Dry Ice Applications: Case Studies

June 18, 2025

Katy Wolf, Ph.D
Consultant

Background

- greenUP! project has focus on EPA's Safer Choice Program
  - Safer Choice program gives labels to certain consumer and institutional products
- P2 Grant proposed to try to get labels for more industrially relevant products to replace products that rely on toxic solvents and certain other toxic ingredients
  - Water-based cleaners used in place of halogenated solvents
  - Water-based cleaners used in place of mineral spirits
  - Soy based cleaners
  - Water-based cleaners for garment cleaning
  - Hydrocarbon with no aromatic components
  - Floor wax strippers without amines and relatively low pH
  - Graffiti removers
  - Floor coatings
  - Acetone and acetone products
  - Dry ice

Background Continued

- Project Issues
  - Many industrial companies do not see a marketing advantage to having an EPA Safer Choice label
  - Approach in industrial applications includes moving to products that improve health and environmental effects but may not be perfect
  - EPA Safer Choice criteria are very stringent and recent modifications have made the standards even more difficult to achieve
  - Program not suited to labels for industrially relevant products
- Webinar Series
  - Cover green industrial products that may or may not be able to get an EPA Safer Choice label
  - All are able to replace more toxic products and improve health and environmental effects

Dry Ice

- Dry ice is carbon dioxide taken from sources that would otherwise be emitted
  - No impact on climate change
  - Carbon dioxide is classified as a green circle solvent in Safer Choice program
  - Could not get Safer Choice label because liquid dry ice and dry ice blasting involves use of equipment
- Dry ice has many advantages
  - No secondary waste
  - Does not conduct
  - Gentle technology so doesn't damage surfaces
  - Can be combined with more aggressive methods if necessary

Webinar Agenda for Case Studies

- Present examples of dry ice blasting and liquid cleaning applications from past EPA grants
  - Energized electrical equipment cleaning
  - Mold cleaning
  - Graffiti removal
  - Boat paint stripping
- Mention other potential applications of dry ice blasting
- Results of test to remove floor wax
- Presentation from Dr. Nelson Sorbo from Cool Clean Technologies, a company that works with liquid dry ice
- Presentation from Ruben Alanis from CryoMode Dry Ice blasting, a contractor that offers dry ice blasting service
- Presentation from Ajit Shahani from eChem, a company that makes safer alternative floor wax strippers

Energized Electrical Equipment Cleaning

- Energized electrical equipment is equipment with current running through it
  - Generally found at electric utilities
- Cleaners must not be conductive
  - Halogenated solvents historically used widely since they have no flash points and are not conductive
    - Cause ozone depletion, global warming and/or are toxic and some are PFAS
- Project conducted by IRTA in Southern California in 2009
  - Sponsored by EPA
  - https://www.irta.us/reports/EPA%20X9969695010%20no%20Appendices.pdf

Energized Electrical Equipment Cleaning Continued

- Involved identifying, testing and demonstrating low-VOC, low toxicity alternatives for cleaning energized and non-energized electrical equipment
- Worked with Southern California Edison
  - Large utility
- Safer alternatives for cleaning energized equipment included deionized water, blasting media, dry ice blasting and liquid dry ice cleaning
  - Spent water and blasting media require discharge or collection and disposal
  - Dry ice sublimates and does not generate any secondary waste

Annualized Cost of Cleaning 60 115 kV Insulators

Method	Capital Cost	Labor Cost	Material Cost	Service/Main-tenance Cost	Total Cost
Water Cloth	-	$2,400	-	-	$2.400
Solvent Cloth	-	$1,800	$1,200	-	$3,000
Media Blasting	-	-	-	$2,500	$2,500
Dry Ice Blasting	$384	$1,800	$386	$167	$2,687


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Liquid Dry Ice Cleaning

- Tested Sno-Gun, made by company called Va-Tran
- Cleaned energized electrical equipment
  - Tested it for cleaning mechanism cabinet at Southern California Edison site
  - Tested it for cleaning telephone switching control panel at Brithinee Electric

Mold Cleaning

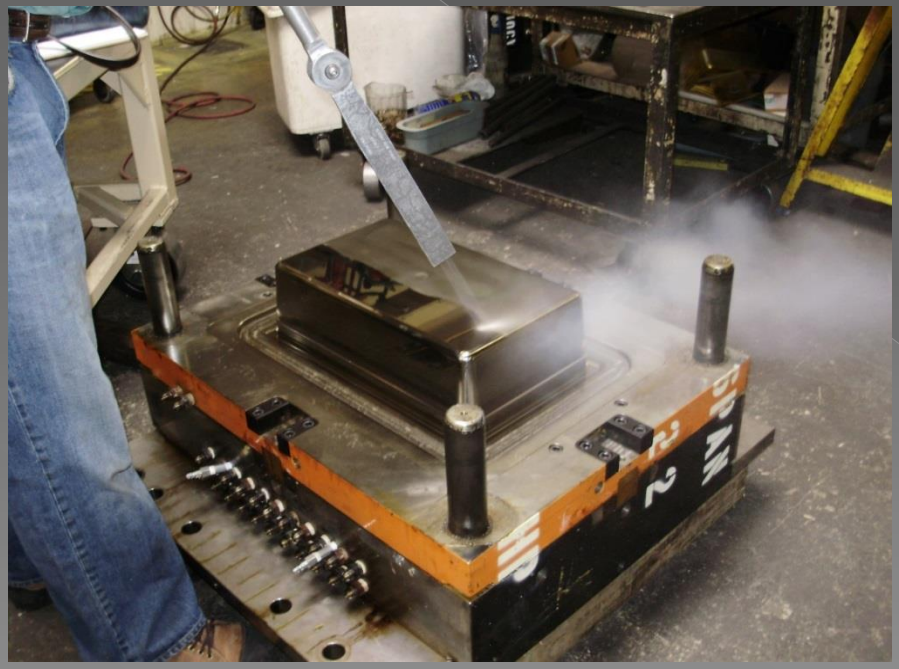
- Molds used to make parts of various kinds
  - Fiberglass, composite, foam, concrete and plastic
- Use high VOC content and toxic materials as mold release agents and mold cleaners
  - Hexane and styrene used for cleaning molds
- Project conducted by IRTA in Southern California in 2013
  - Sponsored by EPA and SCAQMD
  - https://irta.us/reports/Finalscaqmdmoldrelrept.pdf

Mold Cleaning Continued

- Project involved working with seven companies who molded parts
- Involved identifying, testing and demonstrating low-VOC alternatives for mold cleaning
- For metal molds, best alternative was dry ice blasting

Annualized Cost of Removing Mold Protectant

Cleaning Method	Cost
Hexane Aerosol Cleaning	$56,174
Acetone/Glycol Ether Cleaning (five-gallon pails)	$22,914
Acetone/Glycol Ether Cleaning (drums)	$11,454
Dry Ice Blasting (no system purchase, same labor)	$3,546
Dry Ice Blasting (no system purchase, double labor)	$7,113
Dry Ice Blasting (system purchase, same labor)	$6,198
Dry Ice Blasting (system purchase, double labor)	$10,680



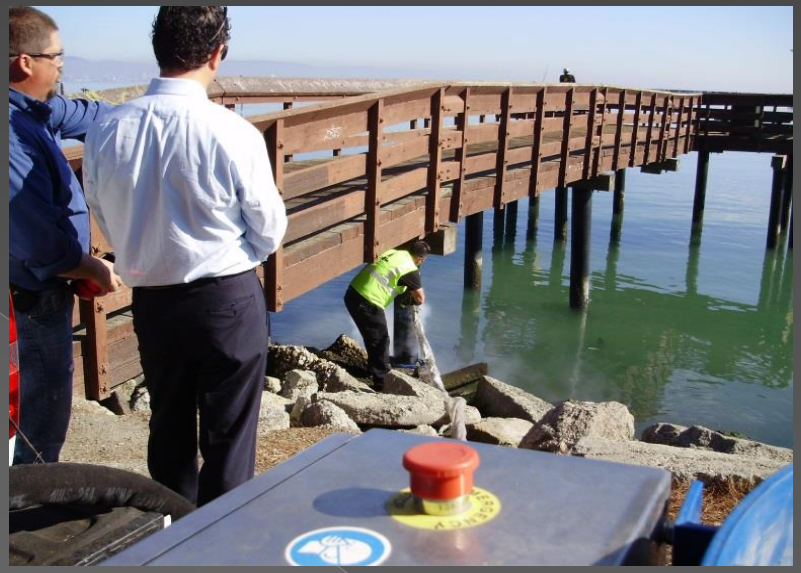
Graffiti Management

- Resource intensive and costly problem for public agencies and private companies
  - Problem has worsened since Covid
- Toxic solvent NMP used in graffiti removers, sodium bicarbonate and water blasting methods used for controlling graffiti
  - NMP is reproductive and developmental toxin and blasting technologies generate large volumes of waste or wastewater
- Project conducted by IRTA in California in 2014
  - Sponsored by EPA, BAAQMD and SF Dep Env
  - https://www.irta.us/reports/GrafEPAfinalrept.pdf

Graffiti Management Continued

- Project involved developing low-VOC content, low toxicity graffiti removers, testing alternative blasting methods and testing protective films and graffiti resistant coatings
- Worked with Port of SF, transportation system, departments of public works and city
- Tested dry ice blasting system extensively
  - Results indicated it can remove light graffiti like spray paint very effectively


AGUA VISTA PARK
PUBLIC
FISHING
PIER
PORT OF SAN FRANCISCO
RESTAURANT RESTROOMS OPEN
DURING DAYLIGHT BUSINESS HOUR




NON-TOXIC
NON-ABRASIVE

Boat Paint Stripping

- Pleasure craft painted with copper antifouling bottom paint
- When boats are cleaned by divers, copper builds up in marine basins and kills marine organisms
- EPA project conducted with Port of San Diego to test alternative boat paints
- Project sponsored by EPA and DTSC to further test alternative hull paints on boats
  - Also tested alternative boat hull stripping methods
- https://www.irta.us/reports/DTSCboatfinalrept1.pdf

Boat Paint Stripping Continued

- Worked with boatyards in San Diego
- Boatyards traditionally used methylene chloride stripping or hand sanding
- Methylene chloride is a carcinogen and has been regulated under TSCA
- Tested alternative blasting methods on boat destined for demolition
- Cost of using three blasting technologies was estimated to be similar
  - Cost slightly lower than cost of using methylene chloride


