Evolving Frontiers of Che mistry

What Should I Do to be There?

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Motivati
on

Edamana Prasad, G. S
ekar

Department of Chemistry, IIT Madras, August 13, 2025

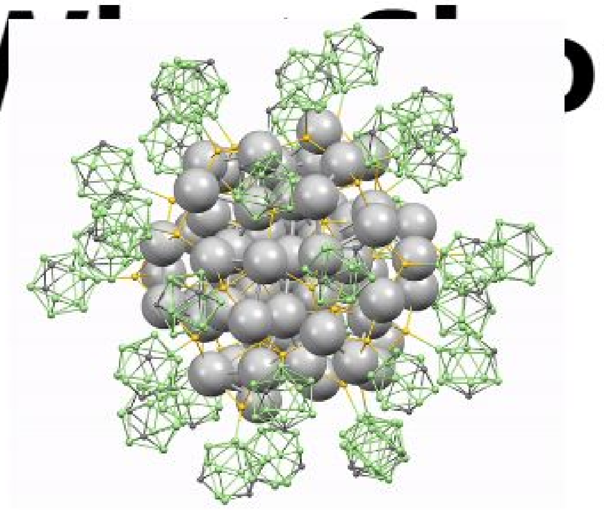
An Institute of Eminence

No. 1

Since 1959

Evolving Frontiers of Chemistry

W… ould I Do to be Th



Co-founder

InnoNano Research Pvt. Ltd.
InnoDI Water Technologies Pvt. Ltd.
VayuJAL Technologies Pvt. Ltd.
Aqueasy Innovations Pvt. Ltd.
Hydromaterials Pvt. Ltd.
EyeNetAqua Solutions Pvt. Ltd.
DeepSpectrum Innovations Pvt. Ltd

Associate Editor

ACS Sustainable Resource Management

Thalappil Pradeep

as

Professor-in-charge

p… c.in

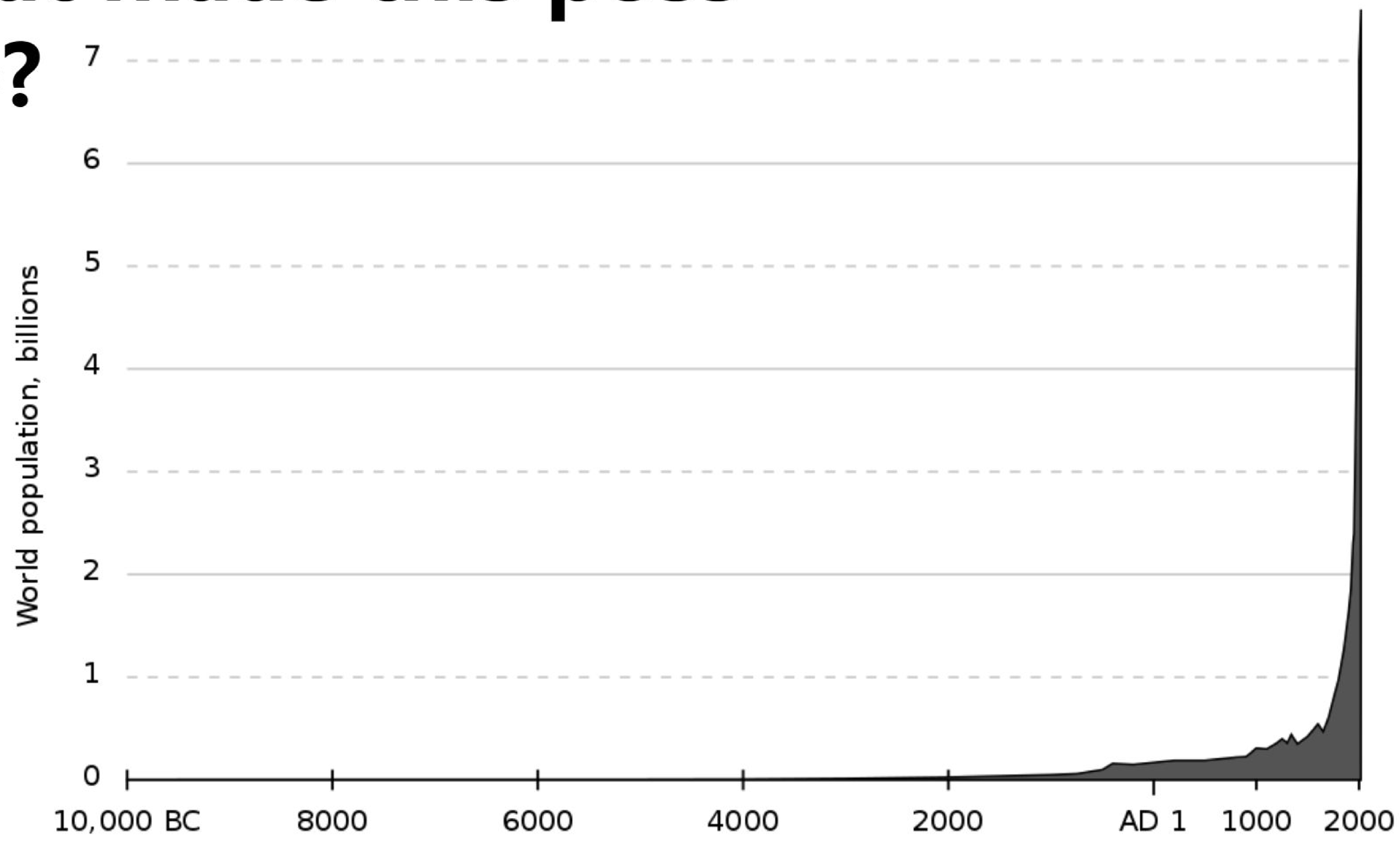
https:… arch.org

International Centre for Clean Water

https://iccw.world

Department of Chemistry, IIT Madras, August 13, 2025

What made this poss ible?



Chemistry is central to the world

Chemistry Reshaped the World

Synthetic Polymers – Bakelite (1907), Nylon (1935), polyethylene, Kevlar.→ Enabled mass production of affordable goods, from packaging to aerospace materials.

Specialty Materials – Teflon, liquid crystal displays, lightweight composites.→ Expanded electronics, safety, and transportation industries.

Chemistry Brought Food on the Table for Masses

Haber–Bosch Process (1909–1913) – Industrial ammonia synthesis.→ Revolutionized fertilizers, pesticides, making modern agriculture possible and sustaining billions of lives.

Medicines and Public Health

Synthetic Pharmaceuticals – Aspirin, penicillin mass production, sulfa drugs, statins.→ Transformed treatment of infections, pain, and chronic diseases.

Vaccines & Diagnostics – Chemistry-enabled adjuvants, mRNA delivery systems, PCR reagents.→ Key to controlling epidemics and improving life expectancy.

Chemistry is central to the world...

Energy Transformation

Fossil Fuel Chemistry – Refining, cracking, and synthetic fuels.→ Powered the industrial and transportation revolutions.

Electrochemistry – Batteries from lead–acid to lithium-ion.→ Enabled portable electronics, electric vehicles, and renewable energy storage.

Understanding and Manipulating Molecules

Analytical Chemistry – NMR, mass spectrometry, chromatography.→ Revolutionized quality control, forensics, and molecular biology.

Supramolecular and Organometallic Chemistry – Opened precision catalysis and smart materials.

Environmental and Green Chemistry

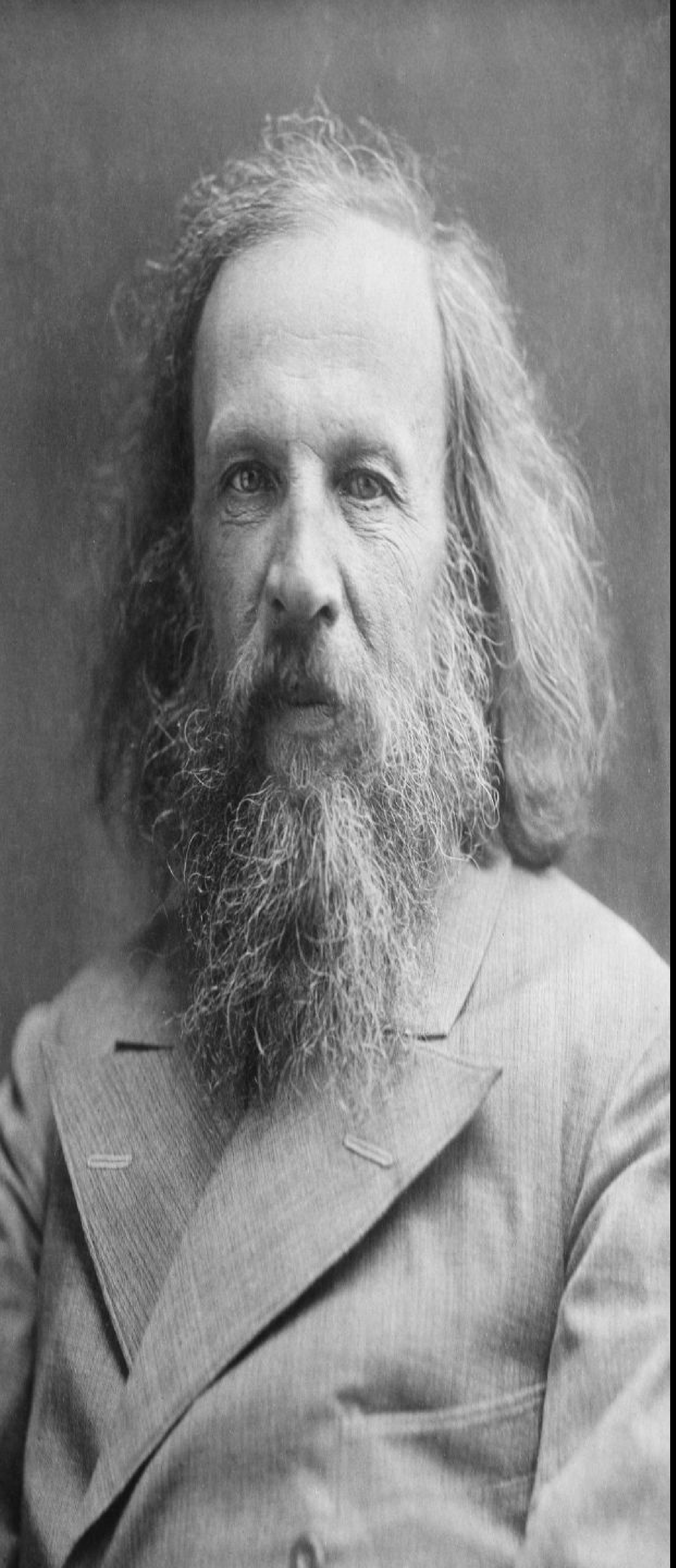
Water Purification – Chlorination, membrane filtration, nanomaterials-based adsorbents.

