When Viewed from Space

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From 2016 to 2018, NASA / Jet Propulsion Laboratory (Cal Tech) conducted an aerial survey of 272,000 facilities and components in California using remote sensing to detect, validate, and quantify methane emissions from California solid waste operations, oil and gas operations, and agricultural operations. The California Methane Survey entailed the flying of the Next Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-NG) over 270 landfills and 166 organic waste facilities in California, repeatedly during the 2016–2018 time frame, to quantify their contribution to the statewide methane budget. The findings obtained emphasize the importance of including the solid waste management infrastructure in climate action and sustainability planning.

DATA PRESENTATION

The following NASA/JPL diagram illustrates the three-tiered observation system utilized for methane:

The interactive website methane.jpl.nasa.gov/ allows the user to explore, analyze, and download methane data derived from airborne remote-sensing, surface monitoring networks, and satellites on an interactive map alongside corresponding infrastructure information. The site allows one to zoom in on specific facilities to look at their “methane plume” and calculated “methane flux” for each facility.

DATA COMPILATION AND CONCLUSIONS

An emitter (or emission source) is the physical or biological activity at a given location that generates methane gas emissions. There are two basic categories of methane emitters: point sources and area sources.

A point source is a condensed surface feature or infrastructure component (typically less than 10 meters across) that emits plumes of highly concentrated methane. Examples of point sources include individual pieces of natural gas infrastructure, oil wells, refineries, gas-capture systems in landfills, wastewater treatment plants, manure management systems at large dairies, and wildfires.

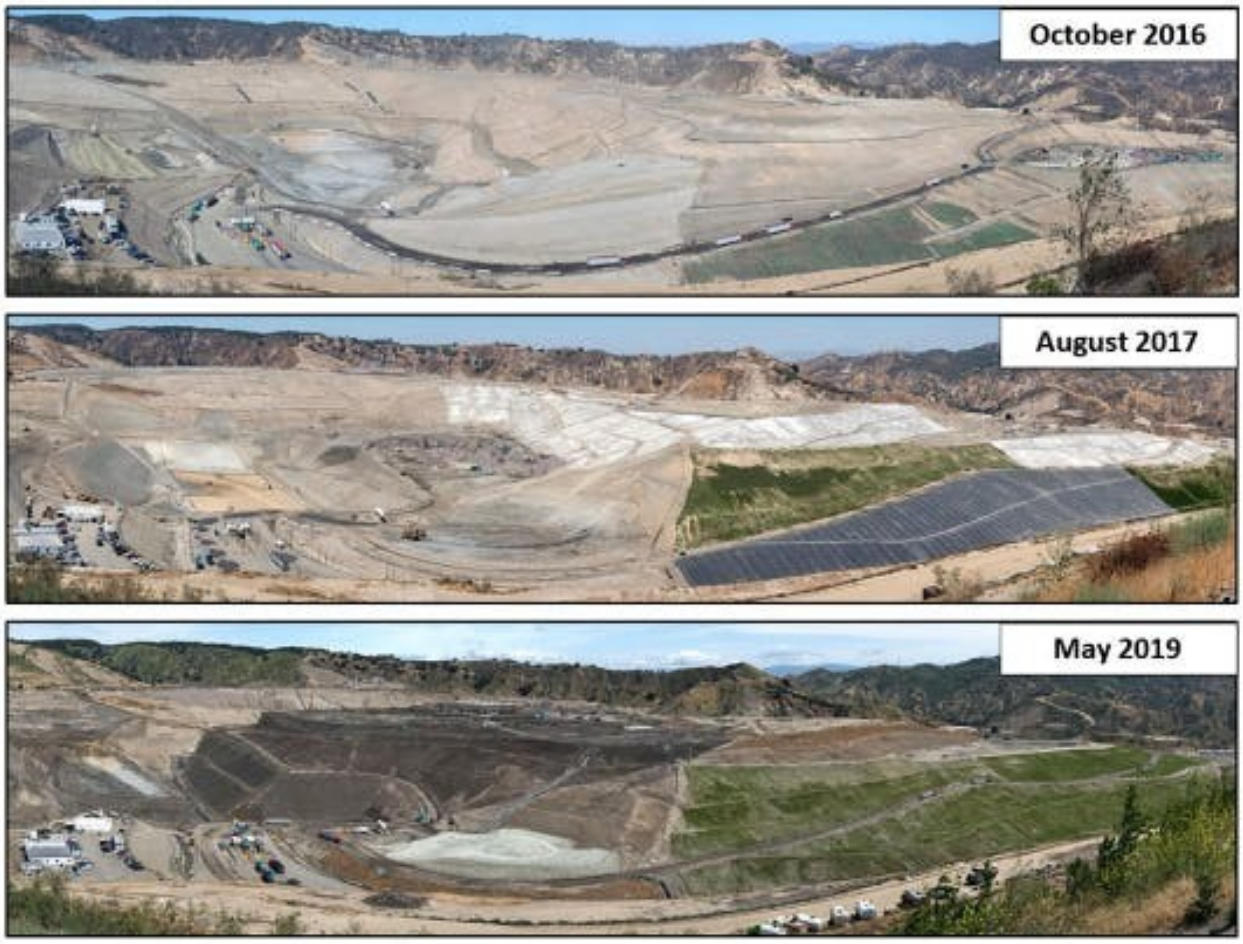
An area source is a group of sources that collectively produce a substantial amount of methane gas. An example of an area source would be a herd of cows on a large dairy farm. Individually, one cow would be contributing a small but measurable methane trace, whereas a large number of cows together can contribute a significant quantity of methane.

