FE/NETL CO_2 Transport Cost Model (2018): Model Overview

NATIONAL ENERGY TECHNOLOGY LABORATORY

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U.S. DEPARTMENT OF ENERGY

FE/NETL CO_2 Transport Cost Model Overview

- **The FE/NETL CO_2 Transport Cost Model (Transport Cost Model) is an Excel-based mathematical model that estimates cost of transporting dense phase (liquid) CO_2 using a pipeline**
  - Single point-to-point pipeline
  - Booster pumps can be included along pipeline
- **Purpose of model is to mimic CO_2 transport operations to estimate costs associated with a potential CO_2 pipeline project and calculate first-year break-even price (in dollars per tonne) that covers all costs and provides investors with desired minimum return on investment**
- **Estimates first-year break-even price for different numbers of booster pumps and determines optimal number of booster pumps**
- **Includes capital and annual operation and maintenance (O&M) costs for pipeline equipment**
- **Provides flexible way for users to tailor the model to fit requirements of each individual project by adjusting parameters (e.g., financial parameters and project duration)**
- **Has engineering module with equations for pipe size, booster pumps, and equipment capital and operating costs**
- **Includes financial module with project cash flows including capital costs, operating costs, debt, equity, depreciation, and taxes**

Note: This presentation is based on material within the NETL document "FE/NETL CO_2 Transport Cost Model (2018): Description and User's Manual"[1]

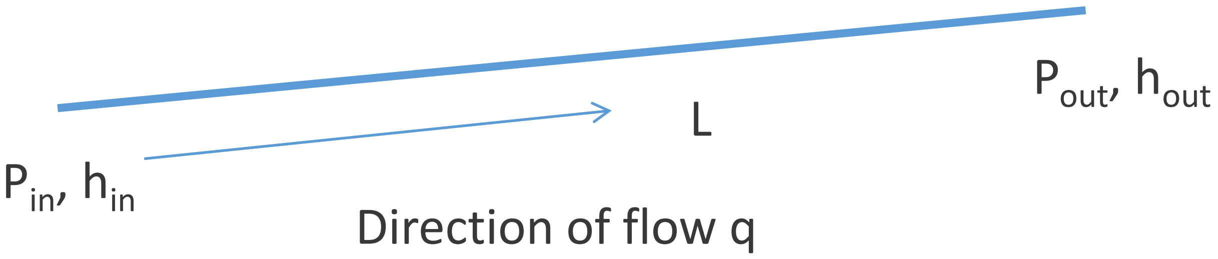
Transport Cost Model Orientation Summary

- **Consists of eight worksheets (first introductory, second and third core, and remaining not critical to functioning of model)**
  - READ_ME_FIRST
  - Main
    - Includes financial module
  - Eng Mod
    - Engineering module
  - PL Pressure Relation
  - Cost Indices
  - Pipe Cap
  - Pipe Cap plot1
  - Pipe Cap plot2
- **Has Visual Basic macros and user-defined functions**

Engineering Module

Pipeline

- **Pipeline costs depend on pipeline length and pipe diameter**
- **Diameter calculated using three 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 based on work done by**
  - McCollum and Ogden[2] and Massachusetts Institute of Technology[3]
    - Influence of elevation tacked on equations
  - Heddle et al.[4]
    - Influence of elevation tacked on equation
    - Listed together with MIT in model as one of three methods
  - McCoy and Rubin[5]
    - Influence of elevation included in equation derivation



P_{in} = 2,200 psig
P_{out} = 1,200 psig

Engineering Module

Pipeline (cont'd)

- **Actual pipe diameter 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: 4, 6, 8, or 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 (NG) pipelines and provided for four categories: materials, labor, right-of-way (ROW) and damages, and miscellaneous**
- **Capital costs estimated using three different regression equations**

Parker[6] (2000 dollars)

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

McCoy and Rubin[5] (2004 dollars)

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

Rui et al.[7] (2008 dollars)

