Planktonic:

In-water Prevention Strategy
Limited/Emerging Supporting Field Data

Benthic:

Unknown Prevention Strategy
No Available Supporting Field Data

Results from several studies indicated that iron-based nanoparticles have the ability to adsorb cyanobacteria and degrade cyanotoxins through oxidative transformation. The technology is used in remediating and treating water, wastewater, and groundwater (Kharisov et al. 2012). No open-water case studies for HCB management were found. Zero-valent iron (nZVI) and bimetallic nanoparticles, such as iron-nickel (Fe-Ni) and iron-palladium (Fe-Pd), can Several studies were reviewed that focused on iron-based nanoparticles and their ability to adsorb cyanobacteria and degrade cyanotoxins through oxidative transformation. The technology is used in remediating and treating water, wastewater, and groundwater (Kharisov et al. 2012). No open-water case studies for HCB management were found. Zero-valent iron (nZVI) and bimetallic nanoparticles, such as iron-nickel (Fe-Ni) and iron-palladium (Fe-Pd), can degrade microcystin-LR (MC-LR) in drinking water treatment, with Fe-Pd showing the greatest degradation of MC-LR over the broadest pH range (~95% removal, Gao et al. 2016). Other metallic or elemental compounds in some nanoparticles include titanium dioxide (Okupnik, Contardo-Jara, and Pflugmacher 2015), zinc oxide (Mahawar et al. 2018), polypyrroles (Hena et al. 2016), graphene and graphene oxide (Malina et al. 2019), copper-char (Li et al. 2019), silver (Duong et al. 2016), and silica (Xiong et al. 2017).

PLANKTONIC	**BENTHIC**
EFFECTIVENESS • Unknown in any field application	**EFFECTIVENESS** • Unknown in any field application
NATURE OF HCB • Effective at pH 7.0 for microcystin variants -LR, -LA, and -YR and at pH 9.0 for MC-RR, as well as cylindrospermopsin • Use is limited to drinking water • Intervention strategy	**NATURE OF HCB** • Unknown
PLANKTONIC AND BENTHIC	
ADVANTAGES • Quick reaction time • Readily adsorbs and destroys many contaminants, including cyanotoxins • Some by-products promote flocculation • Can use magnetic particles • Possible reuse	
LIMITATIONS • No field applications • nZVI has poor performance but is effective when paired with other metal ions • May bind other compounds before cyanotoxins • Unknown long-term environmental impact • Reused particles only 30%–40% effective after eight uses	

COST ANALYSIS

Cost information is scarce due to the recent development of the technology and the limited commercialization of the products (Adeleye et al. 2016).

Relative cost per growing season: Nanoparticles (iron-based)

ITEM	**RELATIVE COST PER GROWING SEASON**

Material	$–$$
Personal Protective Equipment	Unknown
Equipment	Unknown
Machinery	Unknown
Tools	Unknown
Labor	Unknown
O&M Costs	Unknown
Other Costs	Unknown
OVERALL	**>$$**

REGULATORY AND POLICY CONSIDERATIONS

Long-term toxicity of nanoparticles in the environment is unknown, which may limit the scope of use or release into the environment. These materials are considered emerging contaminants by USEPA (2014). There are federal and local regulations based on intended use and application area.

CASE STUDY EXAMPLES

Laboratory-scale: nZVI and bimetallic nanoparticles (Fe-Ni and Fe-Pd) have been used to degrade MC-LR in drinking water. Fe-Pd showed the greatest degradation of MC-LR (~95% removal) with the broadest pH range. Ni and Pd act as a catalyst for the degradation of MC-LR, whereas nZVI alone tends to readily form iron oxides and hydroxides in water, reducing its surface reactivity with MC-LR (Gao et al. 2016).

The highest adsorption rate for MC-LR, -LA, and -YR was at pH 7.0, whereas the highest rate for MC-RR and cylindrospermopsin was at pH 9.0. Removal from potable water can be done using magnetophoretic nanoparticles of polypyrrole. Adsorption capacity dropped to 30–40% after reusing eight times. Polypyrrole/Fe_3O_4 had a high potential to remove cyanotoxins and could potentially be a cost-effective solution based on its reusability (Hena et al. 2016).

Adeleye et al. (2016) noted that there is still the likely persistence of some nanomaterials in the environment after use. They also suggested that research is needed to focus on predicting nanocomposite toxicity, so each new particle does not have to be tested individually.