Methane reduction has been increasingly prioritized and targeted by California through recent legislation, (e.g., AB 32, SB 1826, and SB 1383). This legislation sets a goal of a 75% disposal reduction of targeted organics to landfills by the year 2025. Significant mandatory programmatic

requirements on businesses and jurisdictions are part of the draft regulatory package currently being finalized as of June 2020.

The principal takeaways from the California Methane Survey described on the website are:

1. Less than 0.2% of infrastructure elements in the state (based on a survey of 272,000 facilities and components) are responsible for 34–46% of total methane emissions in California.
2. Waste management facilities (predominantly landfills) are the largest methane point source emission elements in California (41% of the NASA study total), driven by a small fraction of landfills; NASA observed these plumes at 30 out of 270 surveyed facilities. (Note that NASA's findings indicate that many of the methane's largest emitters appear to be highly intermittent, and there are malfunctions or leaks from the other oil and gas facilities, and the agricultural facilities.)



CASE STUDY: SUNSHINE CANYON LANDFILL

A representative example of how the NASA/JPL methane survey data and aerial photos were beneficially utilized by regulatory agencies and by industry is the Sunshine Canyon Landfill Odor Mitigation Study. Regulatory agencies and the industry have beneficially utilized this study, which was developed in collaboration with NASA/JPL and their program outputs, including the methane survey data and aerial photos.

Odor Mitigation Measures

The Sunshine Canyon Landfill is one of the largest municipal solid waste landfills in California

(currently disposing of 8,000+ tons per day). The landfill is owned and operated by Republic Services since 2009. The landfill was experiencing a high number of odor complaints primarily due to the long-term impact resulting from operational methods by the landfill's previous owner/operator, and from the implementation of a non-traditional daily cover practice (a minimum of 9 inches of compacted soil, without a peel-back requirement to mitigate landfill odors) that was mandated by the landfill's land-use regulator. This resulted in a significant negative impact on the existing landfill gas collection system, resulting in perched water/leachate that impacted the landfill gas collection (LFG) system's efficiency (flooding of the gas collection wells and saturation of the landfill mass).