CF 3172 ER

Other Potential Dry Ice Blasting Applications

- Company called Cold Jet sells dry ice blasting equipment
- Have range of case studies on website at https://www.coldjet.com/
  - Asphalt equipment cleaning is interesting application
    - Potential for reusing the asphalt
  - Printing equipment cleaning
  - Brewing equipment cleaning
  - Aerospace parts cleaning
- Tested dry ice blasting with Cold Jet for removing floor wax
  - Was successful on panels, need to test on floor

Safer Alternative Floor Wax Stripping

- Schools and public buildings have vinyl composition tile (VCT) flooring
  - Requires stripping and waxing over life of floor
  - Floor wax strippers on market contain amines and are high pH
    - Amines cause asthma and are sensitizers and high pH products can injure workers
  - Many floor waxes contain fluorosurfactants which are PFAS
- Worked with supplier and formulator to develop two floor wax strippers with no amines and relatively low pH in past EPA project

Alternative Floor Wax Stripping Continued

- Procedure for using floor finish strippers
  - Dilute liquid floor stripper with water
  - Apply stripper with floor machine with Hi-Pro pad
  - After it bubbles up, use wet vac, rinse with water, use wet vac again and flush residue (wax, stripper and water) into the sewer
- Options for stripping floor finishes
  - Use floor wax strippers with no amines and relatively low pH and use finishes with no fluorosurfactants
  - Tested dry ice blasting successfully for stripping floor wax on panels
    - Advantage is that residue can be collected instead of discharged to sewer
    - Plan to test dry ice stripping on floor in the future and evaluate feasibility and cost effectiveness

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Green Innovations Floor Finish Stripper

Ajit & Kory Shahani

President, VP - eChem

About eChem

- Incorporated in 2003
- Primary markets for metal processing (cleaning, degreasing, passivation, etc.) are Aerospace and Biomedical
- Based in Southern California – Conversant with SCAQMD rules and regulations
- Multiple projects handled requiring low to no VOC chemistries
- Collaborated with Dr. Fruscella in developing floor strippers and graffiti removers

Floor Wax Stripping Products

Worked with IRTA on flooring project sponsored by EPA	• eChem and Dr. William Fruscella, Ph.D. worked with IRTA on formulating the strippers
Aim was to develop two safer floor wax stripping products	• No amines • Relatively low pH
New floor finish strippers had to meet CARB requirements in California	• Floor wax stripper must specify a dilution ratio for light or medium build-up of polish that results in an as-used VOC concentration of 3 percent by weight or less • Floor wax stripper must specify a dilution ratio for heavy build-up of polish that results in an as-used VOC concentration of 12 percent by weight or less
Developed two strippers	• One contained solvent • One was solvent-free • Both have zero VOC content and should be used with Hi-Pro pad

Stripper Testing

Tested strippers with IRTA in a variety of different locations in schools and public buildings

Tested extensively with Riverside School District

- Learn stripping procedures and requirements for effective strippers
- Tested three stripping products
- Compared to current stripping product that contained amines, a toxic solvent and had high pH
- Two formulations worked best for stripping multiple coats of wax

Tested at SCAQMD

- Compared to current stripper with amines and high pH
- Preferred the stripper containing solvent because it left a non-slip surface

Stripper Testing Continued

Tested strippers at San Francisco City Hall

- Both strippers worked well

Tested strippers at Irvine school district

- Alerted staff to advantages of Hi-Pro pads and they adopted them
- Pads can be recycled and reused
- Stripper with solvent worked effectively

Tests of Safer Strippers

BEFORE

AFTER

Recent Activities

Didn't commercialize strippers at the time because of Covid

Decided to commercialize strippers a few years ago

Contacted by Coast Guard training facility who had seen IRTA report

Tested both strippers	Coast Guard preferred solvent-free stripper	Purchasing large quantities	Are largest current customer

Contact Information

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COOL® CLEAN TECHNOLOGIES

CO_2 Spray Technology: Safer Alternatives – Dry Ice Cleaning Webinar

June 18, 2025

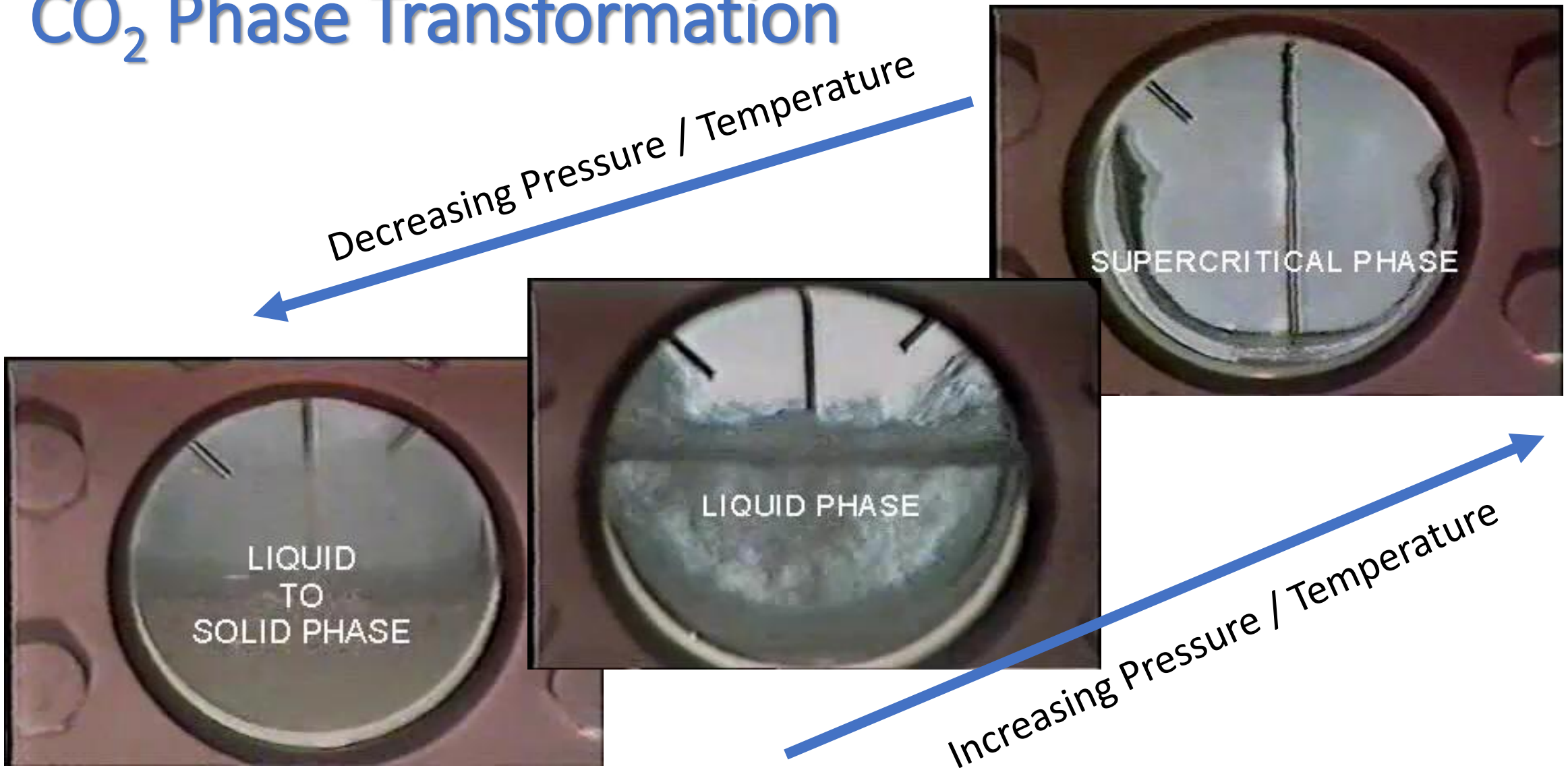
Who Is Cool Clean Technologies?

- A company that uses CO_2 in all phases:
  - For cleaning and surface preparation of precision surfaces;
  - Machine tool cooling and lubrication for precision machining;
  - Selective extraction.
- Strong Proprietary Products - Patents and Know-How
- All our processes have these important attributes:
  - Are effectively dry;
  - Generate Zero to trace byproducts;
  - No Touch spray cleaning;
  - Lower energy costs;
  - Environmentally friendly.

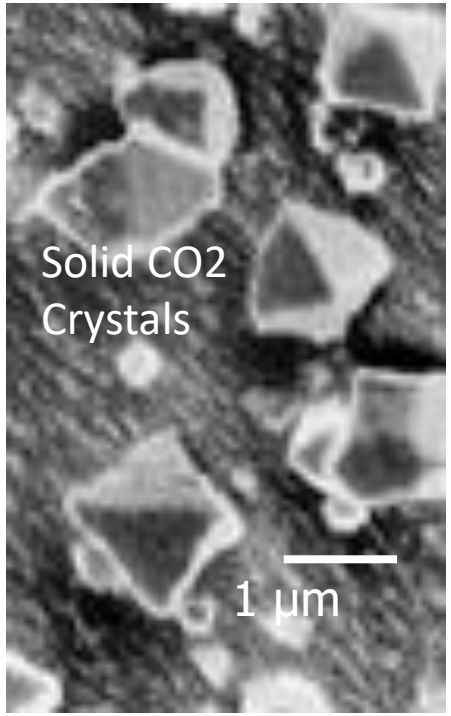
CO_2 is a Recyclable and Renewal Resource

- The CO_2 Generators (ranked based on CO_2 Purity):
  - Ethanol plant production;
  - Ammonia production;
  - Natural gas sweetening;
  - Ethylene Oxide Production;
  - Coal to Liquid;
  - Gas to Liquid;
  - Hydrogen (Refinery);
  - Industrial iron/steel furnaces;
  - Cement plant / Lime kiln exhausts.
- The Recycled CO_2 Users (2018 percentages):
  - Fertilizer/Urea manufacturing (57%);
  - Oil / coal bed methane recovery (34%);
  - Food and beverage additives (6%) ;
  - Weld gas; (2%)
  - Fire extinguisher;
  - CO_2-Based Cleaning Technology.

