On-Board Power and Thrust generation for the Explorer Family of Robots for the inspection of Unpiggable Natural Gas Pipelines

DoT/PHMSA Contract #: 693JK31810002

DoT/PHMSA Research Project Debriefing

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and

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Sponsors and Research Team

- Sponsors: PHMSA/DoT and NYSEARCH/NGA
- Team members:
  - Invodane Engineering (system developer)
  - Concepts NREC (subcontractor for turbine/generator system development)
  - NYSEARCH (technical management)
  - NYSEARCH Technical Advisory Board (overall system engineering

Background

- *Explorer* is a family of robots designed to provide in-line inspection for natural gas unpiggable[1] pipelines under live conditions developed with funding from NYSEARCH and PHMSA over the last 18+ years
- All carry
  - an axial MFL sensor for corrosion detection
  - An optical sensor for dent, mechanical damage, and ovality detection

[1]limited or no flow pipelines, valves, short-radius and mitered bends, back-to-back bends, lack of pre-built launch and receive equipment

Background (cont'd)

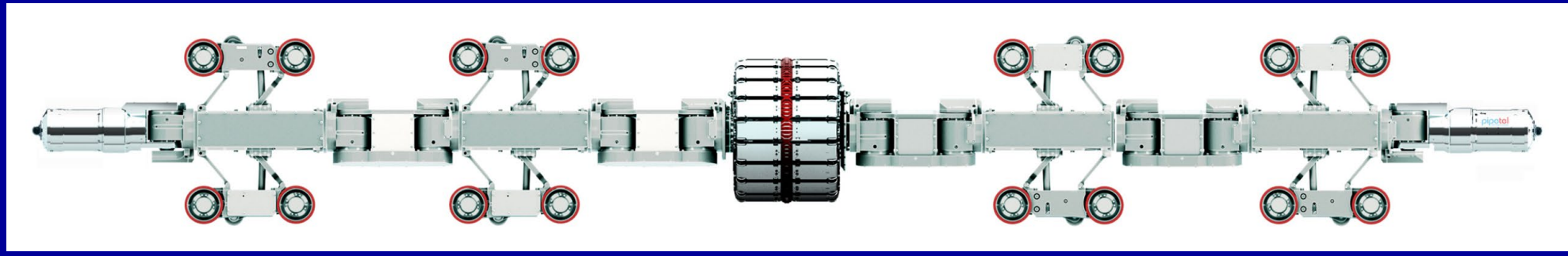
- Additional sensing capabilities exist on individual robots; such as crack sensor, material characterization, short bend inspection, etc.
- Tetherless operation
  - wireless communication to the operator
  - on-board batteries for power supply
- Launched via off-the-shelve fittings

Background (cont'd)

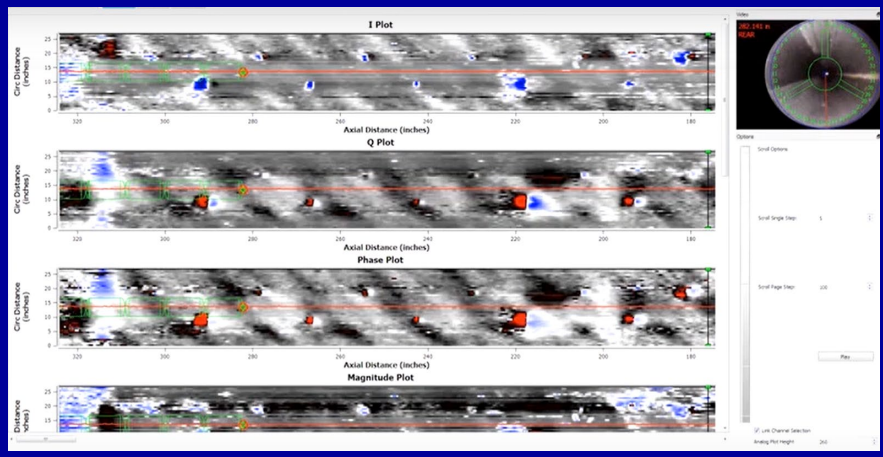
- Technology commercialized via
  Pipetel Technologies, an intero company
- Robot sizes available
  - Explorer 6
  - Explorer 8
  - Explorer 10/14
  - Explorer 16/18
  - Explorer 20/26
  - Explorer 30/36

Background (cont'd)

