Puna Geothermal Venture Flow Testing: Facility Design Upgrades and Results

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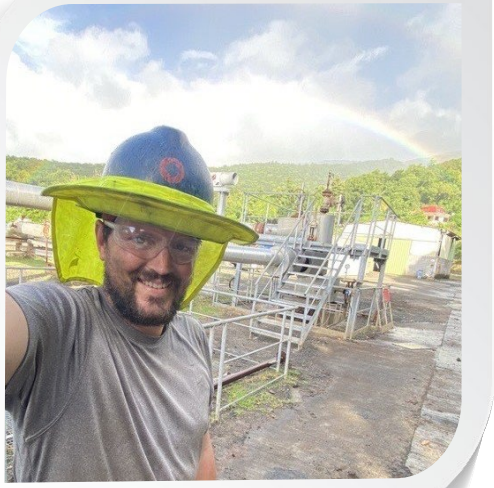
KS-22 Flow Test



KS-19 Flow Test

Puna Geothermal Venture Project Overview

1981-1993
- Exploration and Development Drilling

1993
- Power station begins to export electricity

2004
- Ormat Acquires PGV

2012
- Ormat installs 8 MW OEC expansion plant

2018
- Kilauea LERZ Eruption: Power station offline

2020
- Power station back online following recovery operations

2022-2023
- Second post-eruption drilling campaign including two flow tests.

Flow Testing at Puna Geothermal Venture

- While atmospheric flows tests are standard practice for geothermal projects around the world, they had not been completed at PGV since 2006 due to complex permit requirements.
  - Maximum duration of 4-hours per day during daylight hours.
  - H2S emissions below 2.27 kg/hr
  - H2S at air monitoring stations below:
    - 25 ppb (1-hr rolling average)
    - 10 ppb (24-hr rolling average)
  - H2S concentrations measured upstream and downstream of abatement at least 2x during the 4-hour test period.
  - Minimum abatement treatment mole ratio of 4 to 1 (NaOH to H2S).
  - Public notification period.