In light of the continued public complaints, the Sunshine Canyon Landfill Local Enforcement Agency (SCL LEA) took the technical lead and with the cooperation of the South Coast Air Quality Management District (SCAQMD), the air quality regulator, and the landfill owner/operator (Republic Services), collaboratively developed a comprehensive suite of best management practices of odor mitigation measures to replace the ineffective current practice. The SCL LEA used innovative data mining and analysis on the parameters affecting LFG and odor emissions at the site, including surface emissions, traffic, tonnage, and meteorological conditions. These data were compiled and correlated with the odor complaints and types of odors, to pinpoint the causes and location of the odors, and locations of the surface emissions. This analysis determined that the odors were primarily from landfill gas emissions "puffing" through the surface (in particular, the side slopes) of the landfill due to the pressure buildup within the landfill's compromised gas collection system.

The landfill operator implemented a comprehensive suite of complementary odor mitigation measures developed jointly with the SCL LEA and the SCAQMD. These measures included the following:

- Application of Alternative Daily Cover (Enviro Cover) to replace compacted daily soil cover
- Dewatering of landfill gas collection wells
- Installation of additional gas collection wells
- Installation of misters along the landfill access road to the working face
- Utilizing mobile misters with odor neutralizer at the working face and select locations (lower elevation ridgeline areas)
- "Odor Patrols" and independent monitors in the community
- Application of odor neutralizer at transfer stations (owned by Republic Services) during the loading of transfer trailers
- The landfill operator hired additional staff to walk the landfill before opening each day and during operations to identify potential odor issues.
- The landfill operator applied innovative and improved industry odor mitigation practices during the construction of new landfill gas collection wells (e.g., larger and more efficient odor vacuum system during drilling).
- Requiring the diversion of organic wastes at the transfer stations owned by Republic Services from landfill disposal (include working with Republic Services customers in implementing edible food recovery programs)
- Increasing the thickness of intermediate cover (with peel-back prior to further filling)
- Utilization of enhanced Posi-Shell (a spray-on, with a patented blend of cement, clay binders, reinforcing fibers, and polymers) on side-slope areas as a remedial intermediate cover on top of

existing enhanced intermediate soil cover to help decrease the permeability of the surface and increase the vacuum system efficiency