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

Where $C_{png-x-i}$ is capital costs of category i using equation from author x, D is pipeline diameter (inches), L is pipeline length (miles [mi], kilometers, or feet [ft]), SA is cross-sectional area of the pipe (ft^2), and a_{i-0}, a_{i-1}, a_{i-2}, a_{i-3} and a_{i-reg} are regression coefficients with a_{i-reg} being region-specific

- **All costs were adjusted to 2011 dollars (2011$)**

Engineering Module

Pipeline (cont'd)

- **Pipeline costs for NG 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 only
- **Annual O&M costs for pipeline assumed to be $8,477/mi-yr based on O&M costs in Bock et al.[8] adjusted to 2011$**

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 O&M costs for booster pumps assumed to be 4 percent 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: $1,244,744 (2011$)[9]
- Pipeline control system: $111,907 (2011$)[9]
- Annual O&M costs for CO_2 surge tank and pipeline control system assumed to be 4 percent of capital costs based on professional judgment
- No costs for high precision CO_2 flow meters (assumed to be borne by CO_2 source and CO_2 storage operators)

Financial Module

- **User specifies several parameters including financial**
  - Start year (2011), length of construction period (3 years), and length of operations (30 years)
  - Distribution of capital costs over construction period (i.e., what fraction of capital costs for each type of equipment occur in each year)
  - Debt/equity ratio (45 percent/55 percent), cost of debt (5.5 percent per year), desired rate of return on equity (12 percent per year), escalation rate (3 percent per year), tax rate (24 percent), project contingency (15 percent)
  - Depreciation method (consists of depreciation method and recovery period for depreciation in model): DB150 – 15 years, SL – 15 years, or SL – 22 years where DB150 is 150 percent declining balance and SL is straight line
- **Model generates cash flow of revenues by multiplying the price for transporting CO_2 by the mass transported in a given year (real and nominal values)**

Note: Numbers in parentheses above are values used to calculate baseline costs for transporting CO_2. The basis of these values are discussed in the User's Manual.[1]

Calculations in Financial Model

- All capital costs are assumed to 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;[10] 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 dollars)

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

- Taxes are calculated using a generic 24 percent tax rate (i_{tax}) to account for federal, state, and local taxes (nominal dollars)

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

Calculations in Financial Model (cont'd)

