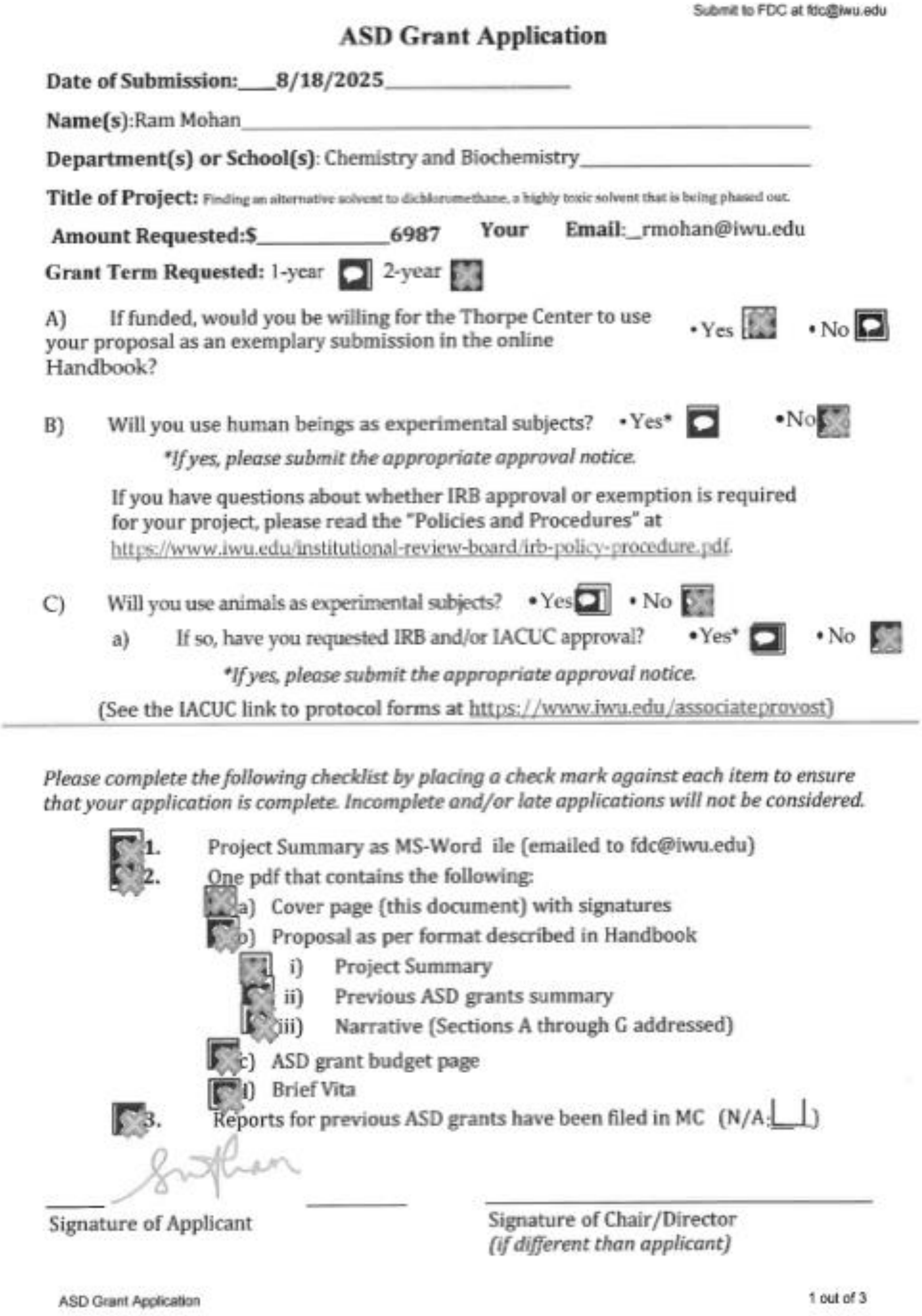


Submit to FDC at fdc@iwu.edu

ASD Grant Application

Date of Submission:___8/18/2025________________

Name(s): Ram Mohan____

Department(s) or School(s): Chemistry and Biochemistry____________________

Title of Project: Finding an alternative solvent to dichloromethane, a highly toxic solvent that is being phased out.

Amount Requested:$___________6987 **Your Email:**_rmohan@iwu.edu

Grant Term Requested: 1-year ☐ 2-year ☒

A) If funded, would you be willing for the Thorpe Center to use your proposal as an exemplary submission in the online Handbook? • Yes ☒ • No ☐

B) Will you use human beings as experimental subjects? • Yes* ☐ • No ☒

**If yes, please submit the appropriate approval notice.*

If you have questions about whether IRB approval or exemption is required for your project, please read the "Policies and Procedures" at https://www.iwu.edu/institutional-review-board/irb-policy-procedure.pdf.

C) Will you use animals as experimental subjects? • Yes ☐ • No ☒

a) If so, have you requested IRB and/or IACUC approval? • Yes* ☐ • No ☒

**If yes, please submit the appropriate approval notice.*

(See the IACUC link to protocol forms at https://www.iwu.edu/associateprovost)

Please complete the following checklist by placing a check mark against each item to ensure that your application is complete. Incomplete and/or late applications will not be considered.

- ☒ 1. Project Summary as MS-Word file (emailed to fdc@iwu.edu)
- ☒ 2. One pdf that contains the following:
  - ☒ a) Cover page (this document) with signatures
  - ☒ b) Proposal as per format described in Handbook
    - ☒ i) Project Summary
    - ☒ ii) Previous ASD grants summary
    - ☒ iii) Narrative (Sections A through G addressed)
  - ☒ c) ASD grant budget page
  - ☒ d) Brief Vita
- ☒ 3. Reports for previous ASD grants have been filed in MC (N/A: ☐)

Signature of Applicant

Signature of Chair/Director
(if different than applicant)

Submit to FDC at fdc@iwu.edu

ASD Grant Budget Page

Faculty Name(s) Ram Mohan

Project Title Finding an alternative solvent to dichloromethane, a highly toxic solvent that is being phased out

A. Equipment Description (please give source of recent estimate) $0

B. Supplies and Services $2987
(please itemize below, & attach an additional sheet, if necessary)

Attached

C. Travel Expenses (please itemize) $0

D. Consultancy Fees $0

E. Living Expenses (see proposal guidelines) $0

F. Student Wages (see proposal guidelines) $0

G. Faculty Stipend (maximum $2,000 per faculty member for 1-year; $4,000 for 2-year) $4000

H. Publication Expenses $0

I. Other $0

TOTAL: $ 6987

(Maximum award $3,500 per individual or $5,500 for a joint proposal from two or more faculty members for a one-year grant and $7,000 per individual or $11,000 for a joint proposal for a two-year grant)

NOTE: *List all expenses, even if the total exceeds the maximum grant. If your budget exceeds the maximum grant, explain how you will make up for the shortfall.*

ASD Grant Application

(Technical words or phrases are in *italics* and are explained in the glossary at the end of the proposal).