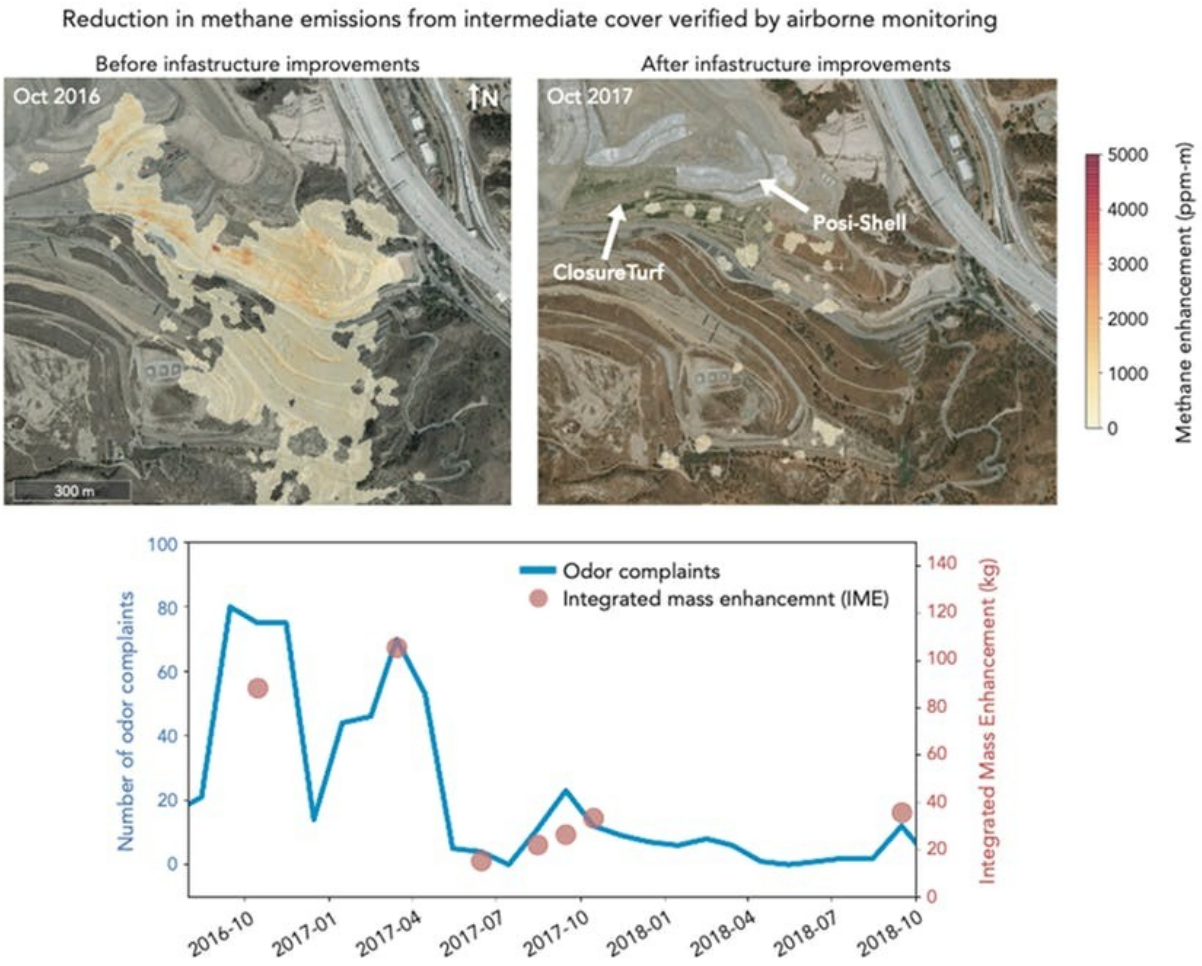
- Utilization of strategic placement of incoming trash against the side-slope areas (as a “buffer” to contain landfill gas and leachate) identified as the areas with the most surface emissions. Note the filling of the "bowl area" over several years. The side-slope areas had the highest surface emissions.
- Use of ClosureTurf (first international application as a temporary intermediate cover for purposes of odor mitigation), complete with surface gas collection system under approximately 30 acres of ClosureTurf
- Independent testing and evaluation by the SCL LEA of the effectiveness of the Posi-Shell and the ClosureTurf (and increased application of vacuum of the landfill gas collection) including installation of surface visqueen at key locations to determine the extent of landfill gas emissions.
- Comprehensive monthly surface monitoring of the 363-acre footprint of the landfill (SCAQMD Rule 1150.1) for instantaneous and integrated surface emissions monitoring; including ongoing SCL LEA analysis of the effectiveness of mitigation measures.
- Continuing comprehensive analysis of meteorological data and correlative analysis with the time of odor complaints.
- Conducting extensive analysis on the time of odor complaints, the number of odor complaints by the time of day, and by type of odor complaints.
- Implementing innovative and pioneering engineering practices developed by Republic Services, e.g., construction of a “gabion cube” that ties directly into the leachate collection system above the bottom liner of the landfill and ties directly to the landfill gas collection system. This is currently being constructed as new cells are developed. The SCL LEA considers this Republic Services patented innovation as one of the most effective landfill gas and leachate control design measures.

Monthly photos of the landfill and documentation of the technical details, the listing of SCL LEA technical reference materials (copies of key reference research papers, along with copies of the data mining and analysis) are available on the SCL LEA website, www.scllea.org.

