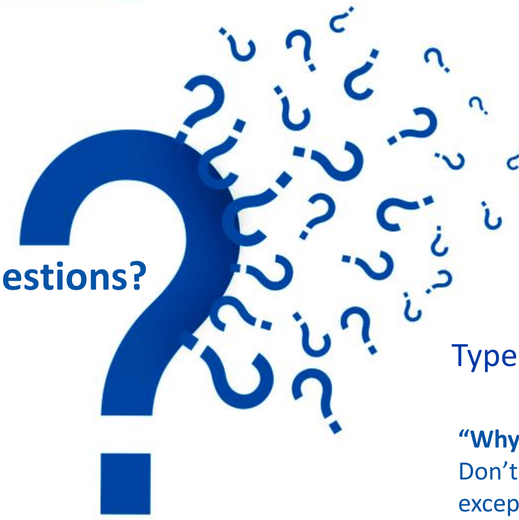
ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®



Have Questions?

Type them into questions box!

"Why am I muted?"
Don't worry. Everyone is muted except the presenter and host. Thank you and enjoy the show.

Contact ACS Webinars ® at acswebinars@acs.org

1

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

http://bit.ly/ACSnewmember

2

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

Benefits of ACS Membership

c&en CHEMICAL & ENGINEERING NEWS

Chemical & Engineering News (*C&EN*)
The preeminent weekly digital and print news source.

SCIFINDER® A CAS SOLUTION

NEW! ACS SciFinder
ACS Members receive 25 complimentary SciFinder® research activities per year.

NEW! ACS Career Navigator
Your source for leadership development, professional education, career services, and much more.

http://bit.ly/ACSnewmember

3

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

@AmericanChemicalSociety

@AmerChemSociety

@AmerChemSociety

LinkedIn https://www.linkedin.com/company/american-chemical-society

Contact ACS Webinars ® at acswebinars@acs.org

4

How has ACS Webinars benefited you?

ACS Chemistry for Life®

"Safety content is always timely and important. Getting the message out is always a challenge and this ACS Webinar presented some good ideas on safety communication that I will apply at our institution."

http://bit.ly/labsafetyACS

Fan of the Week

Henry VanBrocklin, PhD
Professor, Radiology and Biomedical Imaging, Chair, Chemistry and Environmental Safety Committee, University of California, San Francisco
ACS member for 36 years strong!

Be a featured fan on an upcoming webinar! Write to us @ acswebinars@acs.org

5

ACS Webinars®

CLICK • WATCH • LEARN • DISCUSS

LIVE | Thursdays at 2pm ET

Learn from the best and brightest minds in chemistry! Hundreds of webinars on diverse topics presented by experts in the chemical sciences and enterprise.

Recordings are an exclusive ACS member benefit and are made available to registrants via an email invitation once the recording has been edited and posted.

Live Broadcasts of ACS Webinars® continue to be available to the general public on Thursdays from 2-3pm ET!

www.acs.org/acswebinars

6

What is ACS on Campus?

ACS Chemistry for Life®

ACS visits campuses across the world offering FREE seminars on how to be published, find a job, network and use essential tools like SciFinder. ACS on Campus presents seminars and workshops focused on how to:

ACS ON CAMPUS

- Publish in top journals
- Find a job
- Effectively use research tools like SciFinder® and ACS ChemWorx
- Communicate your science
- Write grant proposals
- Build industry partnerships
- Prepare for a changing employment landscape

http://acsoncampus.acs.org

#HeroesofChemistry
ACS Heroes of Chemistry Award

ACS Chemistry for Life®

*The **ACS Heroes of Chemistry Award** is the Annual award sponsored by the American Chemical Society that recognizes talented industrial chemical scientists whose work has led to the development of successful commercialized products ingrained with chemistry for the benefit of humankind.*

2018 Winners: AstraZeneca DuPont Pfizer SeattleGenetics

www.acs.org/heroes

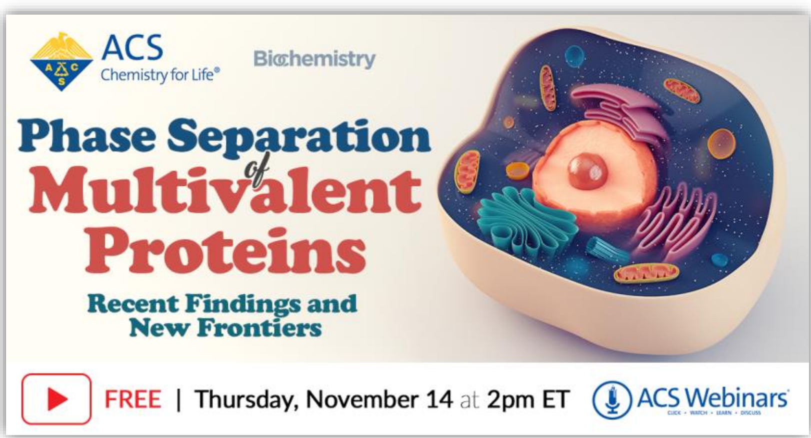
An individual development planning tool for you!

https://chemidp.acs.org

9

Upcoming ACS Webinar!

www.acs.org/acswebinars



https://www.acs.org/content/acs/en/acs-webinars/technology-innovation/phase-separation.html

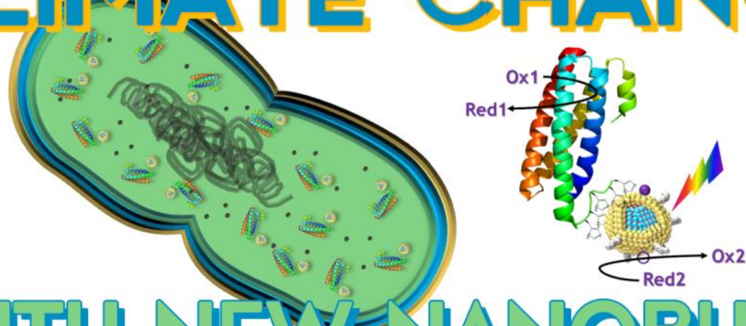
10

Resources from Industry Member Programs!

11

ACS Industry Member Programs

COMBATING CLIMATE CHANGE



WITH NEW NANOBUGS

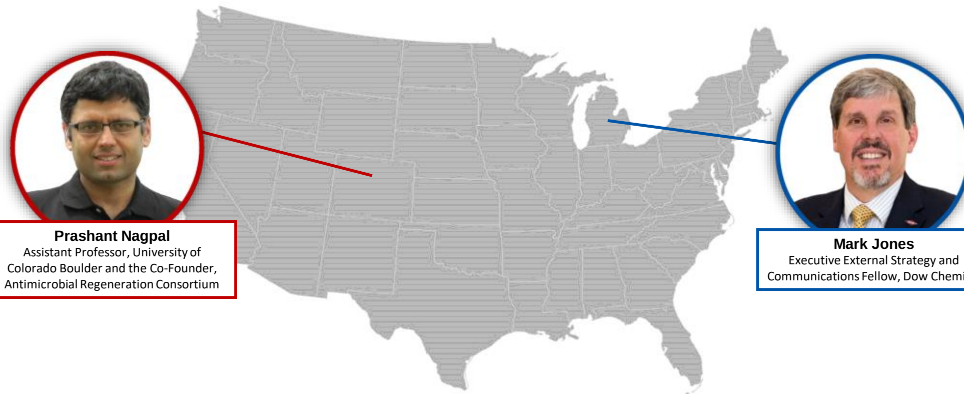
THIS ACS WEBINAR WILL BEGIN SHORTLY...

