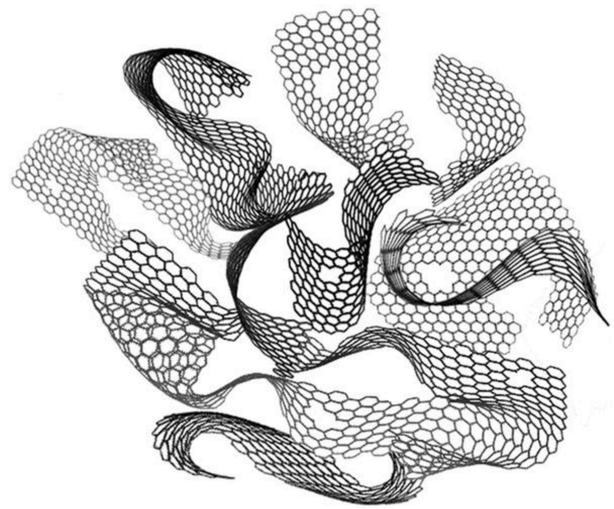
LASER INDUCED POROUS GRAPHENE SPONGE

Capstone Spring 2015

Amine Oueslati - Group Leader
Eric Bailey - Deputy Leader
Allen Chang - Treasurer
Katherine Atwater - Secretary
John Mecham - Design Team Leader
Griffin Godbey - Research Team Leader



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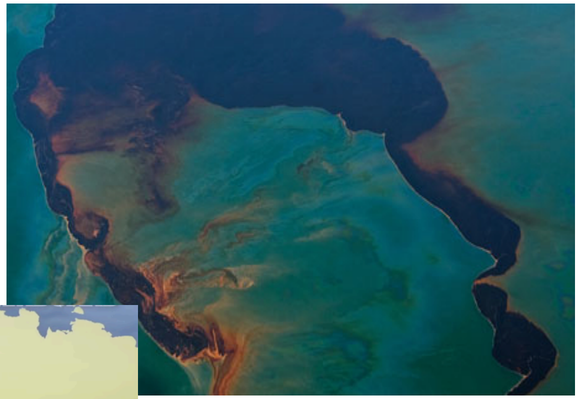
Motivation and Background

Motivation

Oil spills significantly impact:

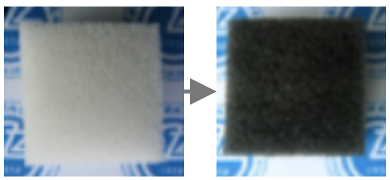
- Wildlife habitats
- World economics
- Ecosystems
- Human Life



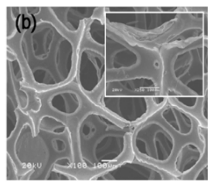
Current Technology

Polyurethane	Spongy graphene	CNT

Polyurethane



Original sponge — Coated sponge

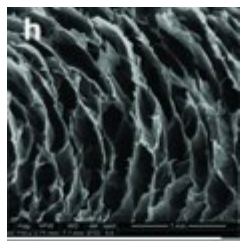


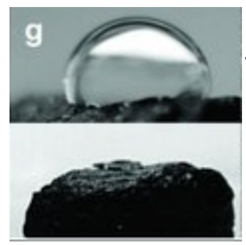
- 30 grams of oil per gram of polymer
- selectivity if coated

- Environmentally harmful
- Complex processing for selectivity
- High volume needed

Zhou, et al., *Ind. Eng. Chem. Res.*, 2013. **52** (27)

Spongy graphene





water

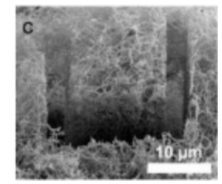
oil

- 70 grams of oil per gram of graphene
- excellent selectivity

- Very expensive
- Not scalable manufacturing
- Very low density
- Poor mechanical properties

Bi, et al. *Adv. Funct. Mater.*, 2012. **22.** p. 4421-25

CNT



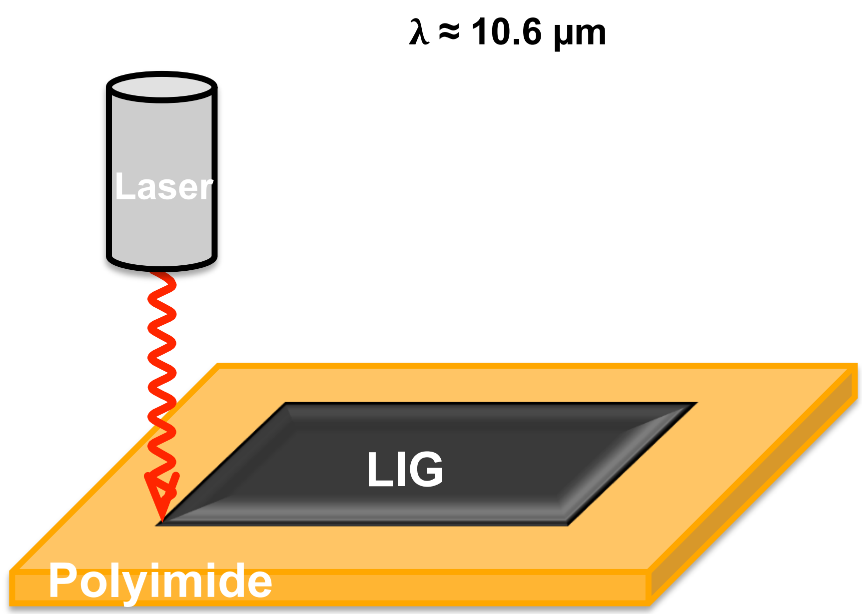
- 80 grams of oil per gram of CNT
- excellent selectivity

