Matrix of Potential Repair Methods for Internal Repair of Pipelines
Award No. DE-FC26-02NT41633
Milestone M9

To capture the results of Subtask 4.1 activities, a Matrix of Potential Repair Methods (M9) was created to compare and contrast the collective knowledge of, and interest in, specific repair methods that should be emphasized in the experimental portion of this project.

The five major feasibility categories defined for the Matrix:

- Technical Feasibility
- Inspectability
- Technical Feasibility of the Process while the Pipeline is In-Service
- Cost
- Industry Experience with the Repair Method

Each feasibility category was then subdivided into capabilities or characteristics to rank. Each capability/characteristic was assigned a unique weight factor to distinguish its importance in the overall repair process feasibility. Weight factors were based on the quantity of survey responses associated with the feasibility capability/characteristic, with the sum of all weight factors being 100%.

For each potential repair process, individual feasibility capabilities were rated on a scale from (-1) to (5) as defined in Table 1.

Rating	Definition of Rating
-1	Unacceptable
0	Unknown Potential - High Risk
1	Marginal Potential - High Risk
2	Development Required - High Risk
3	Development Required - Low Risk
4	Acceptable - No Risk
5	Ideal - No Risk

Table 1 - Key to Ratings in Potential Repair Process Matrices (Table 2 - Table 3)

Each rating was then multiplied by its unique weight factor to arrive at the weighted score for the individual feasibility capability. Five feasibility characteristics were determined to be "show stoppers," given the fact that an unacceptable rating for these capabilities would negate repair process feasibility.

The five show stoppers were identified as:

- Ability to Perform the Process Out-of-Position
- Technical Feasibility of the Process Itself
- Ability of the Process to Match the Strength of the Base Material
- Technical Feasibility of Performing the Process In-Service
- Material Cost

The rating of each show stopper was multiplied by 25 to produce the corresponding weighted score.

The Matrix of Potential Repair Methods is subdivided into three technology specific tables: Potential Welding Repair Methods (Table 2), Potential Liner Repair Methods (Table 3), and Potential Surfacing Repair Methods (Table 4).

Feasibility Category	Weight Factor	Capability or Characteristic to Rank	Welding Processes											
			GTAW		GMAW		FCAW		SAW		Laser		Explosive	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Technical		Out-of-Position Applicability	2	50	3	75	3	75	-1	-25	2	50	1	25
		Process Technical Feasibility	2	50	3	75	-1	-25	-1	-25	0	0	-1	-25
	5%	Process Robustness	2	10	3	15	2	10	0	0	2	10	1	5
	10%	Repair Permanence	2	20	3	30	2	20	0	0	2	20	1	10
	10%	Process Deployment Risk	2	20	5	50	-1	-10	0	0	1	10	-1	-10
	5%	Remote Operation Feasibility	2	10	3	15	-1	-5	0	0	1	5	0	0
		Ability to Match Strength of Pipe Material	3	75	4	100	4	100	0	0	3	75	3	75
	1%	Ability to Match Pipe Corrosion Resistance	3	3	4	4	4	4	0	0	4	4	3	3
	1%	Ability to Effect Patch Repair	2	2	3	3	-1	-1	0	0	2	2	-1	-1
	5%	Ability to Effect Circumferential Repair	2	10	3	15	-1	-5	0	0	2	10	1	5
	10%	Ability to Negotiate 3D Bends	3	30	3	30	3	30	3	30	0	0	0	0
	5%	Metallurgical Bond	5	25	5	25	5	25	5	25	5	25	2	10
	1%	Mechanical Bond	5	5	5	5	5	5	5	5	5	5	2	2
Inspectability	5%	Ability to Inspect via Pigging	5	25	5	25	-1	-5	0	0	5	25	0	0
	5%	Radiographic Flaw Detectability	5	25	5	25	5	25	5	25	5	25	-1	-5
In-Service	7%	Low Power Required (Process Efficiency)	4	28	4	28	4	28	1	7	-1	-7	-1	-7
	5%	Pipeline Depressurized, But Not Evacuated	2	10	2	10	2	10	0	0	0	0	0	0
	5%	Pipeline Pressurized	0	0	0	0	0	0	0	0	0	0	-1	-5
		Technical Feasibility	2	50	2	50	-1	-25	0	0	0	0	2	50
Cost	5%	Process Development	1	5	3	15	0	0	0	0	1	5	0	0
	10%	Process Application	1	10	4	40	0	0	0	0	0	0	0	0
		Material	2	50	4	100	4	100	0	0	1	25	0	0
History	5%	Industry Experience with Process	0	0	4	20	4	20	0	0	0	0	2	10
	100%			513		755		376		42		289		142

