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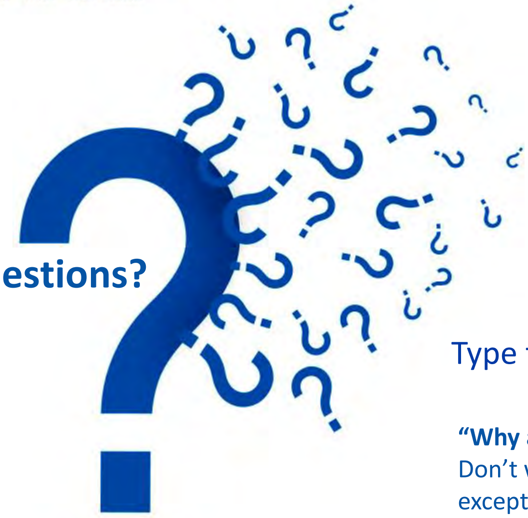

Have Questions?

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.

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From renewable fuels to creating the materials for the technology of tomorrow, chemistry plays a pivotal role in advancing our world. Meet the chemists that are building a better world and see how their science is making it happen.

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https://www.acs.org/content/acs/en/acs-webinars/videos.html

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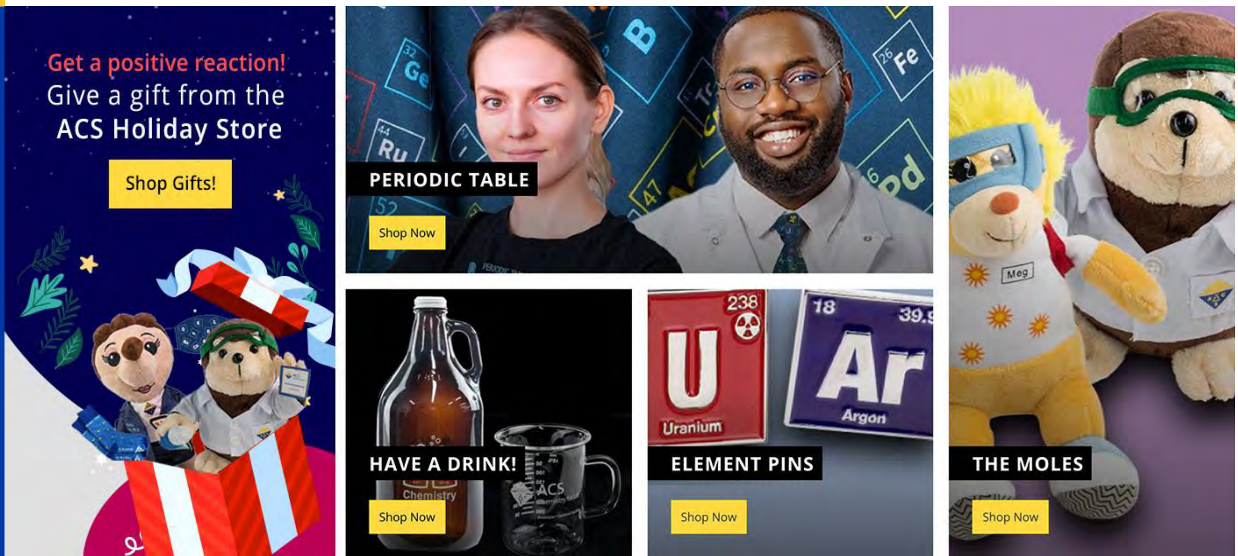

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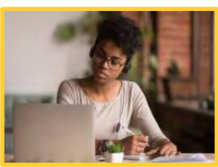
ACS Career Navigator: Your Home for Career Services

ACS Chemistry for Life®

Whether you are just starting your journey, transitioning jobs, or looking to brush up or learn new skills, the **ACS Career Navigator** has the resources to point you in the right direction.

We have a collection of career resources to support you during this global pandemic:



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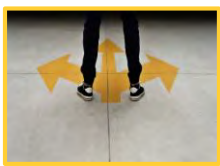

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ACS Webinars

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ACS Chemistry for Life®

We believe in the strength of diversity in all its forms, because inclusion of and respect for diverse people, experiences, and ideas lead to superior solutions to world challenges and advances chemistry as a global, multidisciplinary science.

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ACS Scholars Endowment Founder Joe Vacca, retired Vice President of Chemistry, Merck & Co., meets with his 2018 ACS Scholar **Johanna Masterson**, now a grad student at Princeton University.

"Chemistry has been good to me...so I wanted to make a significant gift to provide that opportunity to others."

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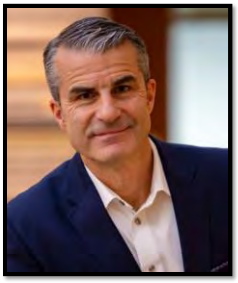
ACS & Cargill Article on Sustainability

How does the chemical industry contribute to planetary sustainability?

Check out this article from *ACS Industry Matters* and discover the way Cargill uses chemistry to tackle the challenge of feeding more people with less land.



Florian Schattenmann,
CTO and VP of R&D at Cargill

www.acs.org/Cargill

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Free ACS Webinars Every Week!

Last Webinar of the Year of 2020

Thursday, December 17, 2020 at 2-3pm ET

Speakers: Victor McCrary, National Science Board and University of the District of Columbia and Barbara Sawrey, ACS Board of Directors and UC San Diego

Register for Free!

What You Will Learn

- How America can continue to lead in fundamental research
- How can American discoveries continue to empower U.S. businesses and entrepreneurs to succeed globally
- How can the U.S. increase STEM skills and opportunities for all Americans
- How does ACS and the chemistry enterprise fit into these questions

Co-produced with: ACS External Affairs & Communications and the National Science Board

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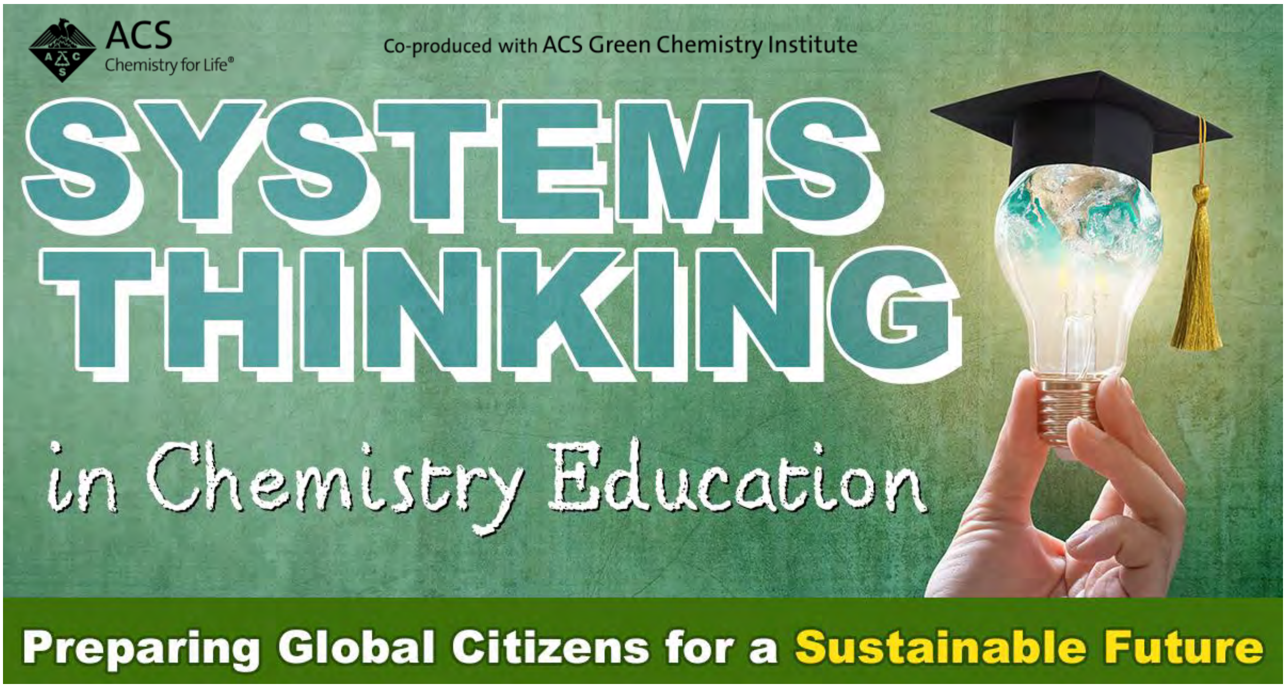

THIS ACS WEBINAR WILL BEGIN SHORTLY...

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Chemistry for Life®

Systems Thinking in Chemistry Education: Preparing Global Citizens for a Sustainable Future

Peter Mahaffy
Professor of Chemistry and Director,
King's Centre for Visualization in Science

MaryKay Orgill
Professor of Chemistry & Biochemistry
University of Nevada, Las Vegas

David Constable
Science Director, Green Chemistry
Institute, American Chemical Society

Presentation slides are available now! The edited recording will be made available as soon as possible.
www.acs.org/acswebinars

This ACS Webinar is co-produced with the ACS Green Chemistry Institute.