12

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

Combating Climate Change with New Nanobugs: Teaching Bacteria to Eat Carbon Dioxide and Light with Quantum Dots



Prashant Nagpal
Assistant Professor, University of Colorado Boulder and the Co-Founder, Antimicrobial Regeneration Consortium

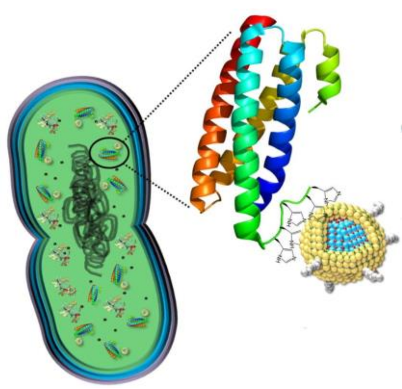
Mark Jones
Executive External Strategy and Communications Fellow, Dow Chemical

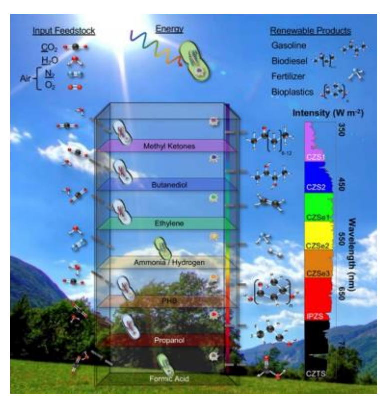
Presentation slides available now! Recordings are an exclusive ACS member benefit.
www.acs.org/acswebinars

This ACS Webinar is co-produced with the ACS Industry Member Programs

13

Combating Climate Change with New Nanobugs:
Teaching Bacteria to Eat Carbon Dioxide and Light with Quantum Dots



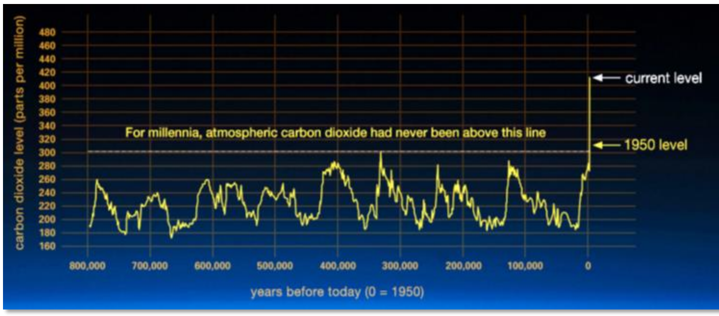


Prashant Nagpal
Department of Chemical and Biological Engineering
Renewable and Sustainable Energy Institute (RASEI)
Materials Science and Engineering
University of Colorado Boulder
www.colorado.edu/lab/nagpal

Antimicrobial Regeneration Consortium, ARC
www.amrconsortium.org

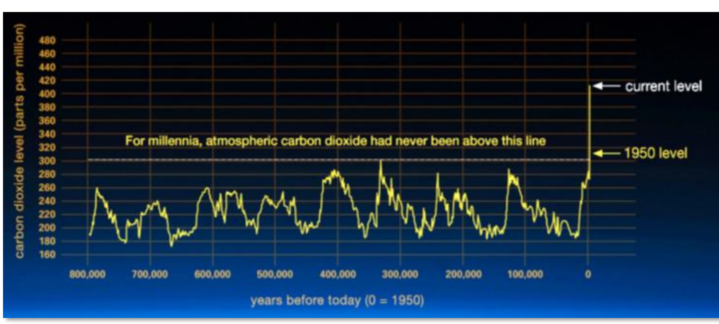
University of Colorado Boulder | Chemical and Biological Engineering | Renewable and Sustainable Energy Institute | 14

Combating Climate Change: Feasible?



https://climate.nasa.gov/evidence

Combating Climate Change: Feasible?



CO_2 at 408 ppm: Highest in 3 million years
17/18 warmest years since 2000

800 million people: 11% of the world's population vulnerable to climate change

Global carbon emissions 2018:
All-time high of **37.1bn tonnes**

https://climate.nasa.gov/evidence

Combating Climate Change: Feasible?

70% of Earth's oxygen comes from oceans…

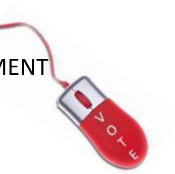
By **2050**, plastic > fish in oceans by weight

We produce ~**381 million tonnes** of plastic each year

https://www.unenvironment.org/interactive/beat-plastic-pollution

Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT



The amount of plastic waste each year (381 million tonnes) **is equivalent to the weight of how many people?**

- Few thousand people
- Population of a large city
- Population of a large country
- Almost entire human population

** If your answer differs greatly from the choices above tell us in the chat!*

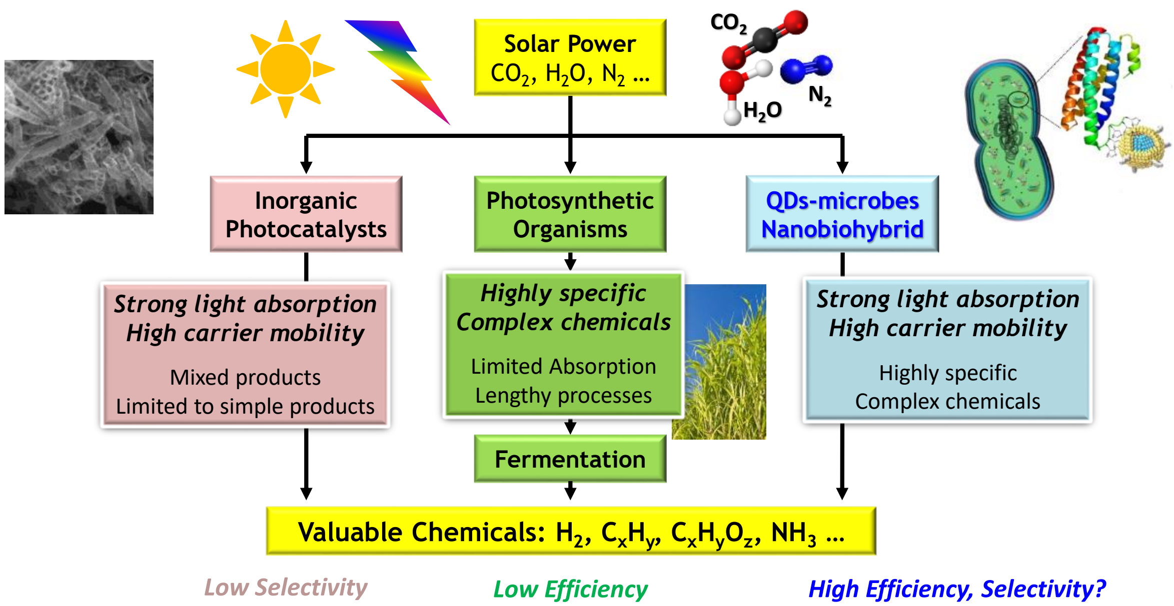
Combating Climate Change: Feasible?

