Pipeline Blending CRADA techno-economic analysis

BlendPATH Webinar

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National Renewable Energy Laboratory (NREL)

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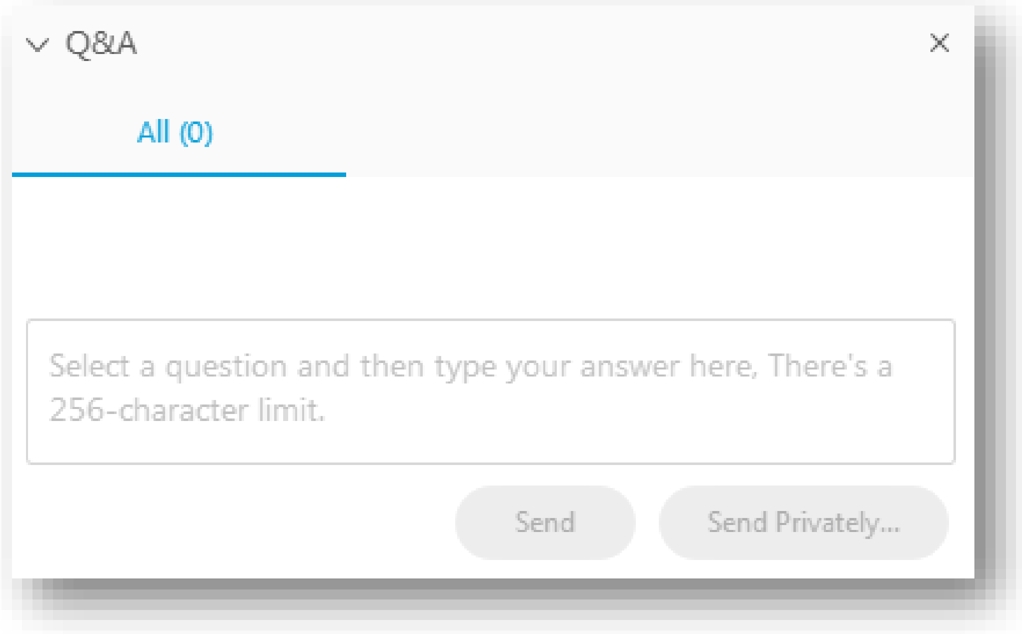
This webinar is recorded and will be posted on NREL's website at [*https://www.nrel.gov/hydrogen/systems-analysis.html*](https://www.nrel.gov/hydrogen/systems-analysis.html)

Questions and Answers

Please type your questions into the **Q&A Box.**



BlendPATH Webinar and Agenda

- Introduction
- BlendPATH methodology
- Installing and running BlendPATH
- Live demonstration

What is the Blending Pipeline Analysis Tool for Hydrogen (BlendPATH)?

- BlendPATH is an NREL-developed Python tool that allows users to answer the following for blending hydrogen to *X%* in pipeline gas:
  - What modifications to a natural gas transmission pipeline network are required?
  - What incremental capital investment and operating expense are required?
- This model targets application at the initial project assessment stage for transmission pipelines
- Intent is to provide the user with an understanding of the <u>most promising opportunities</u> before proceeding with more detailed pipeline inspections based on “probable” economic outcome