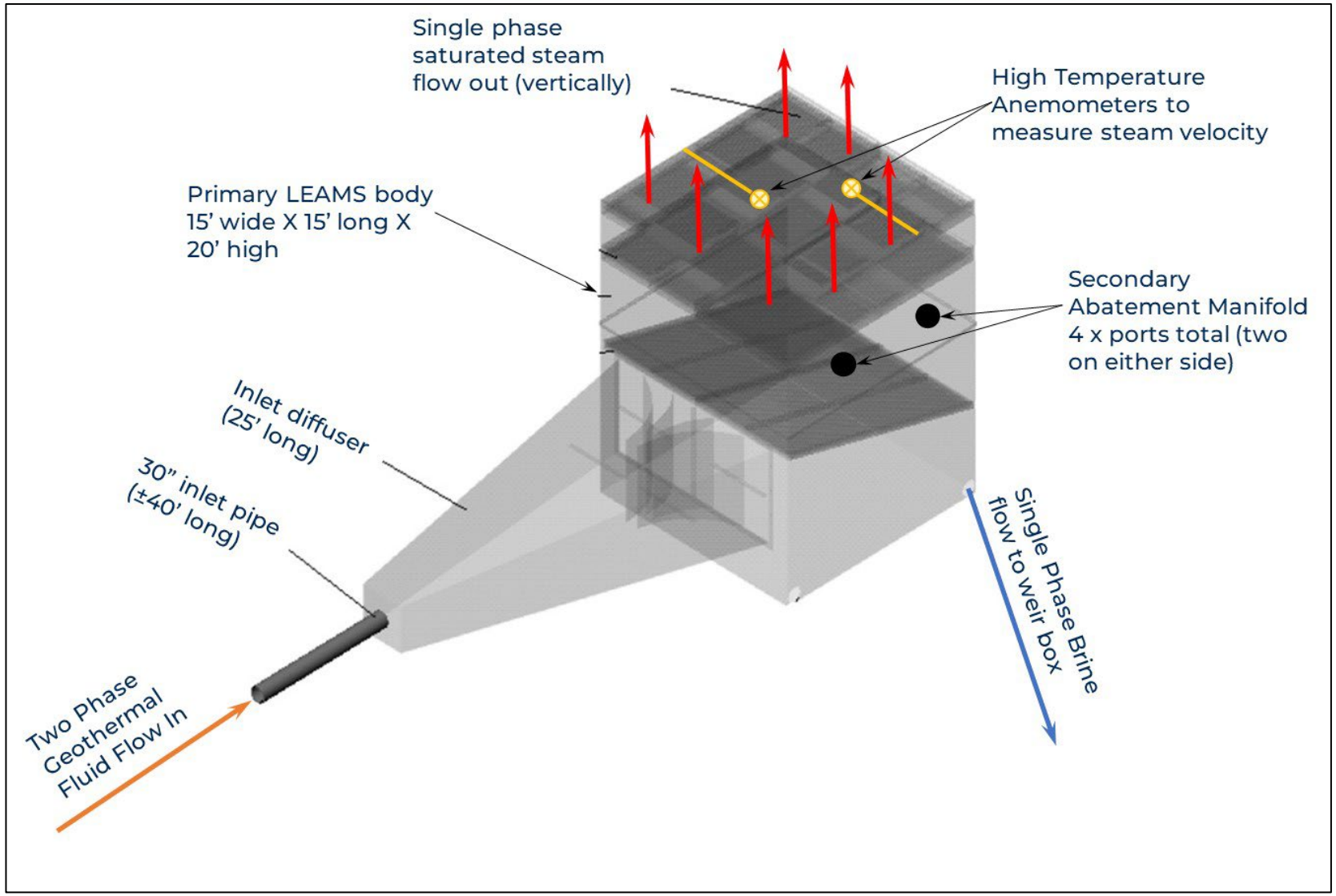
Upgraded Flow Test Facility Design

- To meet the strict permit requirements, Ormat/PGV teamed up with Two-Phase Engineering and Research (TPE) and West Coast Geologic (WCG) to design an upgraded facility.
- Primary goals of the upgraded facility:
  - Ensure safety of testing personnel, the local community, and the environment.
  - Meet all permit requirements
  - Optimize H2S abatement efficiency.
  - Improve separation efficiency to ensure no carryover of caustic treated brine.
  - Implement real time metering of steam flow and H2S emissions.

