NASA Rocket Propulsion Test Replacement Effort for Oxygen System Cleaner – Hydrochlorofluorocarbon (HCFC) 225

• Background
• Problem Scope
• Current Applications
• Replacement Search and Test Strategy
• Implementation
• Look Ahead
Background – Ozone Depleting Substances (ODS)

- Freon - CFC-113 historically used in oxygen system applications
- International and domestic environmental legislation were drivers for 1996 production phase-out
  - Montreal Protocol of 1987
  - Clean Air Act Amendments of 1990
- HCFC-225 implemented as an interim replacement for CFC-113 in LOX/GOX cleaning / verification applications.
  - Production phase out Jan 1, 2015 - no longer available for procurement after 2014 – may be reclaimed/recycled
  - Mission critical requirements for most HCFCs after 2014 would have to be negotiated with the Environmental Protection Agency (EPA) if material is available.
Relative US Contribution of High Global Warming Potential (GWP) Gases

- ODS Substitutes, while a small fraction of overall greenhouse gases (GHG), are potent greenhouse sources.

Effect of ODS Reduction on GWP Sources

- As use of ozone depleting CFCs has gone down, use of long-lived Hydrofluorocarbons (HFCs) has gone up.
- Many HFCs are potent greenhouse gases.

Image Source: Science Daily Feb. 24, 2012
http://www.sciencedaily.com/releases/2012/02/120224110737.htm
Problem Scope

- HCFC-225 has been replaced in most small component NASA applications but is still the primary material used at MSFC and SSC to clean propulsion systems and their test stands.
- At present, no alternative has been identified meeting all criteria:
  - Non-flammable with LOX / GOX
  - Compatible with materials used in LH2/LOX propulsion systems and test stands
  - An effective cleaner on the soils that must be removed
  - Usable on large scale hardware without very high capital equipment costs
- Testing is required to identify and qualify a replacement before stockpiles are depleted at MSFC and SSC.
Applications - MSFC and SSC

- **MSFC:** Cleaning/Verification of propulsion systems, complex geometries and large components. Baseline solvent for comparative testing.

- **SSC:** Cleaning /Verification of valves, large components, propulsion systems and test stands. Baseline solvent for comparative testing.

- **WSTF and others:** Baseline solvent for comparative testing.
Space Launch System (SLS) Program Agreement

- **Proposed approach to address HCFC 225 availability**
  - Identify candidate cleaners
  - Conduct test program to select HCFC-225cb (Asahiklin AK-225G) replacement for cleaning and verification of propulsion oxygen systems.
  - Down-selected cleaner(s) implementation plan
    - Develop material specifications
    - Identify facility modification associated with new materials
    - Procure support hardware, facility modifications, filter/distillation systems, etc
    - Update paperwork – procedures, specifications

- **Risk Mitigation – stockpile to allow implementation time**
  - MSFC maintaining HCFC 225 ~ 10 year stockpile - estimate considering current usage rate
  - SSC does not maintain a stockpile therefore SLS funded 5 year stockpile (now on hand)
Replacement Search and Test Strategy
Scoping the Replacement Program

• **Extensive literature search**
  • Previous testing references - program plans and data
  • Projected EPA restrictions
  • Replacement solvent developer data
  • Environmental Office – HCFC 225 users and quantities
  • ASTM Test Methods

• **Personal contacts and surveys**
  • Agency working groups
  • Local Environmental Office & Population-Environment Research Network (PERN)
  • Agency and commercial aerospace oxygen system operators/users
  • Solvent developers/vendors
  • Propulsion hardware developers, cleaning contractors, etc
  • MSFC, SSC, and Michoud Assembly Facility (MAF) users
Scoping the Replacement Program

• Identify solvent applications
  • Review current applications and acceptance criteria
  • Identify any unique concerns / limitations
  • Review existing oxygen compatibility data
  • Review similar user application solutions
  • Solvent vendor experiences

• Test program definition
  • Identify common and most critical materials
  • Identify contaminants that must be removed
  • Solvent candidates identified
  • Baseline characterization of solvent candidates
  • Pre-screen candidates for contaminant solvency
  • Material compatibility testing
  • Oxygen compatibility testing
  • Cleaning Effectiveness
  • MSFC and SSC operator’s component level applications testing
## Literature Search


