Final Report

Date of Report:	*January 15, 2007*
Contract Number:	*DTPH56-06-T-0008*
Prepared for:	*The U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration*
Project Title:	*Real-time Active Pipeline Integrity Detection (RAPID) system for Direct Assessment of Corrosion in Pipelines*
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Objectives

It is the intent of this project to conduct a cost-benefit study for the development of a ***Real-time Active Pipeline Integrity Detection*** **(RAPID)** system that can be used for built-in in-situ assessment of the health of new and existing pipelines. This cost-benefit study will be used to determine if such a system can:

- Reduce the total structural inspection costs for pipeline structures
- Avoid unplanned pipeline failure and even catastrophic failures
- Provide maintenance credit by reducing the number of maintenance activities when the structural condition assessment shows no need of the scheduled work

The study will utilize as a basis Acellent's sensor network based Structural Health Monitoring technology. Acellent's technology utilizes a network of distributed piezoelectric sensors/actuators embedded on a thin dielectric carrier film called the SMART layer®, to query, monitor and evaluate the condition of a structure. Diagnostic signals obtained from a structure during monitoring are processed by a portable diagnostic unit. With appropriate diagnostic software, the signals can be analyzed to ascertain the integrity of the structure being monitored.

Team Collaboration

The proposed project will be led by Acellent Technologies, Inc. supported by ConocoPhillips and BP. ConocoPhillips and BP are international pipeline companies that are the leaders in the pipeline transportation business for a number of years. The companies transport crude oil and refined products and operate pipelines in several regions worldwide. The proposed project work will conducted by the team members as follows:

1. BP and ConocoPhillips will select the pipeline platform at the start of the project
2. BP and ConocoPhillips will work with Acellent to develop the requirements for the RAPID system based on the chosen platform.
3. BP and ConocoPhillips will also provide data required to conduct the cost-benefit study e.g. inspection costs, duration of inspection etc.
4. Acellent will conduct a cost-benefit analysis based on the information received from BP and ConocoPhillips.
5. Acellent, BP and ConocoPhillips will evaluate the cost study at the end of the program with DOT for a go/no-go decision on further development.

Activities/Deliverables

The following activities/deliverables have been worked on during this project. This draft report constitutes one of the deliverables in the schedule.

Contractor Team: Acellent Technologies, Inc

Technical and Deliverable Milestone Schedule

Item No.	Task No. (per proposal)	Activity/Deliverable ACTIVITY/DELIVERABLE	Quarter No.	Expected Completion Date/Mos	Payable Milestone TITLE	Projected Federal Payment	Projected Partner Cost-Sharing
1	1	Kick-off meeting	1	1 month	Pipeline platform identified	$4,766	$3,000
2	2	Establishment of requirements for RAPID system design	1	3 months	Requirements for RAPID system defined based on platform	$18,445	$24,166
3	5	1st Quarterly Status Report	1	3 months	Submit 1st quarterly report		$100
		First Payable Milestone	1	3 months	SUBTOTAL	$23,211	$27,266
4	3	Cost-Benefit Assessment: Approach	2	4 months	Draft memorandum on approach	$3,000	$3,000
5	3	Cost-Benefit Assessment: Started	2	6 months	Data collection for ROI analysis and model	$11,059	$14,625
6	5	2nd Quarterly Status Report	2	6 months	Submit 2nd quarterly report		$100
		Second Payable Milestone	2	6 months	SUBTOTAL	$14,059	$17,725
7	3	Cost-Benefit Assessment: Draft	3	7 months	Draft Report on cost-benefit assesment and review	$14,100	$9,200
8	3	Cost-Benefit Assessment: Complete	3	8 months	Final Report on cost-benefit assesment	$9,200	$9,200
9	4	Final meeting for review and go/nogo	3	8 month	Decision on system development	$4,766	$3,000
10	4.1	Revise project statement of work	3	8 month	Submission of mod request if descision is positive	$1,366	$826
10	5	Prepare and Submit Draft Final Report	3	8 month	Submit draft final report		$100
11	5	Address Technical Comments and Submit Final Report	3	8 month	Submit final report	$500	$500
		Third Payable Milestone	3	8 months	SUBTOTAL	$29,932	$22,826
					GRAND TOTALS	**$67,202**	**$67,816**