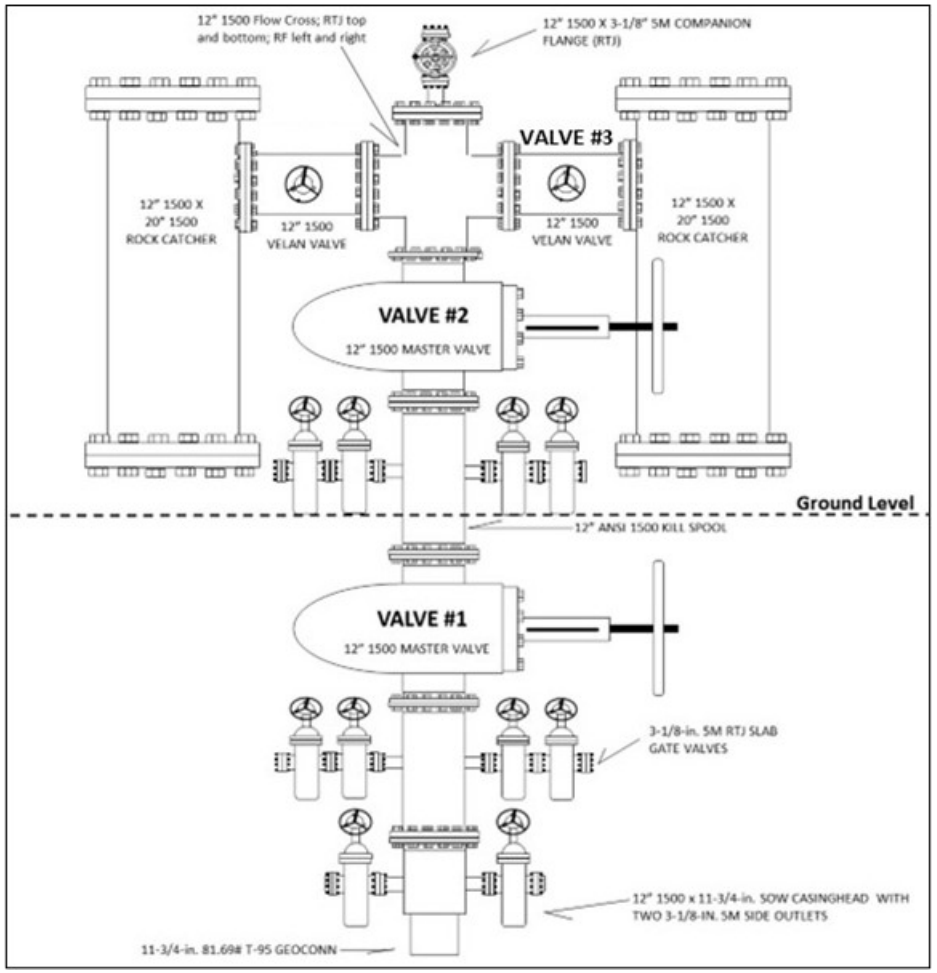
Upgraded Flow Test Facility Design

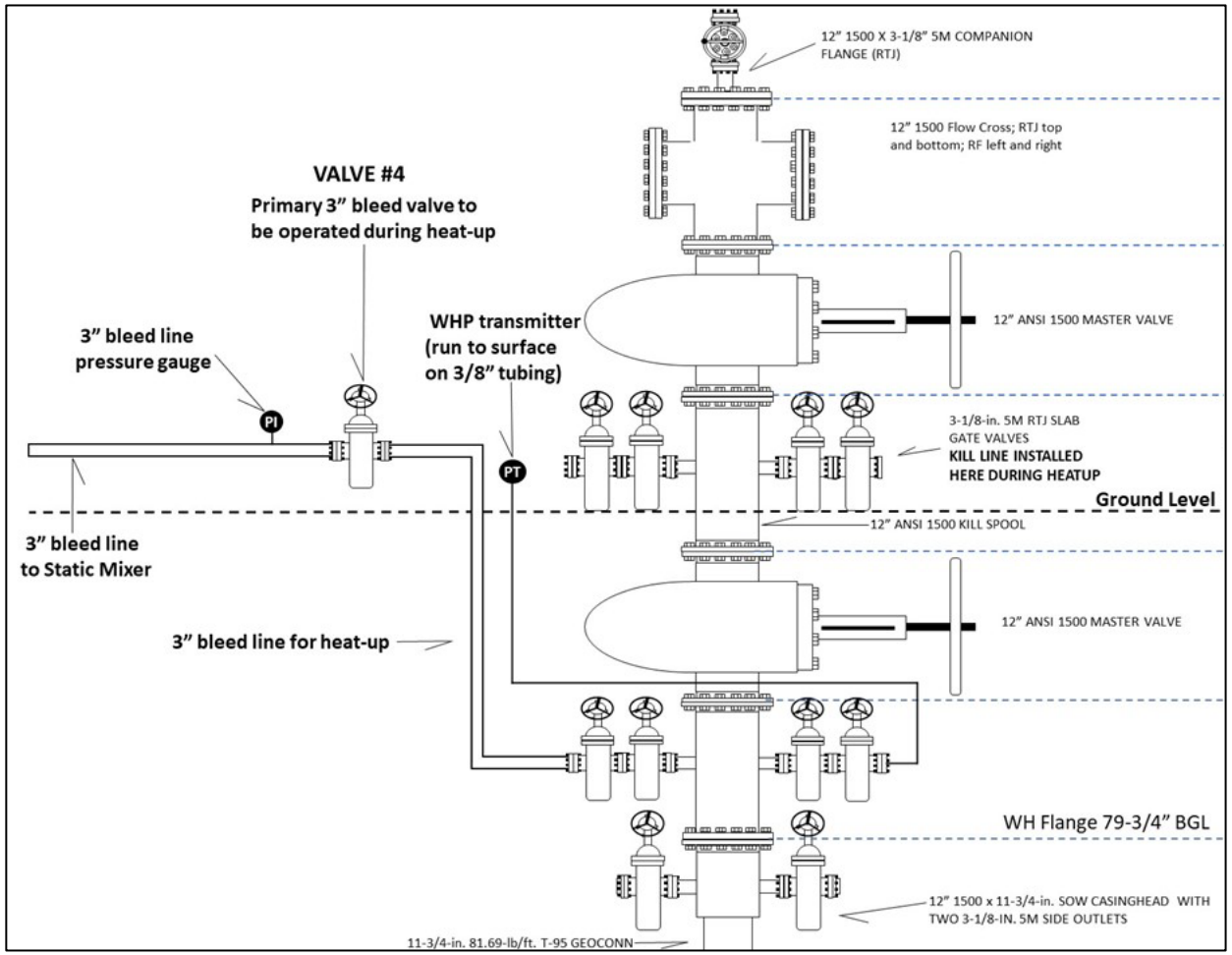
- The goals of the upgraded facility were addressed by implementing the following:
  - LEAMS muffler designed by TPE in late 1990s procured and sent to PGV.
  - Secondary abatement manifold installed to treat steam inside the LEAMS.
  - Static mixer assembly installed on 3” bypass for use during initial well startup.
  - James tube removed in favor of a 30” inlet pipe to reduce fluid velocity and improve separation efficiency.
  - Steam flow metered using high temperature anemometer (Kurz Instruments).
  - Two H2S monitors installed directly on the muffler outlet to measure H2S concentrations in venting steam in real time (3-4 additional monitors on the ground in working area).
  - Chelated zinc solution added to brine flow through weir box to ensure H2S stays in solution.
  - Part of the plant’s permanent tie-in piping used to allow use of remote operated CVs.
  - Redundancy of all critical abatement related surface equipment:
    - Primary and backup generators for powering abatement pumps.
    - Primary and backup high pressure abatement pumps for the main dosing location.
    - Primary and backup abatement ports installed at the main dosing location.
    - Abatement at both the main dosing location and via the secondary LEAMS manifold.