- **NAVSEA Project Number 72530** “Evaluation of Solvent Alternatives for Cleaning of Oxygen Systems, 1999.” (Beeson, H; Biesinger, P. Delgado, R. Antin)


Solvent Replacement Project Experience

• Space Shuttle Program
  – Solid Rocket Motor Program - Ozone Depleting Chemical Effort
  – Shuttle Environmental Assurance efforts
• U.S. Army Research Laboratory, “Laboratory Evaluation of Alternatives to n-Propyl Bromide for Vapor Degreasing”
  – Four HFC/HFE azeotropes with tDCE were tested vs. nPB
  – Vertrel SDG, AE3000ATE, and Vertrel Sion (Azeo-A1) performed well.
  – ARL still seeking vapor degreasing solvents that are VOC exempt and low GWP.
• Defense Logistics Agency (DLA) - Aviation Hazardous Minimization and Green Products Branch, “Solvent Replacement for HCFC-225 for Cleaning Oxygen System Components”
  – DoD user customers include USAF, NAVSEA, and NAVAIR.
  – Propulsion system and breathing oxygen system cleaning
  – 3M L14780 (HFE7000/tDCE) and Honeywell Solstice PF (1233zd(E)) being tested versus AK-225cb and Capstone 4-I
Multiple NASA organizations are engaged in working groups/communities comprised of stakeholders in industrial cleaning and aerospace precision cleaning:

- MSFC, SSC, WSTF - NASA Precision Cleaning & Contamination Control (PC3) Working Group
- KSC, MSFC, SSC, WSTF - NASA Technology Evaluation for Environmental Risk Mitigation (TEER M) Principal Center
- MSFC/Jacobs - ASTM Committees:
  - G4 on Compatibility and Sensitivity of materials in Oxygen Enriched Atmospheres
    - Task groups on cleaning oxygen systems
  - E21 on Space Simulation and Applications of Space Technology
    - Subcommittee E21.05 on Contamination
- MSFC - Established technical communications with key solvent suppliers at DuPont, 3M, Asahi Glass Co. (AGC Chemicals), Microcare, Petroferm
# Considerations - Solvent Balancing Act

## Safety, Health, and Environmental Requirements

### Environmental
- ODP - ozone depleting potential
- VOC - volatile organic compound
- HAP – hazardous air pollutant
- GWP – global warming potential

### Safety and Health
- Human Toxicity
- Flammability (human safety)

### International Influence – Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH)

## Performance Requirements and Cost Considerations

### Materials Compatibility
- Nonmetals – swelling, cracking
- Metals – corrosion, Stress Corrosion Cracking (SCC)

### Cleaning effectiveness
- Common contaminants- Greases, oils
- Effective cleaner (cold, flush, etc.)

### Oxygen compatibility

### Cost Considerations
- Cycle time (manufacturing schedule impact)
- Capital equipment
- Energy usage
- Solvent stability/recyclability/disposal

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Restrictions are expected to increase with time
# Applications - What Are Other User Solutions?

<table>
<thead>
<tr>
<th>User</th>
<th>Hardware cleaned</th>
<th>Design solution</th>
<th>Limitations for MSFC/SSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSTF</td>
<td>Test equipment, life support systems</td>
<td>Aqueous ultrasound immersion</td>
<td>Ultrasound does not scale up for large items, cost, corrosion</td>
</tr>
<tr>
<td>KSC</td>
<td>Ground Support Equipment</td>
<td>Two step co-solvent process of HFE71DE followed by HFE7100 / Aqueous ultrasound</td>
<td>Cost and cycle time, not fully LOX compatible</td>
</tr>
<tr>
<td>PWR</td>
<td>Rocket engines</td>
<td>Cyclohexane/ Dry / Lock-up and Sniff Test</td>
<td>Highly flammable, safety precautions are costly</td>
</tr>
<tr>
<td>ULA</td>
<td>Rocket LOX tanks and components</td>
<td>Trichloroethylene (TCE) vapor degreasing – sealed system</td>
<td>Carcinogen, VOC, HAP, high capital equipment cost</td>
</tr>
<tr>
<td>MAF</td>
<td>External Tank LOX tank</td>
<td>Aqueous spray (tanks) w/TCE flush verification</td>
<td>Very high capital cost, TCE hazards</td>
</tr>
<tr>
<td>VACCO</td>
<td>LOX valves</td>
<td>Aqueous with AK225 or HFE7100 verification</td>
<td>Scale up/ corrosion, HFE7100 not very effective cleaner</td>
</tr>
<tr>
<td>Navy</td>
<td>Breathing oxygen</td>
<td>Navy Oxygen Cleaner (NOC) - aqueous</td>
<td>Scale up/ corrosion</td>
</tr>
<tr>
<td>Hamilton Sunstrand</td>
<td>Orion Environmental Control and Life Support System (ECLSS)</td>
<td>Vertrel MCA &amp; HFE7100 co-solvent process</td>
<td>Cost and cycle time, scale up</td>
</tr>
<tr>
<td>USAF</td>
<td>Breathing oxygen systems</td>
<td>Perfluorbutyl iodide (PFBI)</td>
<td>Corrosive to aluminum</td>
</tr>
</tbody>
</table>
Drivers for Solvent Replacement Efforts

