



# **Alternative Green Solvents Project**

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2012 International Workshop on  
Environment and Energy  
December 4-7

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# Precision Cleaning Background

- Necessary for safe and proper functioning of equipment
- Mainly halogenated solvents
  - Carbon tetrachloride
  - Trichloroethylene (TCE)
  - CFC-113
- No longer used due to health/regulatory concerns

# Precision Cleaning at KSC

- Small % of total parts
- Used for liquid oxygen (LOX) systems
- Dual solvent process
  - Vertrel MCA  
(62% decafluoropentane (DFP) and 38% *trans*-dichloroethylene)
  - HFE-7100  
(methyl nonafluorobutyl ether)
- DFP has long term environmental concerns



# Specifications and Analysis

- Highest level at KSC – 25A (NASA KSC-C-123J)
- Verified by particle counting and non-volatile residue (NVR) analysis



Particulate Matter Contamination Levels			NVR Contamination Levels		Visible Contamination Levels	
Level	Particle Size Range $\mu\text{m}$ (micrometer)	Maximum Number of Particles per 0.1 $\text{m}^2$	Level	Maximum NVR (mg/0.1 $\text{m}^2$ )	Level	Definition
25	<5	Unlimited*	A	1.0	GC	Freedom from manufacturing residue, dirt, oil, grease, etc.
	5 to 15	19				
	>15 to 25	4				
	>25	0				

# Project Goals

- Identify potential replacements
  - 22 wet chemical processes
  - 3 alternative processes
- Develop test procedures
  - Contamination and cleaning
  - Analysis
- Use results to recommend alternative solvents/processes

# Candidate Process Criteria

- Good solvency
- Low toxicity
- LOX compatible
- Environmentally friendly
- Low surface tension
- High vapor pressure
- Inexpensive



# Processes Evaluated

Pure Solvents	Proprietary Solvent Formulations	Alternative Technologies
Acetone, ethanol, cyclohexane, ethyl acetate, isopropyl alcohol, NMP, limonene, ethyl lactate, 1-bromopropane, methyl myristate, tert-butyl acetate	Entron Aero, Citricolv, Inland Isoprep, Inland AV-OP-125, Inland Breakthrough, Inland Skysol, Steposol SB-W, Steposol SB-D, Steposol SC, Steposol M-8-10, Vertec Bio	Atmospheric plasma glow discharge (AGPD), supercritical carbon dioxide (SCCO <sub>2</sub> ), carbon dioxide snow

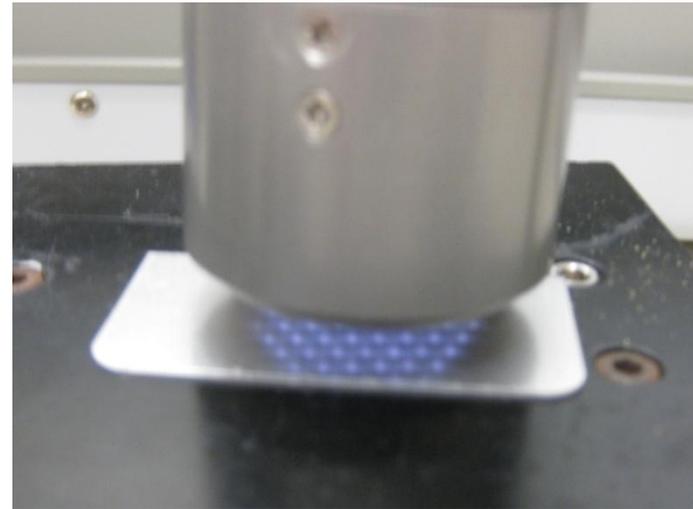
# Candidate Solvents

- Easiest to integrate with existing process
- Avoided highly halogenated solvents
- Augmented with sonication, directed pressure, etc.
- May be recycled to reduce waste stream



