Green Chemistry and Energy

Novel mesoporous silica for catalytic applications
The Institute of Bioengineering and Nanotechnology (IBN) is the world’s first bioengineering and nanotechnology research institute. Since 2003, IBN has been conducting interdisciplinary research bridging science, engineering and medicine. The Institute’s strengths lie in its synthetic capability for chemicals, materials and biologics. IBN has developed unique technology platforms that combine novel catalytic chemistry, biomaterials, nanofabricated devices and microfluidic systems with biological engineering. Its highly collaborative environment also promotes the sharing of ideas, expertise and infrastructural support, and a culture that encourages innovative research and the nurturing of young talents.

IBN’s research activities are focused in the following areas:

**Nanomedicine**, where functionalized polymers, hydrogels and biologics are developed as therapeutics and carriers for the controlled release and targeted delivery of therapeutics to diseased cells and organs.

**Cell and Tissue Engineering**, where biomimicking materials, stem cell technology, microfluidic systems and bioimaging tools are combined to develop novel approaches to regenerative medicine and artificial organs.

**Biodevices and Diagnostics**, which involve nanotechnology and microfabricated platforms for high-throughput biomarker and drug screening, automated biologics synthesis, and rapid disease diagnosis.

**Green Chemistry and Energy**, which encompass the green synthesis of chemicals and pharmaceuticals, catalytic conversion of biomass, utilization of carbon dioxide, and new nanocomposite materials for energy applications.

IBN has a portfolio of 500 active patents/patent applications on its inventions, and has successfully licensed over 80 patents/patent applications. The Institute welcomes industrial and clinical collaborations to co-develop its technologies.

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Customized N-Heterocyclic Carbene–Palladacycle Precatalysts and Mesocellular Foam Supported Palladium Nanoclusters for Organic Transformations

NHCs have recently attracted considerable attention as ligands in transition metal mediated organic transformations, due to their numerous advantages compared to phosphine ligands in terms of safety, stability and activity. On the other hand, palladacycles are characterized by superior thermal stability compared to other palladium precatalysts. Currently, a very limited number of NHC-ligated palladacycles have been prepared, and their preparation routes are unattractive due to the high cost associated with palladacycle precursors and the use of highly sensitive isolated carbenes. In addition, no general synthetic approach has been developed to date for this class of Pd complexes, which accommodates a wide range of carbenes and a wide range of ligands, capable of palladacycle formation. At IBN, we have developed a one-step preparation of NHC-palladacycles without immediate isolation. In addition, we have also developed a siliceous mesocellular foam support system for the deposition of palladium-based catalyst nanoclusters which improves the stability of such catalyst, thereby lowering overall costs.

Advantages:

NHC-Palladacycle Precatalysts
- A three-component reaction sequence with carefully optimized timing for the addition of each component.
- No special equipment or technique is needed.
- NHC palladacycle yields are generally in the range of 80-90%.
- The multicomponent nature of the method opens the possibility that a number of novel precatalysts (including chiral ones) can be prepared in a combinatorial fashion in a single step, so as to facilitate catalyst optimization.

Supported Pd Nanoclusters
- Method of deposition takes 5-10 minutes.
- Pd nanoclusters are more active than commercially available polymer- or carbon-supported catalysts due to non-swelling characteristic, high surface area and ultralarge pore of the MCF support and the stabilization by urea or thiourea ligand.
- It has been demonstrated to have yield in the range of 80-90% for these reactions: Suzuki, Heck, transfer hydrogenation of ketones, hydrogenation of olefins, reductive amination of aldehydes under hydrogen, hydrogenolysis of epoxides and diols.

Application:
- Pd-mediated reactions that are used to synthesize pharmaceutical intermediates, fine chemicals, advanced materials and specialty polymers.
Enzymes are being increasingly exploited as biocatalysts for synthesis of pharmaceuticals and fine chemicals because they provide high enantio- and region-selectivity and are more environmentally friendly. However, the use of enzymes is limited due to their unstable nature and the stringent requirements for their surrounding environment. Enzyme immobilization systems thus offer an attractive alternative to allow for recycling and continuous operation.

