

## TITLE

### PROCESSES TO PREPARE FLUOROOLEFIN COMPOSITIONS AND USES THEREOF

## FIELD

**[0001]** The present invention relates to processes to prepare fluoroolefin compositions comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (*E*-HFO-153-10mczz) and uses in thermal management applications.

## BACKGROUND

**[0002]** A growing public awareness of the environmental impacts from the extraction, transportation and use of fossil fuels are motivating a new environmental sustainability driver in the form of regulations and reduction in output of CO<sub>2</sub> equivalence in the atmosphere. In particular, new environmental regulations on refrigerants have forced the refrigeration and air-conditioning industry to look for new refrigerants with low global warming potentials (GWP). Replacement refrigerants with low global warming potential (GWP) and ozone depletion potential (ODP) for both existing and new applications in thermal management segments will need to adhere to these new regulations.

**[0003]** Certain hydrofluoroolefins, such as *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (*E*-C<sub>2</sub>F<sub>5</sub>CH=CHC<sub>2</sub>F<sub>5</sub>, *E*-HFO-153-10mczz), are believed to meet both goals. In particular, *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene may be useful in heat transfer fluid applications (e.g., immersion cooling systems, data-center cooling systems or thermal management solution for EV batteries). Accordingly, the present application provides new processes for preparing *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and compositions comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene.

## SUMMARY

**[0004]** The present invention relates to compositions comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (*E*-HFO-153-10mczz, *E*-CF<sub>3</sub>CF<sub>2</sub>CH=CHCF<sub>2</sub>CF<sub>3</sub>), processes of preparing such compositions and their use.

**[0005]** The present invention provides a process for preparing *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene comprising contacting 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane (HCFC-548mafd,  $\text{CF}_3\text{CF}_2\text{CHClCH}_2\text{CCl}_2\text{CF}_3$ ) with HF in the presence of a fluorination catalyst in a reactor, to obtain a process mixture comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene.

**[0006]** In certain embodiments, the process is performed at a temperature of about 250-450°C, a pressure of about 0 to 200 psig. Preferably, the temperature is in the range of about 275 to about 380°C. Preferably the pressure is in the range of about 30 to 180 psig or about 40 to 150 psig, or about 60-120 psig.

**[0007]** The present invention also provides a composition comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (*E*-HFO-153-10mczz), and at least one additional compound chosen from 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCFO-153-9mbzz), 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (HCFO-152-10mcxz), 2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene (HCFO-2536mxzzx), 2-chloro-1,1,1,5,6,6,6-heptafluorohexa-2,4-diene (HCFO-2537mxzzy), 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene (HCFO-1538mxzd), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-11mcyz), 1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (HFO-152-11myz), 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HCFO-152-10mdz), 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene (HCFO-1528mdcxx), 1-chloro-3,3,4,4,5,5-hexafluoro-2-(trifluoromethyl)cyclopent-1-ene, 1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HFO-153-10mzz),  $\text{C}_6\text{F}_{10}$  isomers, hexafluorobutene isomers (HFO-1336 isomers),  $\text{C}_5\text{HF}_9$  isomers,  $\text{C}_6\text{F}_{12}$  isomers,  $\text{C}_6\text{HF}_{11}$  isomers,  $\text{C}_5\text{H}_2\text{F}_8$  isomers,  $\text{C}_5\text{HClF}_8$  isomers,  $\text{C}_6\text{F}_8$  isomers,  $\text{C}_6\text{HF}_9$  isomers,  $\text{C}_6\text{ClF}_9$  isomers, 2-chloro-1,1,1,4,4,4-hexafluoro-2-butene (HCFO-1326mxz), 2-chloro-1,1,1,4,4,4-hexafluorobutane (HCFC-346mdf) and 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane (HCFC-548mafd). The composition may be prepared by the process disclosed herein.

**[0008]** The composition disclosed herein can be used as a refrigerant, heat transfer fluid, foam expansion agent, power cycle working fluid, among other uses. It has also, advantageously, been found that the composition has low global warming potential.

Thus, a composition comprising *E*-HFO-153-10mczz may be a good candidate for replacing higher GWP compounds in many uses.

**[0009]** In one embodiment, the composition of this invention can be used as a working fluid in an immersion cooling unit. An immersion cooling unit includes an immersion cell, defining an internal cavity, a heat generating electronic or electrical component positioned in the internal cavity, a working fluid which partially fills the internal cavity and at least partially immerses the heat generating electronic or electrical device, and a condensing coil positioned inside the cavity above the working fluid, wherein the working fluid is a composition comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, and at least one additional compound chosen from 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCFO-153-9mbzz), 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (HCFO-152-10mcxz), 2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene (HCFO-2536mxzxx), 2-chloro-1,1,1,5,6,6,6-heptafluorohexa-2,4-diene (HCFO-2537mxzzy), 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene (HCFO-1538mxzd), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-11mcyz), 1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (HFO-152-11myz), 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HCFO-152-10mdz), 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene (HCFO-1528mdcxx), 1-chloro-3,3,4,4,5,5-hexafluoro-2-(trifluoromethyl)cyclopent-1-ene, 1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HFO-153-10mzz), C<sub>6</sub>F<sub>10</sub> isomer, hexafluorobutene isomers (HFO-1336 isomers), C<sub>5</sub>HF<sub>9</sub> isomer, C<sub>6</sub>F<sub>12</sub> isomers, C<sub>6</sub>HF<sub>11</sub> isomers, C<sub>5</sub>H<sub>2</sub>F<sub>8</sub> isomer, C<sub>5</sub>HCIF<sub>8</sub> isomers, C<sub>6</sub>F<sub>8</sub> isomers, C<sub>6</sub>HF<sub>9</sub> isomers, C<sub>6</sub>CIF<sub>9</sub> isomers, 2-chloro-1,1,1,4,4,4-hexafluoro-2-butene (HCFO-1326mxz), 2-chloro-1,1,1,4,4,4-hexafluorobutane (HCFC-346mdf) and 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane (HCFC-548mafd). The composition may be prepared according to the process disclosed herein.

**[0010]** The structures of such compounds are provided in Table 1.

TABLE 1

| Name                                                  | Formula                            | Compound                 |
|-------------------------------------------------------|------------------------------------|--------------------------|
| 1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene               | $C_2F_5CH=CHC_2F_5$                | HFO-153-10mzz            |
| <i>E</i> -1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene     | <i>E</i> - $C_2F_5CH=CHC_2F_5$     | <i>E</i> -HFO-153-10mczz |
| <i>Z</i> -1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene     | <i>Z</i> - $C_2F_5CH=CHC_2F_5$     | <i>Z</i> -HFO-153-10mczz |
| 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene           | $CF_3CF_2CF=CHCF_2CF_3$            | HFO-152-11mcyz           |
| <i>E</i> -1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene | <i>E</i> - $CF_3CF_2CF=CHCF_2CF_3$ | <i>E</i> -HFO-152-11mcyz |
| <i>E</i> -1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene | <i>E</i> - $CF_3CF=CHCF_2CF_2CF_3$ | <i>E</i> -HFO-152-11myz  |
| <i>Z</i> -1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene | <i>Z</i> - $CF_3CF_2CF=CHCF_2CF_3$ | <i>Z</i> -HFO-152-11mcyz |
| <i>Z</i> -1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene | <i>Z</i> - $CF_3CF=CHCF_2CF_2CF_3$ | <i>Z</i> -HFO-152-11myz  |
| 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene      | $CF_3CF_2CCl=CHCF_2CF_3$           | HCFO-152-10mcxz          |
| 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene      | $CF_3CCl=CHCF_2CF_2CF_3$           | HCFO-152-10mdz           |
| 2-chloro-3,3,3-trifluoropropene                       | $CF_3CCl=CH_2$                     | HCFO-1233xf              |
| 2,3,3,3-tetrafluoropropene                            | $CF_3CF=CH_2$                      | HFO-1234yf               |
| 1,3,3,3-tetrafluoropropene                            | $CF_3CH=CHF$                       | HFO-1234ze               |
| dichloropentafluorobutene isomers                     | $C_4HCl_2F_5$                      | HCFO-1325 isomers        |
| 2-chloro-1,1,1,4,4,4-hexafluoro-2-butene              | $CF_3CCl=CHCF_3$                   | HCFO-1326mxz             |
| chloropentafluorobutene isomers                       | $C_4H_2ClF_5$                      | HCFO-1335 isomers        |
| 1,1,1,4,4-pentafluoro-3-chlorobutene                  | $CF_3CH=CClCF_2H$                  | HCFO-1335mxz             |
| hexafluorobutene isomers                              | $C_4H_2F_6$                        | HFO-1336 isomers         |

| Name                                                | Formula                                                      | Compound          |
|-----------------------------------------------------|--------------------------------------------------------------|-------------------|
| 1,1,1,4,4,4-hexafluoro-2-butene                     | $\text{CF}_3\text{CH}=\text{CHCF}_3$                         | HFO-1336mzz       |
| trichlorotrifluorobutene isomers                    | $\text{C}_4\text{H}_3\text{Cl}_2\text{F}_3$                  | HCFO-1343 isomers |
| E-1,2-dichloro-4,4,4-trifluoro-2-butene             | $\text{CF}_3\text{CCl}=\text{CHCH}_2\text{Cl}$               | E-HCFO-1343mxz    |
| Z-1,2-dichloro-4,4,4-trifluoro-2-butene             | $\text{CF}_3\text{CCl}=\text{CHCH}_2\text{Cl}$               | Z-HCFO-1343mxz    |
| 1,1,4,4,4-pentafluoro-2-butene                      | $\text{CF}_3\text{CH}=\text{CHCHF}_2$                        | HFO-1345mzz       |
| 3,3,4,4,4-pentafluorobut-1-ene                      | $\text{CH}_2=\text{CHCF}_2\text{CF}_3$                       | HFO-1345zf        |
| chlorotrifluorobutene isomers                       | $\text{C}_4\text{H}_4\text{ClF}_3$                           | HCFO-1353 isomers |
| nonafluoropentene isomers                           | $\text{C}_5\text{HF}_9$                                      | HFO-1429 isomers  |
| octafluoropentene isomers                           | $\text{C}_5\text{H}_2\text{F}_8$                             | HFO-1438 isomers  |
| 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene | $\text{CF}_3\text{CCl}=\text{CClCF}_2\text{CHClCF}_3$        | HCFO-1528mdcxx    |
| 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene    | $\text{CF}_3\text{CCl}=\text{CHCHClCF}_2\text{CF}_3$         | HCFO-1538mxzd     |
| chloro-nonafluorohexene isomers                     | $\text{C}_6\text{H}_3\text{ClF}_9$                           | HCFO-1539 isomers |
| 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene      | $\text{CF}_3\text{CClF}=\text{CHCH}_2\text{CF}_2\text{CF}_3$ | HCFO-1539mbzz     |
| 2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene   | $\text{CF}_3\text{CCl}=\text{CHCH}=\text{CClCF}_3$           | HCFO-2536mxzzx    |
| 2-chloro-1,1,1,5,6,6,6-heptafluorohexa-2,4-diene    | $\text{CF}_3\text{CCl}=\text{CHCH}=\text{CFCF}_3$            | HCFO-2537mxzzy    |
| dodecafluorohexane isomers                          | $\text{C}_6\text{H}_2\text{F}_{12}$                          | HFC-53-12 isomers |
| tetrachlorohexafluoropentene isomers                | $\text{C}_5\text{Cl}_4\text{F}_6$                            | HCFO-1416 isomers |
| chlorotrifluoromethane                              | $\text{CClF}_3$                                              | CFC-13            |
| trifluoromethane                                    | $\text{CHF}_3$                                               | HFC-23            |

