CO2 Technology: An Environmentally Friendly Dry Method to Address Cleaning, Cooling and Extraction Challenges
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 of our processes have these important attributes:
  - Are effectively dry;
  - Generate Zero to trace byproducts;
  - No Touch spray cleaning;
  - Lower energy costs;
  - Environmentally friendly.
Core Competencies

Spray Cleaning:
• Particle Removal
• Surface Preparation
• Residue Removal

Dry Machining:
• External Cooling
• Milling, Grinding and Turning
  • Dry Drilling
• CFRP Stackup Drilling
• Plastic Deburring and Machining

Value Add Extraction
• Precision Degreasing
• Silicone Extraction
• Aerospace Outgassing
• Porous Metal Cleaning
• Botanical & Hemp Oil Extraction
# Industries and Markets Served

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<th>Machine Tool Cooling</th>
<th>Selective Extraction</th>
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<td>Biofuels</td>
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<td>Bonding / Surface Prep.</td>
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<td>Dry Cleaning (Garments)</td>
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<td>HDD</td>
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<td>Machining, Dry / Precision</td>
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<td>Medical Device Mfg., Implants</td>
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<td>Stampings</td>
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Outline of Presentation

• CO2 Technology Background
• CO2 Spray Technology
  • Background
  • Key Applications
  • O&M Costs
• CO2 Pellet Blast Cleaning Systems and Applications
• CO2 As A Machine Tool Coolant
• Dense Phase CO2 Extraction and Cleaning
CO2 Technology Background
CO2 is Recyclable & Renewable

- A by-product of:
  - Refineries;
  - CaCO3 wells;
  - Natural gas sweetening;
  - Synthesis gas production (H2 & NH3);
  - Flue Gases from fossil fuel-fired power plants;
  - Industrial steel furnaces;
  - Cement plant / Lime kiln exhausts;
  - Ethanol plant production;
  - Fermentation/digestion processes.

- Used in:
  - Chemical Production – urea, methanol, carbonates;
  - Food and beverage additives;
  - Weld gas;
  - Fire extinguisher;
  - Oil / coal bed methane recovery.
  - CO2 Process Technology
CO2 is Readily Available

Simple supply system with tank capacity to meet your volume requirements…
CO2 Exposure Information

- 400 ppmv: Nominal CO2 outdoor concentration
- 1,000 ppmv: US EPA / ASHRAE maximum continuous concentration
- 5,000 ppmv: OSHA PEL TWA / ACGIH TLV-TWA occupational exposure limit for CO2
  - PEL = Permissible Exposure Limit
  - TLV = Threshold Limit Value
  - TWA = Time Weighted Average
- 30,000 ppmv: ACGIH TLV-STEL for short term 15 minute exposure
  - STEL = Short Term Exposure Limit
  - If during an 8-hour work shift (and before it has ended) a worker is exposed to a substance in excess of the threshold limit value, time weighted average exposure permitted exposure level for the entire shift, then that exposure has exceeded the short term exposure limit or STEL
CO₂ Phase Transformation – Video (3)

Saturated LCO₂ at room temperature (860 psig / 60 bar-g).

