

# Response to Comment on “Screening New Persistent and Bioaccumulative Organics in China’s Inventory of Industrial Chemicals”: A Call for Further Environmental Research on Organosilicons Produced in China



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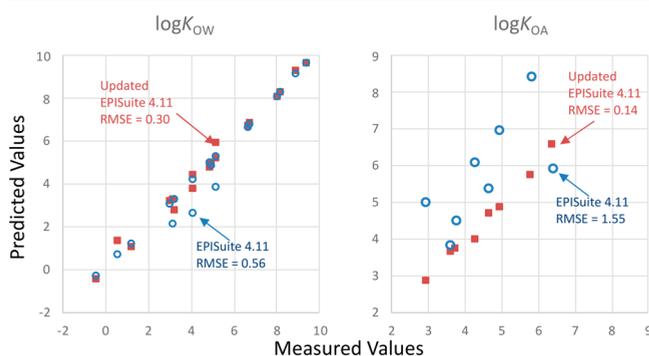
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Guerrero and Thomas<sup>1</sup> from the Global Silicones Council have commented on our study of the Inventory of



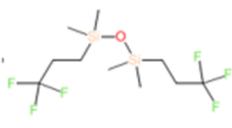
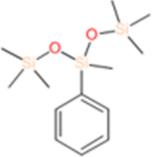
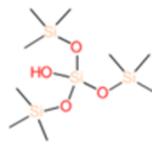
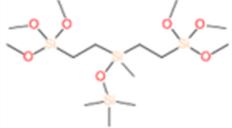
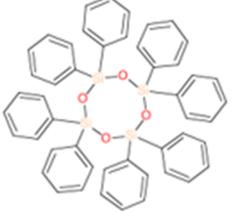
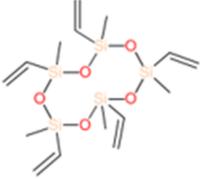
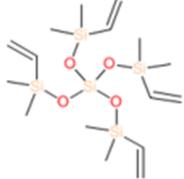
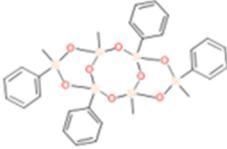
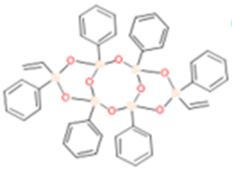
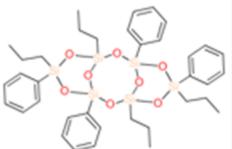
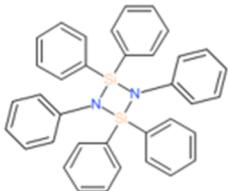
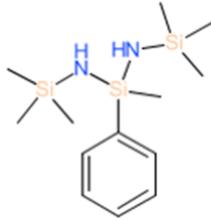
**Figure 1.** Comparisons of measured  $\log K_{OW}$  and  $\log K_{OA}$  values of organosilicons with EPISuite predicted values (v4.11 before and after the update in 2017 that added additional data of organosilicons for the model training).

Existing Chemical Substances of China (IECSC) that highlighted some lesser-known organosilicons via an in-silico screening.<sup>2</sup> They contended that the screening results of organosilicon compounds were highly uncertain because (1) the tools we used to generate physicochemical properties and environmental fate data are not suitable for organosilicon substances; (2) some environmental transformation processes such as hydrolysis were not considered, and (3) the in silico model was overly simplistic. Here we provide our responses to the comments. Based on our screening and additional weight of evidence, we highlight some organosilicons produced in China that deserve further environmental research.