CO_2 Phase Transformation

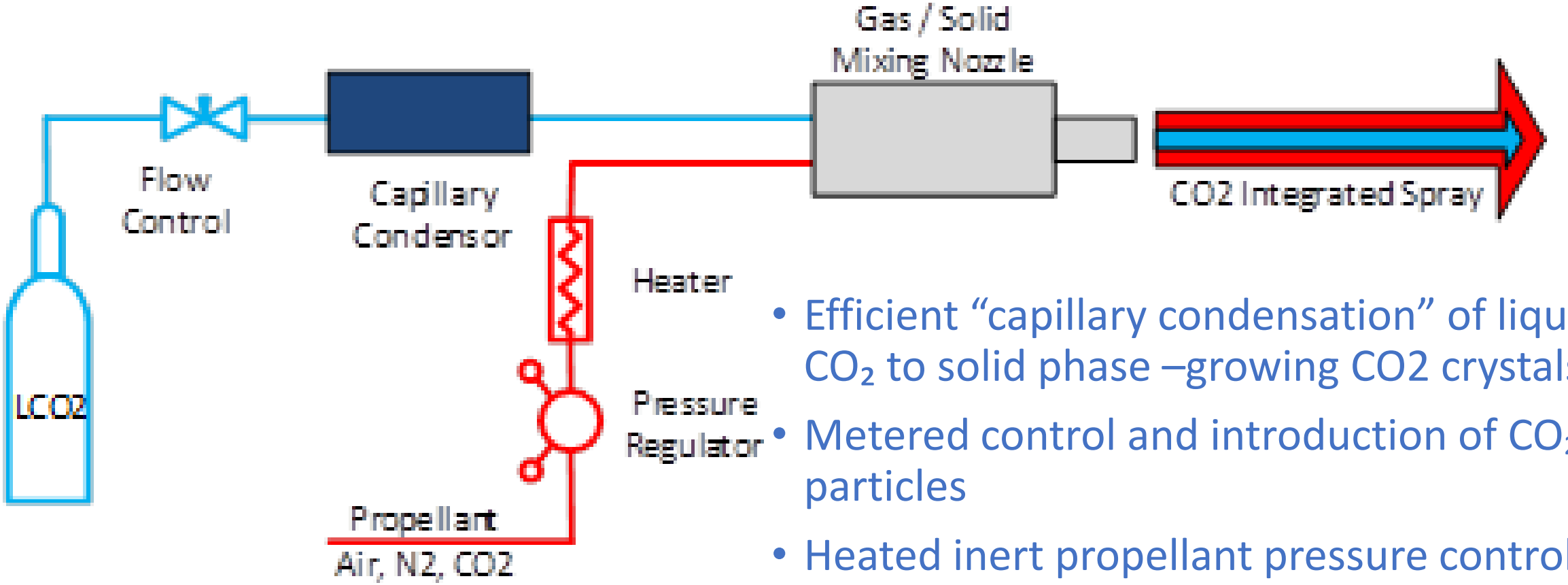


Solid CO2 Particle Characteristics



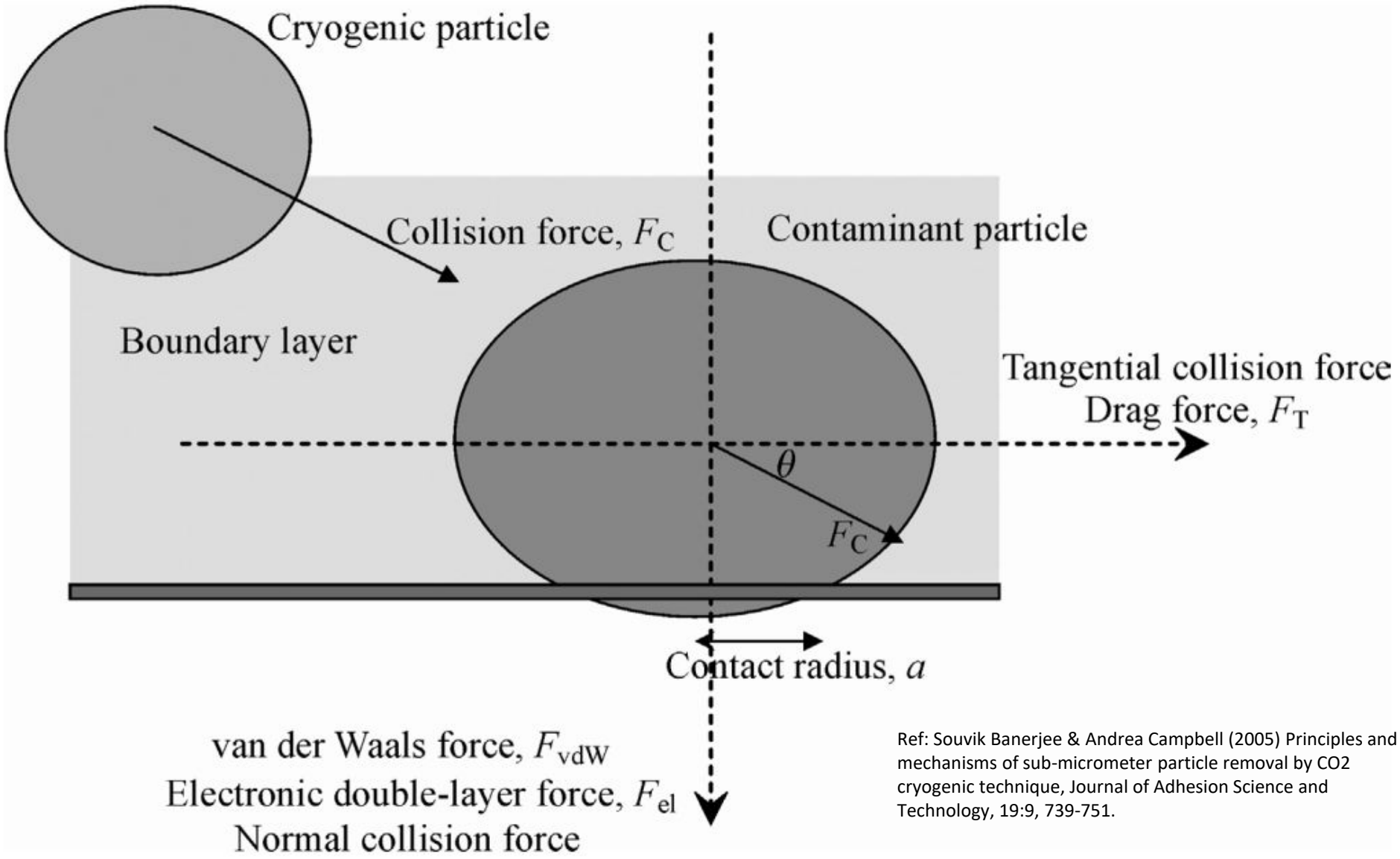
- Impact phenomenon – ablation and phase change (solid->gas, solid->liquid->gas)
- Hardness – <2 Hm (examples: 1 – talc, 2.5 - fingernail, 3 – calcite, 5.5 – glass, 7 – quartz, 9 - AlO)
- Particle Size – < 0.5 microns to > 500 microns, range adjustable (coarse/fine)
- Impact Stress - up to 130 Mpa (18,850 psi), pressure/particle size/distance dependent

CO_2 Spray Technology



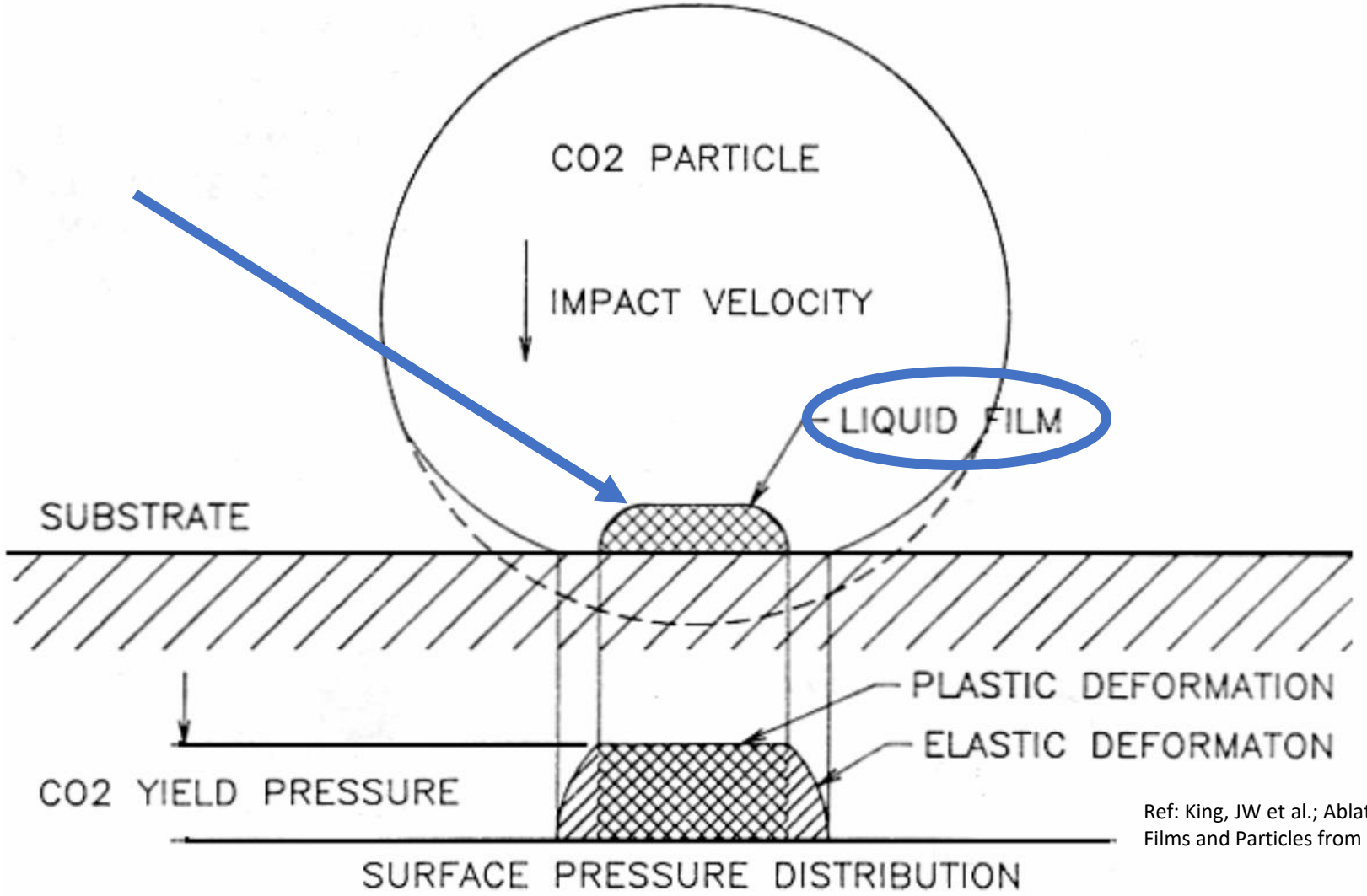
- Efficient "capillary condensation" of liquid CO_2 to solid phase –growing CO2 crystals
- Metered control and introduction of CO_2 particles
- Heated inert propellant pressure control
- Adaptable to existing assembly platforms

How Does CO_2 Spray Remove Particles?