- Very expensive
- Complex, resource intensive processing
- Very low density

Hashim, et al., *Sci. Rep.*, 2012. 2:**363.** p. 1-8

Laser-Induced Graphene

- Laser ablation of polyimide
- Controllable properties
- Cost effective and scalable



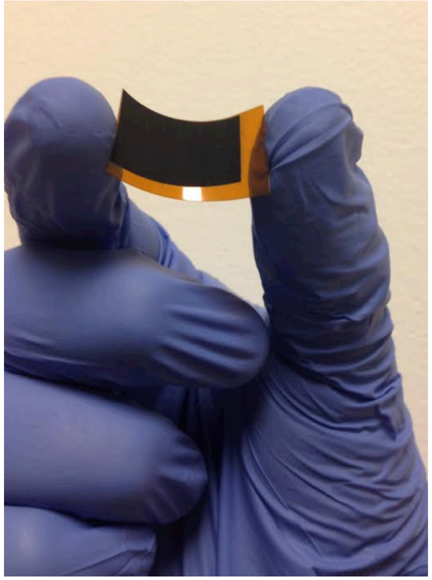
Design Goals

Main Objective:

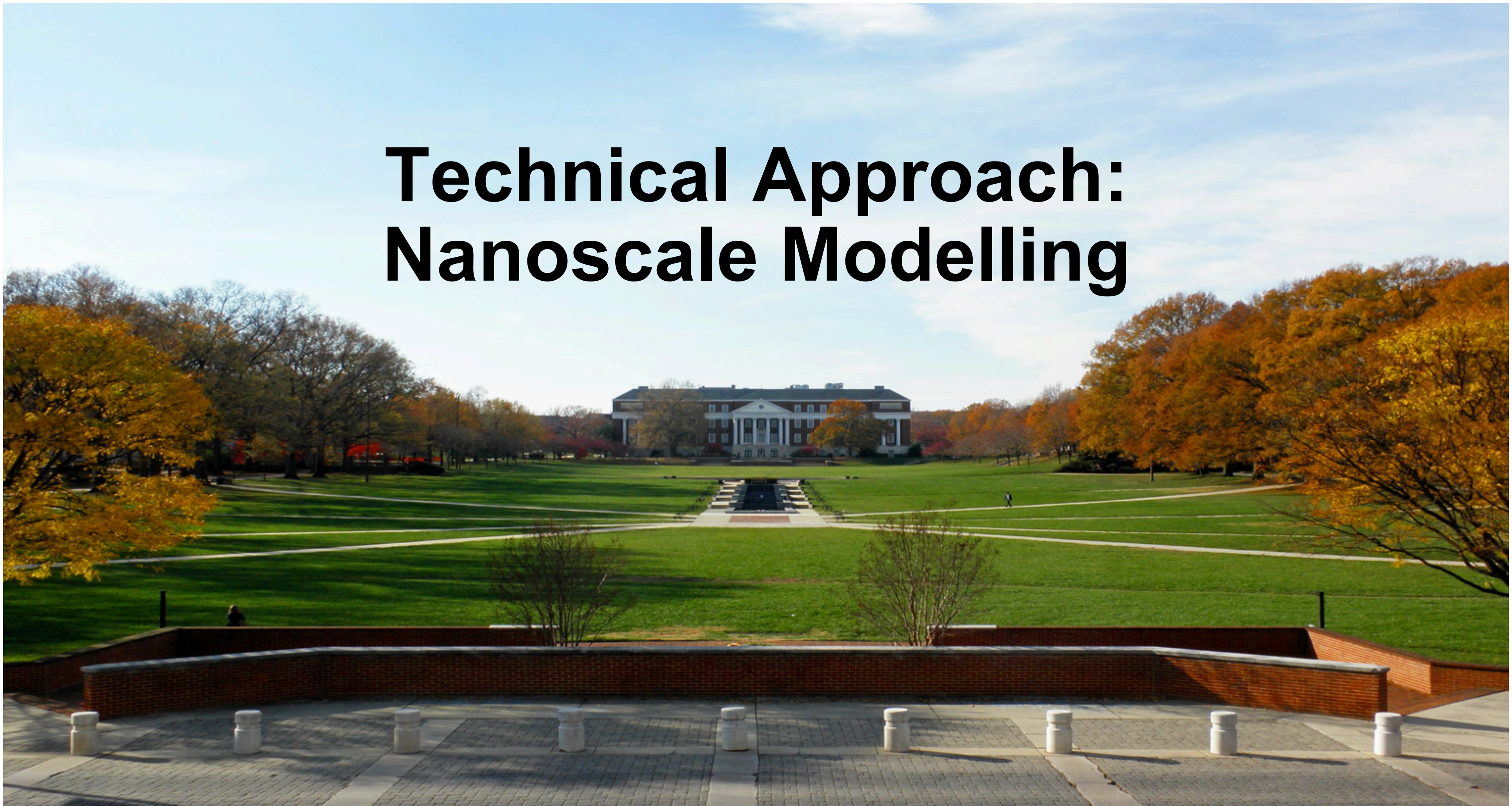
Design a LIG sponge for oil sorption

Design Goals:

- Develop atomistic model to understand nanoscale interaction of oil-graphene
- Develop model to understand bulk fluid flow of oil through porous graphene
- Determine a relationship between LIG pore size and oil sorption