Table 2 - Potential Welding Repair Methods

Feasibility Category	Weight Factor	Capability or Characteristic to Rank	Liner Processes									
			Fiber-Reinforced Composite		Steel Coil		Shape Memory Alloy		Reeled Composite		Solid Expandable Tubulars	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Technical		Out-of-Position Applicability	2	50	3	75	3	75	2	50	3	75
		Process Technical Feasibility	2	50	3	75	3	75	2	50	2	50
	5%	Process Robustness	1	5	2	10	2	10	1	5	2	10
	10%	Repair Permanence	2	20	3	30	3	30	1	10	2	20
	10%	Process Deployment Risk	2	20	0	0	0	0	1	10	2	20
	5%	Remote Operation Feasibility	2	10	1	5	0	0	1	5	2	10
		Ability to Match Strength of Pipe Material	2	50	1	25	1	25	-1	-25	2	50
	1%	Ability to Match Pipe Corrosion Resistance	3	3	2	2	2	2	2	2	2	2
	1%	Ability to Effect Patch Repair	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	5%	Ability to Effect Circumferential Repair	3	15	2	10	2	10	2	10	2	10
	10%	Ability to Negotiate 3D Bends	3	30	0	0	0	0	1	10	-1	-10
	5%	Metallurgical Bond	0	0	-1	-5	-1	-5	-1	-5	-1	-5
	1%	Mechanical Bond	2	2	0	0	1	1	1	1	2	2
Inspectability	5%	Ability to Inspect via Pigging	2	10	0	0	2	10	0	0	2	10
	5%	Radiographic Flaw Detectability	-1	-5	0	0	0	0	-1	-5	0	0
In-Service	7%	Low Power Required (Process Efficiency)	3	21	3	21	3	21	3	21	2	14
	5%	Pipeline Depressurized, But Not Evacuated	3	15	2	10	2	10	3	15	2	10
	5%	Pipeline Pressurized	3	15	2	10	2	10	3	15	1	5
		Technical Feasibility	3	75	2	50	2	50	3	75	2	50
Cost	5%	Process Development	3	15	2	10	1	5	3	15	2	10
	10%	Process Application	3	30	3	30	2	20	3	30	1	10
		Material	2	50	3	75	-1	-25	3	75	-1	-25
History	5%	Industry Experience with Process	3	15	3	15	-1	-5	3	15	0	0
	100%			495		447		318		378		317

Table 3 - Potential Liner Repair Methods

Feasibility Category	Weight Factor	Capability or Characteristic to Rank	Surfacing Processes							
			Electroless Nickel		Thermal Spray		Carburization		Explosive	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Technical		Out-of-Position Applicability	1	25	0	0	0	0	1	25
		Process Technical Feasibility	1	25	1	25	-1	-25	0	0
	5%	Process Robustness	0	0	1	5	0	0	2	10
	10%	Repair Permanence	0	0	1	10	0	0	2	20
	10%	Process Deployment Risk	0	0	0	0	0	0	0	0
	5%	Remote Operation Feasibility	0	0	0	0	0	0	0	0
		Ability to Match Strength of Pipe Material	0	0	-1	-25	0	0	2	50
	1%	Ability to Match Pipe Corrosion Resistance	1	1	2	2	0	0	3	3
	1%	Ability to Effect Patch Repair	0	0	2	2	0	0	0	0
	5%	Ability to Effect Circumferential Repair	0	0	2	10	0	0	2	10
	10%	Ability to Negotiate 3D Bends	0	0	0	0	0	0	0	0
	5%	Metallurgical Bond	2	10	-1	-5	0	0	2	10
	1%	Mechanical Bond	2	2	2	2	0	0	1	1
Inspectability	5%	Ability to Inspect via Pigging	0	0	0	0	0	0	1	5
	5%	Radiographic Flaw Detectability	2	10	2	10	0	0	2	10
In-Service	7%	Low Power Required (Process Efficiency)	0	0	0	0	0	0	0	0
	5%	Pipeline Depressurized, But Not Evacuated	0	0	0	0	0	0	-1	-5
	5%	Pipeline Pressurized	0	0	0	0	0	0	-1	-5
		Technical Feasibility	3	75	1	25	0	0	-1	-25
Cost	5%	Process Development	0	0	0	0	0	0	0	0
	10%	Process Application	0	0	0	0	0	0	0	0
		Material	0	0	0	0	0	0	0	0
History	5%	Industry Experience with Process	-1	-5	1	5	0	0	0	0
	100%			143		66		-25		109

