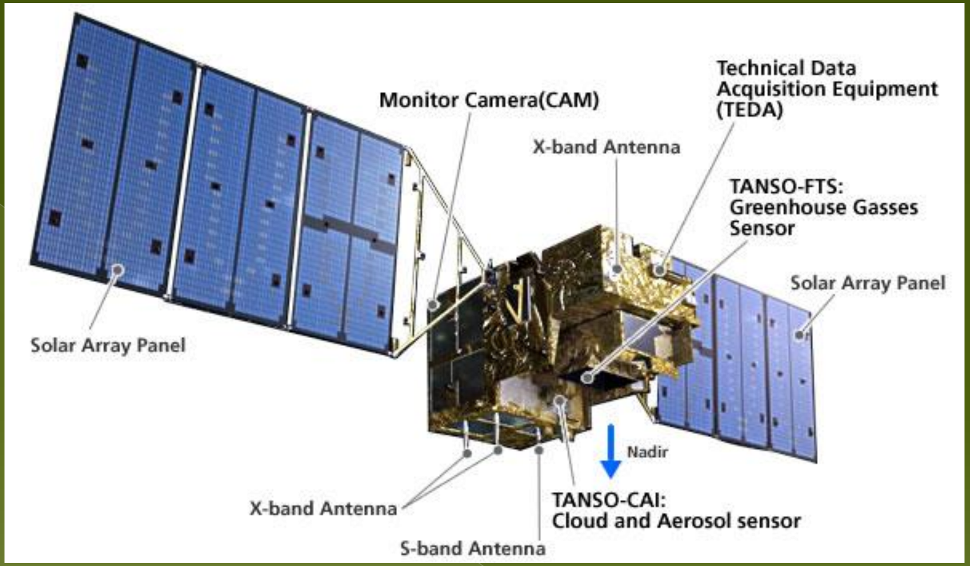


Fig. 11. Computed total adsorbed lead (a) and total aqueous lead (b) after 100 years of CO_2 intrusion in sensitivity run (log*K* galena $= -13.97$) and base model (log*K* galena $= -14.4$).

Zheng *et al.*, 2009

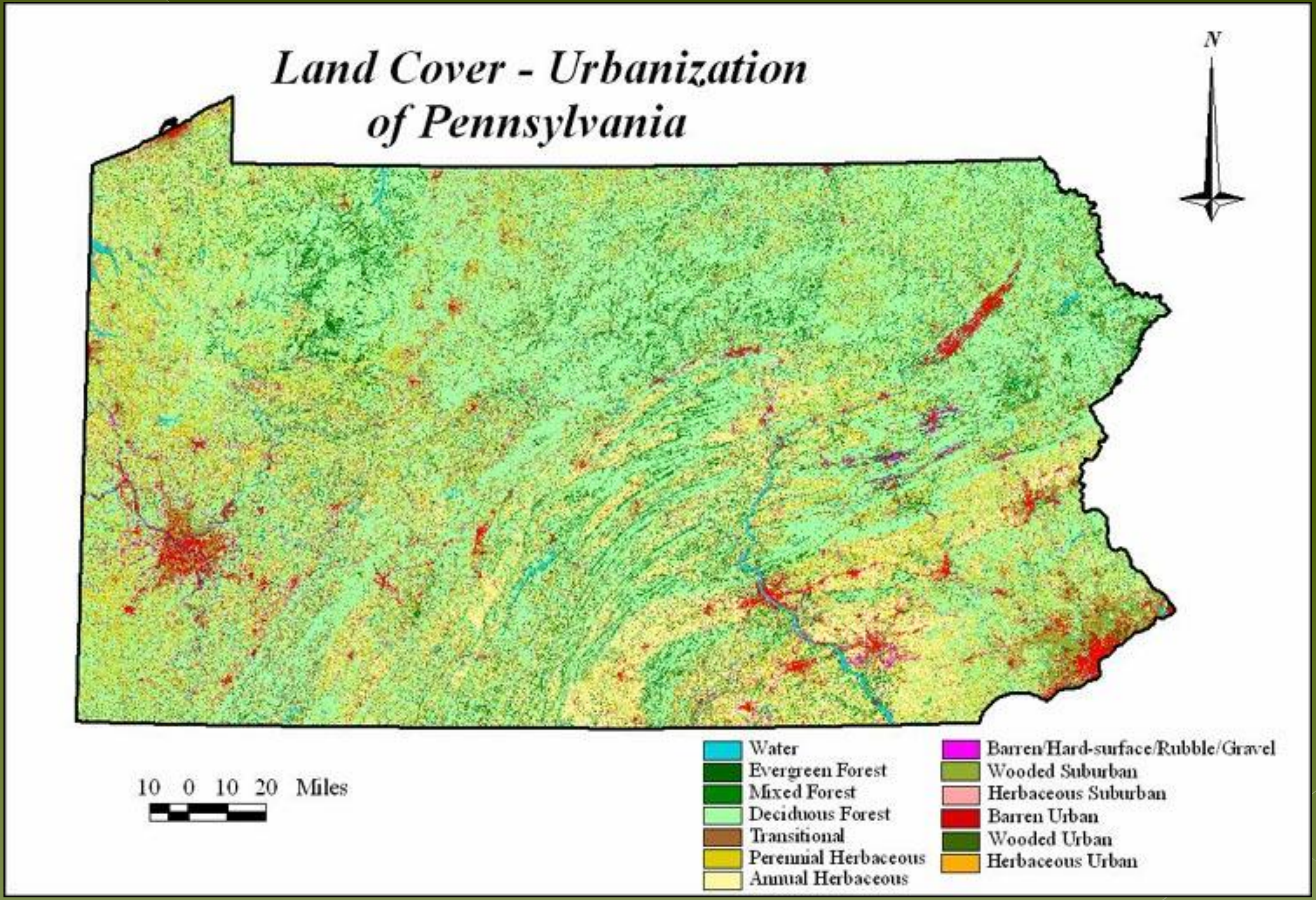
Light Detection and Ranging (LiDAR)