Technical Approach: Nanoscale Modelling



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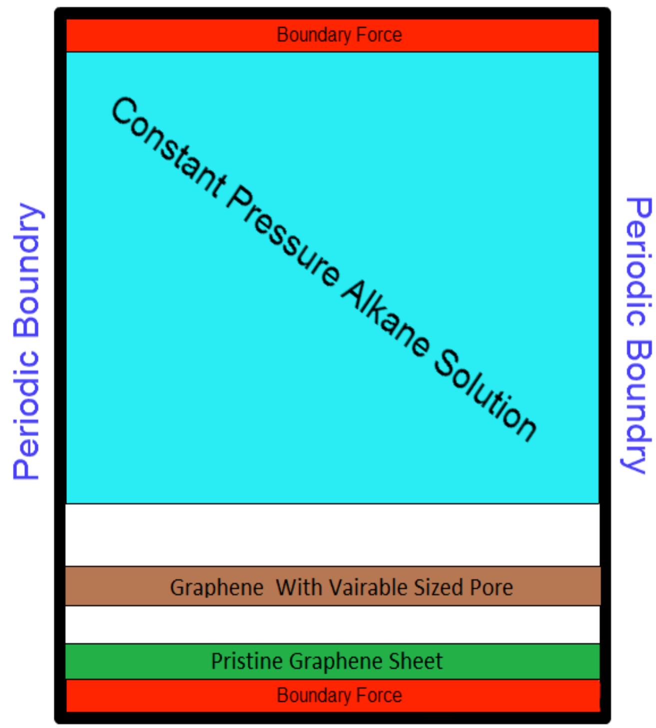
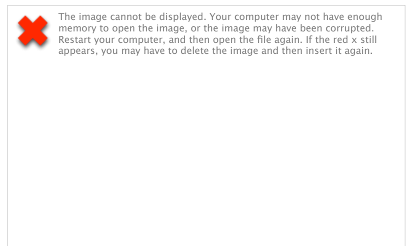
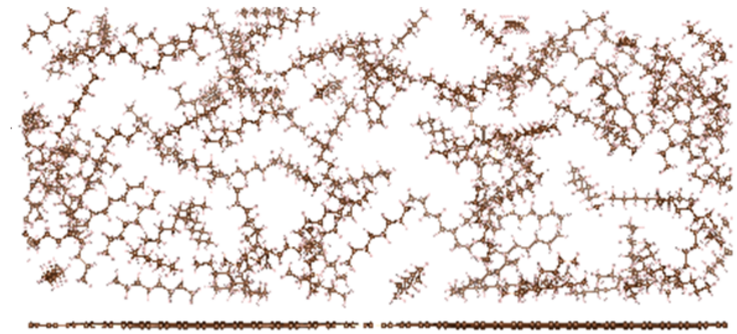
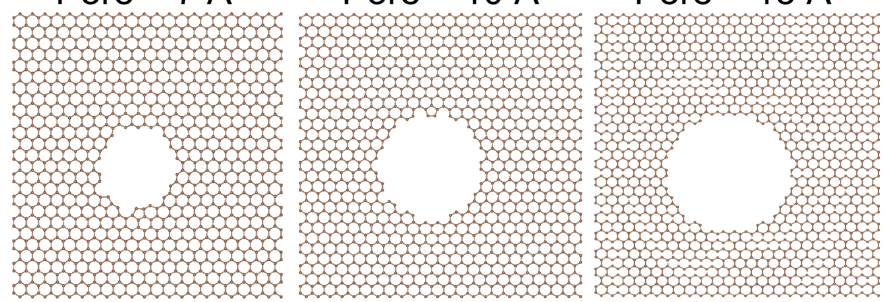
Simulation Design



