3rd Annual ACS GCI Roundtable Poster Reception

Developing a network to foster the development and marketing of industrially-relevant, greener alternatives

June 19, 2013

North Bethesda Marriott & Convention Center

Sponsored by:

ILSI Health and Environmental Sciences Institute and Renewable Citrus Products Association

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1. **Packaging Sustainability and Performance: Emulsifiable Diester Solvents for Oil and Gas**, Amit Sehgal[1], David Fluck[1], Subramanian Kesavan[1], Dominique Labarre[2], Arnaud Bourdette[2], Ruela Pabalan[1], Charles Aymes[3], 1. Solvay Research & Innovation Center, Bristol, PA19007, USA, 2. Solvay Research & Innovation Center, Aubervilliers, Cedex 22600, France, 3. Solvay Novecare, Cranbury NJ 08512, USA

   Performance-in-application is a critical pre-requisite for successful adoption of Sustainable Technologies. We have developed a new class of biodegradable, non-toxic and non-flammable, high-performance solvents (e.g. Rhodiasolv® IRIS – dimethyl methylglutarate) to replace traditional hazardous solvents used in Oil and Gas Applications. Optimized synthetic routes to these alkyl dibasic ester solvents allow access to a broad range of solvencies necessary for different solvent functions.

   The synergy of surfactants and blends of Rhodia's solvents were exploited to provide novel mixtures as well as infinitely dilutable microemulsions to replace or extend functions of current solvents. Our formulation discovery cycle will be discussed: from exploring properties (solvency), to developing delivery platforms by high-throughput mapping of phase behavior. This platform has been further extended to auto-emulsifible solvent blends that allow spontaneous emulsification of the organic phase into water without imparting any mechanical energy. Such emulsifiable low vapour pressure solvent platforms help translate intrinsic solvency to effective delivery in performance and cost. We will also present performance data on crude oil clean-up, tar sand, bitumen and asphaltene removal, as well as, solvent blends to potentially replace aromatics, terpenes and butyl ethers.

2. **Arizona Chemical – Renewable Resources. Endless Possibilities™** Paul Williams and Alan Phillips[2], 1. Arizona Chemical, 1221 W Lathrop Ave, Gate A, Savannah, GA. 31415. 2. Arizona Chemical Company, LLC, 4600 Touchton Road East, Suite 1200, Jacksonville, FL 32246.

   Arizona Chemical's vision is to be the world's leading innovator in sustainable chemical solutions. Three key drivers to illustrate this are through being; a Forerunner in Biorefining, a Leader in Creating Sustainable Innovation and making Intelligent Use of Resources.

   This poster highlights Arizona Chemicals commitment to Green and Sustainable chemistry. Arizona Chemical utilizes a non-food bio-based material to make innovative products with high bio-renewable contents. To validate our commitment to sustainability, Arizona Chemical has published three Sustainability reports and is working on number four. The 2011 sustainability report, which achieved a Global Reporting Initiative (GRI) B level score, is available at http://www.arizonachemical.com/en/Sustainability/Sustainability-Report-2011/

   Further; Arizona Chemical focuses on a holistic process to maximize the utilization of raw materials and co-product streams that we refer to as Cascading Use. This is part of making Intelligent Use of Resources. Therefore a natural raw material should always be used to its full

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potential through the value chain by building on what nature provided to enhance value towards end-use markets before considering use for energy production. This holistic approach should be applied when assessing all aspects of sustainability, and requires a broad system view taking into account alternative uses, the carbon footprint of substitutes and emission avoidance.

3. **ACS GCI Chemical Manufacturer's Roundtable: Pursuing green chemistry and engineering for a sustainable business and environment**. ACS GCI Chemical Manufacturer's Roundtable, 1155 Sixteenth St, NW, Washington, DC 20036.

   The mission of the ACS GCI Chemical Manufacturer's Roundtable is to provide leadership and education in the interpretation and implementation of green chemistry and engineering principles as applied in the chemical manufacturing industry by providing a consistent source of credible, scientifically sound information on the application of the principles to chemical manufacturing industry stakeholders to influence policy, standard setting organizations, and third parties directly relevant to the chemical manufacturing industry. This poster will highlight two current projects including results from a survey on green chemistry implementation in the industry as well as an effort to influence the research and implementation of alternative separations technologies.

