CHEMICAL SCIENCE AND CHEMICAL INDUSTRY: PAST, PRESENT AND FUTURE

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National Seminar on
Chemistry in Human Welfare
Science City, Kolkatta

August 2, 2011

International Year of CHEMISTRY 2011

- Celebrate the achievements of chemistry
- Improve public understanding of chemistry
- Champion the role of chemistry in addressing the critical challenges of our society
  - Food and nutrition
  - Clean water
  - Sustainable energy
  - Climate change
- Broader outreach and engagement
- Get younger people more interested in chemistry

Chemistry is the central, useful and creative science : Ronald Breslow

Madame Curie, Nobel Prize in Chemistry , 1911

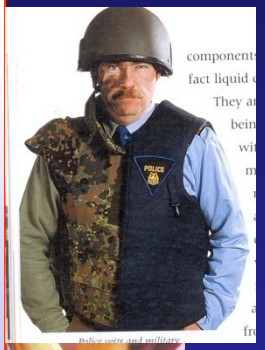
Earnest Rutherford, The Structure of the Atom. 1911

CHEMISTRY CREATES MATTER THAT NEVER EXISTED BEFORE eg. PLASTICS, DETERGENTS, DRUGS, INSECTICIDES, ETC.

Central

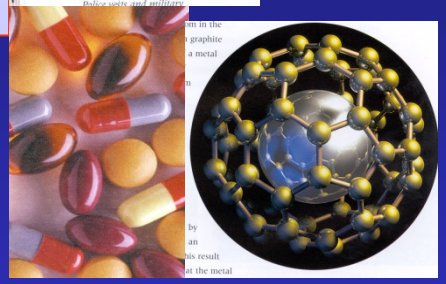
Underpins many other scientific disciplines

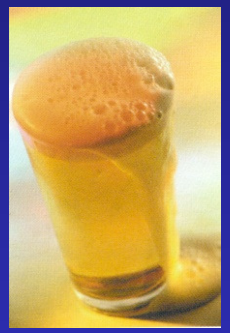
Biology, geology, material science

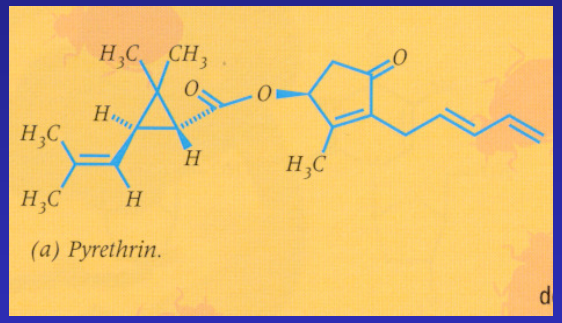


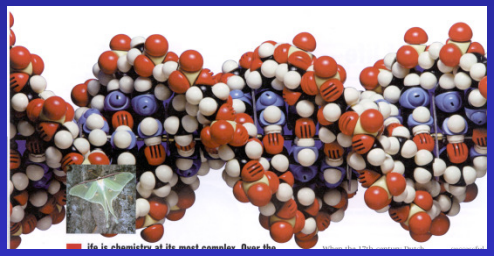
Creative

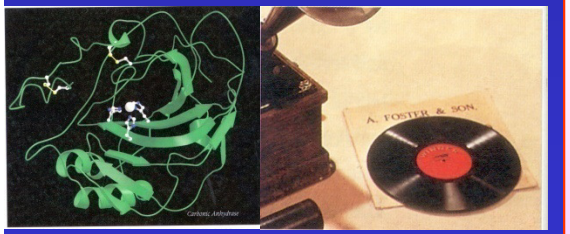
Designs structures with new and unique properties





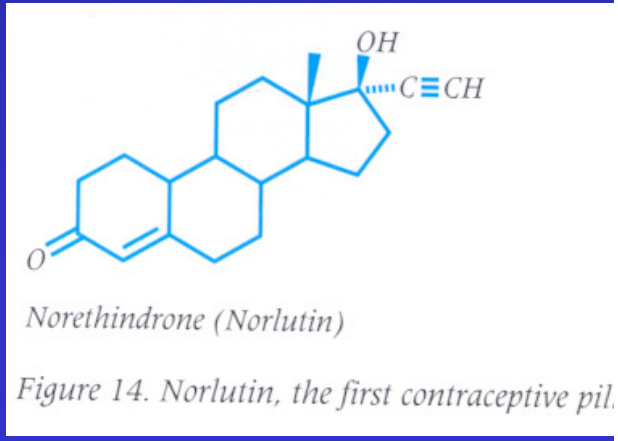






Useful

Provides many materials essential to everyday life, knowledge to better human, veternary and plant care, better food, environment

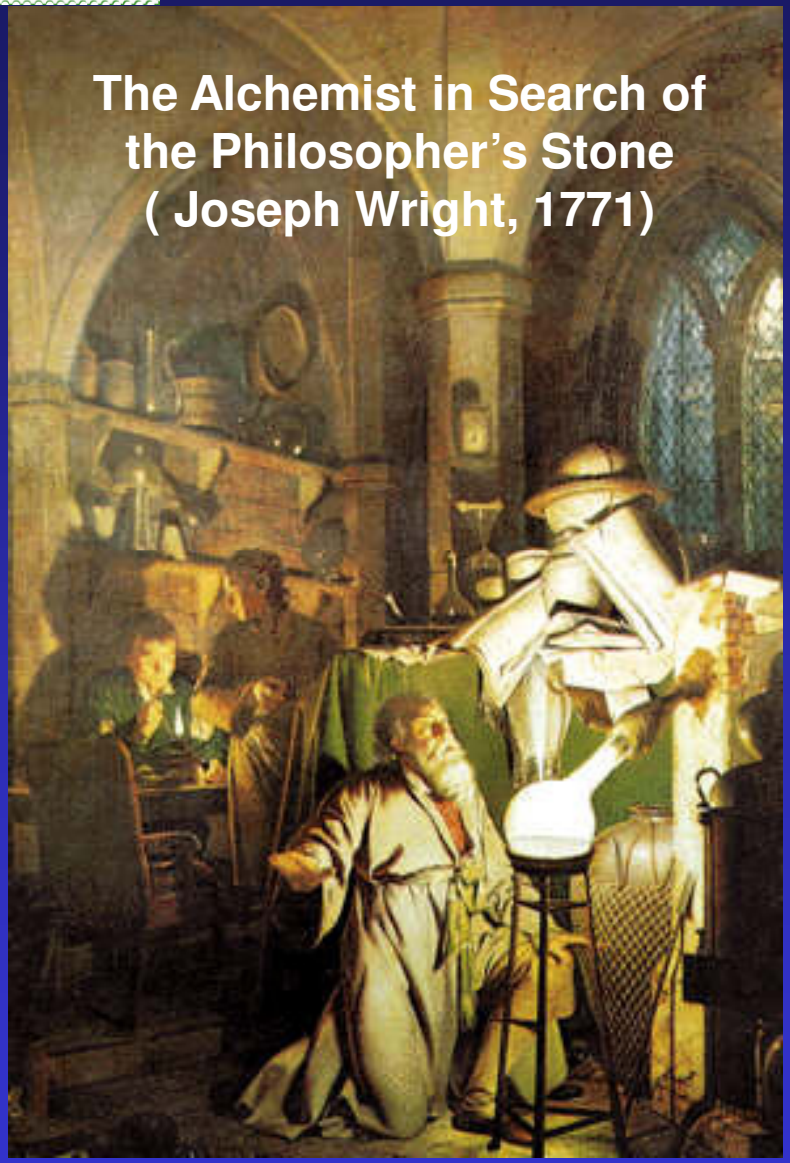


CHEMICAL SCIENCE AND CHEMICAL INDUSTRY

- **Chemical science and industry have been closely intertwined throughout its history**
- **Creation of wealth has always been the underlying motivation for many of the epoch making discoveries**
- **More than any other breed of scientists, chemists have always exhibited a heightened awareness of society's problems and an altruistic desire to solve them**
- **For over a century and a half, academic and industrial chemistry have enjoyed a healthy and symbiotic relationship. Every major landmark in applications of chemistry can be traced back to the fundamental insights gained through painstaking and sustained research in academia**

CHEMICAL SCIENCE AND INDUSTRY: THREE PHASES OF EVOLUTION

- **Post Industrial Revolution (1760-1915)**
- **World War I and II (1915-1950)**
- **The Era of inexpensive Petroleum (1950- 2000)**



Hennig Brandt of Hamburg (1630 -1710)

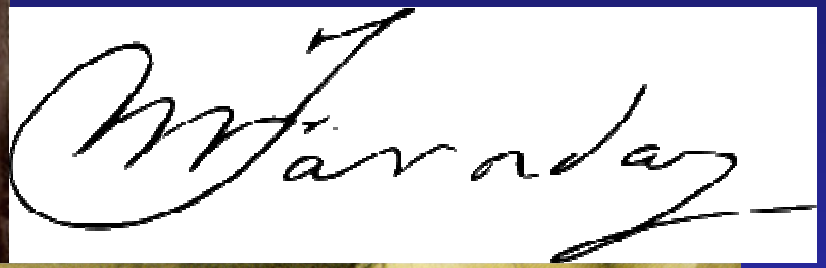
Discoverer of Phosphorous

The chemical reaction Brandt stumbled on was as follows. Urine contains phosphates PO_4^{3-}, as sodium phosphate (i.e. with Na^+), and various carbon-based organics. Under strong heat the oxygens from the phosphate react with carbon to produce carbon monoxide CO, leaving elemental phosphorus P, which comes off as a gas. Phosphorus condenses to a liquid below about 280°C and then solidifies (to the white phosphorus allotrope) below about 44°C (depending on purity).

This same essential reaction is still used today (but with mined phosphate ores, coke for carbon, and electric furnaces).

The phosphorus Brandt's process yielded was far less than it could have been. The salt part he discarded contained most of the phosphate. He used about 5,500 litres of urine to produce just 120 grams of phosphorus. If he had ground up the entire residue he could have got 10 times or 100 times more (1 litre of adult human urine contains about 1.4 g phosphorus).

MICHAEL FARADAY
(1791- 1867)



The most influential scientist in the history of science

Faraday's Laboratory

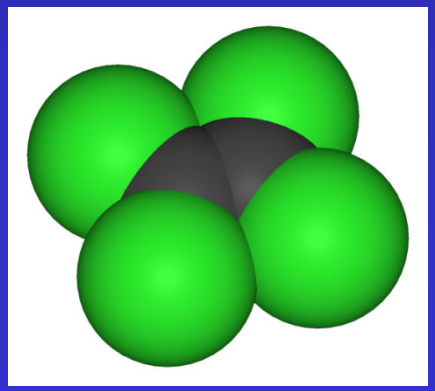
- **One of the first scientists in the post – industrial revolution who established the methods of evidence based proof of hypothesis**

- **Contributed to both science and its applications; Studied pollution of river Thames, developed the first optical glass, studied the chemistry of flames and established that fine dust of coal can combust spontaneously**

MICHAEL FARADAY : A PIONEER IN CHEMISTRY

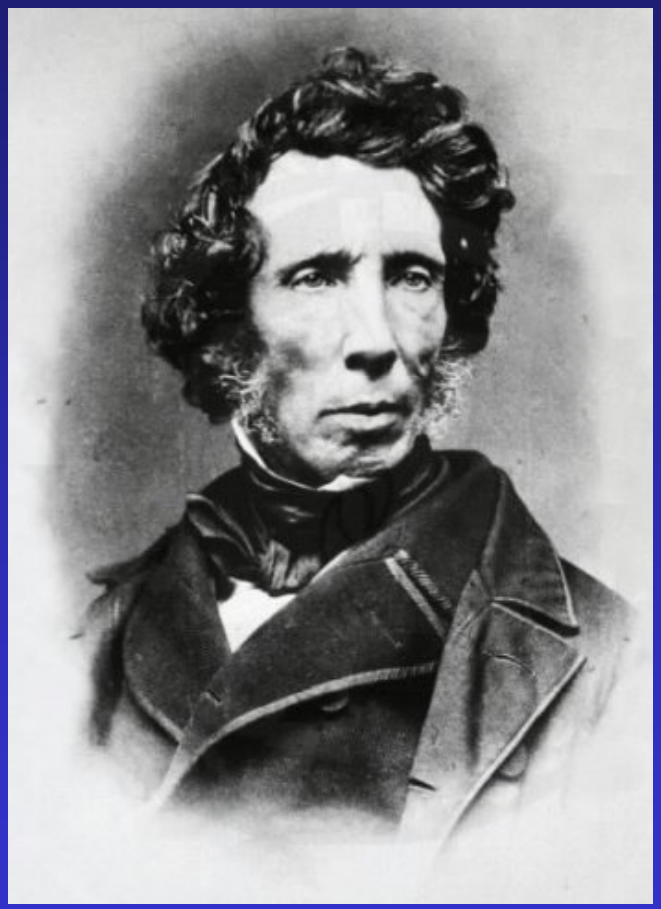
- **Discovery of Benzene**
- **Laws of electrolysis; concept of anode, cathode, electrode and ions**
- **First demonstration of decomposition of magnesium sulfate by applying electrical potential; Design of a voltaic pile consisting of seven half penny pieces, seven discs of zinc and filter paper soaked in salt water (1812)**
- **First synthesis of hexa-chloroethane and tetrachloro-ethylene (1820)**
- **Identification of isoprene as a constituent of natural rubber , now known as poly(isoprene) (1826)**