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Peter Mahaffy
Professor of Chemistry and Director,
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THE KING'S UNIVERSITY
KCVS.ca
King's Center for Visualization in Science

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@peter.mahaffy

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WHAT YOU WILL LEARN

- ✓ What a systems thinking approach looks like in chemistry education: its essential characteristics and the benefits of its use
- ✓ How a systems thinking approach extends and differs from context-based approaches to chemistry teaching and learning
- ✓ How a systems thinking approach can prepare students to become global citizens capable of taking informed action to support planetary sustainability

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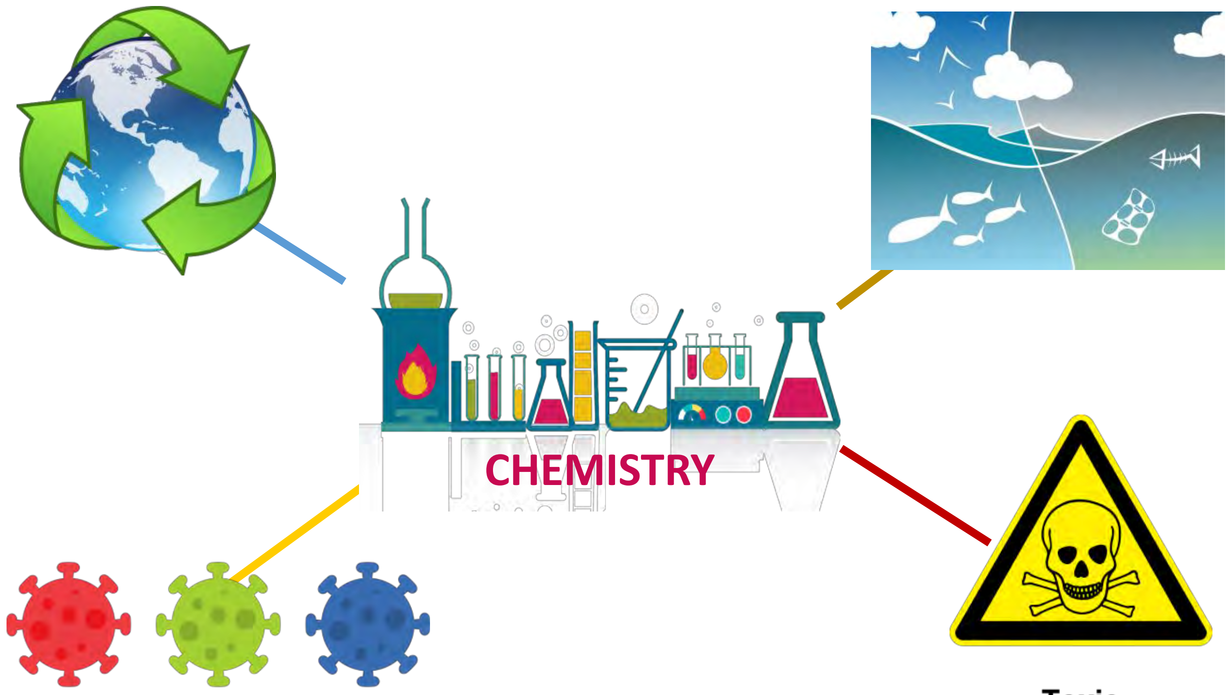

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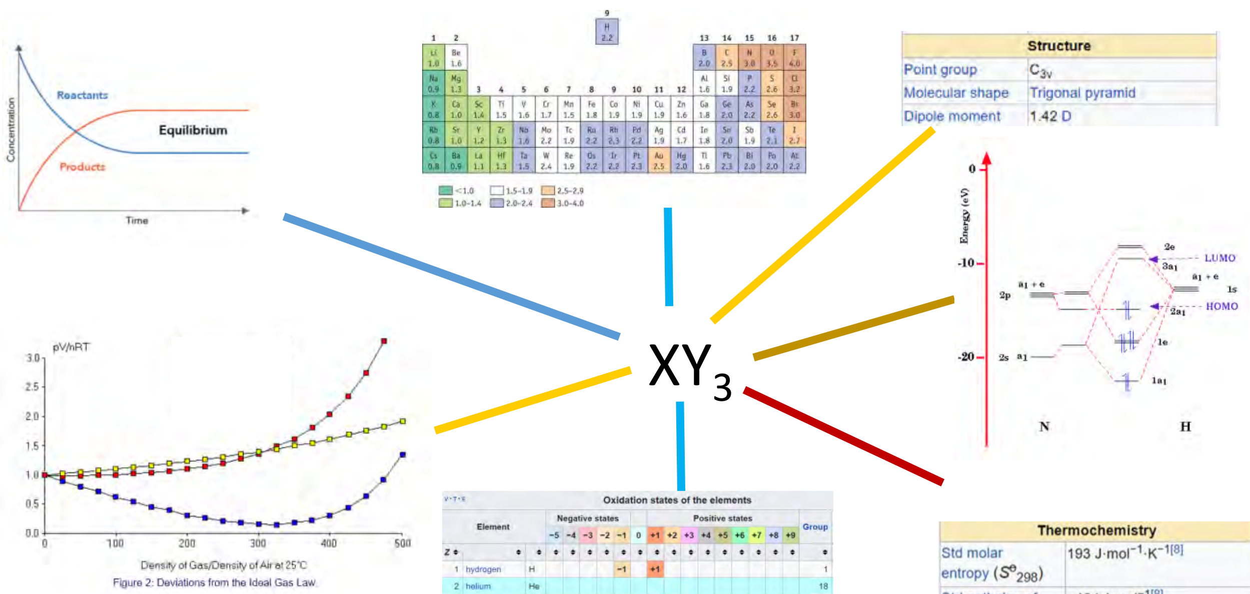

Structure	
Point group	C_{3v}
Molecular shape	Trigonal pyramid
Dipole moment	1.42 D

Oxidation states of the elements																	
Element			Negative states						Positive states								Group
			−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
Z																	
1	hydrogen	H					−1		+1									1
2	helium	He																18
3	lithium	Li							+1									1
4	beryllium	Be						0	+1	+2								2
5	boron	B	−5				−1	0	+1	+2	+3							13
6	carbon	C		−4	−3	−2	−1	0	+1	+2	+3	+4						14
7	nitrogen	N			−3	−2	−1		+1	+2	+3	+4	+5					15
8	oxygen	O				−2	−1	0	+1	+2								16
9	fluorine	F					−1											17

Thermochemistry	
Std molar entropy (S°_{298})	193 $J \cdot mol^{-1} \cdot K^{-1}$[8]
Std enthalpy of formation ($\Delta_f H^{\ominus}_{298}$)	−46 $kJ \cdot mol^{-1}$[8]

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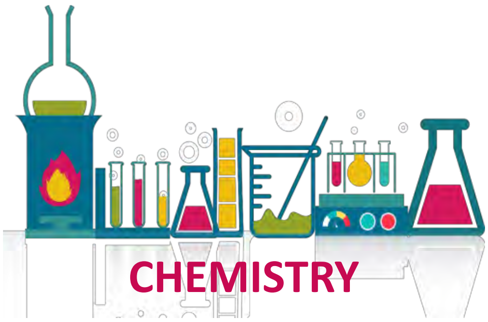
CONTEXT-BASED TEACHING AND LEARNING

