Supporting Information

A. Potential Parameters for R134a

The potential¹ includes pairwise interactions between all atoms, with a Coulomb and a Lennard-Jones component

$$U_{\text{int}} = \sum_{a \in Ab \in B} 4\varepsilon_{ab} \left[\left(\frac{\sigma_{ab}}{r_{ab}} \right)^{12} - \left(\frac{\sigma_{ab}}{r_{ab}} \right)^6 \right] + \sum_{a \in Ab \in B} \sum_{r_{ab}} \frac{q_a q_b}{r_{ab}},$$
(S1)

where U_{int} is intermolecular interaction energy, sites *a* belong to molecule *A*, sites *b* belong to molecule *B*, and the separation between site *a* and site *b* is r_{ab} . ε_{ab} is the well depth for short-range interactions, σ_{ab} is the core diameter for the Lennard-Jones potential, and *q* is the partial charge of each site. For the Lennard-Jones interactions between unlike atoms, the Lorentz-Berthelot combining rules are used. Thus, the Lennard-Jones interactions are calculated using the arithmetic mean of the core diameters and the geometric mean of the potential well depths.

$$\sigma_{ij} = \frac{1}{2} \left(\sigma_i + \sigma_j \right) \tag{S2}$$

$$\varepsilon_{ij} = \sqrt{\varepsilon_i \varepsilon_j} \tag{S3}$$

The intramolecular energy includes a bond angle bending and a torsion term. The bond lengths are rigid. A harmonic potential controls bond-angle bending:

$$U_{bend} = \frac{k_{\theta}}{2} \left(\theta - \theta_0\right)^2 \tag{S4}$$

where θ is the variable bond angle of a simulated molecule, θ_0 is the equilibrium bond angle, and k_{θ} is the force constant. The following functional form describes the torsion angle potentials:

$$U_{torsion} = C_0 + C_1 [1 + \cos(\phi)] + C_2 [1 - \cos(2\phi)] + C_3 [1 + \cos(3\phi)]$$
(S5)

where ϕ and C_i are the dihedral angle and the Fourier coefficients in the cosine series function, respectively. The parameters are summarized in Tables S1 and S2.

	Bond length (Å)	Angle (deg)	$\frac{k_{ heta}}{(\mathrm{K/rad}^2)}$	$\begin{array}{c} C_0/k_B \\ (\mathrm{K}) \end{array}$	C_1/k_B (K)	C_2/k_B (K)	$\begin{array}{c} C_3/k_B \\ (\mathrm{K}) \end{array}$
CC	1.529						
CF	1.360						
СН	1.090						
∠CCH		110.7	18889.4				
∠CCF		109.5	25185.8				
∠HCH		107.8	16622.6				
∠HCF		107.0	20148.7				
∠FCF		109.1	38786.2				
∠FCCF				11.35	1.96	-24.5	1070.18
∠FCCH				-29.32	1.59	9.96	1064.65

TABLE S1: Structural parameters of the molecular model

TABLE S2: Potential parameters of the molecular model

Atom/group	$\varepsilon/k_B(\mathbf{K})$	$\sigma(\text{\AA})$	<i>q</i> (e)
C (CF ₃)	47.00	3.60	0.547
C (CH ₂ F)	47.00	3.60	0.041
Н	10.00	2.50	0.104
F	24.00	2.92	-0.199

B. Growing procedure for a R134a



Figure S1. Schematic of the growing procedure of an R134a molecule in a CBMC move. F is fluorine, C is carbon, and H is hydrogen. Numbers 1 to 8 denote the order of the atom in the procedure.

The growing procedure for an R134a molecule is shown in Figure S1. Apart from the regrowth move, in which atom F1 is kept fixed, atom F1 is inserted randomly in different places N_i ($N_i = 10$) times in the simulation box. This process is known as multiple first bead insertions.² One choice out of these is selected with a probability P_i^1 .