| Name                                             | Formula                                                                              | Compound                                              |
|--------------------------------------------------|--------------------------------------------------------------------------------------|-------------------------------------------------------|
| 1-chloro-1,1,2,2,2-pentafluoroethane             | CClF <sub>2</sub> CF <sub>3</sub>                                                    | CFC-115                                               |
| 1-chloro-1,2,2,2-tetrafluoroethane               | CHClF <sub>2</sub> CF <sub>3</sub>                                                   | HCFC-124                                              |
| 1,1,1,2,2-pentafluoroethane                      | CF <sub>3</sub> CHCF <sub>2</sub>                                                    | HFC-125                                               |
| 2-chloro-1,1,1-trifluoroethane                   | CF <sub>3</sub> CH <sub>2</sub> Cl                                                   | HCFC-133a                                             |
| 1,1,2,2-tetrafluoroethane                        | CHF <sub>2</sub> CHF <sub>2</sub>                                                    | HFC-134                                               |
| 1,1,1-trifluoroethane                            | CF <sub>3</sub> CH <sub>3</sub>                                                      | HFC-143a                                              |
| 1,1,1,2,2,3,3-heptafluoropropane                 | CF <sub>3</sub> CF <sub>2</sub> CHF <sub>2</sub>                                     | HFC-227ca                                             |
| 1,1,1,3,3,3-hexafluoropropane                    | CF <sub>3</sub> CH <sub>2</sub> CF <sub>3</sub>                                      | HFC-236fa                                             |
| 1,1,1,2,2-pentafluoropropane                     | CF <sub>3</sub> CF <sub>2</sub> CH <sub>3</sub>                                      | HFC-245cb                                             |
| 1,1,1,2,2,4,4,4-octafluorobutane                 | CF <sub>3</sub> CH <sub>2</sub> CF <sub>2</sub> CF <sub>3</sub>                      | HFC-338mf                                             |
| dichloropentafluorobutane isomers                | C <sub>4</sub> H <sub>3</sub> Cl <sub>2</sub> F <sub>5</sub>                         | HCFC-345 isomers                                      |
| 2-chloro-1,1,1,4,4,4-hexafluorobutane            | CF <sub>3</sub> CH <sub>2</sub> CHClCF <sub>3</sub>                                  | HCFC-346mdf                                           |
| heptafluorobutane isomers                        | C <sub>4</sub> H <sub>3</sub> F <sub>7</sub>                                         | HFC-347 isomers                                       |
| 2,2,4-trichloro-1,1,1-trifluorobutane            | CH <sub>2</sub> ClCH <sub>2</sub> CCl <sub>2</sub> CF <sub>3</sub>                   | HCFC-353maf                                           |
| chloropentafluorobutane isomers                  | C <sub>4</sub> H <sub>4</sub> ClF <sub>5</sub>                                       | HCFC-355 isomers                                      |
| 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane | CF <sub>3</sub> CF <sub>2</sub> CHClCH <sub>2</sub> CCl <sub>2</sub> CF <sub>3</sub> | HCFC-548mafd                                          |
|                                                  | C <sub>5</sub> H <sub>2</sub> F <sub>8</sub>                                         | C <sub>5</sub> H <sub>2</sub> F <sub>8</sub> isomers  |
|                                                  | C <sub>5</sub> HCIF <sub>8</sub>                                                     | C <sub>5</sub> HCIF <sub>8</sub> isomers              |
|                                                  | C <sub>5</sub> HF <sub>9</sub>                                                       | C <sub>5</sub> HF <sub>9</sub> isomers                |
|                                                  | C <sub>6</sub> ClF <sub>11</sub>                                                     | C <sub>6</sub> ClF <sub>11</sub> isomers              |
|                                                  | C <sub>6</sub> ClF <sub>9</sub>                                                      | C <sub>6</sub> ClF <sub>9</sub> isomers               |
|                                                  | C <sub>6</sub> Cl <sub>3</sub> F <sub>7</sub>                                        | C <sub>6</sub> Cl <sub>3</sub> F <sub>7</sub> isomers |
|                                                  | C <sub>6</sub> Cl <sub>4</sub> F <sub>6</sub>                                        | C <sub>6</sub> Cl <sub>4</sub> F <sub>6</sub> isomers |
|                                                  | C <sub>6</sub> HCIF <sub>10</sub>                                                    | C <sub>6</sub> HCIF <sub>10</sub> isomers             |

| Name | Formula                                        | Compound                                               |
|------|------------------------------------------------|--------------------------------------------------------|
|      | C <sub>6</sub> HClF <sub>8</sub>               | C <sub>6</sub> HClF <sub>8</sub> isomers               |
|      | C <sub>6</sub> HCl <sub>2</sub> F <sub>9</sub> | C <sub>6</sub> HCl <sub>2</sub> F <sub>9</sub> isomers |
|      | C <sub>6</sub> HCl <sub>2</sub> F <sub>7</sub> | C <sub>6</sub> HCl <sub>2</sub> F <sub>7</sub> isomers |
|      | C <sub>6</sub> HCl <sub>3</sub> F <sub>8</sub> | C <sub>6</sub> HCl <sub>3</sub> F <sub>8</sub> isomers |
|      | C <sub>6</sub> H <sub>2</sub> ClF <sub>9</sub> | C <sub>6</sub> H <sub>2</sub> ClF <sub>9</sub> isomers |
|      | C <sub>6</sub> H <sub>2</sub> ClF <sub>7</sub> | C <sub>6</sub> H <sub>2</sub> ClF <sub>7</sub> isomers |
|      | C <sub>6</sub> HF <sub>11</sub>                | C <sub>6</sub> HF <sub>11</sub> isomers                |
|      | C <sub>6</sub> HF <sub>9</sub>                 | C <sub>6</sub> HF <sub>9</sub> isomers                 |
|      | C <sub>6</sub> H <sub>2</sub> F <sub>10</sub>  | C <sub>6</sub> H <sub>2</sub> F <sub>10</sub> isomers  |
|      | C <sub>6</sub> H <sub>2</sub> F <sub>8</sub>   | C <sub>6</sub> H <sub>2</sub> F <sub>8</sub> isomers   |
|      | C <sub>6</sub> H <sub>4</sub> F <sub>6</sub>   | C <sub>6</sub> H <sub>4</sub> F <sub>6</sub> isomers   |
|      | C <sub>6</sub> F <sub>12</sub>                 | C <sub>6</sub> F <sub>12</sub> isomers                 |
|      | C <sub>6</sub> F <sub>10</sub>                 | C <sub>6</sub> F <sub>10</sub> isomers                 |
|      | C <sub>6</sub> F <sub>8</sub>                  | C <sub>6</sub> F <sub>8</sub> isomers                  |
|      | C <sub>6</sub> H <sub>10</sub>                 | C <sub>6</sub> H <sub>10</sub> isomers                 |
|      | C <sub>7</sub> H <sub>5</sub> F <sub>7</sub>   | C <sub>7</sub> H <sub>5</sub> F <sub>7</sub> isomers   |

### **BRIEF DESCRIPTION OF THE FIGURE**

**[0011]** Figure 1 provides a flow diagram for a process useful to prepare *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene according to an embodiment of this invention.

### **DETAILED DESCRIPTION**

**[0012]** The present invention relates broadly to compositions comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (*E*-HFO-153-10mczz, *E*-CF<sub>3</sub>CF<sub>2</sub>CH=CHCF<sub>2</sub>CF<sub>3</sub>), processes of preparing such compositions and their use.

### **GENERAL TERMS**

**[0013]** Compounds may be referred to herein by the compound name (e.g., *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene) or ASHRAE designation (e.g., *E*-HFO-153-10mczz, or more simply, *E*-153-10mczz) or chemical formula (e.g., CF<sub>3</sub>CF<sub>2</sub>CH=CHCF<sub>2</sub>CF<sub>3</sub>) and optionally prefaced by “CFC”, “HCFC”, “HFC”, “CFO”, “HCFO”, or “HFO”, meaning “chlorofluorocarbon”, “hydrochlorofluorocarbon”, “hydrofluorocarbon”, “chlorofluoroolefin”, “hydrochlorofluoroolefins”, or

“hydrofluoroolefin”. The absence of the preface does not change the meaning of the compound.

**[0014]** The term “isomers” is used to represent one or more compounds having the recited chemical formula that are identified using standard analytical techniques (GC and GC-mass spectrometry). The isomers may include one or more compounds having the recited chemical formula, such as linear, branched and cyclic compounds). Alternatively, isomers may include unsaturated compounds (having a double bond) or cyclic compounds having the same chemical formula or multiple unsaturations (two or more double bonds) or combinations with cyclic structures.

**[0015]** More specifically, when a compound is recited as a chemical formula, one or more isomers having the recited formula are included. For example, the chemical formula “C<sub>6</sub>HF<sub>11</sub>” includes compounds having the recited chemical formula (e.g., C<sub>6</sub>HF<sub>11</sub>) are included (such as linear, branched and cyclic compounds).

**[0016]** In addition, with respect to compounds having unsaturation (double bond), the compound may have “E-” and “Z-” isomers. If neither “E-” nor “Z-” are identified, the compound disclosed may contain one or both isomers. Specific isomers are identified as “E-” or “Z-”. For example, HFO-152-11mcyz may include one or both of E-HFO-152-11mcyz and Z- HFO-152-11mcyz, whereas specific isomers are identified as “E-HFO-152-11mcyz” and “Z-HFO-152-11mcyz”.

**[0017]** As used herein, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having” or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a composition, process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such composition, process, method, article, or apparatus. Further, unless expressly stated to the contrary, “or” refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

**[0018]** The transitional phrase "consisting of" excludes any element, step, or ingredient not specified. If in the claim, such would close the claim to the inclusion of materials other than those recited except for impurities ordinarily associated therewith. When the phrase "consists of" appears in a clause of the body of a claim, rather than immediately following the preamble, it limits only the element set forth in that clause; other elements are not excluded from the claim as a whole.

**[0019]** The transitional phrase "consisting essentially of" is used to define a composition, method that includes materials, steps, features, components, or elements, in addition to those literally disclosed provided that these additional included materials, steps, features, components, or elements do not materially affect the basic and novel characteristic(s) of the claimed invention, especially the mode of action to achieve the desired result of any of the processes of the present invention. The term "consisting essentially of" occupies a middle ground between "comprising" and "consisting of".

**[0020]** Where applicants have defined an invention or a portion thereof with an open-ended term such as "comprising," it should be readily understood that (unless otherwise stated) the description should be interpreted to also include such an invention using the terms "consisting essentially of" or "consisting of."

**[0021]** Also, use of "a" or "an" are employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

**[0022]** Where a range of numerical values is recited herein, unless otherwise stated, the range is intended to include the endpoints thereof, and all integers and fractions within the range. It is not intended that the scope of the invention be limited to the specific values recited when defining a range. Moreover, all ranges set forth herein are intended to include not only the particular ranges specifically described, but also any combination of values therein, including the minimum and maximum values recited.

**[0023]** The term “compound” as used herein is meant to include all stereoisomers, geometric isomers, tautomers, and isotopes of the structures or chemical described. Compounds herein identified by name or structure as one particular tautomeric form are intended to include other tautomeric forms unless otherwise specified.

**[0024]** When an amount, concentration, or other value or parameter is given as either a range, preferred range or a list of upper preferable values and/or lower preferable values, this is to be understood as specifically disclosing all ranges formed from any pair of any upper range limit or preferred value and any lower range limit or preferred value, regardless of whether ranges are separately disclosed. Where a range of numerical values is recited herein, unless otherwise stated, the range is intended to include the endpoints thereof, and all integers and fractions within the range.

**[0025]** As used herein the term “about” in certain embodiments can be quantified to mean  $\pm 1\%$ ,  $\pm 2\%$ ,  $\pm 3\%$  up to and including  $\pm 10\%$  of the stated value, and all whole numbers and fractions therebetween.

#### **PROCESS DESCRIPTION**

**[0026]** The present invention describes processes for preparing a mixture or a composition comprising, consisting of, or consisting essentially of *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and one or more additional compounds.

**[0027]** In one embodiment, the present invention provides a process for preparing *E*-HFO-153-10mczz comprising contacting HCFC-548mafd with HF in the presence of a fluorination catalyst in a reactor.

**[0028]** The present invention provides a process for preparing *E*-HFO-153-10mczz comprising contacting HCFC-548mafd with HF in the presence of a fluorination catalyst in a reactor, to obtain a process mixture comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, wherein the process is performed at a temperature of about 250-450°C, a pressure of about 0 to 200 psig. Preferably, the temperature is in the range of about 275 to about 380°C, or such as about 300-380°C. Preferably the pressure is in the range of

HCFC-548mafd with HF are from about 30 to 180 psig or about 40 to 150 psig, or about 60-120 psig, such as about 80 psig.