NASA and SCL LEA Collaboration

During the analysis of the results from NASA's repeated flyovers, they noted a significant change in the methane plumes and the methane flux over the 2016–2018 monitoring. NASA provided the pictures of the methane plumes to the SCL LEA and inquired as to the potential contributing factors that were driving this significant reduction of methane emissions at the landfill. The SCL LEA shared with NASA the data mining/analysis tools collected from the Sunshine Canyon Landfill Odor Mitigation Case Study and the corresponding results, for NASA to independently verify the impact of the odor mitigation measures. NASA utilized the data to provide a cross-check of the observed methane plumes and conduct a cross-check on their model that calculates the methane flux.

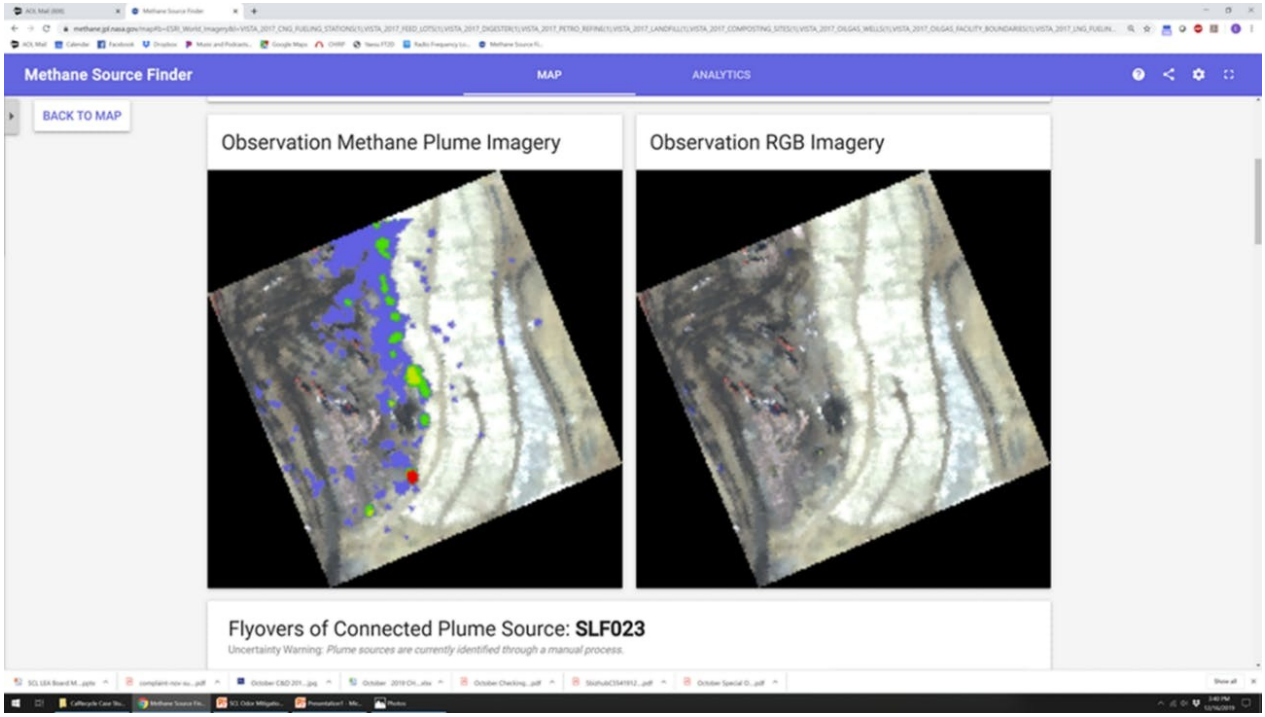
The following graphic shows the striking difference between the methane plume at the landfill in 2016, before implementing the SCL LEA-recommended odor mitigation measures, and in 2017, with these measures in place, working cooperatively with SCAQMD and the landfill operator/owner.