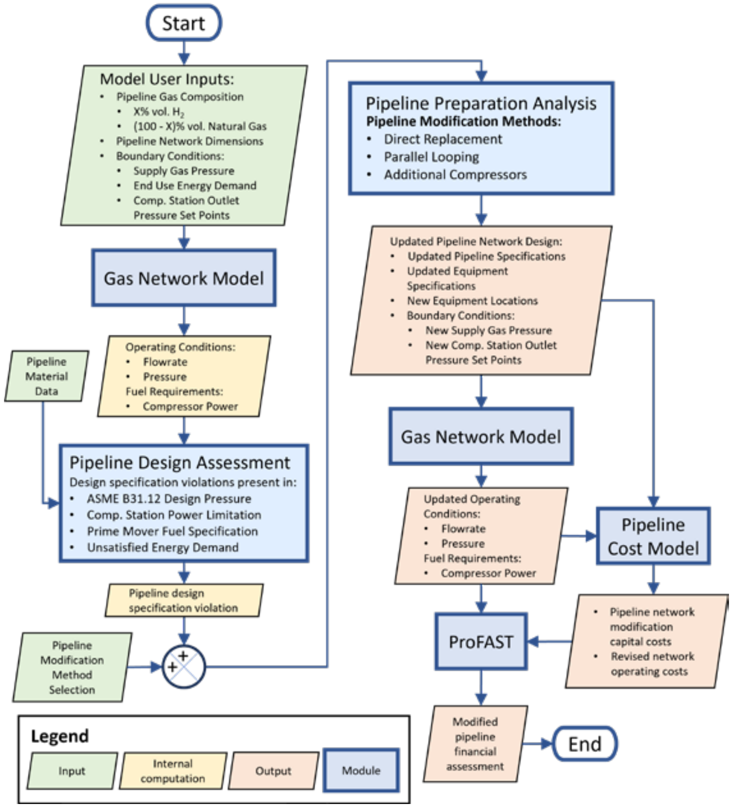


Figure 1: Blending Pipeline Analysis Tool for Hydrogen framework.

This webinar focuses on the initial release of BlendPATH and its current capabilities as a research tool; given this, BlendPATH is subject to limitations

- BlendPATH analysis is currently limited to linear pipelines
- Depending on the pipeline network analyzed, BlendPATH might not currently be capable of analyzing blends up to 100 vol.% hydrogen
- The initial release of BlendPATH requires SAInt[+], a commercial integrated energy system modeling platform with capabilities in gas pipeline hydraulics and Python API access
- BlendPATH does **NOT** qualify pipeline networks nor modifications thereof for hydrogen blending, despite applying ASME B31.12* in an assessment
    - Pipeline network qualification will require additional evaluation, independent of BlendPATH application, as specified in ASME B31.12*
    - It is the sole responsibility of the pipeline owner and operator to ensure that their pipeline qualifies for ASME B31.12* and other relevant regulations and that any present defects in the pipeline network are acceptable at the operating pressure chosen for blending hydrogen

[+] A version of BlendPATH with an open-source gas pipeline hydraulic model is in development

* Or any industry standard succeeding ASME B31.12 for hydrogen pipelines

Agenda

Introduction

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BlendPATH apportions the modeled pipeline network into segments for design pressure rating and pipeline network modification

- BlendPATH application requires a converged simulation instance of natural gas pipeline network operation without hydrogen blending as an analysis starting point
- Within the pipeline design assessment module, BlendPATH divides the modeled pipeline network into separate pipe segments
- A pipe segment is defined here as groups of consecutive pipes that can withstand the same design pressure throughout for line packing purposes
- Pipe segments are delimited within BlendPATH by the following network structure elements:
  - Compressor or pressure reduction stations
  - Changes in nominal pipe diameter

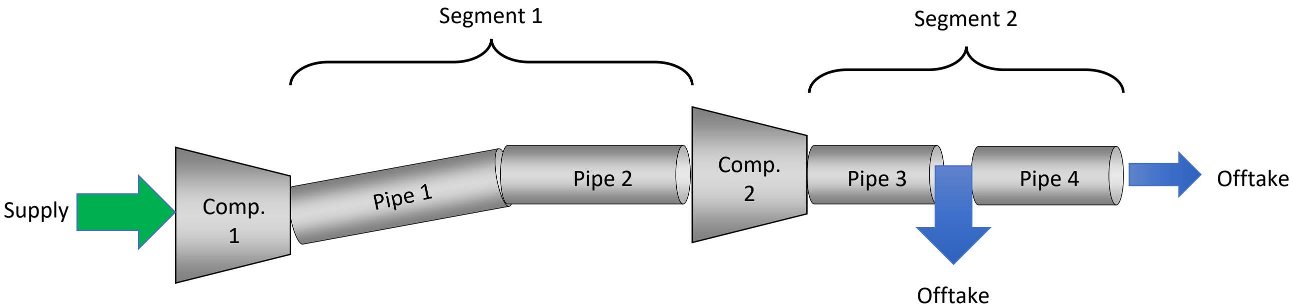


Figure 2: Example of pipe network segmentation.

