

## **Narrative of Research and Teaching Activities of the Ontario Chair in Green Chemistry and Engineering Activities at Trent University: 2012 - 2013**

This narrative examines the activities of the Ontario Research Chair in Green Chemistry and Engineering at Trent University, Professor Suresh Narine, under three headings - teaching, outreach and research activities.

### **1.0 Teaching Related Activities:**

The Ontario Research Chair in Green Chemistry and Engineering at Trent University was slated to have the following teaching related activities from 2011 (text in *italics* are cut and pasted from the original application to COU):

*The proposed Chair will have the following teaching responsibilities:*

#### *Undergraduate*

- *Department of Physics, first year course, 2010: "Physics for the Life Sciences".*
- *Departments of Physics and Chemistry, fourth year course, 2011: "Physics and Chemistry of Colloidal Biomaterials"*
- *Department of Chemistry, fourth year course, 2012: "Techniques in Green Chemistry: Organic Synthesis Reactions Suitable for the Conversion of Lipid Molecules into Toxin-Free Polymers."*
- *Development in 2013 of a Trent Centre for Community Based Education community-based course: "Biomaterials- Chemistry, Ethics, and Economics".*
- *Supervision of senior undergraduate students (up to 10 per year) in project-based courses.*

#### *Graduate*

- *Materials Science and Environmental and Life Sciences Graduate Programs, 2010, "Biomaterials"*

Professor Narine was successful in securing two major research Chairs in 2011 - the Ontario Research Chair in Green Chemistry and Engineering and the Senior NSERC/GFO/ERS Industrial Research Chair in Lipid Derived Biomaterials. Due to the unusual amount of research activity and research administration that Professor Narine is engaged in as a result of holding two major research chair positions, ***his teaching load at Trent University has been reduced to zero.***

### **1.1 Courses Offered**

Despite this teaching reduction, in 2013, Professor Narine taught the graduate level course: **Topics in Biomaterials: Lipid Based Materials - Green Chemistry and Materials Physics**. This course was offered to graduate students in the Materials Science graduate program at Trent University and University of Ontario Institute of Technology (UOIT), graduate students in the Environmental and Life Sciences graduate program at Trent University and graduate students in the Sustainable Studies graduate program, and to senior undergraduates from Trent University.

The second year undergraduate course “**Thermal Physics**” was also taught by Prof. Narine during the 2012- 2013 academic year (Dr. Narine is cross-appointed between the Departments of Chemistry and Physics and Astronomy)

### **1.2 Undergraduate Students Supervised**

Three undergraduate students were supervised in 2012 - 2013:

1. Mark Baker – 4<sup>th</sup> year Undergraduate Physics Student, University of Western Ontario
2. Benjamin McPhail, 3<sup>rd</sup> year Undergraduate Chemistry Student, Trent University
3. Jennifer Morgan, 3<sup>rd</sup> year Undergraduate Chemistry Student, Trent University

One exchange student was supervised in 2013, from Brazil, funded through a joint Brazil-Canada Research Partnerships Grant with University of Toronto, Trent University and Universidade Estadual de Paulista (UNESP),

1. Danielle Chiarelli Goncalves – Ph.D. Student.

### **1.3 Graduate Supervision**

There are ten (10) graduate students currently in the research program, either solely supervised or co-supervised by Professor Narine; two students have already graduated from the program. Student’s projects are all related to Biomaterials, but range widely in terms of focus:

1. **Jiaqing Zuo, MSc. Graduated, April 2011.** *Synthesis, Physical Properties and Biodegradability of Polyester Amides derived from lipid based components.* Supervised by Dr. Narine, Jiaqing Zuo is a chemist who is originally from China. She is now a senior research scientist working for a private company in Toronto, developing lipid based polymers.
2. **Ghazaleh Pourfallah, MSc., Graduated, January 2013** *Structure and functionality of green polyesters.* Supervised by Dr. Narine, Ms.Pourfallah is originally from Iran. She is currently pursuing a Ph.D. in Australia.