Project work conducted

In this project, a cost-benefit model has been developed to determine the business case for developing the RAPID system and continuing the project in collaboration with the industrial partners and DOT. Description of the tasks conducted along with the results of the cost-benefit study are presented below.

Kick-off meeting

The meeting for the project was held on May 17th, 2006. The attendees at the meeting were:

1. Mamdouh Salama – Conoco Phillips
2. John Nyholt – BP
3. Amrita Kumar - Acellent Technologies, Inc.
4. Shawn Beard - Acellent Technologies, Inc.
5. Robert Hannum - Acellent Technologies, Inc.
6. Pin Yu - Acellent Technologies, Inc.

The meeting started by discussing the problem applications that need to be addressed for typical pipelines. These include:

1. Corrosion from outside
2. Cracking at the weld
3. Leaks
4. Erosion
5. Strain (2-4%)
6. Temperature

Primary Concerns
The primary concerns for Acellent's system were discussed. There is concern that the SMART layer based sensor system will not be applicable to thick pipelines. Bonding issues are also of great concern since the system needs to be bonded onto the metal pipeline structure.

Platform and Installation
Two methods of installation were discussed

1. Retrofit of existing pipelines. This will need to be done on-site and is more challenging.
2. Installation in new pipelines. This can be done during manufacturing itself. The sensors can be bonded between the metal pipe and the insulation

Pipelines are both above ground and underground and it typically costs a minimum of $3000 to dig up a single location for a pipeline. If the pipeline is under the seabed then the costs are much higher.

Based on these discussion, it was agreed that the focus will be on monitoring of new pipelines.

New pipelines examples

- Alaska to chicago pipeline
- McKenzie gas pipeline in Canada
    - Both use strain based design
    - Both want online monitoring
    - Do not want to hydrotest (can cost millions of $)
- Preferred method monitoring from fabrication till pipeline installation
- Other subsea pipelines
    - Require 20 year life for the sensors

Establishment of requirements for RAPID design

Acellent has also discussed the requirements of design of the RAPID system. The current sensor system was used as a basis for developing the requirements.

Criteria/Requirements
The criteria for an on-line system that would be useful to BP and Conoco and to the pipeline industry in general include