The Pipeline Design Assessment module identifies design pressure violations according to the user-specified ASME B31.12 design option for blending

- BlendPATH simulates operating conditions to meet end use energy demands in the existing network via the gas network hydraulic model (e.g., SAInt) while accounting for a user-specified X % vol. of H_2 in pipeline gas
- The Pipeline Design Assessment module assesses and updates pipeline segment design pressures (aka maximum allowable operating pressure) based on the user-specific ASME B31.12 design option
  - ASME B31.12 allows three design options to qualify and rate pipelines for blending (see Table 1)
  - Design options require varying extents of pipeline material characterization for qualification
- BlendPATH identifies which segments' operating pressures exceed (and therefore violate) their updated ASME B31.12 design pressures and earmarks these segments for modification

$$P = \frac{2St}{D} FETH_f$$

- S – SMYS
- t – Thickness
- F – Design factor
- H_f – Material performance factor
- T – Temperature derating factor
- E – Longitudinal joint factor
- D – Diameter
- P – Pipeline Segment Design Pressure

Figure 3: ASME B31.12 design pressure formula

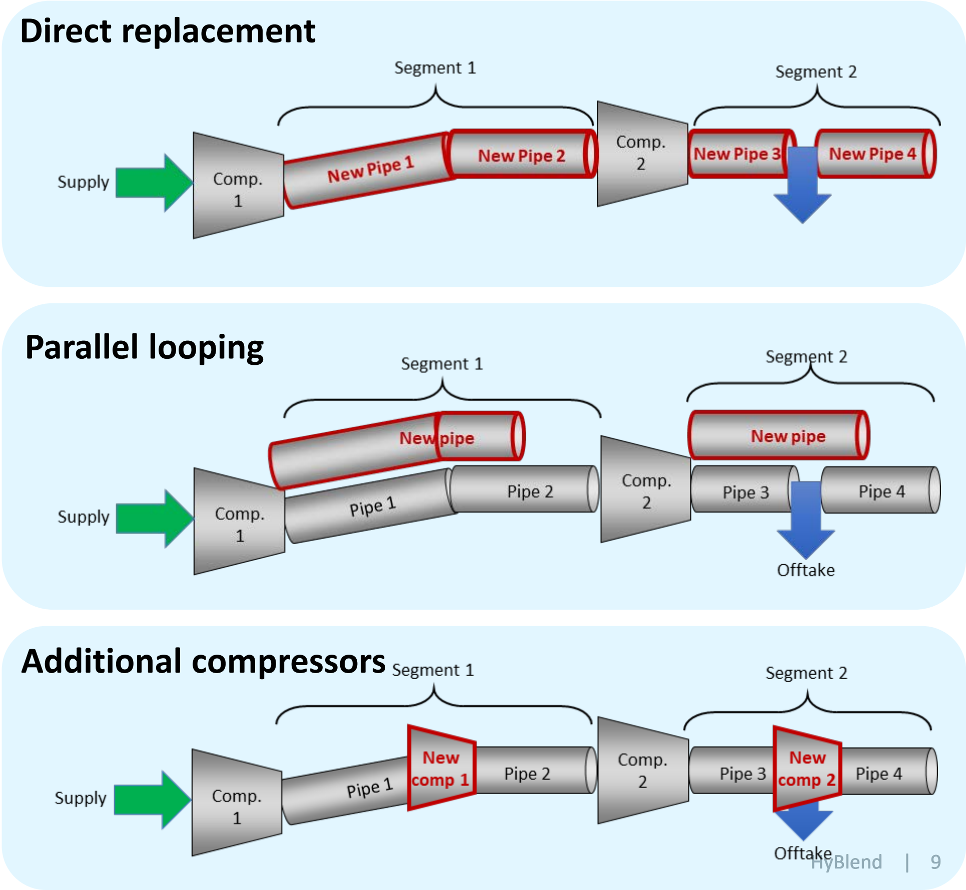
Table 1: ASME B31.12 design factor per design option