A Voltaic Pile

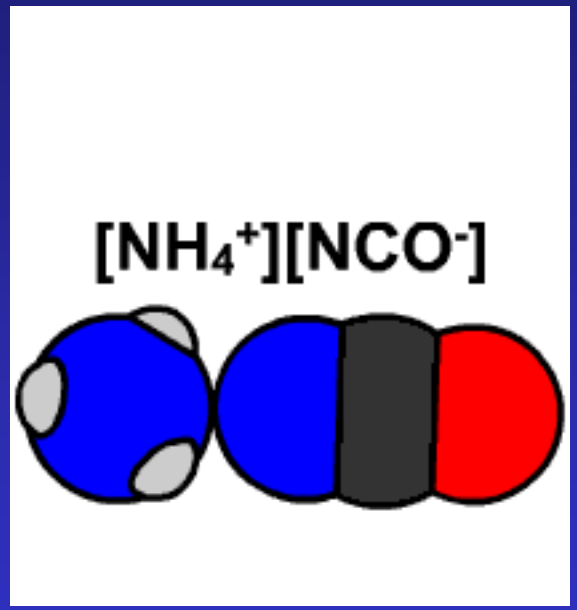


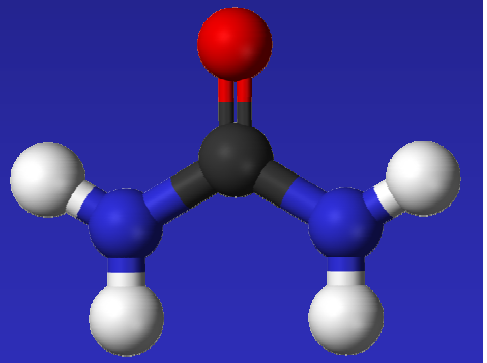
Tetrachloroethylene

CHEMICAL REVOLUTION : EARLY BEGINNINGS



Freidrich Wohler (1800 – 1882)





Annalen der Physik und Chemie, 88(2), 253-256 (1828)

Chemistry creates its own object. This creative power, similar to that of arts distinguishes it fundamentally from the other natural and historical sciences

Marcellin Bertholet, 1860

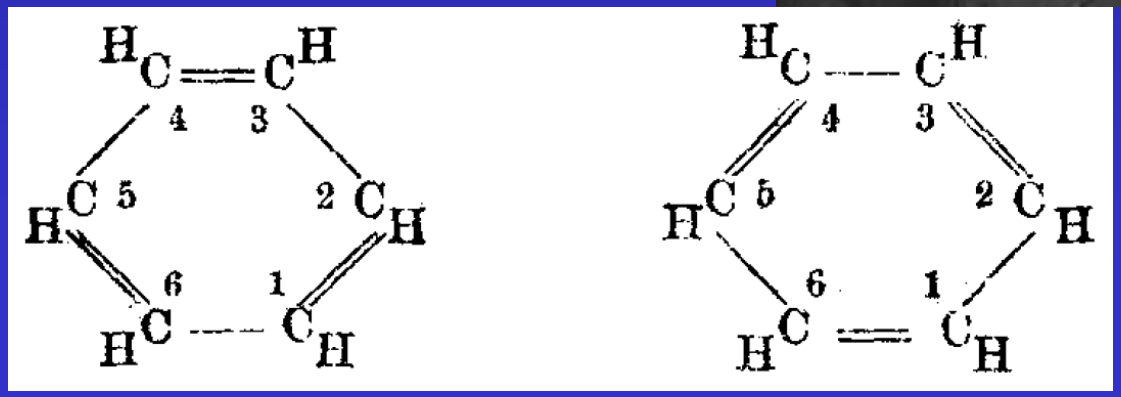
(1827- 1907)

CHEMICAL REVOLUTION : UNDERSTANDING CHEMICAL STRUCTURES

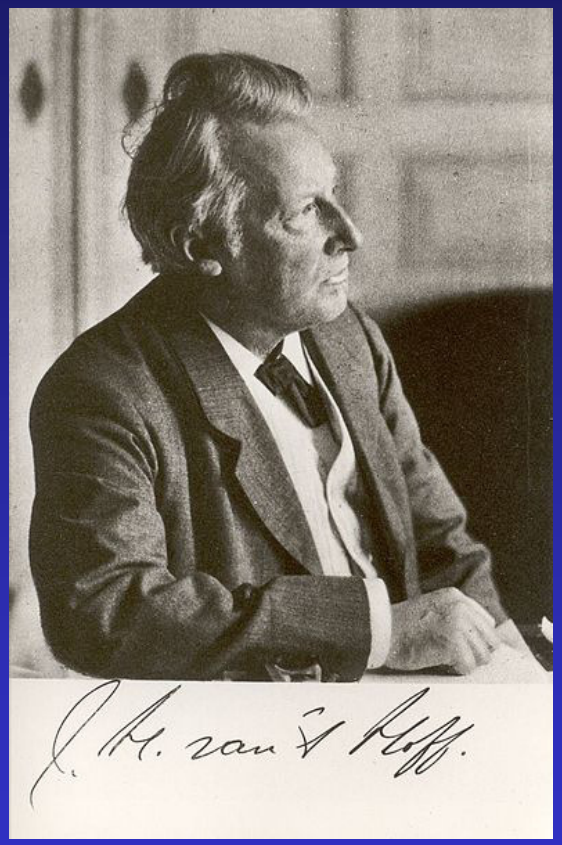
- **The Theory of Chemical Structure (1857-58)**

- **Structure of Benzene published in *Bulletin de la Society Chimique de Paris, 3(2), 98-110 (1865)***

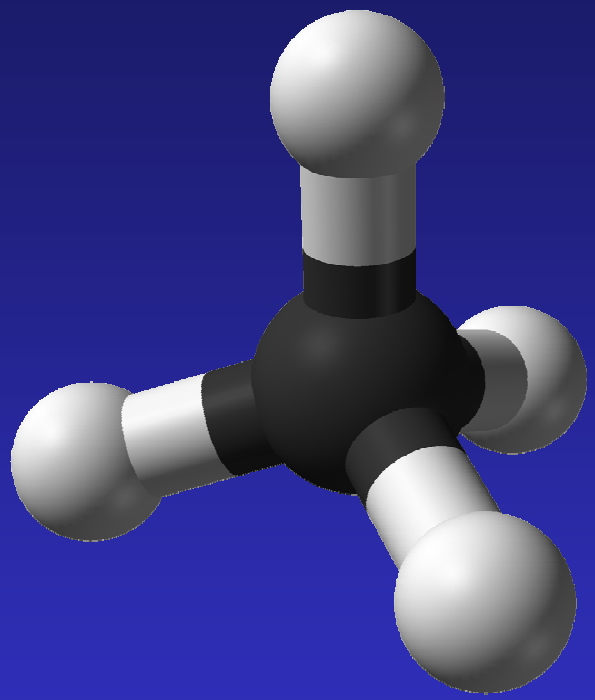
Auguste Kekule (1829 -1896)



CHEMICAL REVOLUTION : UNDERSTANDING CHEMICAL STRUCTURES



Jacobus van't Hoff (1852-1911)



The Tetrahedral Nature of Carbon

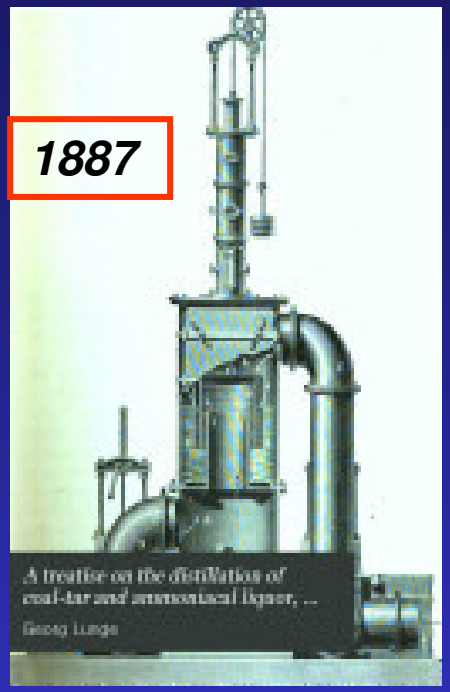
(La Chimie dans l'espace, 1874)

First Nobel Prize in 1901

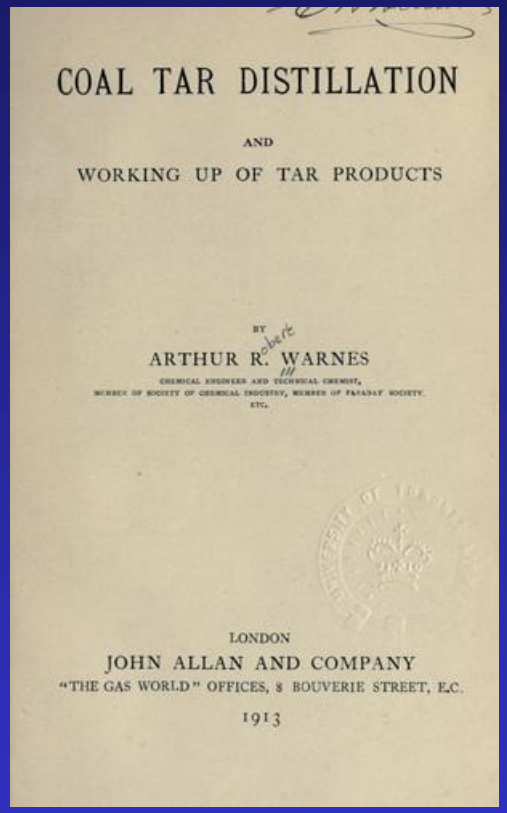
DESTRUCTIVE DISTILLATION : THE APPLICATION OF PHYSICAL PROCESSES I N CHEMICAL SCIENCE

Distillation emerges as a process to produce chemical building blocks

- **Wood distillation : Terpenes, Guaicol, methanol**
- **Coal Tar Distillation: Benzene, cresol, phenol, aniline, naphthalene etc.**
- **Distillation of Natural Rubber : Isoprene**



1887



COAL TAR DISTILLATION

AND

WORKING UP OF TAR PRODUCTS

BY

ARTHUR R. WARNES

LONDON

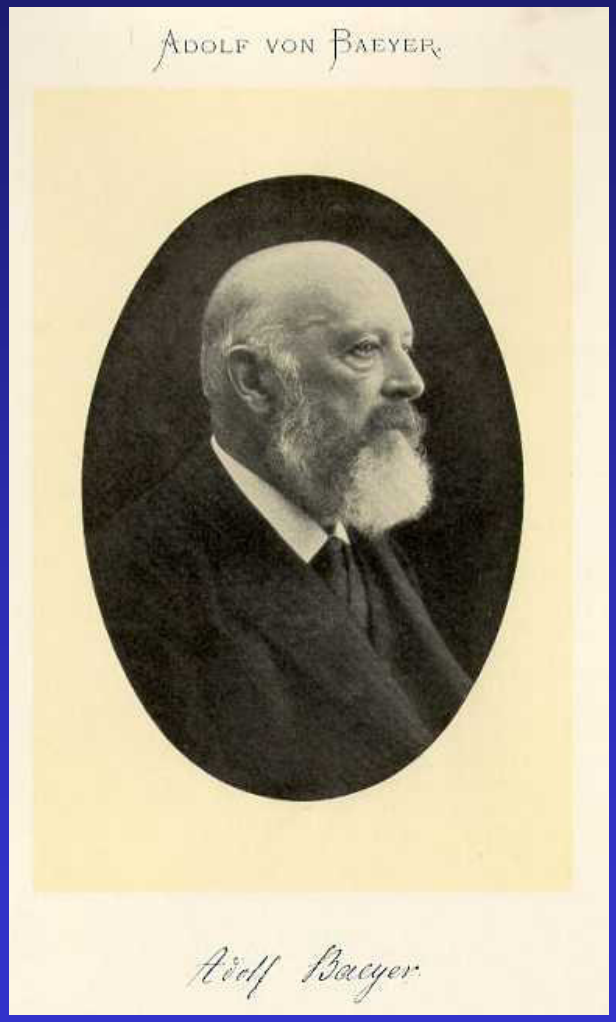
JOHN ALLAN AND COMPANY

"THE GAS WORLD" OFFICES, 8 BOUVERIE STREET, E.C.