Conventional enzyme immobilization employs reversed micelles made from ionic surfactants, but non-ionic surfactants are usually included to minimize the negative effects of the ionic reversed micelles on the enzyme activity. This conventional system has a major drawback in that the high concentration of low-molecular-weight surfactants causes difficulties in product separation and enzyme recovery. This invention overcomes this drawback by using thermosensitive and reversed micelles assembled from an amphiphilic copolymer, which allows for a temperature-controlled release of the immobilized enzymes. This amphiphilic copolymer displays a lower critical solution temperature (LCST). Increasing the temperature of the surrounding environment of the micelles slightly above the LCST causes the deformation of the reversed micelles, releasing the enclosed enzymes and stopping the enzymatic reaction.

**Advantages:**
- Compared to conventional ionic and non-ionic surfactant micelles, the micelles developed in this invention provide greater stability.
- The immobilized enzymes can be recovered by simply increasing the environmental temperature to a value slightly higher than the reaction temperature.

**Application:**
- Immobilizing enzymes for the synthesis of chiral pharmaceuticals.
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Catalytic and Biological Applications of Magnetic Nanoparticles

Silica-coated magnetic nanoparticles have been developed by IBN. The silica surfaces of these nanoparticles may be modified with various functional silanes. These modified particles can be used for immobilizing various metal nanoparticles, as well as homogeneous catalysts, in order to catalyze organic reactions. The magnetic nanocatalysts can then be easily separated using magnetic force and recycled. The silica surfaces may also be modified for biological applications. The magnetic property of these particles will be very useful as contrast agents for MRI and as drug carriers.

Advantages:
- The invention provides for the easy modification of silica-coated magnetic nanoparticles through well-defined silica modification methods.
- It allows the easy recycling of magnetic nanocatalysts without the need for filtering or centrifuging.

Application:
- This technology can be used in catalytic reactions and biological applications of magnetic nanoparticles.

Magnetic quantum dots consisting of CdSe and Fe(O) under UV excitation and magnetic harvesting, showing both fluorescence and magnetic properties.
Immobilization of Homogeneous Catalysts and Biocatalysts on Nanoporous Materials and Circulating Flow-Type Reactor

IBN researchers have developed novel heterogenized catalysts by immobilizing various homogeneous catalysts on siliceous mesocellular foams. A novel pre-capping method was developed to minimize the interactions between the immobilized catalytic species and the silica surface, which facilitates uniform distribution of the immobilized complexes, as well as provides easy control of the catalyst loading. This technology has been successfully applied to the immobilization of chiral bisoxazoline catalysts and ring-closing metathesis catalysts. The immobilized bisoxazoline:Cu(I) catalysts are comparable to their homogeneous counterparts in terms of high enantioselectivity. They further provide excellent recyclability for asymmetric cyclopropanation reactions. The immobilized ring-closing metathesis catalysts show excellent activity and recyclability in the synthesis of various cyclic compounds. Using click chemistry, novel silane moieties have been successfully employed as the linker groups to immobilize various types of complexes, including organometallic and organo catalysts. In addition, enzyme catalysts have been immobilized on nanoporous materials. The fixated biocatalysts are more thermally stable and easily recovered for reuse. The various heterogenized catalysts can be employed in continuous flow reactors to enhance the productivity and simplify the industrial processes.

Advantages:
- The heterogenized catalysts offer comparable enantioselectivity as their homogeneous counterparts.
- They also feature excellent recyclability and a high loading of homogeneous catalysts.
- They reduce the contamination of products by toxic transition metals.
- The circulating flow-type reactor provides for high on-stream time and less catalyst attrition by a continual removal of side products and gases that disturb catalytic beds.
- Biocatalysts can be loaded in a high quantities in short period of time.
- The immobilized enzymes are more thermally stable and hardly leached from the nanoporous support.
- The heterogenized biocatalysts can be directly employed in continuous flow reactors.