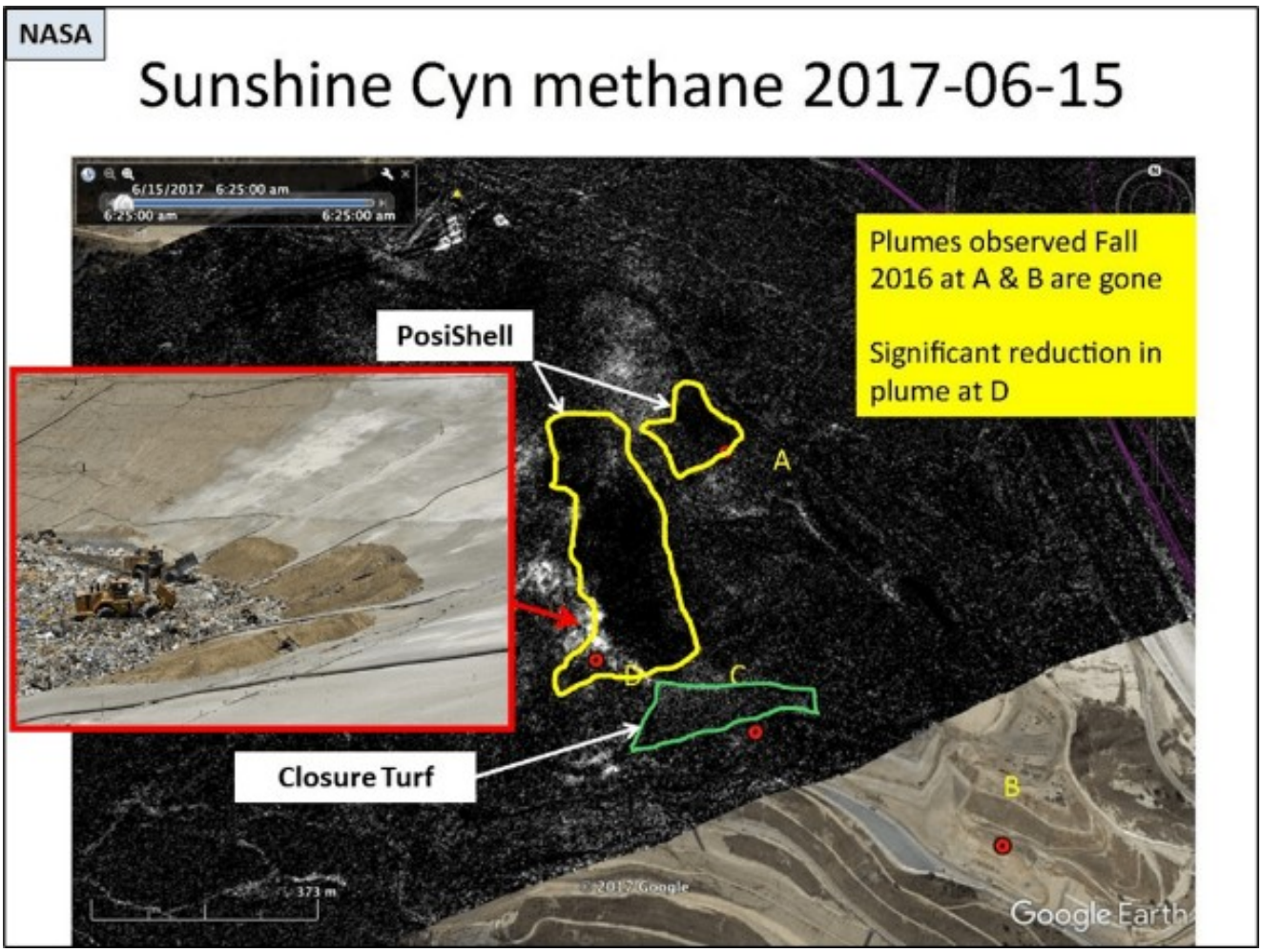
The SCL LEA facilitated site visits for NASA staff to tour the Sunshine Canyon Landfill and to help them to familiarize themselves with the odor mitigation measures up close, focusing on the enhanced efficiency of the upgraded landfill gas collection system. The correlation of the increased

quantity of landfill gas collected and a significant decrease in odor complaints are a clear indication that these measures have been working.