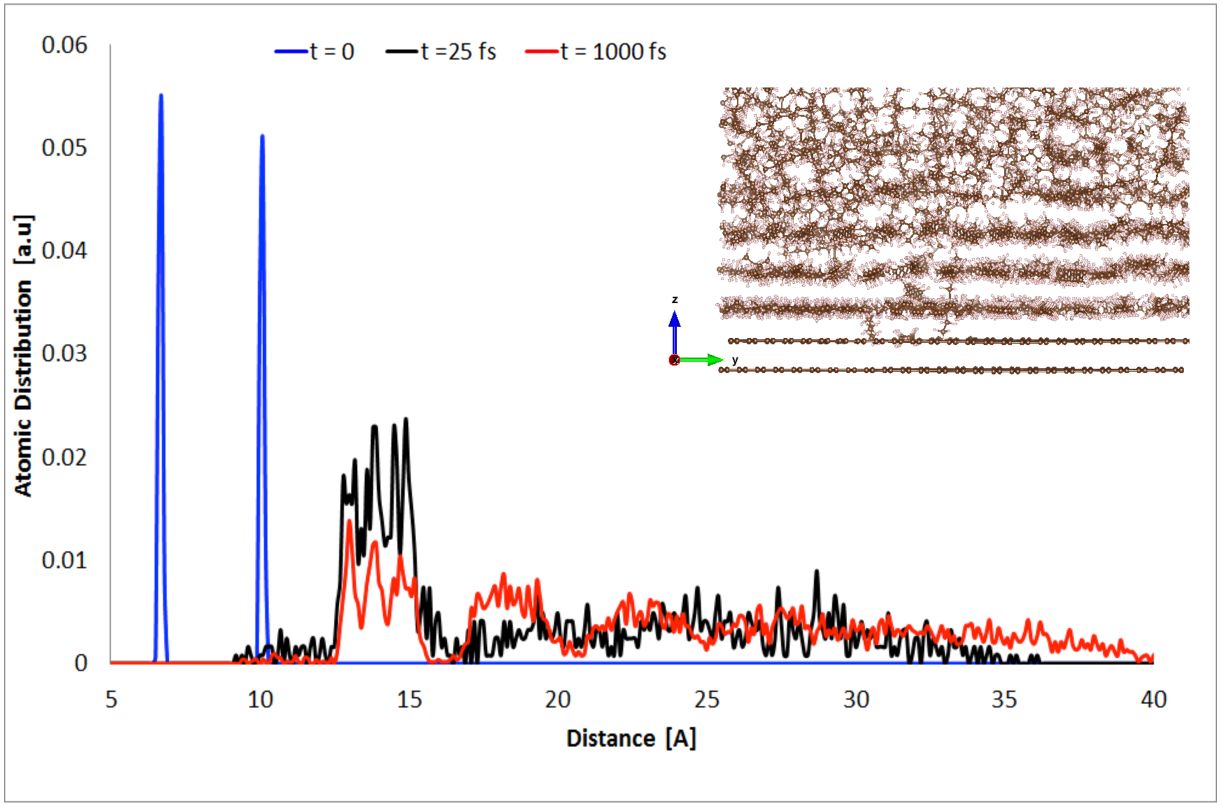


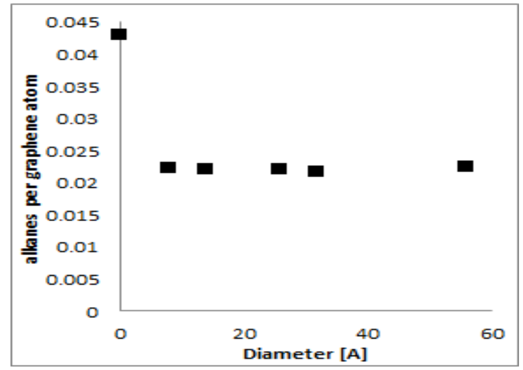


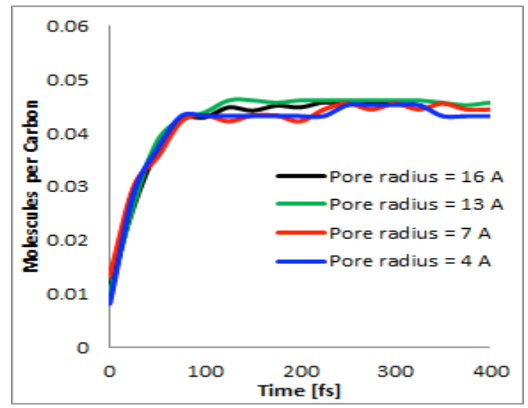
Pore – 7 Å Pore – 10 Å Pore – 13 Å



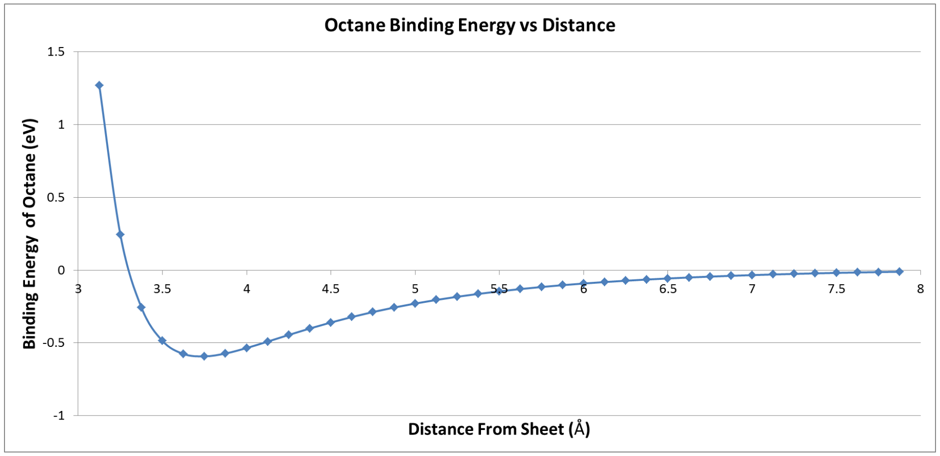
Simulation Results

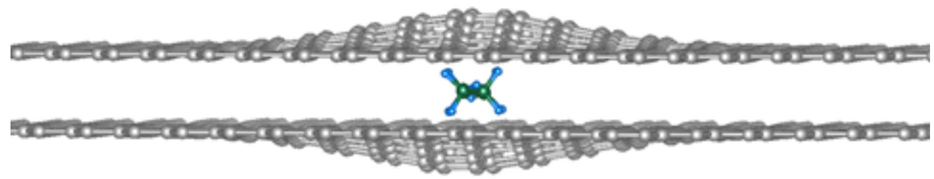


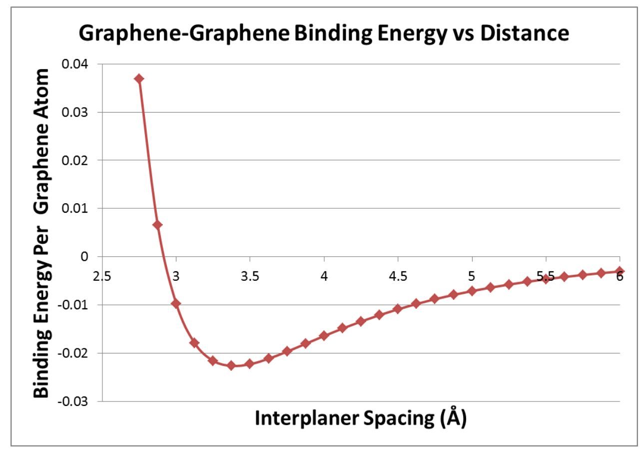


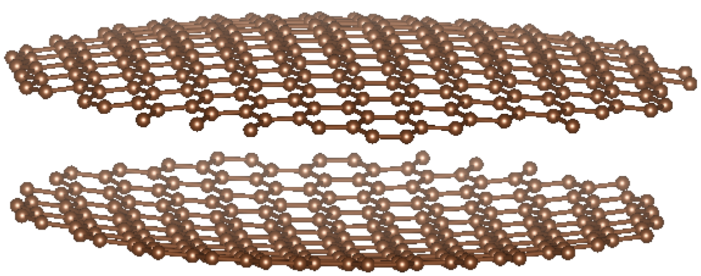


Simulation Results



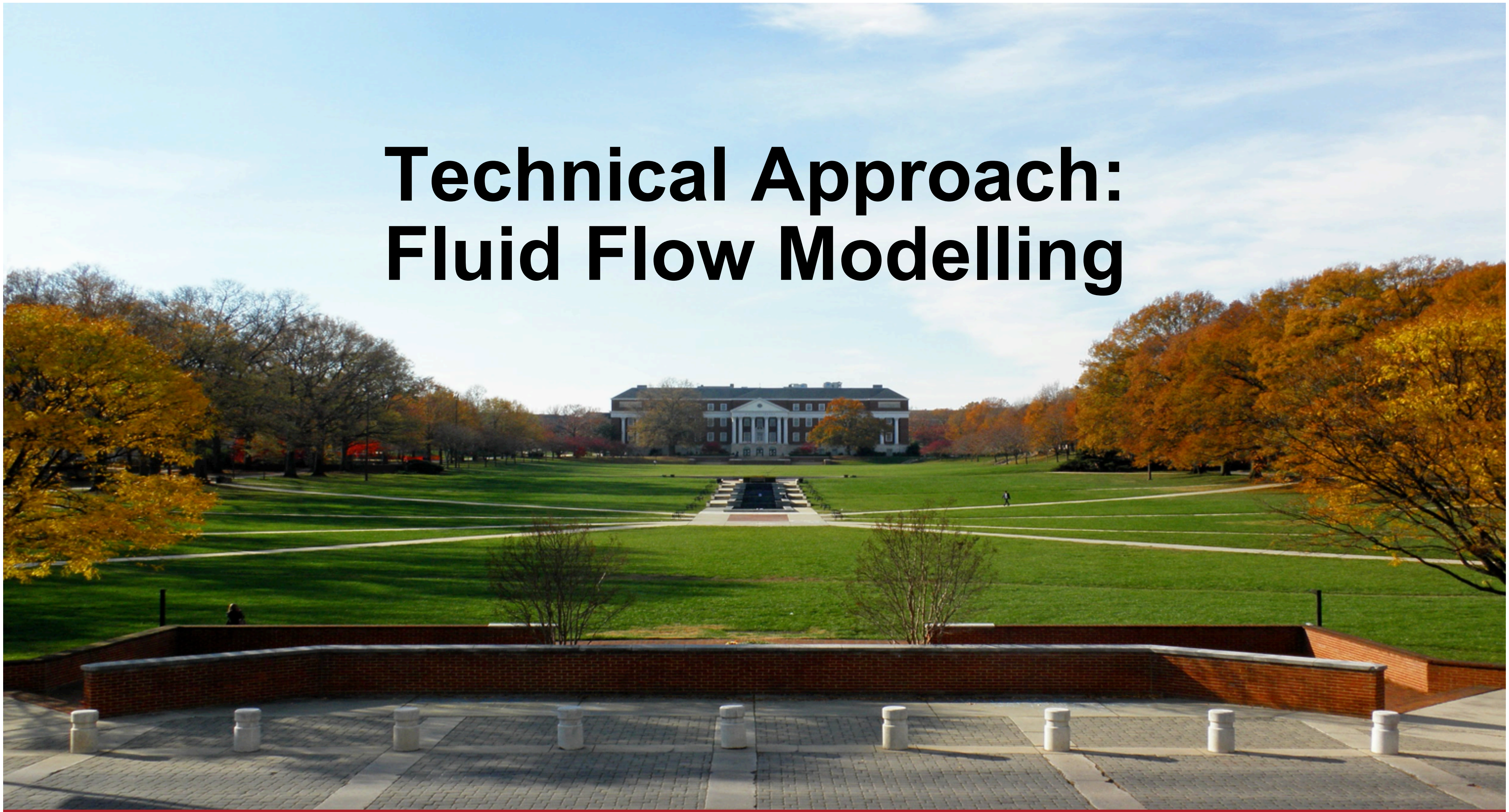






~600 stretched graphene atoms

Technical Approach: Fluid Flow Modelling



Fluid Flow Modeling Background

Goal:

Implement Darcy's Law to understand bulk fluid flow through porous media.

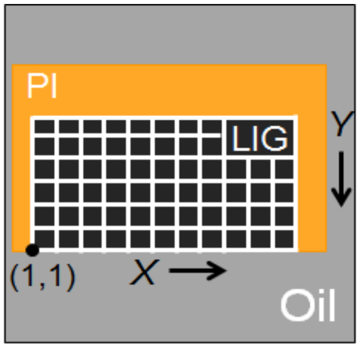
$$\left(\frac{\partial^2\Psi}{\partial X^2}+\frac{\partial^2\Psi}{\partial Y^2}\right)=-\omega \qquad U\frac{\partial\omega}{\partial X}+V\frac{\partial\omega}{\partial Y}=\frac{\varepsilon}{Re}\left(\frac{\partial^2\omega}{\partial X^2}+\frac{\partial^2\omega}{\partial Y^2}\right)-\frac{\varepsilon^2}{DaRe}\omega-\frac{F\varepsilon^2}{\sqrt{Da}}\lVert \mathrm{v}\rVert\omega$$

