TOWARDS A SUSTAINABLE WORLD OF MATERIALS: ISSUES AND OPTIONS

Dr. S. Sivaram,
National Chemical Laboratory,
Pune-411 008, INDIA

Tel : 0091 20 2590 2600
Fax : 0091 20 2590 2601
Email : s.sivaram@ncl.res.in
Visit us at : http://www.ncl-india.org

Climate Change India 2008
Pune

April 23, 2008

FOUNDATION OF HUMAN CIVILIZATION

- Energy
- Materials

HUMAN IMPACT ON PLANET EARTH

- Population
- Consumption
- Technology

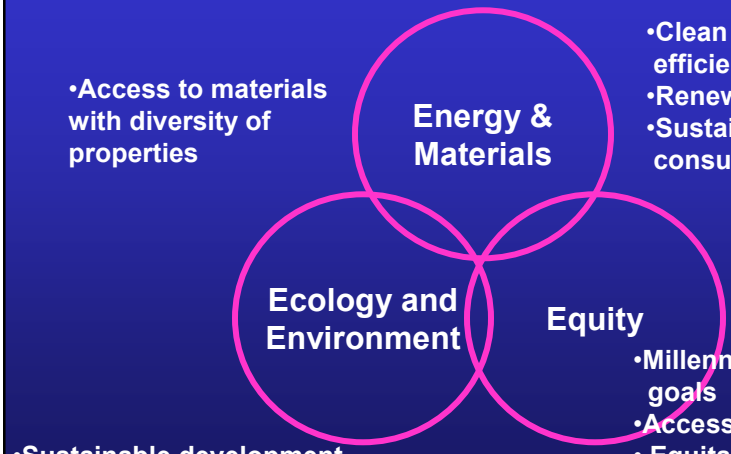
SUSTAINABLE DEVELOPMENT

"Development that meet the needs of the present without compromising the ability of future generations to meet their own needs"

In other words, each generation must bequeath to its successor at least as large a productive base it inherited from its predecessor

Brundtland Report
World Commission on Environment and Development

3 E PRINCIPLE



•Access to materials with diversity of properties

•Clean energy / energy efficiency
•Renewable energy
•Sustainable consumption

•Sustainable development
•Materials from biomass/Degradable materials
•Decarbonization

•Millennium development goals
•Access and entitlement
• Equitable distribution
•Climbing the economic ladder

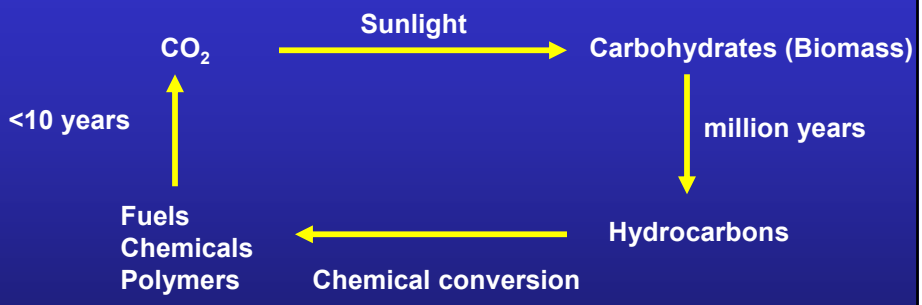
THE ISSUE OF CLIMATE CHANGE

- Major agenda for the globe

  - Clinton Global Initiative
  - The Stern Review
  - UN Inter Government Panel on Climate Change
  - The World Sustainability Report

Climate Change issues represent both a challenge and an opportunity

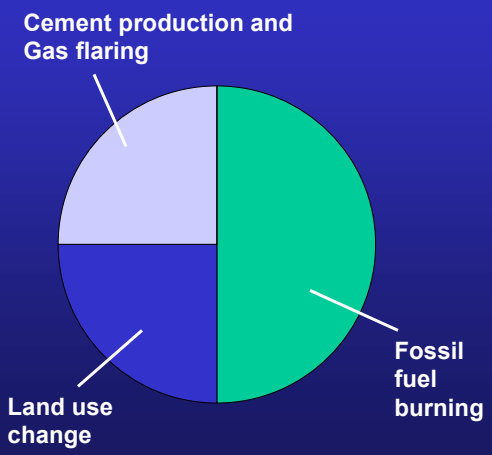
GLOBAL CARBON CYCLES : THE KINETIC CONUNDRUM



We release more CO_2 than we sequester as fossil resource!