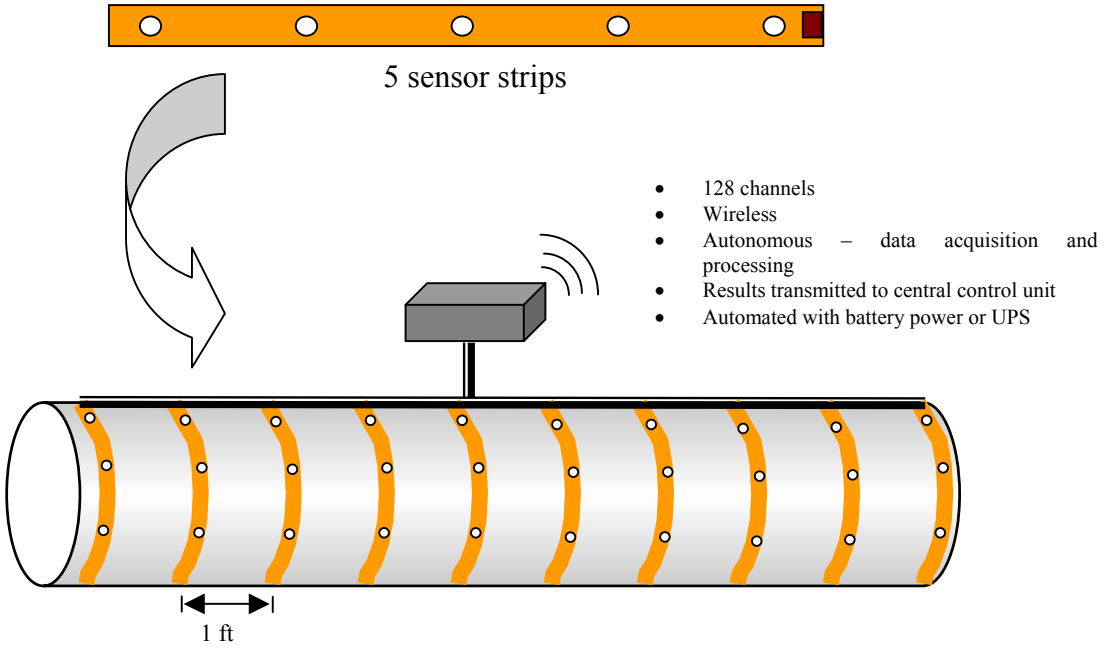
- Wireless
- Autonomous
- Automated with battery power
- Maintenance free
- Reliability
- Applicability to any pipeline - gas or oil
- Easy to install during manufacturing between the pipe and the insulation layers
- Optimized sensor spacing for maximum coverage
- Sensitivity to detect changes in wall thickness equal to or better than current practices

Current practices
The current practice is to use Intelligent pigging once every 3 years (as per regulations) at a cost of $1M for100 miles of pipeline. If there are any problems, then the pipeline is inspected every 6 months. The sensitivity to detect changes in wall thickness is +- 20% of the pipe thickness.

Potential application areas
1. Elbows
2. Joints
3. If it works extend to full pipes

Cost benefit assessment

For the purpose of conducting the cost-benefit analysis, Acellent has assumed the following configuration.



It is assumed that sensor strips containing 5 sensors each will be placed approx. 1 ft apart. A 128 channel hardware that can connect to 128 sensors will be connected to the strips. Therefore each hardware can connect to approx. 25 sensor strips. The hardware will also house the software and will be able to acquire and process the data and send information on damage in the pipeline wirelessly to a central location.

For new pipelines, the sensors can be integrated with the pipeline during manufacturing itself. For existing pipelines, the sensors will need to be surface mounted on the pipeline in the field.

Since the sensors are integrated with the pipeline, at scheduled intervals or at any given time, operators or inspection personnel can instruct the hardware to scan the pipeline for any damage. If any damage is found then appropriate action can be taken.

For this study, preliminary cost models were developed by Acellent and sent to BP and Conoco-Phillips. Details were provided by the partners to add to the cost model.

Assumptions

Pipeline

On-shore oil export pipeline		
Pipeline Length	**10**	km
Pipeline Length	**6.214**	miles
Pipeline Diameter	**12.75**	inch
Design Life	**25**	years
Throughput	**100**	mbd
Cost per bbl of lost production	**45**	$

Hardware	**Unit Cost**		**Frequency**	
Access Fittings	$5,000	each	4	one off
Coupon Assemblies	$1,000	each	4	one off
ER Probes	$1,000	each	4	one off
ER Data Collection/Transmitters	$6,000	each	4	one off
On-lines DCS	$15,000	each	1	one off
Flexi-mat	$80,000	each	2	one off
Corrosion Monitoring Spool	$500,000	each	1	one off

Material	Cost k$/Tonne Final Pipe	Material Cost ($MM)
X-65	1.5	$1.2
Clad 316L	12	$9.5
Clad 825	23	$18.3
Clad 625	30	$23.9

Support/Activity	**Unit Cost**		**Frequency**		
Coupon pull/analysis	$500	per pull per location	4	per location	
ER probes maintenance	$750	per day per location	1	per location	
Support for Spool	$1,000	per day	6	per location	Total $17,000