Due to the large number of chemicals currently used in commerce, risk assessors often adopt a tiered approach for evaluating potential hazards. High-throughput screening is first used to identify and prioritize chemicals that require more in-depth investigations and assessments.<sup>3,4</sup> The objective of our study was to perform a first-tier assessment and select chemicals in the IECSC that have environmental fate and partitioning behavior similar to that of persistent organic pollutants (POPs). Due to large data gaps, chemical assessments at this stage, including our study,<sup>2</sup> involve estimated values, simplifications and assumptions based on weight of

evidence and the precautionary principle.<sup>5</sup> For example, octanol is often used as a proxy for organic matter complexation in soil and sediment, and is a well-established model simplification, given the paucity of measurements for many chemicals on water–soil partitioning. When no data are available for processes such as hydrolysis, a precautionary assumption is often that the transformation does not contribute to the loss of chemicals. While it is recognized to take a conservative approach, the value of in-silico screening for identifying POP-like chemicals, including organosilicons, is well-established by previous work using approaches similar to ours.<sup>6,7</sup> It is particularly important to avoid false negatives as false positives can be identified/ruled out by more in-depth analysis.<sup>8</sup> In our paper,<sup>2</sup> we acknowledged the uncertainty inherent in such screening results that originate from the nature of quantitative structure–property relationships (QSPRs) and environmental fate models.<sup>9,10</sup> We excluded chemicals for which the QSPRs are unsuitable (Table S8 of Zhang et al.<sup>2</sup>) and discussed the general uncertainty involved in our screening results.

We agree with Guerrero and Thomas that greater uncertainty may exist in QSPR predicted properties of organosilicons compared to other neutral organics.<sup>11</sup> Available measured physicochemical properties and environmental fate data are limited to a few linear and cyclic volatile methylsiloxanes and therefore the training data set for QSPRs does not comprehensively cover the diverse structures of organosilicons. Nevertheless, the use of EPISuite (v4.11–2012)<sup>12</sup> for organosiloxanes has been justified in a review by Rucker and Kummerer.<sup>13</sup> Specifically, these authors highlight that (1) the training set includes organosilicons and (2) the discrepancies between the predicted physicochemical properties and available measurements are not significantly higher than those between different measurements (1 for log octanol–water partition coefficient ( $K_{OW}$ ) and 1.5 for log air–water partition coefficient ( $K_{AW}$ )). Further, EPISuite

	<b>A</b> CAS RN 690-56-2 Name 1,1,3,3-tetramethyl-1,3-bis(3,3,3-trifluoropropyl)-Disiloxane Structure 	<b>B</b> CAS RN 546-44-1 Name 1,1,1,3,5,5,5-heptamethyl-3-phenyl-trisiloxane Structure 	<b>C</b> CAS RN 17477-97-3 Name tris(trimethylsilyloxy)silanol Structure 	<b>D</b> CAS RN 108427-71-0 Name bis(trimethoxysilyl)ethyl tetramethyl disiloxane Structure 
<b>E</b> CAS RN 546-56-5 Name octaphenyl-cyclotetrasiloxane Structure 	<b>F</b> CAS RN 33204-76-1 Name 2,6-diphenylhexamethyl-cyclotetrasiloxane Structure 	<b>G</b> CAS RN 17704-22-2 Name Pentamethylpentavinyl cyclopentasiloxane Structure 	<b>H</b> CAS RN 60111-54-8 Name tetra(dimethylvinylsiloxy)silane Structure 	<b>I</b> CAS RN 67763-03-5 Name methyl phenyl silsesquioxanes Structure 
<b>J</b> CAS RN 68957-07-3 Name vinyl-terminated phenyl silsesquioxane Structure 	<b>K</b> CAS RN 68037-90-1 Name tetrphenyl-tetrapropyl-silsesquioxane Structure 	<b>L</b> CAS RN 1020-84-4 Name octamethylcyclo tetrasilazane Structure 	<b>M</b> CAS RN 1829-40-9 Name hexaphenyl-cyclodisilazane Structure 	<b>N</b> CAS RN 24385-32-8 Name 1-methyl-1-phenyl-N,N'-bis(trimethylsilyl)-silanediamine Structure 

**Figure 2.** Examples of organosilicons in the Inventory of Existing Chemical Substances of China. The compounds in panels A–D meet the screening criteria. The compounds in panels E–N were selected based on their structural similarity to the legacy methylsiloxanes.

predicted properties used previously in in-silico screening have helped identify new organosilicons, some of which were measured in the environment and are deemed as assessment priority by the scientific community.<sup>6</sup> Therefore, we used EPISuite predicted properties for organosilicons except organohalosilanes that are known to be highly reactive and normally used to produce other organosilicons.