Green Synthesis – Atom economy, biodegradable materials, CO_2 utilization.

Everyday Life Improvements

Dyes & Pigments – Synthetic indigo, azo dyes.→ Democratized fashion and consumer goods.

Consumer Chemistry – Detergents, personal care products, cosmetics.



Great pioneers

Dmitri Ivanovich Mendeleev

Bei der Vergleichung der gefundenen Zusammensetzung des Korns mit der des Mehls ergiebt sich, dass verloren gingen:

Asche	Kleber	Stärke	
0,043 Proc.	1,142 Proc.	6,459 Proc.,	zusammen 7,644 Proc.

Davon wurden verstäubt 3,988 Proc. Mehl, also beträgt die Differenz der Analysen etwa 3,7 Proc. Verf. glaubt, dass diese Differenz im Stärkegehalt zu suchen ist, weil dieser sich nicht genau bestimmen lässt. — Die Zusammensetzung einer Mehlprobe, welche noch alle Kleie enthielt, stimmte fast völlig überein mit der des ganzen Korns. Es wurde gefunden:

Wasser	10,743								
Stickstoff	2,506								
Stärke	64,475		Fe_2O_3	CaO	MgO	KO	NaO	PO_5	
Asche	1,503,	worin	0,852	4,246	14,721	31,898	0,704	49,720	= 102,141.

Dagegen hatte ein Mehl des ganzen Korns, aus welchem 13 Proc. Kleie abgesondert war, folgende Zusammensetzung:

Wasser	10,548								
Stickstoff	2,518								
Stärke	65,660		Fe_2O_3	CaO	MgO	KO	NaO	PO_5	
Asche	1,032,	worin	1,338	5,085	12,425	31,456	1,878	48,761	= 100,943.

(Ann. Ch. Pharm. 149, 343.)

Ueber die Beziehungen der Eigenschaften zu den Atomgewichten der Elemente. Von D. Mendelejeff. — Ordnet man Elemente nach zunehmenden Atomgewichten in verticale Reihen so, dass die Horizontalreihen analoge Elemente enthalten, wieder nach zunehmendem Atomgewicht geordnet, so erhält man folgende Zusammenstellung, aus der sich einige allgemeinere Folgerungen ableiten lassen.

			Ti = 50	Zr = 90	? = 180
			V = 51	Nb = 94	Ta = 182
			Cr = 52	Mo = 96	W = 186
			Mn = 55	Rh = 104,4	Pt = 197,4
			Fe = 56	Ru = 104,4	Ir = 198
			Ni = Co = 59	Pd = 106,6	Os = 199
H = 1			Cu = 63,4	Ag = 108	Hg = 200
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,5	Br = 80	J = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	?Di = 95		
		?In = 75,6	Th = 118?		

1. Die nach der Grösse des Atomgewichts geordneten Elemente zeigen eine stufenweise Abänderung in den Eigenschaften.

2. Chemisch-analoge Elemente haben entweder übereinstimmende Atomgewichte (Pt, Ir, Os), oder letztere nehmen gleichviel zu (K, Rb, Cs).

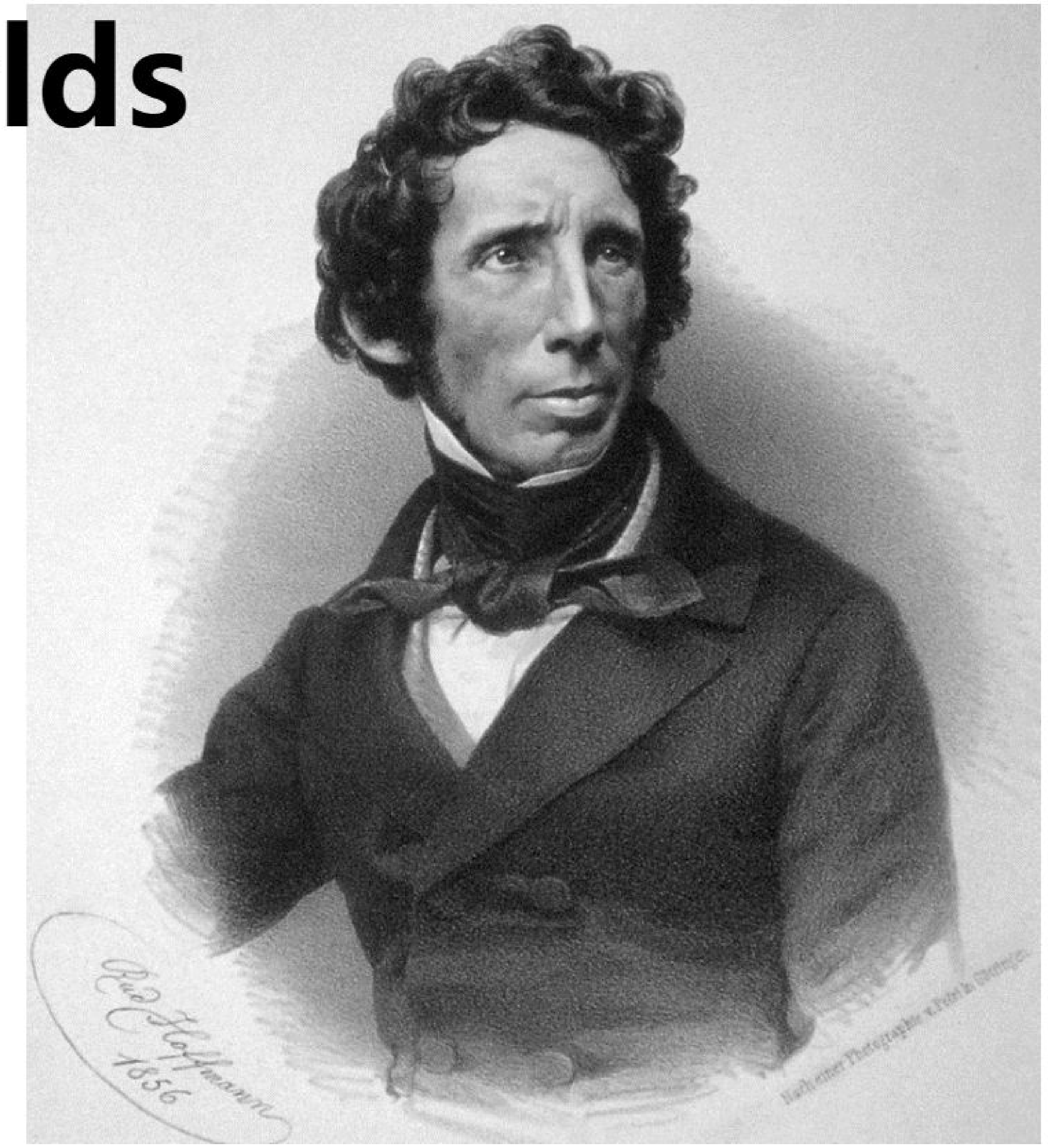
3. Das Anordnen nach den Atomgewichten entspricht der *Werthigkeit* der Elemente und bis zu einem gewissen Grade der Verschiedenheit im chemischen Verhalten, z. B. Li, Be, B, C, N, O, F.