The photos provided by NASA illustrate the effectiveness of the various mitigation measures taken at the landfill. The following photo from the Methane Survey Project illustrates the location and concentration of methane. The picture on the right is an aerial photograph without the methane plumes. One can see the effectiveness of the Posi-Shell (white-colored) layer, and that the source and methane emissions are at the edge of the Posi-Shell. The edge is where the Posi-Shell and the compacted intermediate cover is being scraped away in preparation for future disposal.



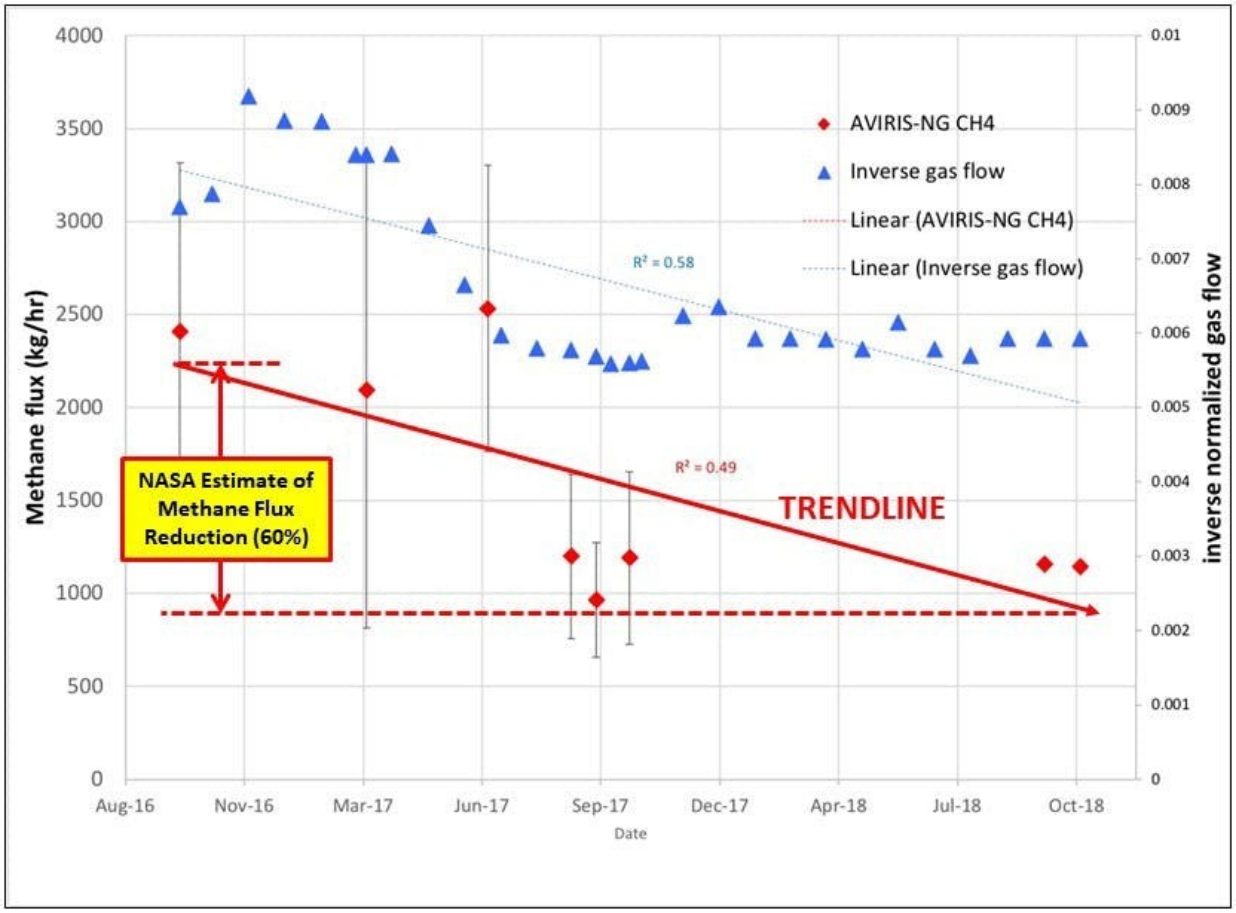
The following NASA photo shows the areas covered by Posi-Shell (outlined in yellow) and by Closure Turf (outlined in green) that have been monitored by NASA and showing that the plumes are gone (Note the comment in yellow by NASA). As shown, Area “D” was found to have a significant reduction in the methane plume, and this is at the “edge” of the Posi-Shell application area, that was being peeled away in preparation for future disposal. The inset photo (outlined in red) shows the edge of the current disposal footprint and the edge of Posi-Shell, and that the Posi-Shell and intermediate cover were being removed in the areas just above the disposal footprint.