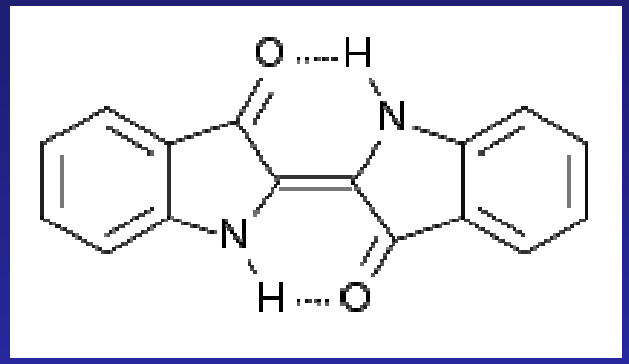
1913

1913

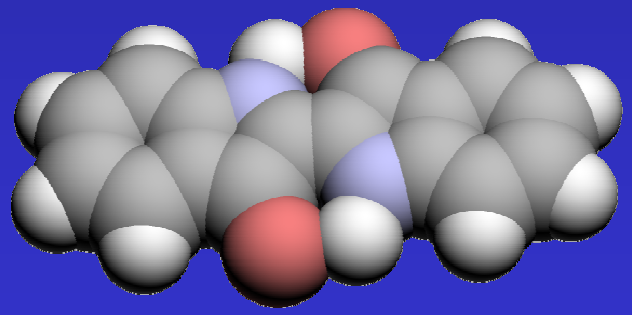
BEGINNING OF INDUSTRIAL CHEMISTRY : THE INDIGO SYNTHESIS



Adolf von Baeyer (1835-1917)



Synthesis of a plant derived natural product, from Isatin and 2-Nitrobenzaldehyde (1878-80)



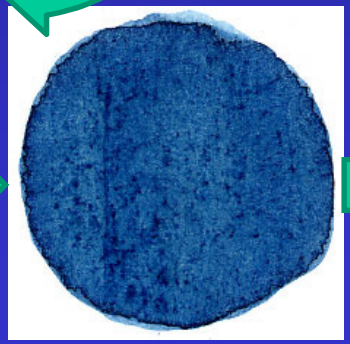
Nobel Prize , 1905

THE DAWN OF THE CHEMICAL INDUSTRY: THE MANUFACTURE OF INDIGO

BASF commences manufacture of synthetic Indigo (1897)

BASF develops a more economic route based on N-2-carboxyphenyl glycine, derived from aniline, which had become just then available from coal tar distillation

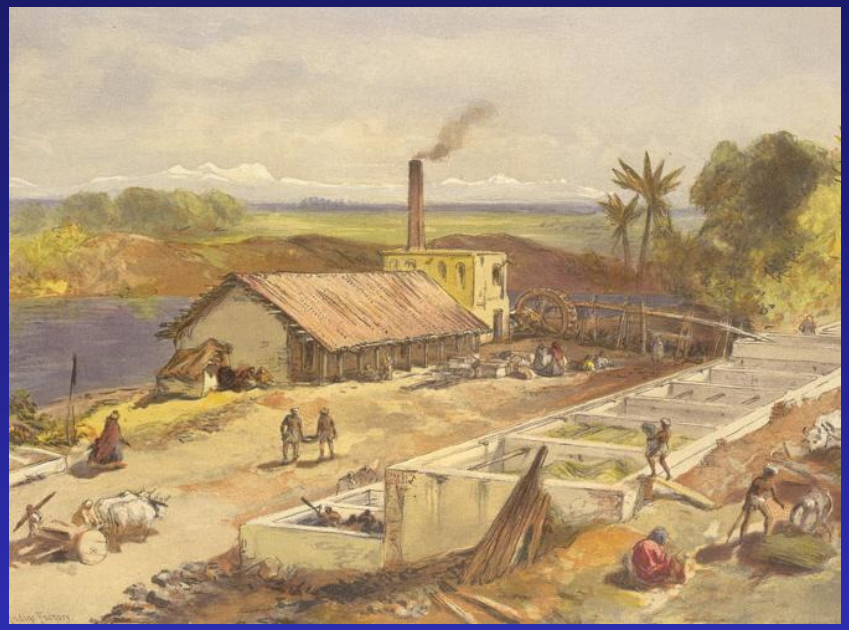
Indigofera Tinctoria



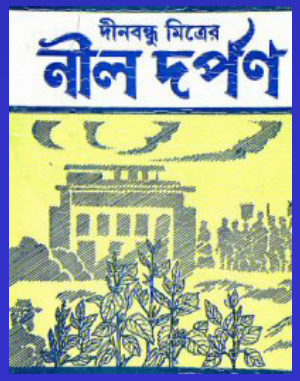
Indigo dye

Blue denim

THE DAWN OF THE CHEMICAL INDUSTRY: THE BENGAL CONNECTION



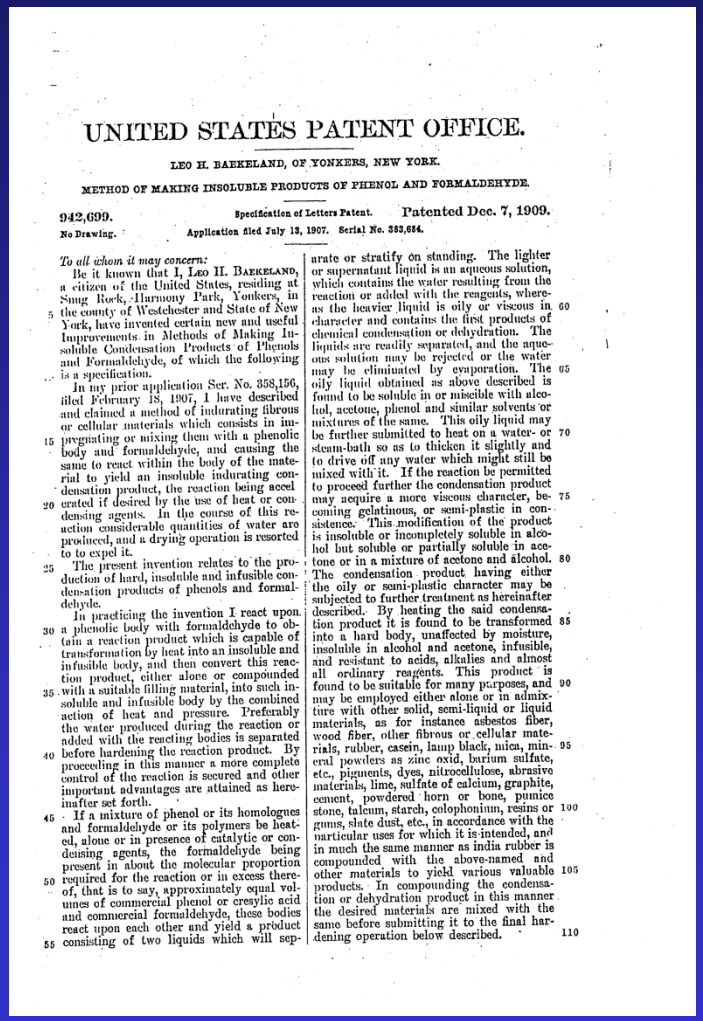
Indigo dye factory in Bengal, circa 1867



Nil Darpan by Dinabandhu Mitra (1860)

- Indigo plantation in Bengal dates back to 1777
- The Indigo Riots (Nil Bidroho) began in Nadia in 1859, an uprising of the farmers against the exploitation by the planters and later spread to Champaran in Bihar in 1868
- There was an anger against the British traders, fresh after the Sepoy Mutiny of 1857
- Regarded as the first non violent passive resistance in Indian history
- India's exports of over 20,000 tons of Indigo to Europe ceases; by 1914 synthetic Indigo completely replaces natural Indigo

THE DAWN OF THE CHEMICAL INDUSTRY: THE MANUFACTURE OF BAKELITE



UNITED STATES PATENT OFFICE.

LEO H. BAEKELAND, OF YONKERS, NEW YORK.

METHOD OF MAKING INSOLUBLE PRODUCTS OF PHENOL AND FORMALDEHYDE.

942,699. Specification of Letters Patent. Patented Dec. 7, 1909.

No Drawing. Application filed July 13, 1907. Serial No. 383,884.

To all whom it may concern:

Be it known that I, LEO H. BAEKELAND, a citizen of the United States, residing at Snug Rock, Harmony Park, Yonkers, in the county of Westchester and State of New York, have invented certain new and useful Improvements in Methods of Making Insoluble Condensation Products of Phenols and Formaldehyde, of which the following is a specification.

In my prior application Ser. No. 358,156, filed February 18, 1907, I have described and claimed a method of indurating fibrous or cellular materials which consists in impregnating or mixing them with a phenolic body and formaldehyde, and causing the same to react within the body of the material to yield an insoluble indurating condensation product, the reaction being accelerated if desired by the use of heat or condensing agents. In the course of this reaction considerable quantities of water are produced, and a drying operation is resorted to to expel it.

The present invention relates to the production of hard, insoluble and infusible condensation products of phenols and formaldehyde.

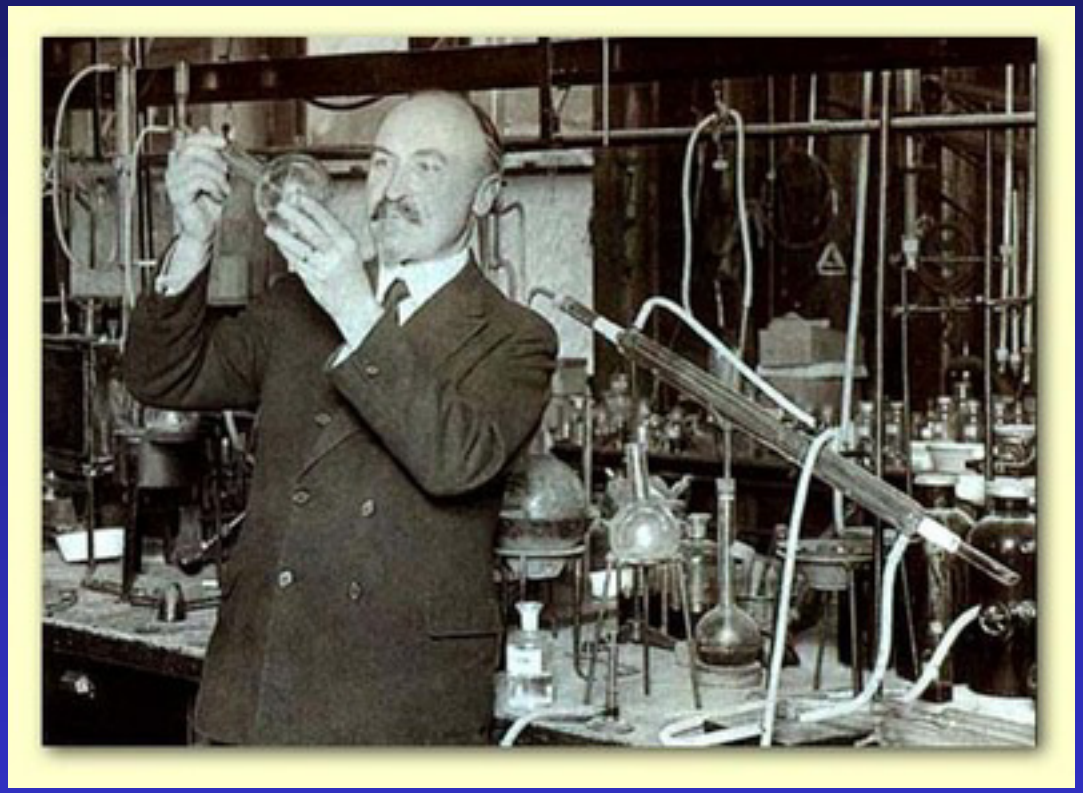
In practicing the invention I react upon a phenolic body with formaldehyde to obtain a reaction product which is capable of transformation by heat into an insoluble and infusible body, and then convert this reaction product, either alone or compounded with a suitable filling material, into such insoluble and infusible body by the combined action of heat and pressure. Preferably the water produced during the reaction or added with the reacting bodies is separated before hardening the reaction product. By proceeding in this manner a more complete control of the reaction is secured and other important advantages are attained as hereinafter set forth.