Project title: ***Finding an alternative solvent to dichloromethane, a highly toxic solvent that is being phased out.***

1. Cover Page: Attached

2. Summary of Project

The utility of synthetic organic chemistry in generating a wide range of useful molecules including life-saving drugs is unquestionable. Work continues to be done to develop new *reagents, catalysts[1] and reactions,*[2] which are then used in the assembly of complex target molecules. Although one of the important components of most organic reactions is the solvent, it has historically received less attention. One of the most commonly used solvents, dichloromethane is now banned for routine use because of its highly toxic and deadly nature. This will have serious implication especially in the pharmaceutical industry where it is one of the most used solvents. Hence it is imperative that alternative, greener solvents be found. The focus of this proposal is to investigate the utility of 2-methyltetrahydrofuran (2-MeTHF), a green and sustainable organic solvent, as a replacement for dichloromethane.

3. Summary of Previous three ASD grants:

3.1. ASD Grant awarded in Spring 2021

Title: *Bismuth(III) compounds catalyzed synthesis of substituted imidazoles:compounds of biological relevance*

Amount: $3469

End Product: The stated goals were achieved. Working with several IWU students I was able to demonstrate that bismuth(III) triflate is an efficient catalyst for the synthesis of substituted imidazoles. This work was published in a peer reviewed international journal, *Green and Sustainable Chemistry.* All co-authors are/were IWU undergraduates.

Reference: Thorp, S. C., Chisari, S. T., David, R. Q. V., Gjata, A., Good, A. L., Lopez, E., Mohan, R. S. Bismuth (III) triflate catalyzed multicomponent synthesis of 2,4,5-trisubstituted imidazoles. *Green and Sustainable Chemistry* **2023, 13,** 209-215. **DOI:** 10.4236/gsc.2023.133011

3.2. ASD Grant awarded in Spring 2019

Title: "*Bismuth(III) compounds catalyzed synthesis of hexahydroimidazopyridines via a multicomponent reaction*."

Amount: $3307.60

End Product: The stated goals were achieved. Working with four IWU students I was able to demonstrate that bismuth(III) chloride is an efficient catalyst for the multicomponent synthesis of hexahydroimidazopyridines. This work was published in a peer reviewed international journal *Green and Sustainable Chemistry.* All co-authors were IWU undergraduates.

Reference: Bismuth(III) chloride catalyzed multicomponent synthesis of substituted hexahydroimidazo[1, 2-*a*]pyridines. Haskin, N. T.; Gungrich, R. A.; Schrader, A.J.; Crosse, M.

R.; Dave, A. Y.; Begari, E.; Mohan, R. S. *Green and Sustainable Chemistry* **2021,** *11*, 89-95.
DOI: 10.4236/gsc.2021.113008

3. 3. ASD Grant awarded in Spring 2017

Title: "*Bismuth(III) salts Catalyzed Addition of Nucleophiles to α, β-unsaturated ketones (chalcones).*"
Amount: $3469.60
End Product: Working with two IWU students (Lauren Yep and Zhijia Geng)) I was able to demonstrate that bismuth(III) bromide is an efficient catalyst for this reaction. The reactions were very clean (i.e. no impurities formed) and the product was obtained in good yields. This work was presented by Lauren and Zhijia at *The Great Lakes American Chemical Society Regional Meeting in Lisle, IL* (May 2019). Posters at this meeting are peer reviewed. I was also invited to give a talk at this meeting and I included results from this project. We plan to get more results on this work using some other catalysts to make a comprehensive manuscript.

How is the present proposal different from my previous projects?

At the first glance it may seem like in all my ASD grant proposals I'm seeking money to buy catalysts and supplies for organic transformations, and hence for the same project! Although the bread and butter of my research program is the use of nontoxic bismuth salts as green catalysts, this proposal represents a very new direction in my research program—search for environmentally benign and sustainable solvents to replace dichloromethane, a deadly solvent.

4. **Narrative** (word count 2226)

4. a. End product of the project

I expect to publish the results as 1-2 manuscripts in international chemistry journals such as *Green & Sustainable Chemistry, Journal of Organic Chemistry or Tetrahedron Letters.* I expect IWU students to be co-authors on these manuscripts.

4. b. Scholarly Significance of the Project:

4. b. i. The Nature of the problem to be examined

A technical description of the proposed work is given in the appendix. A less technical description is given here. Research in my group is focused on developing environmentally friendly *synthetic methodology*.[3] With increasing environmental concerns, it is imperative that the methods used to synthesize useful molecules such as lifesaving drugs, pesticides, fungicides, insecticides, perfumes, etc. be environmentally benign. For example, it is ironic that as recent as ten years ago, *cancer-causing chemicals*[4] have been released into the environment in the process of synthesizing anticancer drugs! With the *Pollution Prevention Act*[5] and heightened awareness for the environment, it is of utmost importance that synthetic chemists develop green and environmentally benign pathways to their target molecules. In other words, it is no longer sufficient to just get to the destination (target molecule)—*The Journey* itself matters (environmentally friendly path) [*Ref 1*]. While we are not targeting the synthesis of any particular drug in my group, we are interested in developing general environmentally friendly methods to convert one *functional group* to another. A *functional group* is defined as an atom or a group of atoms that define the properties of a compound. For example, although the structures (shown below in Figure 1) of both ethyl alcohol (alcohol found in beverages) and cholesterol look very different at the first glance, the properties of these compounds are remarkably similar in many respects because they both contain the same functional group (the hydroxy group, highlighted by the box). *Functional group is where all the action takes place during a chemical reaction***.**

