# FE/NETL $CO_2$ Transport Cost Model

## Model Overview

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July 11, 2014

DOE/NETL-2014/1668

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

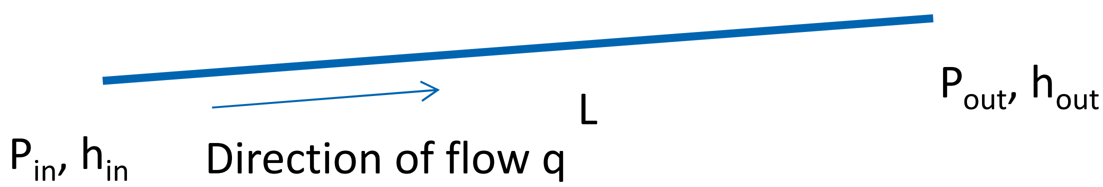
# Overview

- **Objective of effort: Develop a mathematical model that estimates the costs of transporting liquid $CO_2$ using a pipeline**
  - Point to point pipeline
  - Booster pumps can be included along pipeline
- **Model calculates break-even first year price for transporting $CO_2$**
- **Model calculates break-even price for different numbers of booster pumps and determines optimal number of booster pumps**
- **Main sheet (with financial model) and Engineering module**

# Engineering Module: Pipeline

- **Pipeline costs depend on pipeline length and pipe diameter**
- **Diameter estimated using equations that estimate the minimum diameter that will support a specified mass flow rate over a specified distance with a specified pressure drop and elevation loss or gain**
  - Equations from McCollum and Ogden and MIT with influence of elevation tacked on
  - Equations from McCoy and Rubin with influence of elevation included in derivation

$P_{in}$ = 2200 psig
$P_{out}$ = 1200 psig



# Engineering Module: Pipeline (Cont’d)

- **Actual diameter for pipe is selected based on standard pipe diameters (i.e., standard pipe is determined by finding the pipe with the smallest inner diameter that exceeds the minimum inner diameter calculated with one of the equations discussed previously)**
- **Standard pipe diameters (specified as inner diameters for smaller pipes and outer diameters for larger pipes):**
  - Inner diameters: 8 and 12 inches
  - Outer diameters: 16, 20, 24, 30, 36, 42 or 48 inches

# Engineering Module: Pipeline (Cont'd)

- **Capital costs based on data from Oil and Gas Journal for natural gas pipelines.**
- **Costs provided for four categories of data: materials, labor, right of way (ROW) and damages, and miscellaneous**
- **Costs estimated using three different regression equations**

  Parker (2004)

  $$C_{png-par-i} = a_{i-0} + L \cdot (a_{i-1} \cdot D^2 + a_{i-2} \cdot D + a_{i-3})$$

  McCoy and Rubin (2008)

  $$C_{png-mcc-i} = 10^{(a_{i-0}+a_{i-reg})} \cdot L^{a_{i-1}} \cdot D^{a_{i-2}}$$

  Rui et al. (2011)

  $$C_{png-rui-i} = e^{(a_{i-0}+a_{i-reg})} \cdot L^{a_{i-1}} \cdot SA^{a_{i-2}}$$

  Where $C_{png-x-i}$ is the capital costs of category i, D is the pipeline diameter in inches, L is the pipeline length in mi or km, SA is the cross-sectional area of the pipe in $ft^2$ and $a_{i-0}$, $a_{i-1}$, $a_{i-2}$, $a_{i-3}$ and $a_{i-reg}$ are regression coefficients

- **All costs were adjusted to be in 2011 dollars**

# Engineering Module: Pipeline (Cont'd)

- **Pipeline costs for natural gas pipeline are adjusted using a factor ($e_{CO2}$) to account for the higher pressures of a $CO_2$ pipeline**
  - Factor applied to materials and labor
- **Annual operation and maintenance costs for pipeline assumed to be $8,500/mi-yr based on O&M costs in Bock et al. (2003) adjusted to 2011 dollars**

