



ENERGY AND MATERIAL CHALLENGES : INDIAN SCENARIO

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

Tel : 0091 20 2590 2614

Fax : 0091 20 2590 2615

Email : s.sivaram@ncl.res.in

Visit us at : <http://www.ncl-india.org>

**Symposium on Energy Materials :
Opportunities and Challenges
CGCRI, Kolkatta**

March 1, 2011



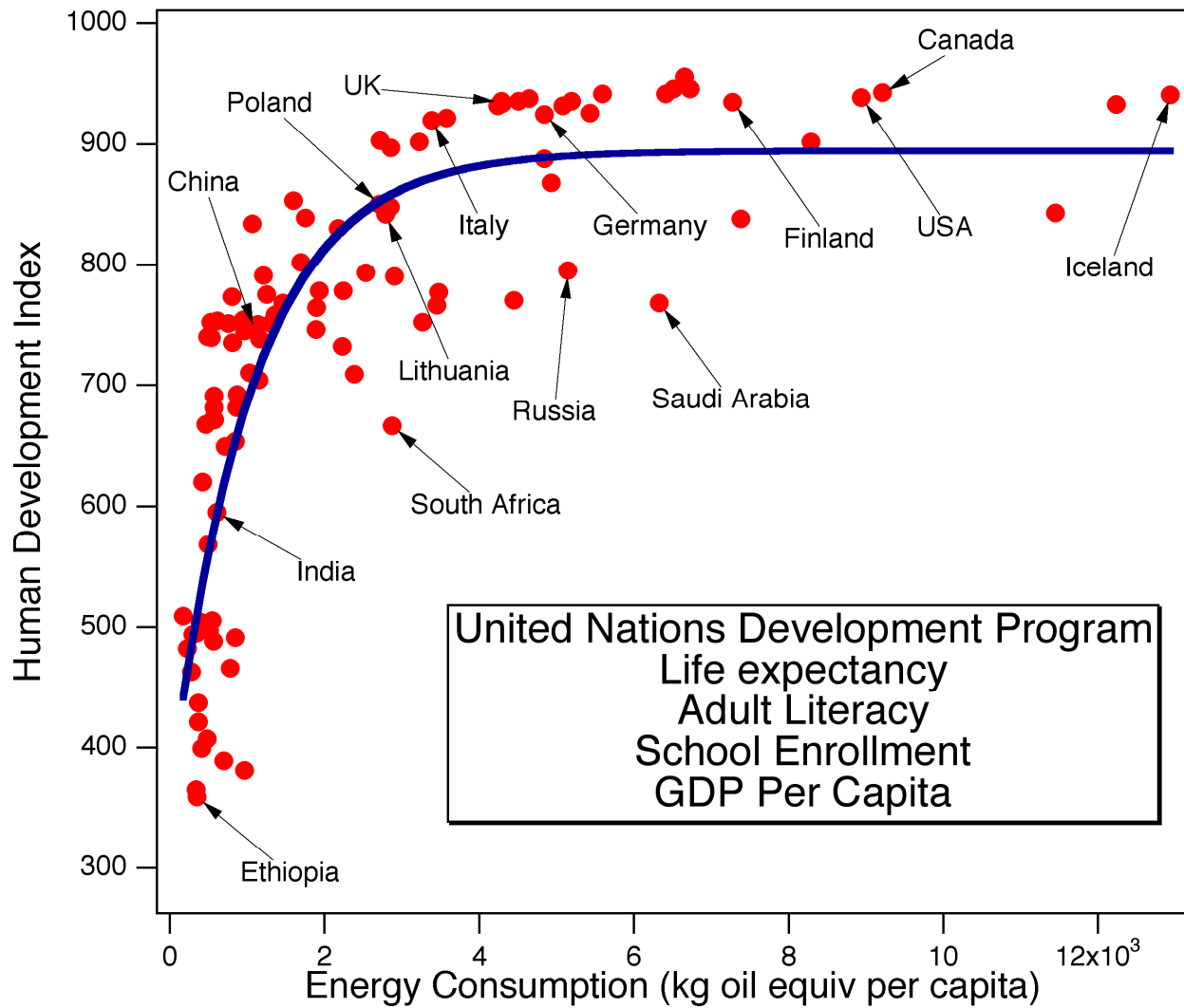
International Year of
CHEMISTRY
2011

INTERNATIONAL YEAR OF CHEMISTRY



- 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

Madam Curie, Nobel Prize in Chemistry , 1911



CHALLENGES IN ENERGY

- **Growth of population as well as economies of the most populous nations**
- **Increasing asymmetry in consumption of energy (two thirds of the world's energy resources are consumed by eight developed countries (G8, 50%) and four emerging economies (Brazil, India, S. Africa and China, 16%)**
- **Cheap energy reserves are limited**
- **Increasing demand for cleaner environment and sustainability in energy use**
- **Increasing the share of renewable energy in consumption**
- **Need to ensure energy for all ; 2 billion people of the world still live without electricity**
- **Distributed and community managed energy production and distribution systems; small is beautiful !**

CHALLENGE OF ENERGY MATERIALS

Can we make a “Materials” difference to a Sustainable Energy future?