ILI	**Unit Cost**		**Frequency**		
Mobilisation	$103,456	per run	Variable		
Guaging/Inspection	$47,553	per run			
Cleaning	$15,101	per run			Total $166,110

UT Inspection	**Unit Cost**		**Frequency**		
Mobilisation	$5,000	per campaign	4	per year	
Measurement/reporting	$110	per location	100	locations	Total $31,000

External Inspection	**Unit Cost**		**Frequency**		
Above ground marker survey	$2,000	day @ 6 miles/day	1	per year	
Excavation for inspection	$10,000	each	1	per year	
Inspection	$5,000	per location	1	per year	Total $16,931

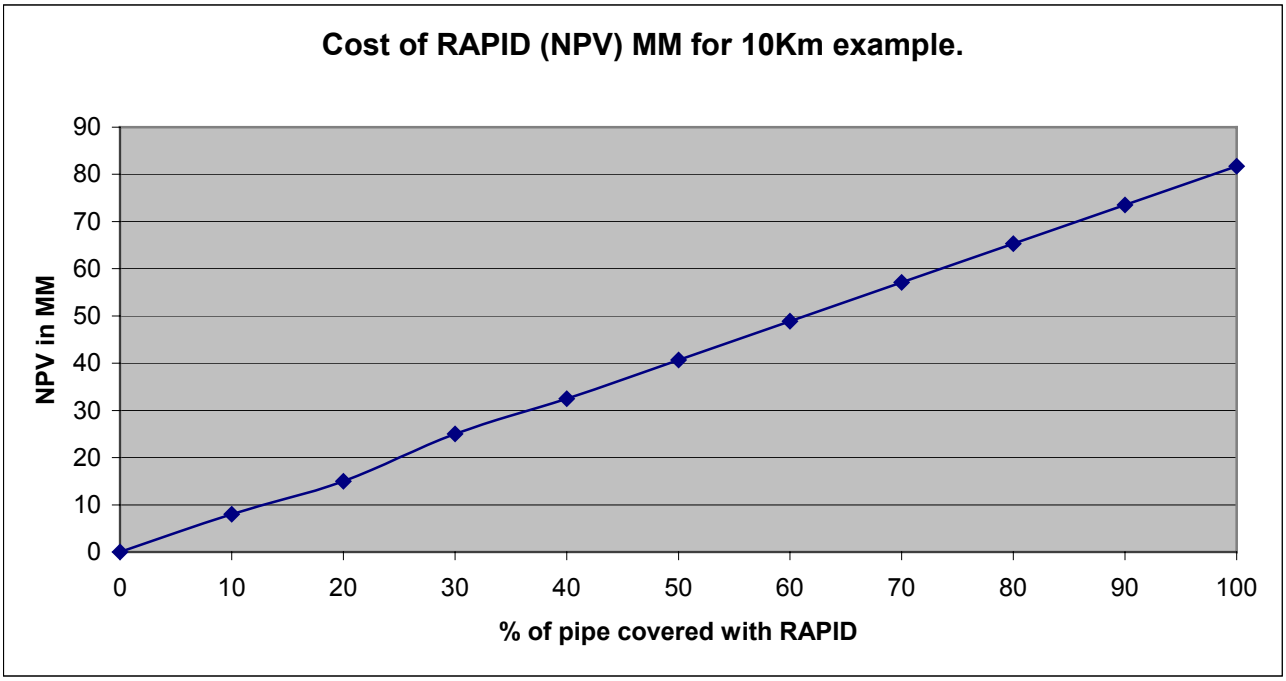
RAPID system

Assumptions:
Sensing method is not point method. The entire area between sensors and sensor strips is evaluated.
Optimal sensor spacing has not yet been defined (1ft used as default).
% Surface Area of pipeline to be monitored input allows for instrumentation of local segments of pipe rather than entire surface.