Answer: Almost entire human population

381 million tonnes= 381×10^9 kg

Assuming an average human weight of 75 kg

381 million tonnes= 381×10^9 /75=5.08 billion people
or ~2/3 of entire human population

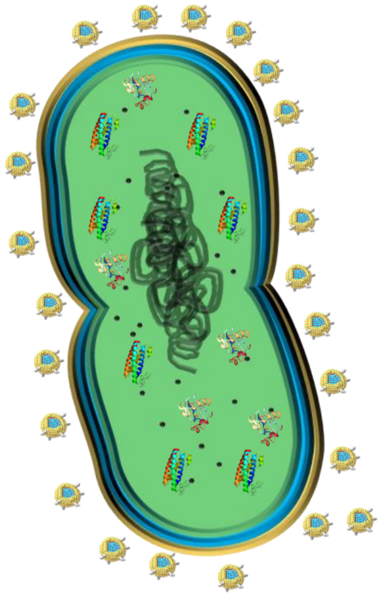


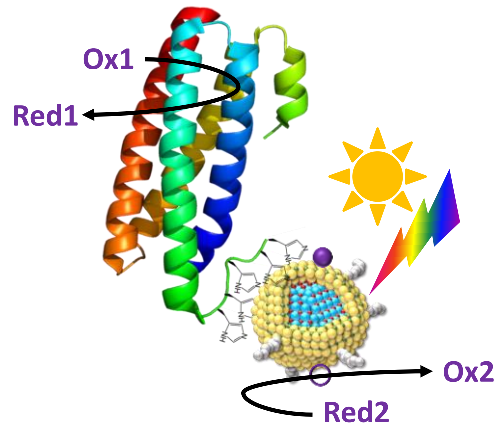
Singh, Beltran, Ribot, Nagpal*, *Nano Lett.*, 14, 597 (2014)
Alivov, Singh, Ding, Cerkovnik, Nagpal*, *Nanoscale*, 6, 18039 (2014)
Sun, Ding, Goodman, Funke, Nagpal*, *Nanoscale*, 6, 12450 (2014)

Ding, Nagpal*, *Nanoscale*, 8, 17496 (2016)
Ding, Nagpal*, *Phys. Chem. Chem. Phys.*, 19, 10042 (2017)

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, *141*, 10272 (2019)

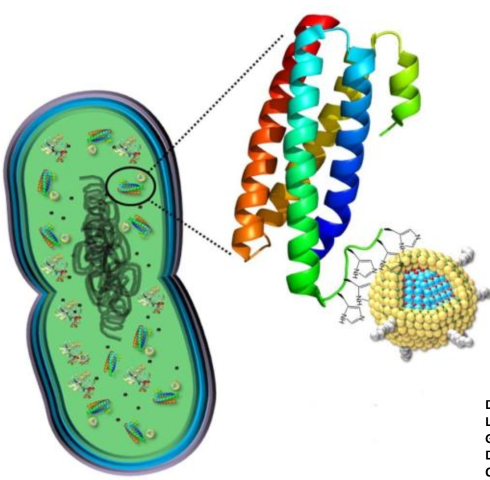
How can we make Nanobugs





QDs uptake by microbes

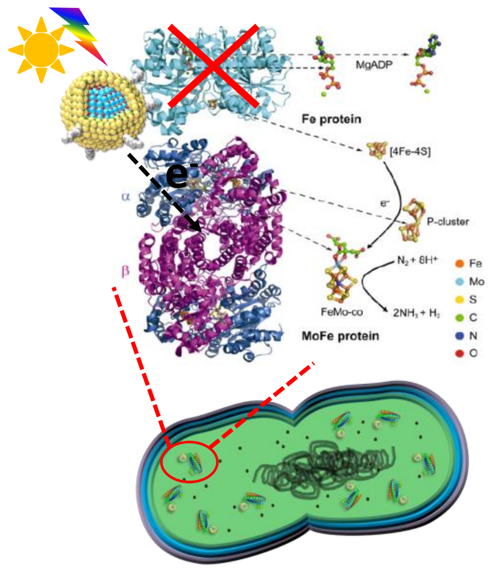
Challenges



- *Quantum Dot (QD) uptake*
- *Site-specific QDs-enzyme binding*
- *Efficient electron transfer*
- *QDs Stability*
- *Low QDs Toxicity*
- *Balanced Electron Flux…*

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, ***J. Am. Chem. Soc.***, 141, 10272 (2019)
Levy, Chowdhury, Nagpal*, ***J. Biol. Eng.***, 13:48 (2019)
Goodman, Levy, Li, Ding, Courtney, Chowdhury, Erbse, Chatterjee, Nagpal*, ***Front. Chem.***, 6,46,1 (2018)
Ding, Nagpal*, ***Phys. Chem. Chem. Phys.***, 19, 10042 (2017)
Courtney, Goodman, Nagy, Levy, Bhusal, Madinger, Detweiler, Nagpal*, Chatterjee*, ***Science Adv.***, 3, e1701776 (2017)
Courtney, Goodman, McDaniel, Madinger, Chatterjee*, Nagpal*, ***Nature Materials***, 15, 529 (2016)
Ding, Nagpal*, ***Nanoscale***, 8, 17496 (2016)
Goodman, Noh, Singh, Cha, Nagpal*, ***Appl. Phys. Lett.***, 106, 083109 (2015)
Goodman, Siu, Singh, Nagpal*, ***Nanoscale***, 7, 18435 (2015)
Goodman, Singh, Ribot, Chatterjee, Nagpal*, ***J. Phys. Chem. Lett.***, 5,3909 (2014)
Singh, Beltran, Ribot, Nagpal*, ***Nano Lett.***, 14, 597 (2014)

Living QD-*A. vinelandii* Nanobugs

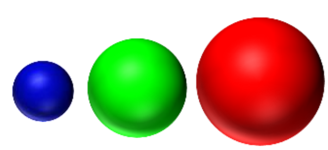


- *Gram-negative diazotroph*
- *Utilizes dinitrogen from air*
- *Can fix nitrogen aerobically*

Nitrogen Fixation: Methods and Protocols, Springer, **2011**

Choosing QDs: Material and Size

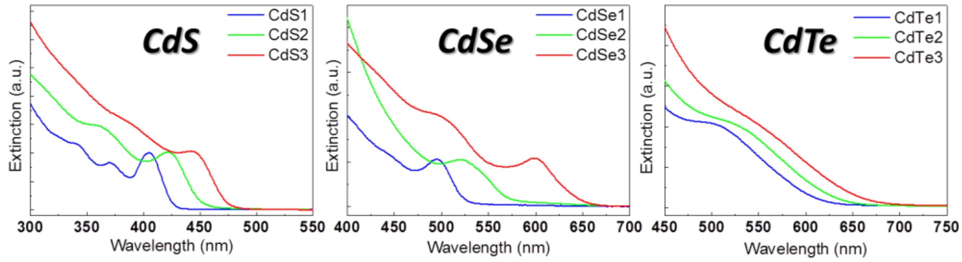
QDs + Purified MFN (1:1, 1 μM)
Argon Atmosphere
100 mM L-ASC, HEPES (pH 7.4)
400 nm LED Irradiation
TON ~ 10,000 (30 min)