- Explorer 20/26

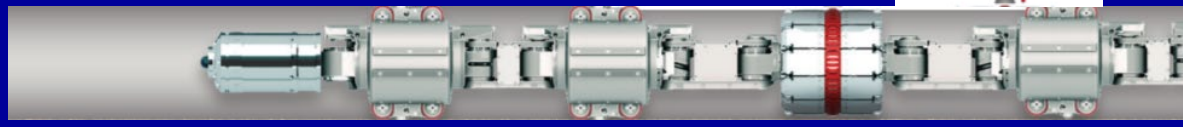


Pipe diameters: 20", 22", 24", 26"
Rated pressure: 750 psig
Inspection speed: 20 ft/min
Bypass: 50%
Operational features: Bi-directional, tetherless, vertical segments, back-to-back elbows, 45-deg mitered bend, 90-deg bend, valve (full port), tees, in-line charging
Sensing capabilities: Video, MFL metal loss, Optical deformation sensor, 1.5D bends



The Problem

- Explorer is currently relying entirely on batteries for power and propulsion
  - we either run the robots for as long as the batteries last, which limits the range, or
  - we use in-line recharging to recharge the batteries while the robot is still in the pipeline
    - extends the range but requires tapping the pipe and parking the robot for many hours



- Could we use the flow inside the pipeline to produce the power and thrust needed? YES!!

Program Objective

- Develop, build, and test an onboard, power & tow generating module for Explorer 20/26
  - Use flow to generate tow force on the robot
  - Use flow to generate electric power for running the robot and storing onto batteries
  - Field-test system
- Commercialize system following successful project completion

Benefits

- Reduce time needed for long inspection runs
- Reduce number of hot taps
- Reduce number of in-line charging points (hot taps)
- Reduce/eliminate time of recharge at in-line charging points
- Reduce required client support
- Reduce significantly overall cost for long inspection runs

Overall Program Structure

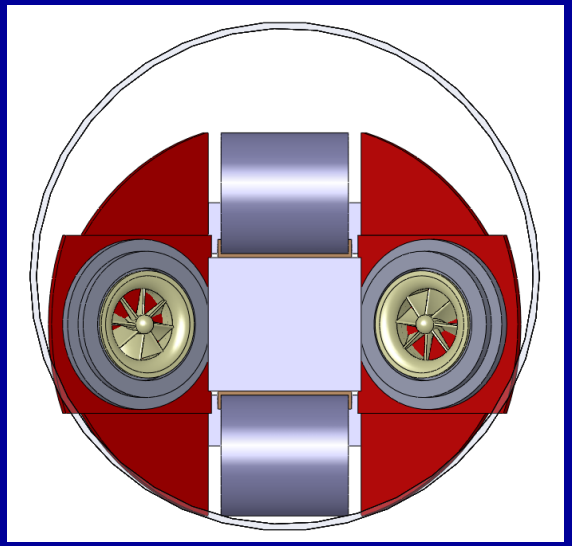
- Phase I: Concept development; completed in 9/17 (w/o PHMSA cofunding)
- Phase II: Design, build and field test; initiated in 8/18 with PHMSA cofunding
  - Carry out system design
  - Manufacture and assemble system
  - Integrate onto Explorer 20/26 and test in lab
  - Carry out field testing (carried out in11/19; some issues identified)
  - Redesign, as needed, and test in lab (completed successfully in 3/21)
- Overall budget: $1,793,590 (50/50 share)

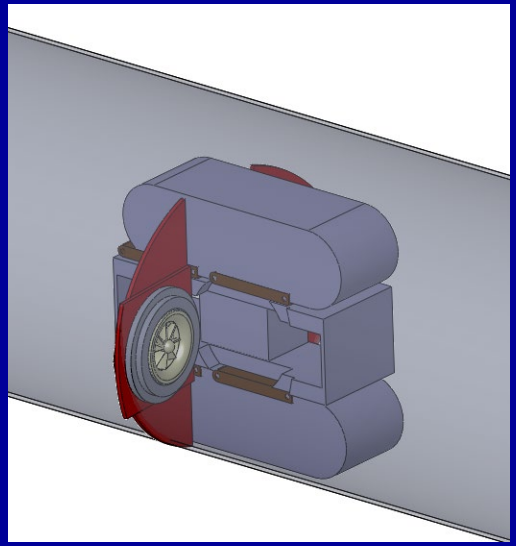
Overall Program Structure (cont'd)

- Final public report issued in 6/21
- Commercialization process initiated in 5/21
- Full commercialization expected in 2022