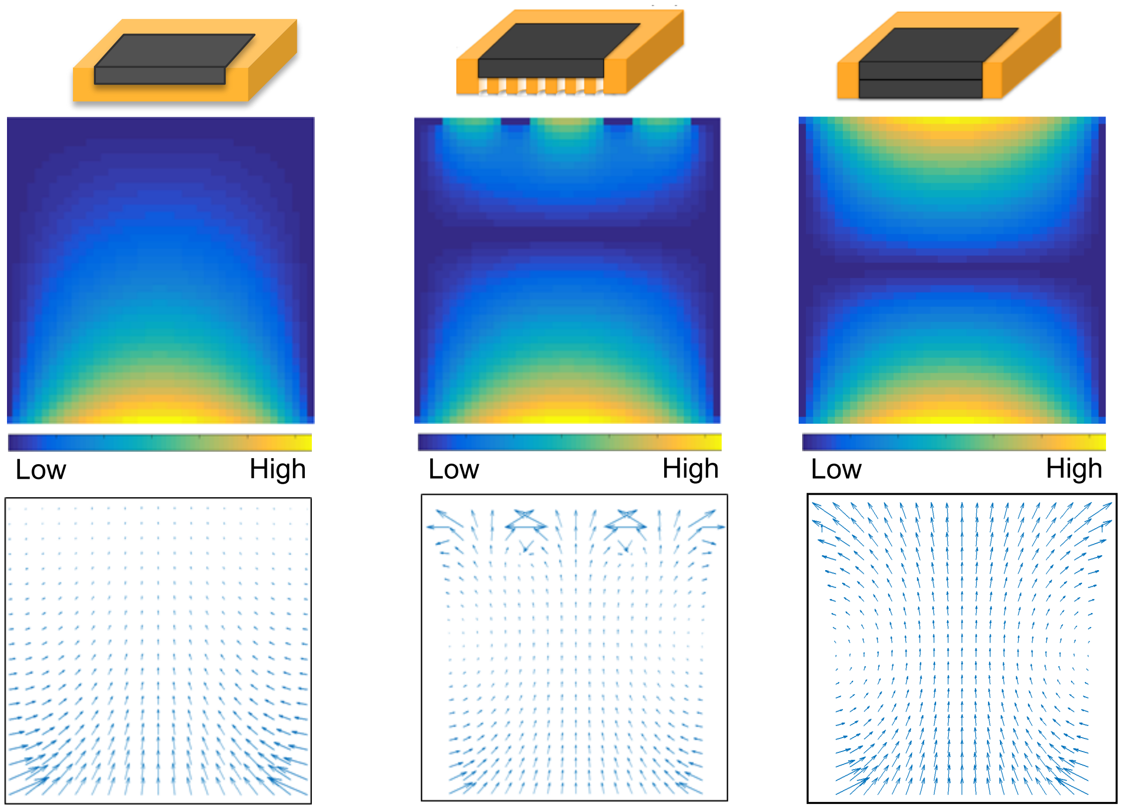
Key Assumptions:

- Air omitted from inside porous graphene (space initially empty)
- Effects of gravity are omitted

Ψ = stream function; X,Y = coordinates; ω = vorticity; Da = Darcy Number; F = geometric function; U,V = interstitial velocity components; ε = porosity; Re = Reynolds Number; v = velocity vector;
(all variables are dimensionless)

Results From Fluid Flow Modelling





Technical Approach: Experimentation

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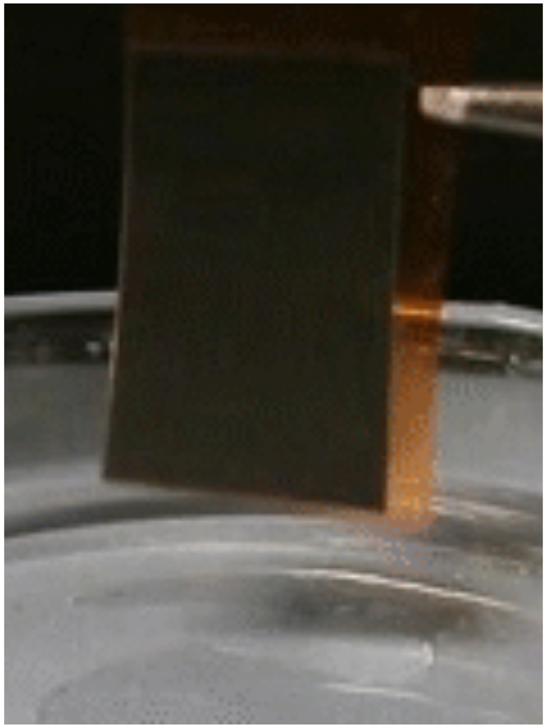
Experimental Procedure

1. Weigh original sample (LIG+PI)
2. Place sample partially in octane
3. Weigh saturated sample
4. Exfoliate graphene from PI
5. Weigh remainder of PI
6. Subtract for mass of LIG