Increase temperature and pressure

Decrease pressure

SUPERCritical PHASE

LIQUID PHASE

LIQUID TO SOLID PHASE
### Key Properties Favorable for Dense Phase CO2 Cleaning

<table>
<thead>
<tr>
<th>Compound</th>
<th>Density (g/ml)</th>
<th>Viscosity (cp)</th>
<th>Surface Tension (Dynes/cm)</th>
<th>HSP Solubility (MPa¹/₂)</th>
<th>Solvent Power (KBv)</th>
<th>Dielectric Constant (E)</th>
<th>Reference State</th>
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<tbody>
<tr>
<td>Solid CO₂</td>
<td>1.6</td>
<td>-</td>
<td>5-10</td>
<td>22</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Liquid CO₂</td>
<td>0.8</td>
<td>0.07</td>
<td>5</td>
<td>7-18</td>
<td>1.6</td>
<td>1.6</td>
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<tr>
<td>Supercritical CO₂</td>
<td>0.5</td>
<td>0.03</td>
<td>0</td>
<td>5-18</td>
<td>Variable Solubility</td>
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<tr>
<td>1,1,1-Trichloroethane</td>
<td>1.4</td>
<td>0.90</td>
<td>21</td>
<td>15.8</td>
<td>7.6</td>
<td>T = 25°C</td>
<td></td>
</tr>
<tr>
<td>Freon 113</td>
<td>1.6</td>
<td>0.68</td>
<td>19</td>
<td>14.9</td>
<td>31</td>
<td>2.4</td>
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<tr>
<td>N-Hexane</td>
<td>0.7</td>
<td>0.31</td>
<td>18</td>
<td>14.9</td>
<td>28</td>
<td>1.9</td>
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<tr>
<td>Perchloroethylene</td>
<td>1.6</td>
<td>0.89</td>
<td>32.3</td>
<td>19.0</td>
<td>90</td>
<td>2.28</td>
<td>T = 25°C</td>
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<tr>
<td>Low Volatility Glycol Ether Solvent</td>
<td>0.91</td>
<td>4.9</td>
<td>28.4</td>
<td>17.3</td>
<td>90</td>
<td>2.28</td>
<td>T = 25°C</td>
</tr>
<tr>
<td>Stoddard Solvent</td>
<td>0.75 – 0.85</td>
<td>2</td>
<td>27 - 50</td>
<td>15 - 16</td>
<td>27 - 45</td>
<td>2 - 3</td>
<td>T = 25°C</td>
</tr>
<tr>
<td>Naptha (140F Solvent, C9-C12)</td>
<td>0.78</td>
<td>2.1 cSt</td>
<td>27 - 50</td>
<td>15.55</td>
<td>30 - 31</td>
<td>2.04</td>
<td></td>
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<tr>
<td>Water</td>
<td>1.0</td>
<td>0.9</td>
<td>72</td>
<td>48</td>
<td>79</td>
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<tr>
<td>Acetone</td>
<td>0.79</td>
<td>0.31</td>
<td>23.3</td>
<td>19.7</td>
<td>20.7</td>
<td>T = 20°C</td>
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<tr>
<td>IPA (2-Propanol)</td>
<td>0.79</td>
<td>1.96</td>
<td>21.7</td>
<td>23.8</td>
<td>18.23</td>
<td>T = 25°C</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- CO₂ Surface Tension < 7% of H₂O
- CO₂ Viscosity < 8% of H₂O
CO2 Spray Technology

Background
Key Applications
Cost of Operation
Integrated Spray CO₂ Technology

- Efficient transformation of liquid CO₂ to solid phase
- Metered control and introduction of CO₂ particles
- Heated inert propellant pressure control
- Adaptable to existing assembly platforms

- Controllable atmospheric condensation – condensation free spray if desired
- 1 to 10 kg/hr (2 to 20 lb/hr) liquid CO₂
- Variable particle size and cleaning energy
- Adaptable to solvent injection as needed
Integrated Spray Composition Control

(Chemical/Physical)

• Cleaning Module Controls
  • Particle Size
  • Chemistry
  • Spray Density
  • Temperature
  • Impact Momentum

• Nozzle Actuation
  • Distance/Angle
  • Time

Inert Gas

Cleaning Energy Variation

CO2

(Chemical/Physical)
How Does CO2 Spray Clean?

• Particles removed by momentum exchange “Billiard Ball Principle”:
  • Particles removed when:
    • $F_{\text{cleaning}} > F_{\text{adhesion}}$
    • $F_{\text{cleaning}} = \text{Particle Momentum} \times \text{Impacted Surface Area} \propto \text{dia}_p^2$
    • $F_{\text{adhesion}} \propto \text{dia}_p$
    • More difficult to remove small particles
      • $F_{\text{cleaning}} = (\propto \text{dia}_p^2) \text{ vs } F_{\text{adhesion}} (\propto \text{dia}_p)$

• Residues solubilized by chemistry:
  • CO₂ particles change upon impact
  • Solid -> Liquid -> Gas
  • Liquid CO₂
    • “Hexane-Like” chemistry:
      • HSP: 9 –18 MPa$^{0.5}$
  • Micro CO₂ gas explosion:
    • Rapid solid to gas sublimation generates a volume of expansion of about 700x

Ref: King, JW et al.; Ablation and Sorptive Removal of Films and Particles from Surfaces Using Carbon Dioxide
CO2 Spray System Schematic

Exhaust Gas System

Propellant

CO2

CO2 Spray Nozzle

Substrate/Surface/Part

Residues removed with CO2 Spray
CO2 Spray Nozzle Offerings

Coaxial Short-range
• ‘Standard’ Spray Configuration
• Provides ‘Soft’ to ‘Moderate’ Particle Impact
• Working distance 10 – 25 mm

