# Detonation Nanodiamond Suspensions

Colloidal suspensions of detonation nanodiamond (DND) in both water and a variety of organic solvents have a wide range of uses, including: (1) drug delivery (2) nanocomposite strengthening (3) electroplating, (4) polishing, and (5) oil and fuel additives. Adámas offers a selection of nanodiamond particle suspensions ranging in size from the fully deagglomerated 4-5 nm primary particles up to 200 nm aggregates for the above applications and many others.

**Content At a Glance:**
This document provides general characteristics of the featured product series to provide you with the necessary information to make a more informed purchase.

- Characterization of the various available DND suspensions
- Characteristics include: DLS size, HRTEM, FTIR, and Raman spectroscopy.
- A list of suggested applications for specified products (see pg. 5)

## ULTRASMALL : 4-5 nm Primary Particles

The ultrasmall series consists of fully deagglomerated primary particles of DNDs. Adámas offers two primary lines of 5 nm primary particles : (1) a standard non-luminescent line, and (2) a fluorescent line which is about 10-20x brighter than typical DNDs. Both of these product lines are sold as colloidal suspensions in water, though suspensions are also available in the following solvents: Polyalplaolefin (PAO) synthetic oil, Kerosene, Ethylene Glycol (EG), N-methyl pyrrolidone (NMP), Glycerol (Gly).

Primary particles of detonation nanodiamond offer a robust platform for the delivery of molecules or drugs, with an extremely high surface area to volume ratio (~350 $m^2/g$) and spherical shape (Fig. 1). Raman spectroscopy verifies the presence of the diamond phase (Fig. 2).

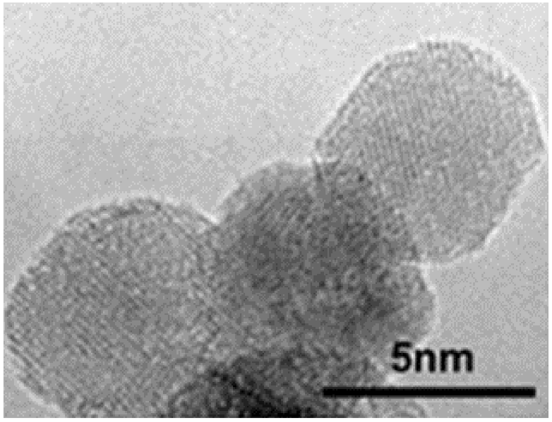


***Figure 1**: High Resolution TEM (HRTEM) image of primary particles of detonation nanodiamond (DND).*

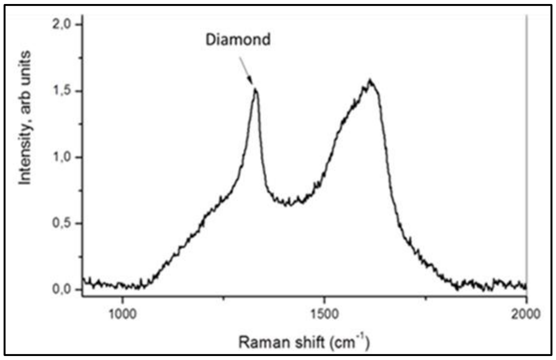


***Figure 2**: Raman specta of 5 nm DND showing characteristic DND Raman peak at 1327 cm$^{-1}$. Courtesy, I. Vlasov.*

The particles also exhibit a rich surface chemistry, which can be easily modified and functionalized using standard reaction procedures. For most bio-applications, the presence of surface terminal carboxylic acid groups (-COOH) can be modified using standard carbodiimide chemistry (e.g. EDC/NHS) for the attachment of primary amine derivatives or proteins. Functional species can be covalently linked, or, in the case where molecule delivery is required, physically adsorbed to the particle surfaces. A typical FTIR spectra for DND is shown in Fig. 3, with carbonyl peak at ~1770 cm$^{-1}$.

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## *ULTRASMALL Standard Series*

The standard 5 nm series consists of two functionalities of particles : carboxylated (-COOH) and hydroxylated (-OH). The carboxylated variant has a negative zeta potential (around -35mV) at pH ~7, wherease the hydroxylated variant has a positive zeta potential (+35mV) at pH ~7. DLS size distributions for these two materials are shown in Fig. 4. Both the hydroxylated and carboxylated versions are sold in water suspensions at 10 mg/mL.