4. **AkzoNobel – Innovation in Product Stewardship**, James LePage, Raj Krishnaraj, Kees van Ginkel and Edwin Bisinger, Akzo Nobel Functional Chemicals, Chicago, IL 60607, United States, 3. Wildlife International, Easton, MD, United States.

   AkzoNobel is the largest global paints and coatings company and a major producer of specialty chemicals. We supply industries and consumers worldwide with innovative products and are passionate about developing sustainable answers for our customers. AkzoNobel is committed to ensuring our products are safe for humans and the environment and in the development of innovative responsible approaches to this end.
   AkzoNobel Functional Chemicals group developed a new chelating agent called Dissolvine ® GLDA as a safe and biodegradable replacement for EDTA, phosphates, and other chelating agents. GLDA has been marketed in Europe for over a decade, but was only widely introduced to the U.S. market in 2010 for use in automatic dish washing products.

   GLDA had previously undergone extensive testing in Europe demonstrating it was readily biodegradable. However biodegradation testing of GLDA inoculated with activated sludge from multiple U.S. waste water treatment plants repeatedly failed these same tests (OECD 301B). Further testing showed sludge would acclimate to GLDA and this presented an exceptional opportunity to study the change in biodegradation of GLDA with time after its introduction to the U.S. market.

   Recently, the U.S. Food and Drug Administration has approved kidney protein biomarker tests to screen drugs for early detection of potential renal toxicity / cancer. This approach offers a fast, non-invasive evaluation of drug or chemical safety and uses fewer animals. AkzoNobel used this

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approach to test GLDA and AkzoNobel may be the first chemical manufacturer to utilize this approach.

5. **Hybrid Polymers: A High Performance and Sustainable Solution**, Klin Rodrigues, Reggie Smith, Akzo Nobel Surface Chemistry, Department of Polymer Chemistry, Chattanooga, TN, 37406, United States.

   AkzoNobel has developed a new, biodegradable biopolymer technology for the Fabric and Cleaning marketplace. Based upon the combination of selected polysaccharides and synthetic monomers, the Hybrid Polymers of this technology readily biodegrade in the environment, offer a preferable carbon footprint, and are effective in replacing synthetic polymers in formulations such as automatic dishwash and laundry detergents. This 2nd Generation technology provides a sustainable and cost effective alternative to existing synthetic options. This paper will provide insight on the latest developments with AkzoNobel Surface Chemistry's readily biodegradable Hybrid Polymer Technology. Specifically, the performance of these polymers in automatic dishwash and laundry detergents, and their positive environmental aspects will be reviewed, including lifecycle analysis.

6. **Laundry Washing Machine Changes and Impact on Detergent Formulation Chemistry**, James S. Pell, and Philip G. Sliva, Amway, Mail Code 31-1B, 7575 Fulton Street, Ada, MI 49355.

   High efficiency washers are significantly impacting washing machine detergency. There is a larger than anticipated reduction in wash water volumes. Even the low water European machines wash volumes dropped from 20 liters to 8 liters. We see improved soil removal, however soil redeposition is becoming more pronounced. This creates a need for improved technology in this important area. It may also offer potential opportunities as concentration limits may spur consideration of chemistry previously not applied.

7. **A Life Cycle Assessment of Renewable and Sustainable Citrus Oils**, Jon Leonard and Richard Pearl, Renewable Citrus Products Association, Florida Chemical, 1785 King Road, Hinckley, Ohio, 44233, United States.

   Citrus oils are the essential oils expressed from peels of citrus fruit during the juicing process. These natural oils are 100% biobased, renewable and sustainable. The Life Cycle Assessment (LCA) for citrus oils has been performed and demonstrates that essential oils derived from citrus have an extremely small carbon footprint, or in other words, a low potential to contribute to global warming. The citrus crop is harvested every year and is fully renewable. In addition, utilizing the peel for citrus oils is a sustainable practice and does not consume a human food crop. d-Limonene, the main constituent of citrus oils, is an unsaturated, cyclic, terpene hydrocarbon with relatively high structural activity compared to saturated alkanes. Citrus oils are employed as alternative biobased raw materials for many different value-added products and are an ideal feedstock for Green Chemistry and Engineering. See EPA www.epa.gov/greenchemistry. Also see ACS www.acs.org/greenchemistry.