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

  $$EBIAT = EBIT - taxespaid$$

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

  $$FCF = EBIAT + \ depreciation\ - CAPEX\ - change\ in\ net\ working\ capital$$

  Where *change in net working capital* is assumed to be zero

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

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

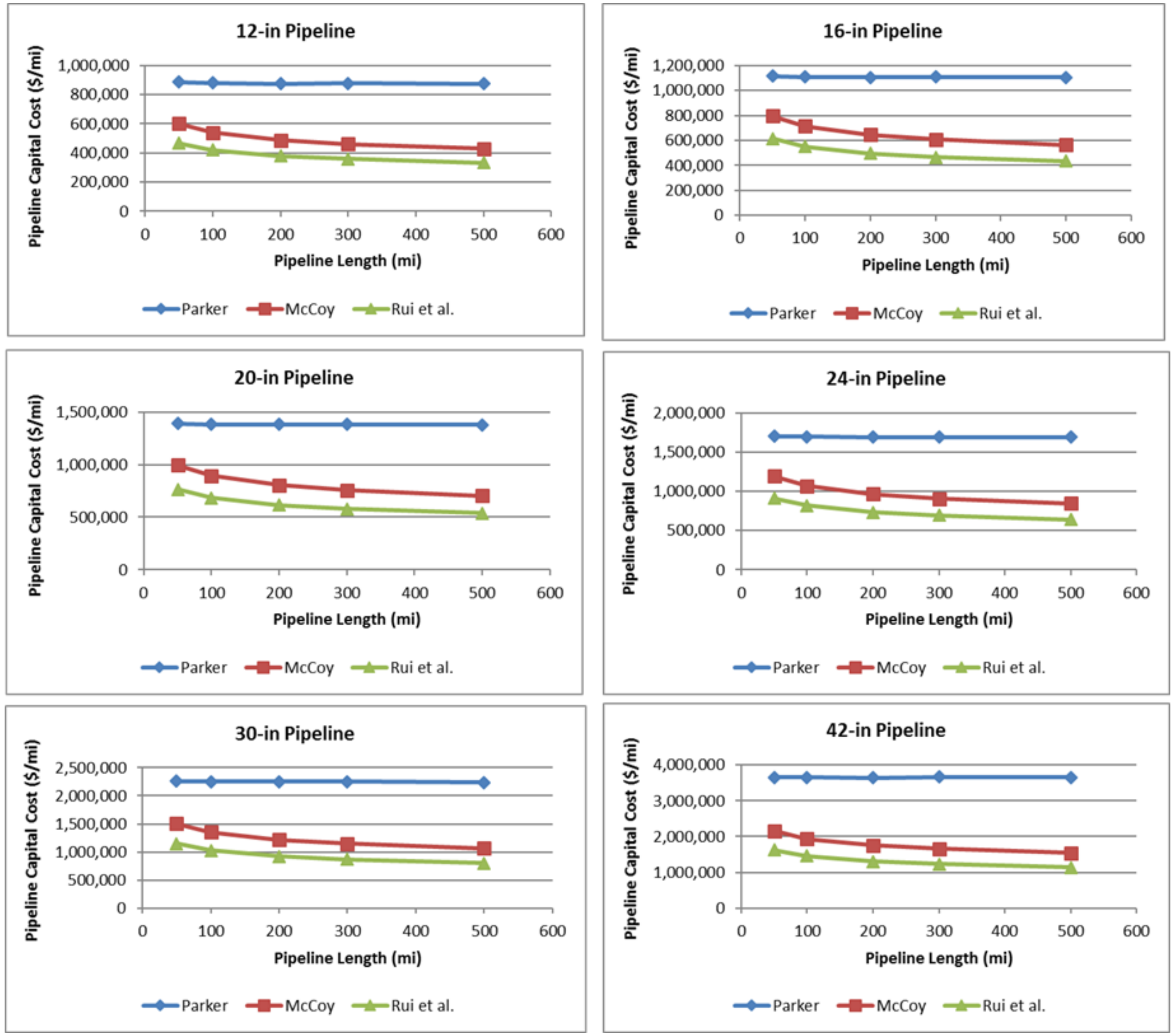
  Where f_{eq} is fraction of financing from equity (dimensionless), $IRROE_{min}$ is minimum desired internal rate of return on equity (percent per year), and i_{debt} is interest rate on debt (percent per year)

- **Discounted FCFs for each year are summed to give the net present value (NPV) of the project to the owners**

Running the Model

- **Model can be run from "Main" sheet in four ways. Methods 2 through 4 require running macro**
  - Method 1: Specify pipeline length (L), first-year price for transporting CO_2, and number of pumps (N_{pump})
    - Model will calculate optimal pipeline diameter and NPV
  - Method 2: Specify L and N_{pump} and run macro
    - Macro will determine optimal pipeline diameter and first-year break-even price of CO_2 for specified number of pumps
  - Method 3: Specify L, list number of pumps where results are desired, and run macro that determines
    - First-year break-even price of CO_2 for every value of N_{pump} up to the maximum number of pumps in the list
    - Optimal pipeline diameter for each choice of N_{pump}
    - Which value of N_{pump} gives the lowest first-year break-even price of CO_2
  - Method 4: List number of pumps and pipeline lengths where results are desired and run macro that
    - Sequences through list of pipeline lengths and finds the number of pumps that gives the lowest first-year break-even price of CO_2 for each pipeline length
- **First-year break-even price of CO_2 is price for transporting CO_2 that makes NPV for the project zero (model presents this price rounded up to the nearest penny)**
  - First-year break-even price is also lowest first-year cost of CO_2 for an operator that wants to transport CO_2