## *ULTRASMALL Fluorescent Series*

The fluorescent 5 nm series only consists of a carboxylated variant with negative zeta potential. The origin of the fluorescence is carbon dot structures on the surfaces of the particles. These fluorescent structures arise from specific processing conditions during the oxidation of the detonation soot following synthesis. These fluorescent particles are not as bright as typical fluorescent dyes, but they offer a unique sub-10nm probe for intracellular tracking and analysis. Although organic dyes can be covalently attached to the surface, they take up valuable surface area in drug delivery applications. Thus, these intrinsically fluorescent particles provide maximum surface area availability for payloads, and an intrinsic means to track the particles. Optimal excitation is around 400 nm, though the use of a laser can provide sufficient luminescence at higher excitation wavelengths. The emission spectra under blue excitation (~ 470 nm) is shown in Fig.6 . Peak emission is about 520 nm. In vitro imaging in MDA MB-231 breast cancer cells with 488 nm laser excitation is shown in Fig. 5.

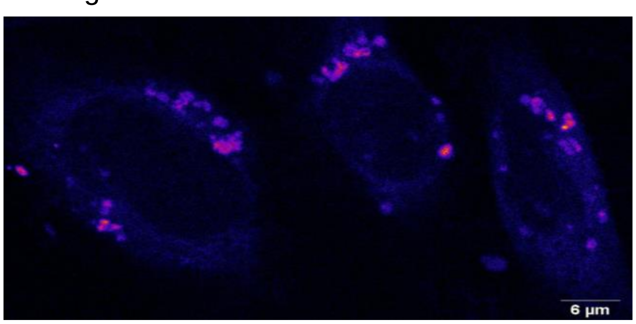


***Figure 5****: 5 nm Fluorescent particles internalized in MDA-MB-231 breast cancer cells. 488nm laser excitation (500-550 emission window). N. Prabhakar, Åbo Akedemi, Finland.*