3. **Prasanth Kumar** transferred from the MSc. into the Ph.D. program in Materials Science and is originally from MG University in Kerala, India - a Chemist, he is working on lipid based polyols and polyurethane foams and is supervised by Dr. Narine.
4. **Latchmi Singh** transferred from the MSc. into the Ph.D. program in Materials Science and is a Chemist from the University of Trinidad and Tobago and from the University of the West Indies. She is working on the synthesis of green lubricants and is supervised by Dr. Narine.
5. **Shegufa Merchant** transferred from the MSc. into the Ph.D. program in Environmental and Life Sciences and is a chemist, who is working on the synthesis of hybrid polymers - silica and lipid based polyester urethanes, and this represents a collaboration between Professor Vreugdenhil's group and Professor Narine's group. Shegufa is from Toronto, India and the Persian Gulf.
6. **Michael Floros** transferred from the MSc. into the Ph.D. program in Materials Science and is a chemist and is working on CLICK and anti-microbial polymer films. Mike is from Aurora, Ontario and is supervised by Dr. Narine.
7. **Thien Nguyen Quoc** is a Ph.D. student in the Environmental and Life Sciences graduate program and is from Viet Nam, working with Professors Neil Emery and Suresh Narine on modification of soybeans so as to influence the fatty acid profiles to be more industrially beneficial to producing green chemicals.
8. **Emily Morrison** is an MSc student in the Masters in Sustainability program, working with Professors Narine and Zohar on a critical analysis of the policy environment governing biomaterials, and its impact on the commercialization of such materials. Emily is from Lucknow, Ontario.
9. **Kira Ramphal** is an MSc. student in the Environmental and Life Sciences graduate program, working with Professors Narine and Emery on the cultivation of novel strains of algae which produce stearidonic acid, and the use of hormonal pathways to cause variations in fatty acid profiles. Kira is from Scarborough, Ontario.
10. **Michael Tessier** is a MSc. student in Materials Science, who is working on lipidic Phase Change Materials for energy storage and is supervised by Professor Narine. Mike is a Physicist from Trent University and originally from Peterborough.
11. **Benjamin Musclow** is a MSc. student in Materials Science, who is working on polymeric coatings for the triggered release of urea fertilizers. He supervised by Dr. Narine and is a Peterborough native with a BSc. degree from Trent University.
12. **Athira Mohanan** is a MSc. student in Materials Science seeking to transfer to the Ph.D. program. She is working on the multi-length scale phase behavior of binary eutectic-forming

lipid molecules and is supervised by Dr. Narine. She is a physicist who is originally from Mahatma Ghandi University, Kerala, India.

## **2.0 Outreach Activities:**

The Ontario Research Chair in Green Chemistry and Engineering at Trent University was slated to have the following outreach activities from 2011 (text in *italics* are cut and pasted from the original application to COU):

*In addition to the plans for technology transfer and commercialization with our commercial partners outlined above, the Chair will also commit to establishing a multi-stakeholder network with representatives from the Ontario Ministry of Agriculture, Food and Rural Affairs, the Ontario Ministry of the Environment, the Ontario Ministry of Natural Resources, Environment Canada, Primary Producers, Processors, Academics and other stakeholders, who will be engaged annually and semi-annually through an annual workshop and 2-3 seminars per year. The intent would be to allow the research advisory committee for the Chair to be guided by interactions with this stakeholder community and to allow the stakeholder community to be informed of new products, processes and understanding developed by the Chair's program.*

Outreach activities did not take the form of a workshop organized at Trent University, as there were multiple opportunities to interact with almost all of the stakeholder groups identified above, at multiple workshops, seminars and individual meetings, laboratory tours and conference call updates during 2011, 2012 and 2013. The idea of a workshop has been replaced by a multi-stakeholder symposium, called the Carbon Conversations, established by Professor Narine and the Trent Centre for Biomaterials Research at Trent University.