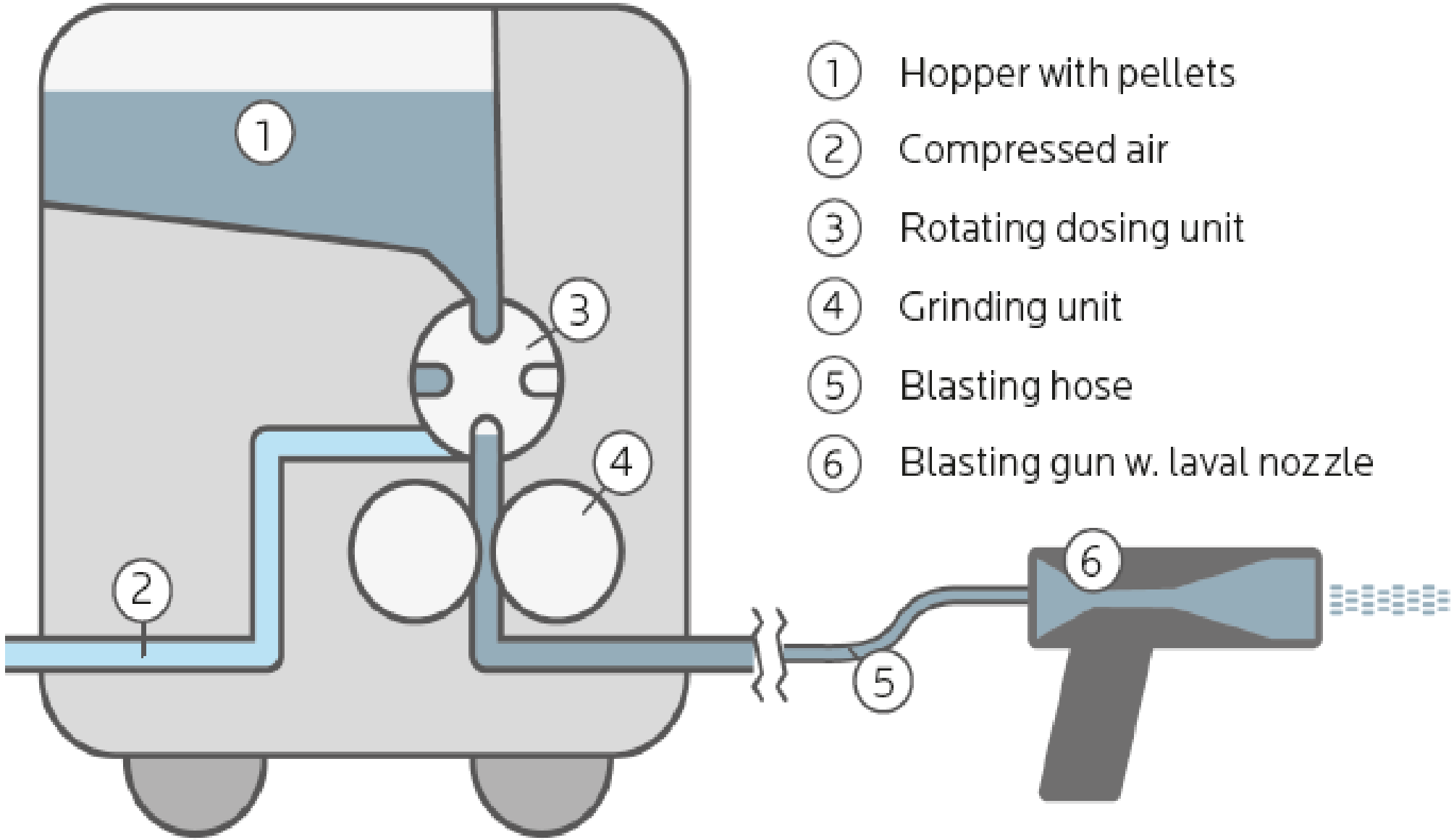
Ref: Souvik Banerjee & Andrea Campbell (2005) Principles and mechanisms of sub-micrometer particle removal by CO2 cryogenic technique, Journal of Adhesion Science and Technology, 19:9, 739-751.

How Does CO_2 Spray Clean Remove Non-Particulate Organic Residues?



Ref: King, JW et al.; Ablation and Sorptive Removal of Films and Particles from Surfaces Using Carbon Dioxide

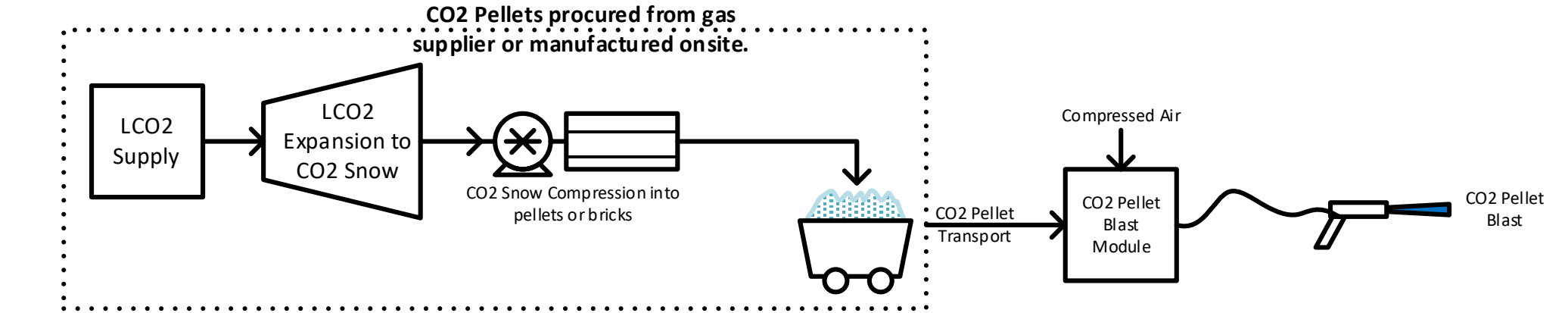
Dry Ice Pellet Blast Technology

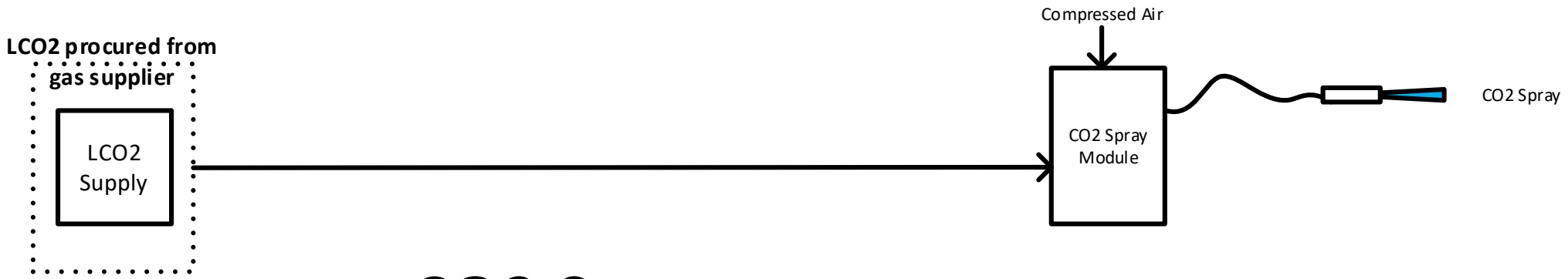


1. Hopper with pellets
2. Compressed air
3. Rotating dosing unit
4. Grinding unit
5. Blasting hose
6. Blasting gun w. laval nozzle