Coanda Long-range
• Long range nozzle system
• Large high momentum particles generated
• Induces ambience into cleaning jet
• Working Distance: 50 – 300 mm

High Energy Wide Angle
• High Energy Nozzle
• Very high momentum particles
• Working Distance: 25 – 250 MM

Removes: Particulate Matter, Finger Prints, Thin Films, Residues
Particle Removal from Plastic Surface (Video)
Fingerprint Removal from Plastic Surface (Video)
Removal of Adhesive from Glass Surface (Video)
CO2 Spray Technology

Background
Key Applications
Cost of Operation
CO2 Spray: Automated In-Line Cleaning System – PCBs

• Requirement:
  • Achieve equivalent or better cleaning method than IPA/Q-tip or tape cleaning of pockets in electronic circuit
  • No damage to fine wires
  • Cleaning system must accept customer specified feed trays

• Result:
  • Cleaner developed that exceeds customer expectations.
Automated In-Line CO2 Cleaning System - HDD

- Integrated into HDD Drive Manufacturing Line
  - 4 nozzle / 2 side cleaner
  - Integrated Cleaning Zone
  - Custom part handling
- Cleaning Rate: < 1 part/5 sec
- Dimensions:
  - Footprint: 750 mm x 1200 mm
  - Load height: 1000 mm
  - Total height: 2000 mm
CO2 Spray Cleaning – Automotive Plastics Cleaning before painting and coating
Cleaning Prior to Painting/Coating

• Benefits of CO2 for pre-treatment:
  • Dry process – No water consumption
  • Low energy usage and operating costs
  • Non-abrasive
  • Easily retrofits to existing machines
  • No touch cleaning
  • Small footprint
CO2 spray cleaning to remove residue on various automotive parts
CO2 Spray Technology

Background
Key Applications
Cost of Operation
CO₂ Spray Cleaning - Costs of Operation

• Depends On:
  • Quality and pressure of CO₂ supplied
    • For small application, high pressure (pressure > 900 psig) bottles
    • For larger systems, gas-phase CO₂ can be a cost effective alternative.

• Most Cost Effective:
  • Source of CO₂ is a low pressure (about 250 psig / 17 bar-g).

• CO₂ Quality Parameters of importance:
  • The typical quality of CO₂ is typically reported as percent purity.
    (Beverage grade CO₂ or better required).
  • Percentage of condensables in the CO₂.
CO₂ Spray Cleaning – Typical Operating and Maintenance Costs

Costs include:
- CO₂
- CDA
- Electricity
- Maintenance
- Labor
- Replacement parts

Does not include cost of capital.

Omega System = 4 cleaning nozzles

Factory Installation: > 6-8 systems/site
System Installation: <= 6-8 systems/site
Effective Cost of Operation

• Assume
  • CO2 Cost = $0.15/lb ($0.33/kg)
  • Nominal CO2 usage rate = 8 lb/hr/nozzle (3.6 kg/hr/nozzle)
  • Nozzle spray coverage area = 1 in (25 mm) diameter
  • Nominal Nozzle actuation = 2 ft/sec (600 mm/sec)

• Result
  • $2/hr/nozzle
  • $.0003/ft² ($0.04/m²)
CO2 Pellet Blast Cleaning Systems and Applications
CO2 Pellet Systems

• Basic Pellet Blast System – The basics
  • Dry ice blasting the media is compressed solid carbon dioxide (CO2) particles.
    • Particles sublimate (vaporize) upon impact with the surface.
    • The solid to vapor sublimation process causes a rapid gas expansion to nearly eight hundred times (800x) the volume of the dry ice pellet in a few milliseconds.
  • Because of the solid CO2 vaporizes, the dry ice blasting process does not generate any secondary waste.
  • All that remains to be collected is the contaminate being removed.
  • The kinetic energy associated with dry ice blasting is a function of the particle momentum (mass density x impact velocity).
  • Since CO2 / dry ice particles have a relatively low hardness, the process relies on high particle velocities to achieve the needed impact energy.
  • The high particle velocities are the result of supersonic propellant or airstream velocities.
How it Cleans