Upgraded Flow Test Facility (LEAMS)

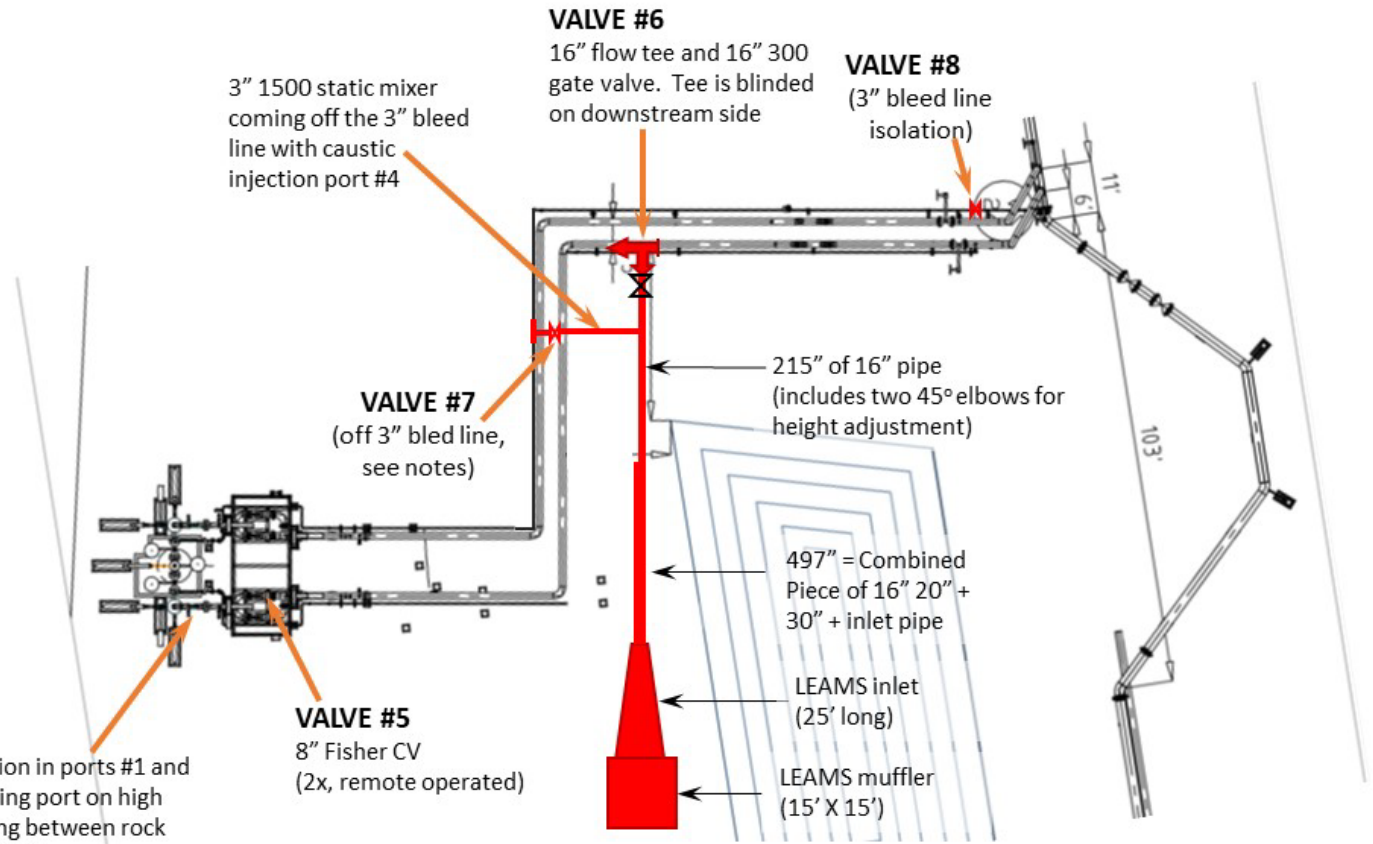


Upgraded Flow Test Facility (Wellhead Assembly)





Upgraded Flow Test Facility (full facility)

