Coatings for Compressor Seals

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Project ID: in011

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Program Overview

Timeline:

- Project Start Date: 4/1/2015
- Project End Date: 11/27/2020

Budget:

- Phase I: $149,877
- Phase II: $998,616
- Phase IIA: $999,781

Barriers:

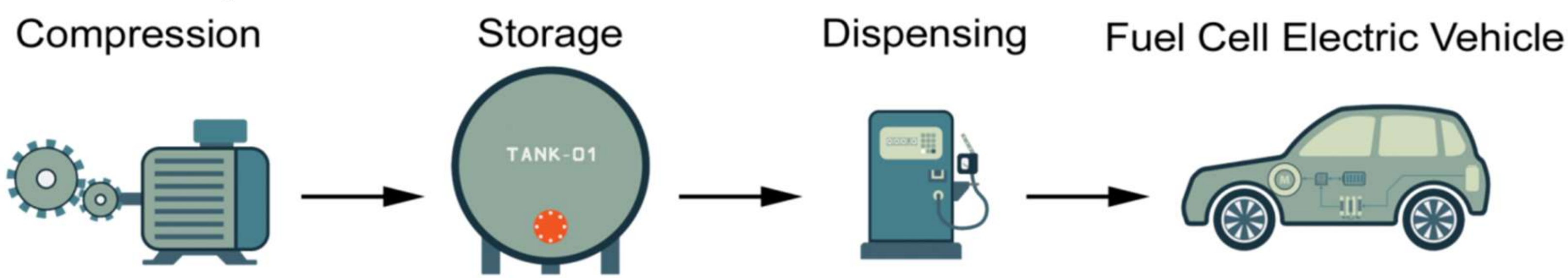
- B. Reliability and cost of gaseous hydrogen compression

Partners:

- National Renewable Energy Laboratory
- Air Liquide
- Takaishi Industries
- Greene, Tweed & Co.
- Oak Ridge National Laboratory
- Hydro-Pac Inc.
- PowerTech

Relevance: Impact of Seal Failures

- Plastic and elastomeric seals are integral to all areas of hydrogen compression, storage, and dispensing (CSD)
- Hydrogen ingress degrades seals
  - Temperature and pressure cycling exacerbate issues
- Wear due to friction in high pressure, high temperature operation degrades seals
  - Frequent seal replacement is required
- Seal failure is a major contributor to process down time
  - Largest cause of unscheduled maintenance
  - >25% of hydrogen leaks
  - Without improvement, redundant compression necessary
  - "In a well-balanced, continuously operated unit, rings should last for six months; however, experienced operators find that compressor piston ring changes are needed at least every 1,000 hours of operation."[1]



1.Parks, Boyd, Cornish, Remick, *Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs*, **2014**

Relevance: Program Goals

- Objective: Make tangible improvements in seal life with vapor deposited coatings
  - **Lubricious coatings** for **dynamic seals** reduce seal wear due to friction
- Improved seal performance benefits operations and cost
  - **3-5x reduction** in frequency of seal maintenance
  - By 2020
    - reduce hydrogen delivery cost from central production to consumer vehicles to **$2.00/gge**, or
    - reduce CSD cost for on-site production to **< $2.15/gge**.