Surface Area of Pipeline	10014	m^2	
Sensor Strip Spacing	**1**	ft	
Sensor Strip Spacing	0.3	m	
Area covered between Sensor Strips	0.31	m^2	
% of pipeline surface to monitor	**5%**		
Surface area to monitor by sensors	501	m^2	
Number of Sensor Strips Required	1640		
Number of sensors required	8202		
Cost per sensor and connector	$10	each	
Cost of sensors and connectors	**$82,021**	**total**	
Number of channels in harware	128		
No. hardware required for pipe	64	128 channels per unit	
Cost of hardware + software	$8,000	per 128 channel unit	
Cost of hardware + software	**$512,631**	**total**	
Cost of cables	$10	per ft	
Length of cable	32808.3	ft	
Cost of cables	**$328,083**	**total**	
Sensor install cost (new)	$50	per sensor	Based on 120 hours at $80 per hour to install 40 sensor strips containing 5 sensors
Sensor install cost (new)	**$410,105**		
Sensor install cost (existing)	$195	per sensor	Based on 480 hours at $80 per hour to install 40 sensor strips containing 5 sensors
Sensor install cost (existing)	**$1,599,409**		
Hardware, software and cable installation	$105	per ft	Based on 50 hours at $80 per hour to install 40ft cables etc.
Hardware, software and cable installation	**$3,444,872**		
Annual Maintenance + upgrade	$42	per ft (or group of 5 sensors)	
Annual Maintenance + upgrade	**$68,898**	per year (5% increase per year)	

Using the assumptions, several cases and scenarios were used to develop the costs for system usage and benefits. The table below shows the different scenarios with and without the RAPID system and ILI (in-line system).

The cost of the RAPID system varies with the amount of coverage as shown the chart below. However since the target for use of the RAPID system is primarily critical areas such as bends in the pipeline, the cost is relatively low.



		1	2	3	4	5	6	7	1+R	2+R	3+R	4+R	5+R	No ILI
Project (new/existing)		New	New	New	New	New	New	New	New	New	New	New	New	New
Include RAPID?		No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Include in-line Spool?		No	No	No	No	No	No	No	No	No	No	No	No	No
ILI Frequency	Every X years	3	3	5	5	5	10	10	3	5	5	10	10	0
	Starting in Year	1	3	1	3	5	3	10	3	3	5	3	10	0
	or													
	in year						3	10						0
	and													
	in year						13	20						0
Days lost production		2	2	2	2	2	2	2	2	2	2	2	2	0
Cost lost production		9000000	9000000	9000000	9000000	9000000	9000000	9000000	9000000	9000000	9000000	9000000	9000000	0
Rapid Acellent System		$0	$0	$0	$0	$0	$0	$0	$4,777,712	$4,777,712	$4,777,712	$4,777,712	$4,777,712	$4,777,712
Current Monitoring Hardware		$227,000	$227,000	$227,000	$227,000	$227,000	$227,000	$227,000	$227,000	$227,000	$227,000	$227,000	$227,000	$227,000
Corrosion Monitoring Spool		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total		$227,000	$227,000	$227,000	$227,000	$227,000	$227,000	$227,000	$5,004,712	$5,004,712	$5,004,712	$5,004,712	$5,004,712	$5,004,712
%DRate		7												
Year		1	2	3	4	5	6	7	1+R	2+R	3+R	4+R	5+R	No ILI+R
1		$9,231,041	$64,931	$9,231,041	$64,931	$64,931	$64,931	$64,931	$137,274	$137,274	$137,274	$137,274	$137,274	$137,274
2		$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$140,891	$140,891	$140,891	$140,891	$140,891	$140,891
3		$64,931	$9,231,041	$64,931	$9,231,041	$64,931	$9,231,041	$64,931	$9,310,799	$9,310,799	$144,689	$9,310,799	$144,689	$144,689
4		$9,231,041	$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$148,677	$148,677	$148,677	$148,677	$148,677	$148,677
5		$64,931	$64,931	$64,931	$64,931	$9,231,041	$64,931	$64,931	$152,864	$152,864	$9,318,974	$152,864	$152,864	$152,864
6		$64,931	$9,231,041	$9,231,041	$64,931	$64,931	$64,931	$64,931	$9,323,371	$157,261	$157,261	$157,261	$157,261	$157,261
7		$9,231,041	$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$161,877	$161,877	$161,877	$161,877	$161,877	$161,877
8		$64,931	$64,931	$64,931	$9,231,041	$64,931	$64,931	$64,931	$166,724	$9,332,835	$166,724	$166,724	$166,724	$166,724