• Several issues are driving the need for cleaning solvent replacements at NASA and DoD:
  – HCFC-225 is a Class 2 ODS
    • No procurement or new use after 12/31/2014
    • Used mainly for cleaning of oxygen systems at MSFC & SSC
  – N-Propyl Bromide revised toxicity ratings
    • OSHA/NIOSH Hazard Alert issued 7/2013
    • Used mainly for vapor degreasing
    • Used by the MSFC ES43 Electronic Parts Fabrication Lab
  – Vertrel MCA groundwater contamination at KSC
    • KSC is seeking non-halogenated alternatives
  – Several currently used solvents are potent GHGs.
  – Many Centers are still using stockpiled CFC-113
    • Expensive to purchase and stock will eventually be depleted.
## What Are Our Critical Selection Criteria?

**Must address:**

1. **Oxygen Compatibility / Flammability:** Test of neat solvent and residue to **NASA-STD-6001 13A / ASTM D2512.** Auto-ignition temperature test per **ASTM G72** for GOX application.

2. **Materials Compatibility:** **Non-metals:** Embrittlement, Leaching, Crazing, Reversion, hydrolosis. **Metals:** Corrosion, Stress Corrosion Cracking, Embrittlemetn, Masking of Crack-like Indications. Characterize changes after immersion in candidate solvents at the use temperature.

3. **Cleaning Effectiveness:** Demonstrate effective removal of key contaminants to below 1 mg/ft² requirement (**MSFC-SPEC-164**) per **ASTM G 121- Standard Test Method for Evaluating the Effectiveness of Cleaning Agents (modified)** and end item configurations.

4. **Processing Evaluation:** Utilize candidate cleaners in component and field cleaning applications at the use site. Obtain support personnel opinions as to performance.
Materials and Contaminants Selection

ASTM MNL36
Safe Use of Oxygen and Oxygen Systems

ASTM G127
Guide for Selection of Cleaning Agents for Oxygen Systems

MSFC USERS:
- Test Org - Valve Lab
- Propulsion Test / Field Cleaning
- MAF STS/ET experience
- M&P Lab

Initial Lists:
- Metals
- Nonmetals
- Contaminants

SSC Users:
- Component Processing Facility
- Calibration lab

History - CFC-113
Replacement Studies
- MSFC
- WSTF
- Rocketdyne
- Boeing
- USAF
- US Navy

MSFC/SSC Working Group scrubs lists into material families to select materials for test plan*

Test Plan Lists:
- Metals
- Nonmetals
- Contaminants

* Metallic and non-metallic material lists were generated then common materials identified. Remaining materials were reviewed for similarity to common materials resulting in a more manageable number for compatibility testing. The most probable contaminants were identified by each Center considering ground support equipment, required processing, assembly, integration, maintenance activities, and facilities exposure, then compared to previous test program lists as well as propulsion component materials use lists.
High GWP Solvents are at risk of regulation

100 Year GWP of CFC Solvent Replacements
CO2 and Methane shown as reference - CFC-113 GWP = 6130

HCFCs banned after 2014

Vertrel MCA contains Vertrel XF

HCFCs at risk of regulation
already regulated in European Union

New class of solvents: hydrofluoro-olefins

Vertrel XF contains Vertrel MCA

HCFC-113 GWP = 6130

HCFC-225cb (AK-225G)
HCFC-141b (Genesolv 2000)
HFO-347mcc (HFE 7000)
HFE-449sl (HFE 7100)
HFE-347pcf2 (AE3000)
HFE-64-13 (HFE 7300)
HFE-569sf2 (HFE 7200)
HFE-449sl (HFE 7100)
HFE-347mcc (HFE 7000)
HCFC-141b (Genesolv 2000)
HCFC-225cb (AK-225G)
Methane
Carbon Dioxide
# Most Probable Replacement Solvents