Applications:
- The immobilized catalysts can be used for large-scale production, both in a batch and a continuous flow reactor.
- The spherical nanoporous materials can be used in HPLC columns.
N-Heterocyclic Carbene Catalyzed Ketone and Imine Hydrosilylation and a Novel Chiral Induction Protocol

Ketone and imine reduction by hydrogenation, hydroboration and hydrosilylation is one of the most ubiquitous protocols in organic synthesis. Hydrosilylation is a particularly attractive process due to the mild reaction condition and inexpensive silane reducing agent. Although hydrogenation is widely practised industrially, it faces shortcomings such as metal leaching, high pressure, expensive catalysts and costly catalyst recycling. Stoichiometric borane reduction or dihydropyridine reduction catalyzed by organocatalysts are plagued by high costs. A number of transition metals complexes, such as Rh, Ti, Ru, Ir, Zn, Pt, Cu and Sn, have displayed high catalytic activity or selectivity in the hydrosilylation of carbonyl compounds, but shared the problem of metal leaching and costly catalyst regeneration as hydrogenation. Researchers at IBN have developed novel hydrosilylation protocols with organocatalysts that are more easily prepared and less expensive, as well as effective silane reducing agents. These organocatalysts are poly-N-heterocyclic carbene (poly-NHC) organocatalysts that enable smooth and clean ketone and imine hydrosilylation.

Advantages:
- Catalyst is recyclable and environmentally friendly.
- Catalyst is metal-free, thus overcoming the problem of metal leaching.
- Protocol requires only 1 equivalent of silane, thereby lowering the overall cost.
- Asymmetric ketone hydrosilylation is achieved with inexpensive and easily accessible secondary alcohol as the chiral source.

Application:
- Metal-free heterogeneous and homogeneous catalysts.
Main Chain Poly-N-Heterocyclic Carbene Catalyst System

Heterogeneous catalysis has many advantages over homogeneous catalysis, but there are certain limitations in the current protocols for producing heterogeneous catalysts via the immobilization of homogeneous catalysts onto inorganic or organic solid supports. Main chain poly-N-heterocyclic carbene (NHC) based heterogeneous catalysts have been developed by IBN, which spontaneously form micro- and nano-sized spherical particles. The poly-NHC colloidal based catalysts show excellent performance both as nucleophilic organo catalysts and organometallic catalysts in many important transformations. This innovation is a major breakthrough in both NHC carbene chemistry and heterogeneous catalysts.

Advantages:
- The properties of these colloids can be easily tailored to form ionic solid particles or free poly-NHC carbene and poly-NHC-metal organometallic particles.
- The catalysts perform well as nucleophilic organo catalysts and organometallic catalysts in many important transformations.

Applications:
- Main chain poly-NHC as metal-free organocatalyst for ketone and imine hydrosilylation.
- Main chain poly-NHC-Pd for heterogeneous Suzuki coupling reaction.
- Copper or poly-NHC-Cu for synthesis propiolic acids from alkynes and CO$_2$. 
Porous Polymer Materials as Heterogeneous Catalysts and Absorbents

Two novel mesoporous/microporous polymer materials have been developed at IBN. Mesoporous polystyrene particles (MPPs) have been developed using siliceous mesoporous cellular foam as a hard template, whereby both the porosity and the surface properties can be tailored for a specific catalyst support. A simple protocol for the catalytic synthesis of microporous and mesoporous polyisocyanurates (PICUs) has also been developed. PICUs possess robust microporosity and mesoporosity constructed from porous organic sheets. They have been demonstrated as catalyst supports for Pd(II), Fe(III) complexes, as well as for Pd or Pt metal nanoparticles. Both MPP and PICU materials are of interest for heterogeneous catalysis, absorbent, gas storage and energy applications. In particular, they may be of interest for hydrogen storage, and as catalyst supports for organometallic complexes, and metal or oxide nanoparticles.

Advantages:
- The MPPs and PICUs can be tailored with a wide range of porosities and surface areas.
- Easy synthesis, stable and permanent porous structure.
- These novel poly-imidazolium, poly-NHC and poly-NHC-metal catalysts can be synthesized and modified easily.
- They have very high concentration of active sites, high activity, stability and reusability.
- The surface of the MPPs can be easily modified, for example, for the immobilization of pyrrolidine.