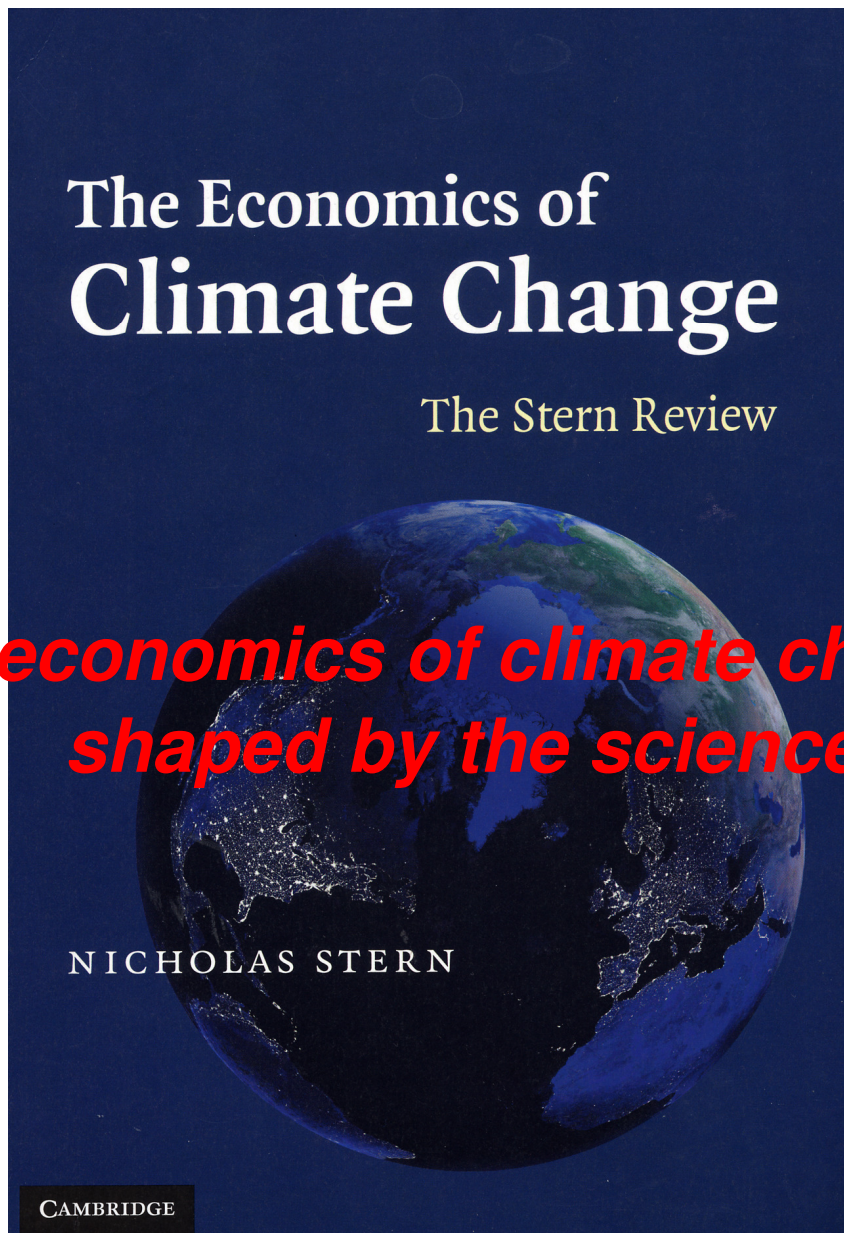
The Economics of Climate Change

The Stern Review

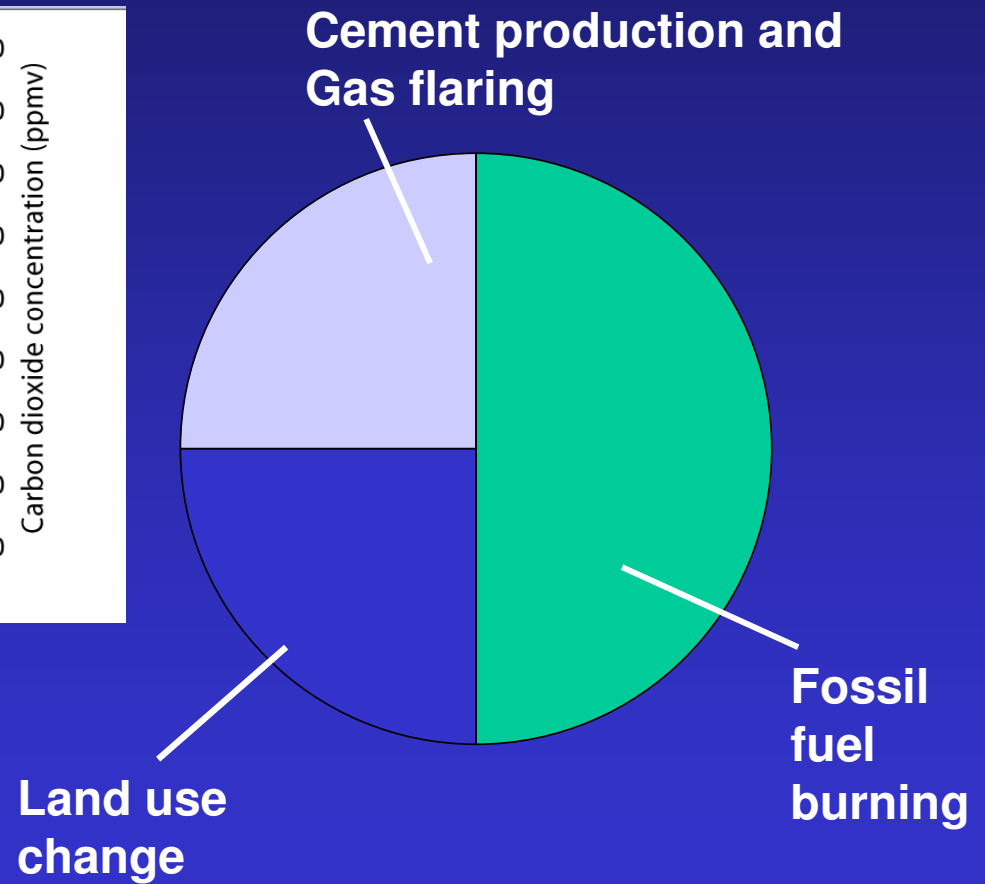