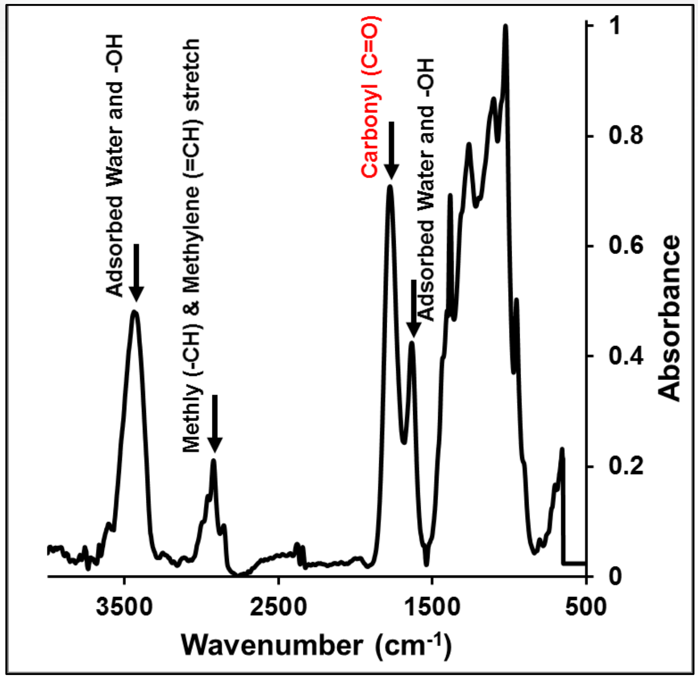


***Figure 3****: FTIR of carboxylated 5 nm material.*

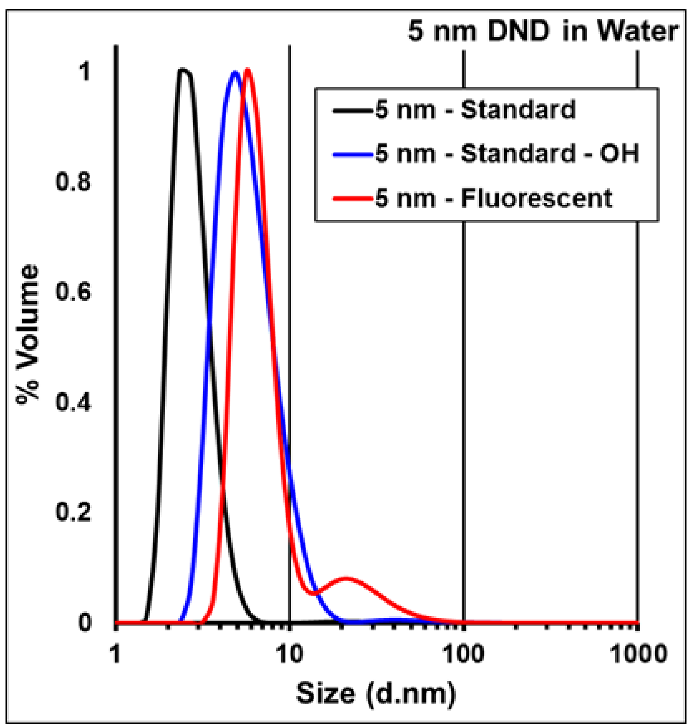


***Figure 4****: Volumetric DLS size distributions of standard and fluorescent series in deionized water.*

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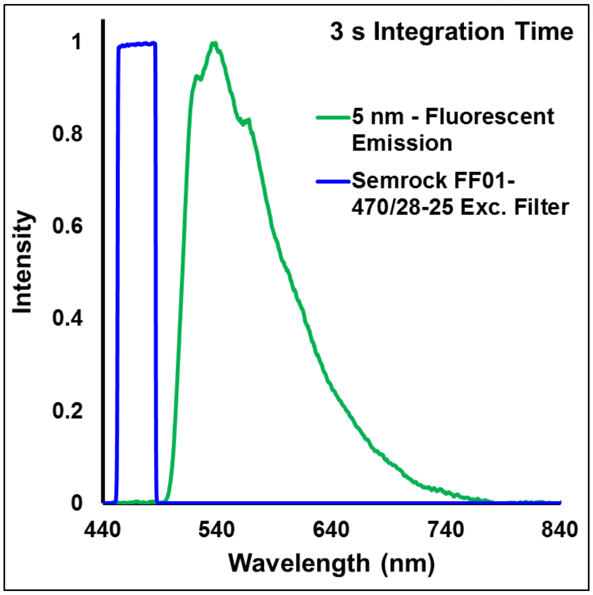


***Figure 6***: *Emission spectra of carbon dot decorated 5 nm fluorescent DND solution under ~470 nm excitation (Semrock) at 1% w/v (10 g/L) concentration.*

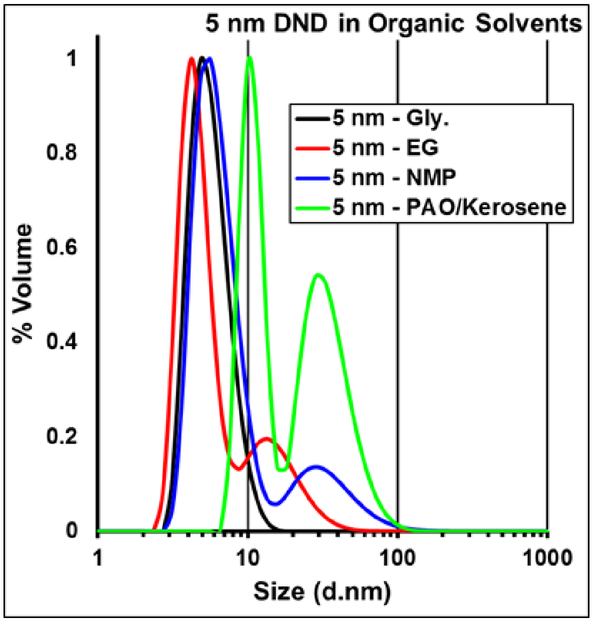


***Figure 7***: *Volumetric DLS spectra of 5 nm particles in a variety of organic solvents.*

## *5 nm Particles in Organic Solvents*

Owing to their small size and rich surface chemistry, 5 nm nanodiamond particles can be stabilized in a large number of different solvent systems. This versatility allows for rapid implementation into your specific application area where solvents other than water are desired. Stable suspensions in base oils and fuels such as polyalphaolefin (PAO) and kerosene can be used in machinery and automobile engines for enhanced fuel efficiency, whereas suspensions in glycerol can be used in biological and pharmaceutical applications. Few (if any) nanoparticle systems can offer this degree of versatility. ***NOTE: the PAO and Kerosene suspensions are mixed with proprietary dispersants which causes the particle size to increase. However, 5 nm particles are used as a precursor for these products.***