9	$64,931	$9,231,041	$64,931	$64,931	$64,931	$64,931	$64,931	$9,337,924	$171,814	$171,814	$171,814	$171,814	$171,814
10	$9,231,041	$64,931	$64,931	$64,931	$9,231,041	$64,931	$9,231,041	$177,158	$177,158	$9,343,268	$177,158	$9,343,268	$177,158
11	$64,931	$64,931	$9,231,041	$64,931	$64,931	$64,931	$64,931	$182,770	$182,770	$182,770	$182,770	$182,770	$182,770
12	$64,931	$9,231,041	$64,931	$64,931	$64,931	$64,931	$64,931	$9,354,772	$188,661	$188,661	$188,661	$188,661	$188,661
13	$9,231,041	$64,931	$64,931	$9,231,041	$64,931	$9,231,041	$64,931	$194,848	$9,360,958	$194,848	$9,360,958	$194,848	$194,848
14	$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$201,344	$201,344	$201,344	$201,344	$201,344	$201,344
15	$64,931	$9,231,041	$64,931	$64,931	$9,231,041	$64,931	$64,931	$9,374,275	$208,164	$9,374,275	$208,164	$208,164	$208,164
16	$9,231,041	$64,931	$9,231,041	$64,931	$64,931	$64,931	$64,931	$215,326	$215,326	$215,326	$215,326	$215,326	$215,326
17	$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$222,846	$222,846	$222,846	$222,846	$222,846	$222,846
18	$64,931	$9,231,041	$64,931	$9,231,041	$64,931	$64,931	$64,931	$9,396,852	$9,396,852	$230,742	$230,742	$230,742	$230,742
19	$9,231,041	$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$239,032	$239,032	$239,032	$239,032	$239,032	$239,032
20	$64,931	$64,931	$64,931	$64,931	$9,231,041	$64,931	$9,231,041	$247,737	$247,737	$9,413,847	$247,737	$9,413,847	$247,737
21	$64,931	$9,231,041	$9,231,041	$64,931	$64,931	$64,931	$64,931	$9,422,988	$256,877	$256,877	$256,877	$256,877	$256,877
22	$9,231,041	$64,931	$64,931	$64,931	$64,931	$64,931	$64,931	$266,475	$266,475	$266,475	$266,475	$266,475	$266,475
23	$64,931	$64,931	$64,931	$9,231,041	$64,931	$9,231,041	$64,931	$276,552	$9,442,662	$276,552	$9,442,662	$276,552	$276,552
24	$64,931	$9,231,041	$64,931	$64,931	$64,931	$64,931	$64,931	$9,453,243	$287,133	$287,133	$287,133	$287,133	$287,133
25	$64,931	$64,931	$64,931	$64,931	$9,231,041	$64,931	$64,931	$298,243	$298,243	$9,464,353	$298,243	$298,243	$298,243
7% DRate	38,195,606	33,457,288	25,104,273	22,022,811	19,331,342	13,976,130	7,784,964	34,817,569	23,383,092	20,691,624	15,336,411	9,145,245	2,116,963
Total NPV	$38,422,606	$33,684,288	$25,331,273	$22,249,811	$19,558,342	$14,203,130	$8,011,964	$39,822,281	$28,387,804	$25,696,335	$20,341,123	$14,149,957	$7,121,674

From the table it can be seen that the cost of using the RAPID system varies depending on the frequency of inspection but is still lower than the cost of inspection every 10 years. The RAPID system can provide benefits through continuous monitoring as opposed to inspection after a specified number of years.