# Engineering Module: Booster Pumps

- **Booster pump costs depend on the maximum power requirement of pump**
  - User specifies pressure at inlet to pipeline and outlet from pipeline
  - Booster pump is assumed to boost pressure from outlet to inlet pressure
  - Booster pumps divide pipeline into $N_{pump}$+1 identical pipeline segments (pressure drop and elevation gain or loss is same in all segments)
- **Annual operation and maintenance costs for booster pumps assumed to be 4% of capital costs based on professional judgment**
- **Annual costs of electricity depends on electricity used by pump and price of electricity**
  - Electricity use depends on efficiency of pump and capacity factor for pump
  - Price of electricity used is average price for commercial electricity (not electricity price for industrial customers)

# Engineering Module: Other Equipment

- **$CO_2$ surge tank (from NETL (2010)): $1,250,000 in 2011 dollars**
- **Control system (from NETL (2010)): $112,000 in 2011 dollars**
- **Annual operation and maintenance costs for $CO_2$ surge tank and control system assumed to be 4% of capital costs based on professional judgment**
- **Note: No costs for high precision $CO_2$ flow meters (assumed to be borne by $CO_2$ source and $CO_2$ storage operators)**

# Main Sheet and Financial Model

- **User specifies: start year (2011), length of construction period (3 years) and length of operations (30 years)**
  - User also specifies how capital costs are distributed over construction period (i.e., what fraction of capital costs for each type of equipment occur in each year)
- **User specifies financial parameters: debt/equity ratio (45%/55%), cost of debt (5.5%/yr), desired rate of return on equity (12%/yr), escalation rate (3%/yr), tax rate (38%), project contingency (15%)**
- **User specifies depreciation method, either 150% declining balance or straight line, and recovery period, either 15 or 20 years**
- **Model generates cash flow of revenues by multiplying the price for transporting $CO_2$ by the mass transported in a given year (model generates real and nominal revenues)**
- **Note: Numbers in parentheses above are values used to calculate baseline costs for transporting $CO_2$**

# Calculations in Financial Model

- **Capital costs are assumed to all occur before the pipeline begins operations**
- **Capital costs in nominal dollars are depreciated using the method selected by the user with depreciation factors from IRS Publication 946; depreciation begins in the first year of operation**
- **Cash flows for revenue, capital costs (CAPEX), O&M costs (OPEX), depreciation and cost of goods sold (COGS, always zero) are all generated in nominal dollars**
- **Earnings Before Interest and Taxes (EBIT) is calculated for each year (nominal $)**

$$EBIT = revenue - COGS - OPEX - depreciation$$

- **Taxes are calculated using a generic 38% tax rate ($i_{tax}$) to account for federal, state and local taxes (nominal $)**

$$taxespaid = i_{tax} \cdot EBIT$$

- **Earnings Before Interest and After Taxes (EBIAT) is calculated for each year (nominal $)**

$$EBIAT = EBIT - taxespaid$$

- **Free cash flow (FCF) is then calculated for each year (nominal $)**

$$FCF = EBIAT + depreciation - CAPEX$$

- **FCF is discounted using the weighted average cost of capital (WACC) as the discount rate**

$$WACC = f_{eq} \cdot IRROE_{min} + \left(1 - f_{eq}\right) \cdot (1 - i_{tax}) \cdot i_{debt}$$

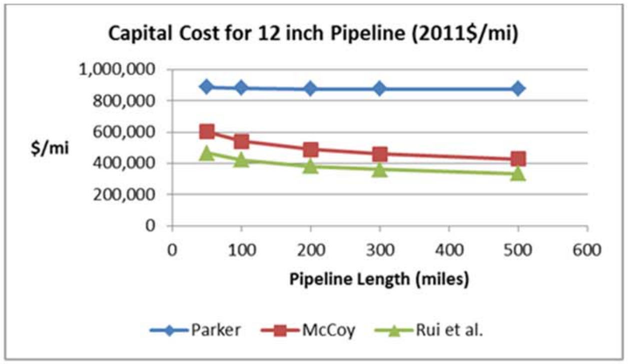
Where $f_{eq}$ is fraction of financing from equity, $IRROE_{min}$ is the minimum desired internal rate of return on equity and $i_{debt}$ is the interest rate on debt