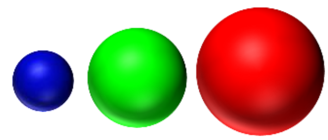
CdX1 **CdX2** **CdX3**

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, *141,* 10272 (2019)

Choosing QDs: Material and Size



QDs + Purified MFN (1:1, 1 μM)
Argon Atmosphere
100 mM L-ASC, HEPES (pH 7.4)
400 nm LED Irradiation
TON ~ 10,000 (30 min)

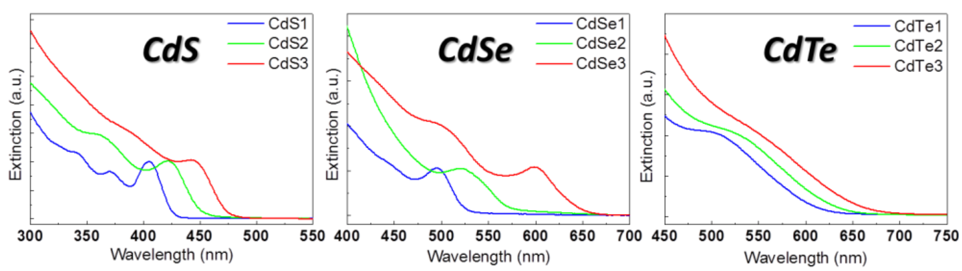


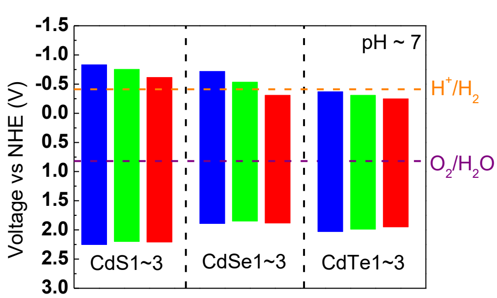
CdX1 **CdX2** **CdX3**

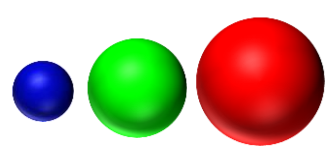
Visible Light Absorption

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, *141*, 10272 (2019)

Choosing QDs: Material and Size





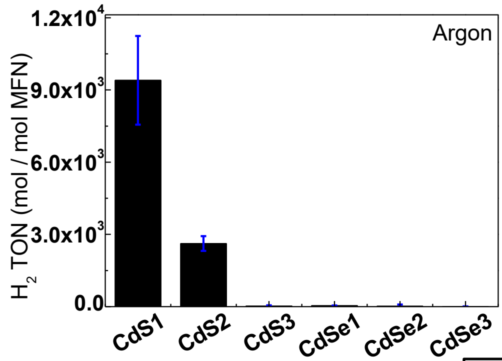


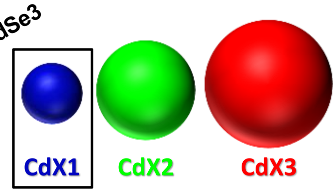
CdX1 **CdX2** **CdX3**

Visible Light Absorption
Tunable Band-edge

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, *141*, 10272 (2019)

Choosing QDs: Material and Size

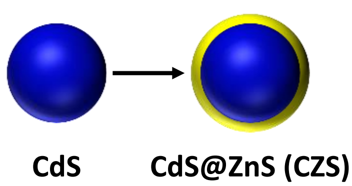


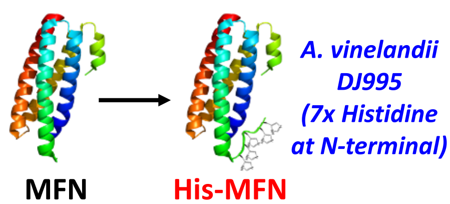


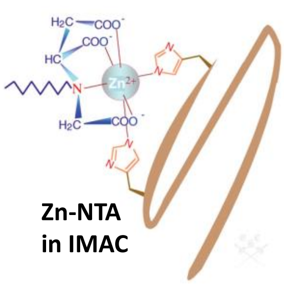
Tunable Band-edge

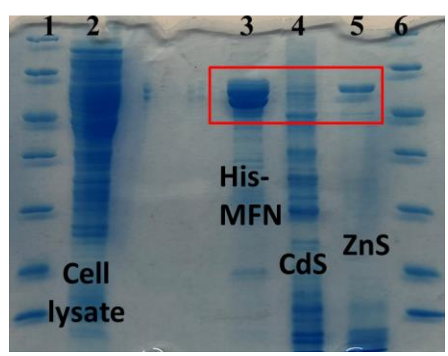
Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, *141,* 10272 (2019)

Selective QDs-Enzyme Coupling: Zn-Histidine



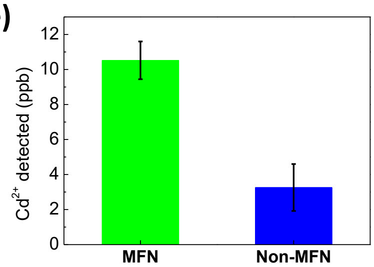


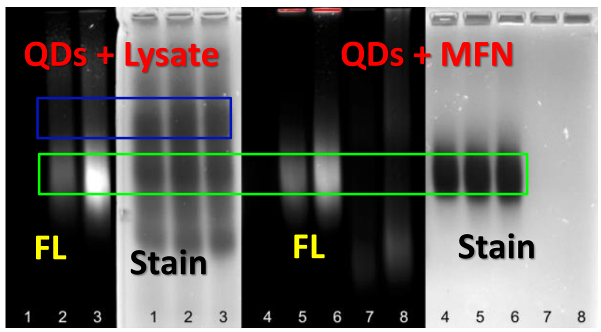




Selective QDs-Enzyme Coupling: Zn-Histidine

CdSe@ZnS (CZSe)

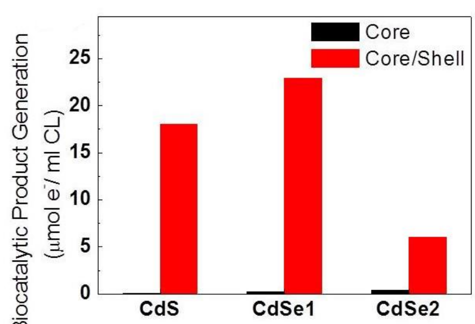




Selective QDs-Enzyme Coupling: Zn-Histidine

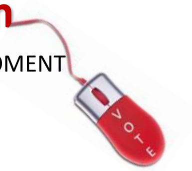
QDs + Cell Lysate
Argon Atmosphere
Light Irradiation

Yield increase significantly after ZnS coating



Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT



If a nanobug has ~10,000 copies of an enzyme of interest, and chosen QD has molecular weight of 120 g/mol, how much QDs are required to make 1 mol of nanobugs?

- 1200 kg of QDs
- 6.023×10^{24} kgs
- 120 kg
- Need more information

** If your answer differs greatly from the choices above tell us in the chat!*

How much QDs are required to make a nanobug?