ANTHROPOGENIC CO_2 EMISSIONS

Year	Accumulated CO_2 emissions petagrams
1850	50
1900	200
1950	250
2000	300



FROM SUSTAINABLE MANUFACTURING TO SUSTAINABLE CONSUMPTION

- Industry and civil society must not look at each other as adversaries , but partners
- Greater efficiency in the use of energy and materials key to reducing green house gas emissions
- Resource conservation, recycle and reuse must become inseparable part of our daily lives
- Focus must shift from only looking at energy use during manufacturing or production to the energy use during the entire lifecycle of the product, from cradle to grave
- Judicious choice of materials to meet the needs of mankind
- Avoid simplistic or expeditious solutions which do not meet long term sustainability metrics

There are enough resources in this world for man's needs , not greed
- Mahatma Gandhi

THE PRINCIPLES OF RESOURCE SELECTION

- Abundance of "cheap" resources will lead to its wasteful use (r-selection)
- Scarcity of resources will lead to more sustainable use (k-selection)
- Post industrial communities represent r-selection; but it is necessary for our survival to move to k-selection
- The easiest way to drive this process is to make resources artificially scarce, before they disappear
- This, however, flies in the face of all that we 'know' about how economics works : 'Cheap' resources are better

THE WORLD OF MATERIALS

- Since the advent of humans on this planet, the growth of civilization has been dependent on materials
- The ages of human-kind have been designated based on man's mastery over materials
  - Stone age
  - Bronze and iron age
  - Steel age
  - Plastics age
  - Silicon Age (?)

Pause and think

Why were most of the ages of man chronicled based on his ability to use materials?

NATURE'S APPROACH TO SUSTAINABLE MATERIALS

- Nature designs material with great care and attention to details
  - Economy in the use of raw materials
  - Minimum use of energy
  - Easy to recycle under ambient conditions

Nature achieves this sophistication through highly organized fabrication methods and hierarchies of structural features

MATERIAL SYNTHESIS : NATURE'S PRINCIPLES

- Optimal use of energy and raw materials
- Minimal energy consumption – most synthesis occurs at <45^{o}C
- Molecular control leading to flawless materials: Self healing and self-correcting principles
- Use of compatible chemistries
  - Ceramics : $CaCO_3$, SiO_2
  - Non-ceramics : Proteins, polysaccharides
  - Water : Plasticizer
  - Partitioning and separations : Lipid (Bilayer membranes)
  - Hydrophobic interaction : Orientation
  - Liquid crystallinity : Processing of materials

Will the twenty first century be the age of bio-inspired organic materials

MATERIAL SYNTHESIS : NATURE'S PRINCIPLES

- Efficient synthesis, if you are prepared to wait long enough
  - Fastest rate of bone growth : 1 μm/day
  - Growth of egg shells : 5 g/day
- Recycling
  - Animals/plant continuously recycle/ repair their constituent materials

Will the twenty first century be the age of bio-inspired materials ?

POLYMER MATERIALS

- Depend on fossil fuels, a finite natural resource
- Persist in the environment, non degradable

Can the materials needs of man be based on the concept of sustainability of both resources and environment?