<table>
<thead>
<tr>
<th>Single Component</th>
<th>KB*</th>
<th>AEL-8hr (ppm)</th>
<th>Caveats</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGC Chemical AE3000 (new) HFE-347pc-f2</td>
<td>13</td>
<td>50</td>
<td>Low KB may not clean well, toxicity</td>
</tr>
<tr>
<td>Honeywell Solstice PF (new) HFO-1233zd (E)</td>
<td>25</td>
<td>300</td>
<td>Boiling point of 66°F – requires pressurized containment, higher vapor losses expected</td>
</tr>
<tr>
<td>Dupont Capstone 4-I Perfluorobutyl iodide</td>
<td>No Data</td>
<td>375</td>
<td>Not compatible with Aluminum, expensive, short supply</td>
</tr>
<tr>
<td>Solvay Solkane 365mfc</td>
<td>14</td>
<td>1000</td>
<td>Unusual flammability characteristics, low KB, may not clean well</td>
</tr>
<tr>
<td><strong>Azeotrope</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGC Chemical AE3000AT (new) 45% tDCE / 55% AE3000</td>
<td>32</td>
<td>200/50</td>
<td>Expected to clean well, may not pass LOX test, toxicity</td>
</tr>
<tr>
<td>3M L-14780 (re-eval) 22% tDCE / 78% HFE-347mcc3 (3M HFE-7000)</td>
<td>Similar to MCA</td>
<td>200/250</td>
<td>Boiling point 82°F – higher vapor losses expected, toxicity, Performed well in past tests</td>
</tr>
<tr>
<td>Dupont Vertrel MCA (re-eval with new stabilizer) 38% tDCE / 62% HFC-43-10mee</td>
<td>20</td>
<td>200</td>
<td>Cleans well but borderline LOX compatible on past tests. Low AIT at high GOX pressure.</td>
</tr>
<tr>
<td>Solvay Solvokane (new) 30% tDCE / balance HFC-365 mfc</td>
<td>25</td>
<td>200/1000</td>
<td>Boiling point 97°F, individual components are flammable</td>
</tr>
</tbody>
</table>

*KB=kauri-butanol value per ASTM D1138, a measure of hydrocarbon solvent power

Highlighted solvents leveraged from Defense Logistics Agency-Aviation test program
## Solvent Candidates Regulatory Status

<table>
<thead>
<tr>
<th>Solvent</th>
<th>ODS SNAP Approved</th>
<th>VOC Exempt</th>
<th>100 Yr GWP</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AK-225G</strong> (HCFC-225cb)</td>
<td>No - Class II ODS</td>
<td>Yes</td>
<td>595*</td>
<td>NA after 2014</td>
</tr>
<tr>
<td><strong>Honeywell Solstice PF</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>4.7 to 7</td>
<td>GWP per EPA site. Vendor claims &lt; 1</td>
</tr>
<tr>
<td>(1233zd(E)) Trans-1-chloro-3,3,3,-trifluoroprop-1-ene</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3M L-14780</strong></td>
<td>Yes</td>
<td>No**</td>
<td>575*</td>
<td>HFE7000 is VOC exempt</td>
</tr>
<tr>
<td>22% tDCE / 78% HFE-347mcc3 (3M HFE-7000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DuPont Vertrel MCA</strong></td>
<td>Yes</td>
<td>No**</td>
<td>1640*</td>
<td>Vertrel XF is VOC exempt</td>
</tr>
<tr>
<td>38% tDCE / 62% HFC-43-10mee</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,1,1,2,2,3,4,5,5-Decafluoropentane (Vertrel XF)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Solvay Solvokane</strong></td>
<td>Yes</td>
<td>No**</td>
<td>794*</td>
<td>Solkane is VOC exempt</td>
</tr>
<tr>
<td>30% tDCE / 70% HFC-365mfc 1,1,1,3,3 Pentafluorobutane (Solkane)</td>
<td></td>
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</tr>
</tbody>
</table>