2015 FCTO MYRD&D – Delivery Section

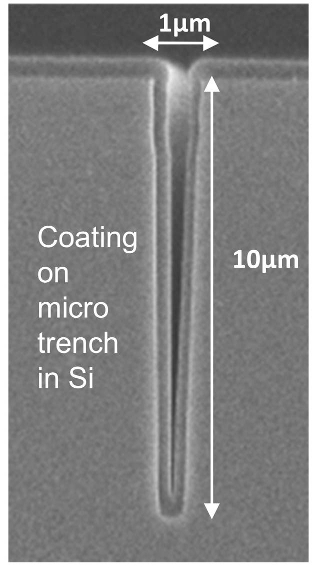
Relevance: Impact in the last year

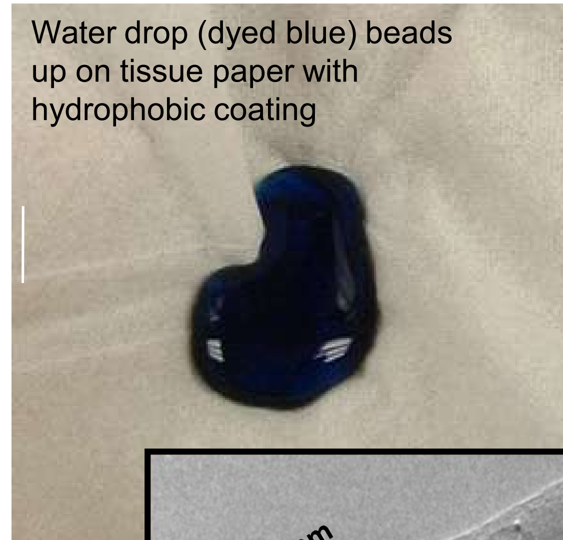
- In the last year GVD has continued testing to establish value lifetime extension for PTFE coatings on rigid polymer seals in hydrogen compressors (field testing performed at NREL)
- Collaboration with Air Liquide established, PTFE-coated seals reduced H_2 leakage in compressors by 36%.
- PTFE-coated seals expected to last 3x as long as uncoated seals, resulting in maintenance savings of $0.25/ kg H_2.

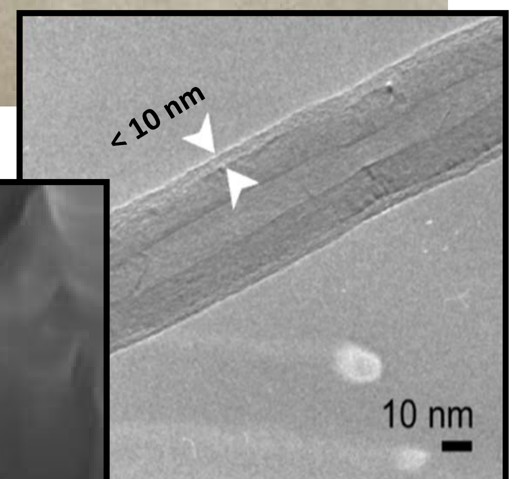
Approach: Chemical Vapor Deposition

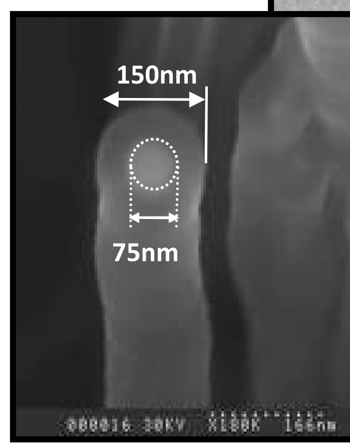
A **room-temperature coating** process which produces **thin coatings** on almost any material.

- "Gentle" application
  - low temperature
  - dry process
  - single-step
- Nano- to micro- meter thicknesses
  - Will not disrupt sealing properties
- Coatings are fully polymerized (no off-gassing, contamination)
- Conformal coating of complex seal geometries
- Scalable and manufacturable compared to competitive solutions