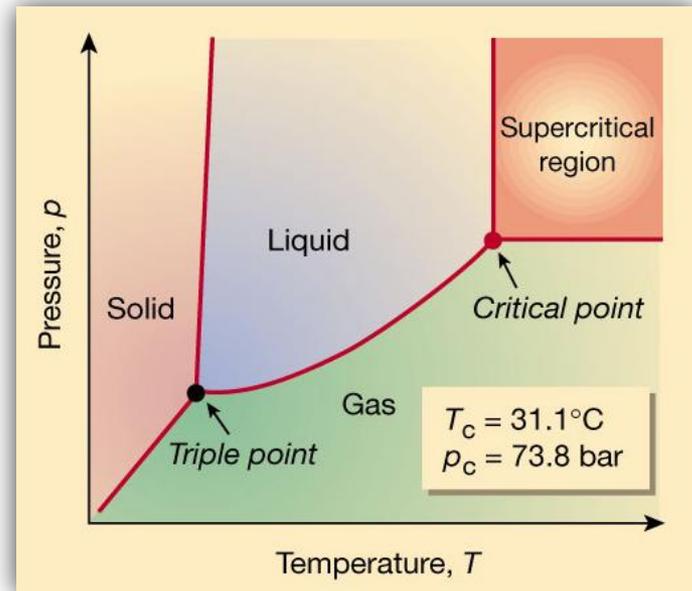
# Plasma Cleaning

- Plasma is an ionized gas (TVs, lightning, etc.)
- Created by applying electrical field to a gas
- Clean via sputtering and/or chemical reaction
- Important parameters: gas type, exposure time, energy



# Supercritical CO<sub>2</sub>

- Has properties of both liquid and gas
- Exists at temps  $>31.1^{\circ}\text{C}$  and pressures  $>1072$  psi
- Dissolves nonpolar molecules and hydrocarbons well
- Cleaning can be enhanced by the use of cosolvents



# CO<sub>2</sub> Snow

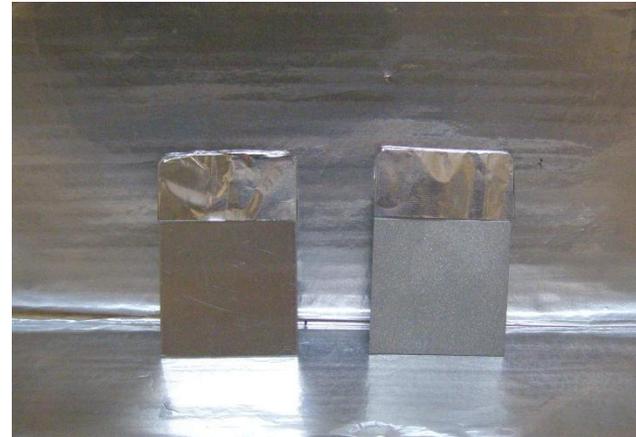
- Cleans via thermo mechanical shock or dissolution
- CO<sub>2</sub> density determines type of cleaning



- Technique is similar to aqueous pressure washing
- Adjustable parameters: nozzle design, velocity, additional propellants