When we further evaluated the EPISuite predictions, we noticed a patch was released to update the EPISuite program with some newly measured data of organosilicon compounds (v4.11–2017). Our previous assessment<sup>2</sup> did not reflect this update, which could affect the screening results for organosilicons. Therefore, we conducted screening for organosilicons in the IECSC using the updated physicochemical properties and compared them with our previous results.

Table S1 lists the updated physicochemical properties and the derived hazard indicators related to the persistence, bioaccumulation and long-range transport potentials of

organosilicons. Comparing the predictions with available measurements in the EPISuite database (Figure 1), we found the previously predicted  $\log K_{OW}$  for some organosilicons were underestimated by 1 and  $\log K_{OA}$  were overestimated by 2. The discrepancies were eliminated with the update so that the root-mean-square-errors for  $\log K_{OW}$  and  $\log K_{OA}$  of the organosilicons were reduced from 0.56 and 1.55 to 0.30 and 0.14. It is noteworthy that some of the measured data were used in the QSPR development so that these root-mean-square-errors do not serve as an external evaluation, which can only be conducted with additional measured data for organosilicons.

Using the updated EPISuite predictions (Table S1), we compared the screening results based on the three screening criteria described in Zhang et al.<sup>2</sup> We found that 1,1,3,3-tetramethyl-1,3-bis(3,3,3-trifluoropropyl)-disiloxane (Chemical Abstract Registry Number (CAS RN): 690–56–2; Figure 2A) as a prioritized compound listed in Table 1 of Zhang et al.<sup>2</sup> still

meets the two screening criteria and deemed as a priority for further investigations and assessments. Of the six organosilicons listed in Table S5 of Zhang et al.,<sup>2</sup> four (CAS RN: 99–58–24, 99–58–35, 62895–99–2, and 172080–99–8) no longer meet the screening criteria based on the updated physicochemical properties. The results for 1,1,5,5-tetramethyl-3-(*n*-propyl)-3-(dimethylsilyloxy)trisiloxane (546–44–1, Figure 2B) and tris(trimethylsilyloxy)silanol (17477–97–3, Figure 2C) remain the same. The updated properties also make eight additional organosilicons, with CAS RNs unique to IECSC, meet at least one of the screening criteria (Table S2). One of these is a disiloxane (CAS RN: 108427–71–0, Figure 2D). The other seven are siloxanol or hydroxy siloxane, which are mono- or dihydroxy analogues of the well-known linear methyl siloxanes.

In addition to the organosilicons prioritized above, we found additional phenyl- (Figure 2E,F and Table S3), vinyl siloxanes (Figure 2G,H and Table S4) and silsesquioxanes (Figure 2I–K and Table S5) in the IECSC that deserve further research to fill the data gaps for environmental risk assessment given the trends of organosilicon production in China and the hazards of the potential transformation products. According to the latest *Catalogue for Guiding Industry Restructuring* issued by the National Development and Reform Commission of China,<sup>14</sup> a restriction has been placed on establishing new facilities that produce methylchlorosilane of <200 kt yr<sup>-1</sup> while production of “new” organosilicons such as phenylchlorosilane, vinylchlorosilane, phenyl silicone rubber, and phenylmethylsilicone resin is encouraged. New foreign and domestic investments have been made to increase the production of the “new” organosilicons in China.<sup>15</sup> From the IECSC, we found a few phenyl- and vinyl- siloxanes, silanes and silsesquioxanes, which have structures similar to those of legacy methyl siloxanes and thus are likely used for the same functions. These compounds have wide applications, including use in personal care products, because the physicochemical properties allow formation of transparent colloids with small droplets.<sup>16,17</sup> Based on the EPISuite predicted properties and model predictions, most of the phenyl- and vinyl- siloxanes do not meet the screening criteria because the phenyl and vinyl groups make the compound less persistent than methylsiloxanes. The C–Si bond has the lowest energy among all bonds in siloxanes.<sup>13</sup> The steric hindrance from phenyl, especially when two are attached to one silicon atom (Figure 2E), makes it a good leaving group and possibly forms benzene under certain conditions. Although the phenylsiloxanes are predicted to be less persistent in the environment, the transformation products could become an environmental and health concern, especially if emissions increase.