POLYMER MATERIALS : DIVERSE RANGE OF APPLICATIONS

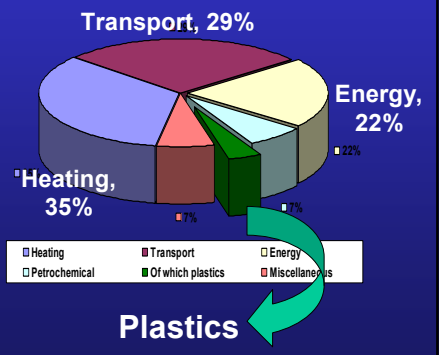
DILEMMA IN MATERIAL CHOICES

- Depletion of fossil resources
- Emission of green house gases
- Land use
- Solid waste disposal
- Profitability to enterprise and create wealth to shareholders

Decisions a society will make depends on how one puts relative values on these choices

MATERIALS AND ENERGY

- Fossil fuels are the source of both energy and polymeric materials, such as plastics, rubbers, fibers
- However, 96 % of the world resources of fossil fuels are burnt as fuels for transportation or home use
- Only 4 % are converted to materials (about 170 million tons) and consumed by all mankind
- Polymer materials , though, derived from non renewable fossil fuels are more sustainable in terms of energy, water, environment and GHG than, say, steel, aluminum, wood, paper or glass based on a life cycle analysis



PAPER vs PLASTIC BAGS : A CASE STUDY

- Plastic bags generates 60 % less GHG emissions than un-composted paper bags. Plastic bags generate ~ 3100 tons of CO_2 equivalent per 100 million bags while un-composted paper bags generate 7600 tons of CO_2 equivalent
- Plastic bags consume less than 4 % of the water needed to make paper bags. It takes 5,530 cubic meters of water to produce 100 million plastic bags, versus, 150, 000 cubic meters of water for an equivalent number of paper bags
- Recycling plastics is far more energy efficient than recycling paper

Dangers inherent in simplistic decisions based on limited data; the law of unintended consequences

FOOD versus FUEL

April 7, 2008

• Using land to grow crops for fuels lead to destruction of forests, wetlands and grasslands that store enormous amount of carbon

Corn diverted to fuel ethanol in USA

↓

Soyabean growers switch to corn in USA

↓

Farmers in Brazil plant soyabean in land previously used as cattle pasture lands

↓

Leads to clearing of forest lands in Amazon rain forest

Law of unintended consequences !

HOW GREEN ARE GREEN FUELS ?

Production stage	Gasoline	Ethanol	Biomass Ethanol*
Make Feedstock	11	72	29
Refine Fuel	47	121	26
Vehicle operation	220	215	215
Carbon uptake credits	0	- 188	- 188
Land use change	0	316	336
Total GHG	**278**	**536**	**418**

** If biomass is grown on land which otherwise will be used for growing corn*

Climate Change Pune 230408

PLASTICS AND THE ENVIRONMENT

Environmental Burden	Polyethylene	Kraft Paper
Energy (GJ) for manufacture	29	67
Air pollution (kg.)		
SO_2	9.9	28.1
NO_x	6.8	10.8
CH_x	3.8	1.5
CO	1	6.4
Dust	0.5	3.8
Waste water burden (kg.)		
COD	0.5	107.8
BOD	0.02	43.1

Compared to paper, plastic grocery bags :

- Consume 50% less energy than paper.
- Generate 8% less solid waste.
- Produce 30% lower atmospheric emissions.
- Release up to 94% fewer waterborne wastes.

Source : Dr. William Rathje, University of Arizona Garbage Project, USA and German federal office

Climate Change Pune 230408

PLASTICS IN TRANSPORTATION

- Plastics contribute to 14 % by weight of a mid sized car, and will increase to 25 % by 2020
- This corresponds to just 2500 $ worth of plastics per car !
- Contributes to less weight, higher fuel efficiency , lesser emissions per km traveled and recyclability
- This translates into a saving of 107 million GJ/ year in fuels and reduction of 10 million tons of CO_2 per year in the EU alone
- 50 % of the new Boeing 787 Dreamliner aircraft structure consist of composite materials, making it 20% lighter and consuming 20 % less fuel ; An airbus A 380 consumes less than 3 L of fuel per 100 km per passenger

PLASTIC CONSERVE RESOURCES

Energy requirements for the production of material used in packaging

(KWh/Kg)

Material	Energy requirement
Aluminium	74.1
Steel	13.9
Glass	7.9
Paper	7.1
Plastic	3.1

Packaging of 500 g of coffee

Packaging Material	Weight (gms)
Glass	500
Tin	130
Plastic	12

REPLACING WOOD WITH PLASTICS : DOES IT MAKE SENSE ?