If a mixture of phenol or its homologues and formaldehyde or its polymers be heated, alone or in presence of catalytic or condensing agents, the formaldehyde being present in about the molecular proportion required for the reaction or in excess thereof, that is to say, approximately equal volumes of commercial phenol or cresylic acid and commercial formaldehyde, these bodies react upon each other and yield a product consisting of two liquids which will separate or stratify on standing. The lighter or supernatant liquid is an aqueous solution, which contains the water resulting from the reaction or added with the reagents, whereas the heavier liquid is oily or viscous in character and contains the first products of chemical condensation or dehydration. The liquids are readily separated, and the aqueous solution may be rejected or the water may be eliminated by evaporation. The oily liquid obtained as above described is found to be soluble in or miscible with alcohol, acetone, phenol and similar solvents or mixtures of the same. This oily liquid may be further submitted to heat on a water- or steam-bath so as to thicken it slightly and to drive off any water which might still be mixed with it. If the reaction be permitted to proceed further the condensation product may acquire a more viscous character, becoming gelatinous, or semi-plastic in consistence. This modification of the product is insoluble or incompletely soluble in alcohol but soluble or partially soluble in acetone or in a mixture of acetone and alcohol. The condensation product having either the oily or semi-plastic character may be subjected to further treatment as hereinafter described. By heating the said condensation product it is found to be transformed into a hard body, unaffected by moisture, insoluble in alcohol and acetone, infusible, and resistant to acids, alkalies and almost all ordinary reagents. This product is found to be suitable for many purposes, and may be employed either alone or in admixture with other solid, semi-liquid or liquid materials, as for instance asbestos fiber, wood fiber, other fibrous or cellular materials, rubber, casein, lamp black, mica, mineral powders as zinc oxid, barium sulfate, etc., pigments, dyes, nitrocellulose, abrasive materials, lime, sulfate of calcium, graphite, cement, powdered horn or bone, pumice stone, talcum, starch, colophonium, resins or gums, slate dust, etc., in accordance with the particular uses for which it is intended, and in much the same manner as india rubber is compounded with the above-named and other materials to yield various valuable products. In compounding the condensation or dehydration product in this manner the desired materials are mixed with the same before submitting it to the final hardening operation below described.

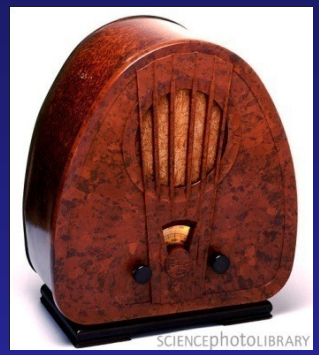
US Patent 942, 699, December 7, 1909

- Baekland set out to discover a substitute for Shellac, then wholly supplied by India to the world
- In the process he made the first man made material, heralding the age of plastics, a discovery considered as revolutionary
- Heat resistant and insulating
- Baekland named his new material Novolak
- He founded a company called Bakelite Corporation in 1910 to manufacture the product

THE DAWN OF THE CHEMICAL INDUSTRY: THE MANUFACTURE OF BAKELITE



Leo Baekland (1863-1944)



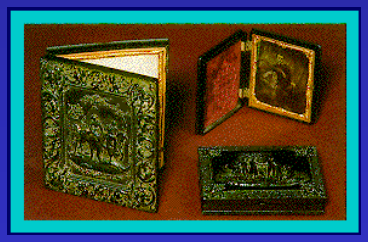
When asked why he chose to work in the field of synthetic resins, he replied" to make money"

POLYMERS FULFILLING MATERIAL NEEDS OF SOCIETY…

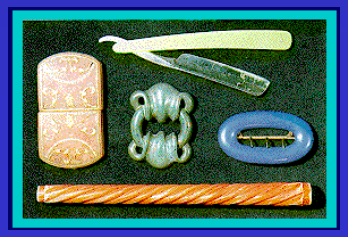
Precursor 19th Century → Semi Synthetics

- 1839 : Natural Rubber
- 1843 : Vulcanite / Gutta Percha
- 1856 : Shellac / Bois Durci
- 1862 : Parkesine
- 1863 : Celluloid
- 1894 : Viscose Rayon
- 1898 : Poly Carbonate

Natural Polymers



Semi Synthetics



1900 – 1950 → Thermoplastics

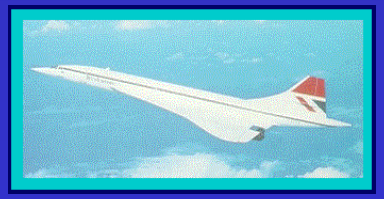
- 1908 : Cellophane
- 1909 : Bakelite
- 1926 : Vinyl or PVC
- 1927 : Cellulose Acetate
- 1933 : Polyvinylidene chloride
- 1935 : Low density polyethylene
- 1936 : Polymethyl Methacrylate
- 1937 : Polyurethane
- 1938 : Polystyrene
- 1938 : Teflon
- 1939 : Nylon and Neoprene
- 1941 : PET
- 1942 : LDPE
- 1942 : Unsaturated Polyester

1950 onwards → Growth Phase

- 1951 : HDPE
- 1951 : PP
- 1954 : Styrofoam
- 1960 : PC, PPO
- 1964 : Polyamide
- 1970 : Thermoplastic Polyester
- 1978 : LLDPE
- 1985 : Liquid Crystal Polymers

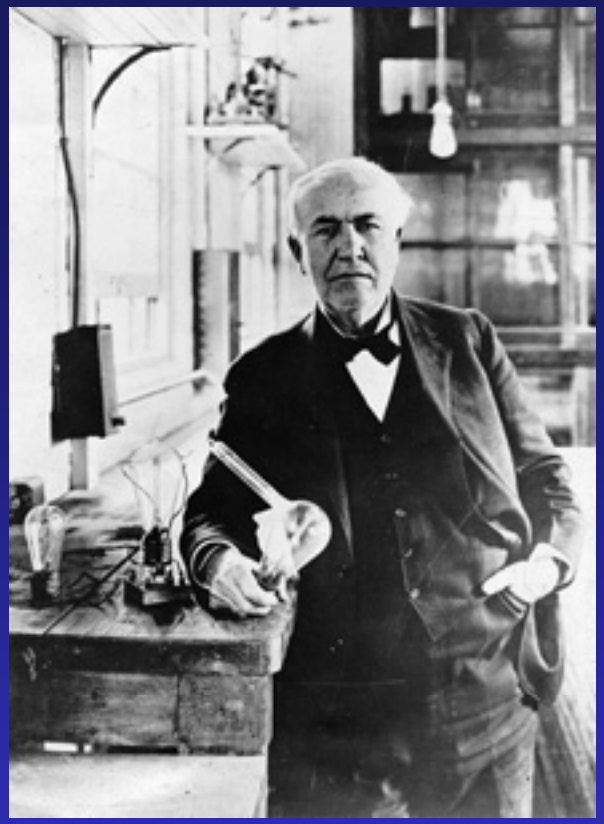
Plastics in Packaging

Hi Tech Plastics



Source : British Plastic Federation Website

EDISON AND MENLO PARK : THE BIRTH OF INVENTION FACTORY

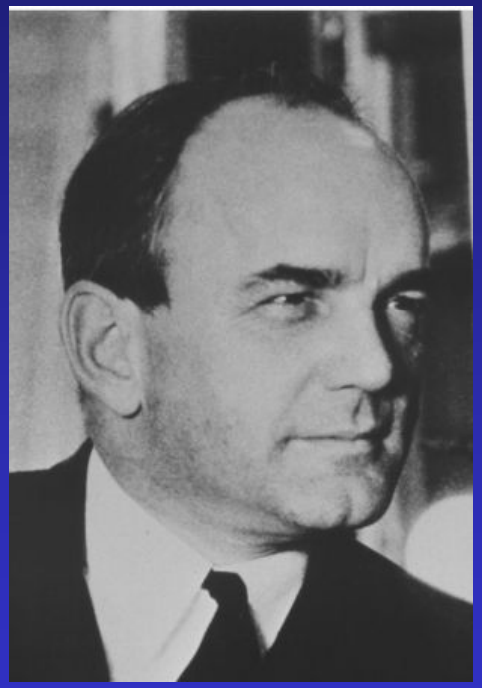


Thomas Alva Edison (1847-1931)

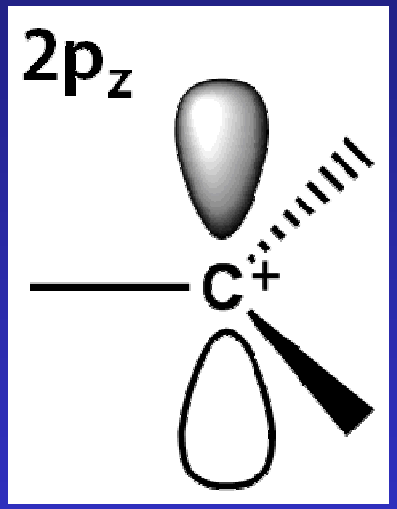
Menlo Park, NJ Laboratory

- Most prolific inventor in the history
- Edison holds the record for the largest number of patents granted to an individual inventor, 1093
- Inventor of phonograph, incandescent bulb, motion picture camera, alkaline battery and many others
- First to organize and manage research , a forerunner to the later day corporate research laboratories of companies
- Assembled a cross functional global team of coworkers, from Germany(glass blowing), Switzerland (watch making),mathematicians, chemists , carpenters and machinists
- In 1900 Menlo Park employed over hundred people who were inventing for a salary and living

CHEMICAL TRANSFORMATION OF HYDROCARBONS: THE CENTRAL ROLE OF CARBOCATIONS



Frank Whitmore (1887-1947)



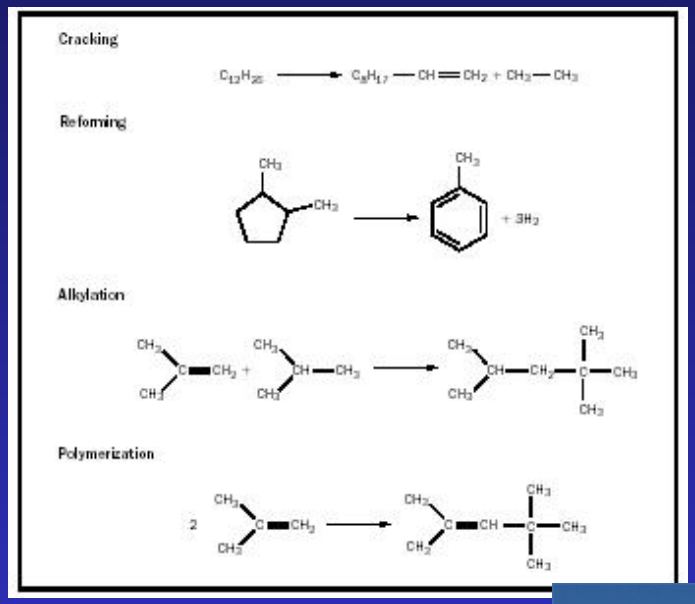
- **First to propose the intermediacy of carbocations in hydrocarbon (olefin and paraffin) reactions under acidic conditions**

- **Seminal paper on intramolecular rearrangements involving the intermediacy of carbocations published in *J.Amer. Chem. Soc.,54, 3274-3283 (1932)***

- **Author of the first advanced book titled *Organic Chemistry, D. Van Nostrand & Co, 1937, 1090 pages***

CHEMICAL TRANSFORMATION OF HYDROCARBONS: CATALYTIC REFORMING AND THE DAWN OF THE PETROLEUM REFINING

Vladimir Ipatieff (1867-1952)



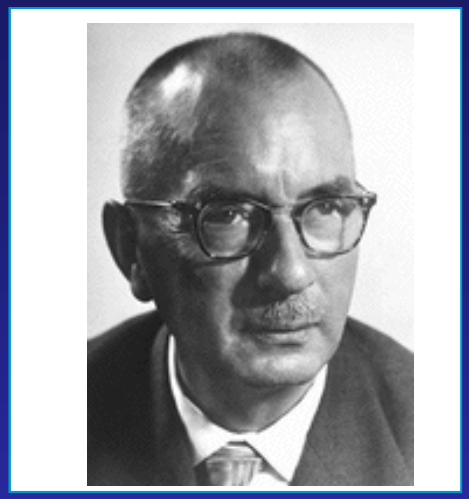
Cracking of hydrocarbons to olefins and dienes and reforming of cycloaliphatics to aromatics could be accomplished over Lewis and Bronsted Acids as catalysts