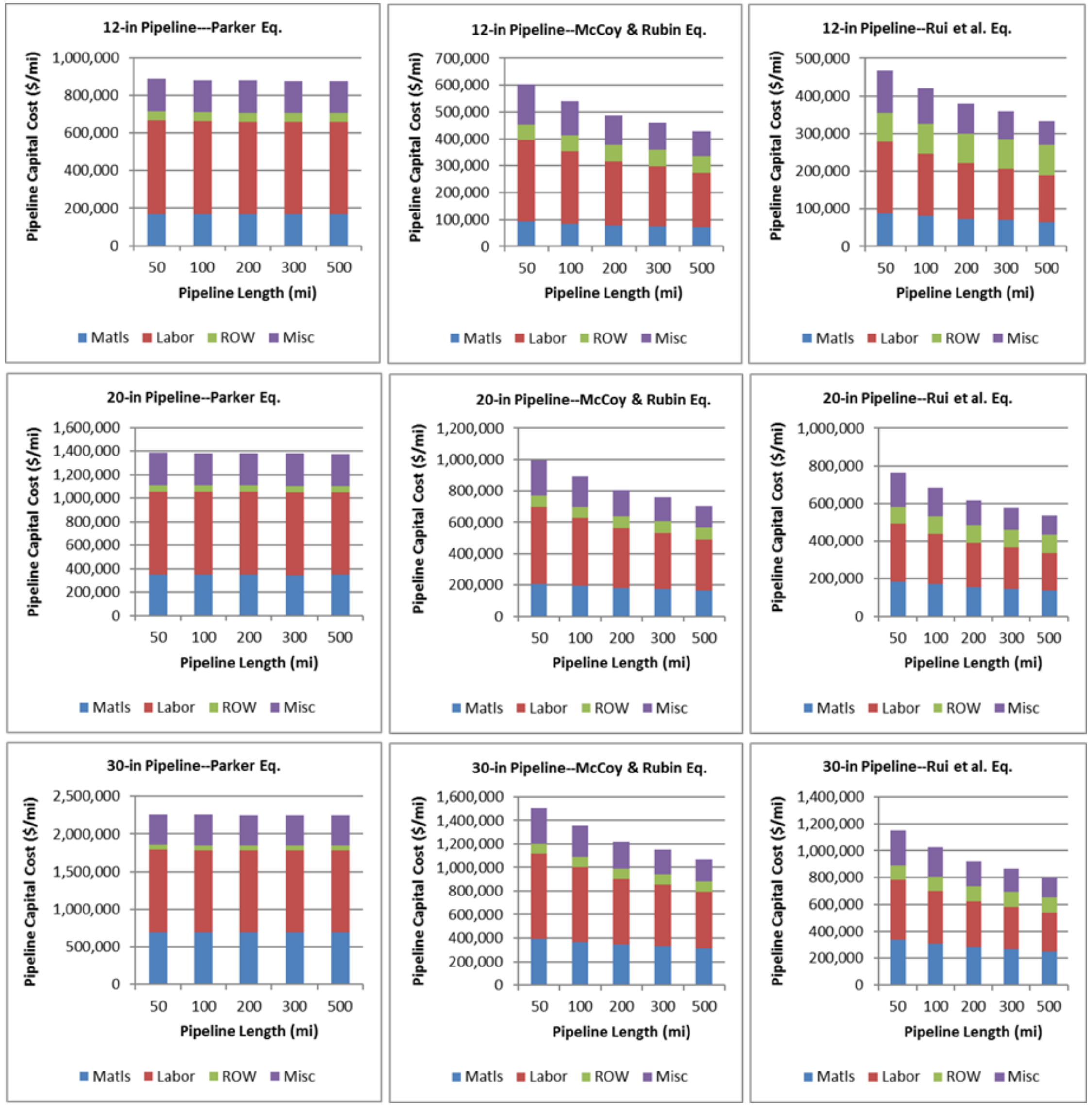
NG Pipeline Capital Costs



Equations from Parker generally give the highest pipeline capital costs followed by McCoy and Rubin and Rui et al.[5,6,7]

Note: Costs are in 2011$/mi, and in McCoy and Rubin and Rui et. al, the Midwest region was selected for the results[5,7]

NG Pipeline Capital Costs by Category



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

Note: Costs are in 2011$/mi, and in McCoy and Rubin and Rui et. al, the Midwest region was selected for the results[5,7]