CO2 Spray vs CO2 Pellet Blast System Comparison

CO2 Pellet Blast

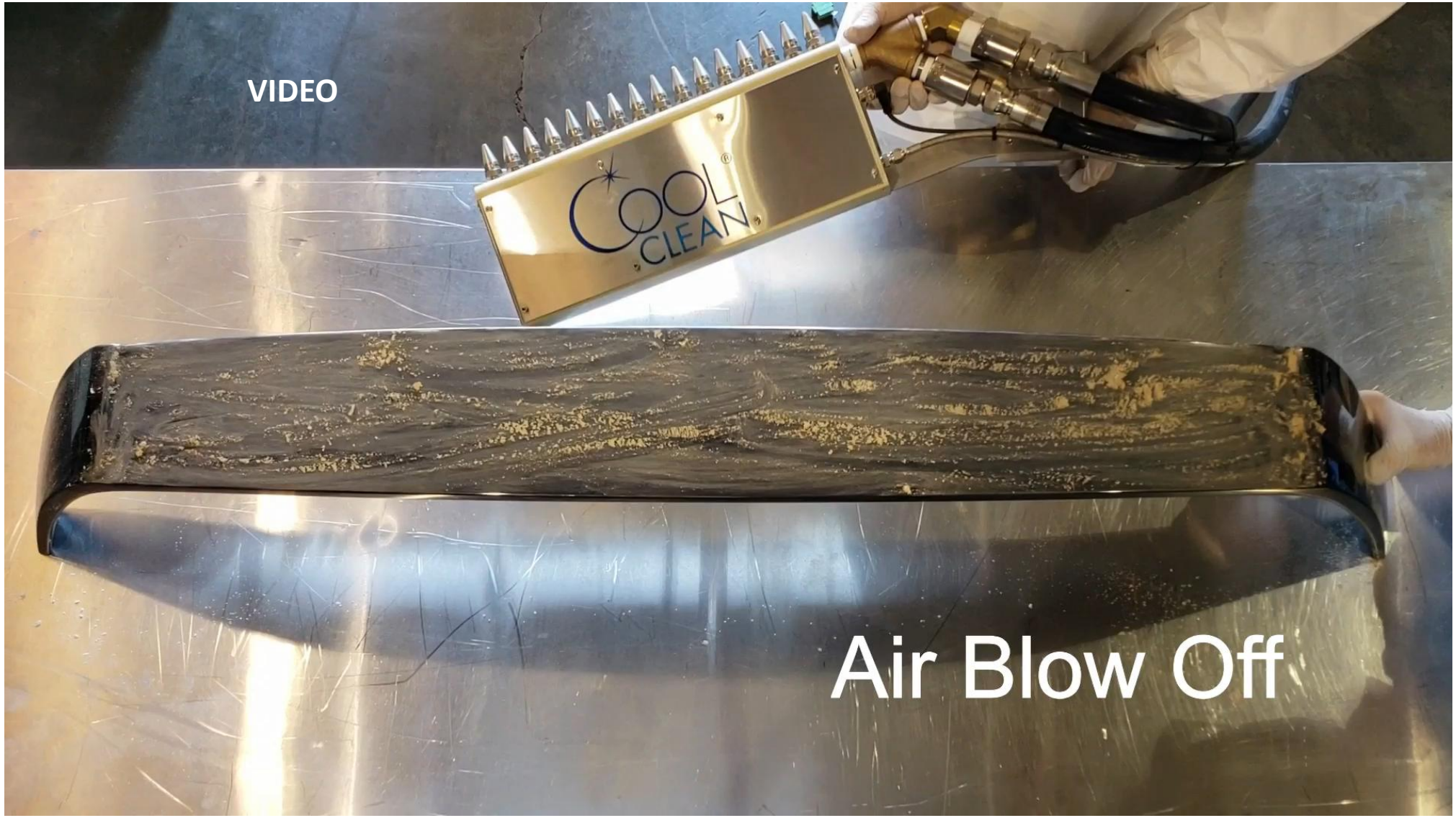




CO2 Spray

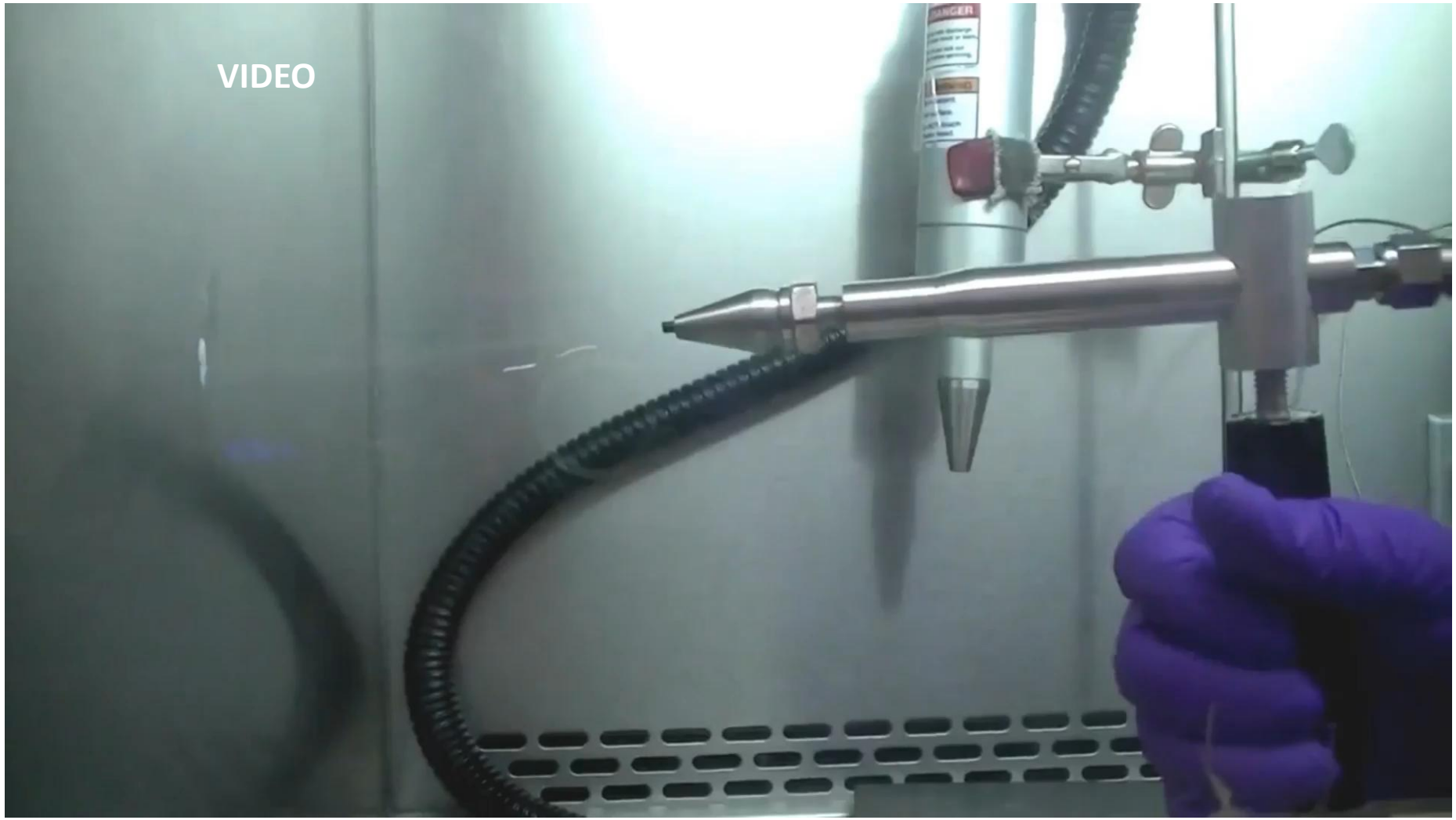
CO2 Spray vs CO2 Pellet Blast Application Comparison