Experimental Findings

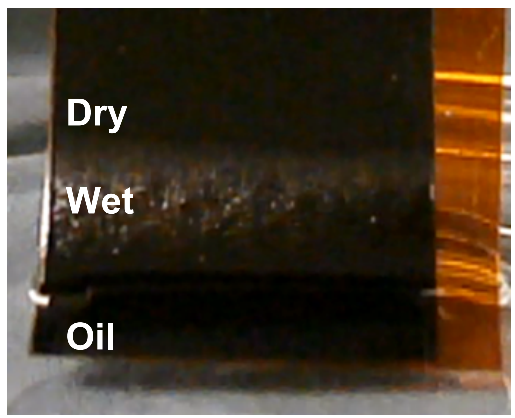
Graphene wetting characteristics

- Verified oleophilic behavior
- Verified hydrophobic behavior

Water Octane

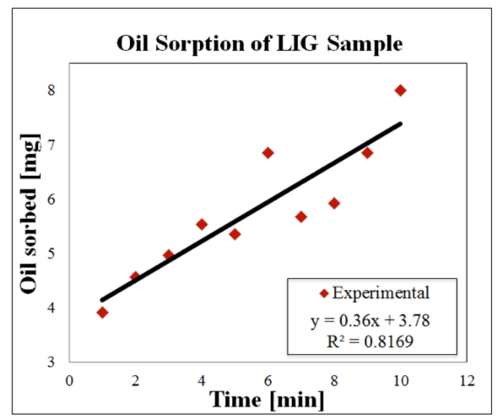
Capillary within graphene

- Increases absorption allowing captured gases to exit the system

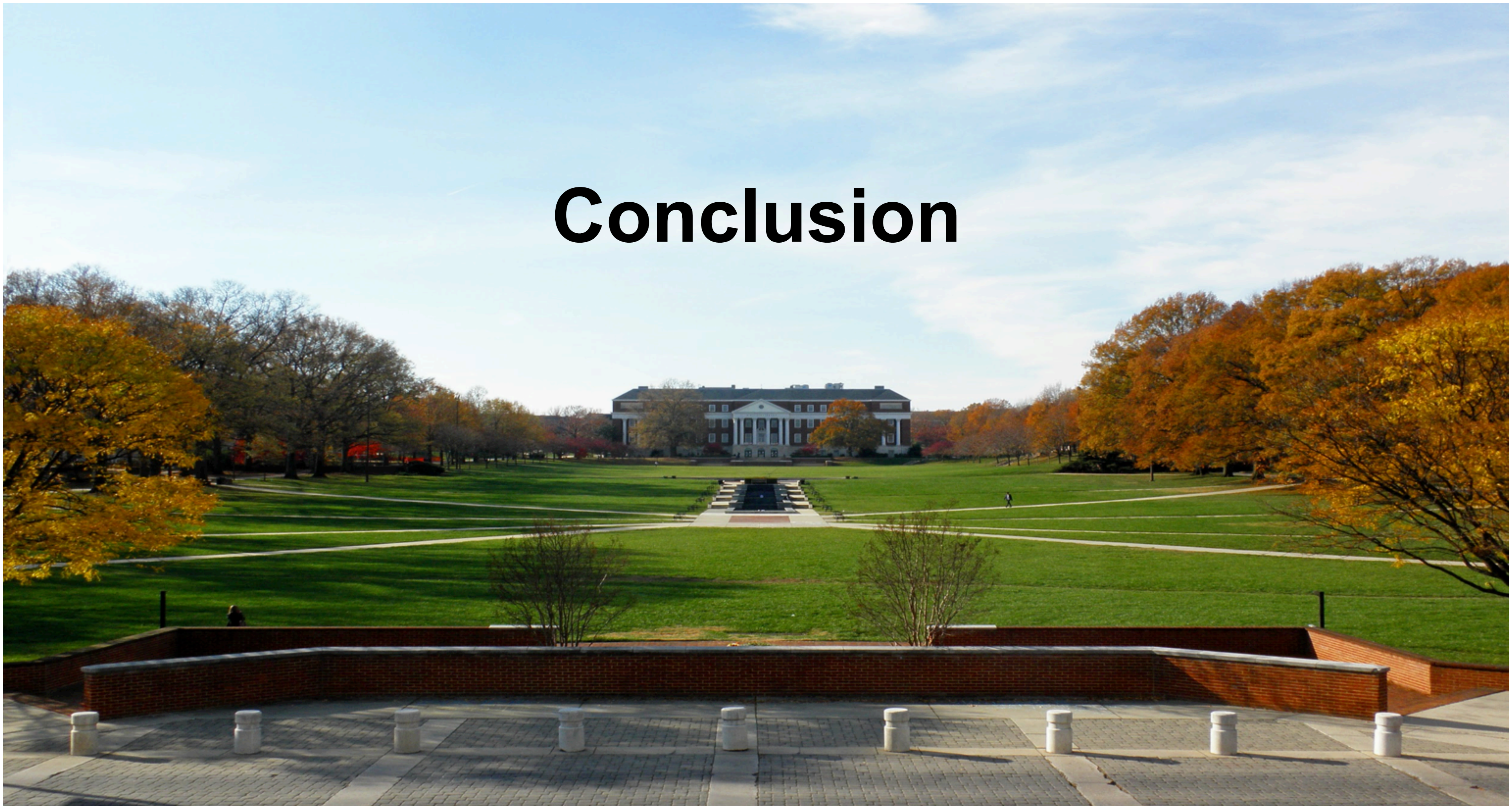


Linear octane absorption v. time

- Supports graphene sheet spacing is too small for alkane bulk absorption



Conclusion

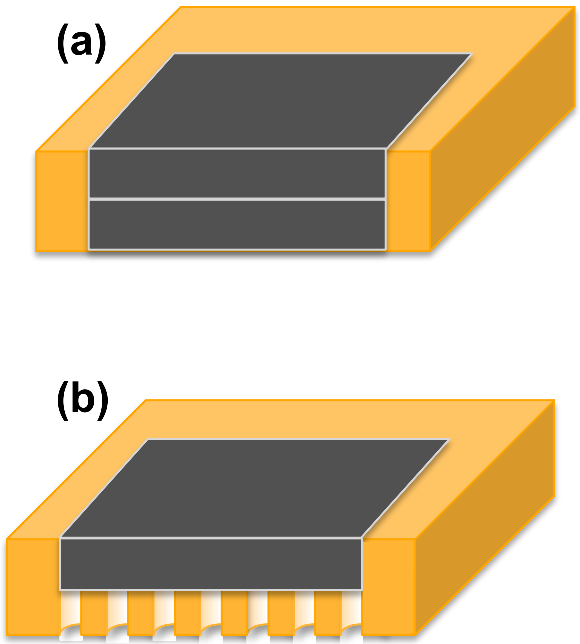


Conclusions

- LIG currently has a lower oil absorption than other carbon-based oil sponge technologies
- Oil sorption is independent of porosity
- The interlayer spacing in the graphene is too small to allow bulk absorption
- Octane layers form over graphene surface
- Current LIG sponge technology has potential if device is open on both sides