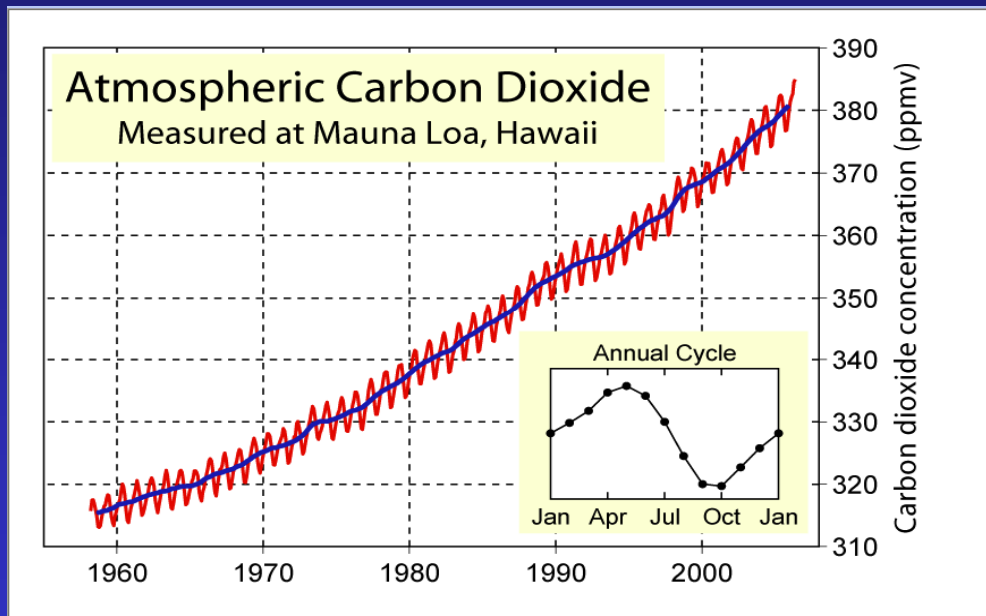
*The economics of climate change is
shaped by the science*