	Design factor, *F*	
Location class	Option A	Option B
Location class 1, Division 2	0.50	0.72
Location class 2	0.50	0.60
Location class 3	0.50	0.50
Location class 4	0.40	0.40

*ASME B31.12 allows a third option where the Design factor, F, is limited to 0.4, which is referred here as ”no fracture control”

BlendPATH modifies pipe segments with design pressure violations to accommodate hydrogen blending and meet pipeline network end use energy demand

- BlendPATH offers three methods (see right) used in industry to modify pipeline segments
- The direct replacement method maintains segment operating pressures by replacing extant pipe with new pipe of same diameter but of the appropriate grade and thickness
- Both parallel looping and additional compressors methods reduce segment operating pressure, but increase volumetric capacity by adding parallel piping or compression stations, respectively



BlendPATH, by default, costs pipe segment modification with publicly available resources and applies ProFAST for economic analysis

- BlendPATH applies pipe material costs in terms of price per weight from Savoy Piping Inc.* for commonly-used line pipe steel grades
- Natural gas transmission pipeline labor, miscellaneous and right-of-way (ROW) cost equations from Brown, Reddi, and Elgowainy (2022) are the default method in costing pipeline segment modifications
- Natural gas compressor station material, labor, ROW, and miscellaneous cost equations from Rui (2011) are the default method in costing compressor station capacity additions
- *All costs can be overridden with user input*
- ProFAST, a pythonic version of H2FAST, compiles capital, operating and financing costs into a levelized cost of transport and provides a cost breakdown
- H2FAST is freely accessible via NREL's website at https://www.nrel.gov/hydrogen/h2fast.html

H2FAST

*https://www.savoypipinginc.com/blog/live-stock-and-current-price.html

Agenda

Introduction

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Live demonstration

BlendPATH is installable as a Python package using pip

- BlendPATH installation requires the user to have Anaconda and Git installed on their server or PC; SAInt is required to run BlendPATH
- BlendPATH code is to be hosted at `github.com/NREL/BlendPATH` and is downloadable by entering the following command in a git bash terminal:

```
git clone https://github.com/NREL/BlendPATH.git
```

- We recommend users to set up a virtual environment for BlendPATH installation and use with the following commands in the Anaconda prompt:

```
conda create -n MY_ENV_NAME python=3.10
conda activate MY_ENV_NAME
cd ~/Documents/GitHub/BlendPATH
pip install .
```

- We recommend that BlendPATH is used though Visual Studio Code with `MY_ENV_NAME`

BlendPATH input files require a specific file structure within the user’s accessed directory

- MY_DIRECTORY
  - MY_PYTHON_SCRIPT.py
  - CASE_STUDY_NAME
    - CASE_STUDY_NAME_Event.xlsx
    - CASE_STUDY_NAME_Network.xlsx
    - CASE_STUDY_NAME_pipe_mech_props.xlsx
    - CASE_STUDY_NAME.json
    - MY_RESULTS_DIRECTORY

- CASE_STUDY_NAME must be the same in all file names
- _Event and _Network files must follow SAInt input file formatting
- _pipe_mech_props specifies the SMYS and SMTS for each pipe
- .json file is optional, and holds ProFAST economic parameters
- An example is provided in the BlendPATH file directory