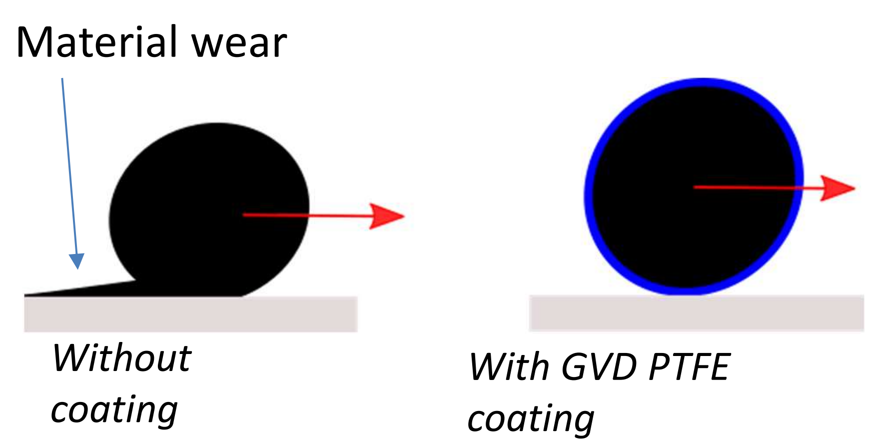




Coated Nanotubes

Approach: Lubricious PTFE Coatings

- <u>Lubricious coatings</u> to reduce mechanical wear on seals
  - Seals move due to designed motion or swelling, thermal expansion
  - Thin PTFE film provides **low coefficient of friction** surface for reduced wear
  - PTFE's coefficient of friction: 0.03-0.05
- Excellent chemical and thermal stability
- Based on GVD's flagship mold release coating
- Annual revenues from related coatings ~ $5 MM



Integration with other DOE entities: GVD is working with Hydrogen Infrastructure Testing and Research Facility at the Energy Systems Integration Facility (ESIF) to test seal lifetimes.

Milestones and go/no-go decisions for 2019-2020 and current status: reached a critical decision point on continuation of hydrogen gas barrier coating in May 2019. Focused efforts on demonstrations of PTFE coatings in hydrogen compressors.

Approach: Phase IIA Objectives

- Field validate a low-friction top coat of polytetrafluoroethylene (PTFE) for friction wear reduction of plastic piston-head seals
- Demonstrate improved seal life (goal of 3-5X increase) in field testing by a hydrogen compressor end user (NREL)

Approach: Prior Work Summary

- Designed a production tool for commercial scale coating of seals
- Demonstrated 70% reduction in mass loss rate for hydrogen compressor gaskets with low-friction coating.
- PTFE coatings on elastomeric coatings outlasted uncoated o-rings by 400x (work with Takaishi Co. Ltd.)
- Established protocol for aggressive lifetime testing at NREL.

2019 Collaborators

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

High-temperature high pressure testing of compressor seals with lubricious coatings