Applications:
- These methods developed by IBN can be used to design novel heterogeneous catalysts and absorbents.
- The poly-imidazolium, poly-NHC and poly-NHC-metal catalysts can be used in many organic transformations, such as C-C coupling reaction (with Pd) and ketone cyanation.
Efficient Catalytic Systems for the Selective Production of Hydroxylmethylfurfural from Glucose and Fructose

A practical catalytic process that can transform abundant biomass into versatile chemicals would provide the chemical industry with renewable feedstocks. Recently, a lot of efforts have been devoted towards converting biomass to 5-hydroxymethylfurfural (HMF), a versatile and key intermediate in biofuel chemistry and the petroleum industry. A new Cr-N-heterocyclic carbene (NHC)/ionic liquid system has been developed by IBN for selective production of HMF from glucose and fructose. This novel catalyst achieved high efficiency from both fructose and glucose feedstocks. It provided high selectivity towards HMF and tolerance towards high substrate loading. It also enabled easy recycling of catalyst and ionic liquid. In addition, IBN scientists developed a novel tetrahydrofuran (THF)-butyl-methyl imidazolium chloride (BMIMCl) biphasic system with simple acid catalysts for fructose conversion to HMF under mild reaction conditions. This enables HMF to be efficiently synthesized at room temperature in the ionic liquid system. The biphasic system was successfully applied to a continuous batch reaction process, and may be suitable for large-scale synthesis of HMF from fructose. In view of the need for an environmentally friendly, cost-effective and efficient production method for 5-hydroxymethylfurfural, an iso-propanol mediated reaction system for the production of 5-hydroxymethylfurfural from sugars was also developed.

Advantages:
- Highly efficient, recyclable system.
- Mild reaction conditions, easy to scale up for large-scale operation.

Application:
- The methods developed by IBN can be applied towards biomass transformation.
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Highly Effective and Efficient Carbon Dioxide Conversion to Carboxylic Acid

The ubiquity of alkynyl carboxylic acids in a vast array of medicinally important compounds as well as their tremendous utility as a synthon in organic synthesis make them particularly attractive targets for pharmaceutical, fine chemical, as well as conductive polymer synthesis. A plethora of well-established methods for the preparation of alkynyl carboxylic acids exists, including CO$_2$ insertion into metal-carbon bond of organometallic reagents, the well-known hydrolysis of bromide and related derivatives, and the oxidation of preoxidized substrates such as alcohols or aldehydes. Despite the efficiency of these conventional procedures, major drawbacks common to all of them are the severe reaction conditions and restrictions associated with organometallic reagent that dramatically limit the synthesis of a wide scope of functionalized propiolic acids. Carbon dioxide is an attractive raw material in terms of its low cost and status as a renewable source. In view of the need for a simple, cost-effective and efficient technology to synthesize propiolic acid, IBN scientists have developed a novel technology to convert carbon dioxide and terminal alkynes into propiolic carboxylic acids.

Advantages:
- Simple, cost-effective, mild reaction conditions.
- Wide scope of substrate tolerance and good yield.
- Different protocols have been developed to target different applications.

Application:
- Carboxylic acid synthesis for the pharmaceutical and fine chemical industries.
Green Chemistry and Energy

Stabilization and Compressive Strain Effect of AuCu Core on Pt Shell for Oxygen Reduction Reaction

A great challenge in fuel cell development involves improving the durability and electrocatalytic activity of Pt-based electrocatalysts, while reducing the Pt loading. We have synthesized core-shell AuCu@Pt nanoparticles, which exhibit superior electrocatalytic activity and excellent stability towards oxygen reduction reaction (ORR). The Au component in the AuCu alloy core is crucial toward stabilizing the Pt shell during ORR. The extraordinary electrocatalytic activity of the AuCu@Pt nanoparticles for ORR is attributed to the compressive strain effect exerted by the AuCu alloy core on the Pt shell, which is induced by the slightly smaller lattice parameter of the AuCu core. In contrast, pure Au core with a larger lattice parameter than Pt would induce a tensile strain effect on the Pt shell, decreasing the electrocatalytic activity of Pt for ORR. Tuning the surface strain in Pt-based nanomaterials can be an effective way to manipulate the specific electrocatalytic activity. Moreover, the replacement of the precious Pt core with less expensive AuCu alloy may significantly reduce Pt loading and the associated catalyst cost, while achieving a superior electrocatalytic activity.