   Cradle-to-Gate Assessment for a Cradle-to-Cradle Product
   Citrus oils differ from petroleum counterparts in that the building blocks (carbon dioxide and water) come from the environment through photosynthesis and most uses return the carbon to

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the environment as part of the carbon cycle. This carbon cycle allows the LCA to track these building blocks from their origin in nature to their return to the environment or "cradle-to-cradle".

Findings Show Environmental Benefits

Overall the results of the LCA indicate that citrus oils have a more favorable and sustainable environmental profile when compared to petroleum-based counterparts.

8. **Greening the supply chain to develop more sustainable formulations**, ACS GCI Formulators' Roundtable, 1155 Sixteenth St., NW, Washington, DC 20036.

   To initiate progress towards informing and influencing suppliers and academia to develop greener alternatives, the ACS GCI Formulators' Roundtable believed it was imperative to define the top areas for opportunities for greener alternatives as identified from a Formulators' perspective. The components of existing formulated products are considered safe and effective; however, it is the intention of the Roundtable to foster the development of innovative greener components to enhance the overall sustainable profile of formulated products. The list was developed with input from all member companies. It is the hope of the Roundtable that this list of opportunities initiates dialogue, research, and development of renewable and more environmentally friendly alternatives. The Roundtable recognizes this as an opportunity for collaboration where appropriate, for funding where feasible, and for global communication as needed to engage the broader audience in this effort to bring greener alternatives into the marketplace.

9. **Pathway towards a Green and Greener Future**, P. Somasundaran, J. Wu, Y. Shen, M. Chin, and C. Lo, SF/IUCRC Langmuir Center for Colloids and Interfaces, Earth and Environmental Engineering, Columbia University, 500 West 120 Street, 918 Mudd, New York, NY 10027.

   Surfactants, polymers including enzymes/proteins, and their mixtures have been widely used in many industrial sectors, such as personal and home care, and pharmaceuticals based on the performance. However, usage of them is raising health and environmental concerns. With increasing regulations on air and wastewater emissions, there is a dire need for discovery and implementation of greener alternatives that are made from sustainable raw materials and minimize hazards to nature upon discharge.

   NSF/IUCRC(Industry/University Cooperative Research Center) at Columbia University is dedicated to advancing, developing, and promoting greener alternatives and particle technologies that lead to less water and energy consumption as well as improved performance. The greener alternatives are subjected to a tool called Greenness Index we have developed to facilitate comprehensive comparison of chemicals all the way from manufacture, processing, discharging to recycling in terms of their social, health and environmental impacts.

   The research endeavors from examination of the behavior of reagents on nano- and micro-levels to development of sustainable systems for low chemical footprint. At a molecular level the interfacial and colloidal behavior of individual and mixed systems of greener alternatives is investigated to develop the structure/property/performance relationships, especially the synergy for performance enhancement within the constraints of energy, environment, and economics. On a mesoscopic scale emphasis is on elucidating the dynamics of interactions among surfactants, polymers, enzymes and nanoparticles that are critical for many applications involving detergency,

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cosmetics, drug delivery, vaccine activation, mineral and oil extraction, biofuels, light harvesters etc.

10. **Novel green catalysts for pharmaceutical and fine chemical production**, Philip G. Jessop[1,2], Paul D. Thornton[1], Andrew Pasternak[1], 1. GreenCentre Canada, Kingston, Ontario, K7L 3N6, Canada, 2. Queen's University, Department of Chemistry, Kingston, Ontario, K7L 3N6, Canada.

    GreenCentre Canada is a government and industry funded Centre of Excellence for Commercialization & Research (CECR), focusing on advancing early stage green chemistry technologies arising from Canadian academic institutions. We are an all-in-one commercialization "ecosystem" that includes technical and commercial assessment, application development, scale-up, testing, and intellectual property management.