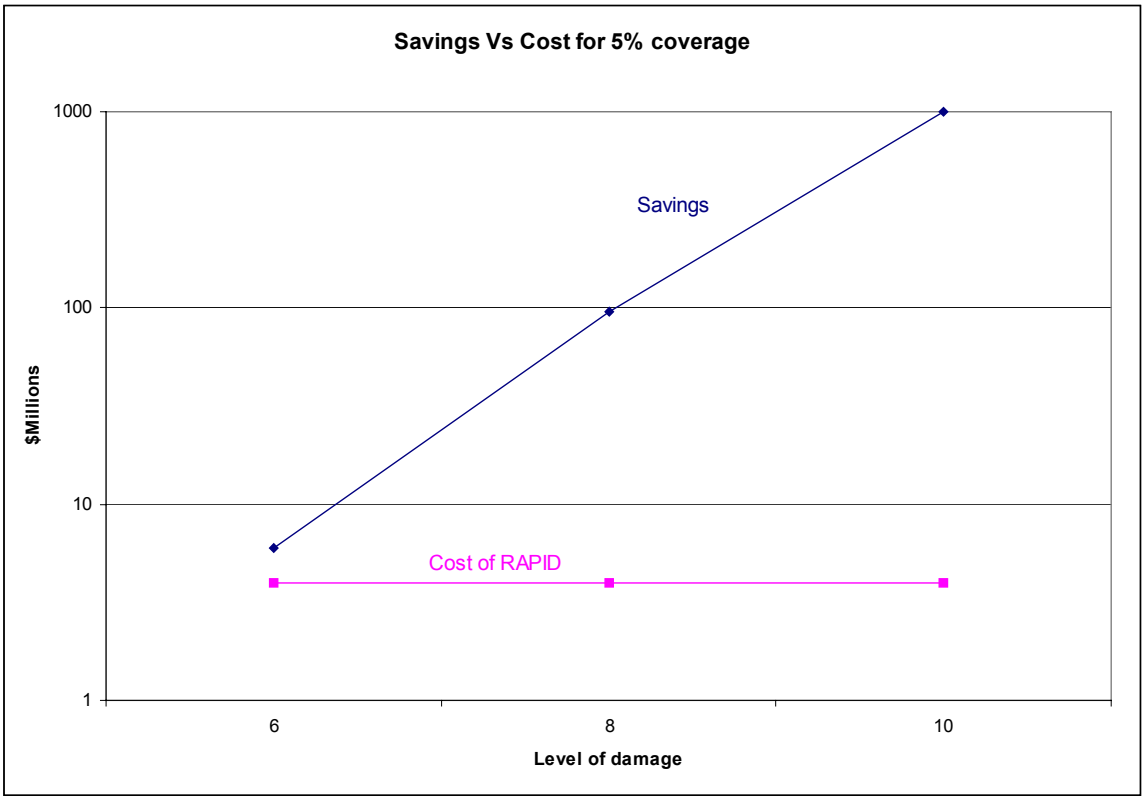
The RAPID system provides most benefit in reducing the **RISK** of pipeline failure. From information gathered from supporting pipeline partners, the failure frequency and the cost of failure are shown below. For our example a failure frequency of 0.01 times/year is assumed.