Table 4 - Potential Surfacing Repair Methods

Figure 1 is a bar chart that contains the total weighted scores for each potential repair technology. It is apparent that, of the three broad categories of repair (welding, liners, and surfacing), repair methods that involve welding are generally the most feasible. Of the various welding processes, gas metal arc welding (GMAW) is the preferred method. The primary factors that make GMAW the most feasible are process technical feasibility and robustness, and industry familiarity with the process. The second most feasible of the three broad categories is repair methods that involve internal liners. Of these, fiber-reinforced composite liners are the most promising. The primary factors that make fiber-reinforced composite liners the most feasible are the ability to match the strength of the pipe material and negotiate bends, and their corrosion resistance. The advantage of using a fiber-reinforced composite liner is somewhat offset by its material cost which is anticipated to be comparatively higher than that of a steel coil liner.

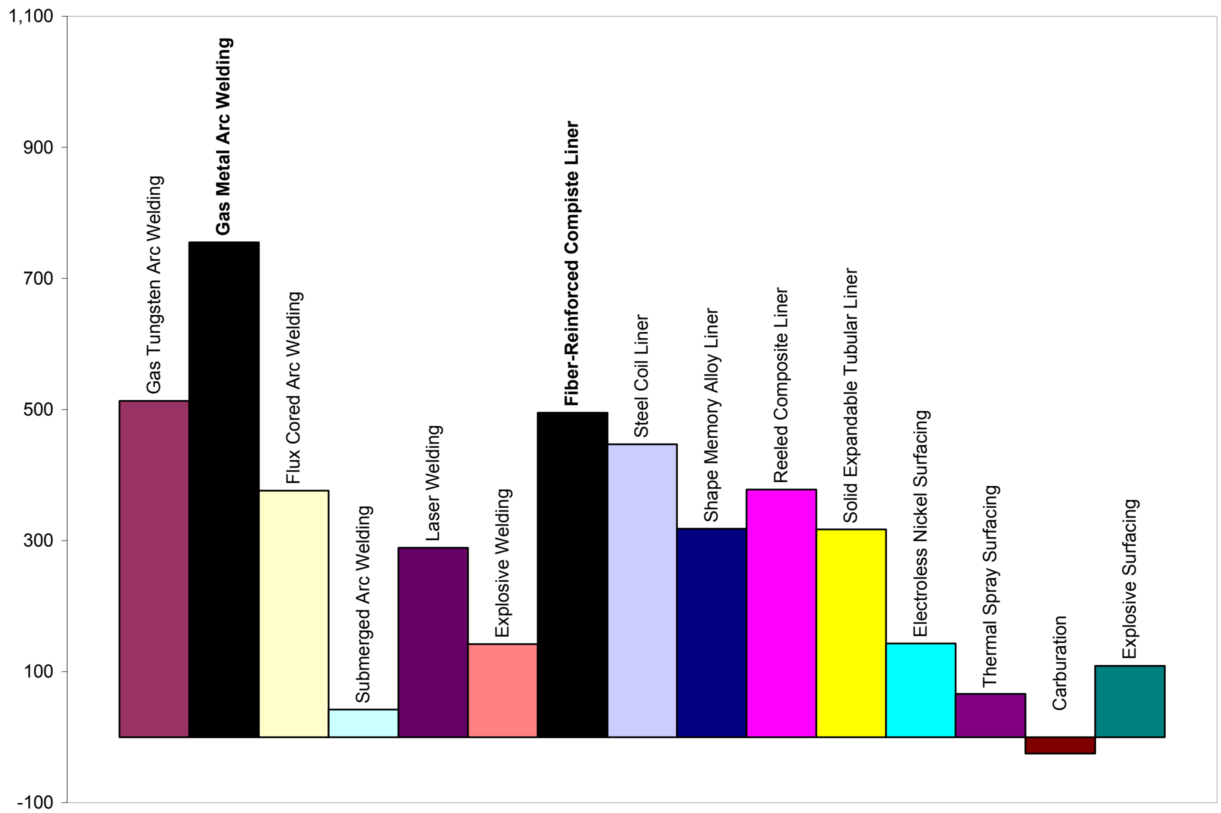

Figure 1 - Weighted Scores of Potential Repair Methods

Based on the results of this evaluation of potential repair methods, the experimental portion of the project will continue to focus on the development of a repair process that involves the use of GMAW welding and on the development of a repair process that involves the use of fiber-reinforced composite liners, unless directed to do otherwise by National Energy Technology Laboratory (NETL). If, during the course of the experimental portion of the project, one of these repair methods proves to be less feasible than anticipated, it will be dropped in favor of the other.