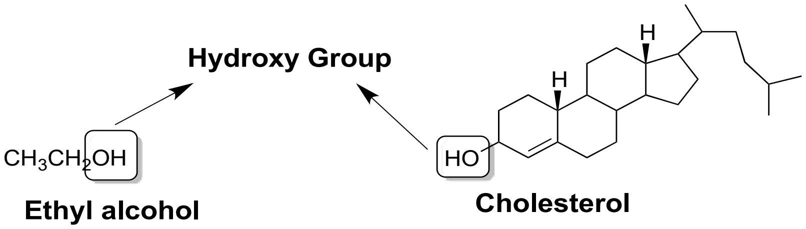
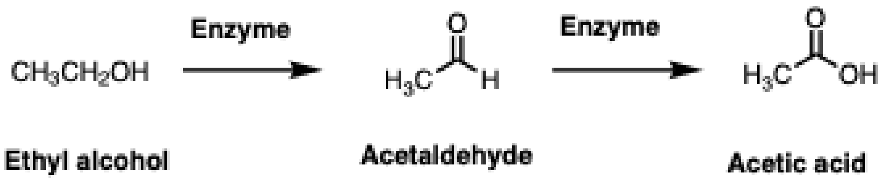


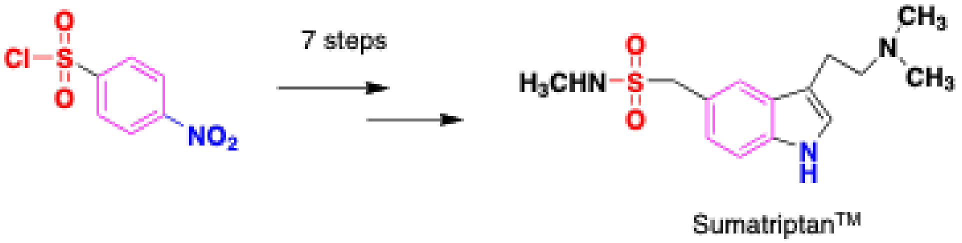
Figure 1

The process of synthesizing a *drug molecule*[6] can often be very long and typically involves a series of steps, each step being the conversion of one functional group to another. Functional group transformation is at the heart of organic synthesis. Even in the human body, functional group transformations are happening at all times. When we imbibe ethyl alcohol, it is converted by an enzyme in the liver to acetaldehyde (the new functional group is an aldehyde), and then to acetic acid, which has the functional group carboxylic acid (Scheme 1).



Scheme 1

Unlike the above conversion, the synthesis of a drug molecule can involve as many as 35 steps. For example, by a series of seven steps (considered a short synthesis!), the molecule shown on the left in Scheme 2 is converted to Sumatriptan™, one of the most widely prescribed migraine medicines.



Scheme 2

Each step in the above sequence is a unique functional group transformation (A→ B), and requires a catalyst and a solvent.

$$\mathbf{A} \xrightarrow[\text{Solvent}]{\text{Catalyst}} \mathbf{B}$$

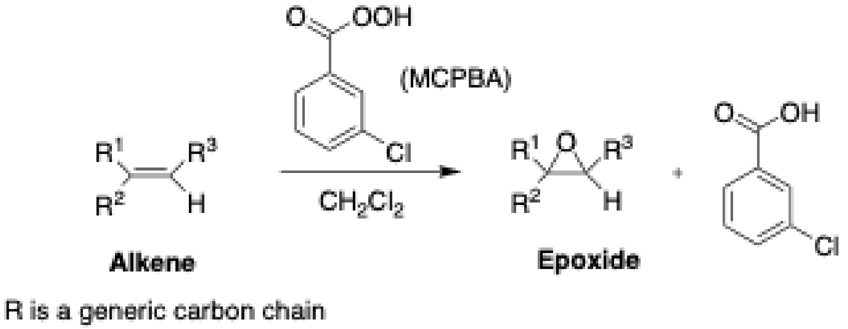
While considerable efforts have focused on finding green, nontoxic catalysts (my own research group focuses on catalysts derived from the green element bismuth), historically much less attention has been devoted by chemists to solvents. One of the most common solvents used in industrial settings (as an *extraction solvent*[7] and as a metal cleaner), consumer products (e.g., paint removers) and pharmaceutical industry is dichloromethane, CH_2Cl_2. Inhalation exposures can result from using consumer products containing dichloromethane such as adhesives, spray shoe polishes, paint and adhesive removers. Additionally, people working in a laboratory setting are likely to inhale dichloromethane even with protective gear because the solvent is very volatile (Boiling point is ~ 40 °C).

What is the problem with dichloromethane?

Dichloromethane, CH_2Cl_2 is toxic and deadly, so it is *ironic* that the efforts to phase it out have come only now and not decades back. Symptoms of over exposure to CH_2Cl_2 include nausea, dizziness, fatigue and headaches. More severe effects include coma and death. According to the Environmental Protection Agency (EPA), 88 people have died from acute exposure to dichloromethane since the late 1990s (*Ref 2*). It was a classic case of familiarity breeds contempt, and chemists in the pharmaceutical industry and workers in the paint industry among others have used it in a cavalier manner. Even short-term exposure to dichloromethane can affect the nervous system. Long term exposure can damage the liver and cause cancer of the liver and lungs. Unfortunately, even standard laboratory nitrile gloves do not offer the needed protection as dichloromethane can penetrate nitrile gloves. I'm pleased to say that we eliminated the use of dichloromethane in our sophomore organic chemistry labs at IWU in 2010, a good 15 years before the EPA ban. We stopped its use completely in 2019 in my research laboratory. The reason this ban has come so late is that it was only in 2016 that the US congress passed legislation to revise the EPA's Toxic Substances Control Act (TSCA). The revised legislation has given EPA sweeping powers to ensure that workers at their workplace were not exposed to carcinogenic and toxic chemicals that are potentially deadly. The first compound to be banned under this legislation was asbestos, dichloromethane is the second. The paint industry used dichloromethane extensively for stripping paint and this caused serious repercussions for the workers. Even with this ban, exceptions are being allowed for the pharmaceutical industry with strict guidelines for monitoring the level of dichloromethane in the air (not a trivial task and requires specialized equipment). Many argue, and I concur that this is not going far enough and we need a complete ban. In my view, the complete ban will come in another couple years, so the sooner we find alternative solvents, the better. Although the exact mechanism of the toxicity of dichloromethane is not well understood, studies indicate that the primary mode of *metabolism*[8] is reaction with a *peptide*[9] called glutathione and formation of carbon monoxide.