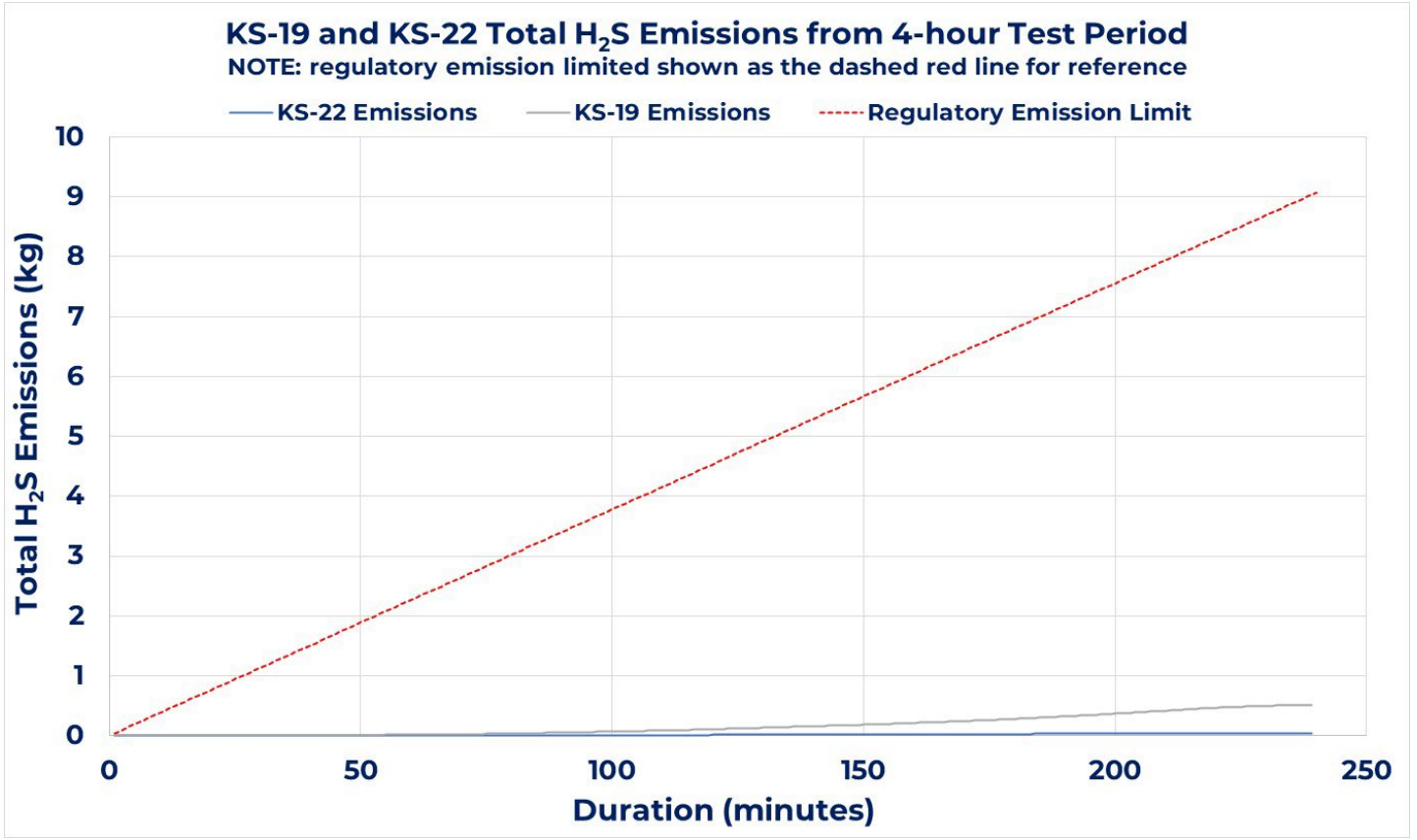


Notes:

- All pipe downstream of VALVE #5 and upstream of VALVE #6 is 16" (0.5" wall) with 300 class flanges
- 16" flow line from tee to LEAMS has 16" 300 isolation valve downstream of tee.
- Blind installed downstream of the 16" tee to avoid plugging dead leg to plant with cleanout material.
- 3" bypass with static mixer installed to increase abatement efficiency during initial well startup.
- Plan is to throttle the well with VALVE #5. This valve will be operated remotely and there are two valves.
- All piping upstream of VALVE #5 is 12" schedule 80 with 1500 class flanges.
- VALVE #7 is the 3" 1500 gate valve just upstream of the static mixer
- VALVE #8 is the 3" 1500 gate valve isolating the downstream plant bleed system.