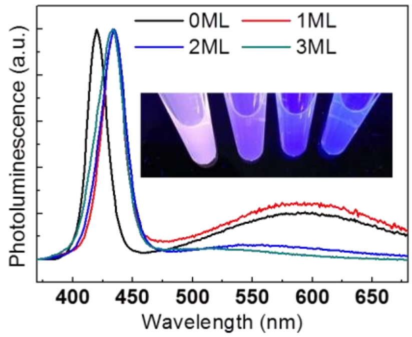
Answer: 1200 kgs

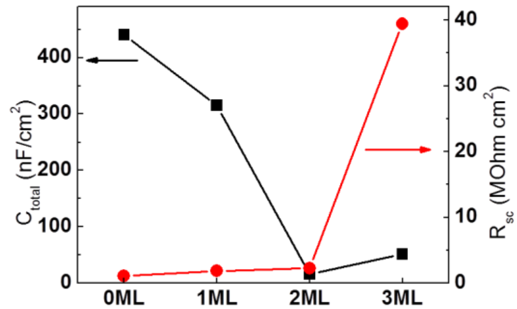
1 mol of nanobugs requires 10,000 mols of QDs (to saturate every enzyme)

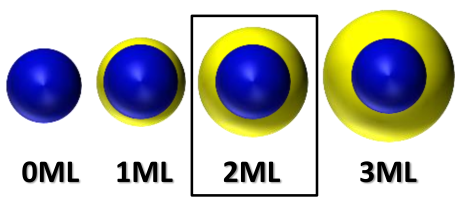
Using QD molecular weight (120 g/mol)

To make 1 mol of nanobugs= 10,000×120g =1200 kgs

Tuning the Shell Thickness



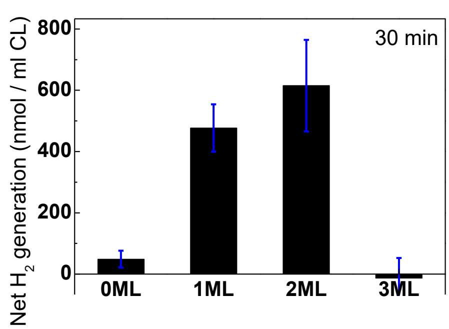




Effective Surface Passivation
Small Electron Transport Barrier

Ding, Nagpal*, *Nanoscale*, 8, 17496 (2016)
Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, *141*, 10272 (2019)

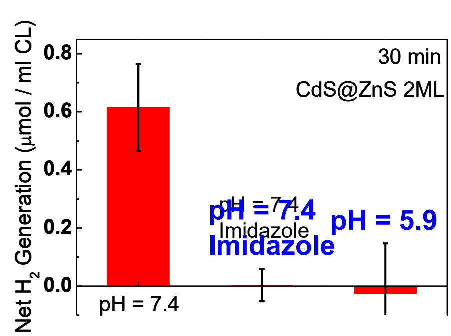
Light-driven QD-Enzyme Biocatalysis



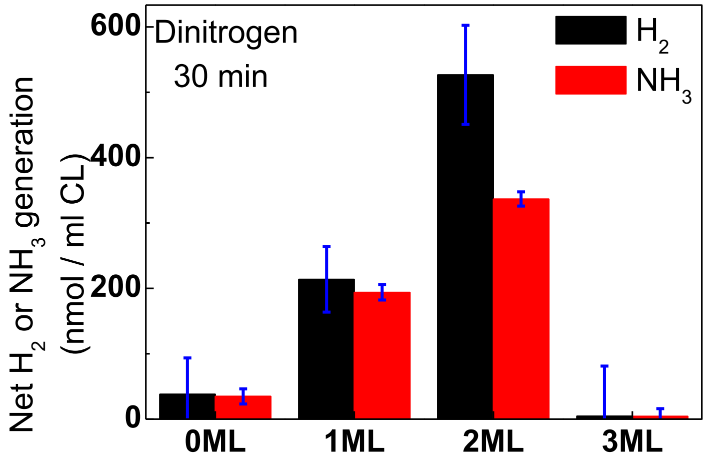
$$2H^{+} + 2e^{-} + nh\upsilon \rightarrow H_2$$

Imidazole:
Competitively binds to zinc

Higher acidity:
Protonates histidine



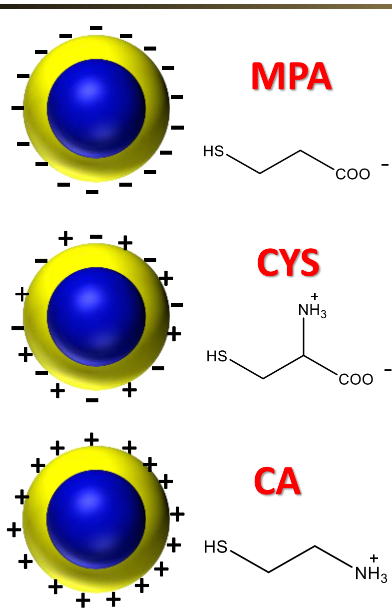
Light-driven Air-Water Reduction

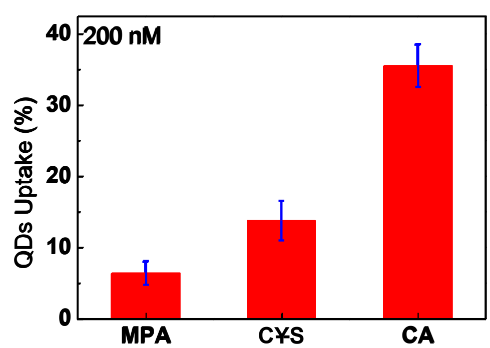


$$N_2 + 8H^+ + 8e^- + nh\upsilon \rightarrow 2NH_3 + H_2$$

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, *141,* 10272 (2019)

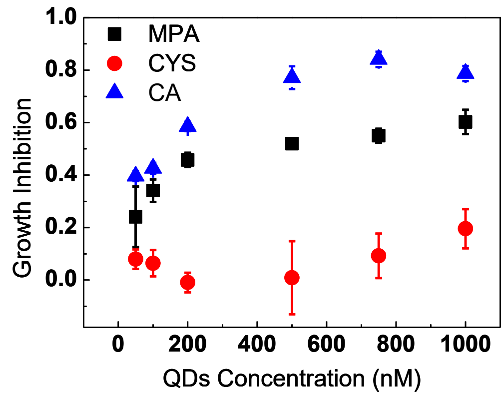
Intracellular Uptake of QDs





Courtney, Goodman, McDaniel, Madinger, Chatterjee*, Nagpal*, *Nature Materials*, 15, 529 (2016)
Courtney, Goodman, Nagy, Levy, Bhusal, Madinger, Detweiler, Nagpal*, Chatterjee*, *Science Adv.*, 3, e1701776 (2017)
Goodman, Levy, Li, Ding, Courtney, Chowdhury, Erbse, Chatterjee , Nagpal*, *Front. Chem.*, 6, 46 (2018)
Levy, Chowdhury, Nagpal*, *J. Biol. Eng.*, 13:48 (2019)
Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, 141, 10272 (2019)