	Forest Cover
• India	20 %
• Developing countries	31%
• World	33%
• Developed countries	36%

Deforestation in last decade ~ 2 million Hectares

6000 MT of plastic furniture saves 140,000 cubic meters of wood or 32,000 hectares of forest !

HOW "GREEN" ARE GREEN PLASTICS?

- Biological breakdown of plastics releases CO_2 and CH_4 - both heat trapping green house gas.
- Fossil fuels are still needed to convert naturally occurring materials to plastics; What is the energy efficiency of this conversion?

Biodegradability has a hidden cost

HOW "GREEN" ARE GREEN PLASTICS : ENERGY REQUIREMENT

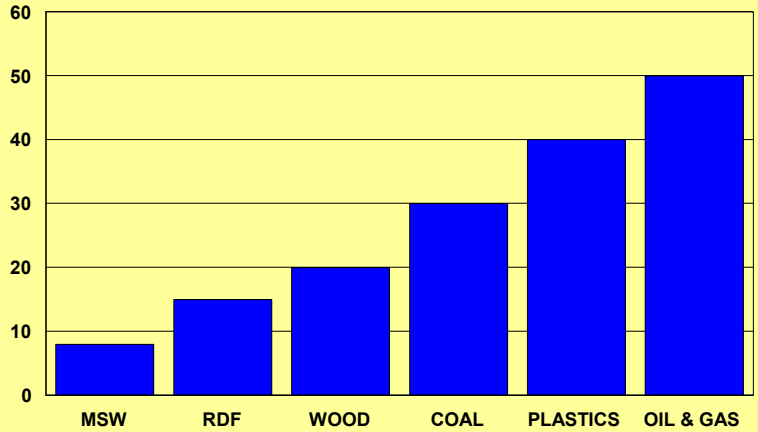
Polymer	Energy, mJ /kg polymer
• PHA (in vivo)	90
• PHA (Microbial fermentation)	81
• PLA	56
• PE	29 + 52*
• PET	37 + 39*
• Nylon	93 + 49*

*Energy required for production + energy inherent in the raw material

Biodegradable polymers need more burning of fossil fuel to generate energy leading to increased emissions of green house gases

Climate Change Pune 230408

PLASTICS ARE AN USEFUL SOURCE OF ENERGY (ENERGY VALUE GJ/TON)



Climate Change Pune 230408

PLASTIC LITTER : THE UGLY SIGHT

- **In spite of low per capita plastic consumption (2.4 kg vs 18 kg global average) and lower content of plastics in solid wastes (3% vs 7% world average), plastics waste in the environment is attracting public and Government's attention**
- **Littering habit, poor civic sense, inadequate mechanism for garbage collection/disposal by civic authorities main cause for the adverse impact of waste plastics in the environment**
- **Heightened social and political attention to the problem has led to increased public debate in the past two years. A more serious discussion of alternatives, legislative interventions as well as educating the consumer are tangible outcomes of this awareness.**

PLASTIC WASTE : THE INDIAN DIMENSION

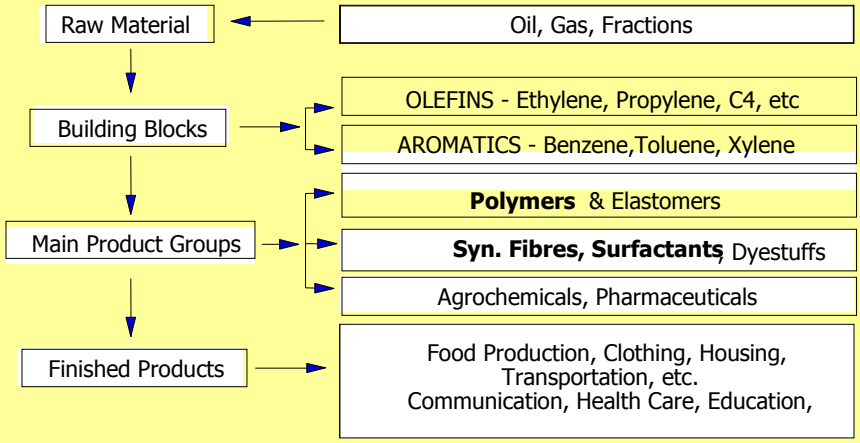
	World	India
. Per capita consumption (kg)	19	2.7
. Recycling	~20%	~60%*
. Plastics in solid waste stream	~7%	~0.5%