- Dry ice cleaning uses CO2 particles or pellets as the blasting medium.
- The compressed air accelerates the dry ice particles to an extremely high speed combined with a jet stream of compressed air, and subsequently blasts them on the object that needs to be cleaned.
- There are multiple cleaning effects imposed on the surface to be cleaned:
  - **The kinetic effect** – Dry ice particles are accelerated to high speeds aimed to impact the surface to clean. Upon contact with particle residues, they exchange momentum and remove the residues from the surface.
  - **The thermal differential expansion effect** - The impact of the particles as they hit the layer of residue. The CO2 particles at -78.5°C cool down, contract and create cracks within the residue. Through the different coefficients of thermal expansion, the compound of surface and residue is loosened.
  - **The microexplosion effect** - Upon impact with a relatively warm surface, the solid CO2 directly transforms (sublimates) from solid to a gaseous state and expands about 700x very rapidly. This expansion literally “explodes” the residue from the surface. At the end of the cleaning procedure the loosened residue can be easily disposed of.
  - **The solvation effect** – When the dry ice particle impacts a warmer surface at high pressure, instantaneously a quantity of liquid CO2 is formed, which has a cleaning chemistry similar hexane. Hence this instantaneous and repeated formation of liquid CO2 at the surface can be used to remove a range of organic residues.

![Diagram showing the cleaning process](image-url)
Overview of Dry Ice Manufacturing

- Equipment Needed: Dry Ice Press / Pelletizer

- Liquid CO2 at a pressure of 220 – 290 psig (15-20 bar-g) is the source of CO2 used in this process.

- Liquid CO2 passes through an expansion valve into an empty chamber.
  - Expansion of LCO2 to atmospheric pressure flashes to solid CO2 and gaseous CO2.
  - Expansion results in a large temperature drop.
  - About 40% of Liquid CO2 mass is transformed into CO2 snow.
  - The balance of CO2 gas is vented or recycled.

- The CO2 snow is then compressed into blocks or pellets.
CO2 Pellet Blast – Range of Cleaning Energy

- Can be gentle enough to remove ink from a business card...

- Or aggressive enough to blow a hole in a piece of wood

Video
Mold Cleaning

• Cleans molds, tools and heavy soiled parts
CO2 Pellet Blast - Applications and Industries

• Plastics Industry
  • Injection Molds
  • Release Agent Removal
  • Tool Cleaning
  • Deburring

• Restoration & Facility Cleaning
  • Post-Fire Restoration
  • Mold Removal
  • Wood Restoration
  • Graffiti Removal

• Electronics & Energy Industry
  • Control Cabinets
  • Circuit Boards
  • Soldering Units
  • Electric Motors
  • Electrical Components

• Metal Processing
  • Machines and Units
  • Molds
  • Tool Cleaning
  • Surface Finishing

• Car Wash Systems
  • Washing technology
  • Aggregates
  • Control Technology
  • Dosing Pumps

• Automotive
  • Engine Components
  • Interiors
  • Underside
  • Rims
  • Brakes

• Food & Beverage
  • Conveyor Belts
  • Filling Systems
  • Packaging Machines
  • Baking Lines

• Aviation
  • Turbines and Engine Parts
  • Technical Components
  • Interior and Avionics
  • Cargo Holds

• Automation
  • Robotic Automation
  • Partial Automation
  • Integrated Cleaning Cell
  • Individual Engineering
CO2 as a Machine Tool Coolant
CO2 as a Dry Coolant

No residue is left behind on parts after machining

Dry

Conventional Messy Coolant

Environmentally Friendly Recycled CO₂

Bringing Cleaning to Machining
Why CO2 as a Machine Tool Coolant?

- “Dry” Machining
  - Machining Without Water or Oil,
  - Everything Dry, Ideal for Composite Material.

- “Clean” Machining
  - Cools without producing a coolant agent waste
  - (spent coolant – oil - water, filters).

- “Green” Pollution Prevention
  - Reduces environmental waste at the source
  - (energy savings, no water pumps, liquid wastes).