4. Die in der Natur verbreitetsten Elemente haben *kleine* Atomgewichte

Unifier of inorganic and organic worlds

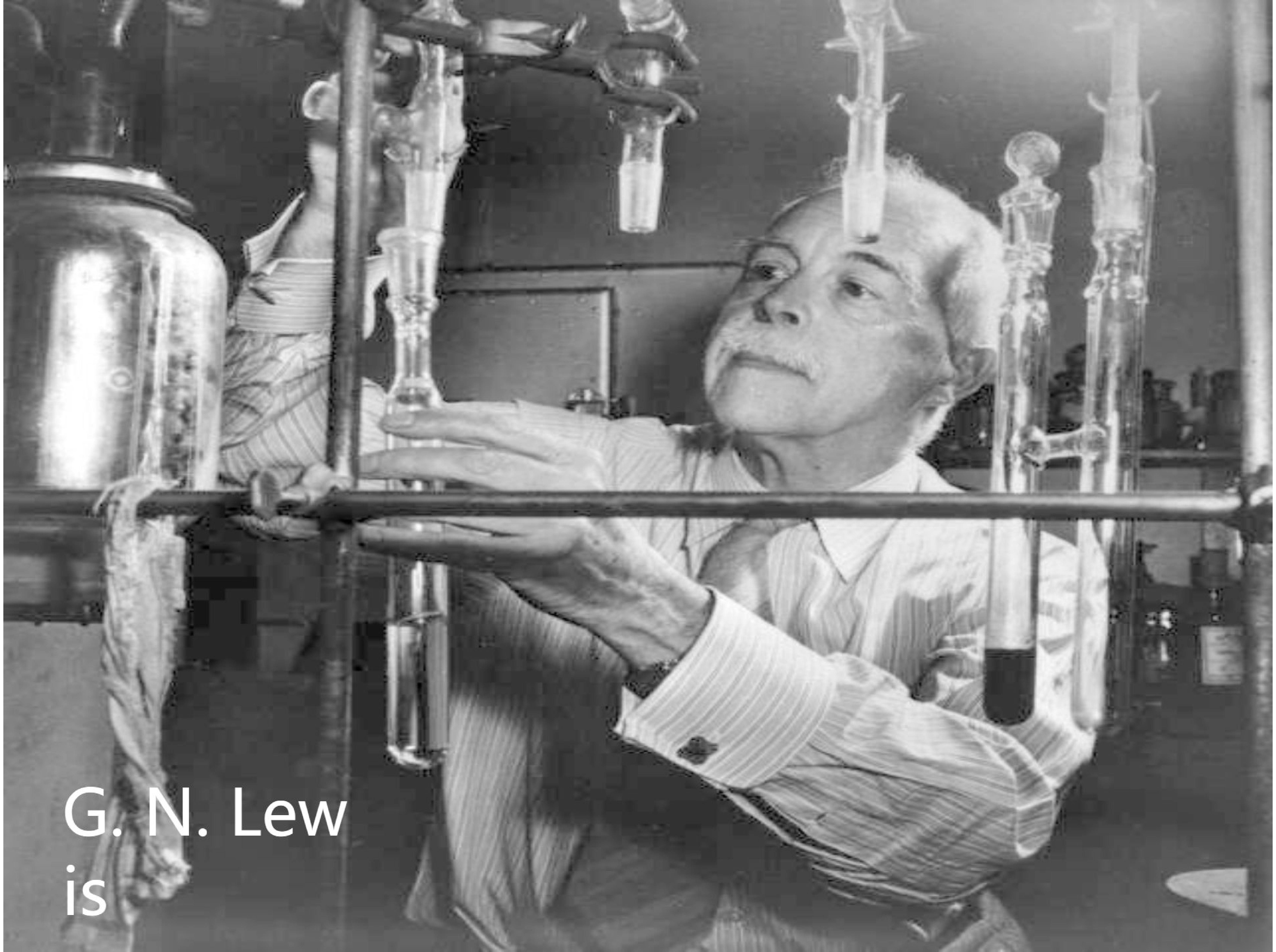
Wöhler made urea 1828, from ammonium cyanate.

In a letter to Berzalius he wrote, 'In a manner of speaking, I can no longer hold my chemical water. I must tell you that I can make urea without the use of kidneys of any animal, be it man or dog.'



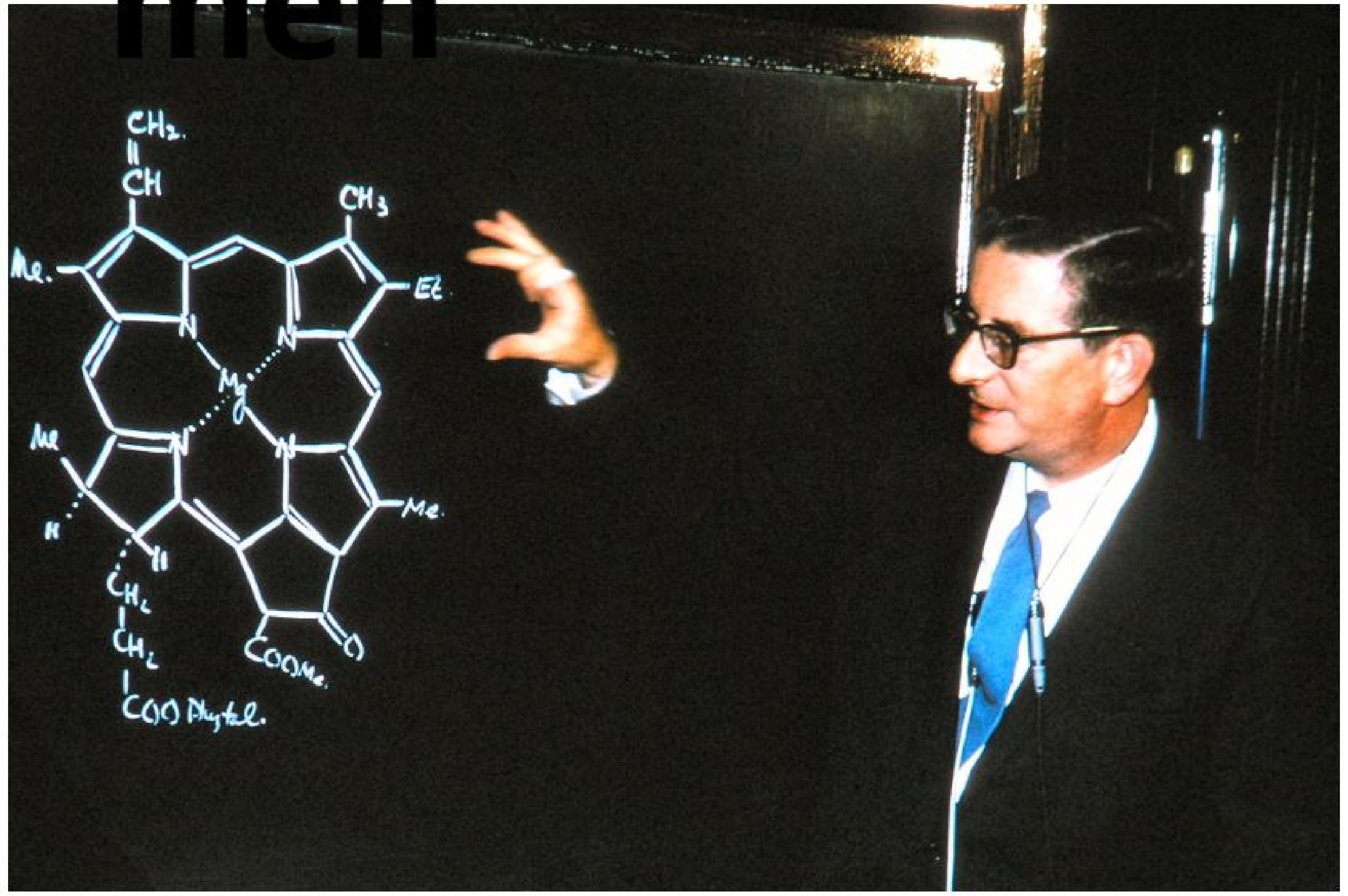
Friedrich Wöhler (1800-1882)

>9 million compounds in 200 years!