Advantages:
- Our core-shell nanocomposite materials exhibit superior catalytic activity and excellent stability toward oxygen reduction reaction.
- The superior catalytic activity of AuCu@Pt/C meets the 2015 target of 0.44 A/mg Pt set by the U. S. Department of Energy (DoE) at 80°C and 0.9 V.
- Our electrocatalyst design approach can be extended to various systems with an alloy core and a Pt-based shell.
- Besides compositional control, the core size and shell thickness of the nanoparticles can be varied to optimize catalytic activity and stability.

Application:
- This technology can be used in cathode catalysts for oxygen reduction reaction in fuel cell systems.
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Synthesis of Functionalized Acetylene from Calcium Carbide

During 1960s and 1970s, calcium carbide-acetylene served as the primary feedstock for a wide variety of commodity and specialty chemicals. Calcium carbide could be synthesized from both coal and lignocellulosic biomass. Thus, it represents an inexpensive and sustainable resource for the chemical industry. IBN has now developed an efficient catalytic protocol to synthesize various functional acetylene derivatives (such as propargylamines, propargylalcohols benzofuran and enamiones) from calcium carbide. The controllable mono-substitution and bis-substitution processes make this system extremely useful in organic synthesis. The direct usage of calcium carbide also avoids many protection and de-protection steps that greatly reduces the number of synthesis steps in the protocol, and provides a more efficient and greener organic synthesis. The newly developed synthesis schemes demonstrate that calcium carbide could play a major role as a sustainable and cost-efficient carbon source in organic synthesis. It would promote the usage of calcium carbide as a platform chemical against the consumption of petroleum.

Advantages:
- Sustainable calcium carbide resource.
- Highly functionalized products.
- Simple process.

Applications:
- Fine chemical synthesis.
- Pharmaceutical synthesis.
High-Yield Synthesis of Proparglyamines

In response to market needs, IBN scientists have developed a technique for more efficient, cost-effective synthesis of proparglyamines that is also tolerant to a wide range of substrates. This involves high-yield catalytic synthesis of proparglyamines in mild conditions from both aromatic and aliphatic alkynes, dihalidemethanes and amines with simple and efficient CuCl catalyst. Compared to other systems, this new approach is attractive for its mild reaction conditions, ease of operation, low cost and tolerance to a wide range of substrates. The new reaction can be conducted in water, organic solvents or neat under mild condition to produce excellent yields.

Advantages:
- Simple operation, mild reaction conditions.
- Low cost, broad substrate scope.

Applications:
- Synthesis of bioactive compounds.
- Pharmaceutical industry.
- Fine chemical synthesis.
Poly-Melamine-Formaldehyde with High Surface Area and Porosity for Carbon Dioxide Capture and Heavy Metal Removal from Water

In view of the need for an inexpensive and effective carbon dioxide capture material to reduce greenhouse gas emissions, IBN scientists have developed an easily produced material that can effectively and efficiently capture and store carbon dioxide. This material has a high surface area (up to 1100 m²/g) and a high density of amine functional groups that enable instantaneous adsorption and completely reversible desorption. Compared to current technology, this poly-melamine-formaldehyde (PMF) material can adsorb over 99% of the carbon dioxide in a mixture of gases (15% carbon dioxide and 85% nitrogen) within 30 minutes.

Heavy metal contamination poses serious hazards to public health and ecosystems, and chronic exposure to contaminated air and water is harmful even in very low concentrations. Researchers have made significant efforts to develop new technologies for water treatment. However, inexpensive, efficient, safe and fast removal of toxic metals from water remains a big challenge. IBN’s new PMF material is an efficient and effective metal-removing material. It is able to rapidly reduce heavy metals in water to less than 0.01 ppb level.