*GWP from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. GWP is for the non-tDCE portion of the solvent. Reference 100 year GWP for CO2 = 1

**These solvents are azeotropes with trans-1,2 dichloroethylene. tDCE has negligible GWP, but is NOT eligible for VOC exemption.
Evolution of Cleaning Solvents

CFCs
- chlorofluorocarbons
  - Class 1 ODS
  - High GWP
  - Freon 113

HCFCs
- hydrochlorofluorocarbons
  - Class 2 ODS
  - High GWP
  - AK-225

HFCs + CHCs
- Blends of CHCs with hydrofluorocarbons
  - High GWP
  - VOC
  - Vertrel MCA
  - Novec 71DE

HFOs
- Hydrofluoro-olefins
- Hydrochlorofluoro-olefins
  - Low GWP
  - VOC exempt
  - Nonflammable
  - Solstice PF

Applies to Refrigerants and blowing agents as well

CHCs
- chlorinated hydrocarbons
  - VOC
  - Flammable
  - Trichloroethylene
  - Trans-1,2 dichloroethylene
Recent Solvent Development – HFOs & HCFOs

- The fluorocarbon industry has recently focused development on hydrofluoro-olefins for low GWP.
- HFOs contain a double bond that breaks down in the atmosphere in a matter of days rather than years, yielding low greenhouse potential. HCFOs also contain 1 or more chlorine atoms.
- DuPont and Honeywell have new HFO / HCFO refrigerants, blowing agents, and solvents.
- **Solvents:**
  - Honeywell Solstice PF (HCFO 1233zd(E))
  - DuPont Sion (HFO w/ ≈ 80% trans-1,2 dichloroethylene)
Testing Results Summary
What we’ve learned:

• The only “non-flammable”, non-aqueous cleaners are halogenated.
• Bio-based solvents are flammable VOCs.
• Most new fluorinated solvents are poor cleaners.
  – DuPont Vertrel XF and HFX, 3M Novec HFEs, Asahi AE3000, Solvay Solkane.
  – These are blended with trans-1,2 dichloroethylene (tDCE) for cleaning power. tDCE is a VOC.
  – Blending suppresses the flammability of tDCE.
  – Also blended with alcohols for flux removal.
  – Only azeotropic blends are stable in composition over time.
  – Blends high in tDCE% are not oxygen compatible.
• Many fluorinated solvents have very high GWP.
Sustainability

- Efforts to qualify replacement solvents support the **NASA Strategic Sustainability Performance Plan:**
  - **Goal 1: Greenhouse Gas Reduction** by seeking solvent alternatives that will reduce Scope 1 Greenhouse Gas (GHG) emissions.
  - **Goal 8: Agency Innovation and Government-Wide Support** by collaborating with multiple NASA Centers and DoD agencies to test and qualify safer and greener cleaning solvent alternatives for numerous federal applications.
Look Ahead

• Bigger Picture / Materials Obsolescence in the future
• Currently no Agency wide materials obsolescence working group
• The SLS Program has a new effort with emphasis on materials obsolescence and environmental regulations.
  – Team is smaller than SEA.
  – Less opportunity for inter-element collaboration on testing of replacement materials.
BACKUP
SSC HCFC 225 Stockpile/Requirements

- SSC does not maintain a stockpile of HCFC 225
  - 7 drums are maintained in the warehouse for use (current verified supply)
  - Replacement drums are purchased to replenish supply as stock is used

- Annual SSC HCFC 225 usage ~ 12-14 drums

- SSC is requesting a five year usage stockpile ~70 drums, should cover needs through 2019

- Required Funding: $1M*
  - Includes costs for 70 drums, long term storage barrels (one time purchase), material sampling, and distillation system maintenance/ops

- Five year stockpile allows time for evaluation and implementation of replacement alternative(s)
  - Update procedures/processes
  - Procure capital equipment
  - Train personnel

* Costs based on present day HCFC 225 market price, may increase as phase out approaches
References

   Note: This compound is commonly referred to as Navy Oxygen Cleaner (NOC).
References


   Note: At the time of this publication, M. Campbell planned to replace TCE with HCFC-225 for verification of the LOX Tank. This was not done because it was found that HCFC-225 was too volatile for capture of an adequate NVR sample in the LOX Tank. Reference: Personal communication with Mike Campbell, March 3, 2008.