**[0029]** The process of the present invention is preferably performed in the presence of oxygen or an oxygen-containing gas, which may be co-fed with the starting material HCFC-548mafd and/or HF. The oxygen-containing gas may be, for example, air.

**[0030]** In the present invention, it has been found particularly advantageous to perform the process of contacting HCFC-548mafd with HF in the presence of a fluorination catalyst at a temperature of about 250-450°C. At temperatures lower than this range, when oxygen is added, the oxygen is less effective at removing tar deposits from the catalyst resulting in faster deactivation. Higher temperatures increase the rate of fluorination of the catalyst also deactivating the catalyst and increases formation of side products.

**[0031]** In one embodiment, a composition comprising *E*-HFO-153-10mczz is produced in one step by fluorination of HCFC-548mafd. More particularly, the process comprises fluorination of HCFC-548mafd by reacting with HF, in the presence of a fluorination catalyst, to make a product comprising *E*-HFO-153-10mczz. The product comprises, consists of, or consists essentially of *E*-HFO-153-10mczz, which is or can be as a heat transfer fluid in applications such as power cycles, high temperature heat pumps and immersion cooling.

#### **Fluorination Catalyst**

**[0032]** The fluorination catalyst used in the process of this invention comprises one or more metals, metal oxides, metal oxyfluorides or metal fluorides. A metal oxide catalyst preferably forms a metal (oxy)fluoride having Lewis acid character. Examples of metals suitable for use in the fluorination catalyst is chosen from one or more of metals selected from Al, Sc, Y, Ti, Zr, Hf, V Nb, Ta, Cr, Mo, W, Mn, Re, Fe, Ru, Co, Rh, Ir, Ni, Pd, Pt, Cu, Ag, Au, Zn, La and Ce.

**[0033]** In certain embodiments, the fluorination catalyst comprises one or more of Al, Zr, Cr, Co and Ni.

**[0034]** In one embodiment, the fluorination catalyst comprises chromium or aluminum. In one embodiment the fluorination catalyst comprises chromium or aluminum and one or more of Zn, Zr, Co, and Ni.

**[0035]** Certain metal oxide or metal fluoride fluorination catalysts may contain one or more additional metals selected from the group consisting of Li, Na, K, Ca, Mg, and Cs. The additional metal may be present in smaller amounts (such in an amount of less than 2000 or less than 1000 or less than 500 or less than 100 or less than 10 ppm).

**[0036]** In certain embodiments, the fluorination catalyst comprises aluminum. The aluminum may be present in the form of aluminum oxide, aluminum fluoride or aluminum oxyfluoride. In certain embodiments the fluorination catalyst comprises Al and one or more of Sc, Y, Ti, Zr, Hf, V Nb, Ta, Cr, Mo, W, Mn, Re, Fe, Ru, Co, Rh, Ir, Ni, Pd, Pt, Cu, Ag, Au, Zn, La and Ce. In certain embodiments the fluorination catalyst comprises Al and one or more of Zn, Zr, Cr, Co, and Ni.

**[0037]** In certain embodiments, the fluorination catalyst comprises chromium. The chromium may be present in the form of chromium oxide, chromium chloride, chromium fluoride or chromium oxyfluoride. Chromium may be in the form of Cr(III), such as Cr<sub>2</sub>O<sub>3</sub>. In certain embodiments the fluorination catalyst comprises Cr and one or more of Al, Sc, Y, Ti, Zr, Hf, V Nb, Ta, Mo, W, Mn, Re, Fe, Ru, Co, Rh, Ir, Ni, Pd, Pt, Cu, Ag, Au, Zn, La and Ce. In certain embodiments the fluorination catalyst comprises Cr and one or more of Zn, Zr, Co, and Ni.

**[0038]** In one embodiment, the fluorination catalyst comprises Cr<sub>2</sub>O<sub>3</sub>. In one embodiment, the fluorination catalyst comprises Cr<sub>2</sub>O<sub>3</sub> and one or more of Zn, Zr, Co, K, Na and Ni. In one embodiment, the fluorination catalyst comprises Cr<sub>2</sub>O<sub>3</sub> and Zn. In one embodiment, the fluorination catalyst comprises Cr<sub>2</sub>O<sub>3</sub> and Co. In one embodiment, the fluorination catalyst comprises Cr<sub>2</sub>O<sub>3</sub> and Ni. In one embodiment, the fluorination catalyst comprises Cr<sub>2</sub>O<sub>3</sub> and Zr.

**[0039]** In one embodiment, the fluorination catalyst comprises Cr<sub>2</sub>O<sub>3</sub> and at least one of Zn, Zr, Co, and Ni, wherein the amount of Zn, Zr, Co, and/or Ni ranges from about 100 ppm to about 10% by weight, based on weight of Cr<sub>2</sub>O<sub>3</sub>. In one embodiment the

fluorination catalyst comprises  $\text{Cr}_2\text{O}_3$  and Zn wherein the amount of Zn is in the range of from about 100 ppm to about 10% by weight, based on weight of  $\text{Cr}_2\text{O}_3$ . In one embodiment the fluorination catalyst comprises  $\text{Cr}_2\text{O}_3$  and Zn wherein the amount of Zn is in the range of from about 100 ppm to about 10% by weight, based on weight of  $\text{Cr}_2\text{O}_3$ . In one embodiment the fluorination catalyst comprises  $\text{Cr}_2\text{O}_3$  and Co wherein the amount of Co is in the range of from about 100 ppm to about 10% by weight, based on weight of  $\text{Cr}_2\text{O}_3$ . In one embodiment the fluorination catalyst comprises  $\text{Cr}_2\text{O}_3$  and Ni, wherein the amount of Ni is in the range of from about 100 ppm to about 10% by weight, based on weight of  $\text{Cr}_2\text{O}_3$ .

**[0040]** In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$ . In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and one or more of Zn, Zr, Cr, Co, and Ni. In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Zn. In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Zn. In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Cr. In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Co. In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Ni.

**[0041]** In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and at least one of Zn, Zr, Cr, Co, and Ni, wherein the amount of Zn, Zr, Cr, Co, and/or Ni ranges from about 100 ppm to about 10% by weight, based on weight of  $\text{Al}_2\text{O}_3$ . In one embodiment the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Zn wherein the amount of Zn is in the range of from about 100 ppm to about 10% by weight, based on weight of  $\text{Al}_2\text{O}_3$ . In one embodiment the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Zr wherein the amount of Zr is in the range of from about 100 ppm to about 10% by weight, based on weight of  $\text{Al}_2\text{O}_3$ . In one embodiment the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Cr wherein the amount of Cr is in the range of from about 100 ppm to about 10% by weight, based on weight of  $\text{Al}_2\text{O}_3$ . In one embodiment the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Co wherein the amount of Co is in the range of from about 100 ppm to about 10% by weight, based on weight of  $\text{Al}_2\text{O}_3$ . In one embodiment the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Ni, wherein the amount of Ni is in the range of from about 100 ppm to about 10% by weight, based on weight of  $\text{Al}_2\text{O}_3$ .

**[0042]** The fluorination catalyst may be on a support ("supported") or unsupported or a mixture of a support with the fluorination catalyst. If a support is present, suitable supports include  $\text{AlF}_3$ , alumina, fluorinated alumina or activated carbon. The fluorination catalyst, for example, may comprise chromium oxide and alumina.

**[0043]** The fluorination catalyst may comprise a metal oxide or metal oxyhalides supported on chromia or alumina, for example oxides of zinc, iron, magnesium or nickel. The fluorination catalyst may comprise a metal oxides/halides/oxyhalides, or mixed metal oxides/halides/oxyhalides supported on carbon, wherein the metal is chosen from one or more of Al, Sc, Y, Ti, Zr, Hf, V Nb, Ta, Cr, Mo, W, Mn, Re, Fe, Ru, Co, Rh, Ir, Ni, Pd, Pt, Cu, Ag, Au, Zn, La and Ce.

**[0044]** In one embodiment, the fluorination catalyst is a chromium-based catalyst, such as chromium oxide ( $\text{Cr}_2\text{O}_3$ ) or fluorinated chromium oxide, which catalyst may either be unsupported, or supported on a support such as activated carbon, graphite, fluoride graphite, or alumina fluoride. The chromium fluorination catalyst may either be used alone, or in the presence of a co-catalyst selected from nickel, cobalt, manganese, potassium, sodium or zinc. In one embodiment, optionally a chromium fluorination catalyst is high surface area chromium oxide, or chromium/nickel on alumina fluoride ( $\text{Cr/Ni/AlF}_3$ ), or chromium halide on carbon, the preparation of which is reported in European Patent EP486333. In another embodiment, the fluorination catalyst is fluorinated Guignet's green catalyst.

**[0045]** In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$ . In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and one or more of Zn, Zr, Cr, Co, and Ni. In one embodiment, the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Zn, or  $\text{Al}_2\text{O}_3$  and Cr, or  $\text{Al}_2\text{O}_3$  and Co, or  $\text{Al}_2\text{O}_3$  and Ni, or  $\text{Al}_2\text{O}_3$  and Zr.

**[0046]** In one embodiment, the fluorination catalyst comprises chromium supported on  $\text{AlF}_3$ , alumina, fluorinated alumina or activated carbon. In one embodiment, the fluorination catalyst comprises chromium supported on alumina.

**[0047]** In one embodiment, the fluorination catalyst comprises zinc supported on  $\text{AlF}_3$ , alumina, fluorinated alumina or activated carbon. In one embodiment, the fluorination catalyst comprises zinc supported on alumina.

**[0048]** The physical shape of the fluorination catalyst is not critical and may, for example, include pellets, extrudates, powders, or granules.

**[0049]** In one embodiment, the fluorination catalyst is shaped into a form, such as granulated, or pressed into pellets. A variety of methods generally known in the art, may be used that are suitable to provide, for example, a packed bed of catalyst in a flow reactor.

**[0050]** In one embodiment, the process comprises activating the fluorination catalyst in a prefluorination treatment prior to contacting HCFC-548mafd with HF in the presence of the catalyst. Activation of the fluorination catalyst is preferably carried out on the final shape of the catalyst; in the event the catalyst is shaped into a form. It should be understood that while the term "fluorination catalyst" is used to refer to metal oxides, including  $\text{Cr}_2\text{O}_3$  and  $\text{Al}_2\text{O}_3$ , herein, the metal oxide will undergo the prefluorination step to generate the active catalyst in situ.

**[0051]** In one embodiment, the catalyst undergoes a prefluorination treatment by passing HF, with or without an inert diluent such as nitrogen, over the catalyst at a temperature within the range of about 250 to 450°C prior to use.

**[0052]** In a particular embodiment, the fluorination catalyst comprises chromium and the fluorination catalyst is activated before use, by a procedure comprising heating the fluorination catalyst to a temperature of from 350°C to 400°C under a flow of nitrogen for a period of time, then heating the fluorination catalyst under a flow of HF and nitrogen or air for an additional period of time in one embodiment of a prefluorination treatment.

**[0053]** After use for a period of time, the activity of the catalyst may decrease. When this occurs, the catalyst may be regenerated, wherein a regenerating step comprises treating the catalyst with oxygen or air at elevated temperature. Optionally, the catalyst is treated with HF at a temperature in the range of 250°C to 450°C, after the treatment with oxygen before the regenerated catalyst is re-used. The regenerating step is

performed after purging the majority of the organic components from the process mixture, wherein the organic materials comprise 548mafd and/or E-153-10mczz.

### **Reaction conditions**

**[0054]** In one embodiment, suitable temperatures for the process of the reaction of HCFC-548mafd with HF are from about 250°C to about 450°C, preferably from about 300°C to about 380°C. Temperature ranges are set to advantageously protect the catalyst from deactivation. It has been found that operating at temperatures outside of the recited ranges results in faster deactivation of the catalyst. For example, it is believed at lower temperatures, carbon deposits remain on the surface of the catalyst. In addition, at higher temperatures, the catalyst is more susceptible to becoming fluorinated in a way that also results in catalyst deactivation. Thus, a balance must be found to address fluorination catalyst deactivation from both carbon containing compounds deposits as well as fluorination of the fluorination catalyst.