NICHOLAS STERN

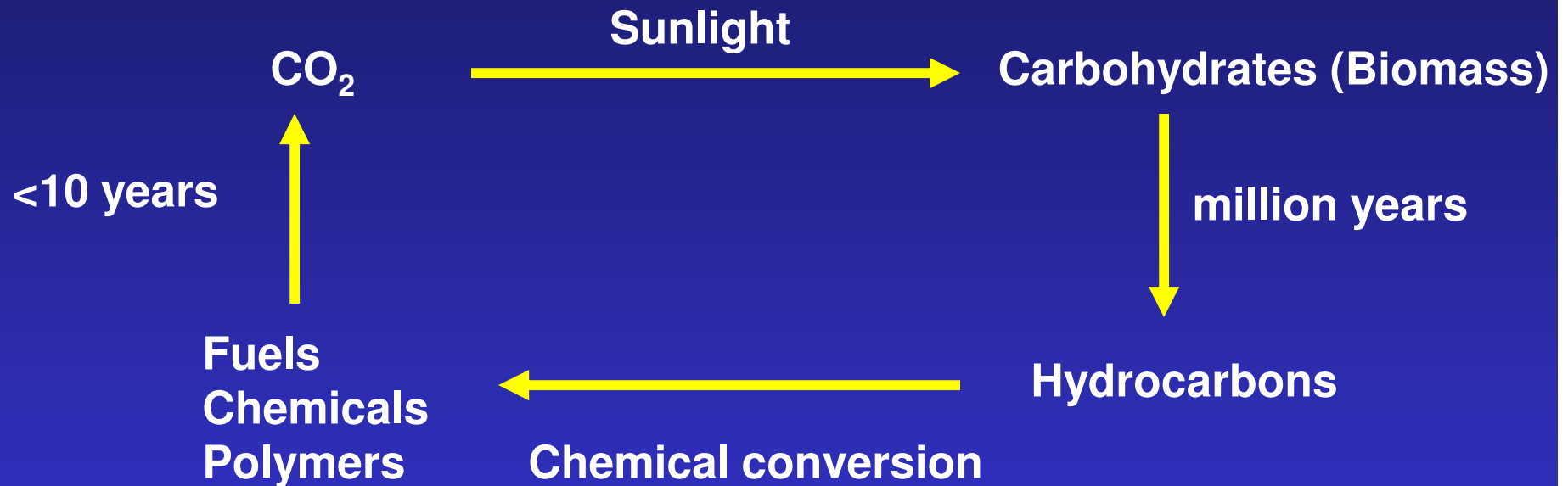
CAMBRIDGE



ANTHROPOGENIC CO₂ EMISSIONS

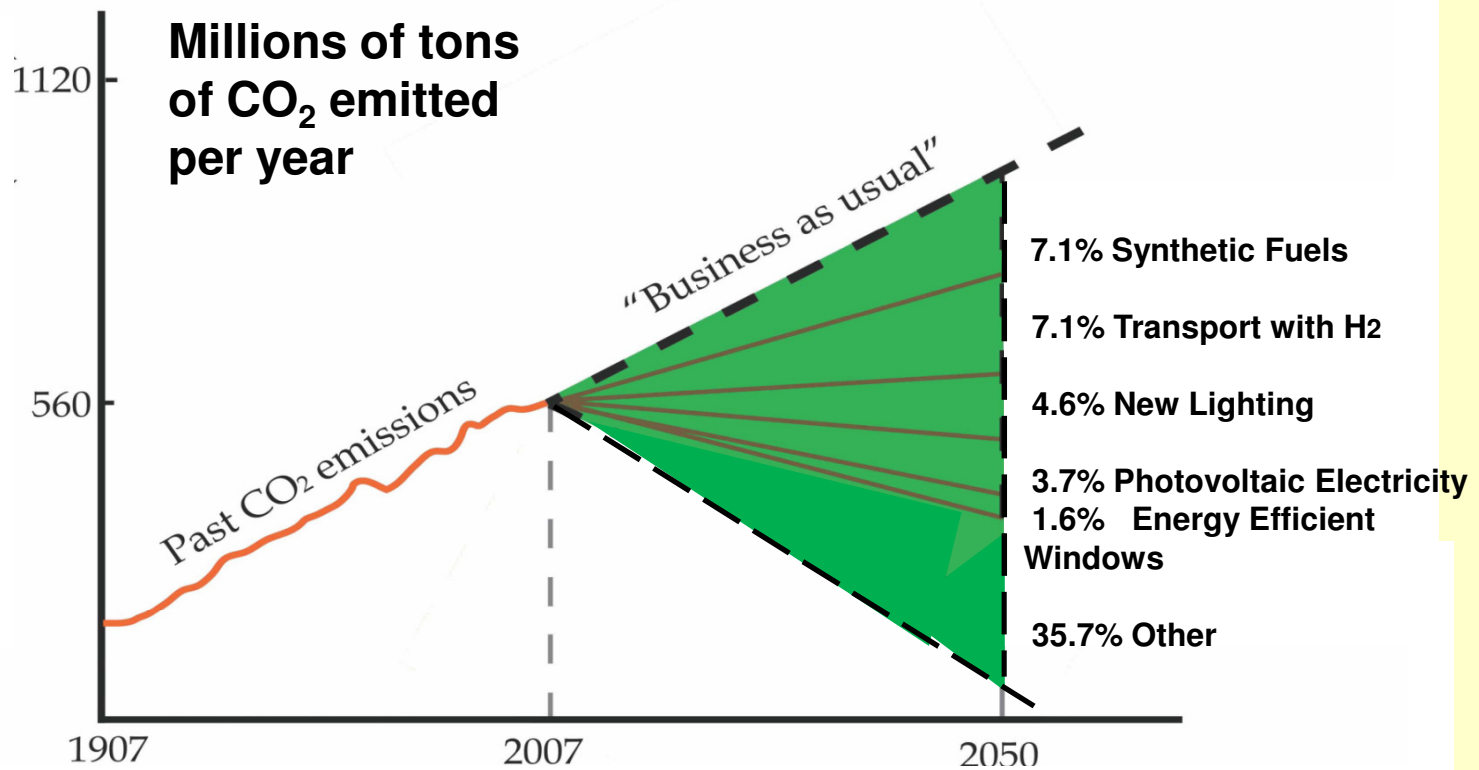