Hydrogen blending analyses are set up as a BlendPATH scenarios in the Python script below

```python
import BlendPATH
import numpy as np

casestudy_name = 'Wangetal2018'
design_option_choice = 'no fracture control'
save_dir = casestudy_name + '/out/DO - ' + design_option_choice + '/'
blendpath = BlendPATH.BlendPATH_scenario(casestudy_name = casestudy_name ,
                        save_directory = save_dir,
                        design_option = design_option_choice,
                        location_class  = 1,
                        joint_factor  = 1,
                        compression_ratio  = 1.55,
                        blending = 0.2,
                        natural_gas_cost = 7.39,
                        hydrogen_cost = 4.41,
                        final_outlet_pressure=3325000,
                        region = 'GP',
                        PL_num_diams = 12,
                        original_CS_rating={'CS1':12.5,'CS2':12.5,'CS3':12.5}
                        )
```

- import BlendPATH: Import BlendPATH Python package
- casestudy_name: Case study name, matches with directory name
- design_option_choice: ASME B31.12 design option to assess modeled existing pipeline
- save_directory: Directory to save results
- location_class: ASME B31.12 location class (1-4)
- joint_factor: ASME B31.12 joint factor
- compression_ratio: Design compression ratio for new compressors
- blending: Mol fraction of hydrogen in blended pipeline gas
- natural_gas_cost: Natural gas cost ($/MMBTU)
- hydrogen_cost: Hydrogen cost ($/kg)
- final_outlet_pressure: Minimum pressure at modeled pipeline terminus (Pa)
- original_CS_rating: Design rating of existing compression stations (MW)

run_mod and run_financial conduct the design modification and economic analyses within BlendPATH, respectively

```
cost_overrides = {k:np.NaN for k in ['OVERRIDE: labor cost ($/in/mi)',
                                     'OVERRIDE: row cost ($/in/mi)',
                                     'OVERRIDE: misc cost ($/in/mi)',
                                     'OVERRIDE: Original pipeline cost ($)']}

blendpath.run_mod('direct_replacement','b')
# blendpath.run_mod('parallel_loop','b')
# blendpath.run_mod('additional_compressors','b')

LCOT = blendpath.run_financial(cost_overrides)

print(f'Levelized cost is: {round(LCOT,5)} $/MMBTU')
```

Cost overrides

Run modification method on case study

Run financial analysis on modification

Print out levelized cost of transport ($/MMBTU)

blendpath.run_mod(mod_type, design_option)

The "design_option" input to run_mod refers to the ASME B31.12 design option users anticipate to pursue qualification for **new** pipe in design modifications

Table 2: run_mod parameter options

Parameter	Options
mod_type	'direct_replacement'
	'parallel_loop'
	'additional_compressors'
design_option	'a'
	'b'
	'no fracture control'

Detailed BlendPATH solutions are located under MY_RESULTS_DIRECTORY in the CASE_STUDY_NAME folder

- MY_DIRECTORY
  - MY_PYTHON_SCRIPT.py
  - CASE_STUDY_NAME
    - MY_RESULTS_DIRECTORY
      - NetworkFiles
        - SAInt network and event files
      - ResultFiles
        - BlendPATH summary files

SAInt network and event files

- The network file after applying the pipeline modification
- Updated inlet pressure to MAOP
- Updated compressor outlet pressure or compression ratio

BlendPATH summary file

- Read out of input variables
- Financial inputs and outputs
- CAPEX and OPEX breakdown
- New pipe and compressor design
- Demand errors*

*Percent unsatisfied energy end use demand with new network design

BlendPATH summary files provide finer detail on achieved solutions regarding network modifications and economic results