**[0055]** In one embodiment, suitable pressures for the process of the reaction of HCFC-548mafd with HF are from about 0 to 200 psig, preferably from about 30 to 180 psig or about 40 to 150 psig, or about 60-120 psig.. Pressure ranges are set to advantageously protect the catalyst from deactivation and to enhance separation and recovery of HCl component of the product. At lower pressures, the recovery of HCl is more complex. In addition, at higher pressures, it is found that the rate of catalyst deactivation increases.

**[0056]** In the process of this invention, it is preferred to have a molar ratio of HF to HCFC-548mafd from about 3:1 to about 50:1, preferably from about 10:1 to about 45:1, more preferred, 15:1 to 40:1. Higher ratios are undesired for overall efficiency of the process, and also impact temperature, pressure and contact time. Lower ratios impact productivity (conversion, selectivity, and yield).

**[0057]** In the process of this invention, comprising contacting HCFC-548mafd with hydrogen fluoride (HF) in a reactor, in the presence of a fluorination catalyst, to produce a process mixture comprising E-HFO-153-10mczz and HCl, an amount of oxygen is optionally added. The oxygen amount added ranges from about 0 to about 10 mole%

based on the amount of organic feed to the contacting step. The organic feed comprises HCFC-548mafd. Optionally, the organic feed further comprises intermediates recycled from separation processes such as those described herein. The intermediates may comprise one or more of  $C_6H_2ClF_9$  isomers,  $C_6HClF_8$  isomers,  $C_6H_2Cl_2F_8$  isomers,  $C_6HCl_2F_7$  isomers and  $C_6HCl_3F_6$  isomers.

**[0058]** Preferably the amount of oxygen added in the process of this invention is greater than 0% and less than 10 mole%, such as from about 0.2 mole % to about 5 mole%, or about 1 mole%. An amount of oxygen added in the process such as in the range of about 0.2 mole % to about 5 mole%, improves life of the fluorination catalyst. In the absence of added oxygen, the rate of catalyst deactivation increases. It is also important to avoid adding too much oxygen in the process. A higher concentration of oxygen, particularly greater than 15 mole% oxygen results in lower yield as there is an increase in the formation of oxygenated byproducts. In addition, a higher concentration of oxygen presents a flammability risk.

**[0059]** In the process of this invention, comprising contacting HCFC-548mafd with hydrogen fluoride (HF), in a reactor, in the presence of a fluorination catalyst, a process mixture comprising *E*-HFO-153-10mczz and HCl, the contact time can be chosen from a range of contact times, such as from as low as about 1 second to 180 seconds. In one embodiment, contact time is from 5 seconds to 120 seconds, or 10-60 seconds or about 15 seconds. It should be appreciated that shorter contact times reduces conversion of the starting material 548mafd. However longer contact times may be undesirable as they may increase formation of byproducts (lower yield, selectivity) for a given set of reaction conditions.

**[0060]** Preferably, the fluorination reaction is carried out in the vapor phase. However, it will be understood by those skilled in the art that the fluorination of HCFC-548mafd may, alternatively, be performed in the liquid phase.

**[0061]** In one embodiment, the HCFC-548mafd starting material may be pre-mixed with the HF, and then introduced into the reactor. In some embodiments, the fluorination catalyst may optionally also be pre-mixed with the HCFC-548mafd and HF.

In another embodiment, the HF may not be contacted with the HCFC-548mafd until both have been introduced into the reactor.

**[0062]** In some embodiments, the reaction of HCFC-548mafd produces an effluent stream comprising a process mixture or composition comprising *E*-HFO-153-10mczz and HCl.

**[0063]** In some embodiments, this step may be conducted in a reactor or reaction zone which is operating in batch, semi-batch, semi-continuous, or continuous modes, to produce a reaction mixture comprising *E*-HFO-153-10mczz. An effluent stream of the reactor or reaction zone comprises the reaction mixture comprising *E*-HFO-153-10mczz and HCl and HF.

**[0064]** For the reaction of HCFC-548mafd and HF, the process mixture comprises *E*-HFO-153-10mczz and HCl, and may further contain excess HF, as well as, optionally, reaction byproducts and intermediates. The reaction byproducts may comprise one or more of HCFO-1539mbzz ( $\text{CF}_3\text{CFCICH}=\text{CHCF}_2\text{CF}_3$ ), HCFO-152-10mcxz ( $\text{CF}_3\text{CF}_2\text{CCl}=\text{CHCF}_2\text{CF}_3$ ), HCFO-2536mxzzx ( $\text{CF}_3\text{CCl}=\text{CHCH}=\text{CClCF}_3$ ),  $\text{C}_6\text{H}_2\text{ClF}_9$ ,  $\text{C}_6\text{HClF}_8$ ,  $\text{C}_6\text{H}_2\text{Cl}_2\text{F}_8$ ,  $\text{C}_6\text{HCl}_2\text{F}_7$ , and  $\text{C}_6\text{HCl}_3\text{F}_6$ .

**[0065]** The process mixture may comprise additional components such as unreacted starting material, HCFC-548mafd ( $\text{CF}_3\text{CF}_2\text{CHClCH}_2\text{CCl}_2\text{CF}_3$ ) and optionally, intermediates and byproducts formed in the process. The intermediates and byproducts may comprise one or more isomers of HCFO-1539. In one embodiment, the intermediates and byproducts comprise HCFO-1539mbzz. The intermediates and byproducts may further comprise at least one of  $\text{C}_6\text{H}_2\text{ClF}_9$ ,  $\text{C}_6\text{HClF}_8$ ,  $\text{C}_6\text{H}_2\text{Cl}_2\text{F}_8$ ,  $\text{C}_6\text{HCl}_2\text{F}_7$ , and  $\text{C}_6\text{HCl}_3\text{F}_6$ . Any of the unreacted starting materials, HF and 548mafd, may be optionally separated and recycled for further reaction. Advantageously, when the process mixture comprises any of HF, HCFC-548mafd, intermediates and byproducts, the process comprises separating the HF, HCFC-548mafd, and intermediates from the process mixture and recycling each of these to the process for contacting with the fluorination catalyst. Intermediates and byproducts may comprise one or more isomers of HCFO-1539,  $\text{C}_6\text{H}_2\text{ClF}_9$ ,  $\text{C}_6\text{HClF}_8$ ,  $\text{C}_6\text{H}_2\text{Cl}_2\text{F}_8$ ,  $\text{C}_6\text{HCl}_2\text{F}_7$ , or  $\text{C}_6\text{HCl}_3\text{F}_6$ .

**[0066]** In one embodiment, the process of this invention involves reacting 548mafd with an excess of HF (HF to organic of about 10:1 to about 30:1) in a vapor phase reactor, producing a product stream comprising *E*-153-10-mczz and HCl. In one embodiment, the catalyst comprises chrome oxide ( $\text{Cr}_2\text{O}_3$ ). The catalyst is dried and partially fluorinated with HF before use. The operating temperature is about 260°C to about 380°C and the operating pressure is about 0 to about 200 psig. The process further comprising adding 0.5 to 5 mole % oxygen in the feed (based on the feed of 548mafd) to maintain / increase catalyst life. In one embodiment, in a continuous process, the reactor is shut down periodically to regenerate the catalyst. Catalyst regeneration may occur over a span of time from about once every year to once every 5 days. For example, catalyst regeneration may occur once every 30 days or once every 20 days or once every 15 days, such as once every 18 days. The reactor has a heat transfer system to achieve and maintain a target operating temperature.

**[0067]** Specific conditions of temperature, pressure, HF:organic ratio, oxygen concentration and contact time are provided, wherein the organic is 548mafd. It has been found that the recited conditions provide limit disadvantages of operating outside of the recited conditions. Disadvantages include one or more of catalyst deactivation, increased difficulties to recover product, increased byproducts (loss of yield, loss of selectivity), lower conversion, need for larger reactor.

**[0068]** After exiting the reactor, the process mixture comprising *E*-HFO-153-10mczz and HCl undergoes distillation to remove HCl. The process mixture further comprises unreacted HF as the process uses an excess of HF. The unreacted HF in the process mixture is preferably then recovered and recycled back to the reactor.

**[0069]** In one embodiment, HF is recovered from the process mixture. HF recovery may comprise a combination of distillation and liquid-liquid phase separation. When the process mixture comprises residual acids, residual acids may be removed from the process mixture by absorbing by  $\text{Al}_2\text{O}_3$  or absorbing into an aqueous medium, which optionally contains dilute base, and neutralizing with dilute base (such as alkali metal hydroxide, including, but not limited to KOH), providing a neutralized stream. Following removal of acids from the process mixture, the neutralized stream is then dried, for

example, using molecular sieves. The dried *E*-HFO-153-10mczz may undergo a final distillation to provide a purified product comprising *E*-HFO-153-10mczz, available for use.

**[0070]** Equipment used in the process of this invention includes feed systems, storage tanks, reactor, distillation columns and the like. Carbon steel may be acceptable for ambient temperature feed systems and storage tanks. The reactor and high temperature portions of the equipment, including the HCl column are preferably constructed of an alloy such as Inconel or Hastelloy. Certain equipment may be lined with PTFE.

**[0071]** In one embodiment of the process of this invention, there is provided a reaction system comprising a reactor and a purification system. The reaction system includes feeds to introduce reactants to the reactor.

**[0072]** The feeds include a reactant HCFC-548mafd feed, a fresh reactant HF feed, and optionally a feed for recycled intermediates, a feed for recycled 548mafd, and a recycled HF feed. The fresh reactant HF feed and optional recycled HF feed may be combined in a single feed for HF to be introduced to the reactor. There is also a fluorination catalyst feed to introduce the fluorination catalyst to the reactor, such as from a catalyst bed.

**[0073]** The feeds may further comprise a recycle stream comprising HCFC-548mafd and intermediates and byproducts. The recycle stream may comprise one or more of HFO-1539mbzz ( $\text{CF}_3\text{CFCICH}=\text{CHCF}_2\text{CF}_3$ ), HCFO-152-10mcxz ( $\text{CF}_3\text{CF}_2\text{CCI}=\text{CHCF}_2\text{CF}_3$ ), HFO-2536mxzzx ( $\text{CF}_3\text{CCI}=\text{CHCH}=\text{CCICF}_3$ ),  $\text{C}_6\text{H}_2\text{ClF}_9$  isomers,  $\text{C}_6\text{HClF}_8$  isomers,  $\text{C}_6\text{H}_2\text{Cl}_2\text{F}_8$  isomers,  $\text{C}_6\text{HCl}_2\text{F}_7$  isomers and  $\text{C}_6\text{HCl}_3\text{F}_6$  isomers. Intermediates may comprise one or more of  $\text{C}_6\text{H}_2\text{ClF}_9$  isomers,  $\text{C}_6\text{HClF}_8$  isomers,  $\text{C}_6\text{H}_2\text{Cl}_2\text{F}_8$  isomers,  $\text{C}_6\text{HCl}_2\text{F}_7$  isomers and  $\text{C}_6\text{HCl}_3\text{F}_6$  isomers.

**[0074]** A reactor process mixture exits the reactor. The reactor process mixture may proceed through a mechanism to separate catalyst from the process mixture in a reaction process mixture. The reaction process mixture proceeds through heat exchangers prior to entering the purification system.