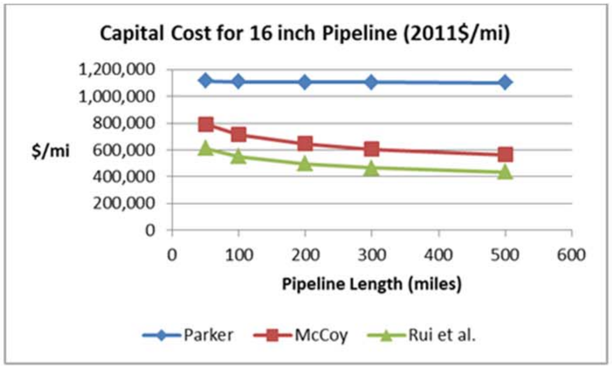
- **The discounted FCF is summed to give the net present value (NPV) of the project to the owners**

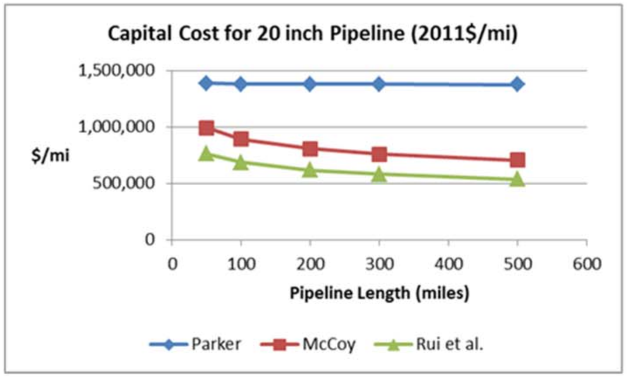
# Calculations in Financial Model (Cont'd)

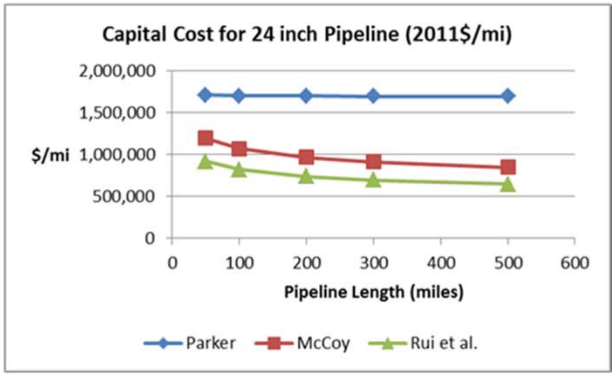
- **The model can be run different ways**
  - The user can specify the pipeline length (L), a first year price for transporting $CO_2$, and the number of pumps ($N_{pump}$); the model will then calculate the optimal pipeline diameter and NPV
  - The user can specify L and $N_{pump}$ and the model will then determine the optimal pipeline diameter. The user can run a macro that will determine the break-even first year price of $CO_2$
    - The break-even first year price of $CO_2$ is the price for transporting $CO_2$ that makes NPV for the project zero (the model presents this price rounded up to the nearest penny)
  - The user can specify L and provide a list of number of pumps and then run a macro that will:
    - Determine the break-even first year price of $CO_2$ for every value of $N_{pump}$ up to the maximum number of pumps in the list (the model will determine the optimal pipeline diameter for each choice of $N_{pump}$)
    - Determine which value of $N_{pump}$ gives the lowest break-even first year price of $CO_2$
  - The user can specify a list of number of pumps and a list of pipeline lengths and then run a macro that will sequence through the list of pipeline lengths and find the number of pumps that gives the lowest break-even first year price of $CO_2$ for each pipeline length
- **The break-even first year price of $CO_2$ is also the lowest first year cost of $CO_2$ for an operator that wants to transport $CO_2$**