Maintaining Cell Viability

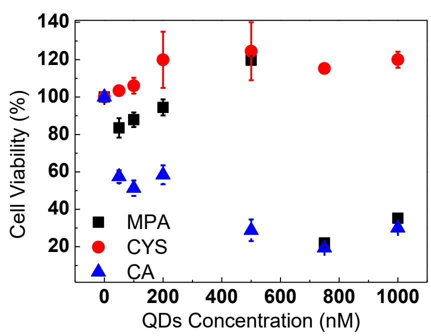


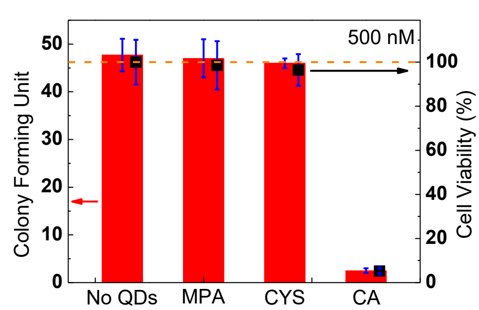
MPA (-): *Some toxicity*

CYS (+-): *Non-toxic*

CA (+): *Highly toxic*

Maintaining Cell Viability



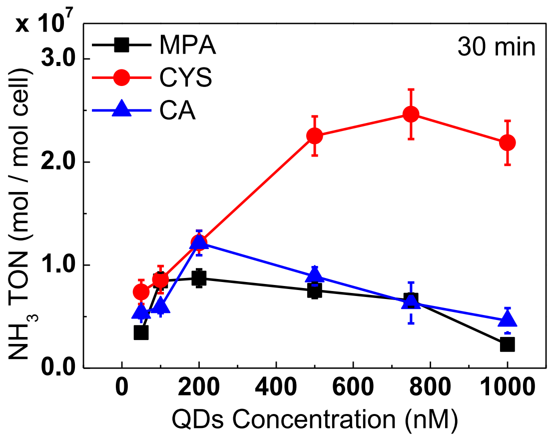


MPA (-): *Toxic at high concentration*

CYS (+-): *Non-toxic*

CA (+): *Toxic even at low concentration*

Light-driven Selective Catalysis by Nanobugs

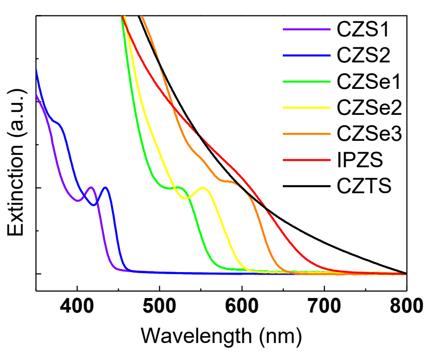


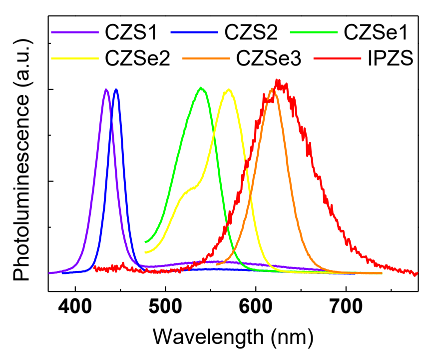
MPA (-):
Low uptake
Toxicity at high conc.

CA (+):
High uptake
Highly Toxic

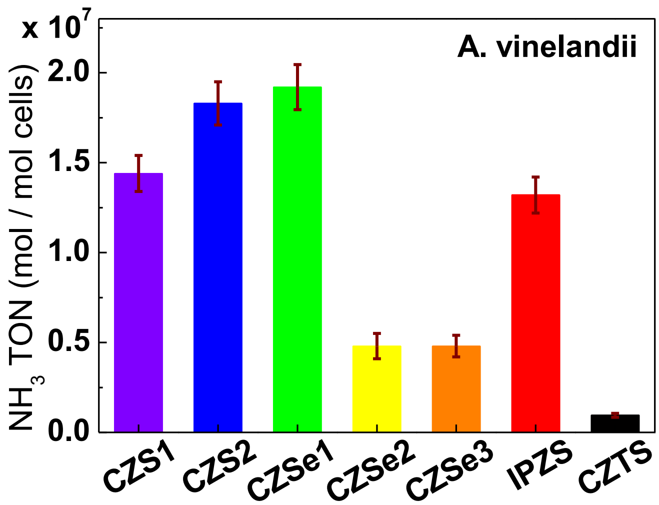
CYS (+-):
Moderate uptake
Non-toxic

Expand the Absorption Spectrum

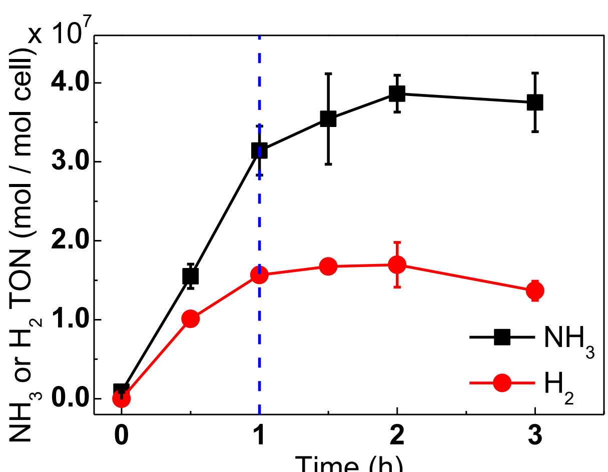




Expand the Absorption Spectrum



Nanobug Factories



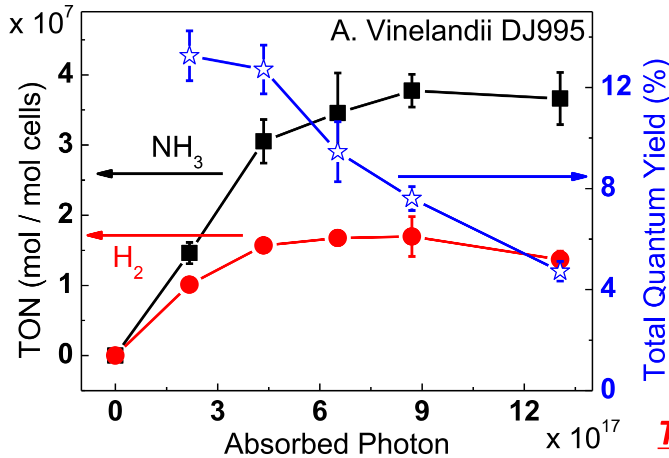
Like Solar Cells

TOF (s^{-1}) in 1 h: ***8730 for NH_3*** ***4350 for H_2***

Total QY: ~ 13 %

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, 141, 10272 (2019)

Nanobug Factories

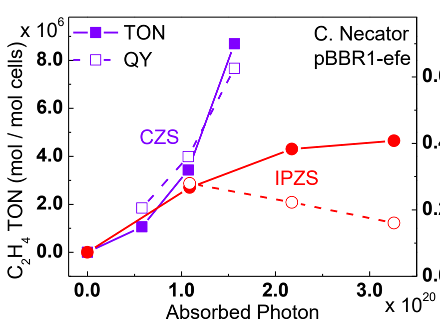


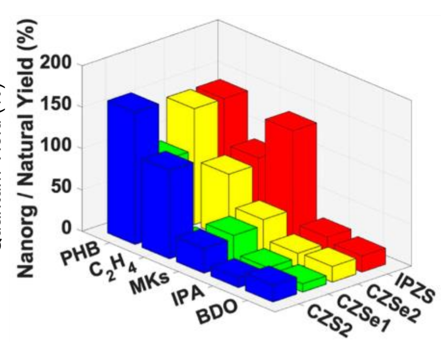
Total QY: ~ 13 %

Conversion Limited by Enzyme turnover Max theoretical QY: 16-20%

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, 141, 10272 (2019)