G. N. Lew
is

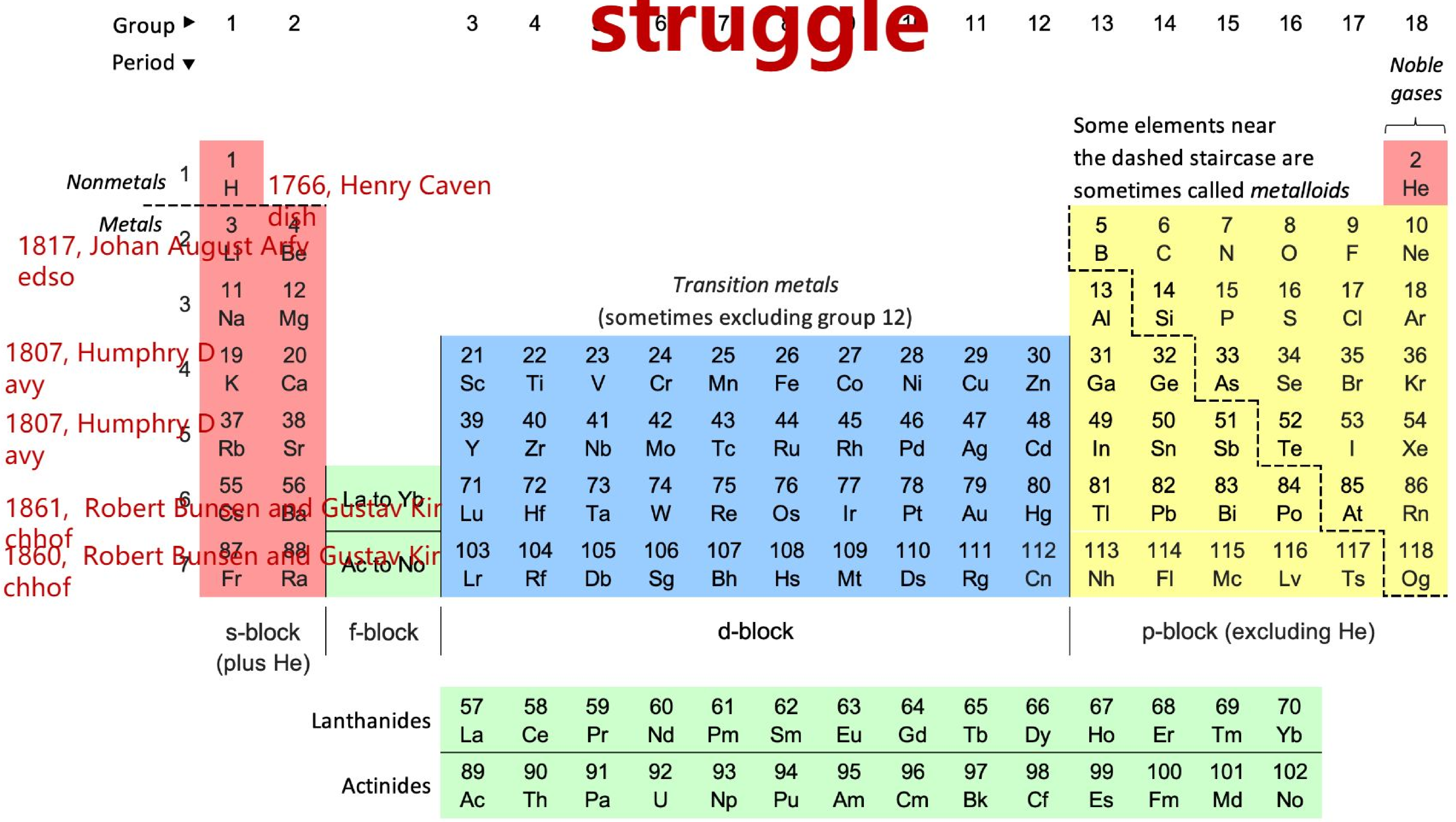
Images from *Wikip*

Master crafts men



Images from *Wikipedia*

Legacy continues - This table is their struggle



From *Wikipedia*

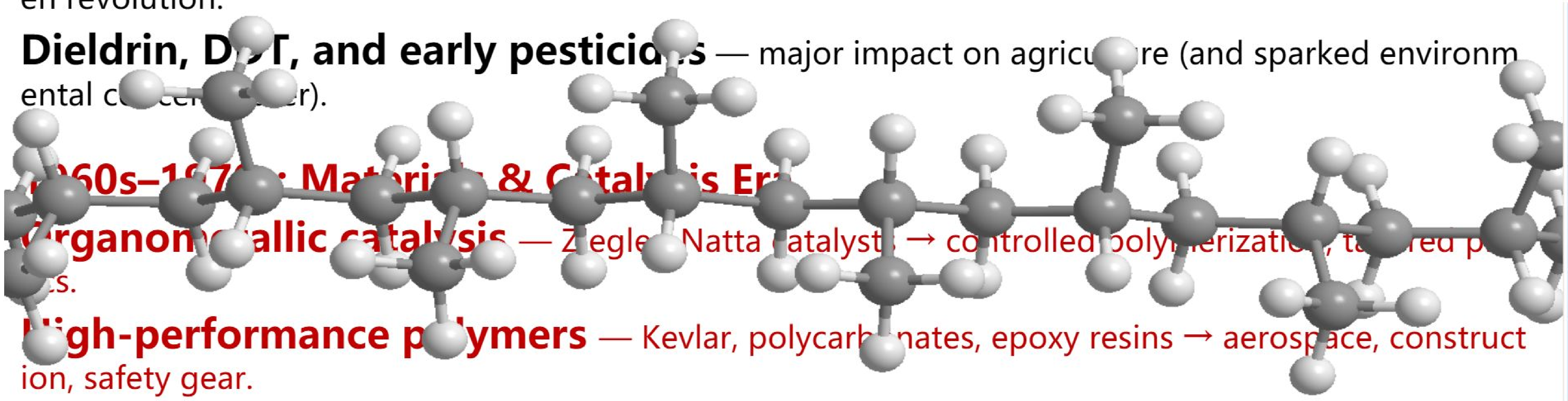
Creativity continued

1940s–1950s: Post-War Chemical Revolution

Synthetic polymers — Nylon, polyethylene, Teflon (PTFE) — revolutionized textiles, packaging, cookware.

Mass production of ammonia (Haber–Bosch scaling) — global fertilizer supply, green revolution.

Dieldrin, DDT, and early pesticides — major impact on agriculture (and sparked environmental concern later).



1960s–1970s: Materials & Catalysis Era

Organometallic catalysis — Ziegler–Natta catalysts → controlled polymerization, tailored plastics.

High-performance polymers — Kevlar, polycarbonates, epoxy resins → aerospace, construction, safety gear.

Semiconductor-grade silicon purification — laid the foundation for microelectronics.

1980s–1990s: Molecular Design & Bio-Chemistry Integration

Supramolecular chemistry — Host–guest systems, crown ethers (Lehn, Cram, Pedersen).

PCR & DNA synthesis chemistry — enabled genomics, diagnostics, biotech industry.

Green chemistry principles (1990s) — preventive sustainability framework in chemical industry.

Image from *Wikipedia*

Expanding horizons

1. Advanced Materials & Nanotechnology
- Atomically Precise Clusters
- 2D Materials
- Metal–Organic Frameworks (MOFs)
- Covalent Organic Frameworks (COFs)
- Supramolecular Assemblies and molecular machines
- Stimuli-responsive polymers and smart materials
- High-entropy alloys and ceramics
- Biomimetic materials

2. Energy & Catalysis
- Photocatalysis for water splitting & CO_2 reduction
- Electrocatalysis
- Solid-state batteries & ionic conductors
- Fuel cells & redox flow batteries
- Solar fuels and artificial photosynthesis
- Perovskites & hybrid photovoltaics
- Operando catalysis studies

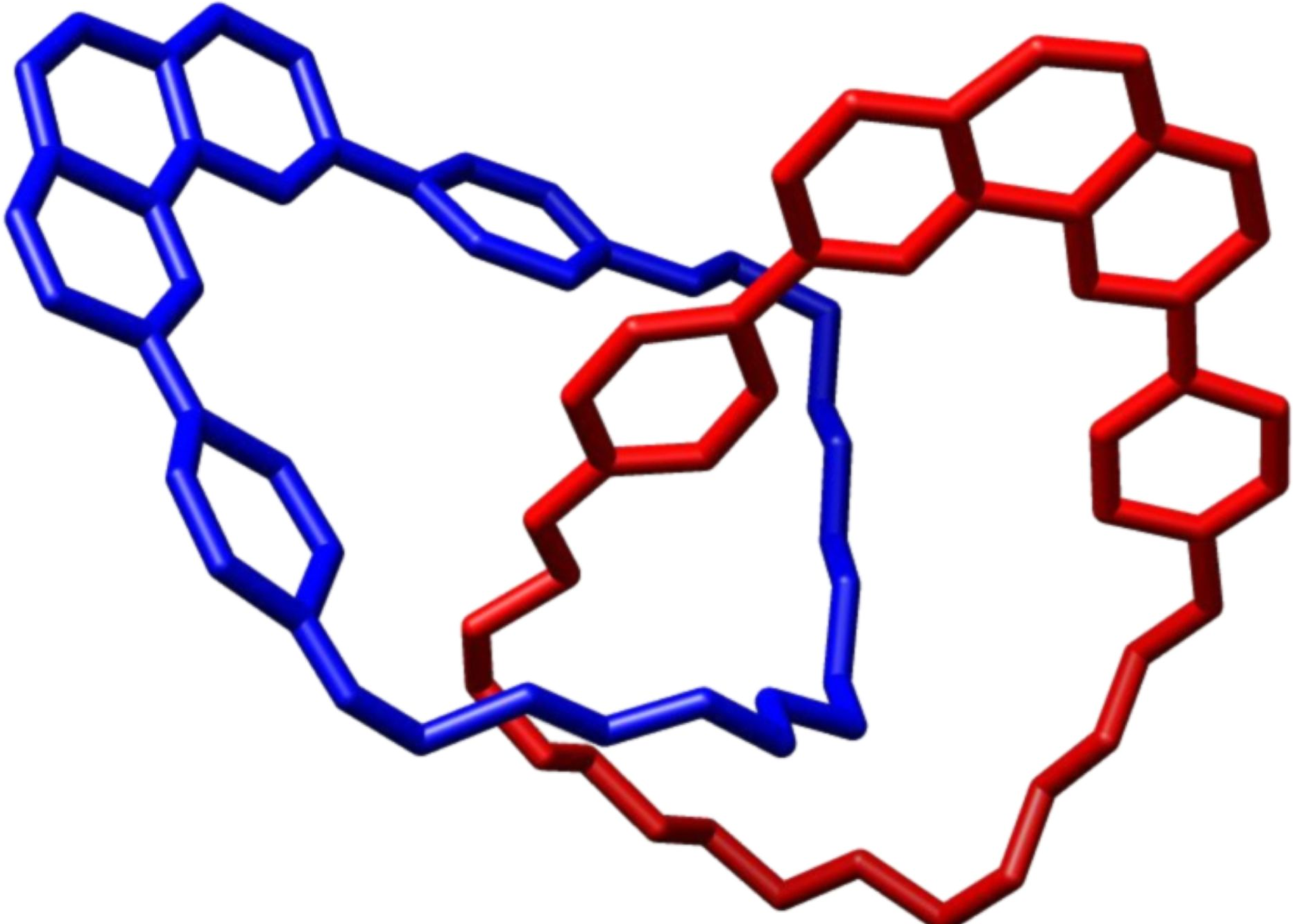
3. Sustainability & Green Chemistry
- Circular chemistry and waste-to-value conversion
- Green synthesis routes (solvent-free, low energy, biocatalytic)

4. Water, Environment & Climate Chemistry
- Advanced water purification
- Arsenic, fluoride, nitrate, and PFAS removal
- Marine chemistry & ocean carbon cycle
- Atmospheric chemistry
- Geoengineering chemistry
- Wastewater-based epidemiology

5. Chemical Biology & Health
- Chemical probes for biomolecular imaging
- Structure-based drug design
- Cryo-EM and NMR-based structural chemistry
- Bioconjugation & click chemistry
- Nanomedicine & targeted drug delivery
- Synthetic biology & metabolic engineering
- Protein and nucleic acid chemistry

6. Computational & Data-Driven Chemis

Continued excellence



Chemistry tomorrow

1. AI-Augmented Molecular Creation

Fully autonomous **self-driving chemistry labs** combining AI, robotics, and high-throughput experimentation.

Predictive modelling of reaction outcomes before synthesis, cutting discovery cycles from years to days.

2. Sustainable Planetary Chemistry

Zero-waste chemical manufacturing via closed-loop, circular processes.

Atmospheric mining — extracting carbon, nitrogen, and rare elements directly from air for fuels and materials.

3. Chemistry Beyond Earth

In-situ resource utilization (ISRU) for Moon and Mars — producing fuel, water, oxygen, and construction materials from local regolith and atmosphere. Synthesis of new materials under extraterrestrial conditions (low gravity, high radiation).

4. Molecular Electronics & Quantum Systems

Designing **molecules as quantum bits (qubits)** for quantum computing. Molecular-scale neuromorphic devices for ultra-low-power AI.

5. Programmable Living Materials

Engineered **hybrid bio–synthetic materials** that sense, heal, and adapt.