In June 2013, the Trent Centre for Biomaterials Research hosted a very successful Carbon Conversation in the middle of the commercial district in Toronto (130 Adelaide Street). Speakers were former President of Guyana, Dr. Bharrat Jagdeo (Times Hero of the Environment, UN Champion of the Earth), Chairman and CEO of Northwater Capital, Mr. David Patterson (Trent Alumni; Northwater invests heavily in alternative, green solutions) and Chair and CEO of NRStor, Dr. Annette Verschueren (NRStor is focussed on energy storage solutions which allows excess energy to be stored for conservation purposes, and intermittent alternative sources of energy such as solar and wind to be harnessed for conventional utilization). The event was well attended by the financial sector, provincial and federal government ministries and institutions and academia. Recordings of this and other Carbon Conversations events have been posted on YouTube and the Trent Centre for Biomaterials Research is now planning the next event.

Specifically, the following stakeholder groups were engaged during 2012 - 2013:

## **2.1 Industry**

The following companies toured the facilities at Trent and held discussions with our team:

1. Grain Farmers of Ontario; this organization represents some 23, 000 farmers in Ontario whose markets are affected by our research activities.
2. Elevance Renewable Sciences; this is our main industrial partner, with multiple projects underway. We have monthly meetings with this group.
3. Swish, a local industry which manufactures cleaners.
4. Northwater Capital; Toronto based intellectual capital investment firm.
5. Ecosynthetix, Burlington based biobased biomaterials company.

## **2.2 Government Ministries**

Staff from the following government ministries toured our facilities and held feedback discussions with our staff:

1. Ontario Ministry of Agriculture, Food and Rural Affairs.
2. Ontario Ministry of the Environment – our team participated in a Green Chemistry Symposium

## **2.3 Enabling Organizations**

The following organizations have also toured our facilities and engaged with our staff:

1. Ontario Bioproducts A team - A specialized business-savvy biomaterials team providing solutions for industry, this organization was put together by a number of university professors working in the biomaterials area, under the leadership of the OAFT. We have been an integral part of this team, and have had numerous meetings with our counterparts across the country.

## **2.4 Universities**

In addition to the above stakeholders, including the list of Universities represented in the Ontario Bioproducts A team, we have also developed close collaborative and communication relationships with the following universities:

1. Professor Mohini Sain, University of Toronto (we have had numerous visits from Professor Sain and his group and have visited his facilities at University of Toronto numerous times).

2. Professors Misra and Mohanty, University of Guelph (we have had several meetings with these stakeholders, from the University of Guelph, and have participated in their workshops).
3. Professor Leonardo Simon, University of Waterloo (Professor Simon visited our laboratory and interacted with our team, and Professor Narine also visited Professor Simon's laboratory at the University of Waterloo - the two groups committed to working on collaborative projects).

## **2.5 Seminars and Presentations**

In addition to the above outreach efforts, Professor Narine and the rest of the staff have been very active in terms of presenting our work at national and international conferences:

1. **Suresh S. Narine**, *Lipid-based Thermoplastics: Understanding Structure-Function*. **Plenary Invited Talk**, Symposio Argentino de Polimeros, Argentina, August 28—03, 2013, Buenos Aires, Argentina. (200 people in audience)
2. Laziz Bouzidi and **Suresh S. Narine**, *Functional Biomaterials derived from vegetable Oils: Foods, Waxes, Chemicals, Lubricants, Polymers and Biodiesel*. **Invited Talk**, AgBiomass National Conference, Canada, August 22—23, 2013, Ottawa, Ontario, Canada.
3. Shegufa Merchant, Shaojun Li, Andrew Vreugdenhil and **Suresh S. Narine**, *Synthesis and molecular weight control of entirely lipid derived aliphatic polyester diols*. 104th Annual AOCS Meeting, April 28—May 1, 2013, Palais de congrès de Montréal, Montréal, Québec, Canada.
4. Jesmy Jose Shaojun Li, Laziz Bouzidi, and **Suresh S. Narine**, *Investigating Structure-Property Relationships in Lipid derived Thermoplastic Polymers*. 104th Annual AOCS Meeting, April 28—May 1, 2013, Palais de congrès de Montréal, Montréal, Québec, Canada.
5. Shaojun Li, Laziz Bouzidi and **Suresh S. Narine**, *Examining the Functionality of Self-Metathesized Vegetable Oil and Controlling the Products by Manipulating Reaction Conditions*. 104th Annual AOCS Meeting, April 28—May 1, 2013, Palais de congrès de Montréal, Montréal, Québec, Canada.
6. Laziz Bouzidi, Latchmi Raghunanan, Shaojun Li and **Suresh S. Narine**, *Use of Vegetable Oil Derived Branched Linear Monoesters and Diesters as Superior Lubricants*. 104th Annual AOCS Meeting, April 28—May 1, 2013, Palais de congrès de Montréal, Montréal, Québec, Canada.
7. **Suresh S. Narine** and Laziz Bouzidi, *Investigating the Eutectic Behavior of Certain Structured TAGs and FAMES*. 104th Annual AOCS Meeting, April 29—May 2, 2013, April 28—May 1, 2013, Palais de congrès de Montréal, Montréal, Québec, Canada.

8. Athira Mohanan, Laziz Bouzidi and **Suresh S. Narine**, *Multi-Length-Scale Structural Elucidation of Mechanisms Responsible for Inhibiting FAME Crystallization*. 104th Annual AOCS Meeting, April 28—May 1, 2013, Palais de congrès de Montréal, Montréal, Québec, Canada. Talk Delivered by Athira Mohanan

9. Latchmi Raghunanan, Laziz Bouzidi, Shaojun Li and **Suresh S. Narine**, *Investigating the Thermal Stability of Linear Diesters Derived from Vegetable Oils: Dependence of Thermal Stability on the Beta Hydrogen and its Environment*. 104th Annual AOCS Meeting, April 29—May 2, 2013, Montreal, QC. Talk Delivered by Latchmi Raghunanan

10. Shaine Joseph, Laziz Bouzidi and **Suresh S. Narine**, *A statistical tool for lipid data segmentation and analysis: Straight Line Analysis Tool (SLAT) Software*. 104th Annual AOCS Meeting, April 28—May 1, 2013, Palais de congrès de Montréal, Montréal, Québec, Canada. Poster presentation.

11. Michael Floros, Shaojun Li and **Suresh S. Narine**, *Using 'Click Chemistry' to Produce Green Monomers and Polymers from Vegetable Oils*. 104th Annual AOCS Meeting, April 28—May 1, 2013, Palais de congrès de Montréal, Montréal, Québec, Canada. Poster presentation.

12. Jesmy Jose and **Suresh S. Narine**, *Synthesis and physical properties of Lipid-based Poly(ester-urethane)s: Effect of varying polyester segment length*, Denton Dallas Texas 18th-21st September 2012.

13. Michael Floros, Leila Hojabri, Eldho Abraham, Jesmy Jose, Sabu Thomas, Laly Potan, Alcides Lopes Leao and **Suresh S. Narine**, *Enhancement of thermal stability, strength and extensibility of lipid-based polyurethanes with cellulose-based nanofibers*, Denton Dallas Texas 18th-21st September 2012.

14. Laziz Bouzidi, Latchmi Raghunanan, Shaojun Li and **Suresh S. Narine**, *Use of Vegetable Oil Derived Branched Linear Monoesters and Diesters as Superior Lubricants*. **Invited Talk**, The Canadian Thermal Analysis Society (CTAS) workshop and exhibition, May 6—May 8, 2013, Oshawa, ON.