**[0075]** In one embodiment, the present invention provides a composition comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (*E*-HFO-153-10mczz), and at least one additional compound chosen from 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCFO-153-9mbzz), 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (HCFO-152-10mcxz), 2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene (HCFO-2536mxzzx), 2-chloro-1,1,1,5,6,6,6-heptafluorohexa-2,4-diene (HCFO-2537mxzzy), 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene (HCFO-1538mxzd), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-11mcyz), 1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (HFO-152-11myz), 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HCFO-152-10mdz), 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene (HCFO-1528mdcxx), 1-chloro-3,3,4,4,5,5-hexafluoro-2-(trifluoromethyl)cyclopent-1-ene, 1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HFO-153-10mzz), C<sub>6</sub>F<sub>10</sub> isomers, hexafluorobutene isomers (HFO-1336 isomers), C<sub>5</sub>HF<sub>9</sub> isomers, C<sub>6</sub>F<sub>12</sub> isomers, C<sub>6</sub>HF<sub>11</sub> isomers, C<sub>5</sub>H<sub>2</sub>F<sub>8</sub> isomers, C<sub>5</sub>HCIF<sub>8</sub> isomers, C<sub>6</sub>F<sub>8</sub> isomers, C<sub>6</sub>HF<sub>9</sub> isomers, C<sub>6</sub>ClF<sub>9</sub> isomers, 2-chloro-1,1,1,4,4,4-hexafluoro-2-butene (HCFO-1326mxz), 2-chloro-1,1,1,4,4,4-hexafluorobutane (HCFC-346mdf) and 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane (HCFC-548mafd).

**[0076]** The purification system comprises distillation columns, absorbers, scrubbers and dryers.

**[0077]** The products from the reaction of the process of this invention may be purified in a series of additional steps.

**[0078]** In one embodiment of the process of this invention, the process mixture is cooled, such as through heat exchangers and is then treated in distillation columns to remove HCl (a product of the reaction) to provide a process stream with reduced HCl. The process stream with reduced HCl further comprises unreacted HF as the process uses an excess of HF.

**[0079]** Following removal of HCl, HF may be removed in a distillation column or a phase separation. Since HF is a reactant in the process, the removed HF is preferably recycled to the contacting step of the process as recycled HF feed. HF removal for recycling may comprise a combination of distillation and liquid-liquid phase separation.

**[0080]** In addition to HCl and HF, the process mixture may comprise residual acids. Residual acids may be removed from the process mixture after removing HCl and HF, by absorbing with Al<sub>2</sub>O<sub>3</sub>, or absorbing into an aqueous medium in an absorber, which optionally contains dilute base (such as alkali metal hydroxide, including, but not limited to KOH). Following removal of residual acids, a scrubbed process mixture is provided.

**[0081]** The scrubbed process mixture may comprise intermediates and byproducts formed during the process. The scrubbed process mixture may comprise one or more HFO-1539mbzz (CF<sub>3</sub>CFCICH=CHCF<sub>2</sub>CF<sub>3</sub>) and HFO-152-10mcdz (CF<sub>3</sub>CF<sub>2</sub>CCI=CHCF<sub>2</sub>CF<sub>3</sub>) and HFO-2536mxzzx (CF<sub>3</sub>CCI=CHCH=CCICF<sub>3</sub>), C<sub>6</sub>H<sub>2</sub>ClF<sub>9</sub> isomers, C<sub>6</sub>HCIF<sub>8</sub> isomers, C<sub>6</sub>H<sub>2</sub>Cl<sub>2</sub>F<sub>8</sub> isomers, C<sub>6</sub>HCl<sub>2</sub>F<sub>7</sub> isomers, and C<sub>6</sub>HCl<sub>3</sub>F<sub>6</sub> isomers. The intermediates may be also removed, such as by distillation and recycled back to the reactor. The intermediates may comprise one or more of C<sub>6</sub>H<sub>2</sub>ClF<sub>9</sub> isomers, C<sub>6</sub>HCIF<sub>8</sub> isomers, C<sub>6</sub>H<sub>2</sub>Cl<sub>2</sub>F<sub>8</sub> isomers, C<sub>6</sub>HCl<sub>2</sub>F<sub>7</sub> isomers and C<sub>6</sub>HCl<sub>3</sub>F<sub>6</sub> isomers.

**[0082]** Following removal of residual acids and intermediates, a scrubbed and distilled process mixture is provided. The scrubbed and distilled process mixture is then dried by passing through a drying agent. The drying agent may be, for example, molecular sieves, providing a dried process mixture. The dried process mixture is distilled using one or more distillation columns to provide a purified product comprising *E*-HFO-153-10mczz. The purified product may comprise greater than 95% or greater than 98% or greater than 99% or greater than 99.5% *E*-HFO-153-10mczz. The purified product may comprise *E*-HFO-153-10mczz and at least one additional compound wherein the amount of *E*-HFO-153-10mczz is at least 99% or at least 99.5%.

**[0083]** In one embodiment, there is provided a composition comprising *E*-HFO-153-10mczz and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCFO-1539mbzz), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-11mcyz) and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (*Z*-HFO-152-11myz). This composition may comprise at least 99% or at least 99.5% *E*-HFO-153-10mczz.

**[0084]** In one embodiment, there is provided a composition comprising *E*-HFO-153-10mczz and 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene. This composition may comprise at least 99% or at least 99.5% *E*-HFO-153-10mczz.

**[0085]** In one embodiment, there is provided a composition comprising *E*-HFO-153-10mczz, 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene and 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene. This composition may comprise at least 99% or at least 99.5% *E*-HFO-153-10mczz.

**[0086]** In one embodiment, there is provided a composition comprising *E*-HFO-153-10mczz, 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene. This composition may comprise at least 99% or at least 99.5% *E*-HFO-153-10mczz.

**[0087]** In one embodiment, there is provided a composition comprising *E*-HFO-153-10mczz and 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene. This composition may comprise at least 99% or at least 99.5% *E*-HFO-153-10mczz.

**[0088]** In one embodiment, there is provided a composition comprising *E*-HFO-153-10mczz and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene. This composition may comprise at least 99% or at least 99.5% *E*-HFO-153-10mczz.

**[0089]** In one embodiment, there is provided a composition comprising *E*-HFO-153-10mczz, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene. This composition may comprise at least 99% or at least 99.5% *E*-HFO-153-10mczz.

**[0090]** In one embodiment, there is provided a composition comprising *E*-HFO-153-10mczz, 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene. This composition may comprise at least 99% or at least 99.5% *E*-HFO-153-10mczz.

**[0091]** The composition comprising *E*-HFO-153-10mczz and one or more additional compounds may be used as a refrigerant. In one embodiment, the composition for use as a refrigerant comprises *E*-HFO-153-10mczz and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.

**[0092]** The composition comprising *E*-HFO-153-10mczz and one or more additional compounds may be used in a heat transfer application. In one embodiment, the composition for use in a heat transfer application comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and Z-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.

**[0093]** The composition comprising *E*-HFO-153-10mczz and one or more additional compounds may be used as a foam expansion agent. In one embodiment, the composition for use as a foam expansion agent comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and Z-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.

**[0094]** The composition comprising *E*-HFO-153-10mczz and one or more additional compounds may be used as a power cycle working fluid. In one embodiment, the composition for use as a power cycle working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and Z-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.

**[0095]** In one embodiment, the composition comprising *E*-HFO-153-10mczz and one or more additional compounds may be used as a working fluid in an immersion cooling unit. In one embodiment, the composition for use as a working fluid in an immersion cooling unit comprises *E*-HFO-153-10mczz and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and Z-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.

**[0096]** In one embodiment, an immersion cooling unit comprises an immersion cell, defining an internal cavity, a heat generating electronic or electrical component positioned in the internal cavity, a working fluid which partially fills the internal cavity and at least partially immerses the heat generating electronic or electrical device, and a condensing coil positioned inside the cavity above the working fluid. In one embodiment of this invention, the working fluid is a composition comprising *E*-HFO-153-

10mczz, and at least one additional compound chosen from 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, 2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene, 2-chloro-1,1,1,5,6,6,6-heptafluorohexa-2,4-diene, 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene, 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene, 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene, 1-chloro-3,3,4,4,5,5-hexafluoro-2-(trifluoromethyl)cyclopent-1-ene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane.

**[0097]** In one embodiment, the working fluid comprises *E*-HFO-153-10mczz and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCF0-1539mbzz), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-11mcyz) and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (*Z*-HFO-152-11myz). In one embodiment, the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene. In one embodiment, the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene and 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene. In one embodiment, the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene. In one embodiment, the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene. In one embodiment, the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene. In one embodiment, the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene. The working fluid may comprise at least 99% or at least 99.5% *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene.

### **DESCRIPTION OF THE FIGURE**

**[0098]** Figure 1 provides a flow diagram for a process useful to prepare *E*-HFO-153-10mczz according to an embodiment of this invention. In Figure 1, there is provided a process system **100** which includes reactor system **101** and purification system **102**. In reactor system **101**, reactant 548mafd feed **103**, fresh reactant HF feed **104** and recycled HF feed stream **105** are mixed into a single feed stream **106** and fed through a series of heat exchangers (**107a**, **107b** and **107c**) and introduced to reactor **109** in feed stream **108**. Heat exchanger **107a** vaporizes feed stream **106**. Heat exchanger **107b** is a process-to-process heat exchanger in which stream from heat exchanger **107a** is heated using the heat from reactor process stream **110**. The heated feed stream from heat exchanger **107b** proceeds through preheater heat exchanger **107c** to provide reactor feed stream.

**[0099]** Reactor feed stream **108** enters tubular reactor **109**, which contains solid fluorination catalyst (not shown). Feed stream **108** reacts in reactor **109** in the presence of solid fluorination catalyst in a vapor phase reaction to produce reactor process stream **110**.

**[0100]** Reactor process stream **110** passes through heat exchanger **107b**, thus cooling stream **110** and providing process stream **111**. Process stream **111** is further cooled by passing through heat exchanger **112**, providing process stream **113**, which enters purification system **102**.

**[0101]** Purification system **102** comprises distillation columns, absorbers, scrubbers, and dryers.

**[0102]** Process feed stream **113** is distilled in HCl distillation column **114** to remove HCl generated in reactor **109**. HCl is removed overhead in stream **115**. Distilled stream **116** then enters HF distillation column **117**, in which HF is removed. A recycle stream comprising HF **118** is removed from column **117**. A portion of stream **118** is mixed with reactant 548mafd feed **103** and fresh reactant HF feed **104** as recycled HF feed stream **105**. A purge stream comprising HF **119** is removed from stream **118**.

**[0103]** After HCl and HF distillation columns, process stream **120** enters absorber **121**. Water is fed to absorber **121** as stream **122**. A solution of HF in water is removed from absorber **121** in stream **123**. Treated stream **124** from absorber **121** is circulated through column **125** in a process step for scrubbing stream **124** with base through scrubber **126**, such as, for example, using an aqueous solution of KOH. Spent KOH solution **127** is removed from scrubber **126** and column **125**. The process stream following scrubbing is removed from column **125** in stream **128**, which is then dried by passing through drying agent column **129**. The drying agent may be, for example, molecular sieves. Dried process stream **130** exits drying agent column **129** for further purification.

**[0104]** Dried process stream **130** enters low boiler distillation column **131** in which low boilers are removed overhead and pass through a condenser in stream **132**. From low boiler distillation column **131**, the process stream **133** passes to distillation column **134**, from which high boilers are purged in stream **136** and product stream **135** comprising E-153-10mczz is provided. Product stream **135** comprising E-153-10mczz may be stored in tank **137** for future or immediate use in manufacture of other fluorochemicals or used in heat transfer applications, such as, for example, in power cycles, high temperature heat pumps and immersion cooling.

**[0105]** Pumps such as illustrated with feed streams **103**, **104** and **105** are used to introduce and/or circulate materials (reactants, intermediates, products) through reaction system **100**. Heat exchangers such as illustrated at **107a-d** are used to manage temperature through reaction system **100**.

**[0106]** Additional components not shown in Figure 1 may include purge lines, heat exchangers, pumps, and vacuum equipment for distillation columns.