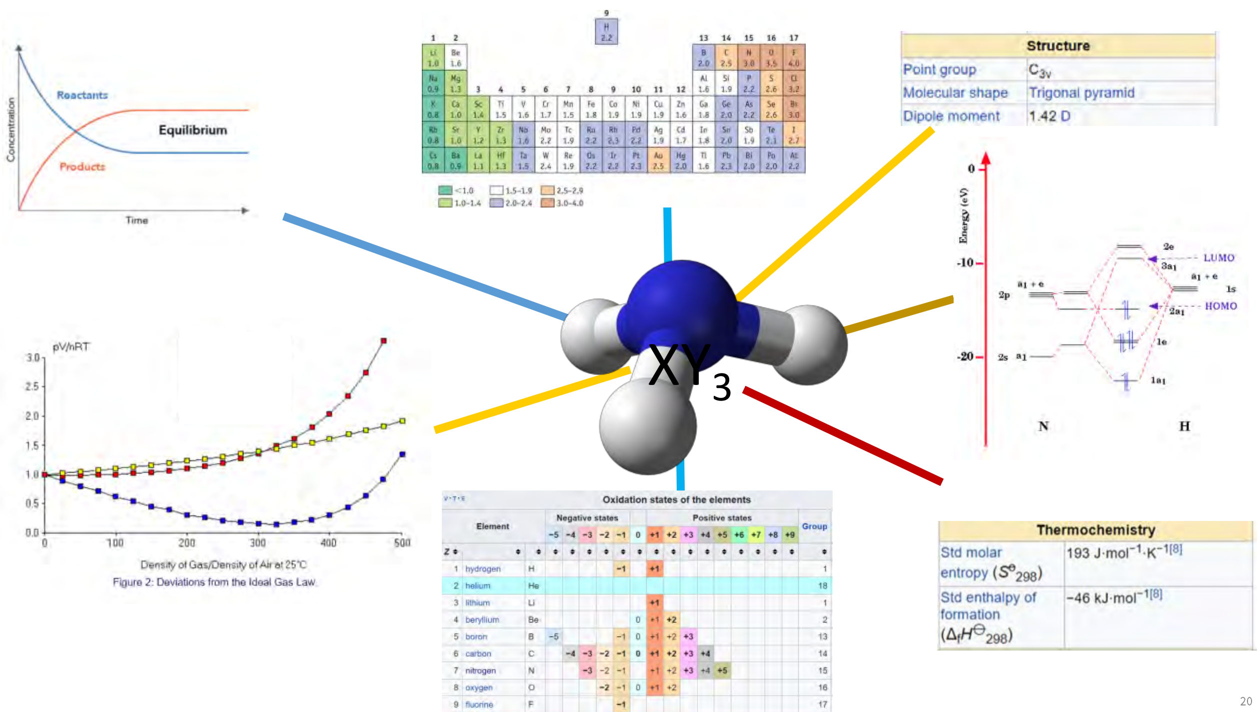


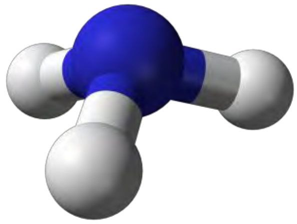
Situates chemistry in real-world contexts

- Motivates students to learn science
- Promotes ability to see connections between chemistry and their everyday world
- Promotes long-term retention of knowledge

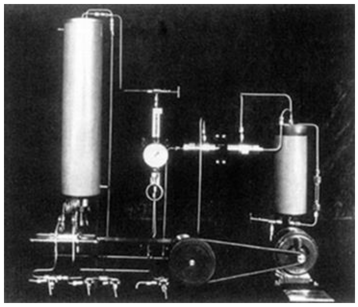
Illustration by Dan Bright, in https://edu.rsc.org/feature/putting-chemistry-in-context/2000106.article

Overton, T. Context and problem-based learning. *New Directions in the Teaching of Physical Sciences,* **2007**, *3,* 7-12; DOI: 10.11120/ndir.2007.00030007.





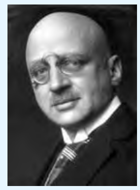
Ammonia, NH_3



$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Haber-Bosch Process

Fritz Haber was a German chemist who received the Nobel Prize in Chemistry in 1918 for his invention of the Haber-Bosch process, the method used in industry to synthesize ammonia from nitrogen and hydrogen gases.



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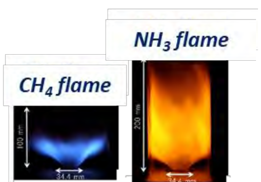
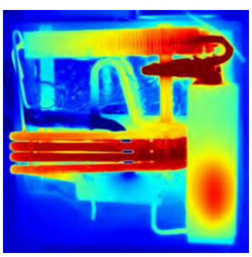
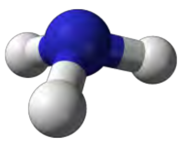


AMMONIA ENERGY ASSOCIATION



G1MFG, en.Wikipedia.com



Scientists discover greener method to produce ammonia

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Agriculture's hunger for nitrogen oversteps planetary boundaries

https://theconversation.com/agricultures-hunger-for-nitrogen-oversteps-planetary-boundaries-10182

https://visibleearth.nasa.gov/images/52827/red-tide-along-florida-panhandle/52828l

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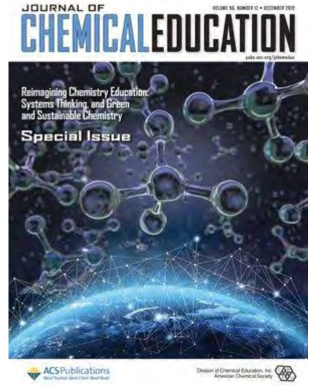
Systems Thinking

“an approach for examining and addressing complex behaviors and phenomena from a more holistic perspective” (Orgill et al., 2019, p. 2720)



December 2019

An IUPAC Project 2017 - 2020

Systems Thinking in Chemistry Education (STICE)

How might systems thinking apply to Chem Ed, and how can that help the next generation address emerging global challenges?

ACS Green Chemistry Institute®

Orgill, M.; York, S.; MacKellar, J. Introduction to systems thinking for the chemistry education community. *J. Chem. Educ.* **2019**, *96* (12), 2720-2729; DOI: 10.1021/acs.jchemed.9b00169.

ACS Editors' Choice

https://iupac.org/projects/project-details/?project_nr=2017-010-1-050 (P. Mahaffy & S. Matlin, project group co-chairs)

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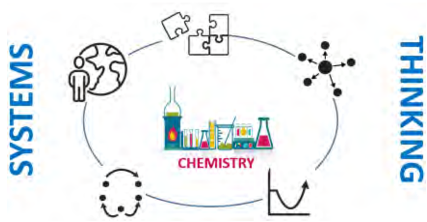
Benefits of Systems Thinking



Promotes learning of chemistry content
- More meaningful learning
- Increased retention of content
- Increased motivation to learn science

Develops the knowledge and skills needed for reasoning about chemical phenomena
- Improved question asking abilities
- Improved critical thinking and problem-solving skills

Prepares students to understand and address complex, real-world problems in order to promote planetary sustainability
- Increased abilities to see connections between chemistry and other disciplines
- Increased abilities to transfer knowledge and skills from one problem situation to another
- Increased sense of ability to effect change in the world around a student

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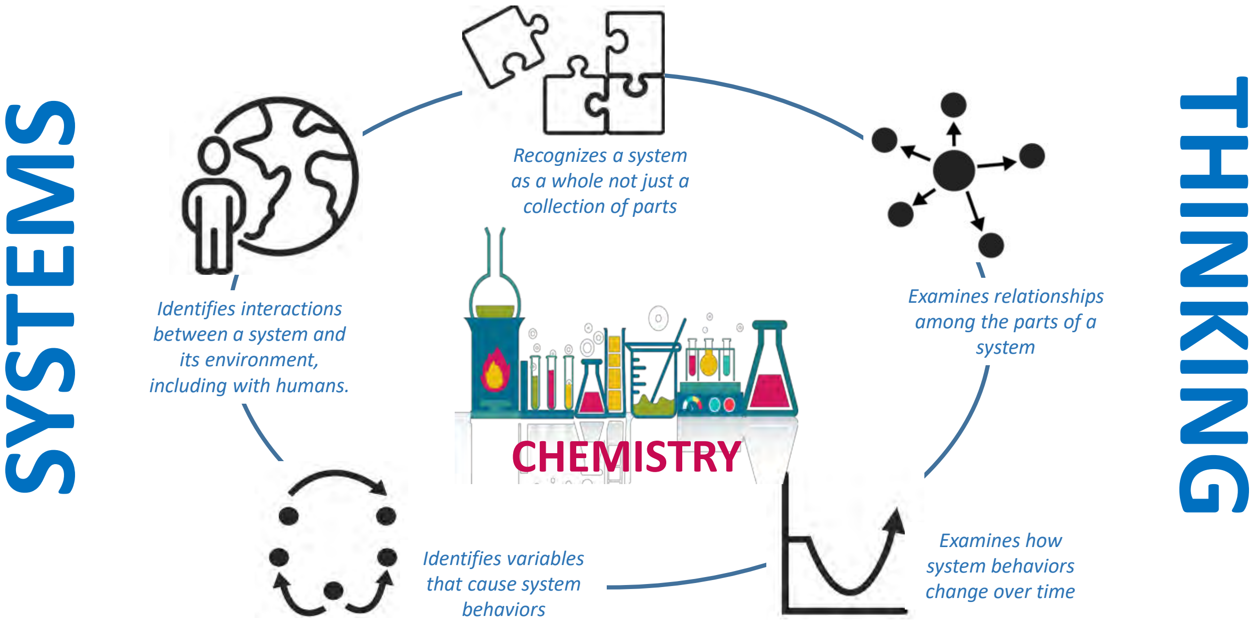
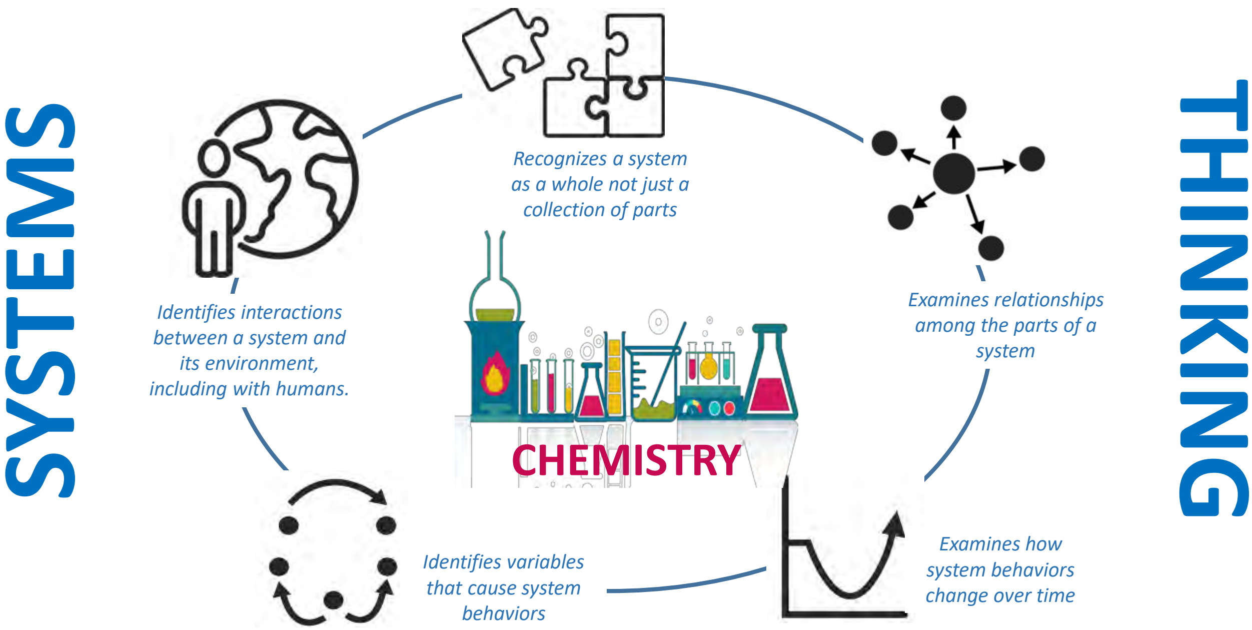