Parameter	Value	Units
Levelized Cost of Transport	0.255628718	$/MMBTU
LCOT: Original network	0	$/MMBTU
LCOT: New pipe	0.102719757	$/MMBTU
LCOT: New compressor stations	0	$/MMBTU
LCOT: Compressor station refurbishmen	0.014989512	$/MMBTU
LCOT: Compressor fuel	0.110810313	$/MMBTU
LCOT: Fixed O&M	0.005184954	$/MMBTU
LCOT: Taxes	0.021671537	$/MMBTU
LCOT: Financial	0.000252645	$/MMBTU
Hydrogen Injection Price	4.40756292	$/kg
Natural Gas Price	7.39	$/MMBTU
Blended Gas Price	13.34242734	$/MMBTU
Pipeline Capacity (daily)	527619.2587	MMBTU/day
Pipeline Capacity (hourly)	21984.13578	MMBTU/hr
Added pipeline	248.5490947	mi
Added compressor stations	0	
Added compressor capacity	0	hp
Compressor fuel usage	182.5806427	MMBTU/hr
New pipe	314657767.6	2020$
New compressor stations	0	2020$
Compressor station refurbishment	45916837.55	2020$
Original network residual value	0	2020$

Summary values

Cost breakdown of new pipe

Pipe Diameter [in]	Length [mi]	Grade	Schedule	Material Cost [$]	Labor [$]	Misc [$]	ROW [$]	l unit cost [$/i	unit cost [$/in-	nit cost [$/in	nit cost [$/in-mile]
26	248.5490947	X60	S Std	195451269.8	82695449.5	36511048.3	0	30244.9564	12796.64373	5649.8741	0

Pipe cost breakdown

Breakdown of original pipe

Pipe Diameter [in]	Length [mi]	Grade	Schedule
26	248.5490947	X60	S Std

Original pipe info

Cost breakdown of compressors

Shaft Power (MW)	Rated Capacity (MW)	d Additional Capa	er of Compressor St	ompressor Station Ca	Cost (2020$)	usage (MMBTU/hr)
5.901907444	12.5	0	0	0	0	59.229599
7.616342545	12.5	0	0	0	0	76.435112
4.674917221	12.5	0	0	0	0	46.9159317

Compressor info

Disclaimer | Inputs | **Results** | New pipe design | Demand errors

Navigation

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Introduction

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Running BlendPATH

Live demonstration

This live demonstration showcases BlendPATH application to a published transmission pipeline case study

- We use a modified version of a Wang et al. (2018) case study for demonstration
- This case study details a 250-mile pipeline over negligible elevation change that consists of a single diameter, grade, and schedule
- This modified case study is distributed as part of BlendPATH under `BlendPATH/examples/Wangetal2018`

Table 3: Modified Wang et al. (2018) pipeline design

Pipeline Segment ID	0	1	2	3
Diameter (DN)	650	650	650	650
Schedule	S Std	S Std	S Std	S Std
Grade	X60	X60	X60	X60
Length (mi)	43.5	80.8	62.2	62.2
Design Pressure (MPa-g)	8.7	8.7	8.7	8.7

Table 4: Modified Wang et al. (2018) pipeline boundary conditions

Boundary Condition	Value	Unit
Gas Supply Pressure	8.7	MPa-g
CS1 Outlet Pressure	8.7	MPa-g
CS2 Outlet Pressure	8.7	MPa-g
CS3 Outlet Pressure	8.7	MPa-g
Off-take 1 Demand	1150	MW
Off-take 2 Demand	2991	MW
Off-take 3 Demand	2301	MW

Wang, B., Y. Liang, J. Zheng, R. Qiu, M. Yuan, and H. Zhang. 2018. “An MILP model for the reformation of natural gas pipeline networks with hydrogen injection” [in en]. Int. J. of Hydrogen Energy 43, 16141–16153.