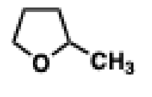
4. b. ii. Scholarly context being addressed

The reaction we plan to study is the epoxidation of alkenes**[10]** which results in the formation of an epoxide[11] as the product. This is an old and well known transformation that is carried out by reaction of an alkene with a reagent called *meta*-chloroperoxybenzoic acid (MCPBA) (Scheme 3).



Scheme 3

This is a very important transformation in organic synthesis as this method allows easy access to a highly useful class of molecules known as *epoxides.* Unfortunately, this reaction works well only in dichloromethane and almost all reports of this transformation use dichloromethane as the solvent. Other solvents provide a low yield of the product. For example, almost no reaction is observed when solvents such as ethanol, CH_3CH_2OH are used. This is attributed to the formation of a *hydrogen bond*[12] between the OH group of the solvent, ethanol and the OH group in MCPBA. Hence we chose this important reaction as a model to find replacement for CH_2Cl_2.



2-MeTHF

Preliminary results obtained in April 2025 in my laboratory by IWU undergraduates showed that 2-methyltetrahydrofuran (2-MeTHF) holds considerable promise as a replacement for CH_2Cl_2. This is very exciting result and we wish to pursue this further as soon as possible so we do not risk getting "scooped." Unfortunately, I was not able to devote time to research in summer of 2025, and hence we are all the more eager to move fast on this important finding.

The core of this two-year proposal is to use 2-methyltetrahydrofuran (2-METHF) as a replacement for dichloromethane for not only epoxidation reactions, but some other important organic reactions previously reported only in dichloromethane, CH_2Cl_2 as well (please see appendix for technical details).

What is 2-MeTHF and why is it an attractive solvent?
2-Methyltetrahydrofuran (2-MeTHF) is touted as a biofuel since it is typically produced from renewable biomass rich with *cellulose*[13], and *lignin*[14] such as corncobs or *bagasse*[15] [*Ref 3*]. 2-Methyltetrahydrofuran has low toxicity and is not carcinogenic, unlike dichloromethane. 2-Methyltetrahydrofuran is approved by the United States Department of Energy as a gasoline additive

4. b. iii. Methodology to be used.

Experimental Steps:

(i) Carry out the epoxidation of a variety of alkenes in 2-methyltetrahydrofuran (2-MeTHF) as the solvent in place of dichloromethane.

Epoxidation is the process of converting the functional group (alkene) to another functional group (epoxide) as shown in Scheme 1 [*Ref 4*]. As can be seen from the scheme, the process involves a reagent (MCPBA) and a solvent, CH_2Cl_2.
This step involves several laboratory operations—the starting materials will be dissolved in the solvent, 2-MeTHF, and the reagent, MCPBA will be added. The progress of the reaction will be followed by *TLC,*[16] and when the reaction is complete (i.e. starting material viz. the alkene is no longer present), the solvent will be removed and the product isolated (details of this process are also given in the appendix). Often, chemical reactions give undesired products (impurities) in addition to the desired product and hence the product must be purified by a technique called *flash chromatography*.[17] A detailed list of alkenes that will be used in shown in the appendix.

(ii) Analyse the products using an NMR spectrometer (please see glossary 19).

(iii) Repeat the reactions on a larger scale (1.0 gram) to demonstrate the practicality of the developed method.

A similar methodology will be followed for part 2 of this project (allylation reaction, which is outlined in the appendix).

4. b. iv. The contribution the individual expects to make with the work.

I expect to publish one manuscript in an international chemistry journal, such as *Green and Sustainable Chemistry, Journal of Organic Chemistry or Tetrahedron Letters.* Student co—authors work in the lab alongside me to carry out the experiments and are also involved in various stages of drafting the manuscript. In sciences this kind of collaboration is the norm and common.

4. c. Professional Significance of the Project

The proposed work is likely to lead to development of a new, green solvent for use in organic transformations. At the end of Spring semester 2025 we carried out this reaction with four alkenes and got very exciting results. These results convince us that 2-MeTHF is a promising solvent and there is a high chance the project will be successful. At the risk of sounding like we are patting our own back, I would like to state that if successful, this would be a very exciting and ground breaking discovery that would attract considerable attention from synthetic chemists, and especially from the pharmaceutical industry. This would also be a new contribution to the field of organic synthesis using a green solvent. With the help of this ASD grant I expect to bring this project to fruition, which should result in increased recognition of my work in the field and will possibly lead to new research collaborations in the future, and possibly attract funding for further work from the pharmaceutical industry. Although this is a faculty development grant, I expect IWU students to be co-authors on any resulting publication. Co-authoring a manuscript is a huge feather in the cap of a student’s CV, and to their interest in pursuing further studies in chemistry.

4. d. Proposed Expenses/Budget Justification

4. d.i. Justification of items listed in budget. I am requesting a two-year ASD grant as the extended time would allow us to thoroughly investigate the multiple applications of the solvent. In addition to a stipend for myself ($4000), funding is also requested to purchase the starting materials for the reactions. These are specialty chemicals not available in the department stockroom. Funding is requested to purchase specialty thin layer chromatography plates (they are quite expensive as can be seen from the budget page) not available in the chemistry stock room. These plates are used to monitor the progress of the reaction. A detailed itemized list is given in the budget summary sheet.

4. d. ii. This proposal is not supported by any external grant. While I do not expect the budget to exceed what is proposed, it is natural that prices can go up due to inflation. This difference will be accounted for by the department budget.