15. **Suresh S. Narine** and Laziz Bouzidi, *Investigating the Eutectic Behavior of Certain Structured TAGs and FAMES*. **Invited Talk**, The Canadian Thermal Analysis Society (CTAS) workshop and exhibition, May 6—May 8, 2013, Oshawa, ON.

16. Athira Mohanan, Laziz Bouzidi and **Suresh S. Narine**, *Multi-Length-Scale Structural Elucidation of Mechanism Responsible for Inhibiting FAME Crystallization*. The Canadian Thermal Analysis Society (CTAS) workshop and exhibition, May 6—May 8, 2013, Oshawa, ON. Talk Delivered by Athira Mohanan

17. Latchmi Raghunanan, Laziz Bouzidi and **Suresh S. Narine**, *Investigating the Thermal Stability of Linear Diesters Derived from Vegetable Oils: Dependence of Thermal Stability on the Beta Hydrogen and its Environment*. The Canadian Thermal Analysis Society (CTAS) workshop and exhibition, May 6—May 8, 2013, Oshawa, ON. Talk Delivered by Latchmi Raghunanan

18. **Suresh S. Narine**, *Remaking the Materials World: Greasy is the new cool*. Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada.

19. Laziz Bouzidi and **Suresh S. Narine**, *Food Lipids: The Original Biomaterial*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada.

20. Jesmy Jose and **Suresh S. Narine**, *Understanding Structure-function of Lipid-derived Thermoplastics*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada.

21. Prasanth S.Pillai, Shaojun Li and **Suresh S. Narine**, *New generation bio-based Polyols and Polyurethane foams*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

22. Shaojun Li, Laziz Bouzidi and **Suresh S. Narine**, *TGBR 1st Generation Green Biolubricants: Oleic Acid Based Monoesters and their Branched Derivatives*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

23. Mark Baker, Laziz Bouzidi and **Suresh S. Narine**, *Keeping Fuels Fluid - The Binary Phase Behaviour of OSO and Methyl Stearate*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

24. Arun Gopinath L, Laziz Bouzidi and **Suresh S. Narine**, *Overcoming the Low Temperature Problem in Biodiesel – Strategies with Oligomers –Dimer - Methyl Palmitate phase behavior*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

25. Shaojun Li, Laziz Bouzidi and **Suresh S. Narine**, *Oligomers from Vegetable Oil: Molecules for Enhanced Biolubricant Formulations*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

26. Shawna Miles, Laziz Bouzidi and **Suresh S. Narine**, *Investigating the Unusual Properties & Behaviour of Liquid Glasses*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

27. Shaojun Li, Leila Hojabri and **Suresh S. Narine**, *Metathesis– A Green Chemistry for Novel and Enhanced Materials from Vegetable Oils*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

28. Latchmi Singh, Laziz Bouzidi, Shaojun Li and **Suresh S. Narine**, *Towards superior bio-based lubricants: structure-property correlations of 2nd-generation esters*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

29. Athira Mohanan, Bruce Darling, Laziz Bouzidi and **Suresh S. Narine**, *Overcoming the Low Temperature Problem in Biodiesel – Strategies with Unsaturated Triglycerides - OPO in Methyl Palmitate*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

30. Shaine Joseph, Sabine McConnell, Laziz Bouzidi and **Suresh S. Narine**, *Biomaterials Database Project*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

31. Shaine Joseph, Dave Evans, Laziz Bouzidi and **Suresh S. Narine**, *SLAT: a Reliable Software to Model Segmented Data from Lipid Studies*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

32. Ghazaleh Pourfallah, Jesmy Jose, Shaojun Li and **Suresh S. Narine**, *Making Biodegradable Polyesters from Vegetable Oil*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

33. Shegufa Merchant, Jesmy Jose, Shaojun Li, Andrew Vreugdenhil and **Suresh S. Narine**, *Imparting Elastomeric Properties to Vegetable Oil derived Poly(ester-urethane)s*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