Of the organosilicons in the IECSC, there are a few silazanes, organosilicon with the Si–N–Si substructure (Figure 2L–N and Table S6). Some of these silazanes have high production volumes in China<sup>18</sup> and can be used as monomers to produce polysilazanes, which are widely used in silicon rubbers and coating materials.<sup>19</sup> Without measured data, it is difficult to evaluate the performance of EPISuite on this group of organosilicons. Comparing to the siloxane analogues, the Si–N bond should be easier to break than the Si–O bond, and thus make silazanes less persistent and tending to undergo hydrolysis and form silanols in the environment.<sup>20</sup>

In summary, we acknowledge that in-silico screening bears uncertainty especially for organosilicons due to the large data gaps and nature of the QSPR and environmental fate models.

Despite these uncertainties, we assert that in-silico screening is a cost-effective approach for prioritizing the large number of chemicals in commerce. Additional work to reduce uncertainty in model input parameters, simplifications and assumptions at the screening stage would be valuable but does not negate the utility of existing screening models. The organosilicon industry is rapidly expanding in China and new groups of organosilicons other than the legacy ones are being produced and used. Information on the environmental fate and risk beyond the legacy ones is extremely limited. To effectively address the issue, we call for further investigations on the environmental chemistry and ecotoxicology of organosilicons and collaborations of academia, industry and decision maker on data sharing and method development.

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## Notes

The authors declare no competing financial interest.

## REFERENCES

- (1) Guerrero, T.; Thomas, K. Comment on “Screening New Persistent and Bioaccumulative Organics in China’s Inventory of Industrial Chemicals” by Zhang et al. *Environ. Sci. Technol.* DOI: 10.1021/acs.est.1c03087
- (2) Zhang, X.; Sun, X.; Jiang, R.; Zeng, E. Y.; Sunderland, E. M.; Muir, D. C. Screening new persistent and bioaccumulative organics in China’s inventory of industrial chemicals. *Environ. Sci. Technol.* **2020**, *54* (12), 7398–7408.
- (3) Embry, M. R.; Bachman, A. N.; Bell, D. R.; Boobis, A. R.; Cohen, S. M.; Dellarco, M.; Dewhurst, I. C.; Doerrer, N. G.; Hines, R. N.; Moretto, A. Risk assessment in the 21st century: roadmap and matrix. *Crit. Rev. Toxicol.* **2014**, *44* (sup3), 6–16.
- (4) Arnot, J. A.; Mackay, D.; Webster, E.; Southwood, J. M. Screening level risk assessment model for chemical fate and effects in the environment. *Environ. Sci. Technol.* **2006**, *40* (7), 2316–2323.
- (5) Burger, J. Making decisions in the 21st century: Scientific data, weight of evidence, and the precautionary principle. *Pure Appl. Chem.* **2003**, *75* (11–12), 2505–2513.
- (6) McLachlan, M. S.; Kierkegaard, A.; Radke, M.; Sobek, A.; Malmvärn, A.; Alsberg, T.; Arnot, J. A.; Brown, T. N.; Wania, F.; Breivik, K. Using model-based screening to help discover unknown environmental contaminants. *Environ. Sci. Technol.* **2014**, *48* (13), 7264–7271.
- (7) Reppas-Chrysovitsinos, E.; Sobek, A.; MacLeod, M. In silico screening-level prioritization of 8468 chemicals produced in OECD countries to identify potential planetary boundary threats. *Bull. Environ. Contam. Toxicol.* **2018**, *100* (1), 134–146.
- (8) Nendza, M.; Kühne, R.; Lombardo, A.; Stempel, S.; Schüürmann, G. PBT assessment under REACH: Screening for low aquatic bioaccumulation with QSAR classifications based on physicochemical properties to replace BCF in vivo testing on fish. *Sci. Total Environ.* **2018**, 616–617, 97–106.
- (9) Zhang, X.; Brown, T. N.; Wania, F.; Heimstad, E. S.; Goss, K.-U. Assessment of chemical screening outcomes based on different partitioning property estimation methods. *Environ. Int.* **2010**, *36* (6), 514–520.