Particle Removal: Air Jet vs CO2 Spray

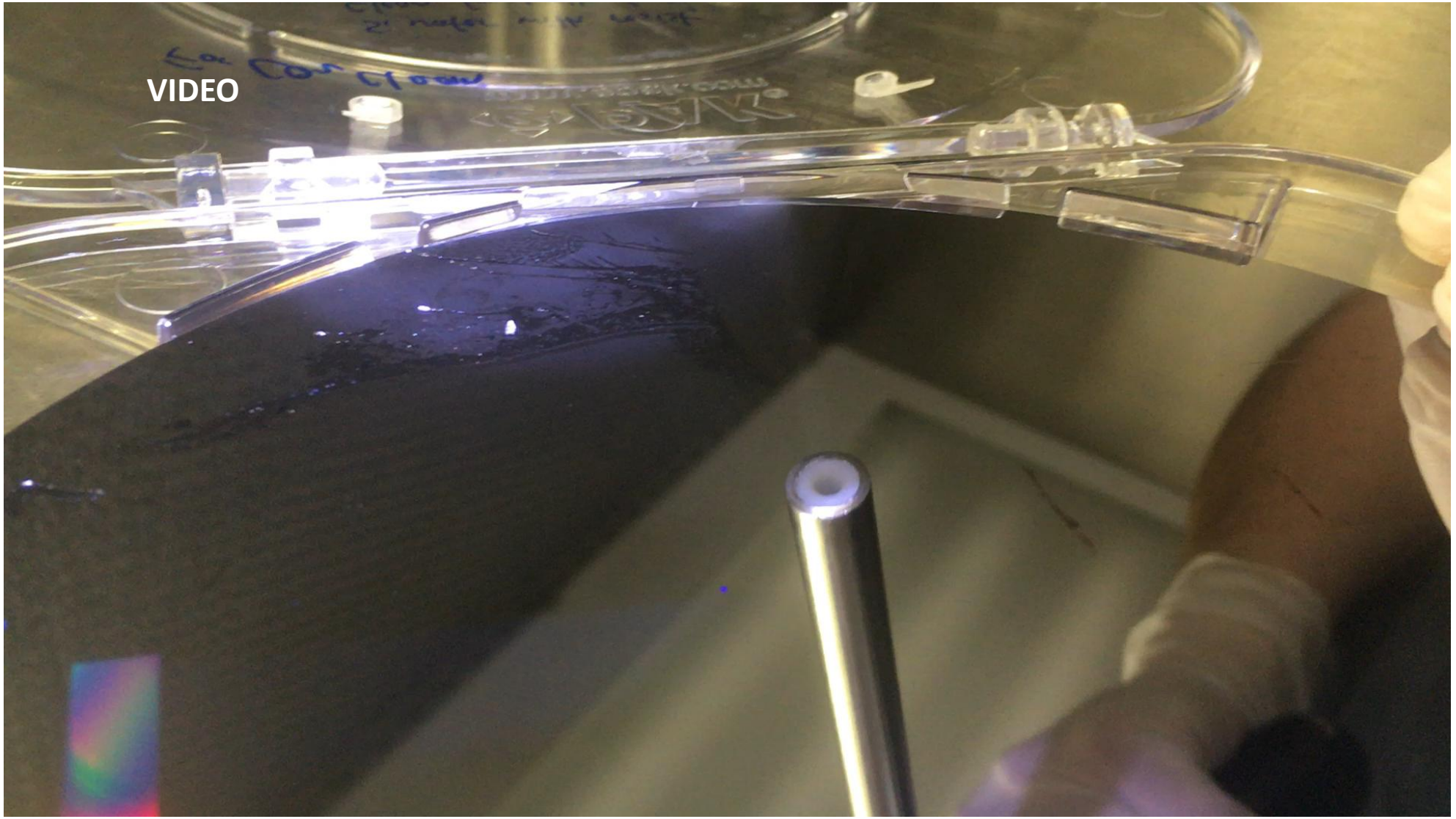


Fingerprint Removal from Optical Surface

Removal of Oily Grime from Metal Surface



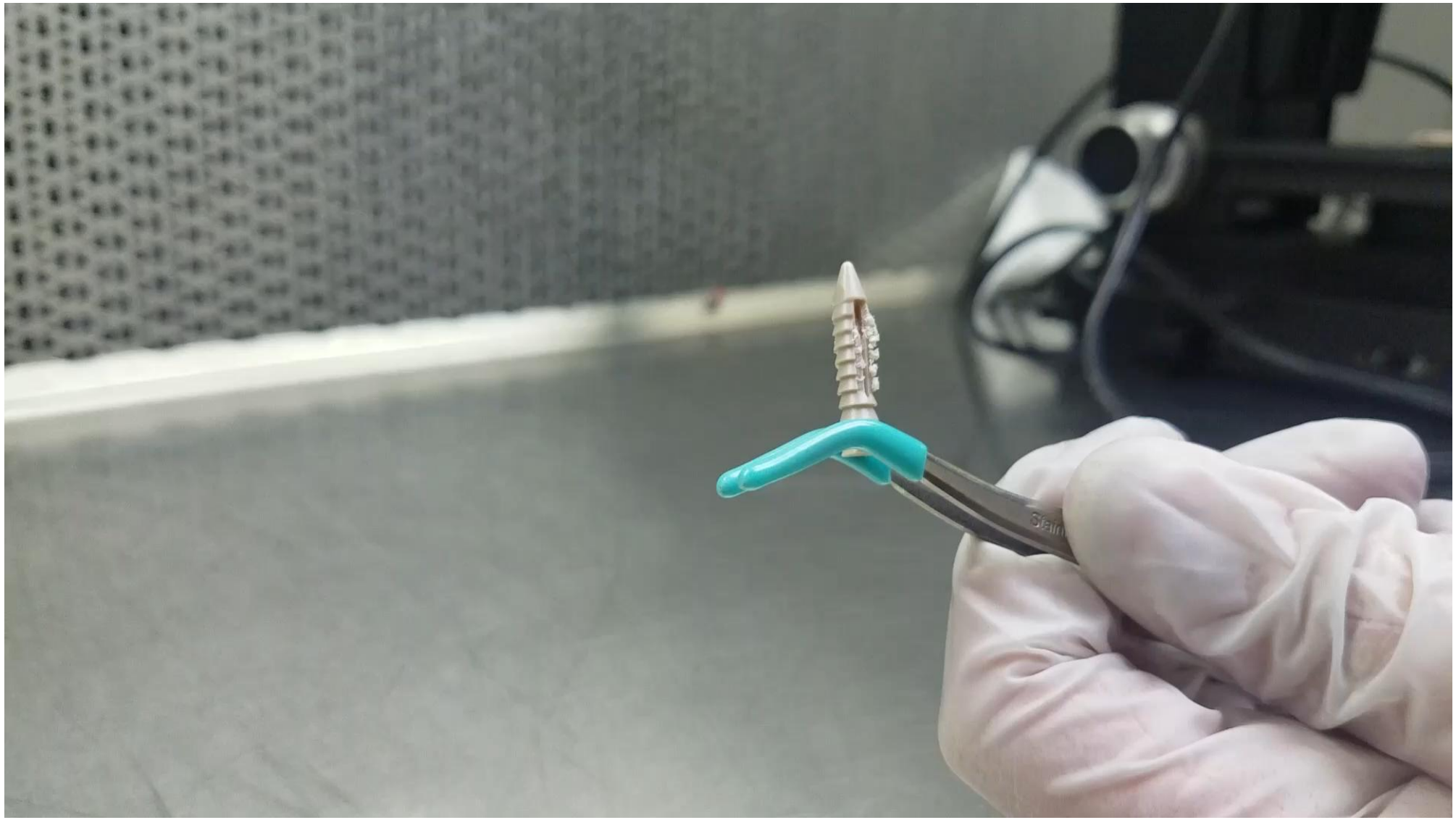
Removal of Harden Photoresist



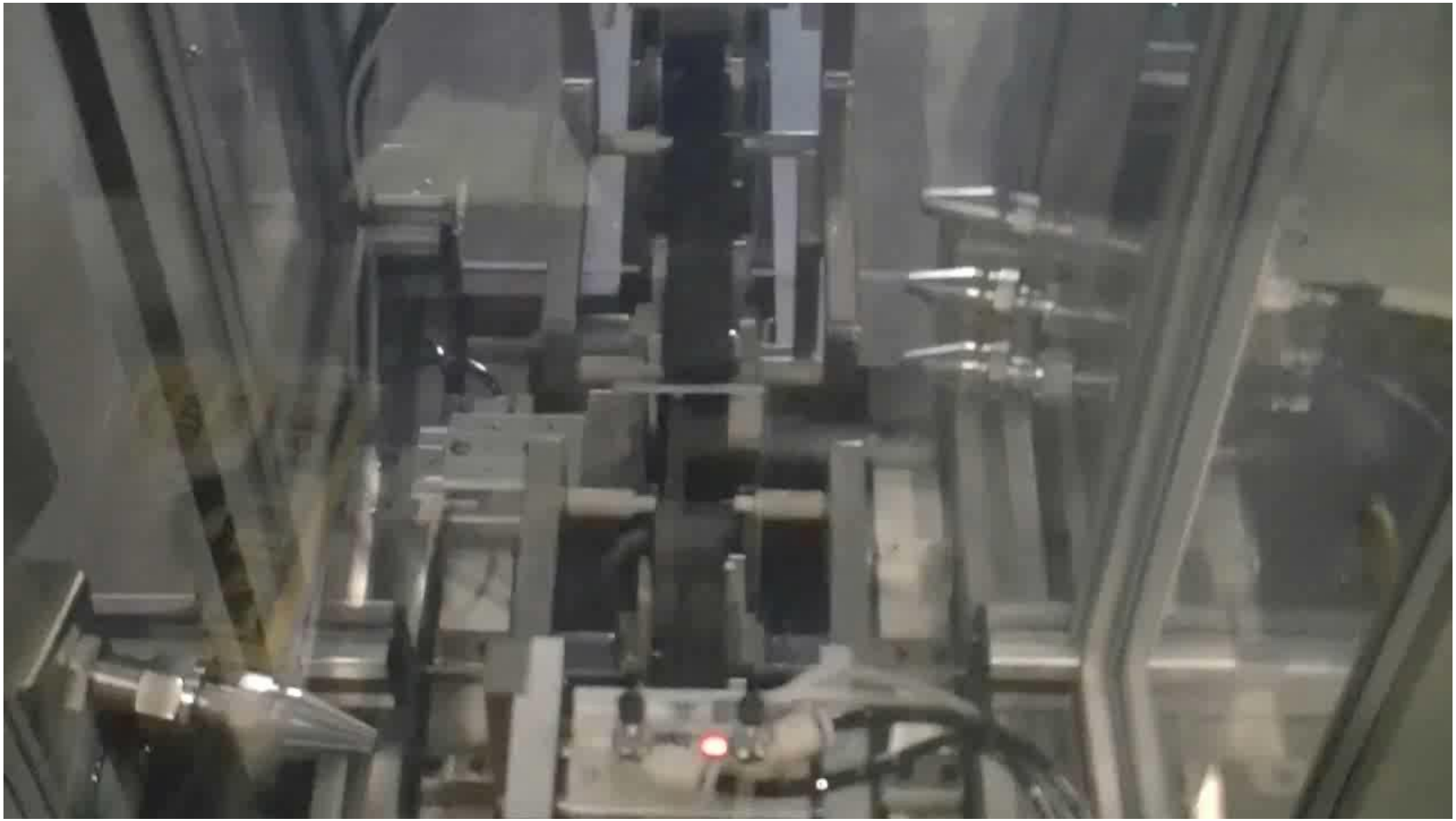
Radial Spray Nozzle for Inside Wall Cleaning

Exterior Automotive Plastics Cleaning

PEEK Deburring with CO2 Spray (Video)



Automated HDD Cleaning System – In-Line Cleaning



Case Study: Replacing 5-Stage PowerWash for Automotive Plastics Cleaning

Current Cleaning Technology – 5-Stage PowerWash / Aqueous Wet Chemical System

- Parts go through water jet-cleaning / pretreatment prior to coating.
- Ovens / fans are then used for the evaporation of water droplets following the pretreatment (Power wash).
- Significant amount (> 50%) of automotive factory energy is consumed in paint line.
- Large footprint
- High investment cost

Case Study: PowerWash / CO2 Spray System Details

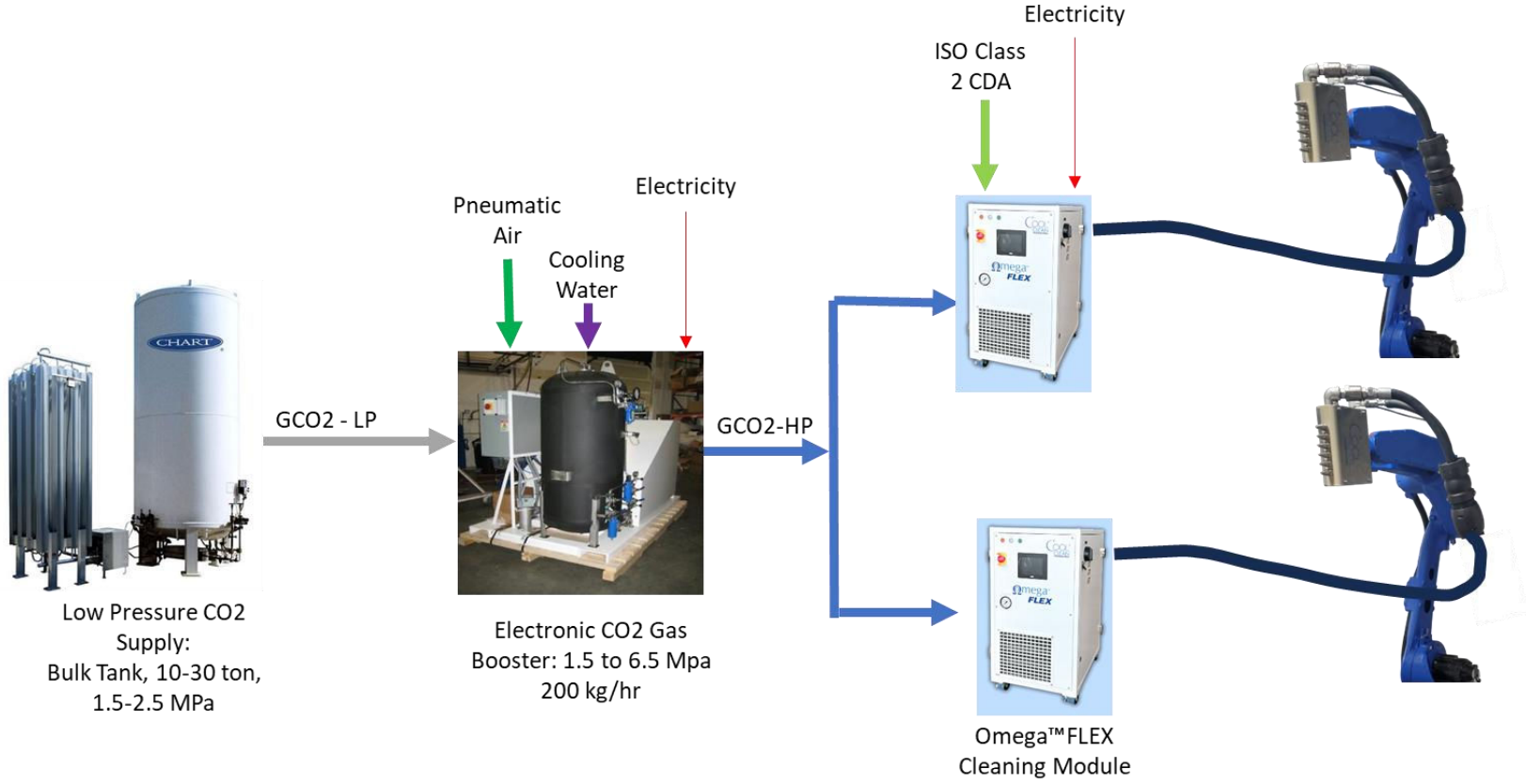
- Automotive Plastics Cleaning Line, SE USA.
- Supplier to OEMs.
- Manufacture exterior components – bumpers, grills, trim.
- Paint Line Characteristics:
  - Process 40 skids of parts per hour,
  - Two shifts / 3900 hrs/yr,
  - Cleaning surface: 8 m^2/skid.
- Currently use 5-Stage Powerwash for product pre-cleaning – prior to painting.
- Regional electric power: mix of nuclear, ng, coal, renewables.
- Considering a switch to CO2 spray.