    GreenCentre Canada is currently developing a series of “best in class” catalysts that address key needs of the pharmaceutical and fine chemicals industries. These include:

    - Amidation catalysts for one-step synthesis of amides at room temperature. Atom economy is exceptionally high and no toxic by-products are produced.
    - Hydrogenation catalysts for selective hydrogenation of esters, amides, imides, imines, esters, and ketones. Each of these catalysts has proven benefits over traditional use of toxic hydride reagents.
    - Heterogeneous BINAP-based flow reactor systems for continuous synthesis of chiral compounds. This novel technology allows creation of long-lived columns for asymmetric hydrogenations and other selective transformation within a flow system.

    This poster will describe the key technical, economic, and green advantages of each of these catalytic technologies.

11. **Catalyst and reactor design for green continuous flow technologies**, Steven R. Saunders[1], Evan A. Davey[2,3], Joel Aponte-Guzman[3], Raynold Shenje[3] , Pamela Pollet[2,3], Stefan France[3] , Charles A. Eckert[1,2,3] ,and Charles L. Liotta[1,2,3] 1. Georgia Institute of Technology, School of Chemical and Biomolecular Engineering, 311 Ferst Dr NW, Atlanta, Georgia, 30332-0100, United States, 2. Georgia Institute of Technology, Specialty Separations Center, Atlanta, Georgia, 30332-0100, United States, 3. Georgia Institute of Technology, School of Chemistry and Biochemistry, Atlanta, Georgia, 30332-0400, United States.

    The pharmaceutical industry has long employed batch processing; however, the application of continuous flow technology to pharmaceutical processes offers a number of green and economic advantages. Continuous flow technology enables greener and more sustainable processes through (1) enhanced mass and energy transport, (2) minimizing waste, and (3) economic benefits by implementing scale-out strategies as opposed to scale-up. Herein, we present the application of continuous flow processing to two pharmaceutically relevant reactions: (1) Homo-Nazarov cyclization forming medicinally active heteroaromatic ring-fused cyclohexanones and (2) Meerwein-Ponndorf-Verley (MPV) reduction of carbonyls to their corresponding alcohols. We have developed Lewis acid and aluminum alkoxide catalysts with enhanced reactivities for the Homo-Nazarov cyclizations and MPV reductions, respectively. For example, the use of aluminum tert-butoxide in an MPV reduction results in reactions that can be completed in as little as 15 minutes owning to a 10-fold increase in the reactivity. We have utilized a Corning Advanced-Flow Glass Reactor and a custom built stainless steel reactor to perform the reactions in. Under the optimum conditions, continuous reactions with short residence times provided quantitative

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conversions and yields. Ultimately, this is the first step of transferring multi-step reaction schemes (intermediate synthesis, product synthesis, separation, and purification) to greener continuous schemes.

12. A microwave reactor suite for seamless-scale up from bench top to continuous-flow manufacturing-scale production, Richard Wagner, Pramod Mohanta, Yin Cheng, and J Hayden Brownell, UpScale Microwave, Corporate R&D, 3070 McCann Farm Drive, Suite 111, Garnet Valley, PA, 19425, United States.

    UpScale Microwave is a US-based manufacturer offering its proprietary suite of microwave chemical processors through direct sale and contract chemical manufacturing. This suite enables scale-up production from grams to tons-per-day and more without reformulation. Our compact, modular, highly adaptable, continuous-flow platform achieves manufacturing-scale production for a wide variety of chemistries. Four chemical production case studies will be presented: Suzuki-Miyaura transformation, condensation, saponification, and transesterification. All four together were completed in two months. In each case, the chemistry protocol was optimized at the milliliter scale and without reformulation was progressively scaled through UpScale Microwave's suite of microwave chemical reactors: from our small B-2 batch reactor (0.05 – 2 L), to our midsized B-12 batch unit (0.1 – 12 L), through to our manufacturing-scale DCF continuous flow reactor (up to 10s tons per day/unit). We observed no significant change in the chemistry outcomes operating with the same process conditions across all reactors while using more environmentally benign solvents and very low catalyst loading. Development time can then be reduced from a year or more to weeks. This work demonstrates general purpose continuous flow processing for commercial-scale manufacturing. Clogging in the flow reactor was not an issue even the case of a crystallizing product. Production rates of 100 kg to 3.5 tons per day were achieved without pushing the limits of the reactor capability. Additional examples including peptide scale up with microwave heating from milliliters, to our B-2 unit (600 mL), through to our 10-liter reactor in our B-12 unit will be presented.