34. Michael Floros, Leila Hojabri, Eldho Abraham, Jesmy Jose, Sabu Thomas, Laly Pothan, Alcides Lopes Leao and **Suresh S. Narine**, *Entirely Lipid Based Thermoplastic Polyurethane Cellulose Nanocomposites*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation

35. Michael Floros, Shaojun Li and **Suresh S. Narine**, *Antimicrobial Plastics and “Click” Chemistry*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

36. Christopher Anzenberger, Shaojun Li and **Suresh S. Narine**, *Novel, Environmentally-friendly Waxes: Clean Syntheses From Sustainable Starting Materials*, Ministry of the Environment Green Chemistry Symposium, November 27, 2012, MOE Toronto, Canada. Poster Presentation.

37. Laziz Bouzidi and **Suresh S. Narine**, *Use of time-resolved X-Ray Diffraction to monitor the difference in phase transformation trajectories of TAGs containing Oleic and stearic acids, as a function of symmetry and cooling rate*. 103rd Annual AOCS Meeting, April 29—May 2, 2012, Long Beach Convention Center, Long Beach, California, USA.

## **2.6 International Collaborations**

An impressive array of international collaborations have been set up as part of the Chair's program:

1. Mahatma Ghandi University, Kerala, India (a number of student and faculty exchanges have occurred, and this is set to continue as we embark on collaborative projects with this university).
2. Universidade Estadual de Paulista (UNESP), Botucatu, Brazil (in addition to student and faculty exchanges, Trent University through the Chair's program, the University of Toronto, and UNESP has been successful in securing funding from the Canada-Brazil Research Partnerships Program, and this is resulting in increased collaboration among these universities).
3. Hebrew University, Jerusalem, Israel (we have had faculty visits from this university and Professor Narine has also visited the Hebrew University. A number of crystallization-based projects have been established).
4. University of the West Indies, Cave Hill, Barbadoes. Major collaborative projects underway in the areas of green chemistry between UWI and Trent, and Professors Narine and Tinto.
5. The TCBR also has close collaborative projects with the Malaysian Palm Oil Board, and Professor Narine and Dr. Hazima Binti Abu Hassan, Director, Malaysian Palm Oil Board, Kuala Lumpur, have visited each other's facilities and have various projects underway.

## **3.0 Research Activities:**

The Ontario Research Chair in Green Chemistry and Engineering at Trent University was slated to have the following research related focus over the course of the program (text in *italics* are cut and pasted from the original application to COU):

- 1) *A fundamental understanding of the crystallization of lipid and modified lipid networks to direct the modification of natural molecular ensembles and processing conditions in order to design crystal network structures with specific physical properties in a stable thermodynamic state.*
- 2) *Development of chemical modification techniques that can alter the chemical functionality of lipids, so as to produce high value chemicals, functional monomers and functional supra-molecular assemblies, including nano-scale delivery systems.*
- 3) *A fundamental understanding of the inter-relationships between the chemical functionality of monomers, processing conditions, derived structural hierarchies, and the resultant physical functionality of the polymer networks created from lipid-derived monomers.*

In 2012-2013, although the research group has made more progress than in any other year since the inception of the Ontario Research Chair in Green Chemistry and Engineering research program, 60 – 70 % of our work is delayed from publication due to the need to file patents. As can be seen below, seven (7) patents were filed in 2012 – 2013 and 3 – 4 additional applications are currently being worked on. Given the confidentiality considerations around patents that are currently being filed, this report refrains from discussing the work implicated, and instead focusses on the published work and patents filed, listed below.

