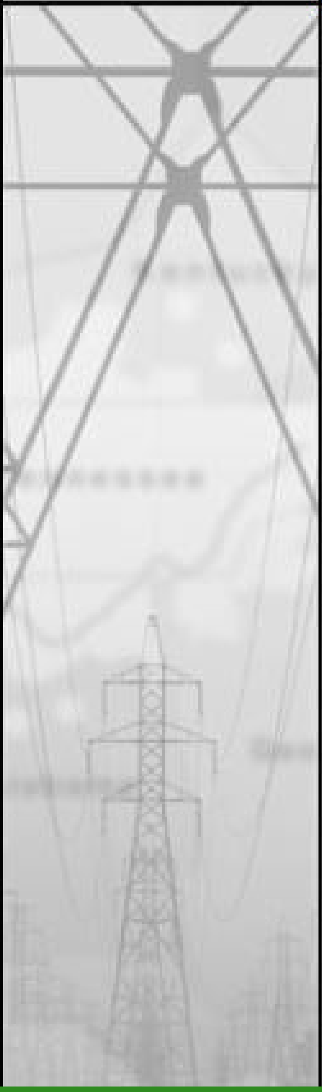
CO_2 Storage and Sink Enhancement: Developing Comparable Economics



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CO_2 Sequestration Options Compared

Storage of Captured CO_2

- Depleted gas reservoirs
- Depleted oil reservoirs
- Deep saline aquifers
- Enhanced oil recovery
- Enhanced coalbed methane recovery
- Ocean pipeline
- Ocean tanker

CO_2 Sink Enhancement

- Forest management
  - New plantations
  - Restoration
  - Agro-forestry
  - Avoided deforestation
- Cropland via reducing tillage (USA)

TVA

General Approach

- **CO_2 capture costs + storage costs (DOE/EPRI, 2000) (this project)**

  compared with

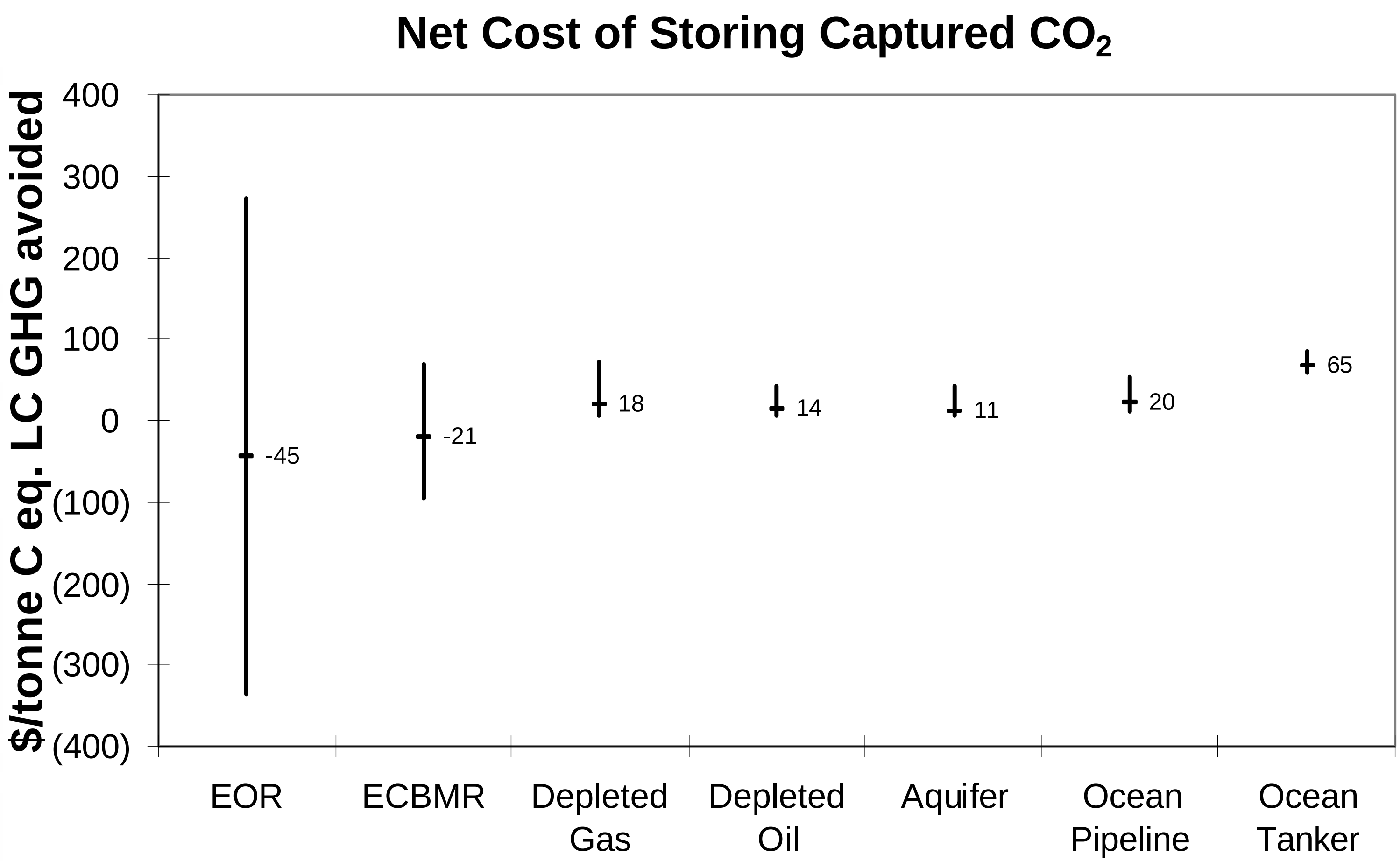
  CO_2 sink enhancement costs (this project)
- Regulated utility perspective
  - Revenue requirement methodology for CO_2 capture and storage
  - Utility-funded forestry and cropland projects
- Life-cycle (LC) GHG avoided basis
- NPV basis (CO_2 sequest. costs and revenues)
- 100-year planning horizon
- Costs on C basis: \$/tonne C