### **Composition and Uses**

**[0107]** In one embodiment of this invention is provided a composition comprising E-HFO-153-10mczz comprising one or more additional compounds. The additional compound may be chosen from 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCFO-153-9mbzz), 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (HCFO-152-10mcxz),

2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene (HCFO-2536mxzzx), 2-chloro-1,1,1,5,6,6,6-heptafluorohexa-2,4-diene (HCFO-2537mxzzy), 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene (HCFO-1538mxzd), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-11mcyz), 1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (HFO-152-11myz), 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HCFO-152-10mdz), 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene (HCFO-1528mdcxx), 1-chloro-3,3,4,4,5,5-hexafluoro-2-(trifluoromethyl)cyclopent-1-ene, 1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HFO-153-10mzz), C<sub>6</sub>F<sub>10</sub> isomers, hexafluorobutene isomers (HFO-1336 isomers), C<sub>5</sub>HF<sub>9</sub> isomers, C<sub>6</sub>F<sub>12</sub> isomers, C<sub>6</sub>HF<sub>11</sub> isomers, C<sub>5</sub>H<sub>2</sub>F<sub>8</sub> isomers, C<sub>5</sub>HCIF<sub>8</sub> isomers, C<sub>6</sub>F<sub>8</sub> isomers, C<sub>6</sub>HF<sub>9</sub> isomers, C<sub>6</sub>ClF<sub>9</sub> isomers, 2-chloro-1,1,1,4,4,4-hexafluoro-2-butene (HCFO-1326mxz), 2-chloro-1,1,1,4,4,4-hexafluorobutane (HCFC-346mdf) and 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane (HCFC-548mafd).

**[0108]** In one embodiment, the composition disclosed herein can be used as a refrigerant, heat transfer fluid, foam expansion agent, power cycle working fluid, among other uses. In one embodiment, the composition disclosed herein is used as a heat transfer fluid. In one embodiment the use as a heat transfer fluid is in a refrigeration system. In one embodiment the use as a heat transfer fluid is in a high temperature heat pump. In one embodiment the use as a heat transfer fluid is in a power cycle, such as an organic Rankine cycle.

**[0109]** In one embodiment, the composition of this invention can be used as a working fluid in an immersion cooling unit including an immersion cell, defining an internal cavity, is provided, wherein an electronic or electrical component is positioned in the internal cavity. In this embodiment, the working fluid partially fills the internal cavity and at least partially immerses the heat generating electronic or electrical device. A condensing coil is positioned inside the cavity above the working fluid.

**[0110]** In one embodiment of this invention, an immersion cooling unit comprises: an immersion cell, defining an internal cavity; i) an electrical component in the internal cavity; ii) a working fluid partially filling the internal cavity; iii) a condensing coil, positioned in the internal cavity above the electrical component; wherein the working fluid at least partially immerses the electrical component; and wherein the working fluid

comprises, consists essentially of, or consists of a composition comprising *E*-HFO-153-10mczz and at least one additional compound chosen from 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCFO-153-9mbzz), 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (HCFO-152-10mcxz), 2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene (HCFO-2536mxzzx), 2-chloro-1,1,1,5,6,6,6-heptafluorohexa-2,4-diene (HCFO-2537mxzzy), 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene (HCFO-1538mxzd), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-11mcyz), 1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (HFO-152-11myz), 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HCFO-152-10mdz), 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene (HCFO-1528mdcxy), 1-chloro-3,3,4,4,5,5-hexafluoro-2-(trifluoromethyl)cyclopent-1-ene, 1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HFO-153-10mzz), C<sub>6</sub>F<sub>10</sub> isomers, hexafluorobutene isomers (HFO-1336 isomers), C<sub>5</sub>HF<sub>9</sub> isomers, C<sub>6</sub>F<sub>12</sub> isomers, C<sub>5</sub>H<sub>2</sub>F<sub>8</sub> isomers, C<sub>5</sub>HCIF<sub>8</sub> isomers, C<sub>6</sub>F<sub>8</sub> isomers, C<sub>6</sub>HF<sub>9</sub> isomers, C<sub>6</sub>ClF<sub>9</sub> isomers, 2-chloro-1,1,1,4,4,4-hexafluoro-2-butene (HCFO-1326mxz), 2-chloro-1,1,1,4,4,4-hexafluorobutane (HCFC-346mdf) and 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane (HCFC-548mafd).

**[0111]** Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. In case of conflict, the present specification, including definitions, will control. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of embodiments of the present invention, suitable methods and materials are described below. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

**[0112]** The following Examples are provided to illustrate certain aspects of the invention and shall not limit the scope of the appended claims.

### **EXAMPLES**

**[0113]** In the following Examples, the letter “T” designates temperature; the letter “P” designates pressures. All temperatures are provided in degrees Celsius (°C).

[0114] Unless otherwise stated, all analyses for products in the following Examples were performed using GC/MS FID and results are reported in GC FID Area%.

### **Example 1. Synthesis of 153-10mczz**

[0115] Into an Inconel (0.5 inch OD) tube reactor was added 4 cc of chromium oxide catalyst (12/20 mesh). The reaction was run by feeding liquid HCFC-548mafd into a heated chamber where it vaporized and mixed with HF and N<sub>2</sub>. The reaction mixture was then allowed to pass through the reactor. Part of the reactor effluent was passed through a series of valves and analyzed by GC/MS. Part of the reactor effluent can also be passed through a caustic scrubber, dried over a desiccant and trap in a dry ice acetone trap. The trapped material is then analyzed by NMR to give *E*-153-10mczz composition listed in Table 2 below.

**TABLE 2**

| Chemical Name                                                      | Compound             | Chemical Formula                                                                     | mole %   |
|--------------------------------------------------------------------|----------------------|--------------------------------------------------------------------------------------|----------|
| <i>E</i> -1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene                  | <i>E</i> -153-10mczz | <i>E</i> -CF <sub>3</sub> CF <sub>2</sub> CH=CHCF <sub>2</sub> CF <sub>3</sub>       | 82.4878% |
| 2-chloro-1,1,1,2,2,5,5,6,6,6-nonafluoro-3-hexene                   | 1539mbzz             | CF <sub>3</sub> CFCICH=CHCF <sub>2</sub> CF <sub>3</sub>                             | 5.8649%  |
| 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene                   | 152-10mcdz           | CF <sub>3</sub> CF <sub>2</sub> CCl=CHCF <sub>2</sub> CF <sub>3</sub>                | 2.5736%  |
| 2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene                  | 2536mxzzx            | CF <sub>3</sub> CCl=CHCH=CClCF <sub>3</sub>                                          | 2.2272%  |
| 2-chloro-1,1,1,5,6,6,6-heptafluorohexa-2,4-diene                   | 2537mxzzy            | CF <sub>3</sub> CCl=CHCH=CFCF <sub>3</sub>                                           | 1.6498%  |
| 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene                   | 1538mxzd             | CF <sub>3</sub> CCl=CHCHClCF <sub>2</sub> CF <sub>3</sub>                            | 1.4435%  |
| 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene                        | 152-11mcyz           | CF <sub>3</sub> CF <sub>2</sub> CF=CHCF <sub>2</sub> CF <sub>3</sub>                 | 1.1631%  |
| 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene                   | 152-10mdz            | CF <sub>3</sub> CCl=CHCF <sub>2</sub> CF <sub>2</sub> CF <sub>3</sub>                | 0.9981%  |
| 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene                | 1528mdcxx            | CF <sub>3</sub> CHClCF <sub>2</sub> CCl=CClCF <sub>3</sub>                           | 0.9074%  |
| 1-chloro-3,3,4,4,5,5-hexafluoro-2-(trifluoromethyl)cyclopent-1-ene |                      | Cyclic-CF <sub>2</sub> CF <sub>2</sub> CF <sub>2</sub> C(CF <sub>3</sub> )CCl-       | 0.6846%  |
| 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane                   | 548mafd              | CF <sub>3</sub> CF <sub>2</sub> CHClCH <sub>2</sub> CCl <sub>2</sub> CF <sub>3</sub> | 0.0000%  |

**Example 2**

[0116] The product produced in Example 1 was purified using methods disclosed herein of including distillation. The composition after purification is provided in Table 3.

**TABLE 3**

| Chemical Name                                     | Compound             | Chemical Formula                                       | Analyzed GC area % |
|---------------------------------------------------|----------------------|--------------------------------------------------------|--------------------|
| <i>E</i> -1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene | <i>E</i> -153-10mczz | $E\text{-CF}_3\text{CF}_2\text{CH=CHCF}_2\text{-CF}_3$ | 99.5%              |
| 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene    | 1539mbzz             | $\text{CF}_3\text{CFCICH=CHCF}_2\text{CF}_3$           | 0.20%              |
| 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene       | 152-11mcyz           | $\text{CF}_3\text{CF}_2\text{CF=CHCF}_2\text{CF}_3$    | 0.10%              |

**Example 3**

Hydrofluorination of HCFC-548mafd to *E*-HFO-153-10mczz, using 4%Zn/Al<sub>2</sub>O<sub>3</sub> catalyst

[0117] 6ml (12-20 mesh) of 4% Zn/Al<sub>2</sub>O<sub>3</sub> catalyst is loaded into a 12 inches long Inconel (0.5 inch OD) tube reactor. The catalyst is activated by HF starting from 150°C and raising to 450°C. The reaction of 548mafd-with HF reaction was tested at conditions listed in Table 4 below. HCFC-548mafd was fed by a pump and went through a vaporizer at 200°C with N<sub>2</sub> and then is mixed with HF and flow through the reactor with catalyst bed. The reactor effluent is analyzed by a GC-MS-FID and shows *E*-HFO-153-10mczz, was produced at high concentration at various conditions. Results are provided in Table 5.

**TABLE 4**

| Sample | Time | T   | P (psig) | 548mafd (ml/hr) | N <sub>2</sub> (sccm) | HF (sccm) |
|--------|------|-----|----------|-----------------|-----------------------|-----------|
| 1      | 1.25 | 280 | 1.3      | 0.15            | 3.09                  | 6.13      |
| 2      | 2.50 | 280 | 1.4      | 0.15            | 3.09                  | 6.10      |
| 3      | 3.75 | 280 | 1.1      | 0.15            | 3.09                  | 6.06      |
| 4      | 5.00 | 280 | 1        | 0.15            | 3.09                  | 6.06      |
| 5      | 6.25 | 280 | 0.9      | 0.15            | 3.09                  | 6.06      |
| 6      | 7.50 | 280 | 0.9      | 0.15            | 3.09                  | 6.13      |

| Sample | Time  | T   | P (psig) | 548mafd<br>(ml/hr) | N <sub>2</sub><br>(sccm) | HF<br>(sccm) |
|--------|-------|-----|----------|--------------------|--------------------------|--------------|
| 7      | 8.75  | 300 | 0.9      | 0.15               | 3.09                     | 6.17         |
| 8      | 10.00 | 300 | 0.9      | 0.15               | 3.09                     | 6.14         |
| 9      | 11.25 | 300 | 0.9      | 0.15               | 3.09                     | 6.16         |
| 10     | 12.50 | 315 | 0.9      | 0.15               | 3.09                     | 6.17         |
| 11     | 13.75 | 315 | 0.9      | 0.15               | 3.09                     | 6.14         |
| 12     | 15.00 | 315 | 0.9      | 0.15               | 3.09                     | 6.10         |
| 13     | 16.25 | 330 | 0.9      | 0.15               | 3.09                     | 6.16         |
| 14     | 17.50 | 330 | 0.9      | 0.15               | 3.09                     | 6.12         |
| 15     | 18.75 | 330 | 0.9      | 0.15               | 3.04                     | 6.05         |
| 16     | 20.00 | 345 | 0.9      | 0.15               | 3.02                     | 6.04         |