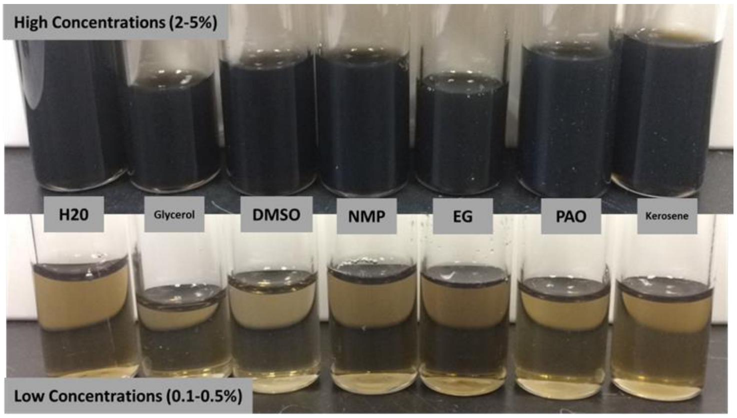


***Figure 8***: *Dispersions of 5 nm particles of DND in a variety of organic solvents at high concentrations (2-5% w/v) and low concentrations (0.1-0.5% w/v). High colloidal stability in a variety of solvents provides functionality in a large number of applications.*

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## INTERMEDIATE : 10-80 nm Aggregates

Sizes above the primary particles of detonation nanodiamond do not exist as monolithic diamond particles. This is an important distinction from other nanoparticle systems and even other types of diamond (such as HPHT particles). DND at these sizes exist as tight, semi-porous clusters of 5 nm primary particles. Adámas offers 10, 15, and 50 nm aggregates of carboxylated (negatively charged) DND as well as an 80 nm positively charged product. DLS size distributions for these products are shown in Fig. 9. All of these products are sold as suspensions in water. Additional sizes can be obtained upon request, contact us at info@adamasnano.com for information.

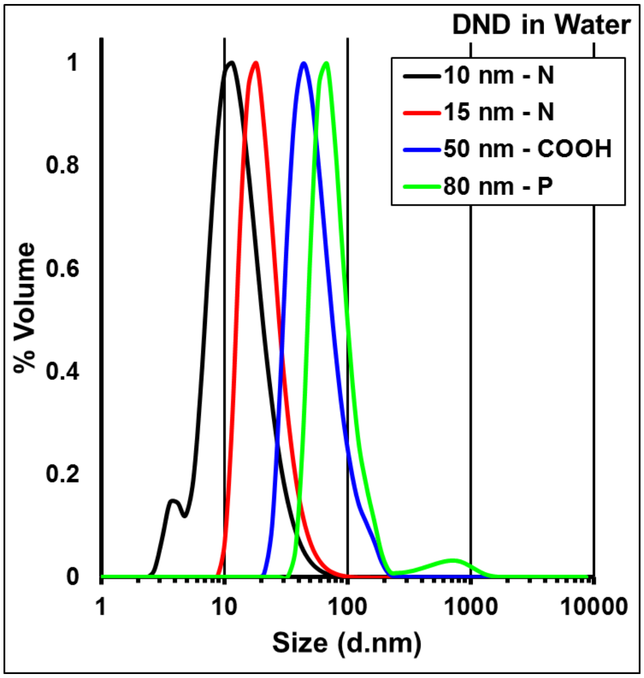
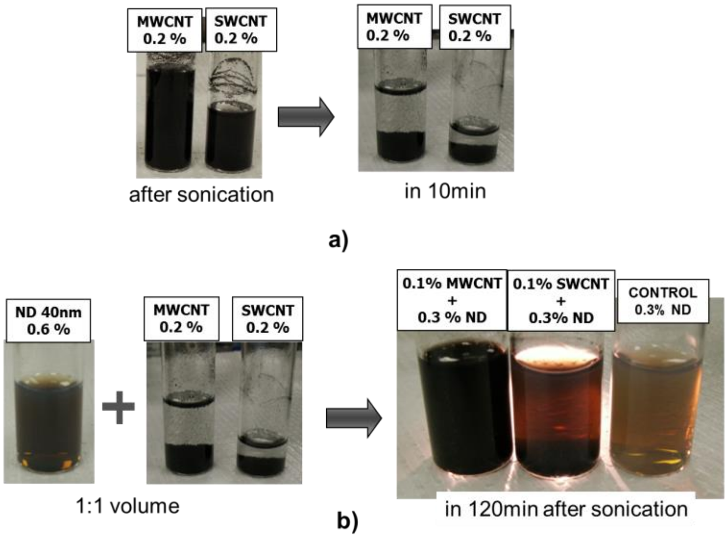