Case Study: PowerWash Production Data

- Operating Systems:
  - Reverse Osmosis: - Rinse water post cleaning,
  - Wastewater Treatment – process of wash water,
  - Spray Water Pumping,
  - Ventilation,
  - Oven ,
  - Chemicals for wash water.
- Regional electric power mix: 266 gm-CO2e/kWhr
- Estimated operation cost: $70/hr.
- Estimated electricity usage: 265 kW.
- Estimated NG usage for ovens: 50 m^3/op-hr.
- CO2e Emissions: 168 kg-CO2e/hr.

Case Study: CO2 Spray Replacement

- Spray Module Requirements;
  - 2 x 6-nozzle Omega™FLEX.
- Estimated facilities:
  - 42 kg/hr CO2,
  - 2.3 m^3/min CDA,
  - 24 kWhr/hr (average of 21 and 27 kWhr/hr).
- Operating cost: $18/hr.
- Energy usage: 30 kWhr/hr.
- CO2e emissions: 26 kg CO2e/hr.



Case Study: PowerWash vs CO2 Spray

- Both system meet the cleaning requirements of the process.
- CO2 Spray provides substantial savings in operating cost, electric power requirements, and CO2e emissions generated.

Cleaning Option	Operating Cost, $/hr	Electric Power, kW	CO2e, kg-CO2/hr
PowerWash	$70	264	168
CO2 Spray	$18	30	68*
Percent Reduction	**74%**	**89%**	**60%***

* Includes 42 kg/hr recycled CO2

Summary

- CO_2 Spray uses recycled CO_2 as a cleaning agent.
- CO_2 Spray has been demonstrated to be a cost effective environmentally friendly cleaning system for many applications.
- Key CO_2 Spray applications:
  - Particle Residue and Removal
  - Electronics and HDD Cleaning
  - Pre-Treatment of Automotive Plastics
  - Precision Cleaning of Optical Surfaces
- CO_2 Spray and CO_2 Pellet Blasting (Dry Ice) cleaning are similar in function but differ in intensity, temperature impact and facilities supply issues.
  - CO_2 Spray Cleaning Intensity – delicate to moderate.
  - CO_2 Pellet Blast Cleaning Intensity – moderate to aggressive.

For Further Information . . .

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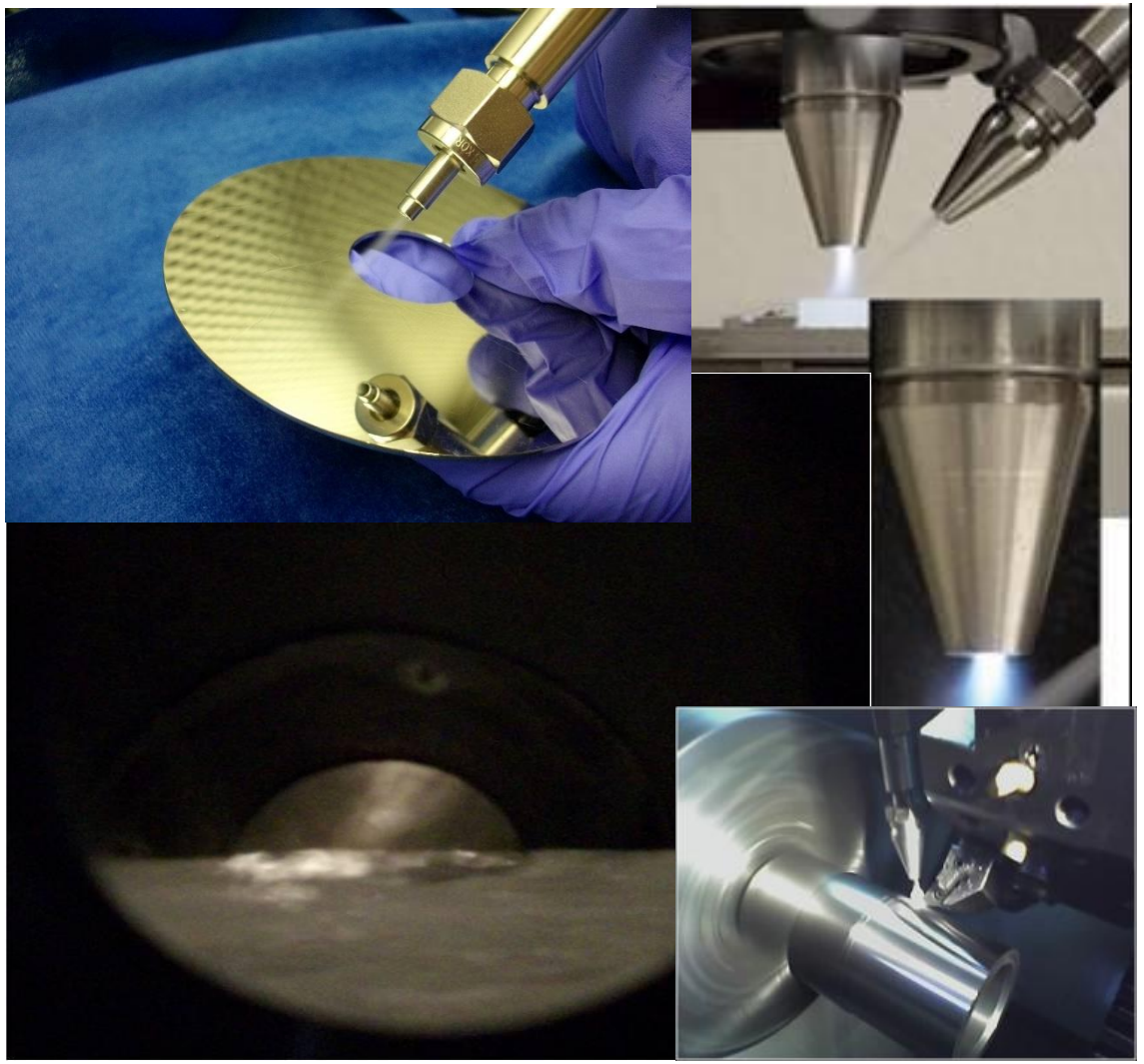

CryoMode

DRY ICE BLASTING

Capabilities Overview

Ruben Alanis - Owner

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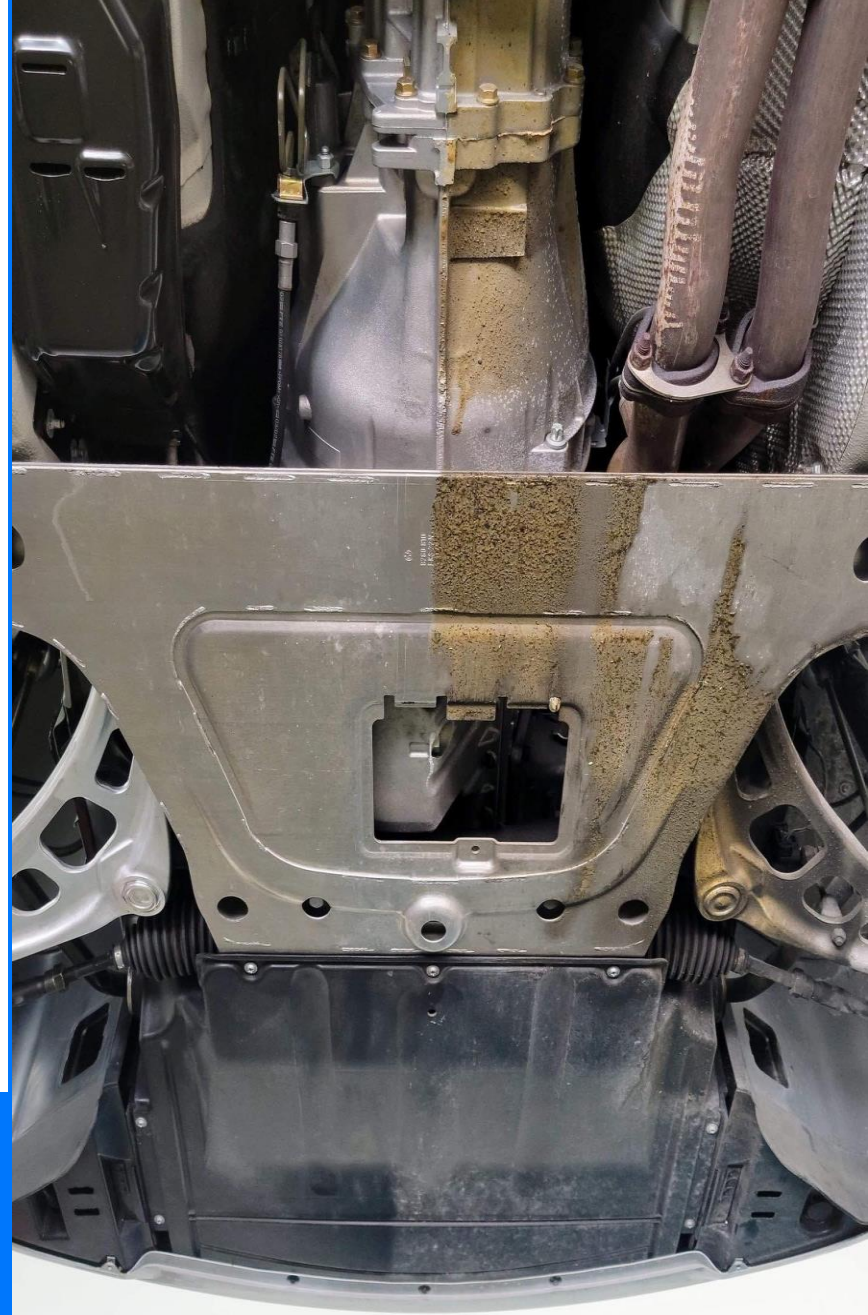


Introduction

Founded in 2022, CryoMode Dry Ice Blasting is the first dedicated dry ice blasting service in the greater Seattle area. Our specialty cleaning services and expertise cover a wide variety of applications in the automotive, residential, commercial, and industrial spaces.