Publication [1] results from our work in both fundamental objectives 1 and 2 – a series of aliphatic monoesters and their branched derivatives were synthesized from vegetable oils. Their viscosity profiles, cold flow characteristics, thermal and hydrolytic stability and resistance to oxidation resulted in a vastly superior range of base oils being developed for use as lubricants (detailed in the issued patent below, [8]). This publication is the fifth in a series which will eventually amount to seven publications reporting on this work. It relates to both fundamental objective 1 (in its focus on understanding the relationship between molecular structure and avoided crystallization) and fundamental objective 2 (in its focus on synthesis of the specialized molecules, in particular focussing on green metathesis routes). Publication [3] focusses on the development of a theoretical understanding of the relationship of the thermal stability of aliphatic esters on their structure, and is important not only to lubricants, but also polyesters in general. It presents convincing arguments, not previously articulated, on the importance of shielding in thermal stability, using high resolution NMR and thermal gravimetric techniques.

Publication [2] results from work in fundamental objectives 2 and three – the work details the synthetic routes that can be utilized to prepare novel diacids, diisocyanates, and diols, for further use as monomers for the production of oligomeric structures for use in the lubricant industry as well as polymers such as polyurethanes, polyesters and polyamides. This work sets a fundamental enabling baseline for many of our other work on polyesters, polyesterurethanes and polyesteramides detailed in last year's report, and also utilized in the patent application on polyesters listed below [14].

Publication [4] focusses on work being performed under both fundamental objectives 1 and 2. A significant amount of our work is now focussed on the green conversion of vegetable oils into a multitude of structures suitable to be exploited from a biorefinery concept. Among the potential uses are chemicals, additives, monomers, lubricants, cosmetics and waxes. One of the common, simple reactions that can be performed under green chemistry conditions is the self-metathesis of vegetable oils. This process can yield a homologous series of oligomers, cyclic structures and a variety of isomers, depending on the reaction conditions (elucidated through our work last year and reported in last year's report). One of the classes that are produced; triacylglycerol oligomers have never been thoroughly investigated from a structure-function perspective. Given their ease of preparation, high yields and the green synthesis route, it is important to determine the applications to which they may be suited. This publication is the first of a series which is aimed at developing an understanding of the way the physical properties of these structures are dependent on their structural variations.

Publications [5 – 7] are focussed on our collaborative work with Professors Alcides Leao, Mohini Sain and Sabu Thomas, in Brazil, Canada and India respectively. This collaboration is focussed on the utilization of cellulose and its nano-scale derivatives in a wide variety of applications from food all the way to packaging and anti-microbial applications.

Patents [9-13] describe the group's highly successful work in developing chemical additives which lower the crystallization temperature of biodiesel. Some 5 – 6 publications were held back due to the need to patent this work, as evidenced by the number of patent applications filed. These publications are now being submitted for publication – they establish a structural disruption strategy at the molecular level, which scales all the way to the macroscale, to prevent nucleation and crystal growth of saturated methyl esters.

### **Manuscripts published in 2012/2013**

1. Laziz Bouzidi, Shaojun Li, Steve Di Biase, Syed Q. Rizvi and **Suresh S. Narine** (2013), *Lubricating and waxy esters, IV: synthesis, crystallization, melt and flow behavior of linear monoesters incorporating 9-decenol and 9-decenoic acid*. Industrial & Chemistry Research, 52 (7), pp 2740–2749. DOI: 10.1021/ie302995z.
2. Latchmi Raghunanan, Jin Yue and **Suresh S. Narine**. (**In Press, 2013**), *Synthesis and Characterization of Novel Diol, Diacid and Di-isocyanate from Oleic Acid*. Journal of American Oil Chemists' Society, DOI: 10.1007/s11746-013-2376-z
3. Latchmi Raghunanan and **Suresh S. Narine** (**In Press, 2013**), *Influence of Structure on Chemical and Thermal Stability of Aliphatic Diesters*, Journal of Physical Chemistry Part B: Biophysical Chemistry, Biomaterials, Liquids, and Soft Matter
4. Shaojun Li, Laziz Bouzidi and **Suresh S. Narine** (2013). *Synthesis and Physical Properties of Triacylglycerol Oligomers: Examining the Physical Functionality Potential*

*of Self-Metathesized Highly Unsaturated Vegetable Oils*. Industrial & Chemistry Research. 52 (6), pp 2209–2219. DOI: 10.1021/ie302921h.