Takaishi Industry Co.,Ltd.
高石工業株式会社

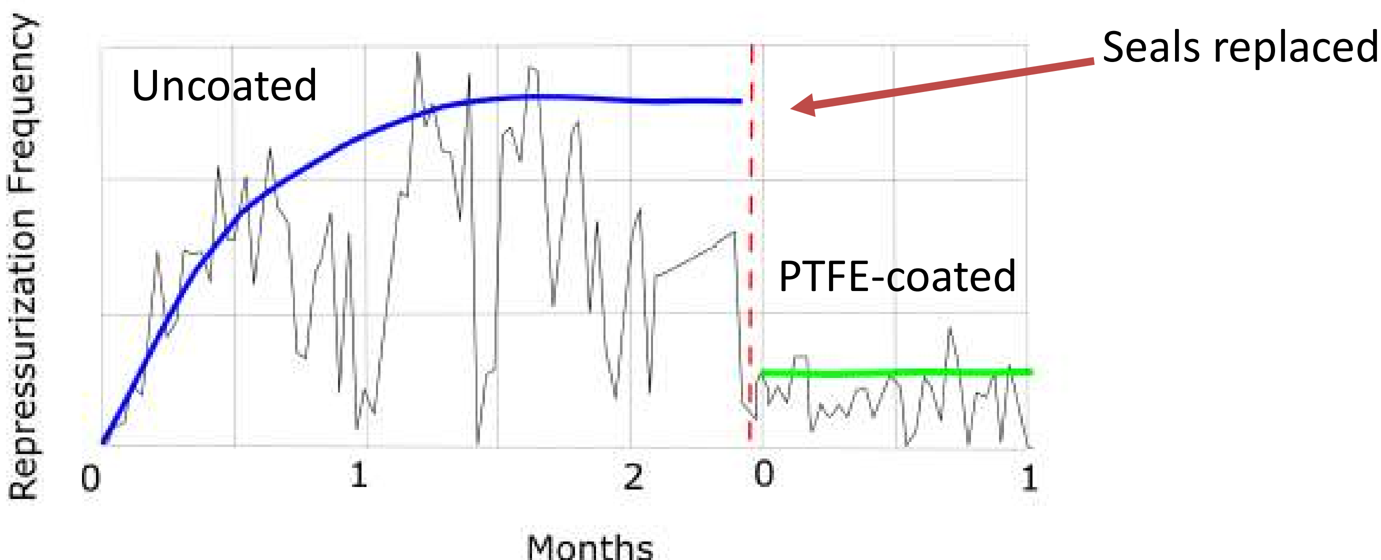
Provision and testing of o-rings

Air Liquide

Provision and testing of o-rings

Accomplishments: Testing of PTFE coated seals with Air Liquide

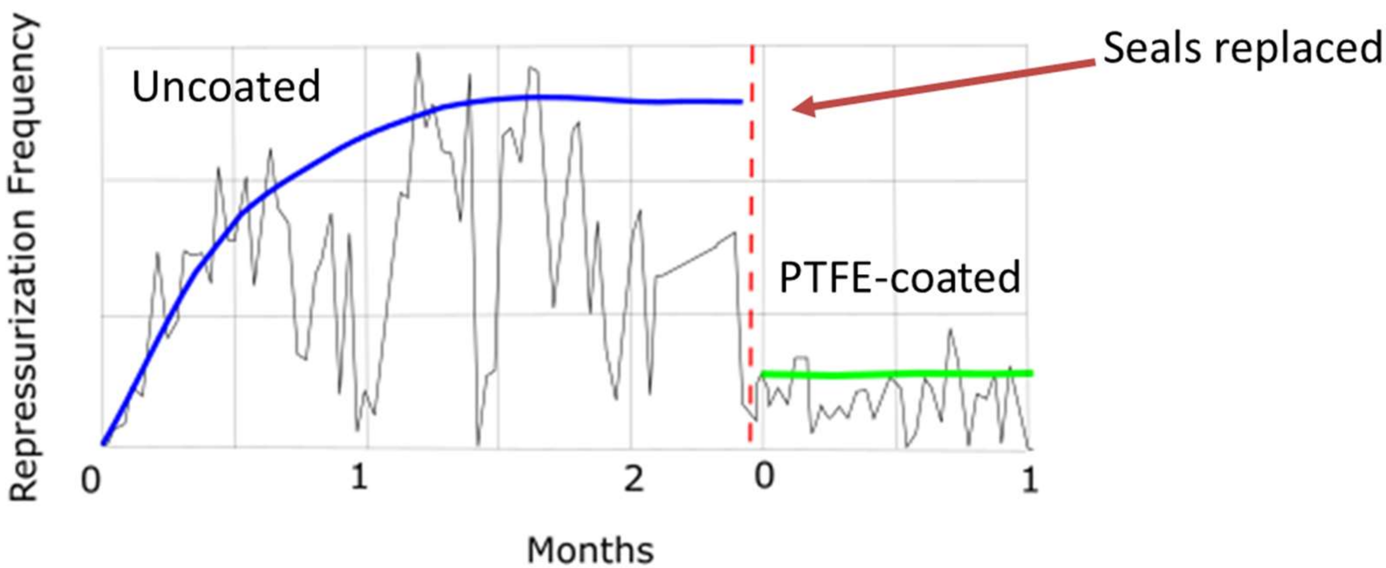
- Data shows Hofer hydrogen compressor activity at hydrogen refueling station in California, operated by Air Liquide.
- Seals are replaced after a set number of repressurization cycles. Typically about every three months.
- **Major project objective met:** Average repressurization frequency reduced by 3x – equates to **factor of ~3 lifetime improvement.**
- Improved lifetime equates to **66% reduction in seal costs**, **3-fold reduction in maintenance downtime.**
- **NREL Report[1]: Increase in mean time between failure from 100 to 365 days results in reduction in station maintenance costs from \$0.36/kg H_2 to \$0.11/kg H_2**



1.Parks, Boyd, Cornish, Remick, *Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs*, **2014**

Accomplishments: Testing of PTFE coated seals with Air Liquide

- Air Liquide: most pressure loss is due to leakage past piston seals.
- Air Liquide noted "remarkable improvements" in hydrogen fuel losses, **down by 36%.**