4. e. Proposed timetable for completion of the end product

All research in my laboratory is done in collaboration with students. I work alongside with them in the lab, and the resulting publication(s) includes students as co-authors. This fall 4 students are expected to work on this project (*Nick Edelen*-senior biology major, *Shamanth Paramkusham*-junior biochemistry major, *Owen Vukelich*-senior chemistry major, *Gavin Wenzel*-senior chemistry major).

October 2025-April 2026	Optimize reaction conditions for the epoxidation project as outlined in section 4.

This involves carrying out each proposed reaction until acceptable yields (> 80%) of products are obtained. In order to optimize the procedure, multiple trials are required. Typically a student works 8 h-10 h a week, hence they can optimize a maximum of 2 reactions in a month on an average.

May 2026: Devote extended time to the project. By working 40 h a week with 2 students, we can make considerable progress and wrap up the first part (epoxidation) of the project. Draft the manuscript for publication.

Fall 2026-Apr 2027 Optimize reaction conditions for the allylation project as outlined in the appendix.

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May 2027 Devote extended time to the project. By working 40 h a week with 2 students, we can make considerable progress and wrap up the first part (epoxidation) of the project. Draft the manuscript for publication.

4. f. Student Assistants Not Applicable (students will not be paid as they will either work as volunteers or for credit, CHEM 499)

4. g. IRB/IACUC Review Not Applicable

References:

[1] Anastas, P. T.; Warner, J. C. *Green Chemistry: Theory and Practice,* Oxford University Press: New York, 1998.

[2] Assessment of Methylene Chloride–Related Fatalities in the United States, 1980-2018. Hoang, A.; Fagan, K.; Cannon, D. L.; Rayasam, S. D. G.; Harrison, R.; Shusterman, D.; Singla, V. JAMA Intern Med. **2021** *19*;181:797–805. doi: 10.1001/jamainternmed.2021.1063

[3] Hoydonckx, H. E.; Van Rhijn, W. M.; Van Rhijn, W.; De Vos, D. E.; Jacobs, P. A. "Furfural and Derivatives". *Ullmann's Encyclopaedia of Industrial Chemistry*. Weinheim: Wiley-VCH).

[4] The Elegance of Epoxidation: Mechanistic Insights, Diverse Applications, and Promising Horizons. Panchal, N. B.; Vaghela, V. M. ***Orient. J. Chem***. **2024**, *40.* http://dx.doi.org/10.13005/ojc/400410

[5] *meta*-Chloroperbenzoic acid (*m*CPBA): a versatile reagent in organic synthesis. Hussain, H.; Al-Harrasi, A.; Green, I. R.; Ahmed, I.; Abbas, G.; Ur Rehman, N. ***RSC Adv.***, 2014, **4**, 12882. https://doi.org/10.1039/C3RA45702H

5. Budget Page

Cost of specialty chemicals needed for project (these are not carried by the department stockroom). Chemicals are available in fixed quantities only.

Item	**Vendor and Catalog #**	**Quantity**	**Cost ($)**
Thin Layer Chromatography plates (for monitoring reactions)	Sigma Aldrich 99571	25 sheets	368
Phosphomolybdic acid (TLC spray reagent)	Sigma-Aldrich 221856	100 g	249
p-Chlorostyrene	Sigma Aldrich C71203-1	10 g	114
p-Methoxystyrene	Sigma Aldrich 141003	25 g	402
Indene	Sigma Aldrich 193828	50 g	170
5-Bromoindene	Sigma Aldrich 729728	5 g	566
trans-β-Methylstyrene	Sigma Aldrich 111848	10 g	279
Dihydronaphthalene	Sigma Aldrich D105937	10 g	279
Diphenylethylene	Sigma Aldrich D206806	25 g	125
Allyl phenyl ether	Sigma Aldrich A35208	25 g	160
Allyltrimethylsilane	Sigma Aldrich 208264	10 g	275
Total (2 year budget)			**2987**

There are no associated travel expenses, consultancy fees, living expenses, student wages or publication fees.

Stipend (Ram Mohan) (2 years)			**4000**

Total Request Budget: **$6987**

Appendix

ASD Grant Application (Submitted by Ram Mohan, Department of Chemistry & Biochemistry)

Project title: *Finding an alternative solvent to dichloromethane, a highly toxic solvent that is being phased out.*

Superscripts refer to footnotes wherein some terms are explained in less technical terms.

Specific Aim 1:
The conversion of a variety of alkenes to epoxides using *meta*-chloroperoxybenzoic acid (MCPBA) as the reagent in 2-methyltetrahydrofuran (2-MeTHF) as the solvent will be carried out. A list of alkenes that will be used are given in Scheme 2. All the alkenes are commercially available. Many of these alkenes are already available in the department stockroom or in my research lab. If they are not available, they will be purchased (and are listed on the budget page). These alkenes are chosen to represent a range of chemical structures. As can be seen in Figure 2, some alkenes contain a ring while other do not. By choosing a variety of alkenes, the versatility of the new method can be demonstrated.