***Figure 9 (right)****: Volumetric DLS size distributions of intermediate size range of DND aggregate suspensions in water.*

ND smaller fractions are excellent surfactants for other nanocarbon materials, such as carbon nanotubes and graphene (U.S. patents 8,070,988 & 8,308,994). Most $sp^2$ carbon nanostructures including carbon nanotubes are hydrophobic and unstable in polar solvents without special surface functionalization (Fig. 10a). However, multi-wall carbon nanotubes (MWCNTs) and single-wall carbon nanotubes (SWCNTs) can form stable colloidal suspensions in the presence of nanodiamonds (Fig. 10b). By adding suspensions of small size ND particles with either positive or negative zeta potential to otherwise unstable aqueous suspensions of CNTs and sonicating the nanocarbon mixture for a few minutes, suspensions of SWCNTs and MWCNTs have been produced maintaining colloidal stability for several weeks and for months, correspondingly. ND/CNT mixtures are also stable in methanol, isopropanol, DMSO, and DMF.

### Nanodiamond as surfactant for Carbon Nanotubes




Hens et al., *Nanoscience and Nanotechnology Letters*, 3 (2011)

***Figure 10****: Photographs showing the colloidal stability of suspensions for SWCNT and MWCNT in water without (a) and with DNDs (b).*

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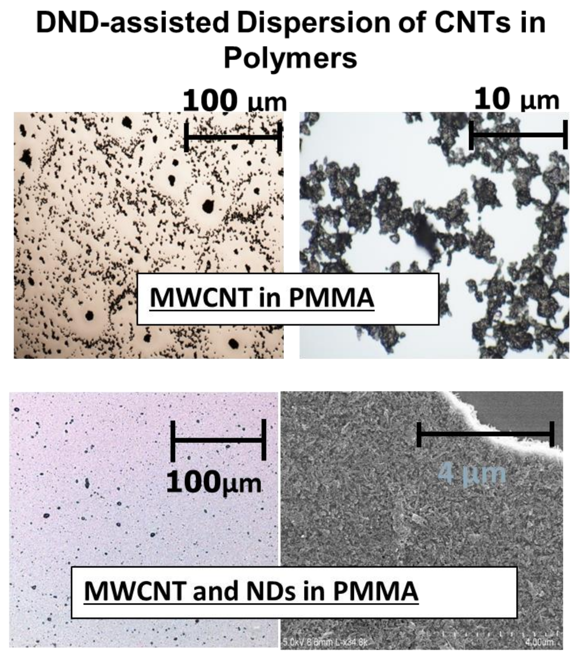
## INTERMEDIATE : 10-80 nm Aggregates

Mechanism for ND-assisted dispersion of CNTs and graphene includes formation of pi–pi bonding between sp2 patches on DND and $sp^2$ carbon atoms on CNT and graphene surfaces, decorating the surfaces. Since ND particles are highly charged in polar solvents, the $sp^2$ nanocarbons interdigitated with charged ND particles also acquire high repulsive forces and resist agglomeration. During sonication NDs also cause debundling of CNTs or graphene constituents. Charged nanodiamond particles can be used to effectively and uniformly disperse the carbon nanotubes or graphene in a polymer matrix, leading to a very homogenous film (Fig.11).




Gokhale et al., *Journal of Microelectromechanical Systems* (2014)

***Figure 11 (right)**: Excellent uniformity of CNT distribution within a polymer film can be obtained with assistance of NDs.*

## D-Polish

D-Polish is a water solution of larger DND aggregates that is suitable for the polishing of semi-precious gemstones. Diamond has long been recognized as a superior polishing agent due to is high hardness. D-Polish can achieve significantly higher quality surface finishes compared to other polishing media currently on the market. The predominantly nanoscale material (mostly <200 nm) ensures that fine surface scratches typically observed with other polishing media will not be present. Fig. 12 shows the particle size distribution for D-Polish.