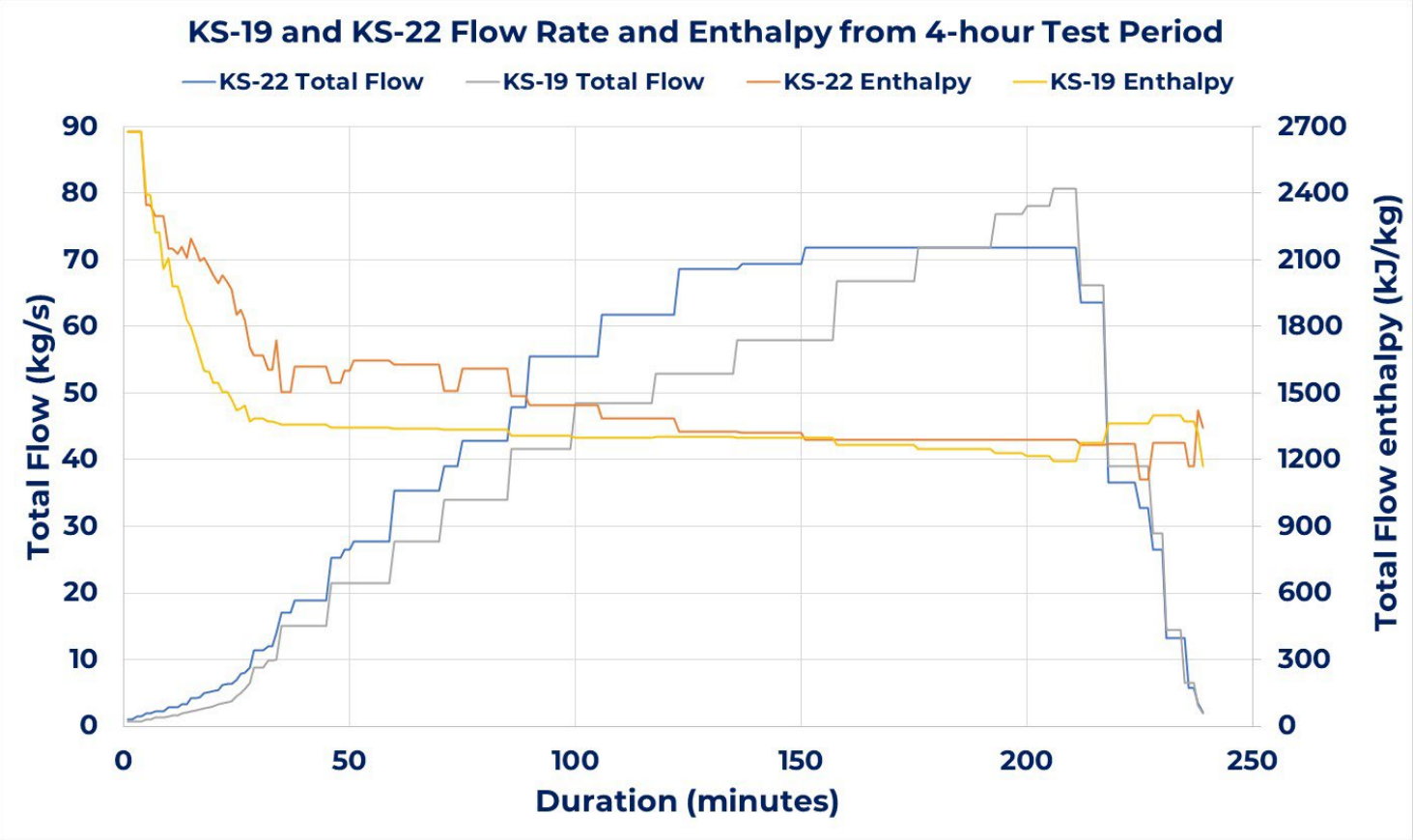
Flow Test Results

- Flow tests successfully completed for new wells in 2023 (KS-19 & KS-22).
- Both tests were completed well within the regulatory limits.
- H2S emissions over 17x below permit limit for first test and over 200x below for second.
- Third test completed in 2024 with no measured H2S emissions.



Flow Test Results

- Both new wells successfully flowed into the plant at the end of the 4-hr test period.
- No impact on generation while bringing new wells in.
- Some drilling debris still observed in plant equipment due to short permitted duration.
- Steam flow successfully metered using high temperature anemometer.



Conclusions

- Atmospheric flow tests can be safely conducted at PGV within the current regulatory constraints.
- However, the limited 4-hr duration is not long enough to fully cleanout drilling debris or get meaningful flow test dataset.
- Use of the upgraded equipment allows wells to be put into plant service seamlessly, with limited to no impact on generation.
- Successful flow tests resulted in significant generation gains.
  - Generation improved by a factor of 100% following first test
  - 150% improvement in generation following second test with a sustained 120% improvement after a year.
- While a change to the regulatory framework would be advantageous, significant gains can still be realized within the existing framework.

Thank You!