* Land filling 3%, Incineration 8%

RECYCLED PLASTICS ACCOUNT FOR 45% OFTHE VIRGIN POLYMER CONSUMPTION

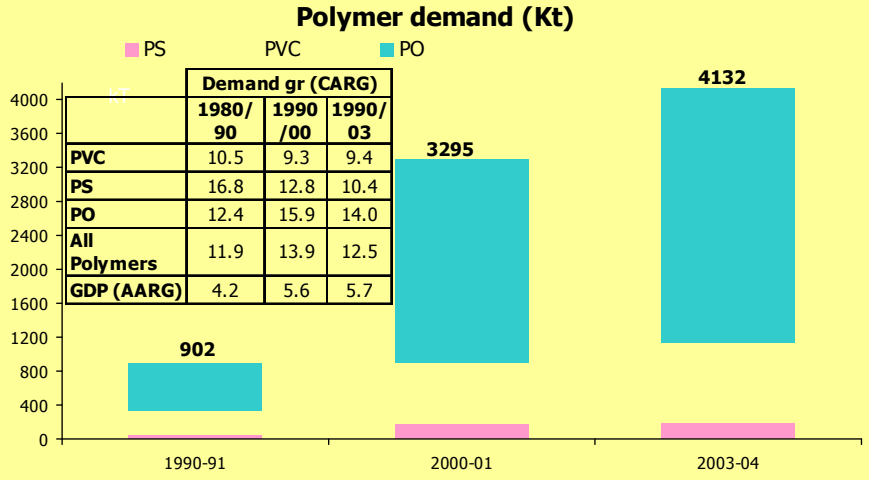
	1999-2000		
KT	Virgin	Recycled	% Share
HDPE	539	319	59
PP	419	250	60
PVC	567	117	21
LD / LLD / HM	403	190	47
Others	112	39	35
Total	2040	915	45

Structure of the Petrochemical Industry



Petrochemicals servicing the entire national economy

Polymer Consumption - India

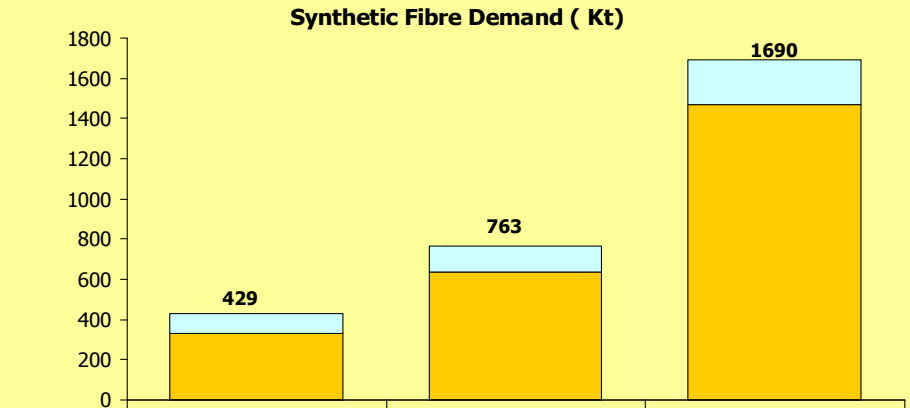


	Demand gr (CARG)		
	1980/90	1990/00	1990/03
PVC	10.5	9.3	9.4
PS	16.8	12.8	10.4
PO	12.4	15.9	14.0
All Polymers	11.9	13.9	12.5
GDP (AARG)	4.2	5.6	5.7