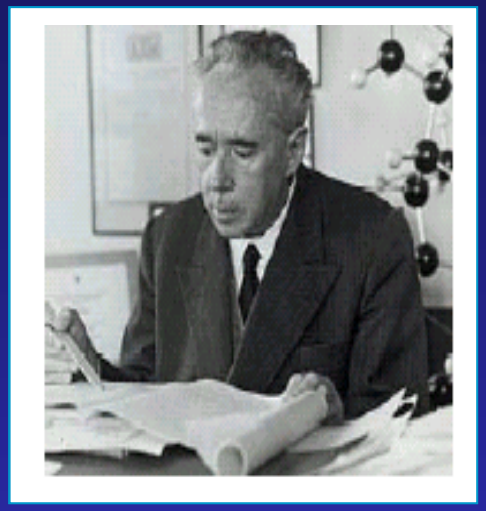
Post WW II petroleum became the provider of building blocks for the chemical industry

BUILDING BLOCKS FOR CHEMICAL INDUSTRY

- **Olefins : Ethylene, Propylene**
- **Higher α-olefins : Butene-1, Hexene-1, Octene-1, …. Octadecene-1**
- **Other olefins : 4-Methyl pentene-1**
- **Cyclic olefins : Cyclopentene, Norbornene, Ethylidene norbornene**
- **Ninety five per cent of the organic chemical industry is derived from ten feed-stocks, namely, methane, ethylene, propylene, C-4 olefins, C-5 olefins, butadiene, benzene, toluene and xylene**
- **Feed-stocks (~10)** → **Basic building blocks (~50)** → **Intermediates (~500)** → **Chemical** products (~70,000)

POLYETHYLENES AND POLYPROPYLENES





BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM 14. APRIL 1960

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 973 626

KLASSE 39c GRUPPE 25c

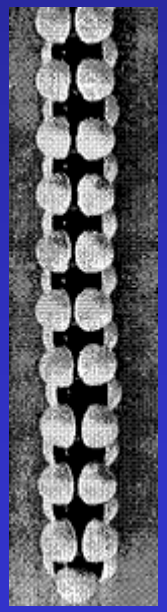
INTERNAT. KLASSE C08f

2,399,398/39c

Dr. Dr. e. h. Karl Ziegler, Mülheim/Ruhr,
Dr. Heinz Breil, Oberhausen (Rhld.), Dr. Erhard Holzkamp, Düsseldorf,
und Dr. Heinz Martin, Mülheim/Ruhr
sind als Erfinder genannt worden

Dr. Dr. e. h. Karl Ziegler, Mülheim/Ruhr

Verfahren zur Herstellung von hochmolekularen Polyäthylenen



CRYSTALLINE HIGH POLYMERS OF α-OLEFINS

Sir:

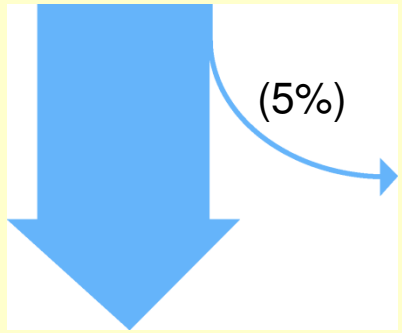
No crystalline polymers of olefinic hydrocarbons containing asymmetric carbon atoms in the principal chain of the macromolecules have been reported. Such a lack of crystallinity has been explained[1] by considering such polymers as copolymers of two types of random distributed monomeric units, differing only in the configuration of their dissymmetric group.

DE 973626
Nov 18, 1953

G.Natta
JACS 77, 1708, 1955
(March 20, 1955)