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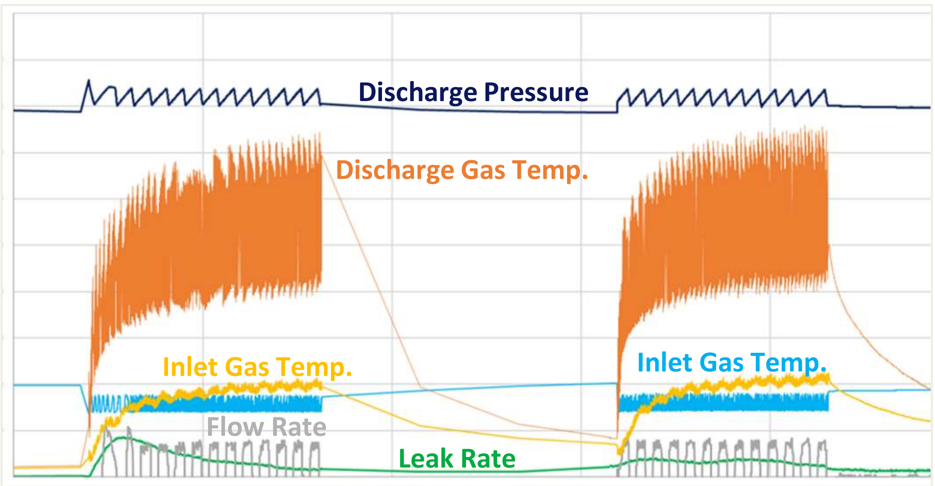
Accomplishments: PTFE-Coated Seal Testing at NREL

- Working with NREL to quantify improved lifetime of seals in HydroPac compressors
- Established test conditions in 2019 for an aggressive thermal cycling with a plan for automated operation to accelerate results.
- Testing of coated and uncoated seals to be carried out at NRELs facility
- Aiming to quantify improved lifetime of seals in HydroPac compressors
- Compressors are run ~8 hours per day.



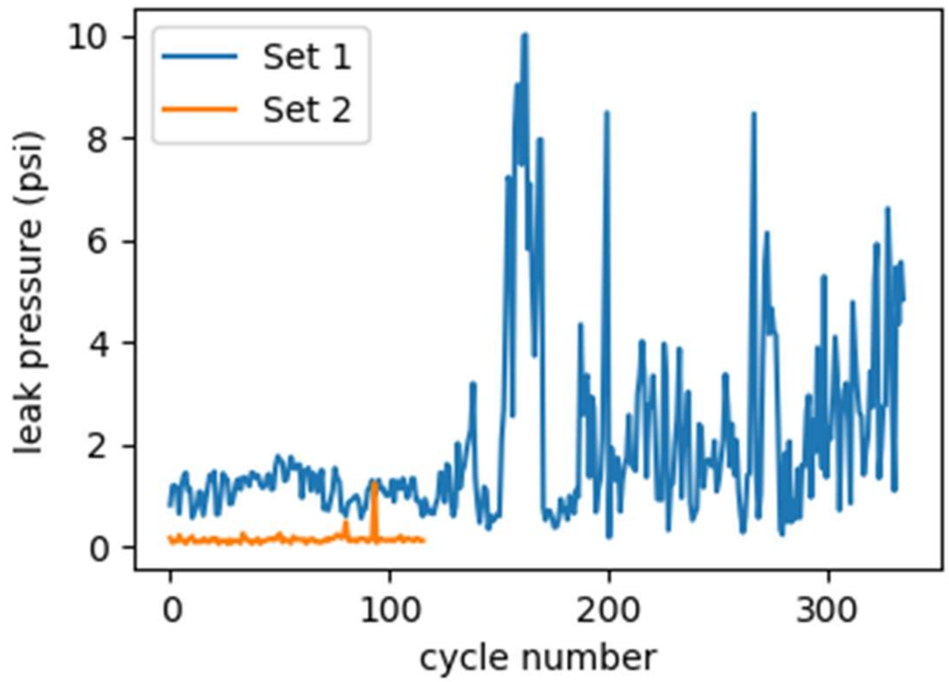
Test Conditions: 30 min on-time, discharge Temperature: 120 °C, inlet pressure: 15-18 Mpa, max flowrate 7.5 kg/hr,
Endpoint: test until flowrate falls to 90% of initial value

Hydropac compressor similar to that used in NREL testing

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Accomplishments: PTFE-Coated Seal Testing at NREL

- First set of uncoated control seals have been run in a Hydropac compressor. Failure detected at ~150 cycles.
- Second set of control seals are currently being run (limited time during March & April).
- Leak pressure is a measure of the hydrogen past the seals between cycles.
- When the second control set has finished, we will begin PTFE coated seals.