REFERENCES

Adeleye, Adeyemi S., Jon R. Conway, Kendra Garner, Yuxiong Huang, Yiming Su, and Arturo A. Keller. 2016. "Engineered nanomaterials for water treatment and remediation: costs, benefits, and applicability." *Chemical Engineering Journal* 286:640-662. doi: https://doi.org/10.1016/j.cej.2015.10.105.

Duong, Thi Thuy, Thanh Son Le, Thi Thu Huong Tran, Trung Kien Nguyen, Cuong Tu Ho, Trong Hien Dao, Thi Phuong Quynh Le, Hoai Chau Nguyen, Dinh Kim Dang, Thi Thu Huong Le, and Phuong Thu Ha. 2016. "Inhibition effect of engineered silver nanoparticles to bloom forming cyanobacteria." *Advances in Natural Sciences: Nanoscience and Nanotechnology* 7 (3):035018. doi: https://doi.org/10.1088/2043-6262/7/3/035018.

Gao, Ying, Feifeng Wang, Yan Wu, Ravendra Naidu, and Zuliang Chen. 2016. "Comparison of degradation mechanisms of microcystin-LR using nanoscale zero-valent iron (nZVI) and bimetallic Fe/Ni and Fe/Pd nanoparticles." *Chemical Engineering Journal* 285:459-466. doi: https://doi.org/10.1016/j.cej.2015.09.078.

Hena, S., R. Rozi, S. Tabassum, and A. Huda. 2016. "Simultaneous removal of potent cyanotoxins from water using magnetophoretic nanoparticle of polypyrrole: adsorption kinetic and isotherm study." *Environmental Science and Pollution Research International* 23 (15):14868-80. doi: https://doi.org/10.1007/s11356-016-6540-5.

Kharisov, Boris I., H. V. Rasika Dias, Oxana V. Kharissova, Victor Manuel Jiménez-Pérez, Betsabee Olvera Pérez, and Blanca Muñoz Flores. 2012. "Iron-containing nanomaterials: synthesis, properties, and environmental applications." *Royal Society of Chemistry (RSC) Advances* 2 (25):9325-9358. doi: https://doi.org/10.1039/C2RA20812A.

Li, Ronghua, Hui Huang, Jim J. Wang, Wen Liang, Pengcheng Gao, Zengqiang Zhang, Ran Xiao, Baoyue Zhou, and Xiaofeng Zhang. 2019. "Conversion of Cu(II)-polluted biomass into an environmentally benign Cu nanoparticles-embedded biochar composite and its potential use on cyanobacteria inhibition." *Journal of Cleaner Production* 216:25-32. doi: https://doi.org/10.1016/j.jclepro.2019.01.186.

Mahawar, Himanshu, Radha Prasanna, Shashi Bala Singh, and Lata Nain. 2018. "Influence of Silver, Zinc Oxide and Copper Oxide Nanoparticles on the Cyanobacterium Calothrix elenkinii." *BioNanoScience* 8 (3):802-810. doi: https://doi.org/10.1007/s12668-018-0543-2.

Malina, Tomáš, Eliška Maršálková, Kateřina Holá, Jiří Tuček, Magdalena Scheibe, Radek Zbořil, and Blahoslav Maršálek. 2019. "Toxicity of graphene oxide against algae and cyanobacteria: Nanoblade-morphology-induced mechanical injury and self-protection mechanism." *Carbon* 155:386-396. doi: https://doi.org/10.1016/j.carbon.2019.08.086.

Okupnik, Annette, Valeska Contardo-Jara, and Stephan Pflugmacher. 2015. "Potential role of engineered nanoparticles as contaminant carriers in aquatic ecosystems: Estimating sorption processes of the cyanobacterial toxin microcystin-LR by TiO2 nanoparticles." *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 481:460-467. doi: https://doi.org/10.1016/j.colsurfa.2015.06.013.

USEPA. 2014. "Technical Fact Sheet – Nanomaterials *EPA 505-F-14-002* ". Washington, D.C.: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. https://19january2017snapshot.epa.gov/sites/production/files/2014-03/documents/ffrrofactsheet_emergingcontaminant_nanomaterials_jan2014_final.pdf.

Xiong, W., Y. Tang, C. Shao, Y. Zhao, B. Jin, T. Huang, Y. Miao, L. Shu, W. Ma, X. Xu, and R. Tang. 2017. "Prevention of cyanobacterial blooms using nanosilica: a biomineralization-inspired strategy." *Environmental Science and Technology* 51 (21):12717-12726. doi: https://doi.org/10.1021/acs.est.7b02985.