DNA-encoded polymers and peptides for programmable medicine and responsive therapeutics.

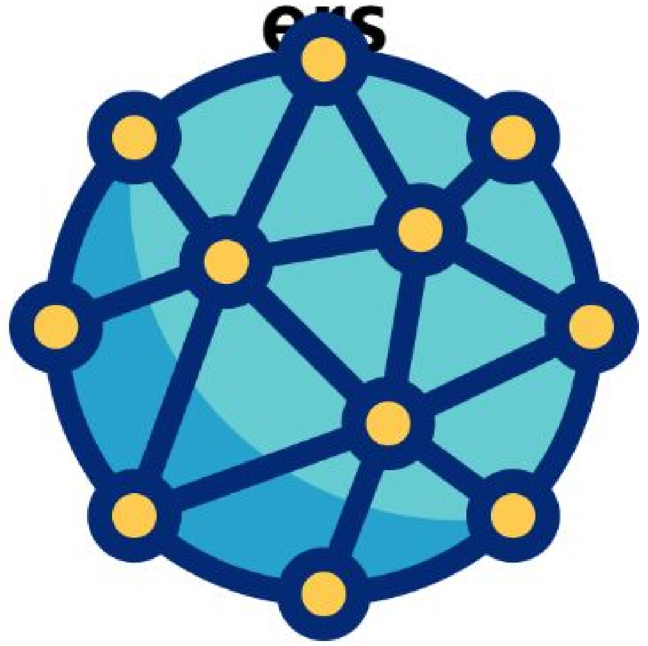
To recollect....

Past

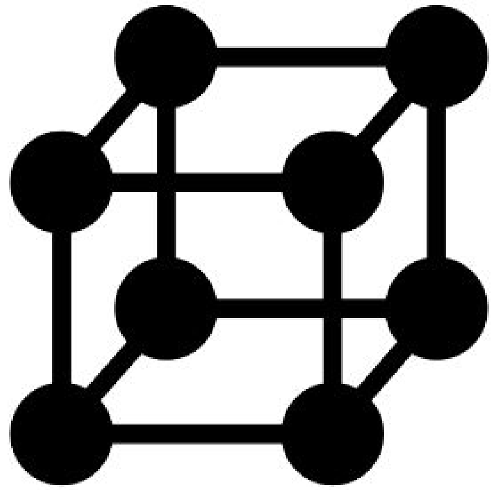
Present

Future

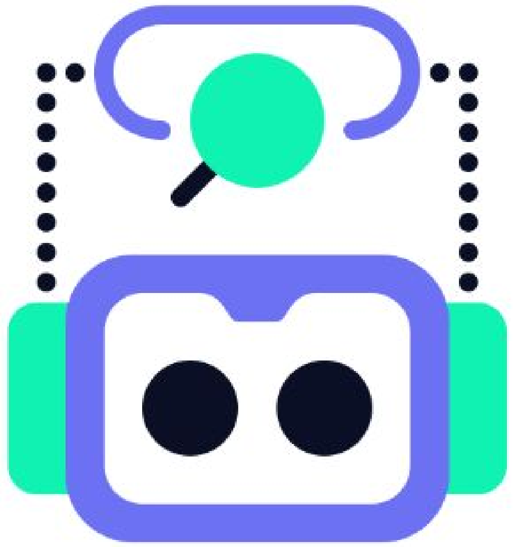
Synthetic polymers

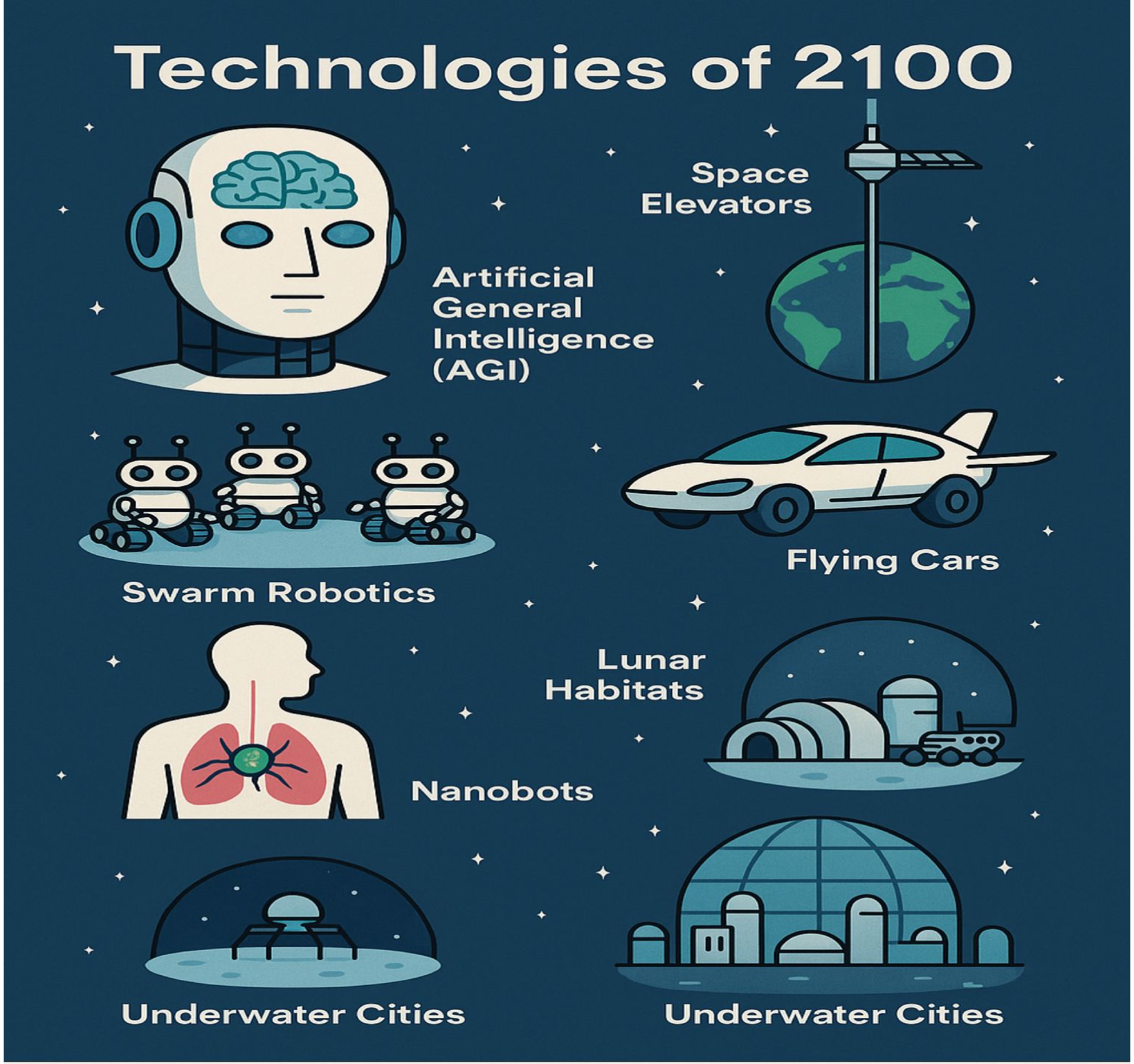


Nanoclusters, MOFs



AI- guided discovery, Chemputer





- Many of you will live to see 2100.
- Your most creative work may happen in 2050.
- How to prepare for 2050?

ChatGPT

Chemistry in 2050

Chemistry has a BIG role to play in that world
.

But it is only one of the components needed.

Chemistry is in materials, functions and appli
cations.

NEW CHEMSTRY is the need.

What are the traits of new che mistry?