- Airborne Laser Swath Mapping (ALSM)
- Orbiting Carbon Observatory (OCO)
  - Launch failure February 24, 2009
  - $250 million loss
  - 2010 - $170 million budget approval
  - 2-year mission life
- Greenhouse Gases Observing Satellite (GOSAT)
  - Launched January 23, 2009
  - Centimeter scale resolution
  - 5-year mission life



Japan Aerospace Exploration Agency

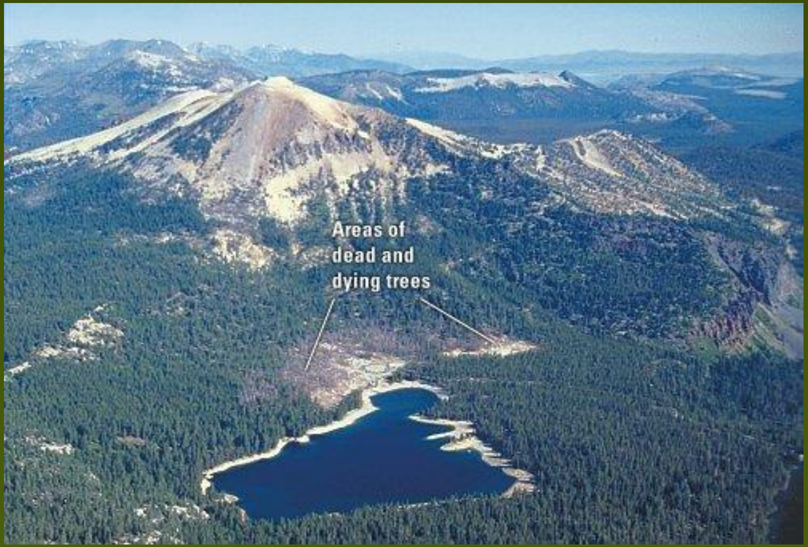
Pennsylvania Land-use



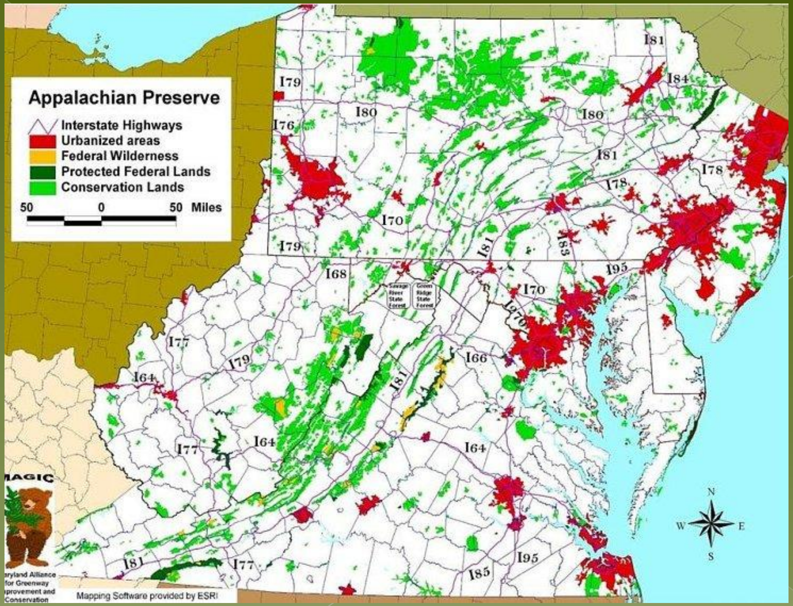
Pennsylvania Bureau of Forestry

Biomonitoring

- Trees are susceptible to changes in soil pH
- +400,000 acres available for reforestation
  - $3.23/tree
  - 440 trees/acre
  - 176,000,000 tree potential
  - 80,000 tons of biomass created
    - Harvest
  - Job creation



PA DCNR



Monitoring Costs

Monitoring Device	Cost ($)	Benefit ($)
LiDAR	1,612,274	0
Borewell Sensors	80,000,000	0
Biomonitoring	336,000,000	568,480,000
DEP Water Network	0	0
Total Costs	-	+150,867,726

McCoy & Rubin (2005)	High Cost ($/ton)	Average Cost ($/ton)	Low Cost ($/ton)
Monitoring Costs	0.10	0.07	0.03
CO_2 Injected (tons)	3,366,000	3,366,000	3,366,000
Total Costs ($)	13,348,000	9,440,000	4,040,000

Should we do this?

- Happy Earth Day
- Problem Statement:
  - ***Examining the implementation of retrofitting and sequestration technologies on a 572MW coal plant in Shawville, PA for Carbon Capture and Storage (CCS) and Enhanced Oil Recovery (EOR) to make the project viable while reducing associated costs.***
- ***Triple Bottom Line 3-B-L***
- ***People***
  - ***Not in My Back Yard (NIMBY)***
- ***Planet***
  - ***Reduced output of Greenhouse Gases***
- ***Profit***
  - ***Expensive project***

ECONOMIC ANALYSIS FOR YEARS 0-10 FOR CO2 EOR

VARIOUS COSTS	PER WELL PER YEAR($)		TOTAL(MM$)
Transportation Costs	$31 million		-310
Capture Costs	0.003264 per scf		-1746.04
Tax Incentives	$90 years 0-5 $50 years 5-10		+2408
reworking on existing wells	181968.75(constant for 1 well)		-.6377