GLOBAL CARBON CYCLES : THE KINETIC CONUNDRUM

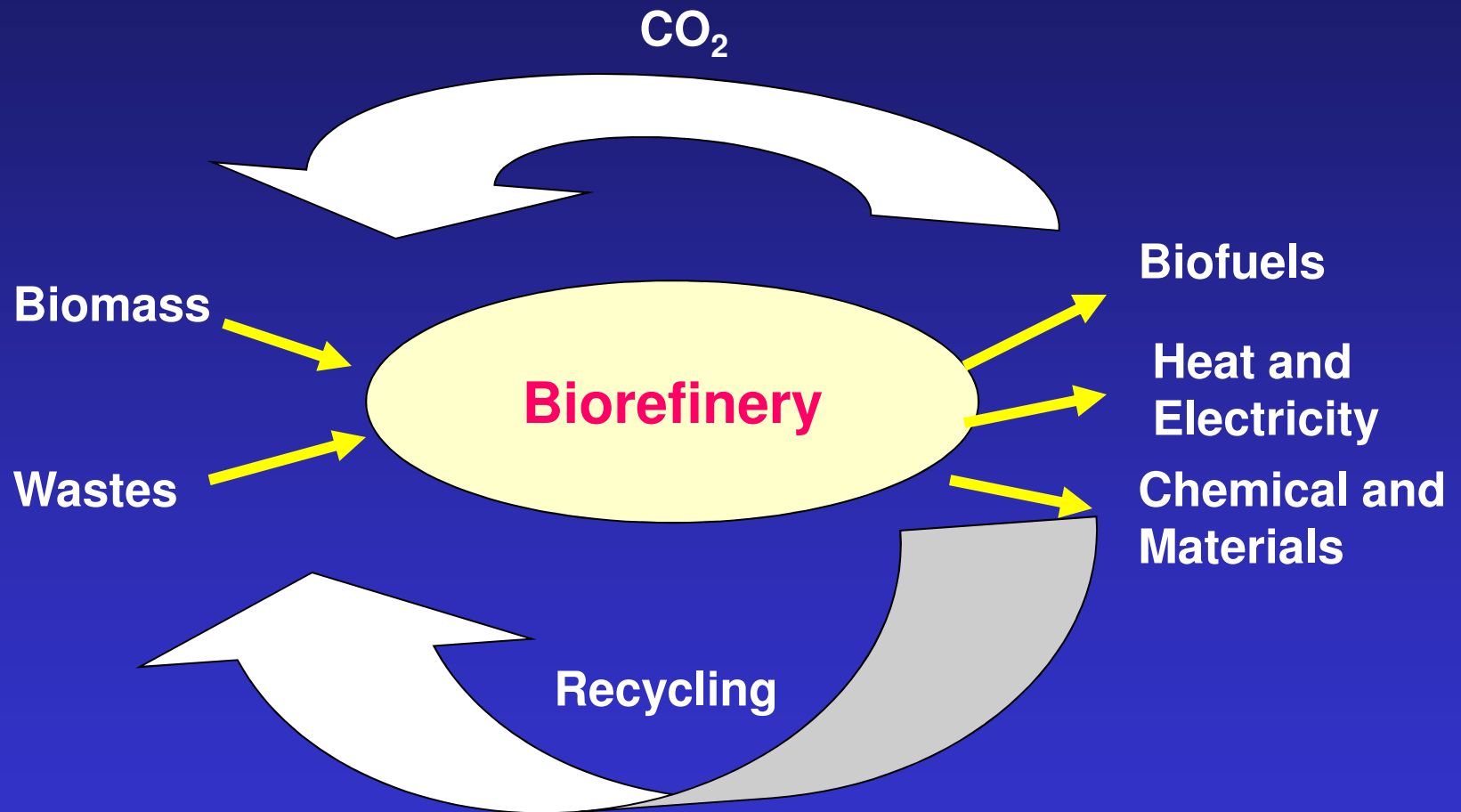


We release more CO₂ than we sequester as fossil resource!