$$P_i^1 = \frac{\exp\left(-\beta U_i^1(ii)\right)}{\sum_{ii=1}^{N_i} \exp\left(-\beta U_i^1(ii)\right)}$$
(S6)

where the subscript *i* means intermolecular interaction and the superscript indicates the order of the atom in a R134a molecule, $\beta = 1/k_BT$ where k_B is the Boltzmann constant, $U_i^1(ii)$ is the intermolecular interaction energy of atom F1 with other molecules in the system. In what follows, analogous notation is used for other intermolecular interaction energies. *ii* is the index (1, 2, 3, 4...) of the different trial positions of atom F1. To insert atom C2, N_i trial positions of C2 are generated randomly on the sphere of radius F1C2 centred at F1. For each of these trial positions the intermolecular energy of C2 is calculated, and we select one position for C2 with probability:

$$P_i^2 = \frac{\exp(-\beta U_i^2(ii))}{\sum_{ii=1}^{N_i} \exp(-\beta U_i^2(ii))}$$
(S7)

Atom C3 is inserted in two steps. First, N_b ($N_b = 1000$) trial positions of C3 are generated randomly on the sphere of radius C2C3 centred at C2 and a F1C2C3 angle (or the first position of C3) is selected with probability:

$$P_{b}^{3} = \frac{\exp(-\beta U_{b}^{123}(ib))}{\sum_{ib=1}^{N_{b}} \exp(-\beta U_{b}^{123}(ib))}$$
(S8)

where $U_b^{123}(ib)$ is the bending energy of the trial F1C2C3 angle number *ib* in the list. Then, the C2C3 bond is rotated randomly N_i times about the F1C2 bond, and the intermolecular energy of C3, U_i^3 , is calculated for each trial position. A position for C3 is selected with probability:

$$P_i^3 = \frac{\exp(-\beta U_i^3(ii))}{\sum_{ii=1}^{N_i} \exp(-\beta U_i^3(ii))}$$
(S9)

For atom F4, N_b trial positions of F4 are generated randomly on the sphere of radius C2F4 centred at C2 and the bending energy for each trial position is calculated. There is no intermolecular energy selection for this atom, and, therefore, F4 position is selected with probability:

$$P_{b}^{4} = \frac{\exp\left(-\beta\left[U_{b}^{423}(ib) + U_{b}^{421}(ib)\right]\right)}{\sum_{ib=1}^{N_{b}} \exp\left(-\beta\left[U_{b}^{423}(ib) + U_{b}^{421}(ib)\right]\right)}$$
(S10)

For atom F5, the same procedure as for atom F4 is performed. There is also no intermolecular energy selection for this atom. The F5 position is selected with probability:

$$P_{b}^{5} = \frac{\exp\left(-\beta\left[U_{b}^{523}(ib) + U_{b}^{521}(ib) + U_{b}^{524}(ib)\right]\right)}{\sum_{ib=1}^{N_{b}} \exp\left(-\beta\left[U_{b}^{523}(ib) + U_{b}^{521}(ib) + U_{b}^{524}(ib)\right]\right)}$$
(S11)

To insert atom F6, we first select a position for it from N_b trial positions generated randomly on the sphere of radius C3F6 centred at C3 according to the probability:

$$P_{b}^{6} = \frac{\exp(-\beta U_{b}^{632}(ib))}{\sum_{ib=1}^{N_{b}} \exp(-\beta U_{b}^{632}(ib))}$$
(S12)

We then perform a torsional selection coupled with an intermolecular energy selection.³ This coupled biased growth performs a separate torsional bias selection for each intermolecular energy selection. The C3F6 bond is rotated randomly N_t times ($N_t = 100$) about C2C3 bond (C2C3F6 angle is fixed) and the torsional energy as well as the intermolecular energy of F6 is calculated at each trial position. A trial position for atom F6 is selected with probability:

$$P_{i}^{6} = \frac{\exp(-\beta U_{i}^{6}(ii)) \times W_{t}(ii)}{\sum_{ii=1}^{N_{i}} \exp(-\beta U_{i}^{6}(ii)) \times W_{t}(ii)} \times \frac{\exp(-\beta [U_{t}^{1236}(it) + U_{t}^{4236}(it) + U_{t}^{5236}(it)])}{W_{t}(ii)}$$
(S13)

where:

$$W_{t}(ii) = \sum_{it=1}^{N_{t}} \exp\left(-\beta \left[U_{t}^{1236}(it) + U_{t}^{4236}(it) + U_{t}^{5236}(it)\right]\right)$$
(S14)