Relevant

Interdisciplinary

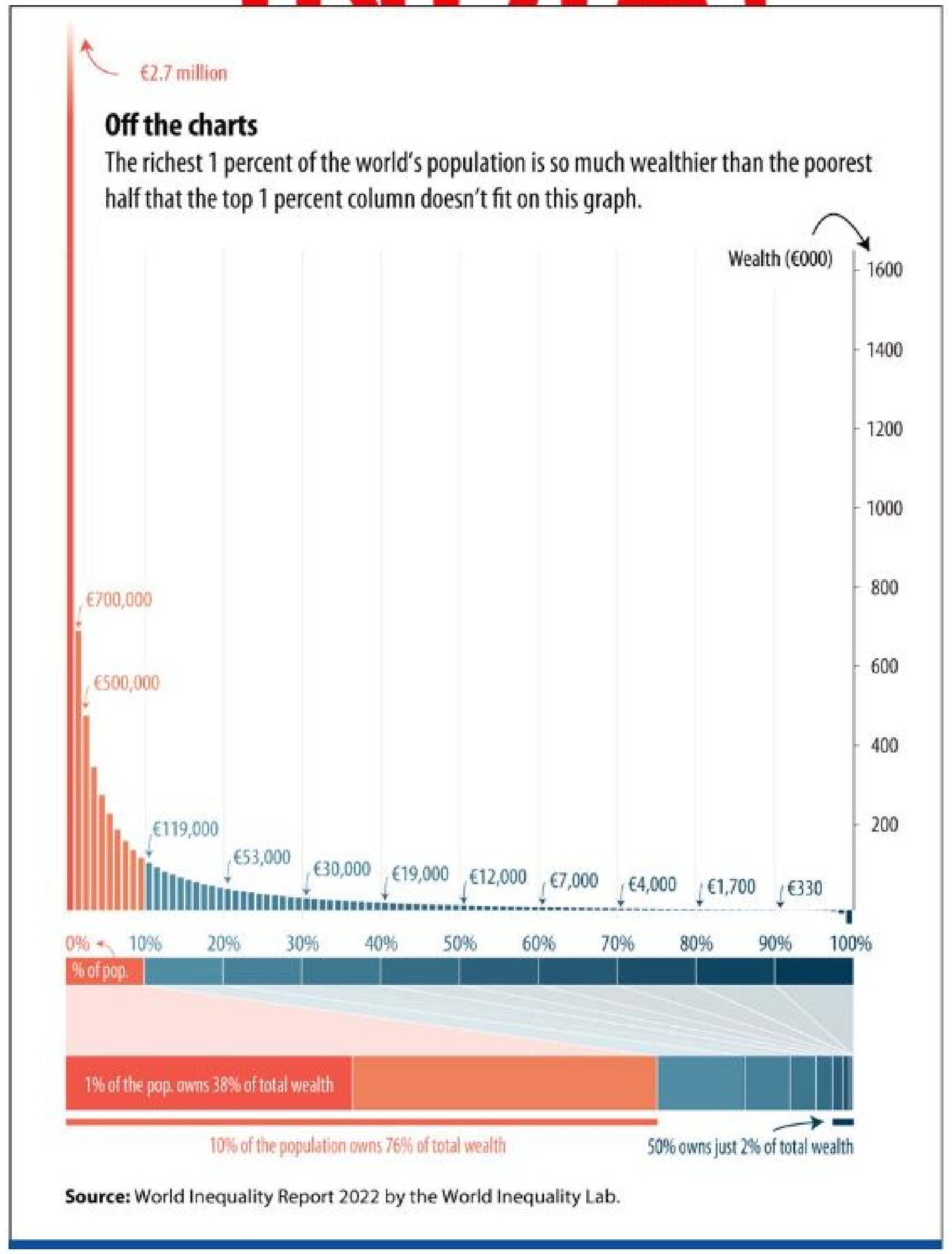
Connected to societal realities

Sustainable

Simple yet complex

Digital

Why do we do chemistry here, in INDIA?



Inequality

No second home

Population

It needs new skills and capa bilities

Pure vs. interdisciplinary chemistry at leading universities

Pure chemistry degrees	Interdisciplinary chemistry degrees
MIT SB in chemistry	SB in chemistry and biology
UC Berkeley BS in chemistry	BS in chemical biology
University of Oxford MS in chemistry	Chemistry modules in materials science and biomedical themes
Natural Science Tripos BS in chemistry	Options to take chemical engineering and materials later
ETH Zurich BS in chemistry	Chemistry + chemical engineering joint majors with materials or biology

Let me be clear…

The world’s top universities still value pure chemistry as the intellectual backbone of the discipline—but they are reimagining how it connects to the rest of science and society. Students can now start in chemistry and end up in biology, materials, climate science, or even AI-driven molecular design—without leaving their department.

Chemistry jobs

Energy, climate& sustainability

- Green process chemists
- Carbon management specialists
- Circular materials scientists

Data and AI-driven chemistry

- Cheminformatics specialists
- Lab automation engineers
- Molecular simulation scientists

Advanced materials & manufacturing

- Battery chemists
- Quantum materials researchers
- Nanomanufacturing engineers
- 3D/4D printing materials scientists

Space, defense & extreme environments

- Astrochemists
- Cryo- and high-pressure chemists
- Specialized coatings and materials scientists

Health, biotechnology & pharma

- Medicinal and computational chemists
- Chemical biologists
- Bioprocess chemists
- Regulatory chemists

Policy, communication & entrepreneurship

- Science policy advisors
- Chemical entrepreneurs
- Science communicators & educators

Reimagining chemistry

More jobs

Chemistry at the Interface with Other Disciplines

- **AI-Driven Molecular Discovery** – Using machine learning for materials and drug design, predictive catalysis, and autonomous laboratories.
- **Chemistry–Biology Convergence** – Understanding life at the molecular level: chemical biology, synthetic biology, and chemical tools for cell imaging and manipulation.
- **Chemistry–Physics Integration** – Quantum materials, single-molecule electronics, and photonic materials.

Sustainable and Planetary Chemistry

- **Green Chemistry & Circular Materials** – Designing processes that eliminate waste, recycle at molecular scales, and work under mild, low-energy conditions.
- **Carbon Capture, Utilization & Storage (CCUS)** – Molecular and catalytic solutions to climate change.
- **Water–Energy Nexus** – Affordable desalination, distributed water purification, and energy-efficient water treatment.
- **Chemistry for Sustainable Agriculture** – Controlled-release fertilizers, green pesticides, and soil regeneration.

Molecular Precision and Functional Matter

- **Atomically Precise Materials** – Noble metal clusters, single-atom catalysts, defect-engineered solids.
- **Programmable Molecular Assemblies** – Self-assembled frameworks, DNA origami, peptide-based materials.
- **Functional Interfaces** – Smart coatings, responsive surfaces, bio–inorganic hybrid systems.

Chemistry for Health and Longevity

- **Next-Generation Therapeutics** – RNA-based drugs, targeted protein degradation, and precision nanomedicine.
- **Diagnostics at the Molecular Scale** – Point-of-care chemical sensors, wearable chemical devices, and real-time metabolic monitoring.
- **Chemical Understanding of Neurodegeneration** – Microtubule dynamics, protein aggregation, and small-molecule modulators.

What is unique at IIT Madras

IIT Madras' Interdisciplinary Ecosystem

Departments, centres, cores, non-profit centres

IITM's Research-First Approach **Unique IITM feature**: Early access to research through Summer Fellowship Programs, project electives, and faculty-led research groups

Conn

limate **Ecosystem around SDGs – programs, start-ups**

Links & Innovation Infrastructure

IITM Research Park, incubation cells, and CSR-funded projects connect students directly to industry needs.

Work on industry-sponsored projects

High-End Instrumentation High-end MS, TEM, etc.

Develop Global Competence Global MoUs with institutions across the world, joint programs with them

Build Communication & Leadership Skills

Student-led programs, Shaastra, CFI, science clubs, Present your work at IITM symposia, mentor school students in chemistry **Example**: Students presenting at Shaastra have won international recognition for sustainable chemistry innovations.

Opportunities@IITM

>400 patents and >1200 papers, >600 crores of research funding, >250 PhDs – every year. Every PhD student gets one funded visit abroad, additional possibility to visit abroad for research, limited support for undergraduate students too. >350 incubated companies, >25 interdisciplinary centres, MoUs with >400 institutions.

Our people, our ecosystem

Baskaran G

Distinguished Visiting Research Chair
Perimeter Institute for Theoretical Physics
Waterloo

Visit Webpage ›

Dr. Raghunath Anant Mashelkar

Padma Vibhushan

Former Director General
Council of Scientific and Industrial Research (CSIR)

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Gopalkrishna Gandhi

Ambassador of India to Norway and Iceland
Former Governor of West Bengal
Secretary to President of India and Vice President of India

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Graham Cooks R

Department of Chemistry
Henry Bohn Hass Distinguished Professor
Purdue University

Hartmut Michel

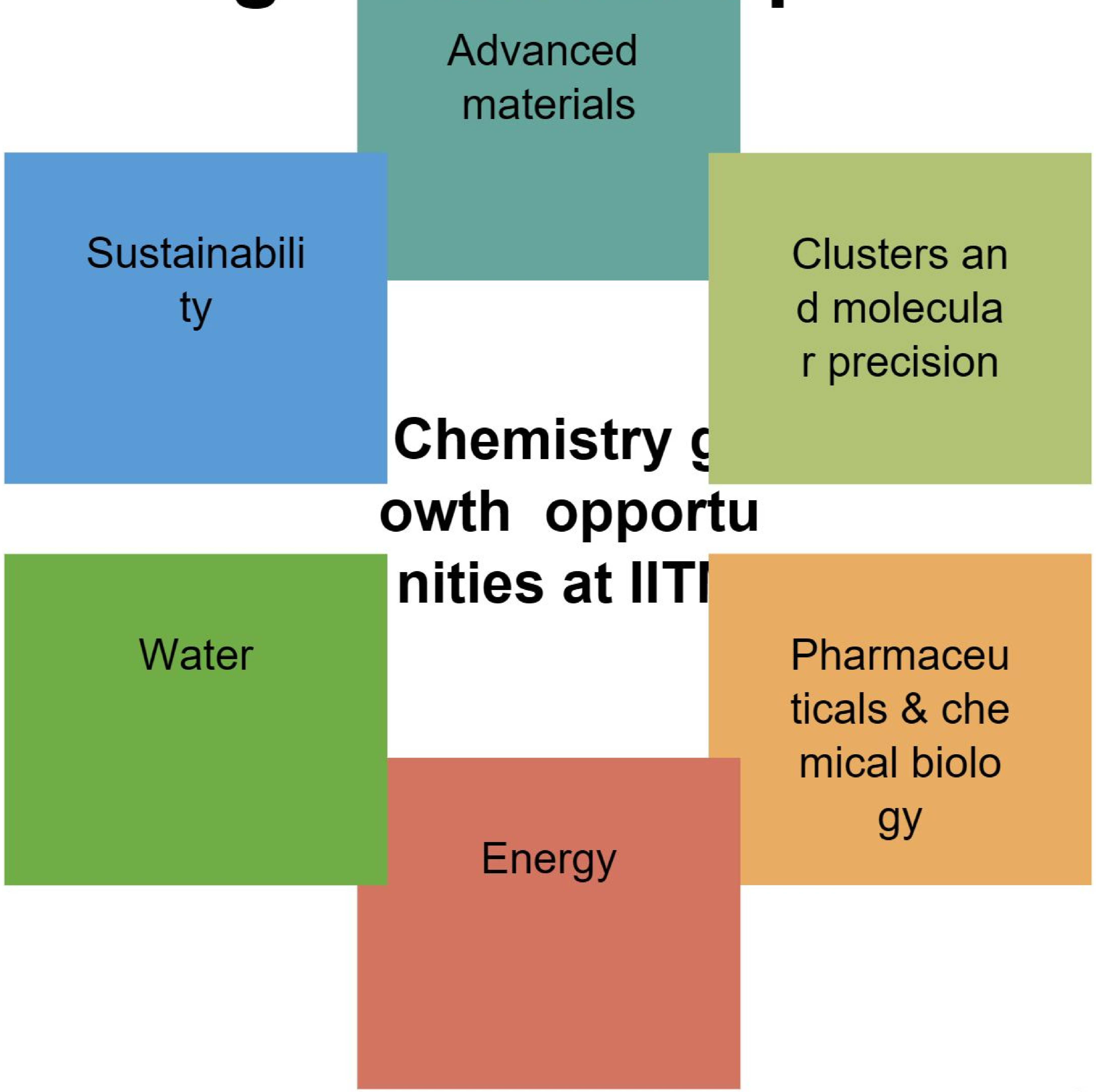
Department of Molecular Membrane Biology
Nobel Laureate
Director Max Planck Institute of Biophysics
Frankfurt am Main