13. **Safe and Efficient GMP Manufacture by Application of a Continuous Flow Ozonolysis Followed by Pinnick Oxidation**, John Tucker, David Yeung, Joe Tomaskevitch, Brian Cochran, Filisaty Vounatsos, Seb Caille, Derek Brown, Tiffany Thiel, Susanna Lai, Wendy Chen and Matt Bio, Small Molecule Process and Product Development, Amgen Inc., One Amgen Center Drive, Thousand Oaks, California 91320.

    Usually exothermic, often requiring the use of heavy metals or cryogenic conditions, oxidations are some of the most energetic and dangerous transformations process scientists encounter. During development of a drug candidate at Amgen, oxidation of an allylic double bond to the corresponding carboxylic acid was being accomplished via catalytic transition metal with a stoichiometric co-oxidant. The process had poor selectivity, low yield, issues with handling, and toxicity concerns. As an alternative, the team pursued the combination of a continuous flow ozonolysis to generate an aldehyde intermediate, followed by Pinnick oxidation to the carboxylic acid. Ozone can potentially generate explosive intermediates, and the Pinnick reaction will generate an explosive gas. The conceptual and exemplified strategies to mitigate chemical and flammability hazards and Green Chemistry implications will be discussed, as will details of a successful GMP scale-up using continuous flow ozonolysis followed by a Pinnick reaction to produce an Amgen drug candidate.

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14. **Enabling Green Chemistry & Engineering in the Pharmaceutical Industry**, ACS GCI Pharmaceutical Roundtable, 1155 Sixteenth St., NW, Washington, DC 20036.

    Launched in 2005, the ACS GCI Pharmaceutical Roundtable (ACS GCIPR) had just 3 corporate members and an ambitious goal: to catalyze the integration of green chemistry & engineering in global pharmaceutical industry. Now eight years later, the pharmaceutical industry is an established leader in green chemistry, and the Roundtable, now with 15 corporate members, has set a framework for future organizations. This presentation will highlight recent accomplishments in three key areas: defining and delivering tools such as one incorporating life cycle assessment considerations into a process mass intensity calculator; educating leaders through the development of business cases for continuous processing; and informing & influencing the research agenda with two new requests for proposals.

15. **Quantifying the value of an ACS GCI Industrial Roundtable**, ACS Green Chemistry Institute®, 1155 Sixteenth St., NW, Washington, DC 20036.

    ACS GCI Industrial Roundtables are non-competitive collaborations designed to catalyze the integration of green chemistry and engineering into the respective industry sector, and ultimately the chemical enterprise. The first Roundtable was established in 2005 with just three members; today there are three Roundtables with a total of 39 corporate members. Annual membership contributions range from $1,000 (Formulators and Chemical Manufacturers) to $25,000 (Pharma) depending on the Roundtable. As with all business decisions, participation in a Roundtable needs to be justified. The example presented here illustrates the benefits associated with the Pharmaceutical Roundtable. This example was selected because this Roundtable has the highest of the annual contribution and demonstrates a benefit of more than 1000%.

16. **The Pfizer Green Journey: A Decade of Green Chemistry in the Pharmaceutical Industry**, Elizabeth Auda[1], Juan C. Colberg[2] and Peter J. Dunn[3], 1. Global EHS, New York, Pfizer Inc. 2. Pharmaceutical Sciences, Connecticut, Pfizer Inc. 3. Global EHS, United Kingdom, Pfizer Limited.

    The Pfizer Green Chemistry program started in Connecticut in 2001. In 2002 the program received a major boost in momentum when Pfizer was awarded the Presidential Green Chemistry Challenge Award for its Sertraline Manufacturing Process. The program then spread quickly throughout the company, at every research chemistry site a Green Chemistry team was formed and Green Chemistry also spread throughout the manufacturing division. In 2012 we had several events to celebrate what we called internally within the company “A decade of Green Chemistry Leadership”. These events included seminars at different sites, collecting a history of the first ten years of the program including capturing the individual stories of around 60 past and present Green Chemistry team members recording how and why they had become interested in Green Chemistry. This poster tries to capture some of the work and success stories of the first ten years of the Pfizer Green Chemistry program.