Basic Concept

- Use a combination of tow-assist ("barrier") and turbine system to provide power for Explorer
  - minimal impact on flow
  - maximize performance of electronics and generator
  - provide pretty consistent performance over a wide range of operating conditions (most challenging task)





Basic Concept (cont'd)

- Flow conditions determine energy balance for the system
- Target: At design point, flow generates all power needs for robot

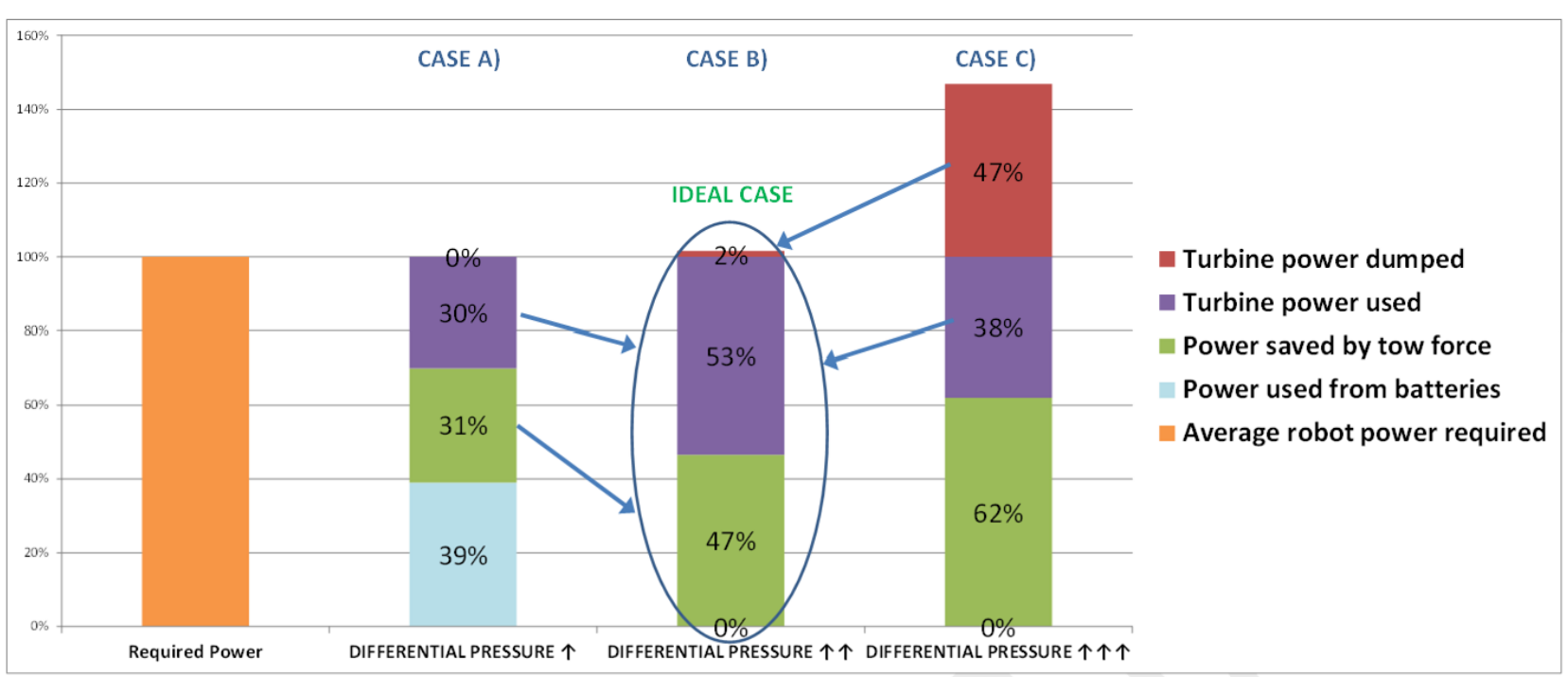


FIGURE 30: ENERGY BALANCE CHART (ESTIMATE)