York, S.; Orgill, M. ChEMIST Table: A tool for designing or modifying instruction for a systems thinking approach in chemistry education. *J. Chem. Educ.* **2020**, *97* (8), 2114-2129; DOI: 10.1021/acs.jchemed.0c00382.

Icons from C&E News Cover Story, Volume 98, Issue 5 c&en



York, S.; Orgill, M. ChEMIST Table: A tool for designing or modifying instruction for a systems thinking approach in chemistry education. *J. Chem. Educ.* **2020**, *97* (8), 2114-2129; DOI: 10.1021/acs.jchemed.0c00382.

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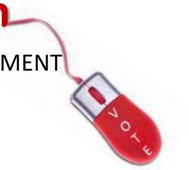
Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT



Which benefit of systems thinking do you think is MOST important for helping students become global citizens who promote a sustainable future?

- Increased retention of chemistry content
- Increased motivation to learn science
- Improved critical thinking and problem solving skills
- Increased abilities to see connections between chemistry and other disciplines
- Increased ability to transfer knowledge and skills to new situations

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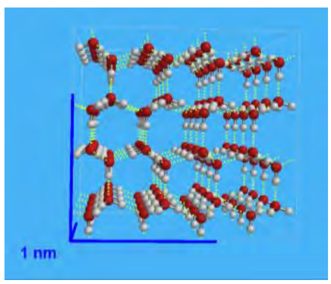
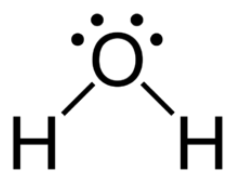


Odyssey Molecular Explorer, Wavefunction, Inc.



Water as a chemical system

Odyssey Molecular Explorer, V6.0 Wave Function Inc,
Lab 69: The Melting Transition at the Molecular Level

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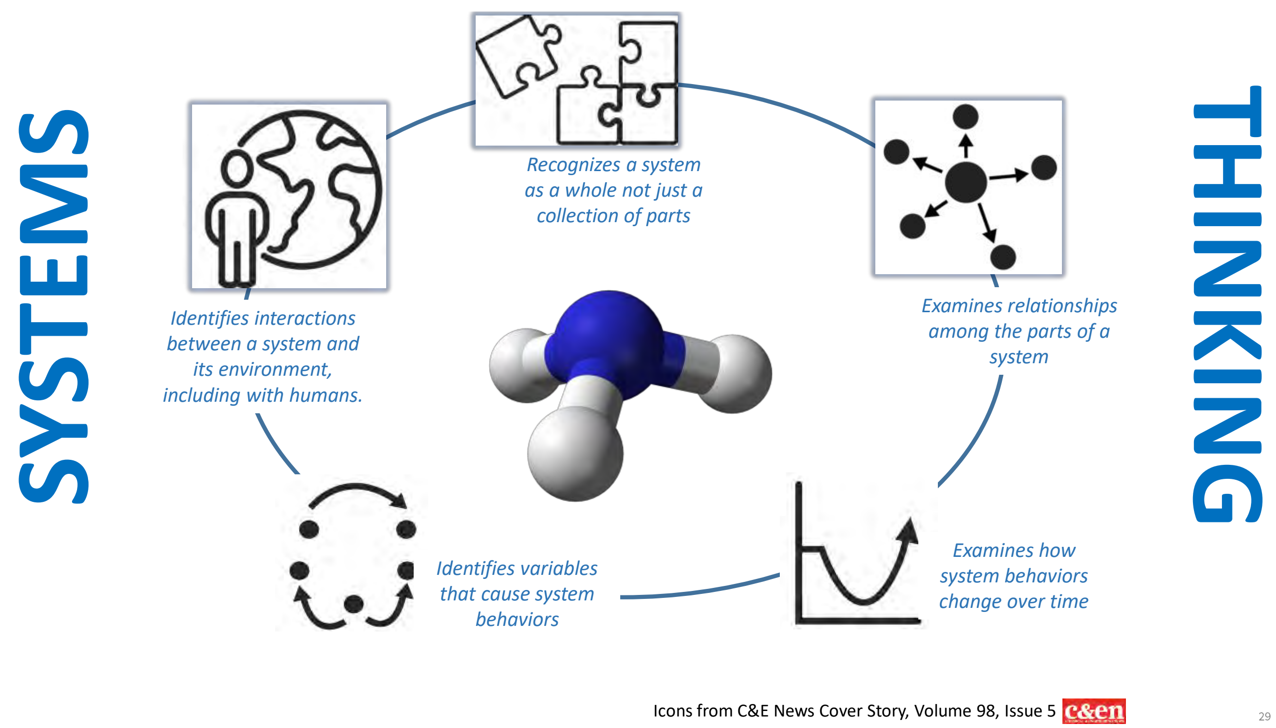
SYSTEMS
THINKING
Recognizes a system as a whole not just a collection of parts
Identifies interactions between a system and its environment, including with humans.
Examines relationships among the parts of a system
Identifies variables that cause system behaviors
Examines how system behaviors change over time
Icons from C&E News Cover Story, Volume 98, Issue 5
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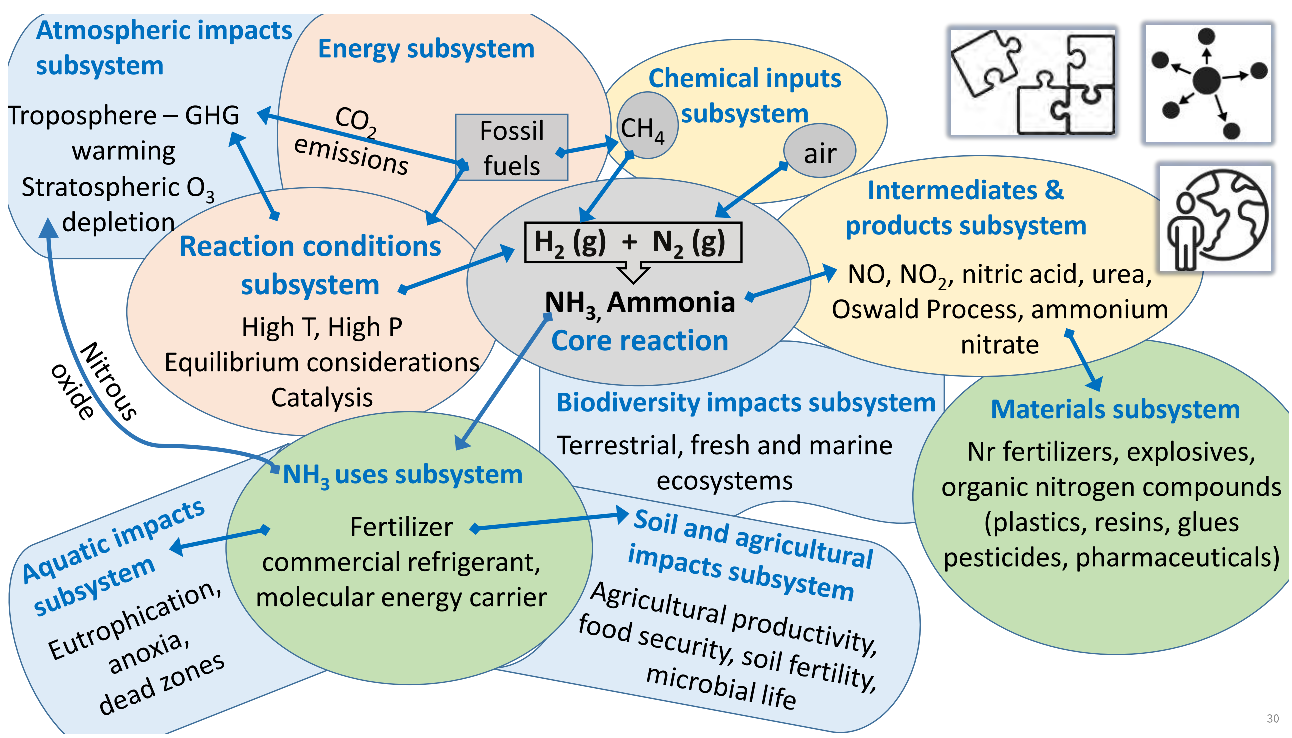
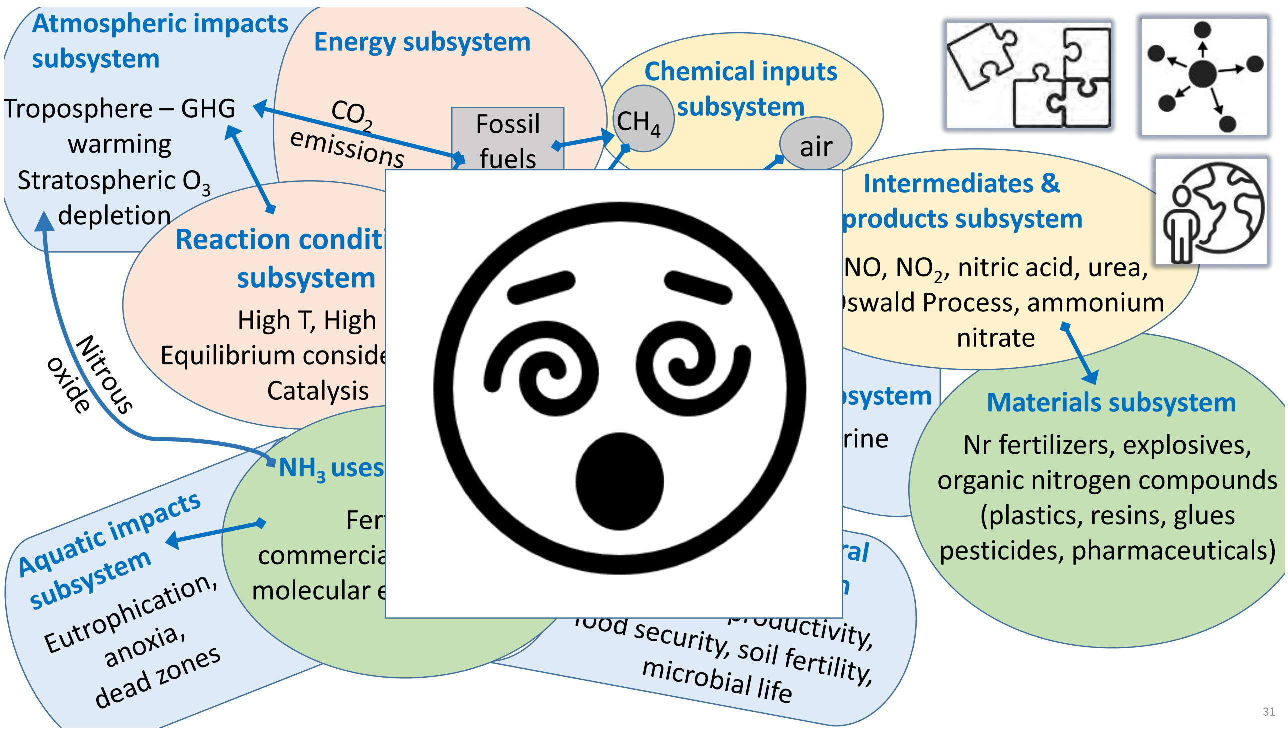