CHEMICAL INDUSTRY : POST WAR STRUCTURE

crude oil

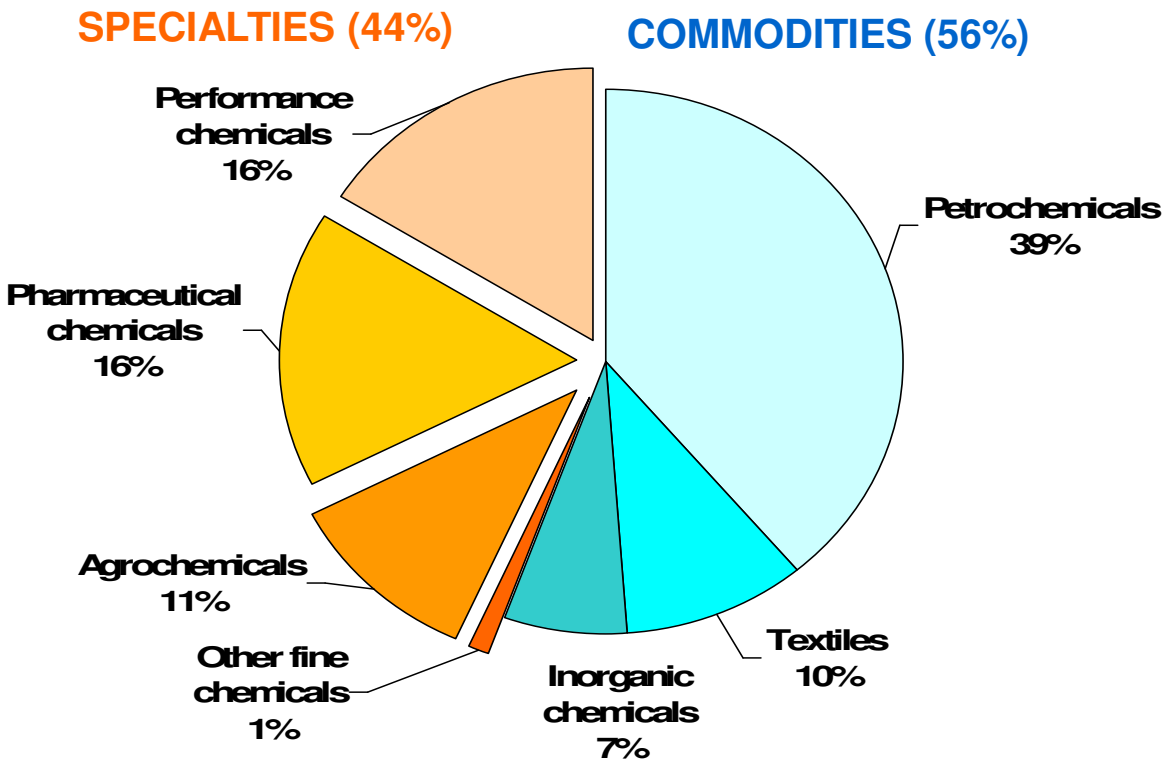


fuel
(energy)
↓
transportation,
heating

petrochemicals
(materials)
↓
commodities
↓
specialties

biological
sources
↓
(synthesis)
↓
pharma

WORLD CHEMICAL MARKETS

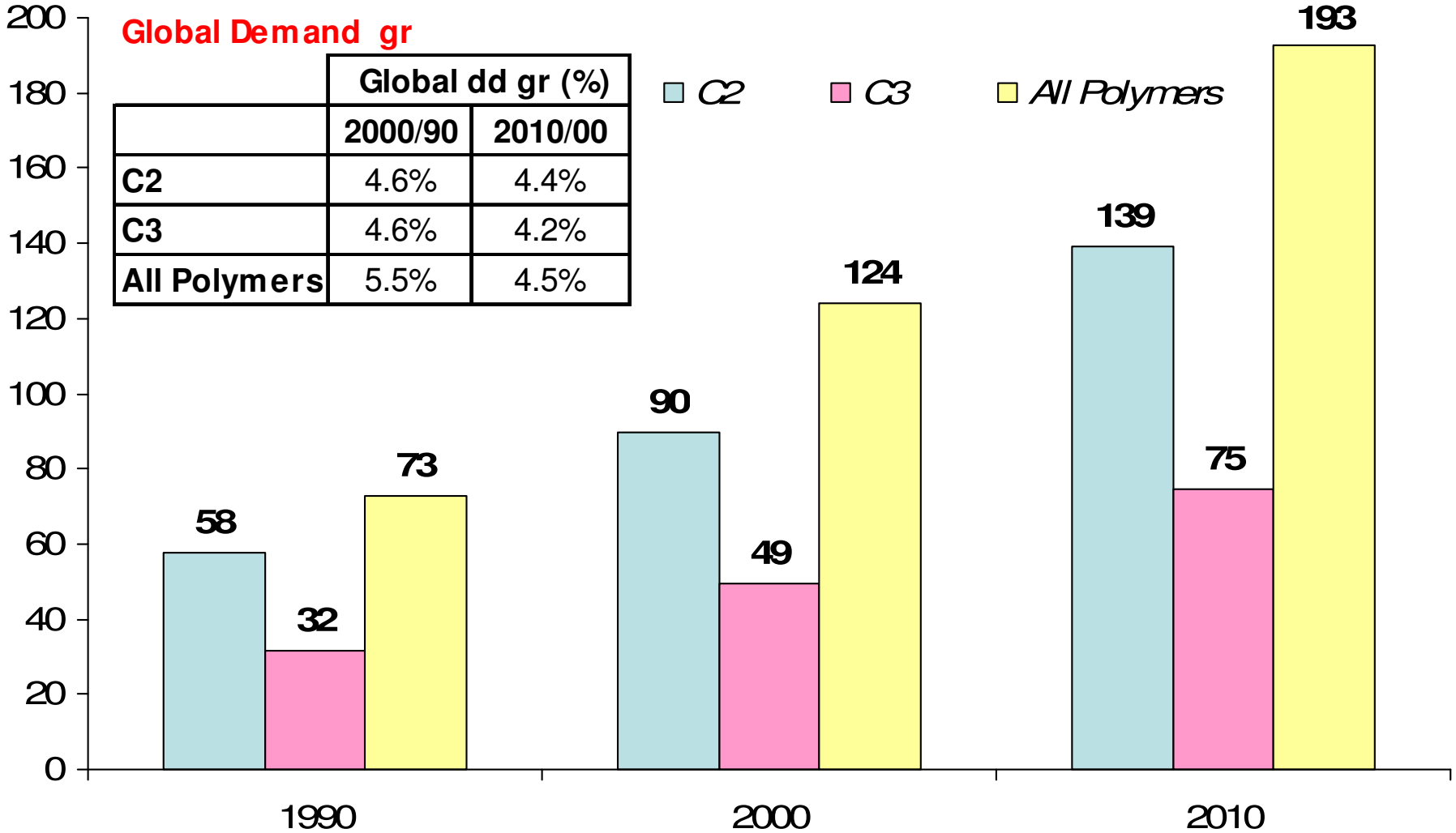


Total Size - 3 tr. USD (2010)
~ 5.3% of global GDP
Growing @ 1.5 times GDP

Petrochemicals dominate with share ~40%

Source: Chem Systems/ BAG

GLOBAL GROWTH IN DEMAND

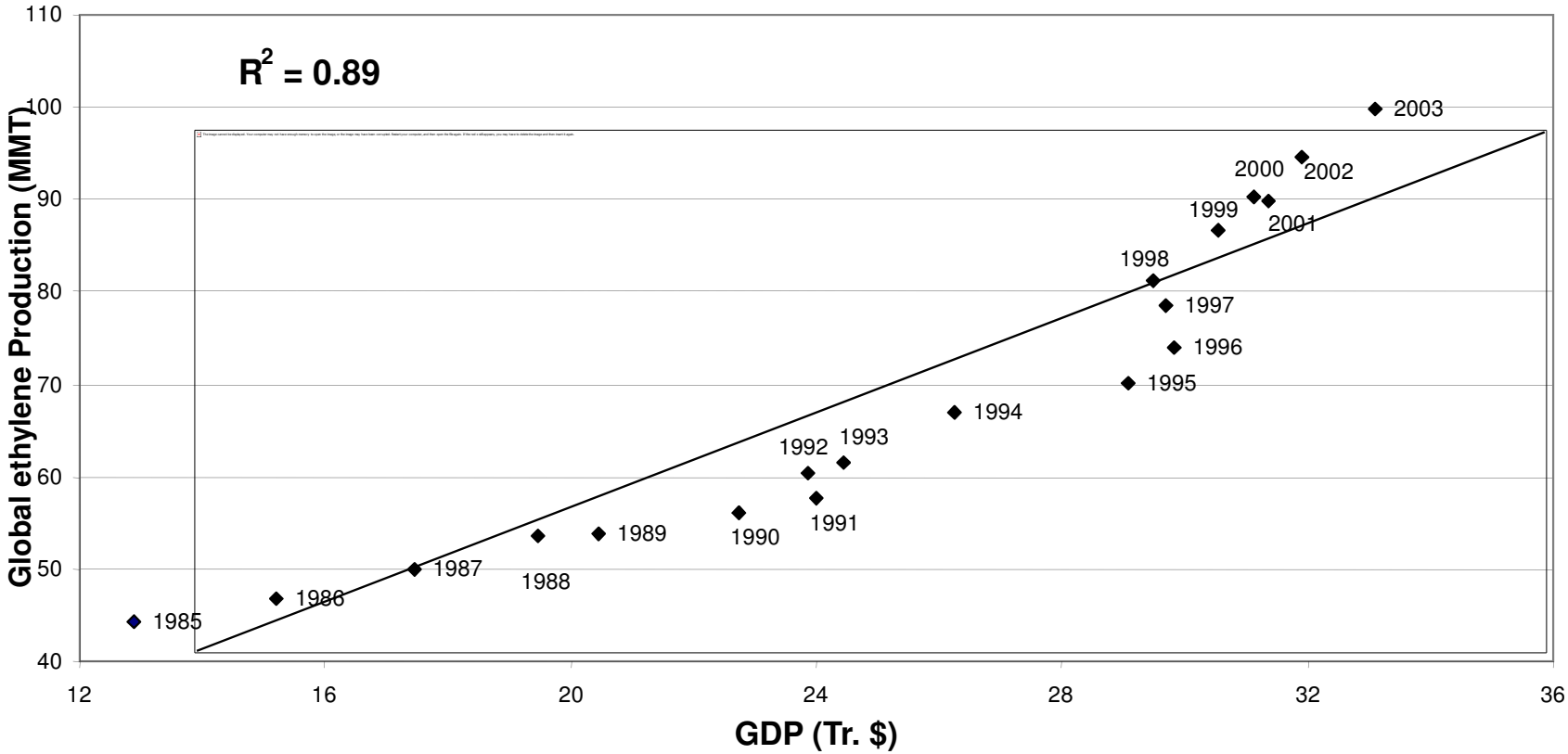


	Global dd gr (%)	
	2000/90	2010/00
C2	4.6%	4.4%
C3	4.6%	4.2%
All Polymers	5.5%	4.5%

Source: Chem Systems,Technon,CMAI, figs for PVC for 2010 pertain to 2006 & that for PS to 2008

. . . Polymer demand to touch 193 mmt by 2010

ETHYLENE CONSUMPTION & GDP



A Strong Correlation over 2 decades

FORCES OF CHANGE IN THE CHEMICAL INDUSTRY

- **Unprecedented rise in fuel and raw material costs**
- **High cost of new product introductions; difficulties in identifying new growth platforms**
- **Increasing regulatory (environment, health and safety) frameworks**
- **Faster technology diffusion / commoditization of products leading to quicker price / margin erosion**
- **Supply chain is taxed by breadth of markets, products and geography**
- **Increased global segmentation in terms of technology providers , low cost producers and large domestic markets**

THE DAWN OF THE INDIAN CHEMICAL INDUSTRY

P.C.Ray (1861-1944)

- India's first chemist and entrepreneur
- Ph D from Edinburgh (1882-87) ; the first Indian scientist to practice chemistry
- A staunch nationalist who understood the power of manufacturing for India's economy
- Established Bengal Chemicals and Pharmaceuticals Works Ltd in 1901 with a capital of Rs 700, drawn from his personal wealth
- Today , Bengal Chemicals and Pharmaceuticals Ltd is a public sector company with a turn over of over 100 crores, having survived many upheavals
- Author of over 100 original scientific papers and a book titled, *A History of Hindu Chemistry (1902)*

Acharya Ray has become many in his pupils and made his heart alive in the hearts of many; and this would not have been possible had he not unreservedly made a gift of himself : Tagore

ACHARYA P.C. RAY AND THE INDIAN CHEMICAL INDUSTRY

- **His discovery of mercurous nitrite (1895) received wide recognition world wide**

- **Great institution builder; created an internationally recognized school of chemistry at Presidency College**

- **Explored the problem of adulteration of ghee and mustard oil, produced sodium phosphate from locally available resources, and attempted to place traditional Indian medicine on a sound scientific footing**

- **A contemporary of J.C.Bose, yet they were like chalk and cheese. Ray was a pedestrian down to earth chemist whereas Bose was an aristocrat, who abhorred creation of wealth through science and sought repeated western approval of his science**

Acharya Ray remarked (1940) that he set up BCPWL to wipe out the idea that the Bengalees were good for nothing in business affairs !

RAJMITRA B.D. AMIN AND THE INDIAN PHARMACEUTICAL INDUSTRY

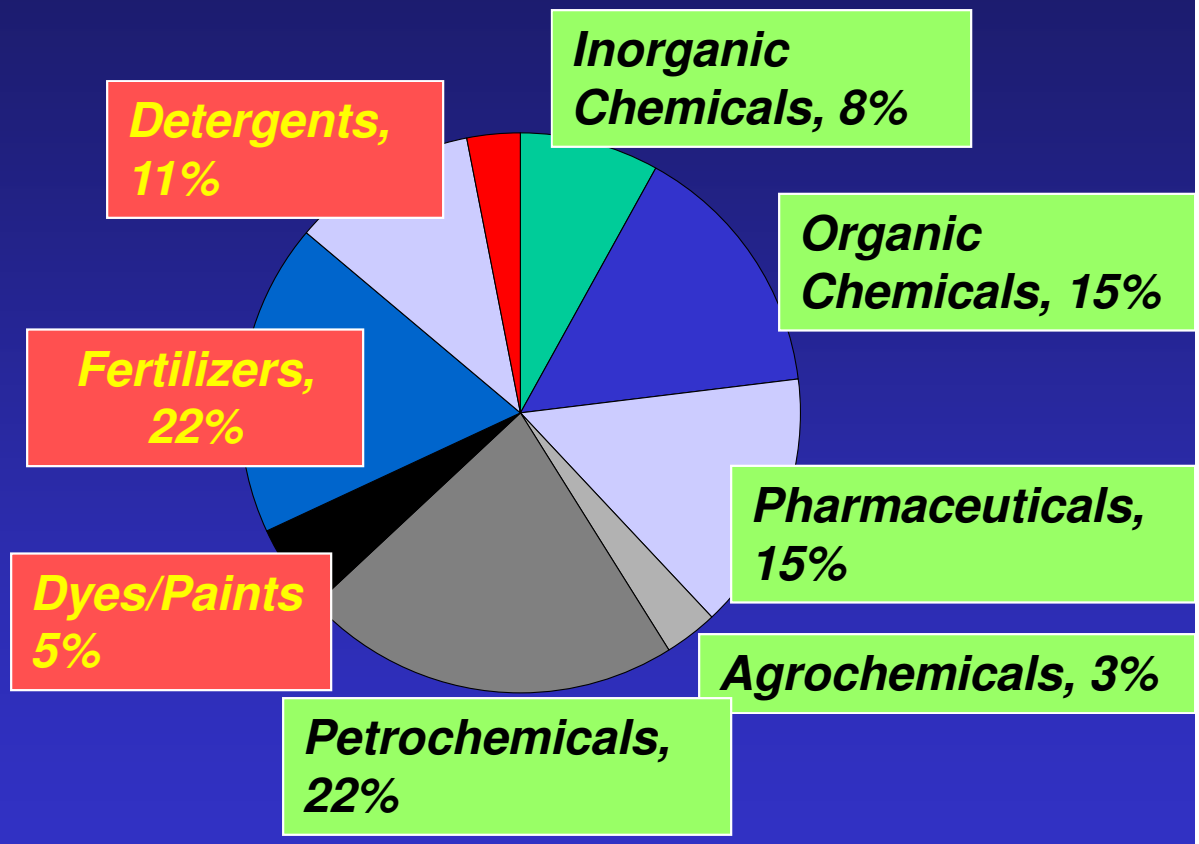
- Founder of Alembic, a hundred year old institution
- Co-founder , with P.C Ray of ICC , 1938
- A great benefactor to the city of Vadodara
- A visionary who created the chemical and pharmaceutical industry in India with a goal of providing employment to educated young men and direct their energy towards scientific research
- Pioneered the manufacture of Penicillin using indigenous technology

EVOLUTION OF INDIAN CHEMICAL INDUSTRY

1900 - 1930	***The beginning; Pharmaceutical and house hold chemical industry was the early pioneer***
1930-1960	***Coal and alcohol based fine chemicals; Chlorine and Chlorinated Chemicals ; Dyestuffs***
1960 -1990	***Agrochemicals, Active Pharmaceutical Intermediates, Polymers and Petrochemicals, Commodity Chemicals***
1990-	***Biopharmaceuticals, New Materials***

INDIAN CHEMICAL INDUSTRY

- Chemical industry in India contributes to 3 % of its GDP and 14 % of its exports
- Revenues : US $ 55 billion in 2007-08 and CAGR of 11 % (2002-07)
- Projected to grow to US$ 75 billion by 2011
- Indian Chemical industry 12 th largest in the world and 3 rd largest in Asia



Commodity chemical industry is technologically mature; all innovations are incremental in nature

POLYMER DEMAND OUTLOOK

Country	2000 (MMT)		Country	2012 (MMT)		*2012 / 2000*
USA	27.3		USA	38.9		*3.6%*
China	16.6		China	38.8		*8.1%*
Japan	9.1		**India**	**12.5**		*14.1%*
Germany	6.4		Japan	9.9		*2.3%*
S. Korea	4.7		Germany	9.4		*3.9%*
Italy	4.7		S. Korea	6.8		*4.8%*
France	4.1		Italy	6.8		*3.8%*
UK	3.5		Brazil	6.7		*7.0%*
Brazil	3.4		CIS	6.2		*9.1%*
India	**3.3**		France	6.1		*4.1%*
Taiwan	3.3		UK	5.2		*4.0%*

Source: CPMA

Potential to be the 3rd, largest market by 2012

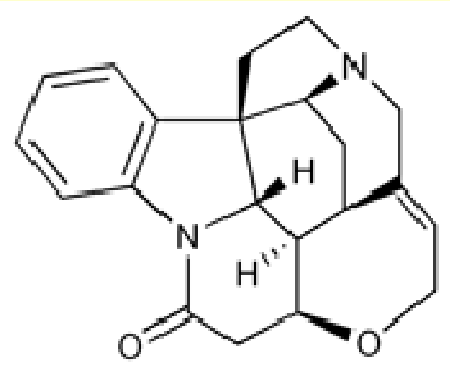
THE INDIAN CHEMICAL INDUSTRY

- Fragmented and low capacity
- Low capital/technology intensity
- Relative unfamiliarity with catalytic processes involving reactor types other than batch stirred tank reactors
- Threat of horizontal transfer of technology
- Limited in house technology development strength
- Inadequate attention towards quality and consistency
- Lack of deep pockets to sustain business cycles
- Poor product marketing skills, especially in global markets
- Easy targets for acquisitions by global companies

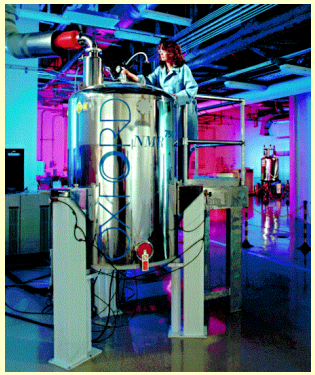
INDIAN CHEMICAL INDUSTRY: CONCERNS

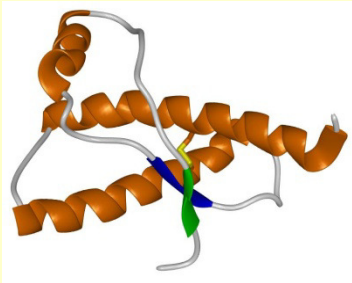
- **Branded as low cost supplier/outsourcing/contract manufacturing entity for fine and specialty chemicals**
- **Innovation deficit; few new product offerings based on proprietary knowledge / IP. Low R&D intensity with the exception of drugs and pharmaceutical sector**
- **Conventional engineering practices**
- **Poor application development skills, especially for specialties**
- **Talent deficit; chemistry and chemical engineering education no longer considered fashionable; serious issues of talent retention/flight**