Advantages:
- Inexpensive, easy to synthesize.
- Highly efficient in removing CO₂ and heavy metals.
- Completely reusable.

Applications:
- Combustion process in power plants.
- Chemical processes that generate carbon dioxide as byproducts.
- Manufacturing process that requires carbon dioxide as a raw material source.
- Drinking water purification.
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Cost-Efficient and Green Production of Xylitol from Hemicellulose

Xylitol is a widely used sweetener in the food, health and pharmaceutical industries. Current industrial methods to produce xylitol involve multiple steps of hydrolysis and tedious purification. The entire process is time-consuming and energy-intensive. In response to the need for a more cost-effective and green method to produce xylitol, IBN researchers have developed a new efficient and green method of producing xylitol from hemicellulose. IBN’s new technique is capable of producing a high yield of xylitol (> 80%), yet it requires a shorter time and less energy. In addition, IBN’s method does not require high-pressure hydrogen gas as a reactant.

Advantages:
- One pot process, mild conditions.
- High yield, low energy consumption.

Applications:
- Biomass conversion.
- Xylitol production.
- Food industry.
- Pharmaceutical industry.

Technology converts biomass to xylitol in one pot.
In response to the growing health threat posed by resistant pathogenic microorganisms, IBN has developed an antimicrobial polyimidazolium polymeric salt with excellent anti-microbial properties. IBN's technology involves main-chain imidazolium polymers or oligomers that can combat a broad spectrum of pathogenic strains, including drug-resistant *Klebsiella pneumoniae*, *Vancomycin-resistant enterococcus*, Methicillin-resistant *Staphylococcus aureus* and fluconazole-resistant yeast *Cryptococcus neoformans*, while displaying minimal hemolysis (HC50/MIC values > 3000). The new materials have demonstrated a very high therapeutic index of 37 for killing *Staphylococcus aureus* under inflammatory conditions *in vivo*. These anti-microbial salts are easily synthesized from inexpensive materials, and possess an amphiphilic structure that is highly effective against yeast-like fungi *C. albicans* and filamentous fungi *Aspergillus niger*. They can efficiently clear *C. albicans* biofilm, and promise an effective therapy for keratitis.

### Advantages:
- Excellent anti-microbial property.
- High selectivity and flexibility in adapting to formulation needs.

### Applications:
- Anti-microbial medication.
- Personal care formulation such as disinfectant cream, solutions, eye care systems.
- Healthcare systems such as equipment and device coating, disinfectant solutions and disposables.
- Household appliances such as refrigerator panels, food packaging material and food storage systems.
- Water treatment.
Green Protocols for Efficient Organic Synthesis

Environmentally benign catalysis is receiving increasing attention in green synthesis. IBN researchers are focused on developing non-toxic, inexpensive and safer catalytic systems for organic synthesis. IBN's technologies include: (i) less toxic copper-catalyzed [3+2] cycloaddition substituted benzenes with allyl halides to form dihydroindenes, (ii) novel chiral dihydroimidazolium cyclophanes as N-heterocyclic carbene precatalysts, and (iii) metal-free regioselective oxidative chlorination of aromatics.

Advantages:
- Simple, cost-effective, mild reaction conditions.
- Wide scope of substrate tolerance and good yield.
- Environmentally benign catalytic system.

Applications:
- Organic synthesis for the pharmaceutical and fine chemical industries.
- Simple synthesis protocol for dihydroindenes.
- New chiral N-heterocyclic carbenes for organic synthesis.
- Green protocol for arene chlorination.
Green Chemistry and Energy

Glucosamine-Conjugated Iron Oxide Nanoparticles for the Separation of Insulin-Secreting Beta Cells