Atmospheric impacts subsystem
Troposphere – GHG warming
Stratospheric O_3 depletion
Energy subsystem
CO_2 emissions
Fossil fuels
Chemical inputs subsystem
CH_4
air
Reaction conditions subsystem
High T, High P
Equilibrium considerations
Catalysis
H_2 (g) + N_2 (g)
NH_3, Ammonia
Core reaction
Intermediates & products subsystem
NO, NO_2, nitric acid, urea, Oswald Process, ammonium nitrate
Nitrous oxide
Biodiversity impacts subsystem
Terrestrial, fresh and marine ecosystems
Materials subsystem
Nr fertilizers, explosives, organic nitrogen compounds (plastics, resins, glues pesticides, pharmaceuticals)
NH_3 uses subsystem
Fertilizer
commercial refrigerant, molecular energy carrier
Aquatic impacts subsystem
Eutrophication, anoxia, dead zones
Soil and agricultural impacts subsystem
Agricultural productivity, food security, soil fertility, microbial life
30



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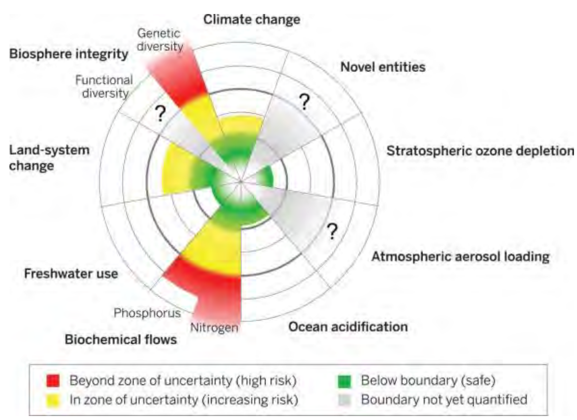
Systems Thinking is identified as one of 5 key competencies as essential for a sustainable future*

UN Sustainable Development Goals

169 targets require strategies based on consideration of systems rooted in the flow of materials and energy: Fundamental chemistry at the heart



Planetary Boundaries Framework

Steffen et. al. Planetary boundaries: Guiding human development on a changing planet, *Science*, **2015**, DOI: 10.1126/science.1259855

*Wiek, A., et. al. Key competencies in sustainability: a reference framework for academic program development, *Sustainability Science* **2011**, 6:2, 203-218

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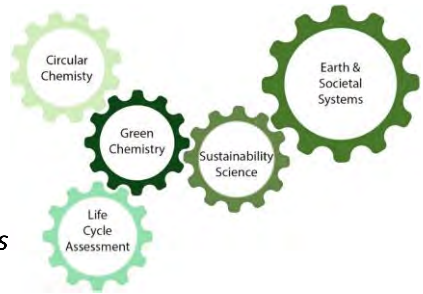
The Molecular/Material Basis of Sustainability

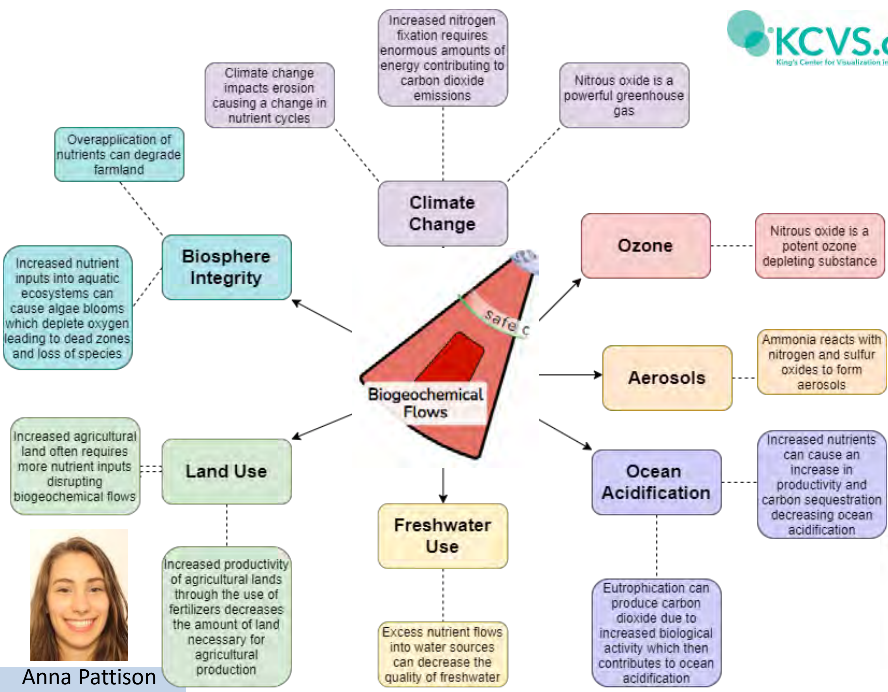
- The flow of material and energy is integral to all aspects of society and the environment.
- Chemistry understands and <u>controls</u> matter through analyzing, synthesizing, and transforming substances.
- ∴ Chemistry education has a special responsibility to address the sustainability of earth and societal systems.
- <u>Molecular basis of sustainability</u>: *"The ways in which the material basis of society and economy underlie considerations of how present and future generations can live within the limits of the natural world."*
- MBOS: Important, but largely invisible aspect of both sustainability agendas and our chemistry courses!