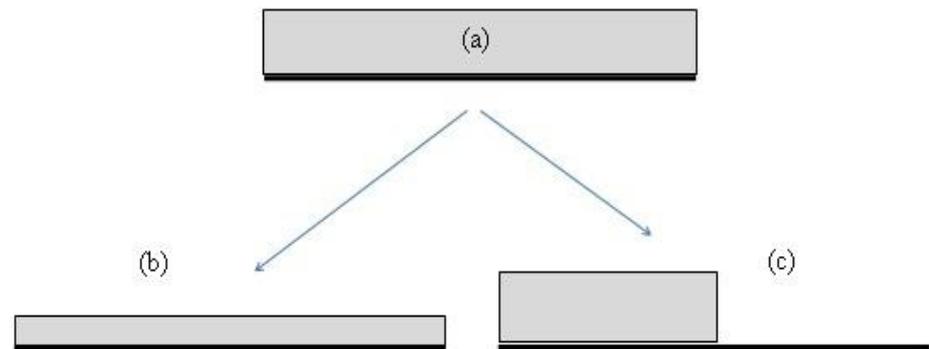
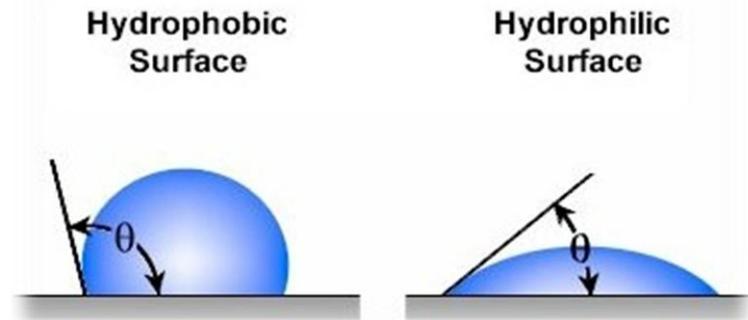
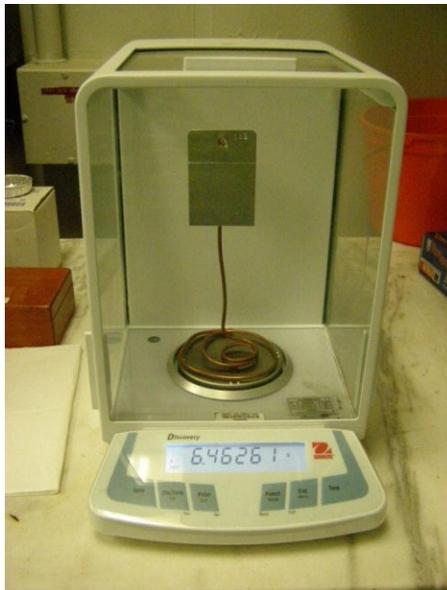
# Solvent Testing Method

- 2" x 2" Al coupons
- Rough and smooth textures
- Sprayed with 5 contaminants
- Rinsed with 15mL of solvent and dried for one hour or...
- Cleaned by alternative process



# Analytical Methods

- Problems w/ NVR
- Gravimetric
- XPS
- Contact angle



# Top 5 Solvent Results

Solvent	83282	5606	Diocetyl Sebacate	Krytox	Braycote
Vertrel	102.7	83.3	98.5	98.6	89.0
1-bromo propane	98.4	117.1	101.0	54.9	20.0
T-butyl acetate	99.1	102.5	99.3	54.1	29.2
Ethyl acetate	93.2	77.8	95.5	75.6	33.6
Isopropyl alcohol	100.4	79.0	98.8	66.6	15.6

Values listed are in % cleaning efficiency determined by gravimetric analysis

# Contact Angle Measurements for Alternative Technologies

Technology	83282	Krytox	Braycote
Contaminated	87.2°	116.3°	108.2°
Vertrel MCA	88.7°	88.5°	96.5°
Plasma	44.4°	59.6°	79.3°
SCCO <sub>2</sub>	<10.0°	109.9°	10.0°
CO <sub>2</sub> Snow	91.5°	105.7°	108.8°

Values listed are in degrees as determined by contact angle measurements

# Conclusions

- No alternative matched Vertrel in this study
- No clear second place solvent
- Hydrocarbons – easy; Fluorinated greases – difficult
- Surface texture has little effect on cleanability
- Fluorinated component may be needed in replacement solvent
- Process may need to make up for shortcoming of the solvent
- Plasma and SCCO<sub>2</sub> warrant further testing

# Continuing Efforts

- Test blends with fluorinated component
- Further testing of plasma and  $\text{SCCO}_2$
- Clean complex hardware



# Continuing Efforts

- Test compatibility with soft goods
- Round robin testing with partnering facilities
- Scale up of technologies
- Assess benefit to other government agencies and private partners

# Team Members

- Dr. Paul Hintze
- Dr. Kathy Loftin
- Dr. Steve Trigwell
- Dr. Robert DeVor
- James Captain
- Drs. Yestrebsky and Clausen at UCF
- Funded by 21<sup>st</sup> Century Launch Complex/GSDO

**Thank you for  
listening!**

**Questions?**