Horst W Hahn

Forschungszentrum Karlsruhe Executive Director
Institute of Nanotechnology
Professor of Materials Science
Frankfurt am Main


No boundaries
Connected globally
No limits
>65,000 alumni for IITM, spread across the world
~400,000 alumni for the IIT system, across the world

Imagine career options



Many others are possibl e too

Building a career in advanced materials

Interact with colleagues working on AI for materials science

Building a career in sustainability

Year 1	Year 2	Year 3	Year 4
Academics • General chemistry • Mathematics I & II • Physics, biology	**Academics** • General chemistry • Mathematics I & II • Physics, biology	**Academics** • General chemistry • Mathematics I & II • Physics, biology	**Academics** • Core courses • Physical chemistry • Analytical chemistry
Co-curricular/skill building • Attend r00 w/other activities • Focus on catalysis, renewable energy	**Co-curricular/skill building** • Attend r00 w/other activities • Focus on catalysis, renewable energy	**Co-curricular/skill building** • Attend Energy consortium activities • Focus on catalysis, renewable energy • Participate in CFI activities	**Research exposure** Focus on catalysis, renewable energy, EV activities
Milestone Identify faculty Attend a NPTEL Course on sustainability	**Milestone** Summer internship Participate in environmental analysis	**Milestone** Co-author a paper Internship at an important university – Zurich, Munch,..	**Career pathway** Career pathways Graduate school (Ph.D., MS) Industry, R&D

Interact with colleagues working on AI for clean water

Let us generalize…

Exposure to AI for sci
ence

Expertise within I ITM

A possible people to look at for BS (chemistry) program

Inputs from Chat GPT

Expertise beyond I ITM

Vivek Polshettiwar

Partha S. Mukherjee

Eswaramoorthy M.

Swaminathan Sivaram

Debasis Das

Ranjani Viswanatha

Vadapalli Chandrasekhar

Rajeev Ahuja

Kannan Srinivasan

K.N. Ganesh

Sarit S. Agasti

Joyanta Choudhury

Satischandra B. Ogale

Bikash C. Pal

Jayanta Haldar

Kanishka Biswas

Ramanarayanan Krishnamurthy

Sampath S

Ankona Datta

P.K. Tewari

K. Geetharni Rajamalli

Subinoy Rana

Buddhadeb Chattopadhyay

Many others can be added

Expertise in indu stry

ChatG
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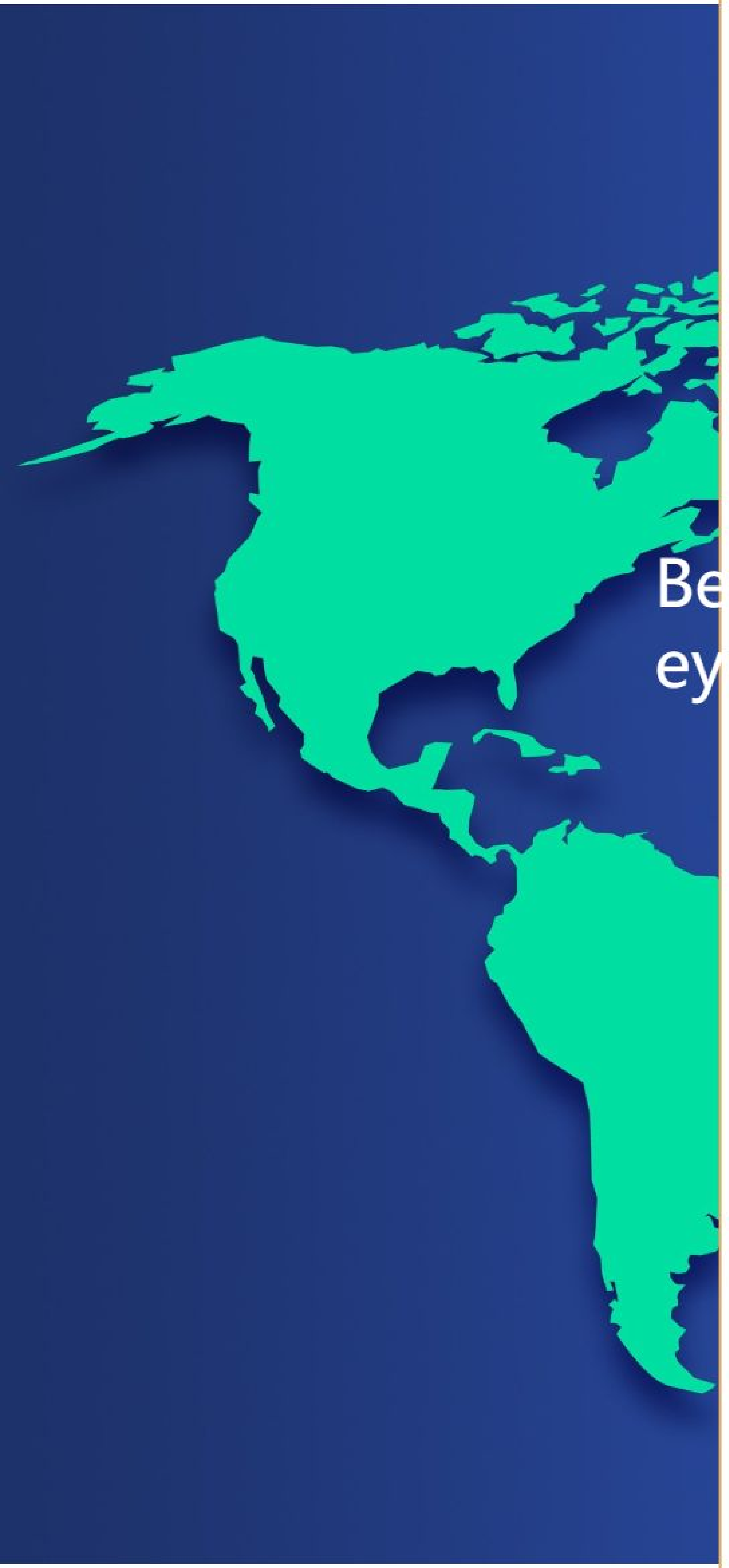
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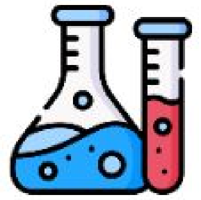
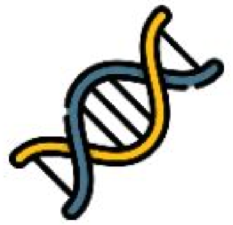
Structuring growth

Courses & Labs ⍰ Faculty Mentors in IITM ⍰ Faculty Mentors Outside IITM ⍰ Global Research Internships ⍰ Industry Exposure ⍰ Career Outcomes

Income expectations

U.S. vs. Indian salaries for B.S. graduates

	$46 – 84 K	Rs. 3 - 7 LPA
	$51-129 K	Rs. 2 – 6 LPA
	$70-125 K	Rs. 3- 8 LPA

How to have inte
rdisciplinary brid
ges with faculty i
n IITM –

Year 1

25-week “Interdi
sciplinary bridges
 for chemistry” le
cture series

Only some of our fac
ulty

Visualizing a plan

Year 1 - 10-week lecture series on emerging directions in chemical sciences – Have a student volunteer to conduct this

Year 2 – Attend one CRSI symposium

Year 2 – Attend one interdisciplinary conference

Year 2 – Attend one seminar a month, outside the department

Year 3 – Present a paper within the department

Year 4 – Present a paper outside the department

Year 4 – Present a paper abroad

Soft skills are important too

What do you hope to have?