CHEMICAL SCIENCE AND INDUSTRY : GREAT SUCCESSES

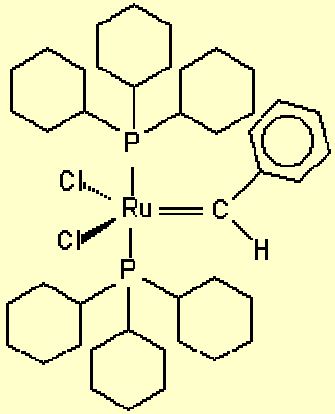


strychnine

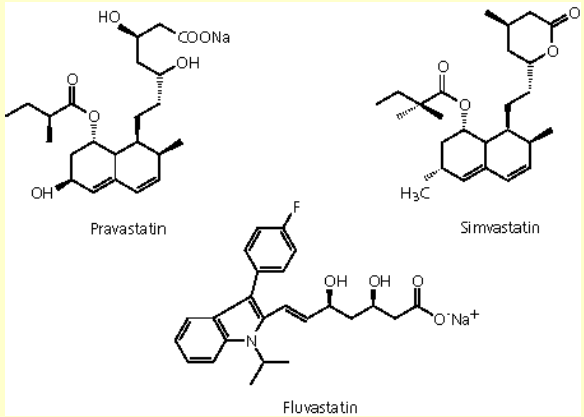




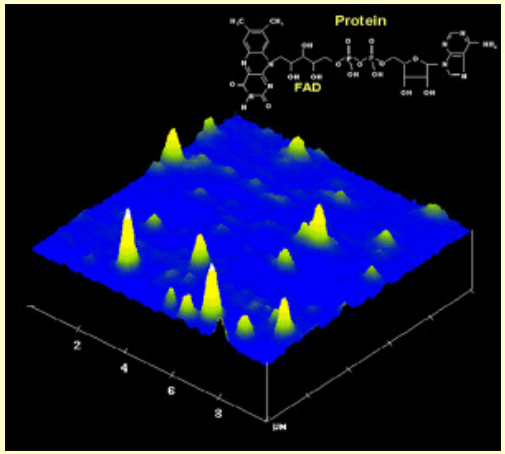
protein NMR



ROMP catalyst



statins



single-molecule spectroscopy

CH_y, NO_x $\longrightarrow$ $CO_2 + N_2$

CHEMISTRY'S HOARY PAST

- **Aspirin, Indigo, ammonia, Antibiotics, Lipitor, Nylon, Teflon, Polyethylene, rayon, synthetic rubber, fuels**

- **Nylon stockings, Hula Hoop, Packaged Foods, Bullet Proof Vests**

Is Chemistry today capable of capturing the public imagination ?

Can you recollect the last major impact making discovery in chemistry ?

C 60 and Graphene ?

Element carbon was once the monopoly of the chemist; it is no more !

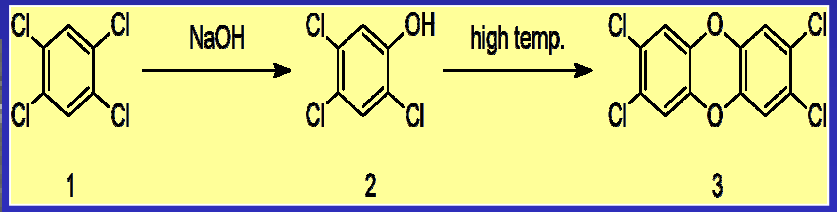
PUBLIC AND GOVERNMENT PERCEPTION OF CHEMISTRY

- **Chemistry is invisible to the public**
- **Chemistry is considered "mature" economically**
- **Chemistry is associated with pollution/global warming**
- **"Good" and "Bad" are not balanced in perceptions of chemistry**

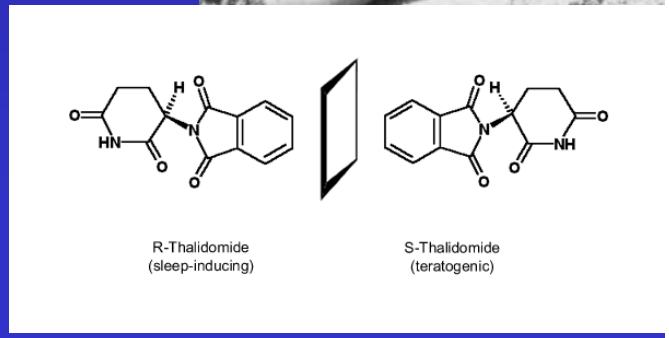
THE UGLY SIDE OF CHEMISTRY

A child victim of the Bhopal gas disaster.

- Minamata
- Love Canal
- Seveso
- Bhopal
- Thalidamide
- DDT



$$H_3C-Hg^+ X^-$$



Bill Bryson, "A Short History of Nearly Everything", Random House, 2003 p. 137:

When the wife of the great Austrian physicist Wolfgang Pauli left him for a chemist, he was staggered with disbelief. "Had she taken a bullfighter I would have understood," he remarked in wonder to a friend. "But a *chemist*. . ."

CHEMISTRY AT CROSSROADS

- Chemistry is at the end of one wave of development and struggling to begin another; perceptible shift in the centre of gravity of the discipline
- There are still many important opportunities in both fundamental and applied science
- Chemistry offers fewer puzzles to solve; What confronts are number of problems
- Longer term curiosity driven research is more important than in the past, but harder to justify

In the future, functions will be more important than molecules. Molecules are no longer enough (they never really were)

CHEMISTRY : CENTRAL SCIENCE

- **Central to the sustenance of civilization on earth**
- **Key to management of resources on this planet**
- **Key to understanding the mysteries of life**

Chemistry is the science of the real world; the world today is searching for innovative solutions for many of its vexing problems. Chemistry must become part of this solution and dispel the image that it is the cause of the problem

CHEMICAL SCIENCES

CHEMISTRY OF MATERIALS

- Natural materials
- Synthetic materials
- Blends, hybrids and Composites
- Nanomaterials

CHEMISTRY OF LIFE

- Origin of life
- Understanding biological processes
- Understanding diseases/ search for cure
- Deeper insight into consciousness and human aging

CHEMISTRY OF ENERGY

- Newer forms of energy and their storage
- Interconversion of energy
- Efficient use of energy

CHEMISTRY OF ENVIRONMENT

- Global climatic changes
- Stratosphere ozone depletion
- Conservation of biosphere
- Quality of air / water
- Adverse consequence of excessive consumption on environment

IS CHEMISTRY SCIENTIFICALLY MATURE? CAN WE...

… *really* understand molecules / reactions?

… engineer function?

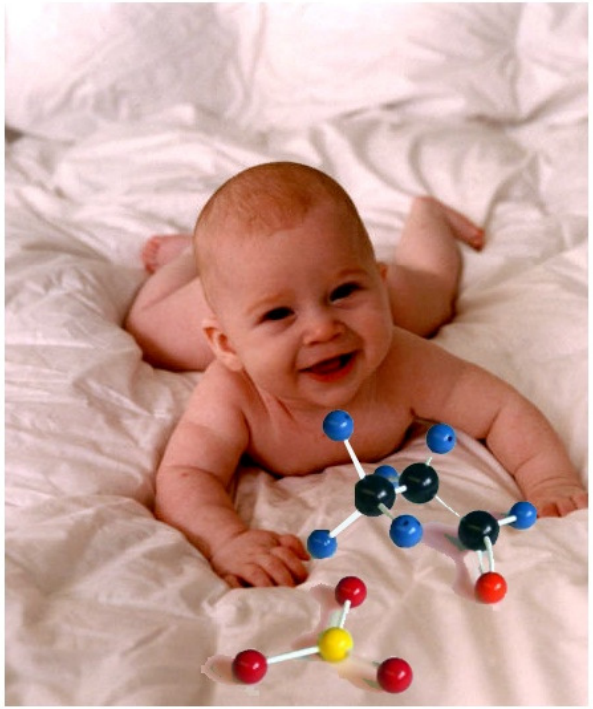
… design drugs?

… make materials by design?

… rationalize the origin of life?

… understand life / thought?

… build a cell?



Chemistry is still in its infancy!

FUTURE OF CHEMISTRY

- **Systems, not molecules**
- **Functions, not molecular structure**
- **Problems, not puzzles**

No longer "What is it?" but "What does it do?
Chemistry must move beyond molecules and learn to solve the entire problem. Only then the flow of ideas, problems and solutions between chemistry and
society will become more animate and visible

IS CHEMISTRY ON THE THRESHOLD OF A NEW REVOLUTION ?

- **Responsibility for solving some of the most interesting problems in science and technology**
- **Exceptionally wide range of tools**
- **Chemistry offers a balance of skills; synthetic, computational, ability to handle complexity**
- **Existing body of knowledge insufficient**

CHALLENGE OR CRISIS OF CHEMISTRY

- **Inadequacies of theory ; eg: Complex and coupled networks, protein- ligand binding, catalysis, non-equilibrium systems, non-covalent interactions**

- **Peer Review Systems: Encourages safe science at the cost of risky science**

- **Demise of industrial R&D Centres : No longer great source of innovation and discovery as well as providers of jobs (DuPont Central R&D, GE Corporate Research, BASF etc)**

- **Teaching Pedagogy , departmental structure and textbooks**

- **Academic Social Systems : Diversity is rejected, conformity is rewarded**

“ It is hard to understand the tightly compartmentalized minds of the chemists of that day. An extreme example at the chemistry library at Cambridge University, an imaginary line divided the room into two parts, one for physical chemists and the one for organic. The library had two sets of the Journal of the Chemical Society, since an organic chemist was not supposed to cross the imaginary line to use the volumes on the physical side of the library, and vice versa “

Frank Westheimer
J. Biological Chemistry, 278,11729 (2003)

BACK TO BASICS

- **Emphasize function**
- **Take control of the systems**
- **Reengineer the transition from university to industry; generate a "new chemical industry"**
- **Reinvent teaching / objectives**
- **Consider the balance between single investigator and collaborative research**
- **Modify/supplement peer review**
- **Focus resources on change**

STRUCTURE OF CHEMICAL SCIENCE

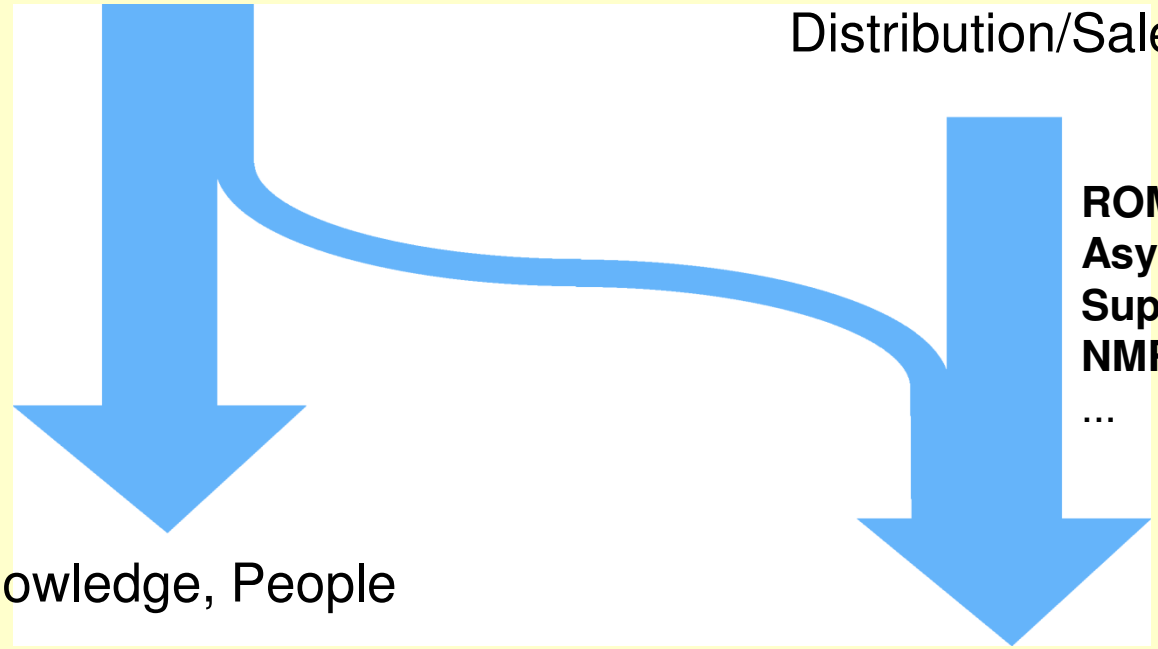
Money

University **Government** Laws, Regulation

Industry

("Liebig" Model:
Professor/Student/Problem/Thesis)