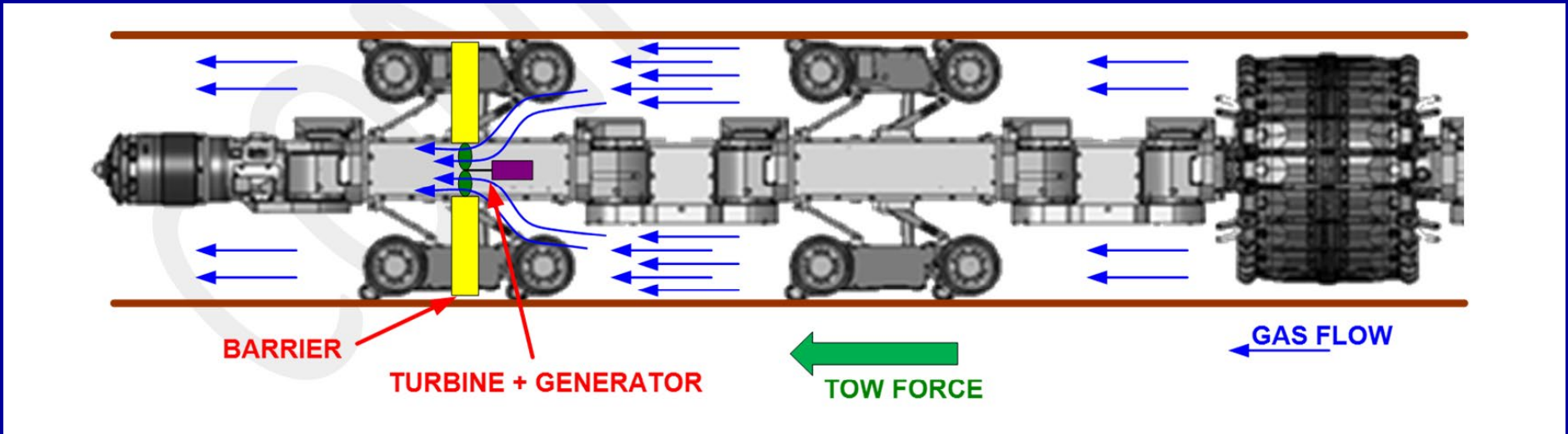
Specifications

- Design Point: Design around lower flow and pressure operating point to maximize performance

Parameter	Target Requirement	Expected Operating Range
Pipeline Flow Speed	2ft/s	1ft/s to 25ft/s
Pipeline Pressure	200psi	≤750psi
Turbine Power	600W	200W to 1000W

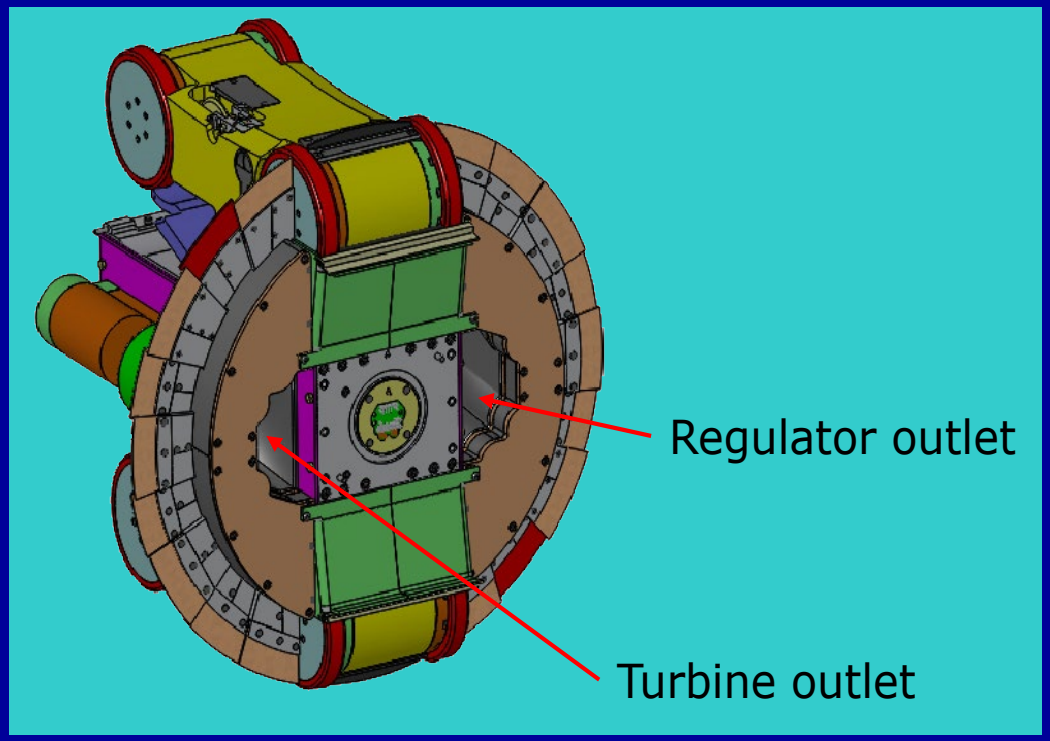
Overall System Configuration

- One of the drive modules has been modified to house the energy harvesting system (system is being pulled; not pushed)