## Alternatives

<table>
<thead>
<tr>
<th>Alternative Approach</th>
<th>Limitations</th>
</tr>
</thead>
</table>
| Aqueous ultrasonic agitation with verification of NVR by analysis of Total Organic Content. Reference ASTM G 144 [1]  
- This test method requires full component immersion and ultrasonic agitation in a tank of deionized water.  
- Used by NASA-WSTF, NASA-KSC, and Pratt & Whitney Rocketdyne (PWR) for cleaning and verification of small components. |  
- Ultrasound does not scale up for large components. This test method is limited to components that are both smaller than one square foot (0.09 m²) of surface area and weigh less than 3.3 lbs (1.5 Kg). [2][3]  
- Not feasible for components installed on test stands and for long tubes and feedlines that will not fit into an immersion tank.  
- Water is corrosive to components where complete drying cannot be assured |
| Aqueous cleaning by immersion, ultrasonic, spray or flush with an alkaline cleaning solution (Navy Oxygen Cleaner, MIL-DTL-24800 [4]) Reference MIL-STD-1330 [5]  
- Used by US Naval Sea Systems Command for cleaning of approved shipboard oxygen systems and shore base facilities. |  
- Not suitable for final cleaning of instruments and gauges such as flowmeters and dead-end pressure switches and transducers, liquid oxygen generating plants and plant piping; not suitable for field wiping (reference MIL-STD-1330 [5] sections 4.4.1.1, 5.4, 5.8.2, and Table E-I) |
## Alternatives

<table>
<thead>
<tr>
<th>Alternative Approach</th>
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</tr>
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</table>
| Two step process: Clean with a non-oxygen – compatible solvent or aqueous agent, rinse and verify with nonflammable solvent (3M Novec 7100 [6])  
- Used by NAVSEA (MIL-STD-1330 [4]), NASA-KSC (KSC-C-123 [7]), Royal Australian Air Force [8] | • Costly, requires additional equipment and doubles required solvent stocks  
• Less reliable verification, higher risk. Novec 7100 is a poor solvent for hydrocarbon oils and greases including silicone and must be used with mechanical agitation or pressure, may not detect all specifics of contaminants (references [5] Table E-I note 5, [8], [9], [10]) |
| Use flammable solvents such as cyclohexane, ethyl acetate, or isopropyl alcohol, for cleaning or for verification after cleaning.  
- Used by PWR [3] [11] | • High risk where complete drying to remove solvent cannot be assured or where processes such as vacuum oven drying are not feasible [3] [11] |
| Clean and/or verify with perfluorbutyl iodide (PFBI)  
- Qualified by USAF for depot cleaning of aviator’s breathing oxygen systems. (There is no aluminum in these high pressure systems.) | • PFBI is corrosive to aluminum, an important light weight metal in for launch vehicle LOX tanks and housings. [12] Corrosion testing is now in progress at MSFC to determine the extent of this risk. |
Alternatives

<table>
<thead>
<tr>
<th>Alternative Approach</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use trichloroethylene (TCE) for cleaning or for verification after cleaning.</td>
<td>• Carcinogen [14], Hazardous Air Pollutant [15]. Unacceptable worker exposure expected and unacceptable release during field cleaning operations.</td>
</tr>
<tr>
<td>• Reported to be used for LOX tank vapor degreasing at United Launch Alliance.</td>
<td></td>
</tr>
<tr>
<td>Clean and/or verify with stockpiled CFC-113, a Class I ODS.</td>
<td>• No current stockpile at MSFC or SSC.</td>
</tr>
<tr>
<td></td>
<td>• Available stockpiles may not be sufficient, losses will occur and deplete stock.</td>
</tr>
<tr>
<td></td>
<td>• Not a long term solution.</td>
</tr>
<tr>
<td>Clean with an alternative non-ODS solvent that meets all performance criteria for oxygen compatibility, cleaning efficiency, and materials compatibility. - No Users.</td>
<td>• No suitable alternative has been identified to date for MSFC/SSC propulsion test oxygen system applications. [12][16][17]</td>
</tr>
</tbody>
</table>
EM50 Solvent Replacement Efforts
MSFC Green Team - January 22, 2014

Mark A. Mitchell – EM50
Nikki M. Lowrey – Jacobs ESSSA