Anastas, P. T., Zimmerman, J. B. The molecular basis of sustainability. *Chem* **2016,** *1*, 10–12

Mahaffy, P. G.; Matlin, S. A.; Whelan, J. M.; Holme, T. A. Integrating the molecular basis of sustainability into general chemistry through systems thinking. *J. Chem. Educ.* **2019**, *96* (12), 2730-2741 ACS Editors' Choice

Mahaffy, P. G.; Matlin, S. A.; Holme, T. A.; MacKellar, J. Systems thinking for education about the molecular basis of sustainability. *Nat. Sustain.* **2019**, *2*, 362– 370



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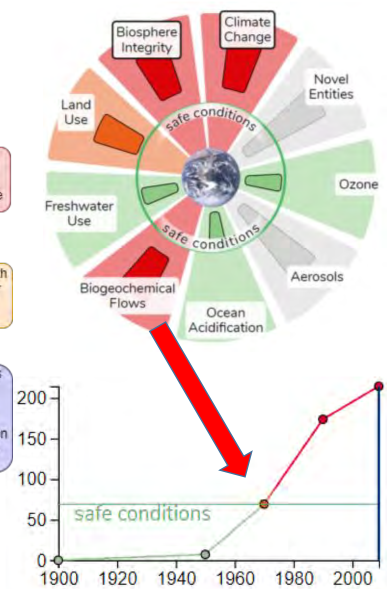
planetaryboundaries.kcvs.ca

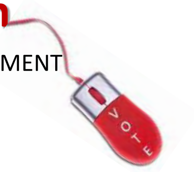


Nitrogen fixation rate Tg/year

Anna Pattison
King's University

Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT



Where do you think ammonia and reactive N best fits into the 1st year post-secondary chemistry curriculum?

- Equilibrium and kinetics
- Thermochemistry
- Structure and bonding
- Main group chemistry
- All of the above

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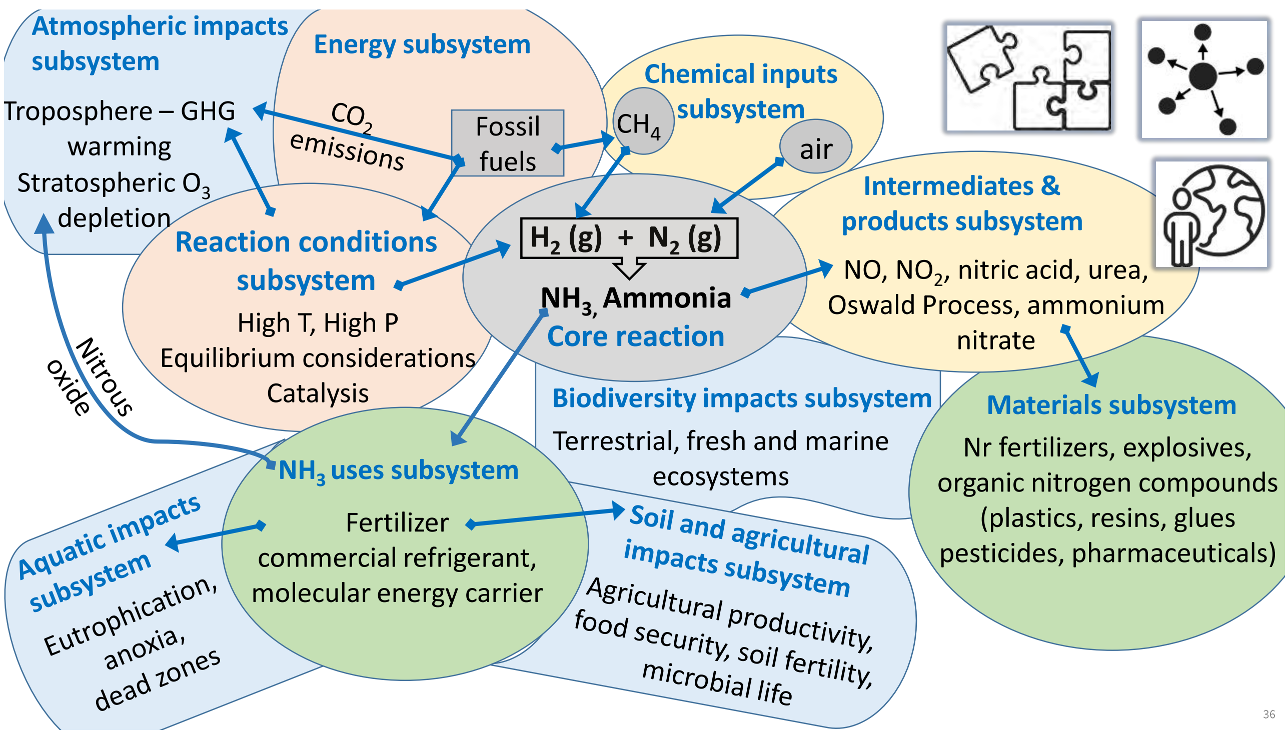

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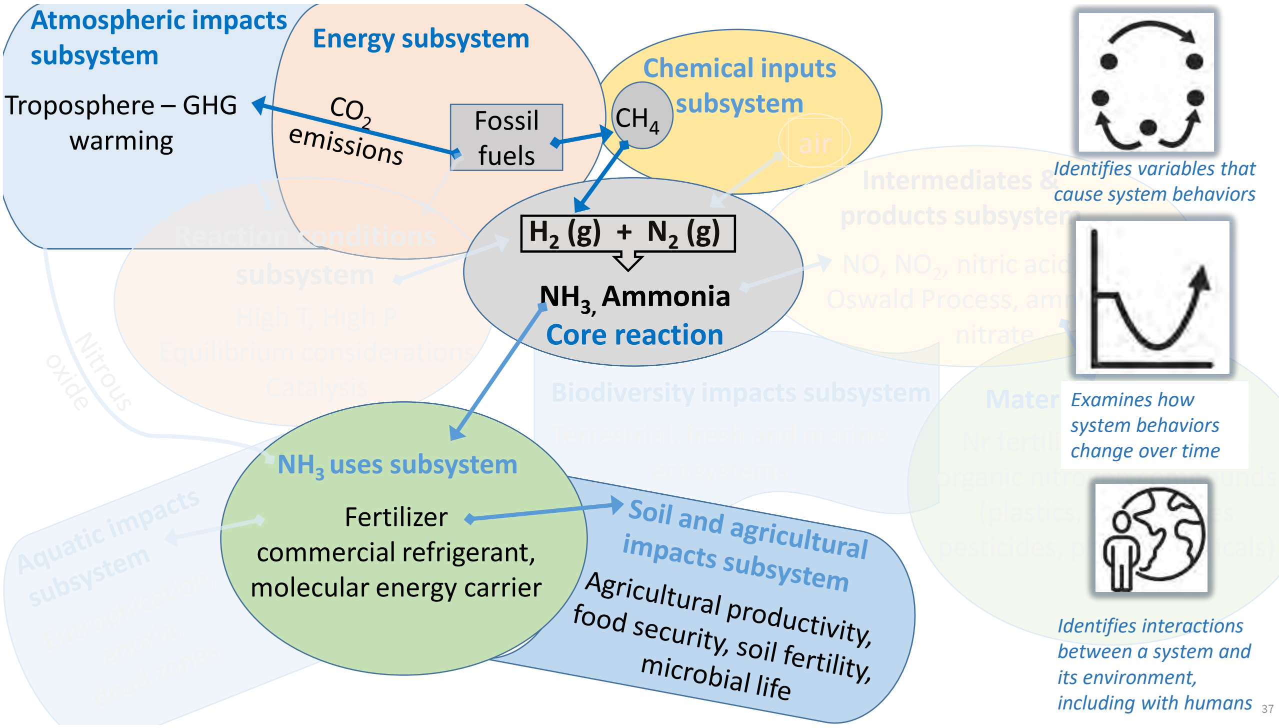
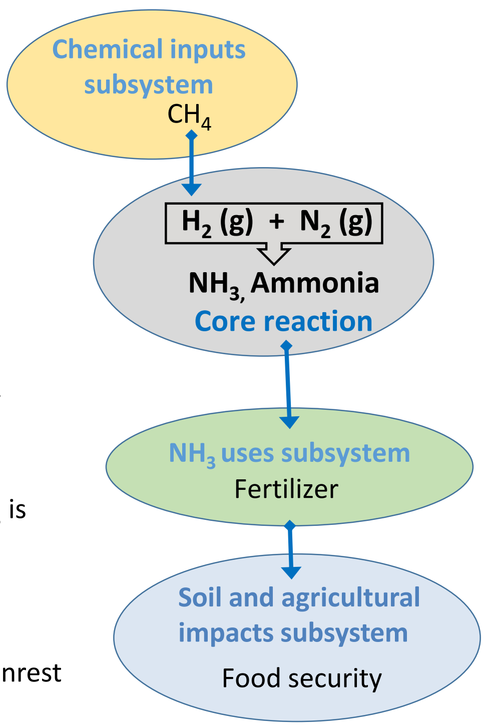