Nanobug Factories

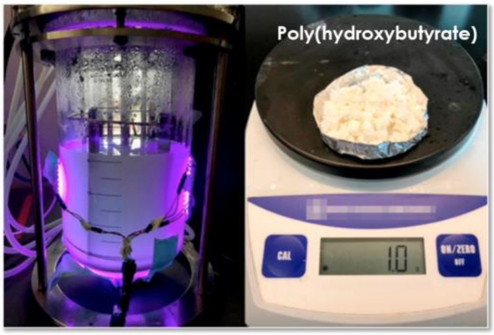


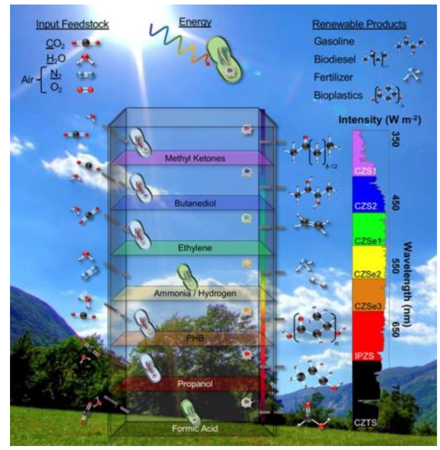


- *Range of fuels, fertilizers, preservatives, bioplastics*
- *Nanobugs utilize CO_2, air, and sunlight*
- *Process can be scaled up efficiently*
- *Tandem Cells for optimal utilization of sunlight*

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, 141, 10272 (2019)

Nanobug Factories

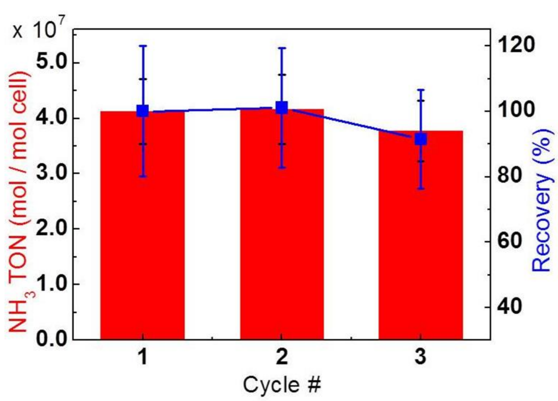




- *Range of fuels, fertilizers, preservatives, bioplastics*
- *Nanobugs utilize CO_2, air, and sunlight*
- *Process can be scaled up efficiently*
- *Tandem Cells for optimal utilization of sunlight*

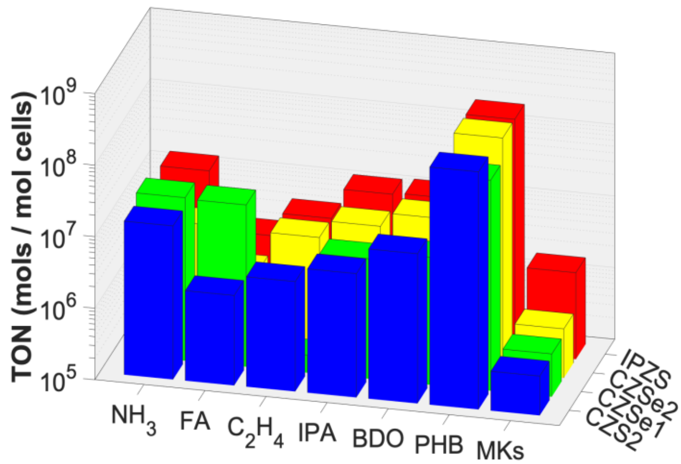
Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, 141, 10272 (2019)

Nanobug Factories



Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, 141, 10272 (2019)

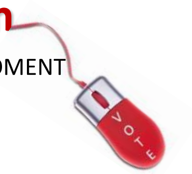
Nanobug Factories



Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, *J. Am. Chem. Soc.*, 141, 10272 (2019)

Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT



If we convert all emitted CO2/year (37.1 bn tonnes) using nanobugs, how much volume of nanobugs would it require?

Nanobugs TON (7.3×1010 mol PHB/mol cells/year)

- A small reservoir or pond
- A large lake
- A whole sea
- An entire ocean

** If your answer differs greatly from the choices above tell us in the chat!*

Combating Climate Change with Nanobugs?

Answer: A large lake

37.1 bn tonnes= 37.1×10^{12} kg= $37.1\times10^{15}/44$ mol CO_2
=8.43×10^{14} mol CO_2

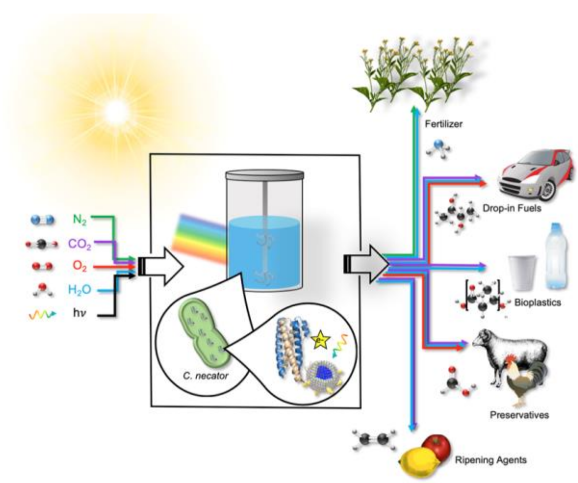
Using PHB = $5\times10^{8}\times$ 365 days/2.5day run/mol cells
TON (5×10^{8} mol PHB/mol cells/run) = 7.3×10^{10} mol PHB/year
= $7.3\times10^{10}\times4$ mol CO_2/year/mol cells ($C_4H_6O_2$)

Total mol cells required= 8.43×10^{14} / $7.3\times10^{10}\times4$=2887 mol

Volume of 1 cell~1 μm^3 or 10^{-15} L
Total volume of cells reqd.=1×10^{-18}m$^3\times2887\times6.023\times10^{23}$
=1.74×10^{9}m^3=1.74 km^3

Approximately a large lake
(e.g. Navajo Reservoir, Colorado, Lake Minnetonka or Calhoun, Minneapolis)

Combating Climate Change with Nanobugs



- *Efficiency like solar-cells*
- *Scalable, low-cost fuel and chemical generation*
- *Easy to implement technology*
- *Sustainable Nanobug factories*

Ding, Bertram, Eckert, Bommareddy, Patel, Conradie, Bryan, Nagpal*, ***J. Am. Chem. Soc.***, 141, 10272 (2019)
Goodman, Levy, Li, Ding, Courtney, Chowdhury, Erbse, Chatterjee, Nagpal*, ***Front. Chem.***, 6,46,1 (2018)
Ding, Nagpal*, ***Phys. Chem. Chem. Phys.***, 19, 10042 (2017)
Courtney, Goodman, McDaniel, Madinger, Chatterjee*, Nagpal*, ***Nature Materials,*** 15, 529 (2016)
Ding, Nagpal*, ***Nanoscale,*** 8, 17496 (2016)
Goodman, Noh, Singh, Cha, Nagpal*, ***Appl. Phys. Lett.***,106, 083109 (2015)
Goodman, Siu, Singh, Nagpal*, ***Nanoscale***, 7, 18435 (2015)
Goodman, Singh, Ribot, Chatterjee, Nagpal*, ***J. Phys. Chem. Lett.***, 5,3909 (2014)
Singh, Beltran, Ribot, Nagpal*, ***Nano Lett.,*** 14, 597 (2014)