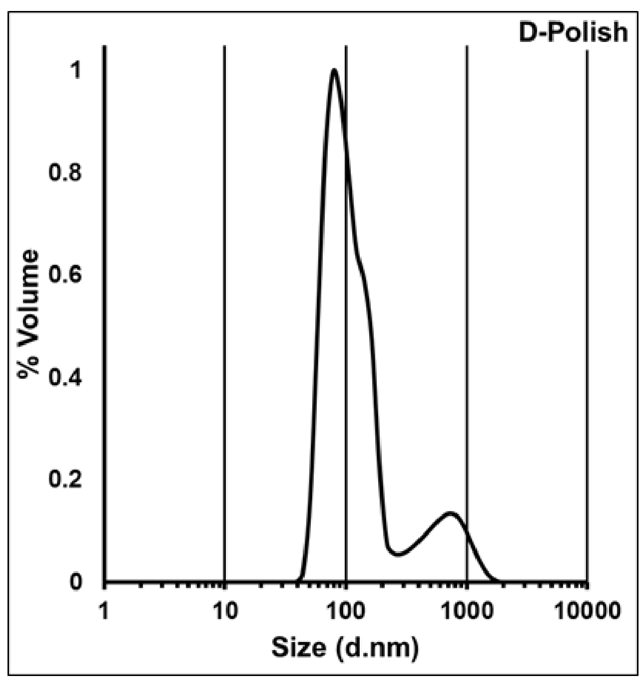



***Figure 12**: Volumetric DLS size distributions of D-Polish suspension diluted in deionized water.*



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| Category | Product | Suggested Application | Sold As* | Cat. No. | Price |
|---|---|---|---|---|---|
| Ultrasmall Size Range (5 nm Primary Particles) | 5 nm Standard | Drug Delivery, Bioconjugation | 10 mg/mL in DI water | ND5nmNH2O100ml<br>ND5nmNH2O500ml<br>ND5nmNH2O1000ml | $98<br>$400<br>$750 |
| | 5 nm Standard -OH | Drug Delivery, Bioconjugation | 10 mg/mL in DI water | ND5nmOHH2O50mL | (?) |
| | 5 nm - Fluorescent | Drug Delivery, Bioconjugation, Intracellular tracking | 10 mg/mL in DI water | ND5nmFlH2O100ml<br>ND5nmFlH2O500ml<br>ND5nmFlH2O1000ml | $110<br>$440<br>$825 |
| | 5 nm – EG | Polymers, Composites | 10 mg/mL in Ethylene Glycol | ND5nmEG100ml | $250 |
| | 5 nm - NMP | Polymers, Composites | 10 mg/mL in N-Methylpyrrolidone | ND5nmNMP100ml | $300 |
| | 5 nm – GLY | Drug delivery, Bioconjugation | 10 mg/mL in Glycerol | ND5nmGly100ml | $250 |
| | 5 nm – PAO* | Fuel/Oil Additive, Lubricants | 10 mg/mL in Polyalphaolefin base oil | ND5nmPAO100ml | $250 |
| | 5 nm – KER* | Fuel-Oil Additive, Lubricants | 10 mg/mL in Kerosene | ND5nmKerosene100ml | $250 |
| Intermediate Size Range (10-80 nm Aggregates) | 10 nm - N | Drug Delivery, Bioconjugation | 10 mg/mL in DI water | ND10nmNH2O100ml<br>ND10nmNH2O1000ml | $90<br>$600 |
| | 15 nm - N | Drug Delivery, Bioconjugation | 10 mg/mL in DI water | ND15nmNH2O100ml<br>ND15nmNH2O1000ml<br>ND15nmNH2O5000ml | $150<br>$1000<br>$3750 |
| | 80 nm - P | Drug Delivery, Bioconjugation, Electroplating (?) | 100 mg/mL in DI water | ND80nmPH2O100ml<br>ND80nmPH2O500ml | $170<br>$750 |
| D-Polish | 150um-Hi | Semi-precious gemstone polishing | 100 mg/mL in DI water | DPolish500ml | $120 |

*Contains proprietary dispersants to assist in colloidal stability