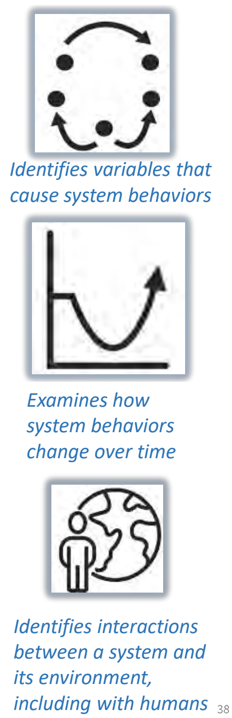
Marc Whalen
Dalhousie Univ.
Canada



H_2 for NH_3 presently mostly produced from CH_4 (steam reforming/ water-gas shift)

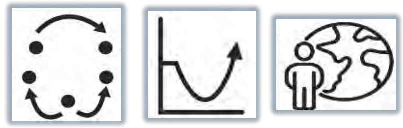
80% of the cost of NH_3 is the cost of natural gas

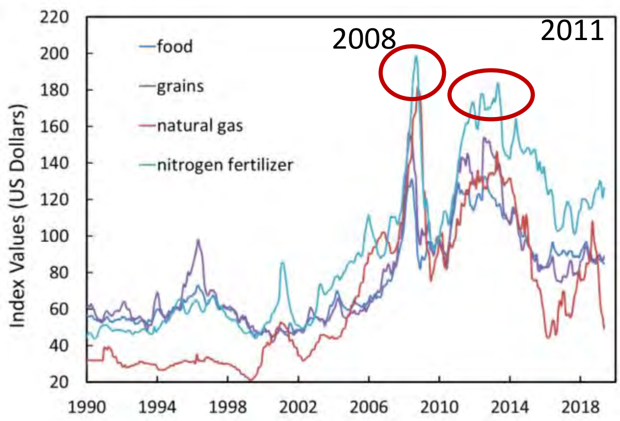
Price spikes have implications for food security and political unrest

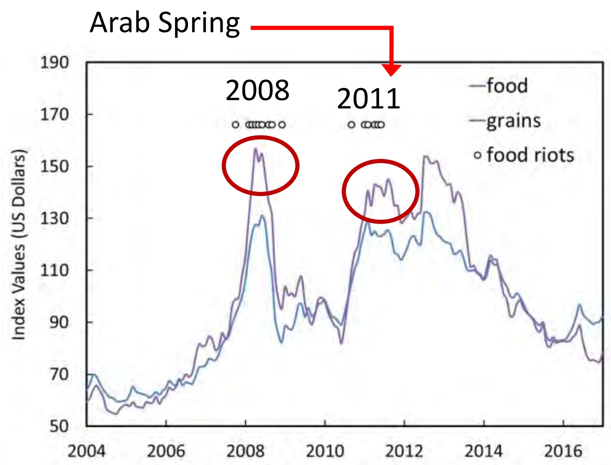


Global prices of fossil fuels, fertilizers, and food are linked

80% of the cost of NH_3 is the cost of natural gas







S. Mueller et al. *Biomass and Bioenergy* **2011**, 35, 1623-32.
H. Gnutzmann et al. *SSRN Electronic Journal* (September 2016).

http://www.fao.org/worldfoodsituation/foodpricesindex/en/
M. Lagi, et al. *SSRN*, 2011. Accessed at: *arXiv:1108.2455*

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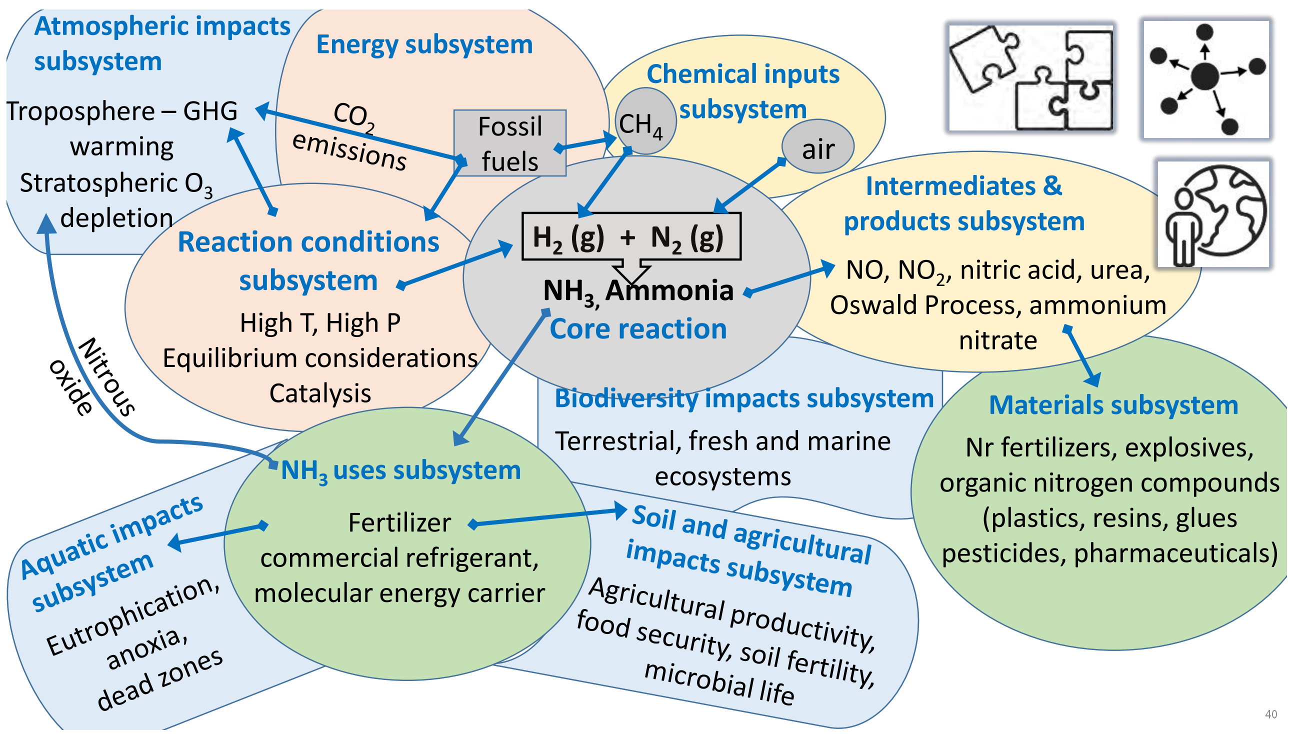

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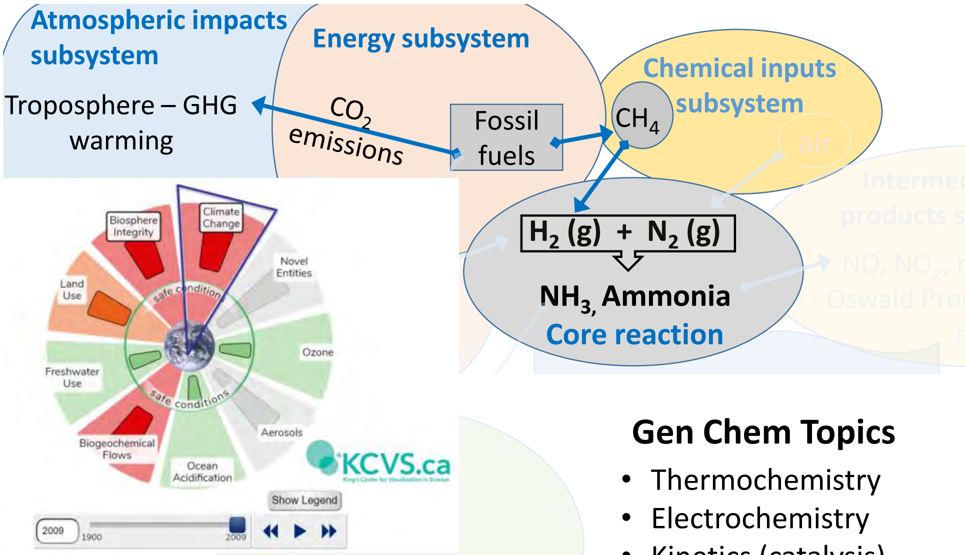
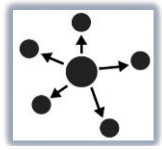