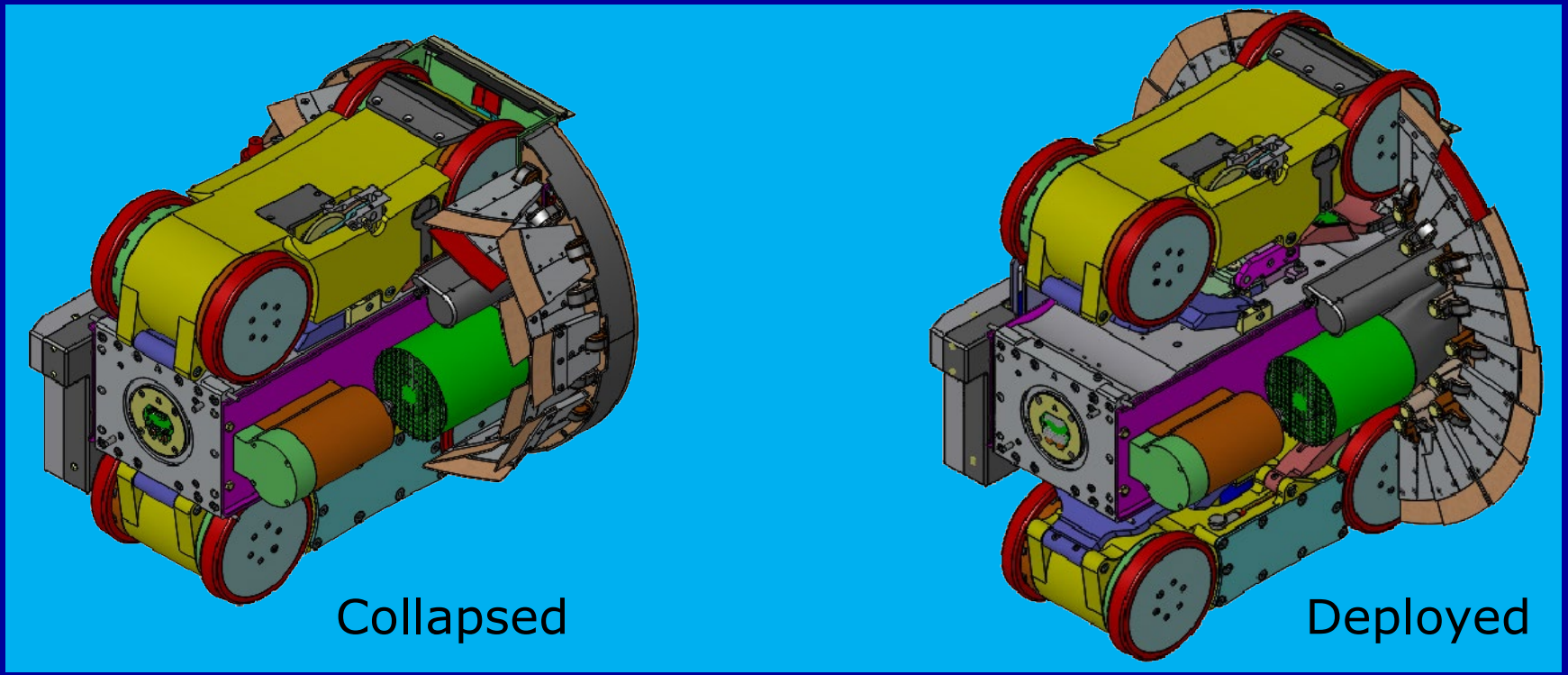
Overall System Configuration (cont'd)

- System consists of:
  - Barrier for tow force generation
  - Turbine/generator for electric power production (designed by Concepts NREC)
  - Pressure regulator for optimizing performance and avoiding damage to system



Overall System Configuration (cont'd)

- Barrier deploys to degree needed, as determined by flow conditions



Failure Mode Effects & Analysis

- 47 important failure modes identified and analyzed
- Catastrophic failure analysis carried out
- Mitigation strategies built into system to minimize impact