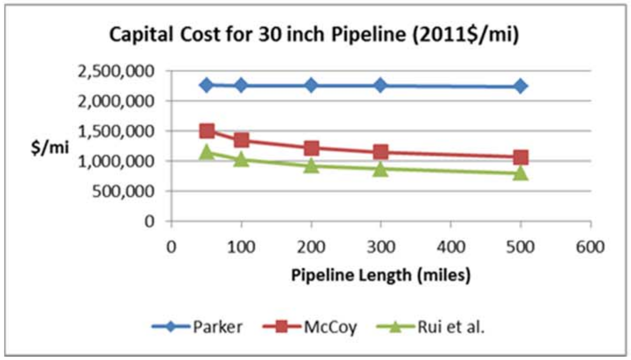
# Pipeline Capital Costs

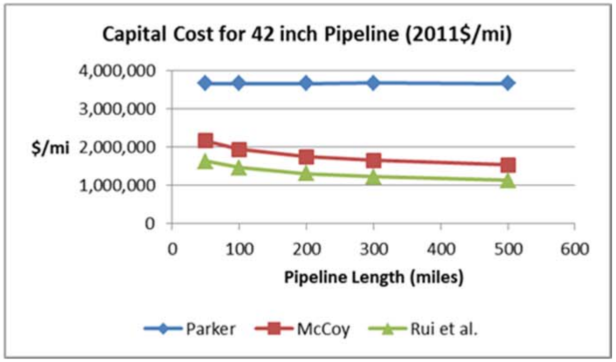



Equations from Parker (2004) give highest pipeline capital costs followed by McCoy and Rubin (2008) and Rui et al. (2011)

Note: Costs are in 2011$/mi

# Pipeline Capital Costs by Category


Labor is typically most significant contributor to total capital costs followed by materials, miscellaneous and ROW

Note: Costs are in 2011$/mi

# Comparison of Pipeline Capital Costs to Published Cost Data

- **Published data for capital costs of two $CO_2$ pipelines were compared to capital costs estimated with the three equations**
  - Equations from Parker (2004) and McCoy and Rubin (2008) give values closest to published cost data for pipelines
  - Equations of Parker (2004) tend to somewhat overestimate costs
  - Equations of McCoy and Rubin (2008) tend to underestimate costs
  - Equations of Rui et al. (2011) tend to significantly underestimate costs
- **Equations of Parker (2004) were used in NETL baseline studies to estimate cost of transporting $CO_2$ by pipeline**

# Example Results 1

| Length of Pipe mi | Optimal No. of Pumps | Pipe Diameter in | Break-even First Year Price $CO_2$ 2011$/tonne | Price per Mile 2011$/tonne-mi |
|---|---|---|---|---|
| 62.0 | 1 | 12.0 | 2.10 | 0.034 |
| 100.0 | 1 | 12.0 | 3.12 | 0.031 |
| 250.0 | 4 | 12.0 | 8.23 | 0.033 |
| 500.0 | 8 | 12.0 | 16.37 | 0.033 |
| 750.0 | 12 | 12.0 | 24.52 | 0.033 |
| 1,000.0 | 16 | 12.0 | 32.67 | 0.033 |

Flow: 3.2 tonnes/yr
Duration: 30 years
Pipeline capital costs: Parker (2004)

# Example Results 2

| Length of Pipe mi | Optimal No. of Pumps | Pipe Diameter in | Break-even First Year Price $CO_2$ 2011$/tonne | Price per Mile 2011$/tonne-mi |
|---|---|---|---|---|
| 62.0 | 0 | 36.0 | 0.67 | 0.011 |
| 100.0 | 0 | 36.0 | 1.07 | 0.011 |
| 250.0 | 1 | 36.0 | 3.01 | 0.012 |
| 500.0 | 3 | 36.0 | 6.36 | 0.013 |
| 750.0 | 4 | 36.0 | 9.36 | 0.012 |
| 1,000.0 | 6 | 36.0 | 12.70 | 0.013 |

Flow: 30 tonnes/yr
Duration: 30 years
Pipeline capital costs: Parker (2004)

# Participants

- Tim Grant (NETL) and Dave Morgan (NETL) worked together to initially conceptualize the model
- Paul Myles (WorkeyParsons) served as the ESPA project manager for this effort
- James Simpson (WorleyParsons) did the initial version of the model (engineering  equations and engineering costs)
- Dave Morgan, Andrea Poe (BAH) and Jason Valenstein (BAH) put together the initial version of the financial model
- Dave Morgan re-organized the model to make its structure similar to the FE/NETL $CO_2$ Saline Storage Cost Model, added the macros and wrote the documentation
- James Black (NETL) reviewed the engineering calculations
- Peter Kabatek (WorleyParsons) reviewed the engineering calculations, engineering costs and the non-financial aspects of the documentation and suggested revisions that were incorporated
- Kristin Gerdes (NETL) and Morgan Summers (NETL) reviewed the financial model and suggested revisions which were subsequently incorporated

# References

- **This presentation is based on the NETL document entitled "FE/NETL $CO_2$ Transport Cost Model: Description and User Guide"**
- **The references cited in this presentation can be found in the reference section of this document**