Published Pipeline Failure Frequencies		
UKOPA (1961-2000)	0.0003	per km.yr
Canada (1983-1997)	0.005	per km.yr
US EPA/DOT	0.00005-0.003	per km.yr

Assumed Failure Frequency **(conservative)**	0.0010	per km.yr
Pipeline Length	10	km
Frequency look-up	**0.010**	/ yr

					Frequency / yr					After 100 yrs	Cost per year		Total cost	
Health and Safety	**Environmental**	**Reputation**	**Potential Financial Impact**	Example Financial Impact	**0.0001**	**0.001**	**0.01**	**0.1**	**1.0**	1	Cost/number of years to happen ($)	**Level of Damage (10-high, 1-low)**	NPV ($mill)	NPV of RAPID ($mill)
> 100 Fatalities or Chronic Illness	Hundreds of thousands of bbls of oil in sensitive coastal area. Prolonged regional/global contamination.	Global outrage, brand damage or change to international legislation	Tens of billions	1E+11	1E+07	1E+08	1E+09	1E+10	1E+11	1000000000	10000000	10	250	4
> 50 Fatalities or Chronic Illness	Tens of thousands of bbls of oil in sensitive coastal area. Prolonged contamination affecting extensive nature conservation or residential area.	International media coverage. Regional outrage. Likely leads to regulation change.	Billions	10000000000	1E+06	1E+07	1E+08	1E+09	1E+10	100000000	1000000	**8**	25	4
> 10 Fatalities or Chronic Illness	Tens of thousands of bbls of oil in sensitive area. Long term damage affecting extensive area.	Regional media coveage. Severe national outrage. Threat of or loss of license to oerate site.	Hundreds of millions	1000000000	1E+05	1E+06	1E+07	1E+08	1E+09	10000000	100000	6	2.5	4
≥ 1 Fatalities or Chronic Illness	Uncontained release of hundreds of bbls oil. Extensive short term pollution/contamination affecting limited area.	National media attention or servere local outrage. Prosecution by regulator.	Tens of millions	100000000	1E+04	1E+05	1E+06	1E+07	1E+08	1000000	10000	**4**	0.25	4
Single permanent/disabling injury. Multiple First Aid Injuries.	Release of material offsite with immediate remediation.	State media coverage.	Millions	10000000	1E+03	1E+04	1E+05	1E+06	1E+07	100000	1000	3	0.025	4
Single Lost Time Injury. Multiple first aid injury.	Onsite release immediate remediation.	Local media coverage.	Hundreds of thousands	1000000	1E+02	1E+03	1E+04	1E+05	1E+06	10000	100	**2**	0.0025	4
Single first aid injury.	Contained onsite release.	No community notification.	Tens of thousands	100000	1E+01	1E+02	1E+03	1E+04	1E+05	1000	10	1	0.00025	4

Assuming that 5% coverage covers all critical hot-spot (curves, bends etc.), then the savings associated with the lowering of the risk as compared to the cost of the system are shown in the chart below. Note that the savings are primarily for high risk areas.



Summary

The proposed project was conducted in collaboration with BP and ConocoPhillips to determine the cost vs benefit of using the RAPID system for detection of pipeline corrosion. A cost model was effectively developed and associated to lowering the risk of pipeline failure. The cost of the system based on an assumed configuration was found to be significantly lower than the amount of savings obtained by lowering the failure risk.

Future actions

Based on the task schedule, a decision was made to "GO" i.e. continue the project development by the DOT contract monitor, Acellent, BP and ConocoPhillips. A revised statement of work, schedule and milestones plan will therefore be submitted as part of this revision.

Payable Milestones

The final payable milestone has been reached as per schedule

7	3	Cost-Benefit Assessment: Draft	3	7 months	Draft Report on cost-benefit assesment and review	$14,100	$9,200
8	3	Cost-Benefit Assessment: Complete	3	8 months	Final Report on cost-benefit assesment	$9,200	$9,200
9	4	Final meeting for review and go/nogo	3	8 month	Decision on system development	$4,766	$3,000
10	4.1	Revise project statement of work	3	8 month	Submission of mod request if descision is positive	$1,366	$826
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		Third Payable Milestone	3	8 months	SUBTOTAL	$29,932	$22,826