- (10) Muir, D.; Zhang, X.; Wit, C. d.; Vorkamp, K.; Wilson, S. Identifying further chemicals of emerging Arctic concern based on 'In silico' screening of chemical inventories. *Emerg. Contam.* **2019**, 5201.
- (11) Buser, A. M.; Schenker, S.; Scheringer, M.; Hungerbühler, K. Comparing the performance of computational estimation methods for physicochemical properties of dimethylsiloxanes and selected siloxanols. *J. Chem. Eng. Data* **2013**, 58 (11), 3170–3178.
- (12) U.S. Environmental Protection Agency *Estimation Programs Interface Suite (EPI Suite) v 4.11*, 2012. <https://www.epa.gov/tscascreening-tools/epi-suite-estimation-program-interface> (accessed Jan 2017).
- (13) Rücker, C.; Kümmerer, K. Environmental chemistry of organosiloxanes. *Chem. Rev.* **2015**, 115 (1), 466–524.
- (14) National Development and Reform Commission of China *Catalogue for Guiding Industry Restructuring (2019 Version)*, 2019. [http://www.gov.cn/xinwen/2019-11/06/content\\_5449193.htm](http://www.gov.cn/xinwen/2019-11/06/content_5449193.htm) (accessed July 2021).
- (15) Hu, J.; Zhang, A.-X.; Chen, L.; Li, W.-Q.; Zeng, X.-H. Progress of Silicone Industry in China in 2019. *Silicone Mater.* **2020**, 34 (3), 68–94.
- (16) Fu, J.-l. Trends of silicone multinational corporation and the development opportunities to Chinese silicone industry (in Chinese). *Fine and Specialty Chemicals* **2016**, 24 (10), 8–14.
- (17) Aziz, T.; Fan, H.; Khan, F. U.; Haroon, M.; Cheng, L. Modified silicone oil types, mechanical properties and applications. *Polym. Bull.* **2019**, 76 (4), 2129–2145.
- (18) Government of Jiujiang. Environmental protection acceptance announcement for Jiujiang Zemei Silicon Materials Co., Ltd. to complete the first phase of productions with an annual output of 3,000 tons of silicone oil with high hydrogen contents, 2,600 tons of hexamethyldisilazane, and 2,000 tons of silicone resin. [https://www.jiujiang.gov.cn/xxgk/zdlyxxgk/sdgjz/hjbh/jsxmhjyxpj/201911/t20191113\\_2160665.html](https://www.jiujiang.gov.cn/xxgk/zdlyxxgk/sdgjz/hjbh/jsxmhjyxpj/201911/t20191113_2160665.html) (accessed July 2021).
- (19) Rossi, S.; Deflorian, F.; Fedel, M. Polysilazane-based coatings: corrosion protection and anti-graffiti properties. *Surf. Eng.* **2019**, 35 (4), 343–350.
- (20) Kavala, M.; Hawkins, A.; Szolcsányi, P. Syntheses and properties of cyclosilazanes and cyclocarbosilazanes. *J. Organomet. Chem.* **2013**, 732, 58–91.