17. **Nickel-Catalyzed Cross-Couplings in Green Solvents,** Liana Hie, Stephen D. Ramgren, and Neil K. Garg, University of California, Los Angeles, Department of Chemistry and Biochemistry, 607 Charles E. Young Drive East, Box 951569, Los Angeles, CA, 90095, United States.

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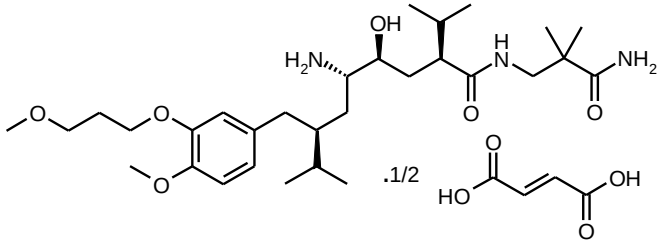
Cross coupling reactions are frequently implemented in the construction of C–C bonds, which are integral motifs found in pharmaceutical compounds, natural products, and materials. Although palladium catalysis has dominated these transformations, alternative metals have been attracting considerable interest. For example, catalysis using nickel has become increasingly more popular because of nickel's low cost and its high reactivity toward substrates that prove challenging with palladium catalysis. However, nickel-catalyzed cross-couplings are typically employed in environmentally unfriendly solvents. This presentation will describe our recent studies carried out in collaboration with the ACS Green Chemistry Institute Pharmaceutical Roundtable to develop Green Ni-catalyzed Suzuki–Miyaura cross-couplings to forge biaryl and hetero-biaryl scaffolds.

18. **PMI-LCA calculations for different routes towards Aliskiren,** Peter Hermsen, André H.M. de Vries, Rinus Broxterman, DSM Innovative Synthesis BV, Corporate Scientist, Postraat 1, 6160 MD, Geleen, The Netherlands.

    Within DSM sustainability is one of the drivers to grow our business, not only for bulk products and materials required for the automotive industry, but also for the production of pharmaceutical active ingredients. Ideally, the sustainability of a certain new route to an API is one of the main drivers in route scouting exercises (“benign by design”). This requires an easy to use tool to allow to quantify the sustainability of different routes. The ACS GCI Roundtable has developed such an tool: the PMI/LCA tool, which meets these requirements, also for convergent routes (see OPRD, 2013, 17, 239).
    Here we are comparing different routes towards Aliskiren (relative complex API launched by Novartis in 2009 for hypertension, structure see below), using this PMI/LCA tool.
    Next to the medchem route, and the commercial production route, 2 newly identified breakthough routes for potential generic production, the PMI/LCA data will be presented.

Aliskiren



19. **Developing Guidance for Alternatives Assessment**, Jennifer Young Tanir, ILSI Health and Environmental Sciences Institute, Scientific Program Manager, 1156 15th Street NW, 2nd Floor, Washington, DC, 20005, United States.

    The ILSI Health and Environmental Sciences Institute (HESI), a global branch of the International Life Sciences Institute (ILSI), currently has a sustainability-focused project on alternatives assessment. With a vision of creating science-based solutions for a sustainable, healthier world, HESI recognizes sustainability as vitally important as it identifies and resolves global health and environmental issues through engagement with scientists from academia, government and industry. As a non-profit organization, HESI provides a unique, objective forum for initiating dialogue among scientists with different perspectives and expertise from a range of sectors including pharmaceuticals, agricultural and industrial chemicals, personal care and consumer product, and others. HESI's broad scientific portfolio spans translational biology, new approaches and techniques, environmental toxicology, and risk assessment.