  (\$10/tonne CO_2 = \$37/tonne C)

Scale

- Storage options sized to accommodate CO_2 from a 404 MW (net) IGCC CO_2 capture plant (DOE/EPRI, 2000)
  - 90% of CO_2 captured
  - 2.16 million tonnes CO_2 captured/year; 80% capacity factor
- Calculated forest and cropland areas required to avoid the same amount of GHG emissions as the CO_2 capture and storage options

Costs


Net Cost of Storing Captured CO_2
$/tonne C eq. LC GHG avoided
400
300
200
100
0
(100)
(200)
(300)
(400)
-45
-21
18
14
11
20
65
EOR
ECBMR
Depleted Gas
Depleted Oil
Aquifer
Ocean Pipeline
Ocean Tanker

Summary: CO_2 Storage Costs ($/tonne C eq. LC GHG Avoided)

- Typical cost ranges for CO_2 storage (transport + injection)
  - Without oil or gas by-product credit: $10 to 20/tonne C
  - With oil or gas by-product credit: credit offsets storage costs
- With oil or gas by-product, net costs vary greatly with:
  - Oil and gas prices
  - Ratio of CO_2 stored to oil or gas by-product
- With more oil or gas per CO_2 stored
  - Lower net CO_2 storage cost
  - Less CO_2 storage capacity

CO_2 Capture Cost (DOE/EPRI, 2000)

IGCC Reference Plant
- 425 MW net
- 43% efficiency

vs.

IGCC CO_2 Capture Plant
- 404 MW net
- 37% efficiency

- $64/tonne C eq. LC GHG avoided in capture process
- IGCC CO_2 capture costs are 3 to 7 times > typical storage costs without by-products