These photos were shared with the landfill operator, who revised their operational procedures and schedule by preparing the future areas before disposal and immediately placing solid waste after removing the Posi-Shell, thus minimizing the time that the enhanced intermediate cover is breached, and reducing the time for methane emissions to be released, by using the disposed-of solid waste as a buffer to contain emissions in this impacted area. NASA noted a significant further reduction in emissions in subsequent flyovers.

It should be noted that these conditions were extraordinary and the NASA flyovers occurred during the short period when the landfill was going through tremendous operational and facility design changes to address the landfill odors resulting from their impacted landfill gas collection system.

Below is a graph showing the calculated Methane Flux (kg/hour) over the time when most of the odor mitigation measures were being implemented (2017–2018). The SCL LEA overlaid the “trendline” analysis to estimate the reduction in the methane flux.



From the above graph, the estimated reduction in methane flux based on the NASA flyovers is approximately 60%. This significant amount of methane flux reduction also directly corresponds to the reduction in odor complaints over the same time and corresponds inversely with the increase in the volume of landfill gas being collected by the landfill.

The SCL LEA separately compiled and analyzed the landfill gas collection data. These data show that there is an estimated 55% to 60% increase in the collected volume of landfill gas because of the addition of the major odor mitigation measures implemented compared to the prior period.

The SCL LEA's holistic systems engineering approach focused on short, medium, and long-term mitigation measures to improve the overall efficiency of the landfill gas collection system. In the short-term approach, alternative daily cover (Enviro Cover) replaced the compacted 9 inches of daily cover soil. The medium-term approach implemented an extensive remedial intermediate cover which reduced the intermediate cover permeability, allowing the landfill's operators to increase the landfill gas collection vacuum. The long-term measures focused on preventative measures that reduced the future generation of landfill gas (e.g., reduction of organic waste to landfill). Since implementing these odor mitigation measures, there has been a significant reduction in the number of odor complaints and nuisance violations, and substantial quantifiable reduction in methane emissions from the landfill. A comparison of the results of the end-of-2018 NASA flyover photos and the methane flux indicates that the Sunshine Canyon Landfill's methane footprint is significantly lower than it was in 2016.

This case study points out the important role that the solid waste management infrastructure has in climate action planning. Additionally, the evidence has shown that solid waste landfills, being a significant point source of methane in California, should take on a higher priority within climate

action plans and sustainability planning for local, State, and Federal jurisdictions. The case study also illustrates that anomalous conditions at landfills that lead to high surface emissions can be mitigated with best management practices, and through the landfill's corporate commitment to innovative engineering design practices for landfills, through improved landfill operations.

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