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TABLE 5

| Sample | 548mafd      | E-153-10mczz | 1233xf | C <sub>6</sub> H <sub>2</sub> F <sub>8</sub> isomers | C <sub>6</sub> H <sub>2</sub> F <sub>8</sub> | 1539 isomers | 1539 isomers | 1539 isomers | C <sub>6</sub> H <sub>2</sub> ClF <sub>7</sub> isomers | C <sub>6</sub> H <sub>2</sub> ClF <sub>7</sub> isomers | Other compounds |
|--------|--------------|--------------|--------|------------------------------------------------------|----------------------------------------------|--------------|--------------|--------------|--------------------------------------------------------|--------------------------------------------------------|-----------------|
|        | GC-FID area% |              |        |                                                      |                                              |              |              |              |                                                        |                                                        |                 |
| 1      | 0.00         | 67.08        | 0.00   | 14.83                                                | 6.79                                         | 0.00         | 0.00         | 0.00         | 3.08                                                   | 0.00                                                   | 8.22            |
| 2      | 0.00         | 75.15        | 0.00   | 6.88                                                 | 0.00                                         | 0.00         | 0.00         | 0.00         | 4.49                                                   | 0.00                                                   | 13.49           |
| 3      | 2.58         | 24.69        | 0.00   | 11.87                                                | 3.27                                         | 31.19        | 4.42         | 0.33         | 15.06                                                  | 4.34                                                   | 2.25            |
| 4      | 13.74        | 17.67        | 0.04   | 3.97                                                 | 1.06                                         | 38.50        | 4.39         | 1.11         | 11.41                                                  | 3.61                                                   | 4.54            |
| 5      | 8.67         | 23.96        | 0.06   | 5.65                                                 | 1.11                                         | 37.47        | 4.24         | 0.72         | 10.17                                                  | 3.34                                                   | 4.67            |
| 6      | 7.54         | 41.82        | 0.10   | 3.93                                                 | 0.77                                         | 23.74        | 2.89         | 0.68         | 8.73                                                   | 3.64                                                   | 6.27            |
| 7      | 4.87         | 48.53        | 0.11   | 3.86                                                 | 0.77                                         | 23.61        | 2.78         | 0.44         | 7.33                                                   | 3.00                                                   | 4.81            |
| 8      | 7.12         | 44.12        | 0.09   | 3.79                                                 | 0.70                                         | 24.87        | 2.91         | 0.64         | 7.90                                                   | 3.29                                                   | 4.64            |
| 9      | 2.02         | 63.96        | 0.12   | 2.65                                                 | 0.59                                         | 11.62        | 1.51         | 0.21         | 5.43                                                   | 2.83                                                   | 9.20            |
| 10     | 2.15         | 63.92        | 0.15   | 2.62                                                 | 0.58                                         | 11.67        | 1.51         | 0.22         | 5.52                                                   | 2.92                                                   | 8.91            |
| 11     | 2.02         | 64.68        | 0.12   | 2.58                                                 | 0.00                                         | 11.54        | 2.06         | 0.22         | 5.39                                                   | 2.83                                                   | 8.62            |
| 12     | 0.51         | 71.56        | 0.25   | 1.99                                                 | 0.00                                         | 5.32         | 1.25         | 0.15         | 3.61                                                   | 2.22                                                   | 13.29           |
| 13     | 0.60         | 71.03        | 0.18   | 1.99                                                 | 0.39                                         | 5.57         | 0.86         | 0.18         | 3.67                                                   | 2.26                                                   | 13.46           |
| 14     | 0.56         | 71.43        | 0.18   | 1.96                                                 | 0.39                                         | 5.44         | 0.85         | 0.18         | 3.58                                                   | 2.20                                                   | 13.42           |
| 15     | 0.28         | 71.09        | 0.29   | 2.17                                                 | 0.32                                         | 3.83         | 0.45         | 0.30         | 2.98                                                   | 1.83                                                   | 16.75           |

**Example 4**

Production, Purification of *E*-153-10mczz and analysis of *E*-153-10mczz product

[0118] In a 1" Hastelloy C tube reactor Cr<sub>2</sub>O<sub>3</sub> catalyst was loaded and activated by HF treatment. Then 548mafd and HF were fed at mol ratio of 1:40 at 30 psig pressure with co-fed of 0.2mol% O<sub>2</sub> at a temperature of 320°C with contact time around 13 seconds. The product was scrubbed by a caustic and collected. The crude product was analyzed by GC-MS-FID. The result of GC analysis is provided in Table 6.

**TABLE 6**

| Compound                                               | FID area% |
|--------------------------------------------------------|-----------|
| HFC-125                                                | 0.0020%   |
| CFC-115                                                | 0.0032%   |
| C <sub>6</sub> F <sub>10</sub> isomers                 | 0.0128%   |
| C <sub>6</sub> F <sub>10</sub> isomers                 | 0.0207%   |
| C <sub>6</sub> F <sub>10</sub> isomers                 | 0.115%    |
| C <sub>5</sub> HF <sub>9</sub> isomers                 | 0.0321%   |
| C <sub>6</sub> F <sub>12</sub> isomers                 | 0.0984%   |
| Z-152-11mcyz                                           | 0.739%    |
| <i>E</i> -153-10mczz                                   | 82.0%     |
| C <sub>6</sub> HF <sub>11</sub> isomers                | 0.0399%   |
| C <sub>6</sub> HF <sub>11</sub> isomers                | 0.0080%   |
| C <sub>6</sub> HF <sub>11</sub> isomers                | 0.0082%   |
| Z-152-11myz                                            | 0.0981%   |
| C <sub>6</sub> HF <sub>11</sub> isomers                | 0.0306%   |
| C <sub>6</sub> H <sub>2</sub> F <sub>12</sub> isomers  | 0.130%    |
| C <sub>6</sub> CIF <sub>9</sub> isomers                | 0.203%    |
| C <sub>6</sub> H <sub>2</sub> F <sub>10</sub> isomers  | 0.125%    |
| C <sub>5</sub> HCIF <sub>8</sub> isomers               | 0.0630%   |
| C <sub>6</sub> H <sub>2</sub> F <sub>10</sub> isomers  | 0.226%    |
| C <sub>6</sub> HCIF <sub>10</sub> isomers              | 1.30%     |
| C <sub>6</sub> HCIF <sub>10</sub> isomers              | 0.691%    |
| C <sub>6</sub> H <sub>2</sub> CIF <sub>9</sub> isomers | 7.64%     |
| C <sub>5</sub> HF <sub>9</sub> isomers                 | 0.152%    |
| C <sub>6</sub> H <sub>2</sub> CIF <sub>9</sub> isomers | 0.228%    |
| C <sub>6</sub> H <sub>2</sub> CIF <sub>9</sub> isomers | 0.621%    |
| C <sub>6</sub> HCIF <sub>8</sub> isomers               | 0.0715%   |
| C <sub>6</sub> H <sub>2</sub> CIF <sub>9</sub> isomers | 0.101%    |
| C <sub>6</sub> H <sub>2</sub> CIF <sub>7</sub> isomers | 0.194%    |
| C <sub>6</sub> Cl <sub>2</sub> F <sub>10</sub> isomers | 0.126%    |

| Compound                                                             | FID area% |
|----------------------------------------------------------------------|-----------|
| C <sub>6</sub> HCl <sub>2</sub> F <sub>9</sub> isomers               | 0.310%    |
| C <sub>6</sub> HClF <sub>10</sub> isomers                            | 0.247%    |
| C <sub>6</sub> HCl <sub>2</sub> F <sub>9</sub> isomers               | 0.296%    |
| C <sub>6</sub> H <sub>2</sub> Cl <sub>2</sub> F <sub>8</sub> isomers | 0.983%    |
| C <sub>6</sub> Cl <sub>2</sub> F <sub>8</sub> isomers                | 0.102%    |
| C <sub>6</sub> HCl <sub>2</sub> F <sub>7</sub> isomers               | 0.169%    |
| C <sub>6</sub> HCl <sub>2</sub> F <sub>7</sub> isomers               | 0.133%    |
| C <sub>6</sub> HCl <sub>2</sub> F <sub>7</sub> isomers               | 0.125%    |
| C <sub>6</sub> H <sub>2</sub> Cl <sub>2</sub> F <sub>6</sub> isomers | 0.311%    |
| C <sub>6</sub> HCl <sub>3</sub> F <sub>6</sub> isomers               | 0.178%    |
| Other compounds                                                      | 2.08%     |

[0119] This crude *E*-153-10mczz was purified in a series of distillation columns, absorbers, scrubbers and dryers as described according to Figure 1. The purified product was analyzed by NMR and GC-MS-FID to determine the composition. The composition is provided in Table 7 and Table 8.

TABLE 7 NMR analysis

| Compound                                              | Formula                                                                        | Name                 | Mole % |
|-------------------------------------------------------|--------------------------------------------------------------------------------|----------------------|--------|
| <i>E</i> -1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene     | <i>E</i> -C <sub>2</sub> F <sub>5</sub> CH=CHC <sub>2</sub> F <sub>5</sub>     | <i>E</i> -153-10mczz | 98.6   |
| <i>Z</i> -1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene | <i>Z</i> -CF <sub>3</sub> CF <sub>2</sub> CF=CHCF <sub>2</sub> CF <sub>3</sub> | <i>Z</i> -152-11mcyz | 1.22   |
| <i>Z</i> -1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene | <i>Z</i> -CF <sub>3</sub> CF=CHCF <sub>2</sub> CF <sub>2</sub> CF <sub>3</sub> | <i>Z</i> -152-11myz  | 0.14   |

TABLE 8 GC-MS-FID analysis

| Compounds                                                                                                        | FID area% |
|------------------------------------------------------------------------------------------------------------------|-----------|
| C <sub>6</sub> F <sub>10</sub> isomers                                                                           | 0.0002%   |
| C <sub>6</sub> F <sub>10</sub> isomers                                                                           | 0.0009%   |
| HFO-1336 isomers                                                                                                 | 0.0007%   |
| C <sub>5</sub> HF <sub>9</sub> isomers                                                                           | 0.0004%   |
| C <sub>6</sub> F <sub>12</sub> isomers /C <sub>5</sub> H <sub>2</sub> F <sub>8</sub> isomers / other compound(s) | 0.0058%   |
| C <sub>6</sub> F <sub>12</sub> isomers                                                                           | 0.0009%   |
| Z-HFO-152-11mcyz                                                                                                 | 0.8150%   |
| E-HFO-153-10mczz                                                                                                 | 99.0500%  |
| Z-HFO-152-11myz                                                                                                  | 0.0083%   |
| C <sub>6</sub> F <sub>10</sub> isomers                                                                           | 0.0040%   |
| C <sub>6</sub> F <sub>8</sub> isomers                                                                            | 0.0036%   |
| HFO-153-10mzz                                                                                                    | 0.0069%   |
| C <sub>6</sub> HF <sub>9</sub> isomers                                                                           | 0.0095%   |
| C <sub>6</sub> HF <sub>9</sub> isomers                                                                           | 0.0008%   |
| C <sub>6</sub> ClF <sub>9</sub> isomers                                                                          | 0.0060%   |
| C <sub>6</sub> HF <sub>9</sub> isomers                                                                           | 0.0019%   |
| C <sub>6</sub> HF <sub>9</sub> isomers                                                                           | 0.0022%   |
| HCFO-1326mxz                                                                                                     | 0.0015%   |
| C <sub>6</sub> HCIF <sub>10</sub> isomers                                                                        | 0.0009%   |
| C <sub>6</sub> H <sub>2</sub> ClF <sub>9</sub> isomers                                                           | 0.0004%   |
| C <sub>5</sub> HCIF <sub>8</sub> isomers                                                                         | 0.0073%   |
| C <sub>5</sub> HCIF <sub>8</sub> isomers                                                                         | 0.0009%   |
| HCFC-346mdf                                                                                                      | 0.0028%   |
| Other compounds                                                                                                  | 0.0661%   |

### CLAIMS

What is claimed is:

1. A process for preparing *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene comprising contacting 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane with an excess of HF in the presence of a fluorination catalyst to obtain a process mixture comprising *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, wherein the process is performed at a temperature of about 250-450°C, a pressure of about 0 to 200 psig.
2. The process of claim 1 wherein the temperature is in the range of about 300 to about 380°C.
3. The process of claim 1 or claim 2 wherein the pressure is in the range of about 30 to about 180 psig or about 40 to 150 psig, or about 60-120 psig.
4. The process of any of claims 1-3, wherein the fluorination catalyst comprises one or more metals, metal oxides, metal oxyfluorides, metal chloride or metal fluorides.
5. The process of claim 4 wherein the fluorination catalyst is a metal oxide and the metal oxide forms a metal (oxy)fluoride having Lewis acid character.
6. The process of claim 1 wherein the metal oxide comprises chromium or aluminum or cobalt or zinc.
7. The process of claim 1 wherein the fluorination catalyst comprises one or more of metals selected from Al, Sc, Y, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Re, Fe, Ru, Co, Rh, Ir, Ni, Pd, Pt, Cu, Ag, Au, Zn, La and Ce.
8. The process of claim 7 wherein the fluorination catalyst comprises one or more of Al, Zr, Cr, Co, Ni and Zn.
9. The process of claim 8 wherein the fluorination catalyst comprises chromium or aluminum.
10. The process of claim 8 wherein the fluorination catalyst comprises chromium or aluminum and one or more of Zn, Zr, Co, and Ni.