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In the fall of 2011, HESI initiated the Emerging Issues Subcommittee on Frameworks for Alternative Chemical Assessment and Selection of Safer, Sustainable Alternatives. The mission of the project is to evaluate and identify key elements/criteria and tools to help trigger and guide the selection of safer, sustainable alternatives while minimizing the likelihood of regrettable substitutions. A workshop was held in February 2013 which focused on three topics: 1) Attributes and tools, 2) Decision-making and weighing and 3) Data gaps. Results of the workshop and of the subcommittee will be submitted for publication in a peer reviewed journal. Guidance from this subcommittee will benefit researchers and companies across the supply chain as they navigate the ever changing landscape of greener alternatives.

20. **Evolution of the GSK Green Reagent Selection Guides**, Joseph P. Adams[1], Catherine M. Alde[1], Ian Andrews[1], Ann M. Bullion[2], Matthew Campbell-Crawford[1], Michael G. Darcy[2], John D. Hayler[1], Richard K. Henderson[3], Catriona A. Oare[1], Israil Pendrak[2], Anikó M. Redman[4], Carolyn Selenski[5], Leanna E. Shuster[6], Helen F. Sneddon[1], and Matthew D. Walker[1]. 1. GlaxoSmithKline, Stevenage, UK. 2. GlaxoSmithKline, King of Prussia, PA. 3. GlaxoSmithKline, Ware, UK. 4. GlaxoSmithKline, Research Triangle Park, NC. 5. GlaxoSmithKline, Tres Cantos, Spain. 6. GlaxoSmithKline, 1250 S. Collegeville Rd., UP1205, Collegeville, PA 19426.

    Following on the principles of the GSK Solvent Selection Guide, the GSK Green Chemistry Team has developed a methodology for scoring the “greenness” of a reagent based on EHS data and information regarding typical use for a given chemical transformation. These methods have been used to develop guides for 15 common chemical transformations. The process for creation of these reagent guides will be presented and discussed.

21. **Recoverable and readily reusable “green” siloxane transfer agent for palladium-catalyzed cross-coupling reactions**, Minh H Nguyen , Dionicio Martinez-Solorio, Adam T Hoye, Amos B Smith, III, University of Pennsylvania, Chemistry, 231 S.34th St., Upenn-Chemistry #173, Philadelphia, Pennsylvania, 19104, United States.

    Palladium-catalyzed Cross-Coupling Reactions (CCRs) are essential transformations for the construction of organic building blocks via the formation of carbon-carbon bonds. The importance of these reactions was honored with the Nobel Prize in Chemistry in 2010. Insofar as green chemistry is concerned, however, numerous unsolved problems remain, including the use of stoichiometric amount of toxic heavy metals (i.e., zinc or tin as in the Negishi and Stille CCRs), additives (i.e., fluoride and strong base in the Hiyama and Suzuki CCRs), elevated temperature, and extended reaction times. In addition, many of the present cross-coupling processes demands multiple time-consuming synthetic manipulations and the subsequent isolation of reactive intermediates in order to generate suitable coupling partners. In response to the above challenges, we have designed, synthesized, and validated a series of recoverable and readily reusable “green” siloxane transfer agents for CCRs of readily available organolithium reagents with aryl and alkenyl iodides. Prevention of waste, atom economy, energy efficiency, limited derivatization, and elimination of stoichiometric amounts of toxic heavy metals have now been addressed, in line with the principles of green chemistry.

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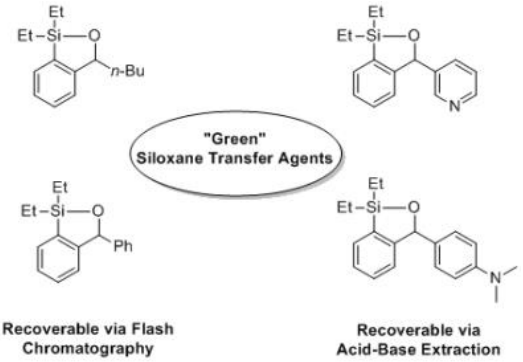

22. **Hydrocarbon synthesis from carbon dioxide and hydrogen: A two-step process**, David M. Drab[1] , Matthew T. Olsen[1], Ramagopal Ananth[3], Dennis R. Hardy[2] , Heather D. Willauer[4], 1. NRC-RAP, US Naval Research Laboratory, Division of Materials Science and Technology, Washington, DC, 20375, United States, 2. Nova Research Inc., Alexandria, VA, 22308, United States, 3. US Naval Research Laboratory, Division of Chemistry, Washington, DC, 20375, United States, 4. US Naval Research Laboratory, Division of Materials Science and Technology, Washington, DC, 20375, United States.