POTENTIAL IMPACT OF ENERGY MATERIALS (UK)



INTEGRATED BIOREFINERIES : WILL IT RESOLVE THE KINETIC CONUNDRUM ?



Provided the land use patterns are not substantially altered

“The Stone Age did not end because we ran out of stones and the Oil Age will not end because we run out of oil”

**Don Huberts
CEO ,Shell**

OPPORTUNITIES IN BIOMASS

- **Bio-fuels**
- **Bio-derived materials**
- **Bio-power (heat and electricity)**

***Estimated size of biofuels market (2010) : US\$ 100 billion
Investment in biofuels grew from \$5 billion in 1995 to 38
billion in 2005***

GLOBAL RENEWABLE ENERGY BY SOURCE (2004)

- Total : 16×10^{18} J (less than 5% of the total)
- Biomass : 56%
 - Bioethanol : 4%
 - Biodiesel : 1%
 - Electricity : 8%
 - Heat : 43%
- Geothermal : 7%
- Hydro power : 12%
- Wind : 9%
- Solar : 16%

• Global market for renewable energy is currently estimated to be US\$ 40 billion, expected to increase to US \$ 170 billion by 2015
• India and China most attractive destination for renewable energy investments

ENERGY AND ENVIRONMENTAL SUSTAINABILITY OF BIOFUELS : NET ENERGY BALANCE AND FUEL-CYCLE ANALYSIS

- **Net Energy Balance (NEB) : Fuel-energy content of petroleum and other energy sources required to produce it**
- **Net Energy Ratio (NER) : Energy output / Energy input**
- **Conversion of one form of energy into a more useful form of energy, e.g., converting crude oil into transportation fuel, is always accompanied by energy loss (2nd Law of thermodynamics)**
- **Thus, all fossil fuels have a negative net energy balance, i.e., $NER < 1$**

NET ENERGY RATIO OF FUELS (US)

Gasoline	0.80
Diesel	0.85
Electricity	0.45
Natural gas (heating)	0.94
Ethanol from corn (without coproduct allocation)	1.06
Ethanol from corn (with coproduct allocation)	1.67
Ethanol from sugarcane (with cogeneration)	>8.0
Cellulosic biomass	>10.0
Biodiesel from soyabean oil	3.00

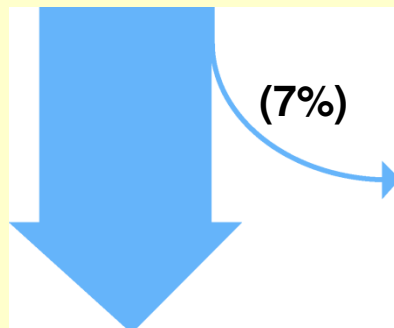
“ The use of vegetable oils for engine fuels may seem insignificant today, but such oils may become, in the course of time, as important as petroleum and coal tar products of the present time”

Rudolf Diesel (1912)

THE ENERGY AND CHEMICAL INDUSTRY



crude oil



fuel
(energy)

transportation,
heating

petrochemicals
(materials)

commodities

specialties

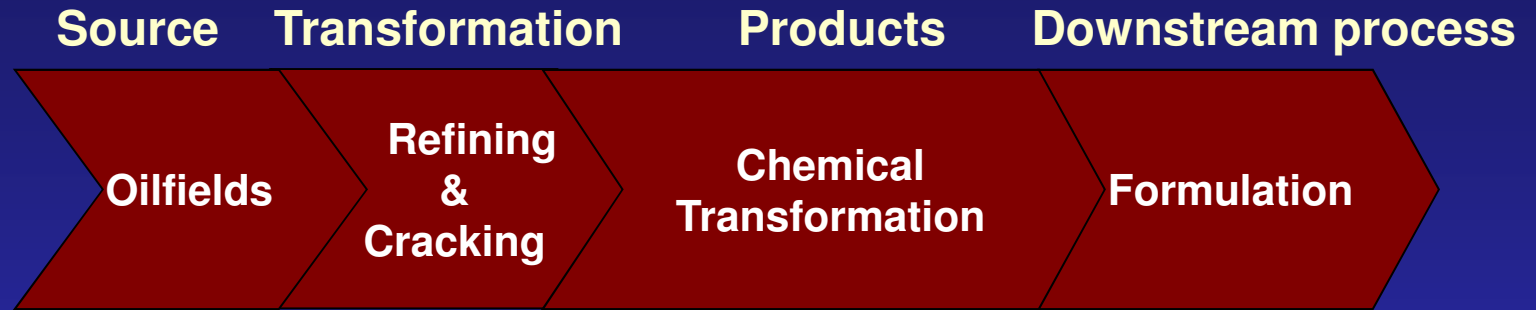
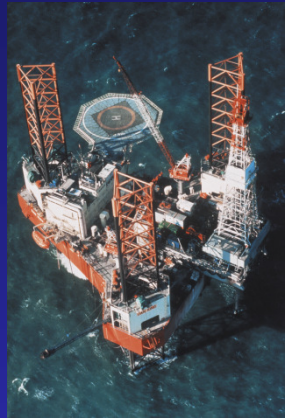
biological
sources