Multiple career options

No career break

Contacts in the country

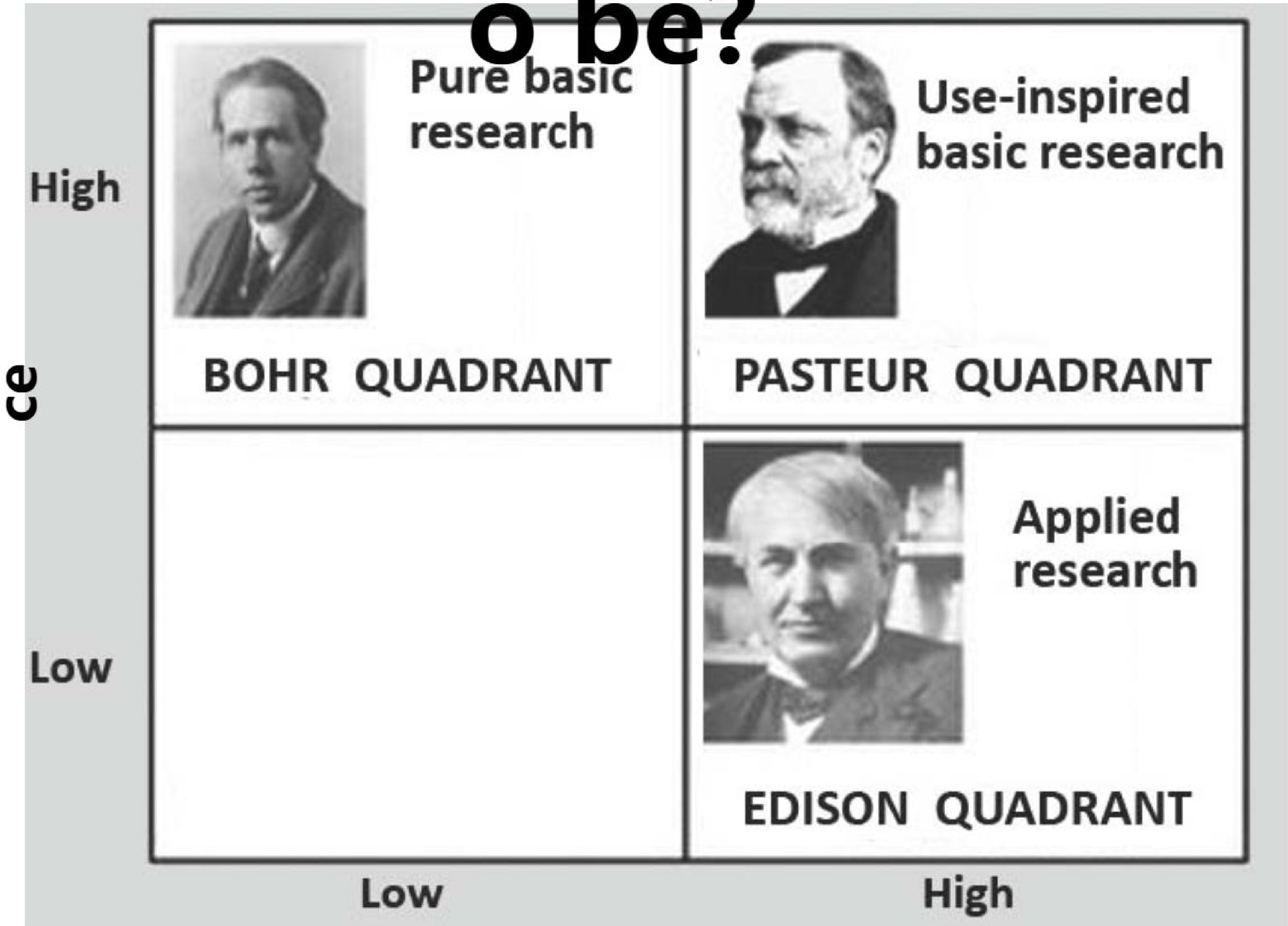
Contacts in industry

Contacts abroad

Peer network in other institutions

Contact builds you
Exposure strengthens you

Where do you want to be?



Excellence

Relevance

Chemistry vs. Data

What do you lo
ve?

BASF Microsoft

Annual revenue (2024 & 2022) $75.7 b $198
b

Total Employees 116,000 135,000

Market capilalisation (value) $3.4 T $3.9 T
(2025 numbers)

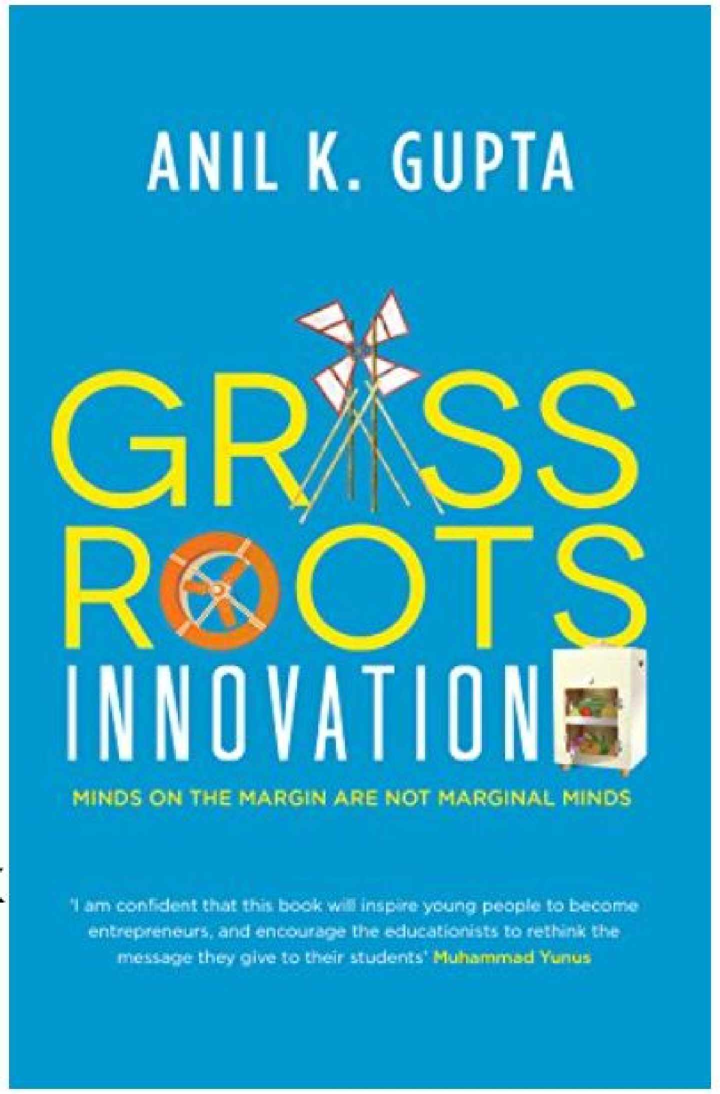
BASF is worth 1/10th of Microsoft

BASF was established in 1865, Microsoft in 19
75

Impact is not revenue

Innovation everywhere – even at the grassroots

Chhaya Thakore, Class VII, presents her idea of an inclined drinking-water pipe to enable children of different heights to drink water easily.



From Anil K. Gupta, Grass Roots Innovation, Random Business, India, 2016

Molecules are not bits!

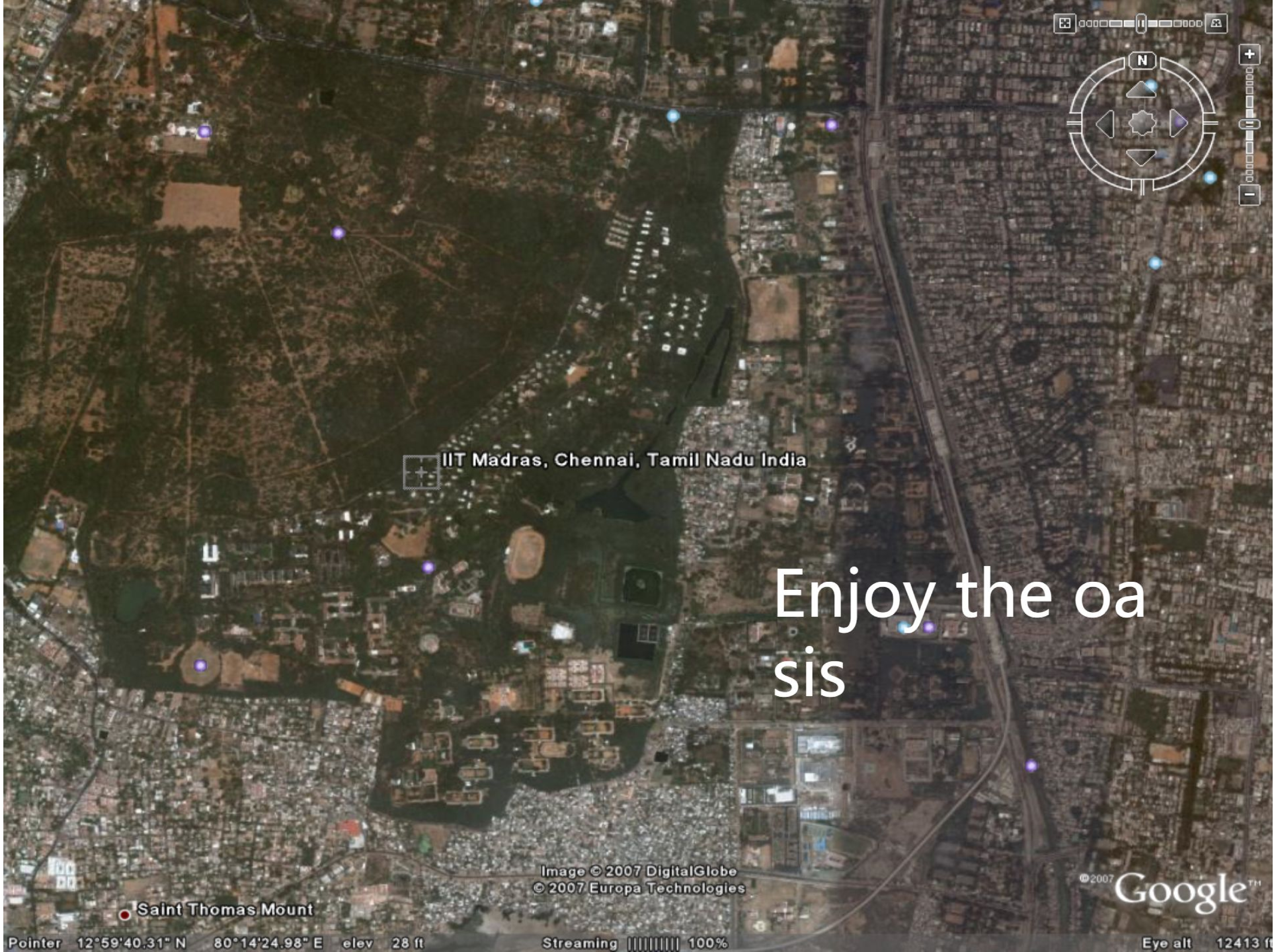
Chemistry is the central science — a path for solving world's biggest problems.

Connect with faculty NOW and start early.

Open your eyes and see the opportunities around. Use resources responsibly. They are for YOU.

Locate your place and chart a plan for YOU.

There are NO institutional barriers.



Enjoy the oa
sis

Indian Institute of Technology Madras

Associate Editor

ACS Sustainable Resource Management

V. Kamakoti

Questions are welco me!