- Technical Advantages of CO2 Coolant
  - Readily Available and Inexpensive
  - Universal, Renewable, Recyclable and Green
  - Excellent Cooling Properties
  - Easy to Control
  - Inert to Most Material, such as CFRP
  - Solid CO₂ Crystals Penetrates Boundary Layer
  - Significant Cooling by Sublimation of CO₂ Crystals
  - No Post Process Cleaning Needed
  - No Waiting for Part To Cool
  - Better Surface Finish Requires Little or No Polishing
\( \text{CO}_2 \) Coolant Effectiveness

- Nominal \( \text{CO}_2 \) coolant temperature = -109 °F (-79°C)
- Solid \( \text{CO}_2 \) particles and \( \text{CO}_2 \) gas emitted from tip
  - Cooling occurs at cut location
  - Jet’s help move chips out of hole
- Effective coolant potential: 55-90 btu/lb (127-207 kJ/kg)
ChilAire™ Benefits – Longer Tool Life

- Reduces Friction => Reduces Tool Temperature
- Can extend tool life by up to 50% vs. Dry
CO2 Cooling

External and thru-spindle cooling on a test piece

Video

Bringing Cleaning to Machining
Turbine Blade Milling – Through-tool (video)

CO2 Through-tool cooling – Operating at 60% greater feed rate.
CFRP Ti Stackup Through Spindle Drilling with ADU – Front Side
CFRP Ti Stackup Through Spindle Drilling with ADU – Back Side
Dense Phase CO2 Extraction and Cleaning
How CO2 Extraction Works

• CO2 Chemistry
  • Alone (neat)
  • In combination with soluble additives
  • In combination with High Boiling Solvents (HBS)
  • Solvency is Tunable

• Operating conditions:
  • Temperature: -50 to 200°C
  • Pressure: 6 to 250 bar.

• Cleaning Mechanism:
  • Tunable solvent cleaning power + physical cleaning action.
Video of Liquid CO2 Cleaning / Extraction
Dense Phase CO2 Cleaning Process: Medical Implantable (Video)
Extraction of Silicones from Breast Implants

- Application
  - Breast Implant Silicone Oil Extraction
- Original Cleaning Method
  - IPA wash system
  - Vacuum Bake Out Oven
  - 16 Hour Cycle time
- Enertia™ System Specification
  - Enertia™ GFx
  - 12 Cubic Foot Cleaning Vessel
- Economic Benefit
  - Replaced IPA wash system
  - Payback by less than 18 months
Silicone Extraction Septa Discs

- Application
  - Silicone Septa Discs for Life Science

- Original Cleaning Method
  - Vacuum Bake Out Oven
  - 30 Hour Cycle time

- Enertia System Specification
  - Enertia GFx
  - 12 Cubic Foot Cleaning Vessel

- Economic Benefit
  - Saved Over 50% on Every Cycle on Utilities
  - Short Cycle Time (70% Reduction)
  - Better Extraction Results
Degreasing of Metal Parts

• Objective:
  • Removal of machining contaminates from metal parts.
  • Contaminates: machining coolant, stamping oil, drawing compounds, grease, particles, other organic and non organic substances.

• Method:
  • Enertia GFx liquid phase extraction
  • CO2 + HBS + ultrasonics (4x1 kW @ 25 kHz)
  • Processing time – 40 minutes

• Results:
  • Parts removed clean and dry.
  • Exceeds customer specifications.
Cleaning of Bank Notes

• Clean bank notes without damaging security features

• Contamination: sebum, oil, food, residues

• Process: SCCO2 Extraction
  • Time: 2 hrs
  • Process Volume: 440 liters
  • Dense note packing: bundles of notes

• Results:
  • Effective cleaning – no security feature damage
Extraction of Botanicals
High Quality Crude Extract Directly out of Machine

Purer & clearer oil that has minimal wax and plant particles

Video
In Summary

• CO2 is an excellent option for cleaning, cooling, or extraction processes requiring:
  • Dry processing;
  • Environmentally friendly;
  • Low cost;
  • Innovative processing.

• Key Technologies / Applications
  • CO2 Spray:
    • Particle Residue and Removal;
    • Electronics and HDD Cleaning;
    • Pre-Treatment of Automotive Plastics;
    • Precision Cleaning of Optical Surfaces.
  • CO2 Pellet Blast:
    • Injection mold cleaning;
    • Heavy residue removal;
    • Plastics deburring.
  • CO2 Machine Tool Cooling:
    • ‘Dry’ machining;
    • CFRP stack-ups / plastics;
    • Titanium, selected SS alloys and super alloys.
  • CO2 Extraction:
    • Precision Degreasing;
    • Silicone Extraction / Aerospace Outgassing;
    • Porous Metal Cleaning;
    • Botanical Oil Extraction.
QUESTIONS?
For Further Information . . .

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