Leak pressures between cycles for Hydropac compressor (two seal sets, both uncoated).

Proposed Future Work: Technology Transfer Activities

- Commercial Interest and Inquiries:
  - Hydrogen Compression & Storage
  - Hydrogen Refueling Stations
  - Hydrogen Purification
- Potential Commercial Partnerships
  - Seal manufacturers
  - Hydrogen compressor manufacturers
  - Valve manufacturers
  - H_2 Fuel Cell Systems Providers
- Intellectual Property
  - IP established based on MIT proof of concept
  - Additional GVD patents to be submitted as required

Any proposed future work is subject to change based on funding levels.

Responses to Reviewer Feedback

Reviewer Feedback 1: The justification of the helium results as a surrogate for hydrogen was not clear. More time should have been spent rationalizing this. There were some data that indicated the hydrogen permeability data did not correlate with the helium permeability data; more time should have been spent discussing this discrepancy.

GVD Response: GVD selected helium as the best possible surrogate for hydrogen due to its similar molecular diameter and their similar condensability. Both helium and hydrogen have relatively low sorptivity and high diffusivity which are the main factors in determining permeability.

Reviewer Feedback 2: The weakness for the project is the fragility of the barrier coating application. As mentioned during the presentation, "Hydrogen permeability did not match the helium permeability due to particulate inclusion in films caused by modification of deposition chamber." If this application can be improved to withstand minor defects, the barrier coating application will be considered excellent

GVD Response: The fragility of the barrier coating is addressable by standardized chamber cleaning, proper surface pretreatment and optimization of the initial planarization layer application.

Reviewer Feedback 3: The need to evaluate hydrogen compatibility with polymers is important. The project appears to significantly overstate the relationship of seal failures with the cost of hydrogen. It is not clear how improved seal performance would ever reduce hydrogen compression, storage, and dispensing costs from $3.50/gge to $2.00/gge. The project makes statements about the impact of seal failures without any evidence or other supporting information.

GVD Response: In stating its business case, GVD is drawing on input from compressor end-users and suppliers that the lifetimes of seals is typically significantly shorter than specifications stipulate. A resource cited earlier in this presentation highlighted the importance and economic impact of seal failures in hydrogen dispensing. That report stated that an increase in time between seal failure would reduce maintenance costs at forecourt dispensing locations of $0.25/kg H_2. The value of improved seals is also validated by the success of companies like Takaishi Industry that offer custom elastomer formulations for hydrogen dispensing applications.

Reviewer Feedback 4: The project should consider analyzing coating efficacy on different polymer systems, since vendors may use a variety of different formulations for their respective seals and O-rings. Such data could possibly show the efficacy and/or generality of the approach for different polymer systems and may help guide manufacturers in polymer selection. The team could consider verifying the uniformity of coatings when a large number of components are coated simultaneously (for higher throughput), as well as when coating components with more complicated geometries.

GVD Response: GVD is currently looking into testing on an expanded set of materials. Specific details of the uniformity are proprietary, but GVD regularly supplies lubricious coatings for rubber o-rings at scale, where the conformal nature of the iCVD coating is reflected in the uniformity of the coating.

Summary

Objective: Reduce costs to Hydrogen Fuel Cell Electric Vehicles and hydrogen processing systems associated with Hydrogen Compressor seal failure. Improve seal life 3-5X.

Relevance: Seal failure is a major contributor (>25%) to hydrogen compressor maintenance, adding significant downtime and cost to operation.

Approach: Improve seal life through two types of coatings. Low friction coatings that reduce wear of dynamic seals, extending seal life.

Accomplishments: GVD's coatings have demonstrated significant reduction in mass loss for dynamic seals and improved lifetime (3x) for rigid polymers seals in hydrogen compressors.

Future Work: Drive toward commercialization by demonstrating reduced wear for low friction coatings in a full operational environment.

Thank you

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