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 and McCoy and Rubin give costs closest to published cost data for CO_2 pipelines[5,6]
  - Equations from Parker tend to somewhat overestimate costs[6]
  - Equations from McCoy and Rubin tend to underestimate costs[5]
  - Equations from Rui et al. tend to significantly underestimate costs[7]
- **Equations from Parker were used in NETL baseline studies to estimate cost of transporting CO_2 by pipeline[6]**

Example Results 1

Length of Pipe mi	Optimal No. of Pumps	Pipe Diameter in	First-Year Break-Even Price CO_2 2011$/tonne	Price per Mile 2011$/tonne-mi
62	1	12	2.00	0.032
100	1	12	2.97	0.030
250	4	12	7.83	0.031
500	8	12	15.59	0.031
750	12	12	23.35	0.031
1,000	16	12	31.11	0.031

Note: These results were produced by using the default values presented in the model but changing pipeline length per values in table above

Example Results 2

Length of Pipe mi	Optimal No. of Pumps	Pipe Diameter in	First-Year Break-Even Price CO_2 2011$/tonne	Price per Mile 2011$/tonne-mi
62	0	36	0.63	0.010
100	0	36	1.01	0.010
250	1	36	2.85	0.011
500	3	36	6.03	0.012
750	4	36	8.87	0.012
1,000	6	36	12.05	0.012

Note: These results were produced by using the default values presented in the model but changing pipeline length per values in table above and annual tonnes of CO_2 transported (on average) to 30 million tonnes per year

References

[1] National Energy Technology Laboratory. FE/NETL CO_2 Transport Cost Model: Description and User's Manual. U.S. Department of Energy, DOE/NETL-2018/1877, Pittsburgh, PA, 2018.

[2] McCollum, D. and Ogden, J., "Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage & Correlations for Estimating Carbon Dioxide Density and Viscosity," Institute of Transportation Studies, University of California at Davis, UCD-ITS-RR-06-14, Davis, CA, 2006.

[3] Massachusetts Institute of Technology (MIT), "Carbon Management GIS: CO_2 Pipeline Transport Cost Estimation," Carbon Capture and Sequestration Technologies Program, MIT, 2009.

[4] Heddle, G., Herzog, H., and Klett, M., "The Economics of CO_2 Storage," Massachusetts Institute of Technology, Laboratory for Energy and the Environment, MIT LFEE 2003-003 RP, Cambridge, MA, 2003.

[5] McCoy, S. and Rubin, E., "An engineering-economic model of pipeline transport of CO_2 with application to carbon capture and storage," *International Journal of Greenhouse Gas Control*, vol. 2, no. 2, pp. 219-229, 2008.

[6] Parker, N., "Using Natural Gas Transmission Pipeline Costs to Estimate Hydrogen Pipeline Costs," Institute of Transportation Studies, University of California at Davis, UCD-ITS-RR-04-35, Davis, CA, 2004.

[7] Rui, Z., Metz, P., Reynolds, D., Chen, G., and Zhou, X., "Regression models estimate pipeline construction costs," *Oil and Gas Journal*, vol. 109, no. 27, pp. 120-127, 2011.

[8] Bock, B., Rhudy, R., Herzog, H., Klett, M., Davison, J., De La Torre Ugarte, D., and Simbeck, D., "Economic Evaluation of CO_2 Storage and Sink Enhancement Options," TVA Public Power Institute, DE-FC26-00NT40937, 2003.

[9] National Energy Technology Laboratory (NETL), "Quality Guidelines for Energy System Studies: Estimating Carbon Dioxide Transport and Storage Costs," U.S. Department of Energy, DOE/NETL-2010/1447, Pittsburgh, PA, March 2010.

[10] Internal Revenue Service (IRS), "How to Depreciate Property, Publication 946," Department of the Treasury, IRS, 2018.

Contacts

- **David Morgan, Ph.D.**
  - David.Morgan@netl.doe.gov
  - 412-386-7405
- **Tim Grant**
  - Timothy.Grant@netl.doe.gov
  - 412-386-5011