Acknowledgements

Nagpal Group members

Graduate Students:

- *Sam Goodman (PhD., 2016)*
- *Yuchen Ding (Ph.D., 2017)*
- *Lee Erik Korshoj*
- *Partha Chowdhury (Ph.D. 2018)*
- *Ibrahim Saleh (Ph.D. 2019)*
- *Max Levy*
- *John R. Bertram*
- *Ameya Prabhune*
- *Shane Bassett*

Postdocs:

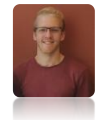
- *Dr. Yuchen Ding*

Alumni :

- *Dr. Gary Abel*
- *Dr. Yahya Alivov*
- *Dr. D.M. Sagar*
- *Dr. FeiFei Li*

Alumni :

- *Dr. Vivek Singh*
- *Dr. Qi Charles Sun*
- *Dr. Sajida A. Khan*
- *Dr. Sepideh Afsari*



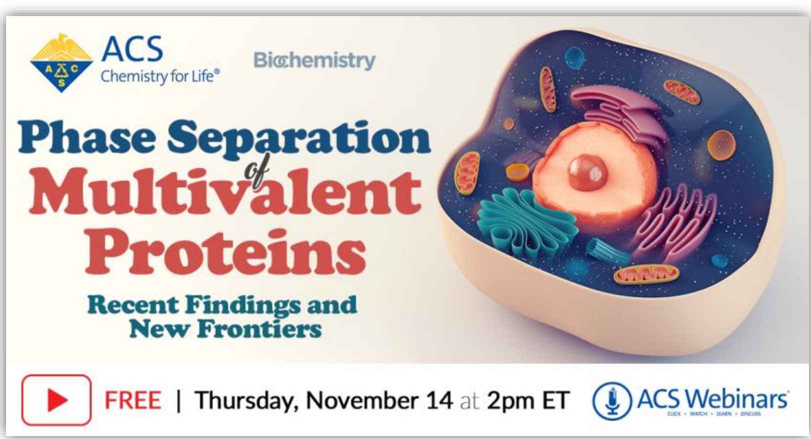
Financial support:

- *NSF CAREER Award*
- *W.M. Keck Foundation Research Award*
- *NSF MRSEC (DMR) IRG-II*
- *Army Research Office DURIP Award*
- *NSF-MRI*
- *NASA-TRISH*
- *DOE-BER*

Upcoming ACS Webinar!

www.acs.org/acswebinars

ACS Chemistry for Life®

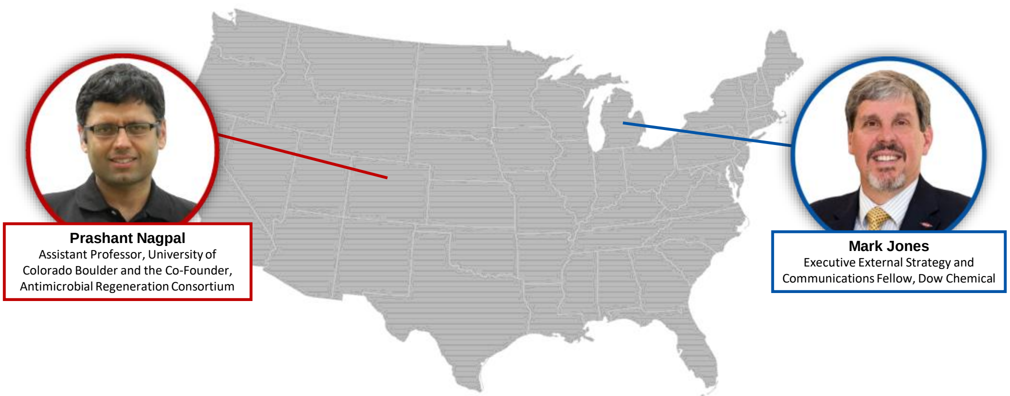


https://www.acs.org/content/acs/en/acs-webinars/technology-innovation/phase-separation.html

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

Combating Climate Change with New Nanobugs: Teaching Bacteria to Eat Carbon Dioxide and Light with Quantum Dots



Presentation slides available now! Recordings are an exclusive ACS member benefit.

www.acs.org/acswebinars

This ACS Webinar is co-produced with the ACS Industry Member Programs

53

Resources from Industry Member Programs!

ACS Chemistry for Life®

54

How has ACS Webinars benefited you?

ACS Chemistry for Life®

"Safety content is always timely and important. Getting the message out is always a challenge and this ACS Webinar presented some good ideas on safety communication that I will apply at our institution."

http://bit.ly/labsafetyACS

Fan of the Week

Henry VanBrocklin, PhD
Professor, Radiology and Biomedical Imaging, Chair, Chemistry and Environmental Safety Committee, University of California, San Francisco
ACS member for 36 years strong!

Be a featured fan on an upcoming webinar! Write to us @ acswebinars@acs.org

55

ACS Webinars®
CLICK • WATCH • LEARN • DISCUSS

@AmericanChemicalSociety

@AmerChemSociety

@AmerChemSociety

LinkedIn https://www.linkedin.com/company/american-chemical-society

Contact ACS Webinars ® at acswebinars@acs.org

56

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS
Chemistry for Life®

http://bit.ly/ACSnewmember

57

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

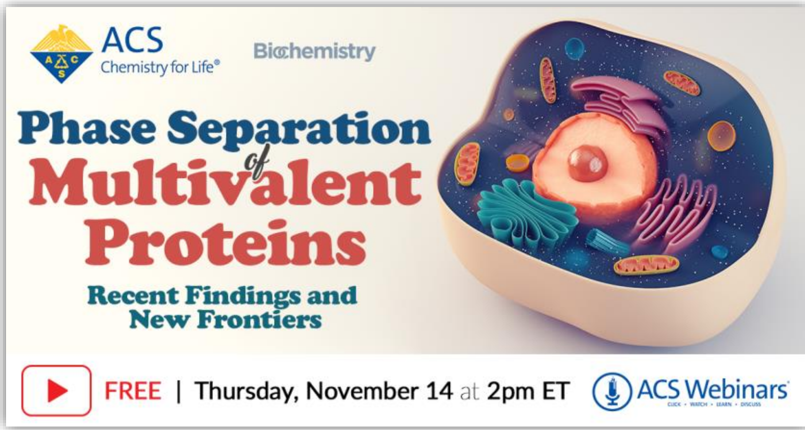
ACS
Chemistry for Life®

ACS Webinars® does not endorse any products or services. The views expressed in this presentation are those of the presenter and do not necessarily reflect the views or policies of the American Chemical Society.

Contact ACS Webinars ® at acswebinars@acs.org

58

Upcoming ACS Webinar!
www.acs.org/acswebinars



https://www.acs.org/content/acs/en/acs-webinars/technology-innovation/phase-separation.html