(synthesis)

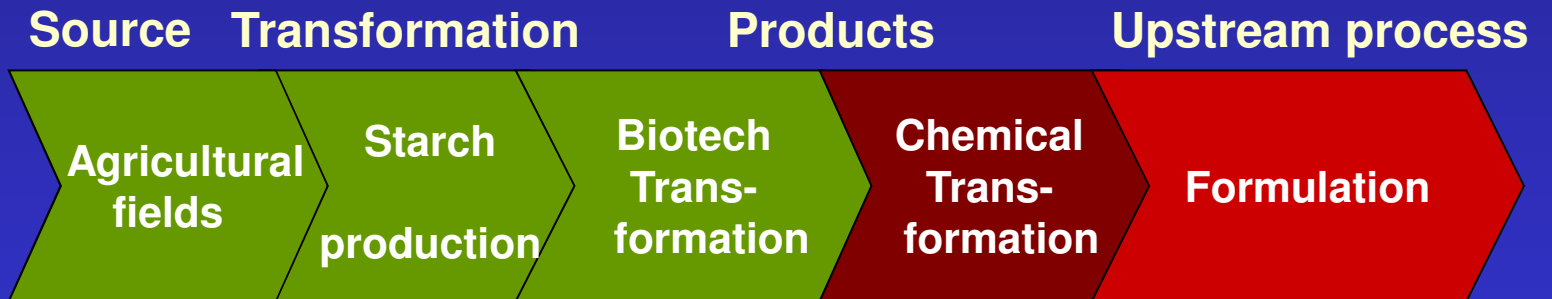
pharma

BIOREFINERY versus PETROLEUM REFINERY

The refinery based on fossil resources



The biorefinery based on renewable resources



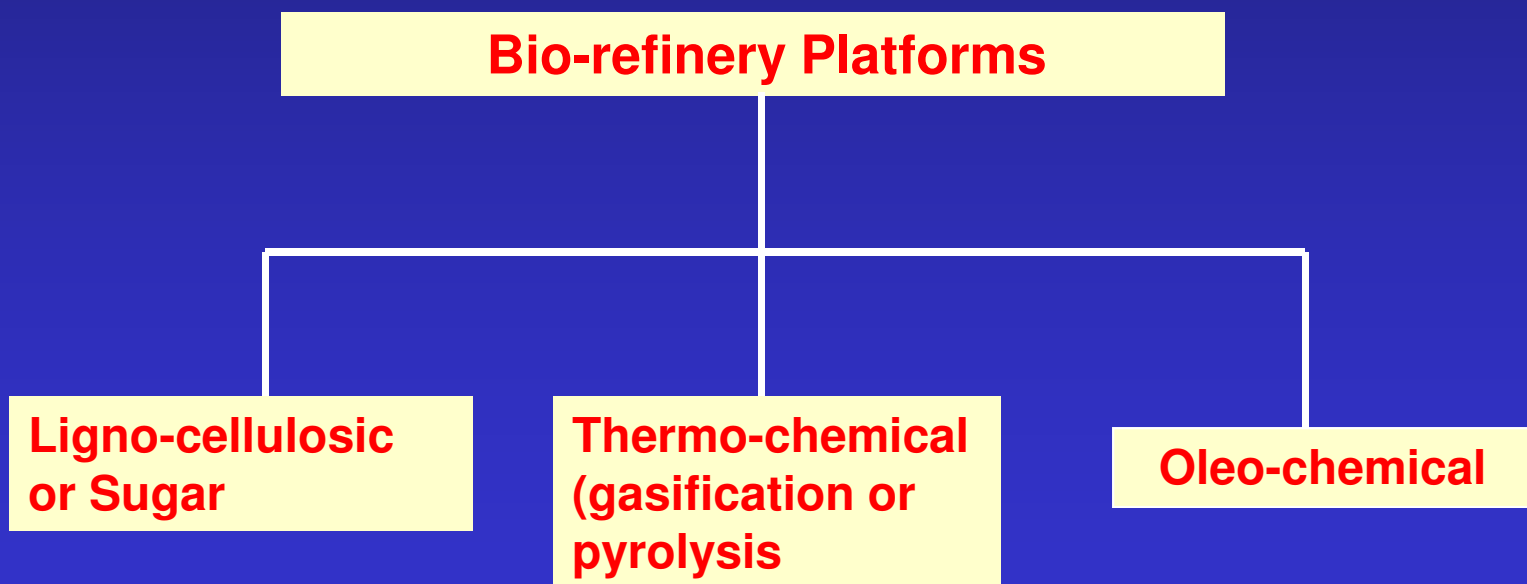
Leading role of biotechnology

Shared role between biotechnology and chemistry

Leading role of chemistry