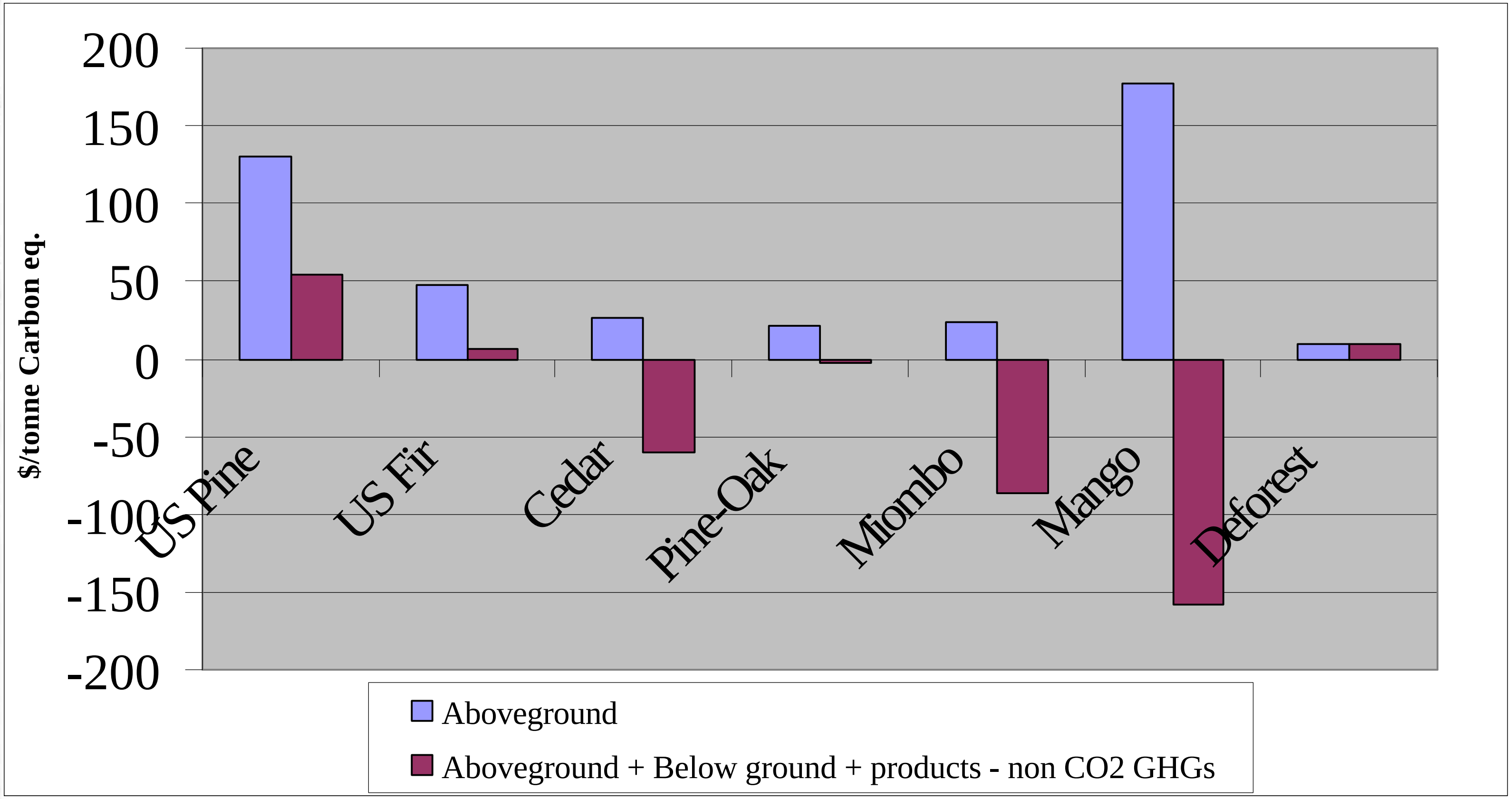
CO_2 Capture + Net Storage Costs: Base Cases, NPV Basis

CO_2 Storage Process	$/tonne C eq. LC GHG avoided
Enhanced oil recovery	15
Enhanced coalbed methane recovery	41
Depleted gas reservoir	86
Depleted oil reservoir	81
Deep saline aquifer	77
Ocean pipeline	89
Ocean tanker	143

Forestry Cases

Management Type	Type of Trees	Country/ region
Plantation	Loblolly pine	USA (South)
Plantation	Douglas Fir	USA (Pacific NW)
Plantation	Spanish Cedar	Mexico
Restoration	Pine-oak	Mexico
Restoration	Miombo	Southern Africa
Agro-forestry	Mango-Tamarind	India (South)
Avoidance of deforestation	Various	Mexico