Additional documentation on BlendPATH is forthcoming; further development for BlendPATH is planned within HyBlend™

- The BlendPATH source code is to be hosted on github.com/NREL via https://github.com/NREL/BlendPATH
- The BlendPATH user manual and technical documentation will be published as an NREL technical report
  - User manual and technical documentation to be added with the BlendPATH source code in the above linked GitHub repository
  - Please direct any questions on BlendPATH and/or this webinar to kevin.topolski@nrel.gov
- Phase II of HyBlend™ is currently being planned
  - Planned Phase II scope includes developments to BlendPATH, in addition to materials and analysis research on blending hydrogen into the natural gas pipeline system
  - Partners to this Phase II will gain access to pre-published research and can provide input on scope
  - If you interested in learning more, contact HyBlend_CRADA@nrel.gov for details

Thank You + Q&A

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Additional resources:

https://www.nrel.gov/hydrogen/systems-analysis.html

https://www.nrel.gov/docs/fy23osti/81704.pdf

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HyBlend
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Back Up

New pipe capital cost includes material, labor, right-of-way, and miscellaneous components

Table 5: Regional pipeline capital cost component correlation parameters adapted from Brown, Reddi, and Elgowainy (2022)

Region	Cost Component	*a*	*b*	*c*
Great Plains, Rocky Mountain	Labor	10406	0.20953	-0.08419
	Miscellaneous	4944	0.17351	-0.07621
	Right-of-way	2751	-0.28294	0.00731
New England	Labor	249131	-0.33162	-0.17892
	Miscellaneous	65990	-0.29673	-0.06856
	Right-of-way	83124	-0.66357	-0.07544
Mid-Atlantic	Labor	43692	0.05683	-0.10108
	Miscellaneous	14616	0.16354	-0.16186
	Right-of-way	1942	0.17394	-0.01555
Great Lakes	Labor	58154	-0.14821	-0.10596
	Miscellaneous	41238	-0.34751	-0.11104
	Right-of-way	14259	-0.65318	0.06865
Southeast, Pacific Northwest	Labor	32094	0.06110	-0.14828
	Miscellaneous	11270	0.19077	-0.13669
	Right-of-way	9531	-0.37284	0.02616
Southwest, California	Labor	95295	-0.53848	0.03070
	Miscellaneous	19211	-0.14178	-0.04697
	Right-of-way	72634	-1.07566	0.05284

$$C_{p,r,t} \quad (2018\$/\text{inch-mile}) = aD^bL^c$$

- Cost correlation are provided by default
- New pipe capital costs **can be overridden** by user input

Table 6: Steel pipe material costs based on weight (Savoy Piping Inc.,)

Grade	Price ($/kg)
B	1.8
X42	2.2
X46	2.4
X52	2.8
X56	2.9
X60	3.2
X65	4.3
X70	6.5

Compressor station capital cost includes material, labor, miscellaneous, and land components

Table 7: Compressor station cost coefficients adapted from Rui (2011)

Component	a	b	c
Material	3175286	532.7853	0.0010416
Labor	1581740	299.2887	0.001142
Miscellaneous	1696686	184.1443	0.0018417
Land	66216.72	0	0.0001799

$$C_{CS,t} \ (2008\$) = a + bS + cS^2$$

- Compressors operating at more than 10% H2 blend and at similar operating pressure are replaced at 60% cost
- Compressor cost is based on cost correlation with compressor capacity in horsepower
- Max compressor capacity is assumed to be 30,000 hp
- Upgrades for compressors are based on average horsepower

Levelized cost of transport is calculated using ProFAST using generally accepted accounting principles

Table 8: Default economic parameters in ProFAST in the absence of user-supplied parameters

Parameter	Value
Analysis start year	2020
Operating life	50 years
Installation months	36 months
Long term utilization	100%
Property tax and insurance	0.9%
Administrative expense	0.5%
Total income tax rate	25.74%
Capital gains tax rate	15%
General inflation rate	1.9%
Nominal discount rate	10%
Debt to equity ratio	1.5
Debt type	Revolving debt
Debt interest rate	3.7%
Cash on hand	1 month

- 30 yr straight line depr
- NPV = 0
- Provides cashflow tables etc