ST about ammonia includes thinking about life cycles of materials

Gen Chem Topics

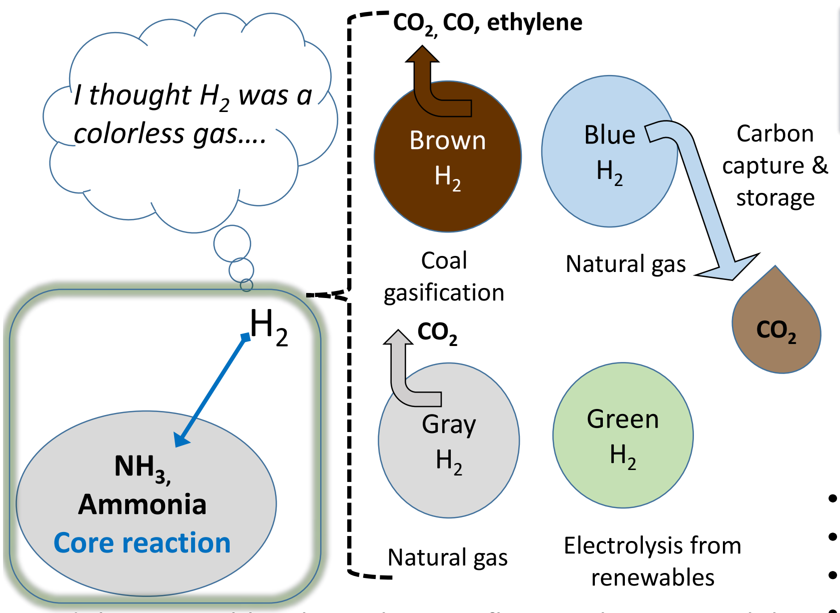
- Thermochemistry
- Electrochemistry
- Kinetics (catalysis)
- Gases (climate change)
- Green/Circular chemistry/LCA

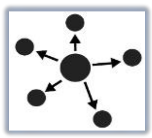


Examines relationships among the parts of a system

Identifies variables that cause system behaviors

Identifies interactions between a system and its environment, including with humans 41





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beyondbenign — green chemistry education

Gen Chem Topics

- Thermochemistry
- Electrochemistry
- Kinetics (catalysis)
- Gases (climate change)
- Green/Circular chemistry/LCA

And those variables that color H_2 influence the sustainability of the ammonia we use to feed the world, keep food cold, and develop a promising low carbon molecular energy carrier!

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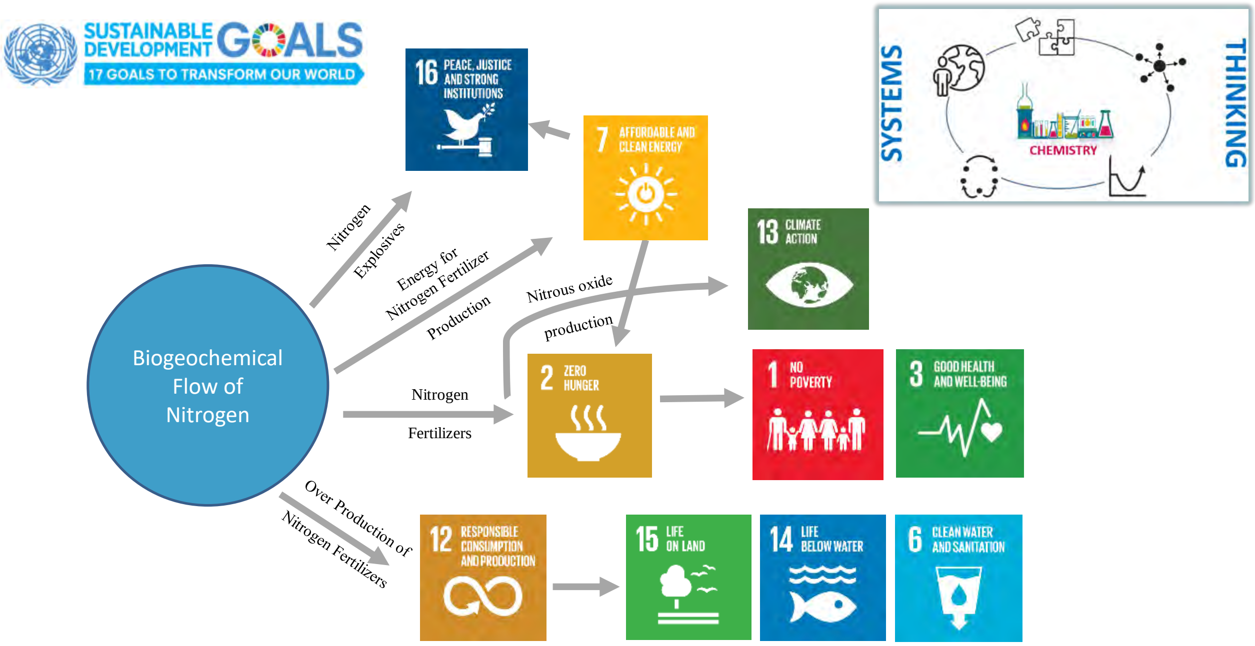

Mahaffy, P. G.; Matlin, S. A.; Holme, T. A.; MacKellar, J. Systems thinking for education about the molecular basis of sustainability. *Nat. Sustain.* **2019**, *2*, 362– 370

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TAKE HOME MESSAGES

- ✓ What a systems thinking approach looks like in chemistry education: its essential characteristics and the benefits of its use
- ✓ How a systems thinking approach extends and differs from context-based approaches to chemistry teaching and learning
- ✓ How a systems thinking approach can prepare students to become global citizens capable of taking informed action to support planetary sustainability

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Additional Resources

Want to know more about systems thinking?

- Orgill, M.; York, S.; MacKellar, J. Introduction to systems thinking for the chemistry education community. *J. Chem. Educ.* **2019**, *96* (12), 2720-2729; DOI: 10.1021/acs.jchemed.9b00169.
- York, S.; Orgill, M. ChEMIST Table: A tool for designing or modifying instruction for a systems thinking approach in chemistry education. *J. Chem. Educ.* **2020**, *97* (8), 2114-2129; DOI: 10.1021/acs.jchemed.0c00382.
- Flynn, A., Orgill, M.K., Ho, F., York, S., Matlin, S.A., Constable, D., Mahaffy, P. Future directions for systems thinking in chemistry education, *J. Chem. Educ***. 2019,** *96*, 3000-3005.
- Mahaffy, P. G.; Krief, A.; Hopf, H.; Mehta, G.; Matlin, S. Reorienting chemistry education through systems thinking. *Nat. Rev. Chem.* **2018**, *2* (126), 1-3, DOI:10.1038/S41570-018-0126.
- References and outcomes from IUPAC Global Systems Thinking in Chemistry Education (STICE) Project https://iupac.org/projects/project-details/?project_nr=2017-010-1-050

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Additional Resources

Want to know more about systems thinking and sustainability?

- Mahaffy, P. G.; Matlin, S. A.; Holme, T. A.; MacKellar, J. Systems thinking for education about the molecular basis of sustainability. *Nat. Sustain.* **2019**, *2*, 362– 370, DOI: 10.1038/s41893-019-0285-3.
- Mahaffy, P. G.; Matlin, S. A.; Whelan, J. M.; Holme, T. A. Integrating the molecular basis of sustainability into general chemistry through systems thinking. *J. Chem. Educ.* **2019**, *96* (12), 2730-2741; DOI: 10.1021/acs.jchemed.9b00390.
- King's Centre for Visualization in Science (KCVS). Planetary Boundaries interactive digital learning resource: *planetaryboundaries.kcvs.ca*

Want to get involved?

- ACS GCI – Green & Sustainable Chemistry Education Module Development Project: https://www.acs.org/content/acs/en/greenchemistry/students-educators/module-development.html
- New IUPAC Global Project: Systems Thinking in Chemistry for Sustainability: Toward 2030 and Beyond (STCS 2030+) - https://iupac.org/project/2020-014-3-050
  - Strengthen contributions of Chemistry as a Sustainability Science, including engaging with IYBSSD 2022
  - Guiding further development of ST in Chemistry Education
  - Engaging further with chemical industry

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Acknowledgements

Planetary Boundaries Learning Resource

KCVS.ca
King's Center for Visualization in Science

planetaryboundaries.kcvs.ca

Rob MacDonald
Peter Mahaffy
Melanie Hoffman
Anna Pattison
Ashley Elgersma

Stockholm Resilience Centre
Sustainability Science for Biosphere Stewardship

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Systems Thinking in Chemistry Education: Preparing Global Citizens for a Sustainable Future

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Professor of Chemistry and Director,
King's Centre for Visualization in Science

MaryKay Orgill
Professor of Chemistry & Biochemistry
University of Nevada, Las Vegas

David Constable
Science Director, Green Chemistry Institute, American Chemical Society

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