For atom H7, N_b random positions of H7 are generated on the sphere of radius C3H7 centred at C3, one of which is selected with the probability:

$$P_b^7 = \frac{\exp\left(-\beta \left[U_b^{732}(ib) + U_b^{736}(ib)\right]\right)}{\sum_{ib=1}^{N_b} \exp\left(-\beta \left[U_b^{732}(ib) + U_b^{736}(ib)\right]\right)}$$
(S15)

Finally, atom H8 is inserted in the same way as atom H7. The probability of selecting one trial position for H8 from N_b random positions is:

$$P_{b}^{8} = \frac{\exp\left(-\beta\left[U_{b}^{832}(ib) + U_{b}^{836}(ib) + U_{b}^{837}(ib)\right]\right)}{\sum_{ib=1}^{N_{b}} \exp\left(-\beta\left[U_{b}^{832}(ib) + U_{b}^{836}(ib) + U_{b}^{837}(ib)\right]\right)}$$
(S16)

C. Vapour-Liquid Equilibrium Properties of R134a

<i>T</i> (K)	$\rho_L (\text{kg/m}^3)$	$ ho_V({ m kg/m}^3)$	U_L (kJ/mol)	$U_V(kJ/mol)$	P (bar)	ΔH (kJ/mol)
220	1461.7 (4.27)	5.624 (0.43)	-13.26 (0.21)	8.992 (0.04)	0.946 (0.08)	24.37 (0.12)
240	1403.1 (8.10)	7.841 (0.95)	-11.35 (0.13)	9.978 (0.07)	1.220 (0.14)	23.20 (0.21)
260	1341.3 (10.4)	12.53 (1.05)	-9.061 (0.17)	10.71 (0.09)	2.415 (0.12)	21.77 (0.28)
280	1273.4 (14.7)	22.38 (1.23)	-7.055 (0.27)	11.31 (0.08)	4.521 (0.23)	20.25 (0.33)
300	1189.4 (16.4)	39.76 (2.76)	-4.717 (0.13)	11.76 (0.09)	8.158 (0.51)	18.28 (0.15)
320	1108.4 (18.4)	64.51 (6.12)	-2.057 (0.19)	12.16 (0.11)	13.09 (0.87)	16.29 (0.25)
340	1051.9 (19.8)	143.7 (9.72)	0.240 (0.18)	11.59 (0.20)	24.39 (0.92)	12.74 (0.34)

TABLE S3: Thermodynamic properties of R134a

* *T*: temperature, *P*: saturated pressure, ρ_L : density of liquid, ρ_V : density of vapour, U_L : configurational potential energy of liquid, U_V : configurational potential energy of vapour, ΔH : the latent heat of vaporization, the numbers in parentheses indicate the statistical uncertainties.

D. Orientational Analysis of Pair Interactions in the First Solvation Shell



Figure S2. Distribution of the angle (α_1) between C2C3 vectors (a), the angle (α_2) between dipole vectors (b), the angle (α_3) between C3F6 vectors (c), and the nearest neighbour interaction in π_F space (d) in liquid R134a at 260 K.



Figure S3. Distribution of the angle (β_1) between C2C3 vectors (a), the angle (β_2) between dipole vectors (b), the angle (β_3) between C3F6 vectors, and the nearest neighbour interaction in π_H space in liquid R134a at 260 K.



Figure S4. Distribution of the angle (γ_1) between C2C3 vectors (a), the angle (γ_2) between dipole vectors (b), the angle (γ_3) between C3F6 vectors, and the nearest neighbour interaction in the space above the central molecule in liquid R134a at 260 K.



Figure S5. Distribution of the angle (Ψ_1) between C2C3 vectors (a), the angle (Ψ_2) between dipole vectors (b), the angle (Ψ_3) between C3F6 vectors, and the nearest neighbour interaction in the space below the central molecule in liquid R134a at 260 K.

References:

¹ R. P. S. Peguin, G. Kamath, J. J. Potoff, and S. R. P. da Rocha, *J. Phys. Chem. B*, 2009, **113**, 178.

² K. Esselink, L. D. J. C. Loyens, and B. Smit, *Phys. Rev. Lett. E: Stat. Phys., Plasmas, Fluids*, 1995, **51**, 1560.

³ M. G. Martin and J. I. Siepmann, *J. Phys. Chem. B*, 1999, **103**, 4508.