operating & maintenance costs	111863.75		-10.06
Co2 recycle cost	700,000Per MMcf/d		-5.13
Co2 recycle O&M cost	1 per Mcf		-.073
Lifting costs	0.3per bbl		-0.12
G&A costs	27965.9.2+0.2*(0.3per bbl)		-2.04
royalties	12.5% of total oil production		-4.57
Income from Oil			+36.59
Monitoring Costs			292.5
total			77.42

Economic analysis OVER 30 years period

VARIOUS COSTS	PER WELL PER YEAR($)		TOTAL(MM$)
Co2 capture cost	. 0.003264per scf	-	-5232.1
Transportation cost	31MM		-930
Tax incentives	$90 years 0-5 $50 years 5-10		+2408
Income from Oil Production	-		+36.59
reworking on existing wells	181968.75(constant for 1 well)		-1.64
converting production well into injection well	78391.25(constant for 1 well)		-0.31
operating & maintenance costs	111863.75		-19.02
Co2 recycle cost	700,000Per MMcf/d		-5.131
Co2 recycle O&M cost	1 per Mcf		-0.073
Lifting costs	0.3per bbl		-0.12
G&A costs	27965.9.2+0.2*(0.3per bbl)		-2.03
royalties	12.5%		-4.57
Monitoring cost	8.7		-552.5
total			-4,302.90

Final Conclusions

- The project is economically feasible in first 10 years
- After that period, EOR incentives decline and project runs in the red
- \$46.87/ton CO_2 captured (30 year levelized cost)

Future Work

- Policies
  - Pipeline transportation
  - Underground injection
  - Long-term storage
  - *ETA: End of 2010*
- *Capture*
- *Transportation*
  - *Focusing on many-to-many sources-to-sinks matching*
  - *Near sequestration sites VS electricity consumers(cities)*
  - *Competition among large CO2 source facilities to seek the best local sequestration sites before others do*
  - *CO2 transportation costs could raise electricity prices even higher above the national average*

    electricity prices even higher above the national average
- *EOR/Sequestration*
  - *Injection well technology*
  - *Calcium hydroxide injection*
- *Monitoring*
  - *Long term sensors*
  - *Implications of leakage*