Future Work

- Compare oil sorption of LIG with different pore characteristics
- Fabricate ideal design using open backside of LIG
- Test sorption with crude oil
- Investigate mechanical stability during sorption and recovery
- Investigate LIG samples with graphene sheet spacing greater than 3.4 Å



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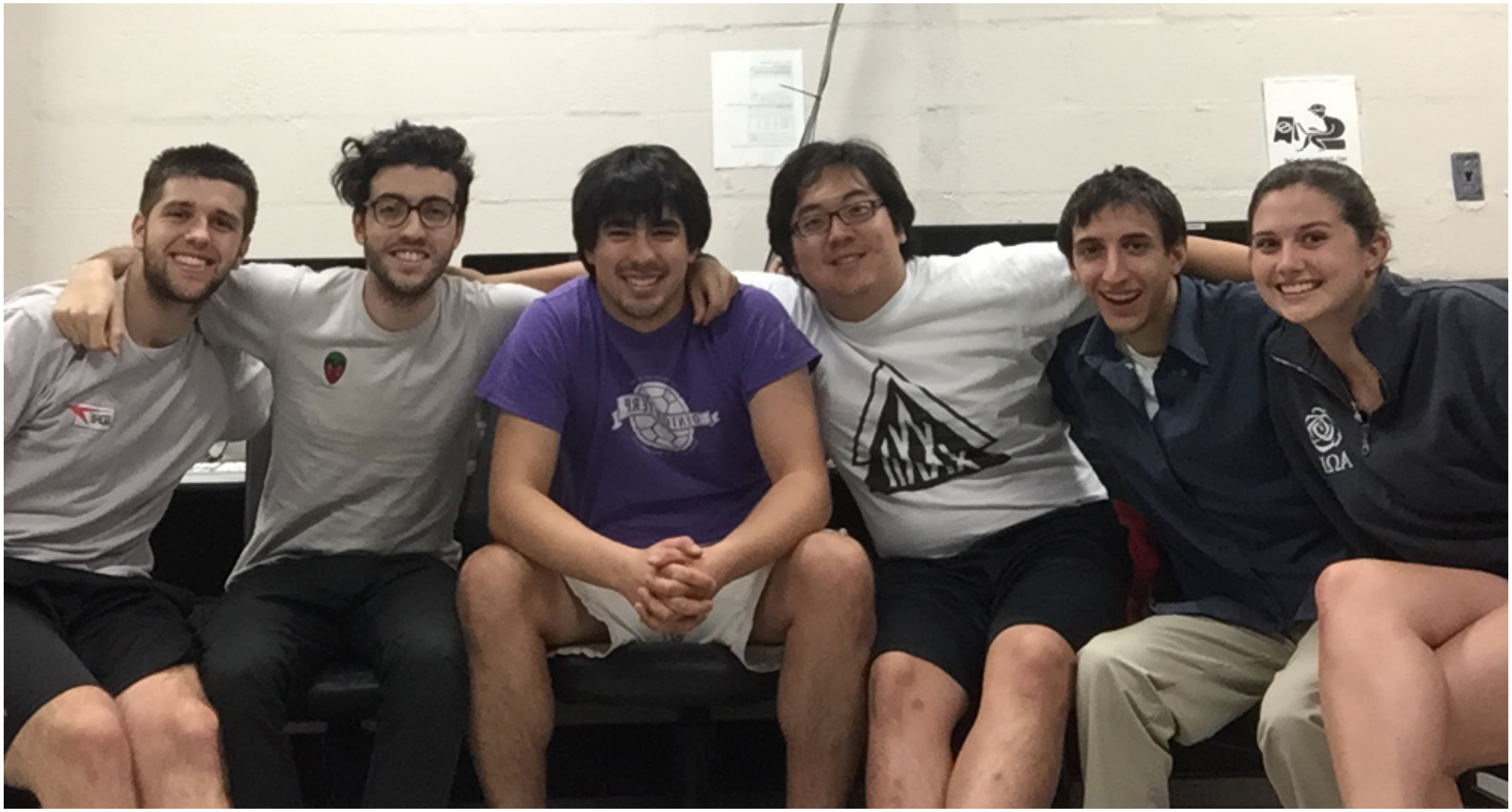

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Supplemental Slides

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BP Deepwater Horizon Oil Spill

Method	Cost	Volume	Selectivity	Recovery	Environmentally Safe
Corexit 9500	~$1 billion*	~21.1 m^3*	Yes	No	No
Polyurethane	$0.513 billion**	~902,000 m^3**	No	No	Yes
CNT sponge	$91.3 billion***	~43,500 m^3***	Yes	Yes	Yes
LIG sponge	$2.52 billion***	~2,640 m^3***	Yes	Yes	Yes

What this table neglects:

- Corexit is dispersant which breaks down oil into smaller pieces to be further broken down by microbes
- Spongy graphene can we reused *at least* 10 times with >99% capacity
- LIG can approximately retrieve 80% of oil back. In the case of the BP oil spill over $300 million.

* - No specification of oil dispersed

** - Assumption: polyurethane only absorbed oil

***- Assuming each unit of volume is used 10 times

http://www.bp.com/en/global/corporate/gulf-of-mexico-restoration/deepwater-horizon-accident-and-response/offshore.html

BP Deepwater Horizon Oil Spill - Summary

Method	Cost	Volume	Selectivity	Recovery	Environ-mentally Safe
Corexit 9500	$$	✦	✔	✖	✖
Polyurethane	$	✦✦✦✦	✖	✖	✔
CNT	$$$$	✦✦✦	✔	✔	✔
LIG	$$$	✦✦	✔	✔	✔