Laboratory Testing

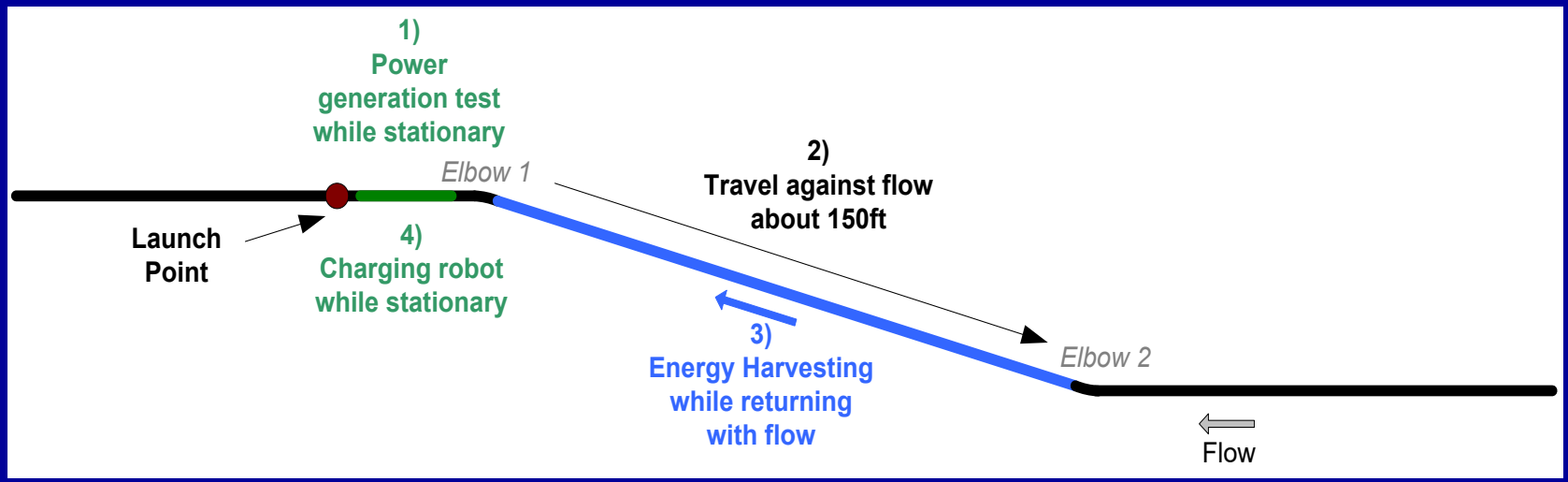
- Extensive testing of system carried out in the laboratory; including debris testing
  - Testing loop operating at near-atmospheric pressure
  - Turbine system performance extrapolated to actual pressure operation using similarity laws to validate turbine/generator design

Field Testing

- System tested on the Explorer 20/26 robot in November 2019 in live pipeline of a NYSEARCH member company
- 24” pipeline operating at 224 psig at time of test
- Purpose: Validate system’s functionality and performance

Field Testing (cont'd)

- Four operational modes tested
  - Power supply mode: generate power to sustain robot without draining batteries
  - Off mode: travel against flow without affecting robot's operational ability
  - Tow mode: harvest gas flow to generate tow while minimizing battery use
  - Charge mode: charge batteries using gas flow



Field Testing Follow up/Redesign

- Results
  - System successfully provided tow force and generated power as designed.
  - Certain operational issues identified with components
    - Barrier design needed to be improved to be more robust
    - Certain mechanical components needed upgrading
    - Electrical upgades needed to increase fault tolerance and minimize noise in sensor readings
- A redesign effort was undertaken to implement the issues identified during field testing
- Redesigned system tested extensively in the lab; performed as expected
- Project completed in March 2021

Overall Results - Conclusions

- We successfully developed a module to be integrated on the Explorer 20/26 robot that harvests flow energy to generate:
  - A tow force on the robot
  - Electric power to run the robot and store in its batteries for future use
- At design pressure and flow, and higher, the robot can operate without drawing any power from its on-board batteries

Technology Transfer

- Commercialization Process
  - Have initiated process to transition the technology to the service provider, Pipetel Technologies (operator training, spare parts, etc.)
  - Once system is tested in a few commercial jobs in 2021, it will be commercially deployed (hopefully in 2022)
- Currently exploring scaling the system for integration on other Explorer robots

Public Information Available

- Public Final Report and this presentation can be found on PHMSA's project public page

  https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=728

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