Cell separation is an important tool used in a wide variety of cell-based biomedical applications. Hence, it is of immense interest to be able to quickly and efficiently enrich and isolate cells of interest. Cell separation techniques, such as size-based sieving and dielectrophoresis, use differences in the physical properties of cells for sorting. However, these techniques are unsuitable when the different cell types exhibit similar physical properties. Magnetic cell separation has become an essential tool for a wide variety of biomedical applications. It is important to extract a highly pure sample of the cell populations of interest from the mixed cell populations for therapeutics and diagnostics. Currently, antibody-functionalized magnetic particles are used to target specific cells of interest. However, immuno-based cell sorting is costly. Our studies have shown that glucosamine may be used as a small molecule targeting moiety for cell separation and imaging through binding the Glut2 surface receptors. The high affinity of glucosamine binding to Glut2 receptors on the surface of the insulin-secreting beta cells enabled us to sort beta cells from the surrounding unwanted cell populations magnetically and by FACS. Insulin-secreting beta cells from artificial cell mixtures, porcine pancreas and differentiated stem cells can be enriched to > 80%. We also present the use of a thrombin-specific cleavable peptide as an intermediary to release the superparamagnetic nanoparticles from cell surfaces to facilitate cell attachment and proliferation. This work demonstrates an important and novel nanoparticle-based platform technology for effective magnetic cell separation. This nanoparticle conjugation platform for cell separation could potentially allow researchers to separate insulin-secreting beta cells differentiated from embryonic stem cells, induced pluripotent cells, or adult stem cells such as bone marrow mesenchymal stem cells.

Advantages:
- Magnetic separation and simultaneous imaging of sorted cells by quantum dots.
- Glucosamine is used as a small molecule targeting moiety instead of expensive antibodies.
- Not dependent on the physical properties of the cell types. Current techniques are unsuitable when the different cell types exhibit similar physical properties.
- Use of thrombin-specific peptide as a cleavable linker for easy recovery of nanoparticles.
- Using thrombin as a digestive protease to remove cell surface-bound nanoparticles, cells were able to adhere and proliferate on culture substrates.

Applications:
- Separation of insulin-secreting beta cells from mixtures of cells, porcine islets and differentiated stem cell populations.
- Use of magnetic properties for the separation of various other cells.
- Cell purification for diabetes research.

Confocal fluorescence images of insulin-secreting beta cells. Images (A) and (B) shows glucosamine-conjugated cGSH-ZnS–CdS–CdSe quantum dots (QDs) targeting only the cell surface. (C) Control experiments shows cGSH–ZnS–CdS–CdSe QDs within the cytosol, indicating non-specific uptake.
Co-Delivery of Doxorubicin and Magnetite Nanocubes by Nanoparticles Synthesized via Nitroxide-Mediated Radical Polymerization

Combining an imaging agent with anti-cancer drugs would allow real-time monitoring of drug distribution to the target tissue, as well as tracking of the effects of the drugs. In particular, nanodevices that combine anti-cancer drugs and superparamagnetic iron oxide nanoparticles have been used for magnetically guided delivery, synergistic hyperthermia therapy and chemotherapy. IBN has synthesized a tri-block or di-block copolymer by nitroxide-mediated radical polymerization (NMRP) that is capable of co-delivering anti-cancer drugs (e.g. doxorubicin) and magnetic resonance imaging agent (e.g. Fe₃O₄ nanocubes). Both the drugs and the imaging agents were loaded in the core of the polymeric nanoparticles by chemical binding, and were protected by the outer shell of the nanoparticles. In vivo studies demonstrated the same biodistribution of anti-cancer drugs and imaging agents, and strong passive targeting for both reagents at the same time. Thus, synergistic functions of the two agents at the therapeutic site was possible.

Advantages:
- NMRP produces functionalized block polymers with very narrow polydispersity without the use of toxic metal catalysts.
- Core-shell particles with excellent stability, high loading capacity and suitable particle size were formed.
- The loading levels of magnetic nanoparticles and doxorubicin could be as high as 28 wt% and 30 wt%, respectively, while the average overall particle size remained at ~ 100 nm.

Applications:
- Coordinated in vivo delivery of anti-cancer drugs and imaging agents.
- Real-time monitoring of the therapeutic effect, magnetically guided drug targeting, and synergistic effects of the two agents at the therapeutic site.