    Exploiting carbon dioxide as a carbon source for the production of value-added hydrocarbons offers a possible solution towards identifying sustainable alternative energy sources. Once realized, these sources would reduce the reliance on increasingly expensive foreign-produced petroleum. Previous work in our group has suggested a two-step synthesis approach to producing liquid hydrocarbons from carbon dioxide and hydrogen. In the first step, a modified alumina-supported K/Mn/Fe catalyst is active for the hydrogenation of carbon dioxide to light olefins. The resulting complex light olefin stream must be further oligomerized to obtain useful liquid hydrocarbons in the second step. The interest in integrating these two processes has led to designing and testing catalysts within fixed-bed, tubular reactors. Here are shown the effects of modifying the surface of iron-based catalysts with a hydrophobic coating to prevent water from deactivating the catalyst active sites. In addition, data from the oligomerization of a model olefin is shown from the use of amorphous silica-alumina (ASA) catalyst pellets optimized to obtain C9-C16 hydrocarbons.

23. **Rational design of green polar aprotic solvents: Synergistic in silico and experimental approach**, Matthew Finn ,Nan An, and Adelina Voutchkova-Kostal, The George Washington University, Department of Chemistry, 725 21st, NW, Corcoran Hall, Room 107, Washington, DC, 20052, United States.

    The need to replace polar aprotic solvents such as DMF, NMP and DMAc is of utmost importance to industry, given the mounting evidence of their adverse biological effects and the potential for regulatory action. The goal of this project was to develop polar aprotic solvents that accelerate synthetic reactions of interest, such as nucleophilic aromatic substitution and Pd-catalyzed couplings, but lack human/eco-toxicity. In addition, the alternative solvents must biodegrade and be competitively priced. Rationally designing a solvent that can meet these criteria can be a challenge; however, by taking advantage of recent advances in computational chemistry, synthetic chemistry and mechanistic toxicology we show it is feasible to optimize performance, toxicity and biodegradability simultaneously.

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24. **Chelating Agent Selection from a Kinetics Perspective: New Insights From Capillary Electrophoresis**, Alan T. Stone[1], Nathan E. Boland[2], and Richard F. Carbonaro[3]. 1. Department of Geography and Environmental Engineering, 313 Ames Hall, Johns Hopkins University, Baltimore, MD 21218. 2. Department of Chemistry, Hall of Science 374, Whitman College, Walla Walla, WA. 3. Mutch Associates LLC, 360 Darlington Avenue, Ramsey, NJ 07446.

In the past decade, four Ph.D. students from the Stone group have used capillary electrophoresis to speciate dissolved metal ions and chelating agents, identify and quantify breakdown products, and explore reaction pathways and rates. Example 1: Nickel(II) equilibrated with EDDA then contacted with CDTA is captured by the stronger chelating agent at a rate proportional to the CDTA concentration. Replace EDDA with NTA and the rate of capture is independent of the CDTA concentration. EDDA and NTA are both tetradentate chelating agents. With EDDA, the reaction can take place through an associative mechanism, but with NTA, the reaction must take place through a dissociative mechanism. Example 2: Chelating agents in contact with chromium(III) oxyhydroxide passive layers slowly generate dissolved chromium(III) complexes. Manganese oxyhydroxides are the only common oxidants capable of converting dissolved chromium(III) complexes into the more toxic (and carcinogenic) chromate ion. Our experiments show that half-lives for oxidation of 1:1 chromium(III)-IDA complexes are less than an hour. 1:2 chromium(III)-IDA complexes react 2000-times slower, 1:1 chromium(III)-HEDTA complexes react one million-times slower, and 1:1 chromium(III)-EDTA complexes are kinetically resistant to oxidation. Quite often, we find that small changes in the identity, number, and arrangement of Lewis Base groups within chelating agent structures yield large, difficult-to-predict effects on reaction pathways and rates.