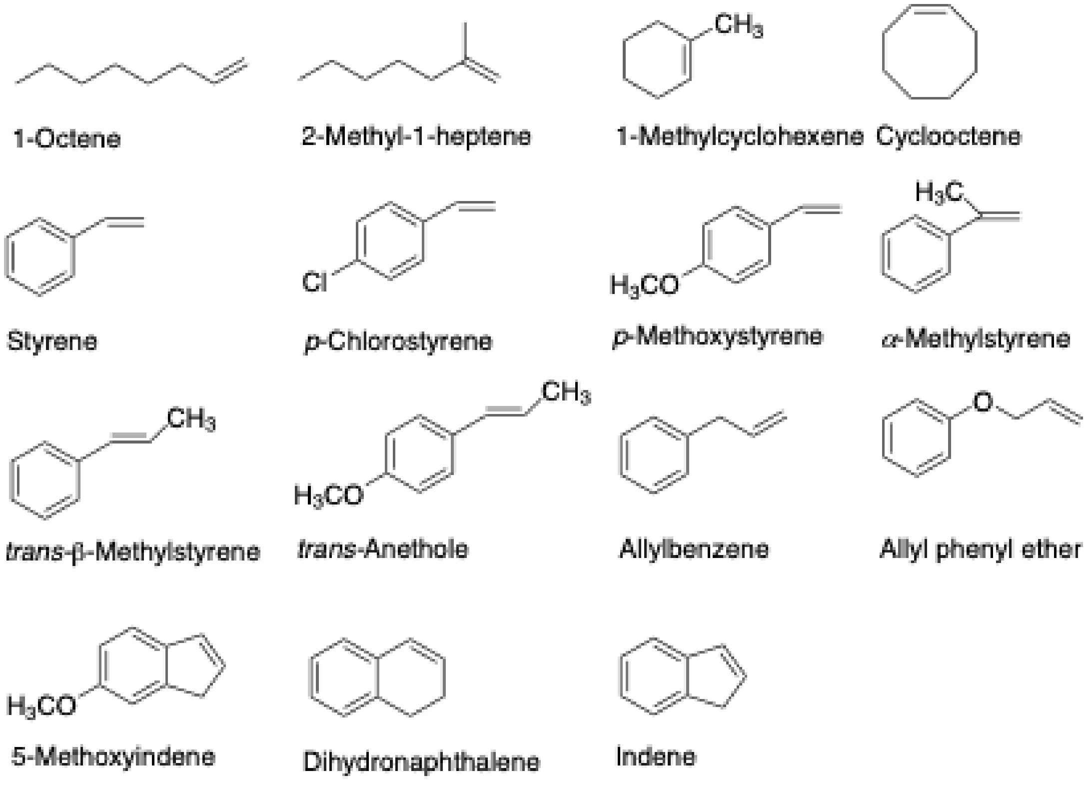
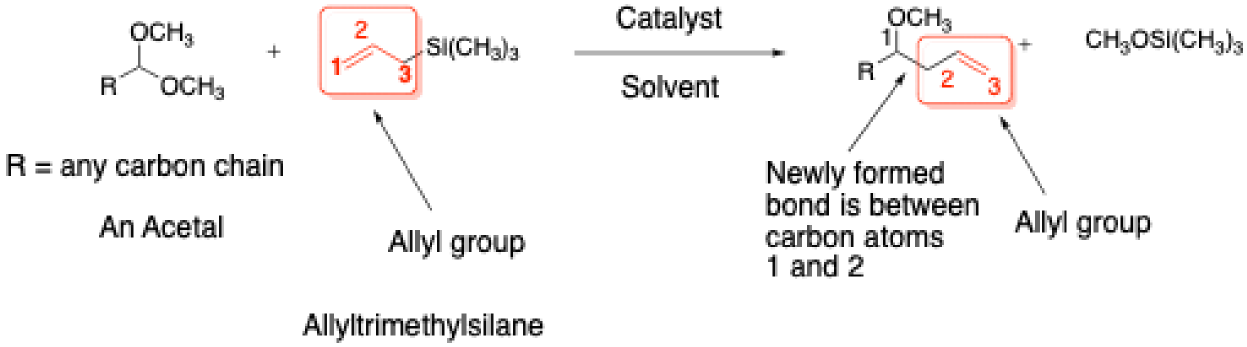


Figure 2

Typical procedure that will be followed: A solution of the alkene in 2-MeTHF will be stirred at room temperature as MCPBA is added over 10-15 minutes. The progress of the reaction will be followed by thin layer chromatography, and when the reaction is deemed complete, the product will be isolated as follows. The reaction mixture will be washed with saturated aqueous sodium carbonate (Na_2CO_3) to remove the acidic by-products, and then washed with saturated NaCl. The organic later (2-MeTHF) will be removed by using a *rotary evaporator*.^{18} The 2-MeTHF that is removed will be collected and re-used, thus further minimizing waste. Product will be characterized by NMR spectroscopy using an *NMR spectrometer*^{19}.

Specific Aim 2:
Investigate the allylation of acetals in 2-methyltetrahydrofuran (2-MeTHF) as a solvent in place of dichloromethane (CH_2Cl_2).

Basically, this is another example of a functional group transformation in which an acetal is converted to a new molecule with increased complexity. Allylation refers to introduction of an allyl group (three carbon chain in which two carbon atoms are connected by a double bond refers to an allyl group; a bond refers to a pair of electrons). Acetal is a type of functional group containing two oxygen atoms attached to the same carbon. (Scheme 4). This reaction is significant and important because it can be used to form the most important bond in organic molecules, viz. a carbon—carbon bond.



Scheme 4

Without a catalyst this reaction does not proceed. The first example of the above reaction is known as the *Hosomi-Sakurai Reaction*^{20} and is shown in Scheme 4. [*Ref 6*] The catalyst used by Sakurai and coworkers was titanium tetrachloride, $TiCl_4$. Titanium tetrachloride is a highly corrosive reagent that is difficult to handle and requires the use of low temperature conditions (-78 °C). Reactions carried out at low temperatures are not desirable from a green chemistry perspective because energy has to be supplied to attain such low temperatures. The even bigger problem is that dichloromethane is required as a solvent for this reaction to work. We have previously reported the utility of bismuth triflate as a catalyst for this reaction, however, that reaction was carried out in dichloromethane without any effort to find alternatives (we reported this in 2002) [*Ref 7*]. The specific goal of this project is to see if dichloromethane can be replaced with 2-methyltetrahydrofuran (2-MeTHF).

The experimental procedure will consist of the following steps:

(1) The starting acetal will be dissolved in 2-MeTHF and stirred. Allytrimethylsilane will be added following by the catalyst. A variety of acetals will be used and representative examples are given in Figure 2.

(2) The progress of the reaction will be followed by thin layer chromatography (TLC). TLC will reveal if there is any acetal remains or whether it is all consumed (which indicates the reaction is complete).

(3) The reaction mixture will be washed with saturated aqueous sodium carbonate (Na_2CO_3) to remove the acidic by-products and then washed with saturated NaCl. The organic later (2-MeTHF) will be removed by using a *rotary evaporator.*

(4) The 2-MetHF that is removed will be collected and re-used, thus further minimizing waste. Product will be characterized by NMR spectroscopy using an *NMR spectrometer*.