11. The process of claim 4, wherein the fluorination catalyst comprises a metal oxide or metal fluoride and contains one or more additional metals selected from the group consisting of Li, Na, K, Ca, Mg, and Cs.
12. The process of claim 11, wherein the additional metal is present in an amount of less than 2000 or less than 1000 or less than 500 or less than 100 or less than 10 ppm.
13. The process of claim 9, wherein the fluorination catalyst comprises aluminum.
14. The process of claim 13, wherein aluminum is present in the form of aluminum oxide, aluminum fluoride or aluminum oxyfluoride.
15. The process of claim 13, wherein the fluorination catalyst further comprises one or more of Sc, Y, Ti, Zr, Hf, V Nb, Ta, Cr, Mo, W, Mn, Re, Fe, Ru, Co, Rh, Ir, Ni, Pd, Pt, Cu, Ag, Au, Zn, La and Ce.
16. The process of claim 15, wherein the fluorination catalyst comprises one or more of Zn, Zr, Cr, Co, and Ni.
17. The process of claim 13, wherein the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$ .
18. The process of claim 17, wherein the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and one or more of Zn, Zr, Cr, Co, and Ni.
19. The process of claim 18, wherein the fluorination catalyst comprises  $\text{Al}_2\text{O}_3$  and Zn, or  $\text{Al}_2\text{O}_3$  and Cr, or  $\text{Al}_2\text{O}_3$  and Co, or  $\text{Al}_2\text{O}_3$  and Ni, or  $\text{Al}_2\text{O}_3$  and Zr.
20. The process of claim 9, wherein the fluorination catalyst comprises chromium.
21. The process of claim 20, wherein chromium is present in the form of chromium oxide, chromium chloride, chromium fluoride or chromium oxyfluoride.
22. The process of claim 21, wherein the fluorination catalyst further comprises one or more of Al, Sc, Y, Ti, Zr, Hf, V Nb, Ta, Mo, W, Mn, Re, Fe, Ru, Co, Rh, Ir, Ni, Pd, Pt, Cu, Ag, Au, Zn, La and Ce.
23. The process of claim 20, wherein the fluorination catalyst comprises  $\text{Cr}_2\text{O}_3$ .
24. The process of claim 20, wherein the fluorination catalyst comprises  $\text{Cr}_2\text{O}_3$  and one or more of Zn, Zr, Co, and Ni.

25. The process of claim 24, wherein the fluorination catalyst comprises  $\text{Cr}_2\text{O}_3$  and Zn, or  $\text{Cr}_2\text{O}_3$  and Co, or  $\text{Cr}_2\text{O}_3$  and Ni, or  $\text{Cr}_2\text{O}_3$  and Zr.
26. The process of claim 20 wherein, the catalyst comprises chromium supported on  $\text{AlF}_3$ , alumina, fluorinated alumina or activated carbon.
27. The process of claim 26 wherein the catalyst comprises chromium supported on alumina.
28. The process of claim 8 wherein, the catalyst comprises zinc supported on  $\text{AlF}_3$ , alumina, fluorinated alumina or activated carbon.
29. The process of claim 28 wherein the catalyst comprises zinc supported on alumina.
30. The process of any of claims 1-29 further comprising, a prefluorination treatment prior to contacting HCFC-548mafd with HF in the presence of the fluorination catalyst in a reactor, wherein the prefluorination treatment comprises passing HF, with or without an inert diluent such as nitrogen, over the catalyst at a temperature within the range of about 250 to 450°C.
31. The process of any of claims 1-30 further comprising, regenerating the fluorination catalyst after the catalyst has decreased in activity, wherein a regenerating step comprises treating the catalyst with oxygen or air at elevated temperature in the condition majority organic materials are purged away.
32. The process of claim 31, wherein the organic materials comprise HCFC-548mafd and/or E-HFO-153-10mczz.
33. The process of any of claims 1-32, wherein the process is performed at a molar ratio of HF to HCFC-548mafd from about 3:1 to about 50:1.
34. The process of claim 33 wherein the molar ratio of HF to HCFC-548mafd is from about 10:1 to about 45:1, or 15:1 to 40:1.
35. The process of any of claims 1-34, further comprising adding an oxygen-containing gas to the process.

36. The process of claim 35 wherein the amount of oxygen added to the process from the oxygen-containing gas is greater than greater than 0% and less than 10 mole%.
37. The process of claim 35 wherein the amount of oxygen added to the process from the oxygen-containing gas is from about 0.2 mole % to about 5 mole%, or from about 1 mole%.
38. The process of any of claims 1-37, wherein the process mixture comprising E-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene further comprises unreacted HF and the unreacted HF is recovered and recycle to the process.
39. The process of any of claims 1-37, wherein the process mixture comprises intermediates and unreacted 548mafd, and the unreacted 548mafd and intermediates are recovered and recycled to the process.
40. The process of claim 39, wherein the intermediates comprise one or more of C<sub>6</sub>H<sub>2</sub>ClF<sub>9</sub> isomers, C<sub>6</sub>HClF<sub>8</sub> isomers, C<sub>6</sub>H<sub>2</sub>Cl<sub>2</sub>F<sub>8</sub> isomers, C<sub>6</sub>HCl<sub>2</sub>F<sub>7</sub> isomers, and C<sub>6</sub>HCl<sub>3</sub>F<sub>6</sub> isomers.
41. A composition comprising E-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (E-HFO-153-10mczz), and at least one additional compound chosen from 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCFO-153-9mbzz), 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (HCFO-152-10mcxz), 2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene (HCFO-2536mxzzx), 2-chloro-1,1,1,5,6,6,6-heptafluorohexa-2,4-diene (HCFO-2537mxzzy), 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene (HCFO-1538mxzd), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-11mcyz), 1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (HFO-152-11myz), 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HCFO-152-10mdz), 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene (HCFO-1528mdcxx), 1-chloro-3,3,4,4,5,5-hexafluoro-2-(trifluoromethyl)cyclopent-1-ene, 1,1,1,4,4,5,5,6,6,6- decafluoro-2-hexene (HFO-153-10mzz), C<sub>6</sub>F<sub>10</sub> isomers, hexafluorobutene isomers (HFO-1336 isomers), C<sub>5</sub>HF<sub>9</sub> isomers, C<sub>6</sub>F<sub>12</sub> isomers, C<sub>5</sub>H<sub>2</sub>F<sub>8</sub> isomers, C<sub>5</sub>HCIF<sub>8</sub> isomers, C<sub>6</sub>F<sub>8</sub> isomers, C<sub>6</sub>HF<sub>9</sub> isomers, C<sub>6</sub>HF<sub>11</sub> isomers, C<sub>6</sub>ClF<sub>9</sub> isomers, 2-chloro-1,1,1,4,4,4-hexafluoro-2-butene (HCFO-1326mxz), 2-chloro-1,1,1,4,4,4-hexafluorobutane (HCFC-346mdf) and 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane (HCFC-548mafd).

42. The composition of claim 41, wherein the composition comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and at least one of 2-chloro-1,1,1,2,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.
43. The composition of claim 42, wherein the composition comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene.
44. The composition of claim 42, wherein the composition comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene and 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene.
45. The composition of claim 42, wherein the composition comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.
46. The composition of claim 42, wherein the composition comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene.
47. The composition of claim 42, wherein the composition comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.
48. The composition of claim 42, wherein the composition comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.
49. The composition of claim 42, wherein the composition comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.
50. The composition of any of claims 42-49, wherein composition comprises at least 99% or at least 99.5% *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene.

51. The composition of claim 42, wherein the composition comprises HCFC-548mafd and one or more of  $C_6H_2ClF_9$  isomers,  $C_6HClF_8$  isomers,  $C_6H_2Cl_2F_8$  isomers,  $C_6HCl_2F_7$  isomers, and  $C_6HCl_3F_6$  isomers.
52. The composition of claim 42 prepared according to the process of any of claims 1-40.
53. Use of a composition comprising *E*-1,1,1,2,2,5,5,6,6-decafluoro-3-hexene and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene as a refrigerant.
54. Use of a composition comprising *E*-1,1,1,2,2,5,5,6,6-decafluoro-3-hexene and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene in a heat transfer application.
55. Use of a composition comprising *E*-1,1,1,2,2,5,5,6,6-decafluoro-3-hexene and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene as a foam expansion agent.
56. Use of a composition comprising *E*-1,1,1,2,2,5,5,6,6-decafluoro-3-hexene and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene as a power cycle working fluid.
57. An immersion cooling unit comprising an immersion cell, defining an internal cavity, a heat generating electronic or electrical component positioned in the internal cavity, a working fluid which partially fills the internal cavity and at least partially immerses the heat generating electronic or electrical device, and a condensing coil positioned inside the cavity above the working fluid, wherein the working fluid is a composition comprising *E*-1,1,1,2,2,5,5,6,6-decafluoro-3-hexene (*E*-HFO-153-10mczz), and at least one additional compound chosen from 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCFO-153-9mbzz), 3-chloro-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene (HCFO-152-10mcxz), 2,5-dichloro-1,1,1,6,6,6-hexafluorohexa-2,4-diene (HCFO-2536mxzzx), 2-chloro-

1,1,1,5,6,6,6-heptafluorohexa-2,4-diene (HCFO-2537mxzzy), 2,4-dichloro-1,1,1,5,5,6,6,6-octafluoro-2-hexene (HCFO-1538mxzd), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-11mcyz), 1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (HFO-152-11myz), 2-chloro-1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HCFO-152-10mdz), 2,3,5-trichloro-1,1,1,4,4,6,6,6-octafluoro-2-hexene (HCFO-1528mdcxx), 1-chloro-3,3,4,4,5,5-hexafluoro-2-(trifluoromethyl)cyclopent-1-ene, 1,1,1,4,4,5,5,6,6,6-decafluoro-2-hexene (HFO-153-10mzz), C<sub>6</sub>F<sub>10</sub> isomers, hexafluorobutene isomers (HFO-1336 isomers), C<sub>5</sub>HF<sub>9</sub> isomers, C<sub>6</sub>F<sub>12</sub> isomers, C<sub>6</sub>HF<sub>11</sub> isomers, C<sub>5</sub>H<sub>2</sub>F<sub>8</sub> isomers, C<sub>5</sub>HCIF<sub>8</sub> isomers, C<sub>6</sub>F<sub>8</sub> isomers, C<sub>6</sub>HF<sub>9</sub> isomers, C<sub>6</sub>ClF<sub>9</sub> isomers, 2-chloro-1,1,1,4,4,4-hexafluoro-2-butene (HCFO-1326mxz), 2-chloro-1,1,1,4,4,4-hexafluorobutane (HCFC-346mdf) and 3,5,5-trichloro-1,1,1,2,2,6,6,6-octafluorohexane (HCFC-548mafd)(HCFC-548mafd).

58. The immersion cooling unit of claim 57, wherein the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and at least one of 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene (HCFO-1539mbzz), 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene (HFO-152-10mcyz) and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene (*Z*-HFO-152-11myz).
59. The immersion cooling unit of claim 57, wherein the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene.
60. The immersion cooling unit of claim 57, wherein the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene and 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene.
61. The immersion cooling unit of claim 57, wherein the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.
61. The immersion cooling unit of claim 57, wherein the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene.

62. The immersion cooling unit of claim 57, wherein the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.
63. The immersion cooling unit of claim 57, wherein the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.
64. The immersion cooling unit of claim 57, wherein the working fluid comprises *E*-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, 2-chloro-1,1,1,2,5,5,6,6,6-nonafluoro-3-hexene, 1,1,1,2,2,3,5,5,6,6,6-undecafluoro-3-hexene and *Z*-1,1,1,2,4,4,5,5,6,6,6-undecafluoro-2-hexene.