(Development, Manufacturing,
Distribution/Sales)

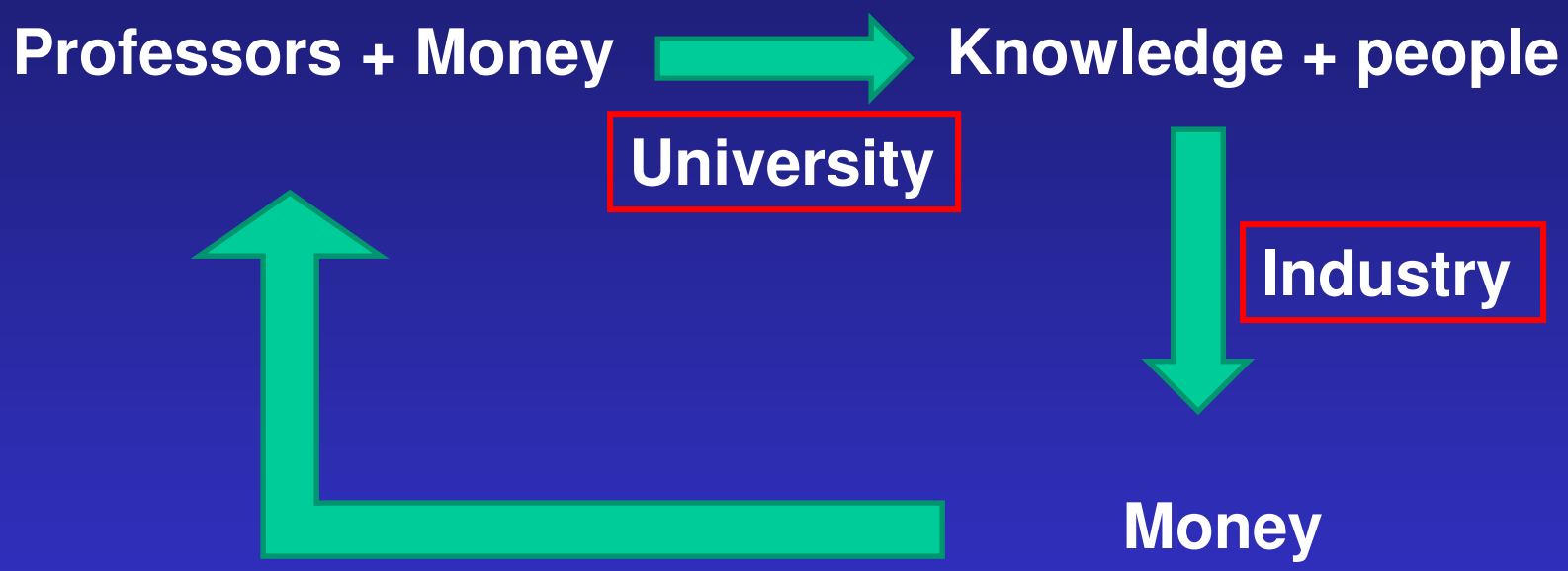


ROMP
Asymmetric catalysis
Superacids
NMR
...

Knowledge, People

Products/Solutions for Problems

LIEBIG'S MODEL



EXAMINE THE MODELS

- **Is the "Liebig Model" obsolete?**

  Systems! Collaborations
- **Is the current model of the university ("a collection of semi-isolated experts") still workable?**
- **Is "molecular synthesis/molecular structure" still supreme ?**
- **Can curiosity-driven research survive?**
- **Chemistry as an art-form.**

THE RESEARCH UNIVERSITY: IS THERE A CHANGE IN THE SOCIAL CONTRACT?

From

Do fundamental research

(and someone will solve social problems)

To

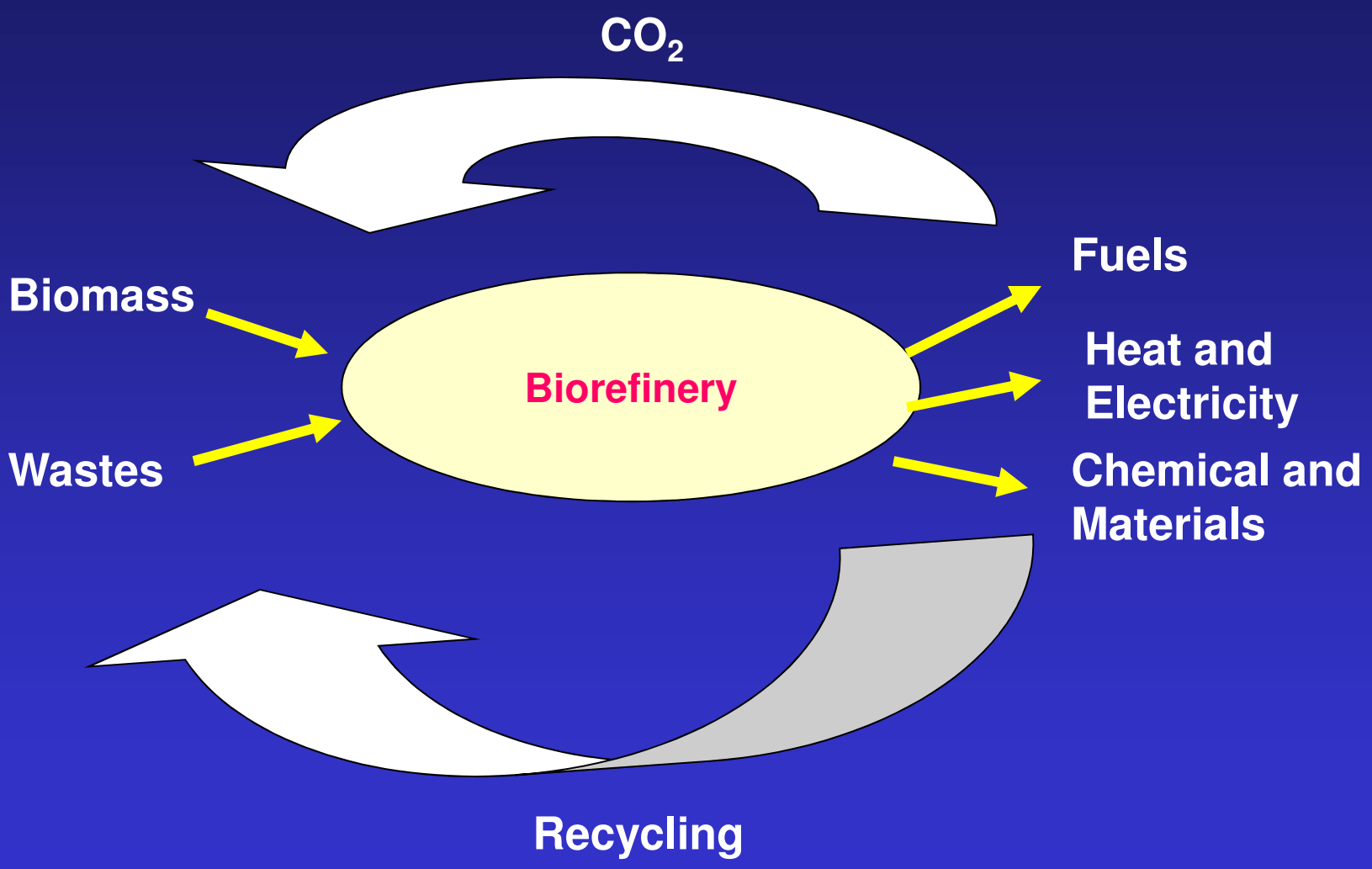
Solve societal problems

(and, by the way, if you want to do some fundamental research, that's OK

CHEMICAL INDUSTRY : 2020 TECHNOLOGY VISION

- Reduce feed stocks losses to waste / byproducts by 90%
- Reduce energy intensity of processes by 30%
- Reduce emissions including CO_2 and effluents by 30%; move towards zero discharge goals
- Increase use of renewable resources as building block for chemicals ; combine judiciously chemical and biological processes to achieve sustainability goals
- Small/ modular chemical plant designs for enhanced safety and reduced quantities of inventory storage
- Increase the conversion of stoichiometric processes to catalytic processes; batch to continuous processes
- Understand better the impact of chemicals and materials on environment, safety and human health

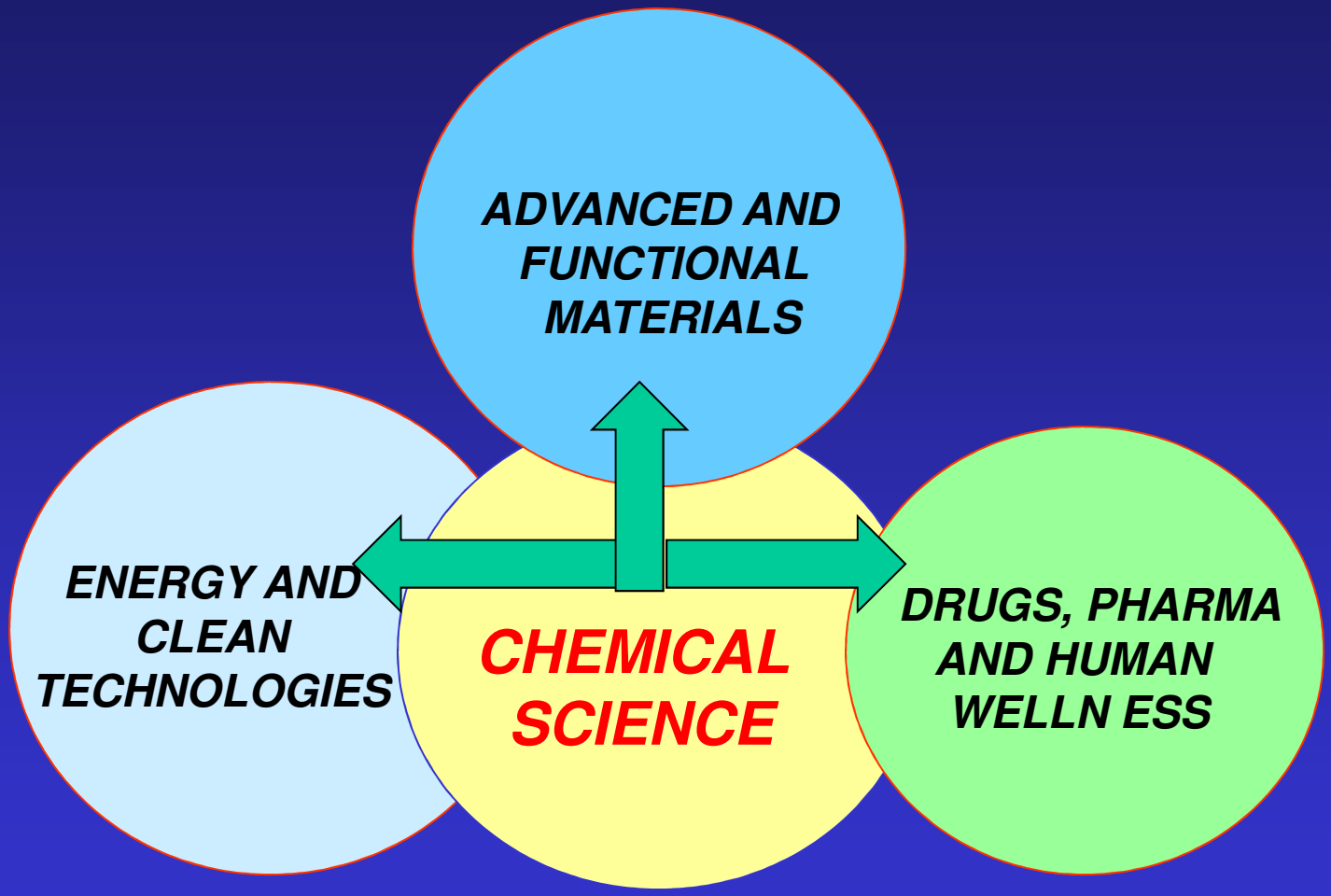
FROM PETROLEUM TO BIOREFINERIES



Chemistry has not lost its identity; it has instead gained important footholds within the domains of other sciences – albeit rarely at the initiative of chemists

D. Seebach

CHEMICALS SCIENCE : AT THE CORE OF MANY EMERGING TECHNOLOGIES



I believe chemistry can be everywhere, if chemistry so chooses or that it can contract into an invisible part of the infrastructure of society

G. M. Whitesides

THANK YOU