The variety of acetals which will be tested is shown below in Figure 3.

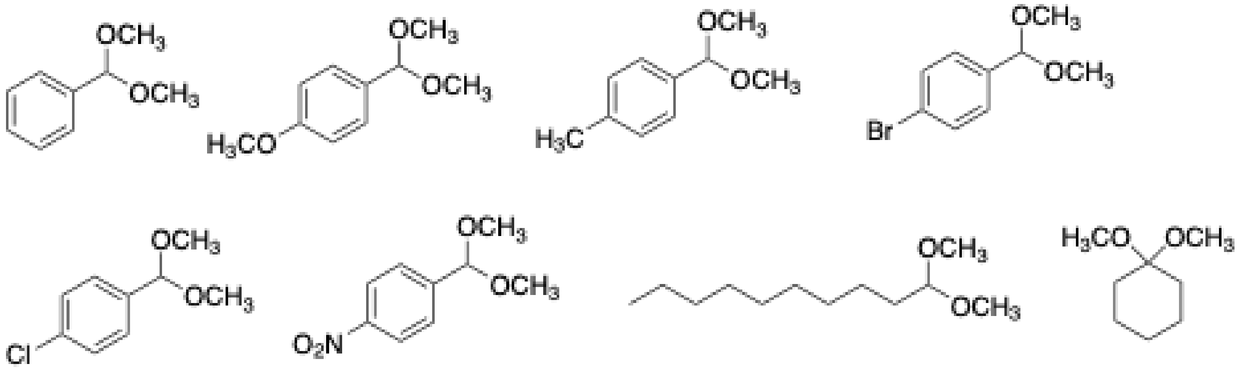


Figure 3

References (Appendix) Continued

[6] (a) Allylsilanes as synthetic intermediates II: Synthesis of homoallyl ethers from allylsilanes and acetals promoted by titanium tetrachloride. Hosomi, A.; Masahiko, E.; Sakurai, H. *Chem. Lett.* **1976**, 941. ttps://doi.org/10.1246/cl.1976.941 (b) Selective allylation of a, b-unsaturated acetals with allylsilanes in the presence of Lewis acid. Hosomi, A.; Endo, M.; Sakurai, H. *Chem. Lett.* **1978**, 499. https://doi.org/10.1246/cl.1978.499

[7] Wieland, L. C.; Zerth, H. M.; Mohan, R. S. Bismuth Triflate Catalyzed Allylation of Acetals: A Simple and Mild Method for Synthesis of Homoallyl Ethers. *Tetrahedron Lett.* **2002**, *43*, 4597. https://doi.org/10.1016/S0040-4039(02)00906-1

Ram S. Mohan
Department of Chemistry & Biochemistry
Illinois Wesleyan University (IWU)
Bloomington, IL 61701 USA

Professional Preparation
Undergraduate Institution: Hansraj College, Delhi, India; Chemistry; BSc (June 1985)
Graduate Institution: University of Delhi, Delhi, India; Organic Chemistry; MSc (June 1987)
Graduate Institution: University of Maryland Baltimore, Chemistry; PhD (May 1992**)**

Appointments

2013-Present	Wendell and Loretta Hess Professor of Chemistry, Illinois Wesleyan University, Bloomington, IL
2009-2013	Earl H. and Marian A. Beling Professor of Natural Sciences, Illinois Wesleyan University, Bloomington, IL.
2007-2009	Professor of Chemistry**,** Illinois Wesleyan University, Bloomington, IL.
2002-2007	Associate Professor of Chemistry, Illinois Wesleyan University, Bloomington, IL
1998-2002	Assistant Professor of Chemistry, Illinois Wesleyan University
1996-1998	Visiting Assistant Professor of Chemistry, Illinois Wesleyan University,
1994-1996	Visiting Assistant Professor of Chemistry, Coker College, Hartsville, SC
1992-194	Postdoctoral Research Associate, University of Illinois Urbana Champaign, IL

Awards and Honors
- **Fulbright Specialist Scholar** (Appointed to Specialist Roster, Oct 2024-2027)
- **Fulbright Academic Excellence Scholar** to India (Jan 2024-July 2024)
- **Kemp Foundation Award for Teaching Excellence (2022),** Illinois Wesleyan University
- **Fulbright-Nehru Visiting Lecturer** to India (St. Joseph's College Bangalore) (Jan 2020 to May 2020). (Program suspended in March due to Covid-19)
- **Fulbright Specialist Scholar** (IIT Indore) September 2019
- **ACS-CEI Award** for Incorporating Sustainability into Chemistry Education, sponsored by the American Chemical Society's Committee on Environmental Improvement (CEI) (2017).
- **Fulbright Specialist Scholar** (Pondicherry University) December 2015
- **Fulbright-Nehru Visiting Lecturer** to India (October 2012 to March 2013).
- **Chemist of The Year 2011** (Illinois Heartland Section of The American Chemical Society).
- **International Union of Pure and Applied Chemistry (IUPAC) Young Observer Award**: (Selected to represent the USA to participate as a young observer in the IUPAC General Assembly and Congress), Glasgow, United Kingdom (August 2009).
- **Pfizer Inc. (St. Louis Green Chemistry Team) Green Chemistry Award** ($5000) in recognition of contribution to green chemistry education and research (2008).
- **The University of Maryland, Baltimore County 2002 Distinguished Alumni Award**.
- **Henry Dreyfus Teacher-Scholar Award** for 2001 (Awarded by The Camille and Henry Dreyfus Foundation, Inc.) (Award amount: $60,000) (November 2001).