. . . growing from 900 Kt in 1990 to 4.1 mmt in 2003-04

Source: Industry

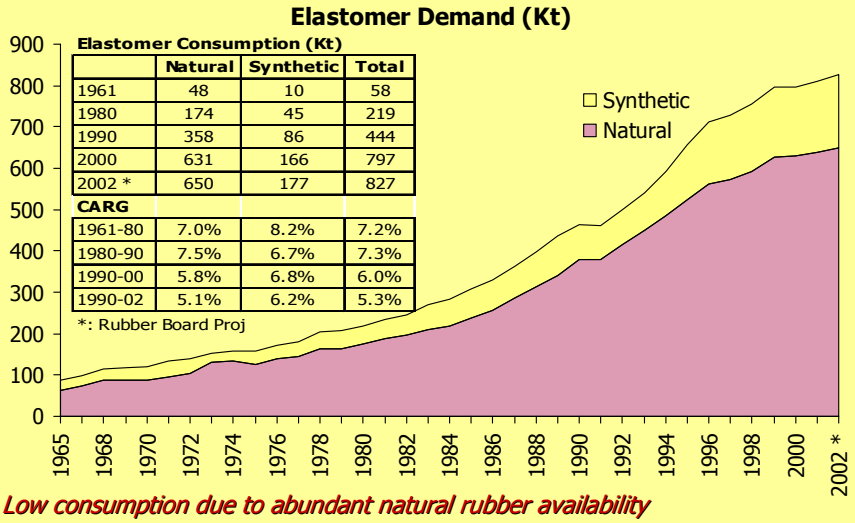
Polyesters lead among fibers



	1990-91	1995-96	2002-03 *
Others	96	129	220
Polyesters	333	634	1470

Source: Industry ,*: estimates

Synthetic Rubber - India



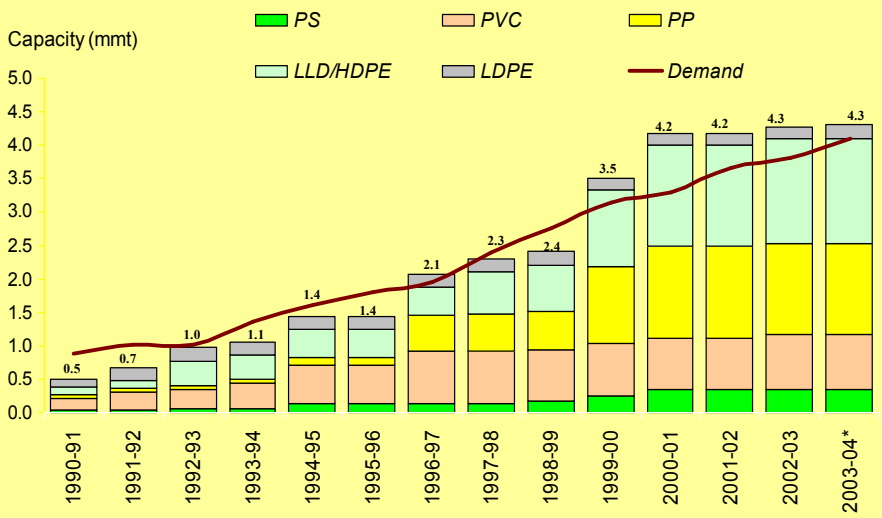
Elastomer Consumption (Kt)

	Natural	Synthetic	Total
1961	48	10	58
1980	174	45	219
1990	358	86	444
2000	631	166	797
2002 *	650	177	827
CARG			
1961-80	7.0%	8.2%	7.2%
1980-90	7.5%	6.7%	7.3%
1990-00	5.8%	6.8%	6.0%
1990-02	5.1%	6.2%	5.3%

*: Rubber Board Proj

Low consumption due to abundant natural rubber availability

Indian Polymer Industry:
Capacity Built Up



Capacity growth matching consistent high demand growth

Polymer Industry - *2010*

India Vision 2010

Country	2000 (MMT)	Country	2010 (MMT)	*2010/ 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%*
Taiw an	3.3	UK	5.2	*4.0%*

India : 3rd largest polymer consumer