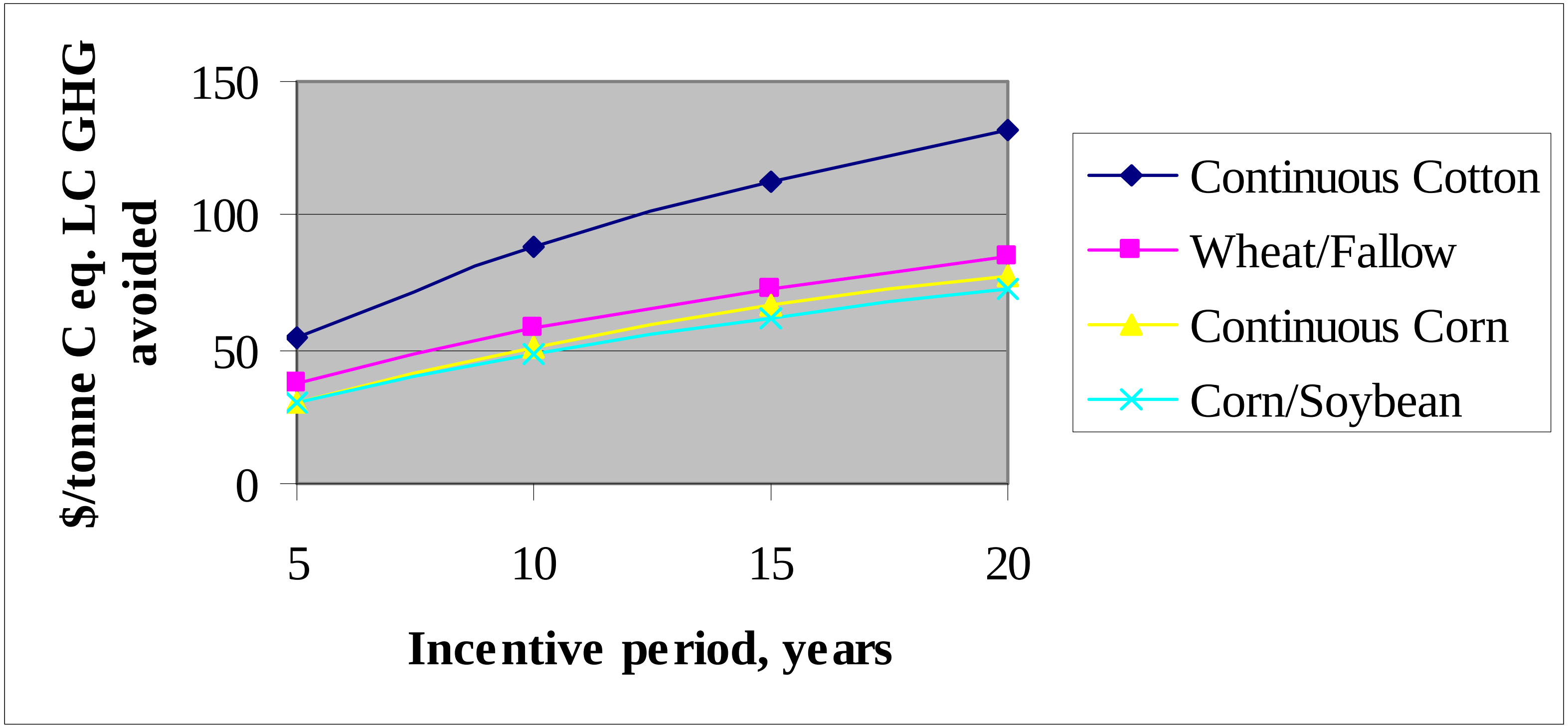
Costs: Medium Productivity Cases, NPV Basis



Reducing Tillage on U.S. Cropland: Factors Affecting Costs

- Adoption incentive paid to farmer by utility
  = f (△ crop yield, △ crop production costs, △ risk)
- Transaction costs
- Monitoring costs
- △ C sequestered in soil organic matter
- △ N_2O emissions from soil
- △ GHG emissions from crop production inputs

Intensive Till to No Till Costs: Base Cases, NPV Basis



Base Case Cost Ranges ($/tonne C eq. LC GHG Avoided, NPV Basis)

- CO_2 capture + net storage costs ($15 to 145)
- Forest management
  - Aboveground + below ground + products - non CO_2 GHGs ($-160 to 55)
- Cropland via reducing tillage
  - 10-year adoption incentive period ($50 to 90)
- Forestry options with valuable products and EOR are least-cost options in situations where they are practical

Collaborators

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