What is dry ice?

- Frozen carbon dioxide
- -109 degrees Farenheit
- Produced locally by companies like AirGas, Linde, Reliant, etc
- 3mm pellets, 500lb containers
- Lasts up to 10 days before complete sublimation

How it works

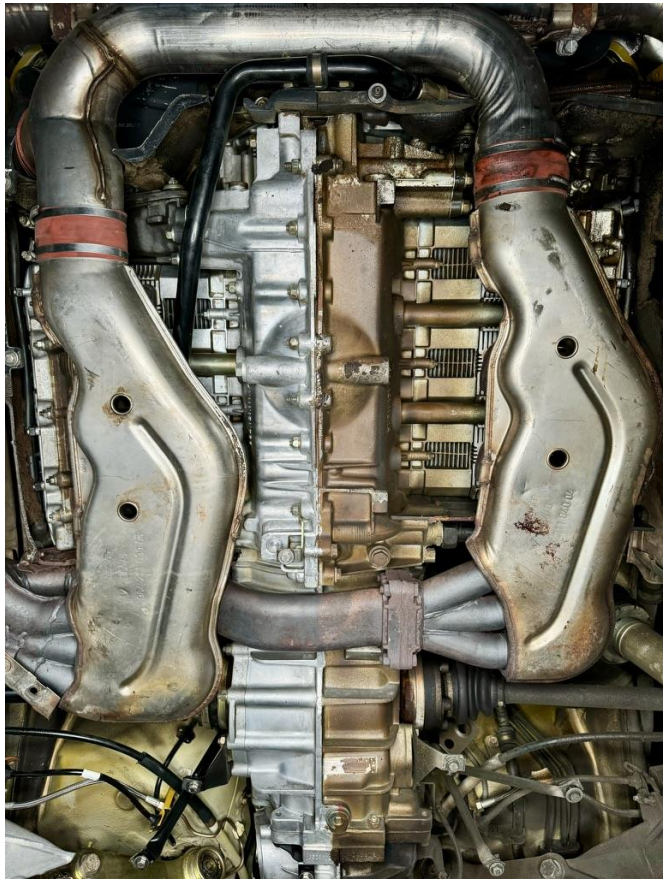
- Ice pellets at up to 150psi
- Surface freeze
- Kinetic energy impact
- Sublimation reaction
- Dirt falls, CO2 turns to gas
- (We sweep/HEPA vacuum…a lot)

Why use dry ice?

- Safe for virtually all surfaces
- Wide range of control
- No liquids or chemicals
- Environmentally friendly
- Saves time
- Cost effective
- Incredible results

Automotive Cleaning

CRYOMODE
DRY ICE BLASTING

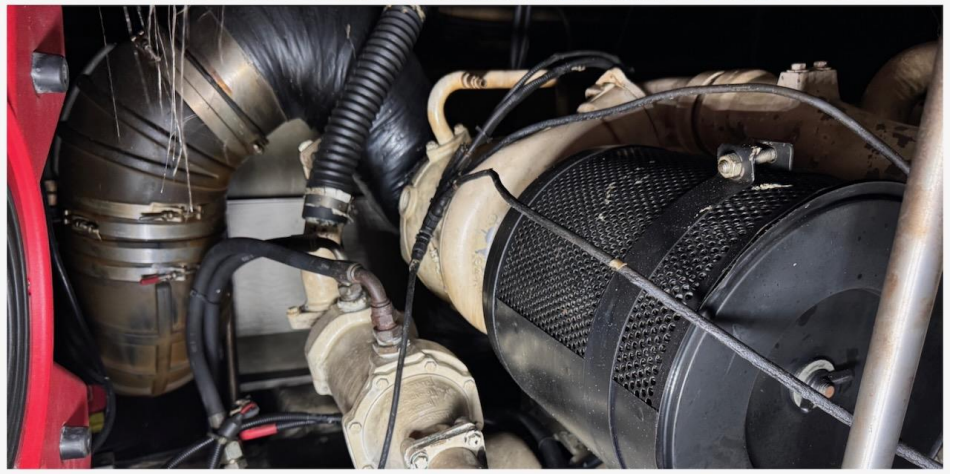


Laser Ablation

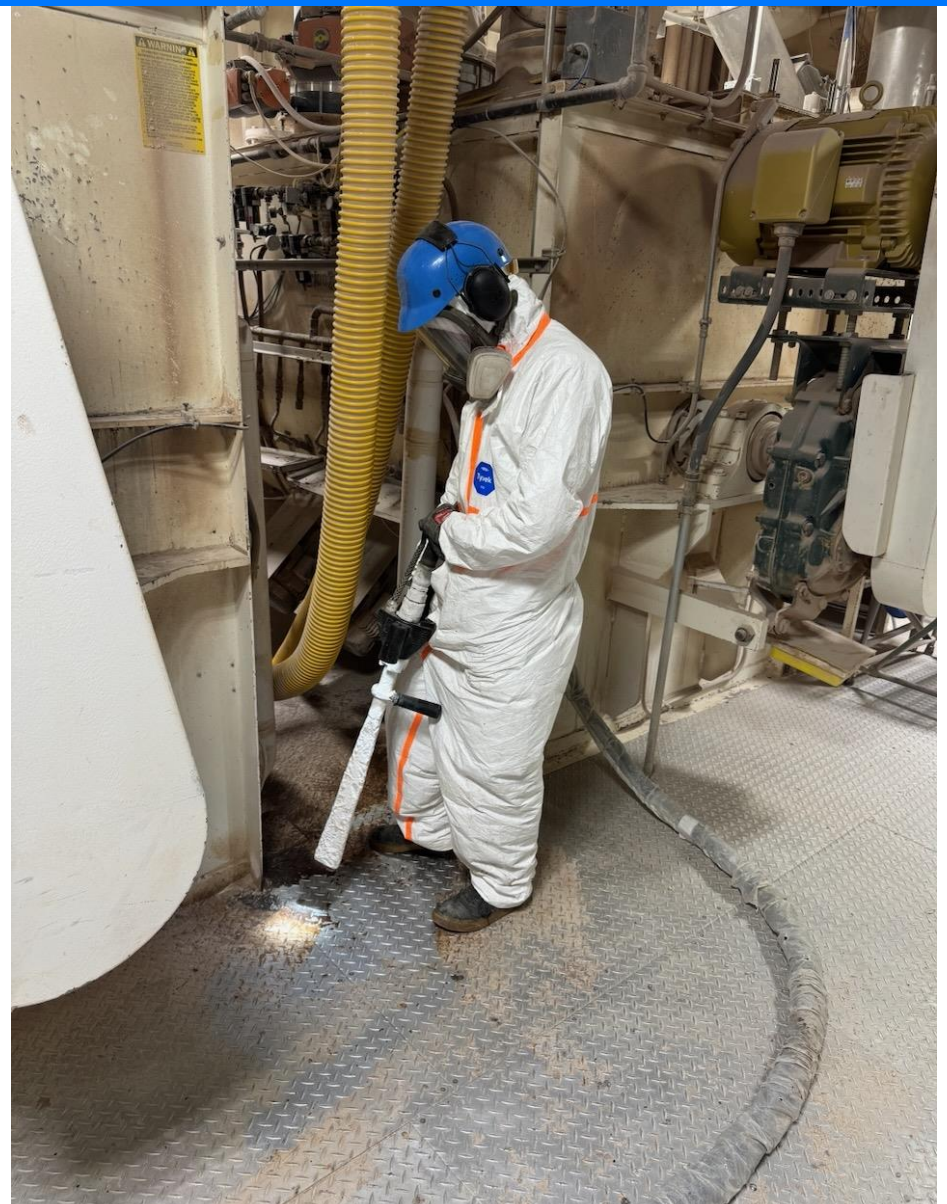
Applications

- Industrial
  - Equipment
  - Power plants
  - Printing presses
  - Holding tanks
- Commercial
  - Food processing facilities
  - Coffee roasters
  - Healthcare facilities
  - Boat hulls
- Residential
  - Mold & fire remediation
  - Masonry, concrete, brick, tile cleaning

Use Case: Fire Remediation

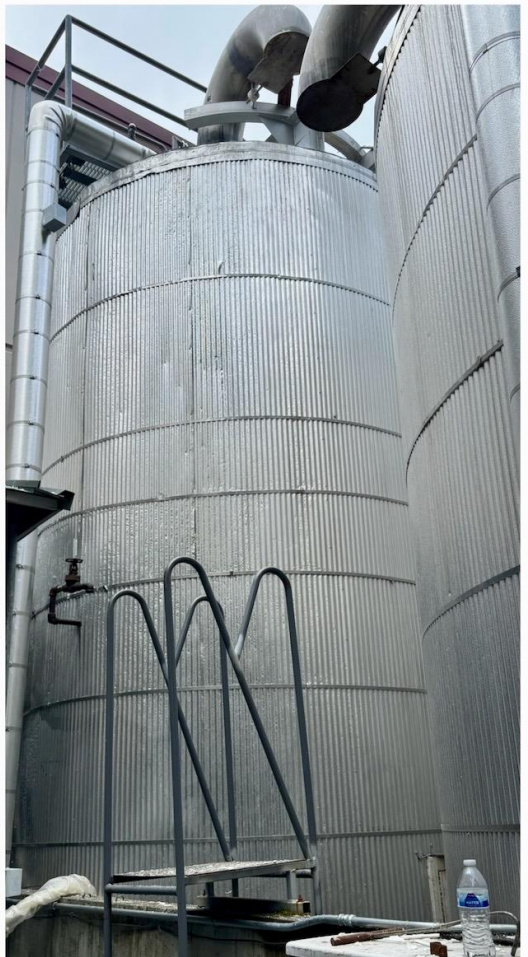


Use Case: Krusteaz



Use Case: Darigold

Use Case: Tank Cleaning



Use Case: Paint Removal

CRYOMODE
DRY ICE BLASTING

Use Case: Graffiti Removal

CRYOMODE
DRY ICE BLASTING