Research Experience

- Experienced in supervising undergraduate laboratory research. Supervised research of > 140 undergraduate students to date. Published **63 manuscripts with 90 undergraduate students as co-authors**; **33 co-authors (2 manuscripts)**, **17 co-authors (3 manuscripts)**, **8 co-authors (4 manuscripts)** and **1 co-author (5 manuscripts),**
- Current research focuses on Green Chemistry: developing environmentally friendly methods for organic synthesis with an emphasis on bismuth compounds and iron compound.
- **Member of Editorial Board:** *Green & Sustainable Chemistry*.
- **External Grants** (Total funding to date: approximately $1,151,110)

Publications (since 2020) (Names in **bold** are IWU student co-authors)

(70) **David, R. Q. V.; Thorp, S. C**.; Mohan, R. S, Environmentally Friendly Organic Synthesis Using Bismuth(III) Compounds: A Mini Review (Invited) in a book titled "Advances in Bismuth Chemistry (Springer). Book in Press (**2025)**

(69) **David, R. Q. V.; Thorp, S. C.**; Mohan, R. S. Environmentally friendly organic synthesis using bismuth(III) and iron(III) compounds as catalysts**.** *Arkivoc* **2025** (2) 202412292 DOI: https://doi.org/10.24820/ark.5550190.p012.292

(68) **Easterday, J. M.; Chisari, S. T., Good, A. L.; Long, P. A.; Schmidt, J. M**. Mohan, R. S. Extraction and Characterization of Natural Products from Fennel Seeds. *Chemical Educator* **2023,** *28,* 135-140.

(67) **Thorp, S. C., Chisari, S. T., David, R. Q. V., Gjata, A., Good, A. L., Lopez, E**., Mohan, R. S. Bismuth (III) triflate catalyzed multicomponent synthesis of 2,4,5-trisubstituted imidazoles. *Green and Sustainable Chemistry* **2023, 13,** 209-215. **DOI:** 10.4236/gsc.2023.133011

(66) **Lopez, E.; Thorp, S, C.,** Mohan, R. S. Bismuth(III) compounds as catalysts in organic synthesis: A mini review. *Polyhedron* **2022,** *222*, 115765.

(65) **Haskin, N. T.; Guingrich, R. A,; Schrader, A. J.; Crosse, M. R**.; Dave, A, Y.; Begari, E and Mohan, R. S. Bismuth(III) chloride catalyzed multicomponent synthesis of substituted hexahydroimidazo[1, 2-a]pyridines. *Green and Sustainable Chemistry* **2021,** *11*, 89-95

(64) Mejia, P. M.; Mohan, R. S. Environmentally Friendly Organic Chemistry Laboratory Experiments for the Undergraduate Curriculum: A Literature Survey and Assessment. *J. Chem. Educ*. **2020**, *97*, 943-959

Glossary

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[1] A *catalyst* is a substance which speeds up the rate of a reaction but is itself not consumed.

[2] The term "*reactions*" refers to a chemical reaction—i.e. how one molecule interacts with another and undergoes a chemical transformation.

[3] Methods to convert one organic molecule into another are called synthetic methodologies.

[4] Dimethyl sulfoxide (a common solvent), benzene and dimethyl sulfate are examples of such compounds.

[5] In 1990, Congress passed the *Pollution Prevention Act,* which introduced the concept of pollution prevention through proper waste disposal, waste treatment, source reduction and source prevention.

[6] The term drug is used to refer to medicinally useful drugs as opposed to drugs that lead to addictions.

[7] Until early 2000s dichloromethane was used to extract caffeine from coffee to make decaffeinated coffee. This process is now discontinued and a new class of solvent known as supercritical carbon dioxide is now used for extraction of caffeine.

[8] *Metabolism* is the process by which the body attempts to eliminate foreign substances. But this process often produces intermediates which can be toxic.

[9] Peptides are medium chain molecules that contain a series (2-50) of amino acids linked together by a bond called a peptide bond. When the number of amino acids > 50, we get a protein.

[10] A molecule that contains a double bond between two carbon atoms is called an alkene. Ethylene, used to make polyethylene is the simplest alkene.

[11] *Epoxides* contain a 3-atom ring, two carbons connected to a third oxygen atom. They are versatile molecules and have numerous applications in the industry including the manufacture of epoxy resins and plasticizers (molecules which make plastic flexible).

[12] A hydrogen bond is a weak chemical bond formed between a hydrogen atom and oxygen, nitrogen or sulfur.

[13] *Cellulose*, the most abundant organic compound on Earth is the component of plant cell walls, providing structural support and rigidity. Cellulose is composed of long, unbranched chains of glucose molecules.

[14] *Lignin* along with cellulose is one of the most abundant materials on Earth and is basically a polymer and is the chief component of wood.

[15] *Bagasse* is a by-product left over from sugar refining with sugar cane as the material. It can be used as an environment-friendly substitute for plastic.

[16] TLC stands for *Thin layer Chromatography* and is a technique to determine the number of components in a mixture. Chromatography (which literally means writing with colors) was once used to separate various colored pigments—but now it is a general technique used to separate molecules and to quantify the amount of each substance in a mixture. In *TLC,* a liquid (mobile phase) moves up a solid adsorbent on a glass or aluminum plate via capillary action. The various components of the mixture are adsorbed at different (since each component is chemically unique) rates onto the adsorbent and hence the mobile phase can push them through the solid phase at different rates, allowing for separation. The various components can be detected (if colored), under ultraviolet light (if UV active) or by spraying with a chemical (stain) that produces colored spots.

[17] In this technique, a glass column packed with silica gel (the desiccant often found inside many packages where dry conditions are needed) is loaded with the product to be purified. With the choice of the right solvents (eluents), the various components of the mixture move at varying rates through the silica column, leading to separation. By collecting multiple fractions and then removing the solvent, the pure product can be isolated. Because the process is quick, it is referred to as flash chromatography (over in a flash!).

[18] A rotary evaporator allows for rapid removal of solvent. Solvent is evaporated under vacuum while the flask is rotated constantly.

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[19] NMR refers to *Nuclear Magnetic Resonance*. This technique, which is essentially the same as MRI used in hospitals, allows chemists to determine the carbon and hydrogen framework of an unknown molecule. Knowing the carbon and hydrogen framework enables one to easily deduce the structure of the unknown molecule. The chemistry department acquired (Fall of 2013) a state-of-the-art NMR spectrometer via a National Science Foundation grant awarded to Dr. Mohan (PI).

[20] It is common practice in organic chemistry to name reactions after the person who invented or developed the reaction. Hosomi and Sakurai were Japanese chemists who developed this reaction in 1976.