5. Cherian, B. M., Leao, A. L., de Morais C. M. R., de Souza, S. F., Sain, M., **Narine, S. S.**, (2013) *Environmental Ageing Studies Of Chemically Modified Micro And Nanofibril Phenol Formaldehyde Composites*, Industrial Crops and Products, 49, pp. 471-483. DOI: 10.1016/j.indcrop.2013.04.033

#### **Book Chapters Published in 2012/2013**

6. Cherian, B. M., de Souza, S. F., Leao, A. L., de Morais C. M. R., **Narine, S. S.**, (2013), *Potential Biomedical Applications of Renewable Nanocellulose*, In: Green Composites from Natural Resources, Ed: Vijay Kumar Thakur, Taylor & Francis, New York, v.1, p. 1-40, ISBN: 978-1466570696.
7. Cherian, B. M., Leao, A. L., de Souza, S. F., de Olyveira, G. M., Costa, L. M. M., Brandão, C. V. S., **Narine, S. S.**, (2012), *Bacterial Nanocellulose For Medical Implants*, In: Advances in Natural Polymers, Eds: Sabu Thomas, P. M. Visakh, Aji. P. Mathew, Springer Berlin Heidelberg, Berlin, v18, p. 337-359, ISBN: 978-3-642-20940-6.

#### **Patents Filed in 2012/2013**

8. **Suresh S. Narine**, Shaojun Li, Ali Mahdevari, Laziz Bouzidi, Steve DiBiase and Syed Abbas. (Filed February 13, 2011) “*Esters for use as a base stock and in lubricant applications*”. Application Number: 13/026,268. Published: US, PCT,EPO, Canada, China and India.
9. **Suresh S. Narine**, Laziz Bouzidi, Bruce Darling, Mark Baker, Shaojun Li and Ali Mahdevari. U.S. Provisional Patent Application (Filed March 15, 2012) “*Certain Dimers as Crystallization Depressants*”. Application Number: 61/798, 974.
10. **Suresh Narine**, Laziz Bouzidi, Bruce Darling, Mark Baker, Shaojun Li, and Ali Mahdevari, U.S. Provisional Patent Application (Filed 14 March 2013) “*Polymorphism and Microstructure of Certain Triacylglycerols and fatty acid methyl esters*” Application Number: 61/785, 418.
11. **Suresh Narine**, Laziz Bouzidi, Bruce Darling, Mark Baker, Shaojun Li, and Ali Mahdevari, U.S. Provisional Patent Application (Filed 13 March 2013) “*Phase behaviors and properties of certain triacylglycerols and fatty acid methyl esters*” Application Number: 61/780, 817.
12. **Suresh Narine**, Laziz Bouzidi, Bruce Darling, Mark Baker, Shaojun Li, and Ali Mahdevari, U.S. and PCT Non-Provisional Patent Application (Filed 15 April 2013) “*Phase behaviors and properties of certain triacylglycerols and fatty acid methyl esters*” Application Number: 13/863, 137.
13. **Suresh Narine**, Laziz Bouzidi, Bruce Darling, Mark Baker, Shaojun Li, and Ali Mahdevari, U.S. Non-Provisional Patent Application (Filed 15 April 2013) “*Phase behaviors and properties of certain triacylglycerols and fatty acid methyl esters*” Application Number: 13/863, 105.
14. **Suresh Narine**, Ghazaleh Pourfallah, Jesmy Jose, Laziz Bouzidi and Shaojun Li, U.S. Provisional Patent Application (Filed 30 August 2013) *Aliphatic Polyesters and Copolyesters Derived from Natural Oils and their Related Physical Properties*, Application Number: 61872594