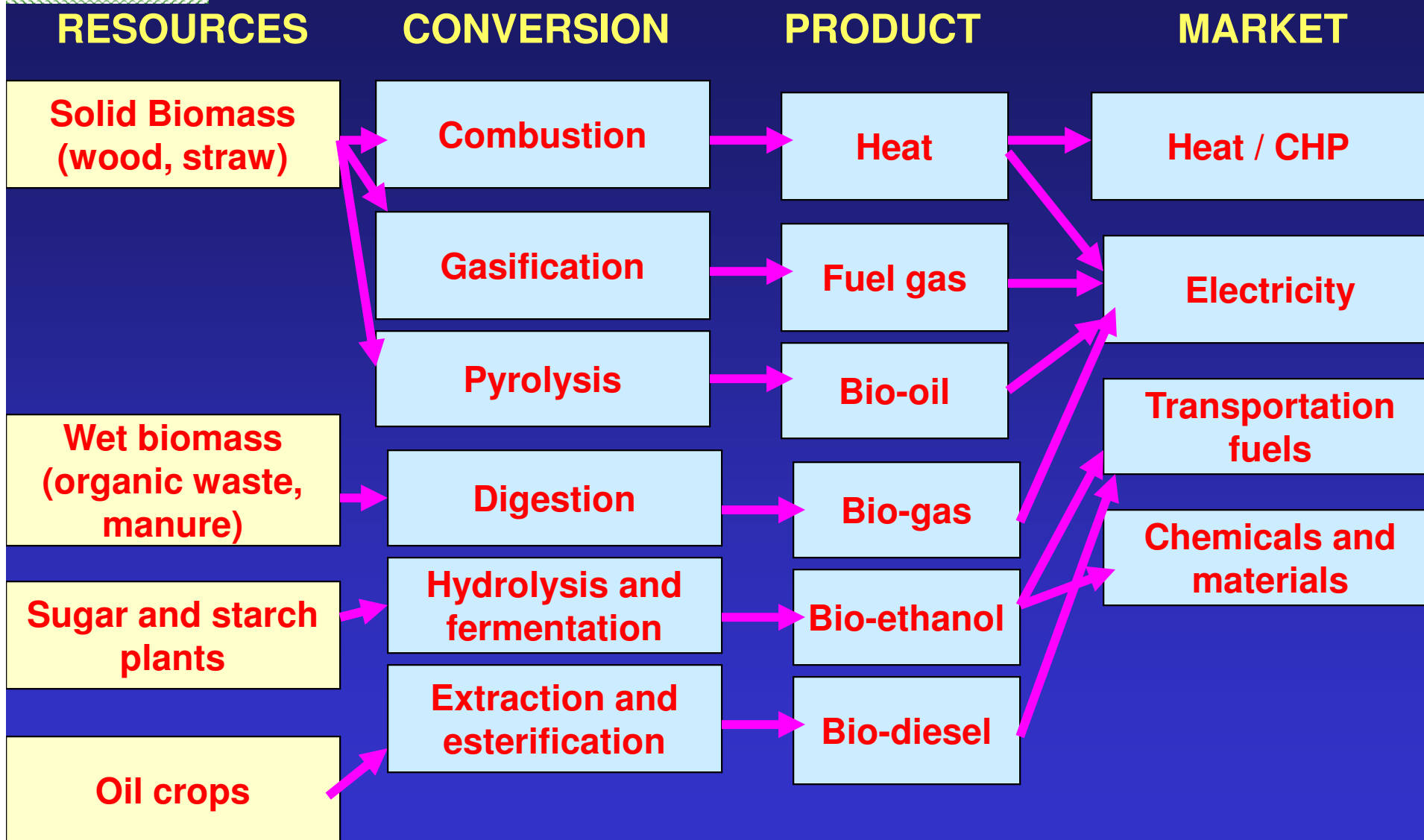
INTEGRATED BIO-REFINERY

A bio-refinery is an entire integrated complex concept of a processing plant in which biomass feed stocks are extracted and converted into a broad spectrum of valuable products, namely, chemicals, materials and energy, analogous to petrochemical refineries

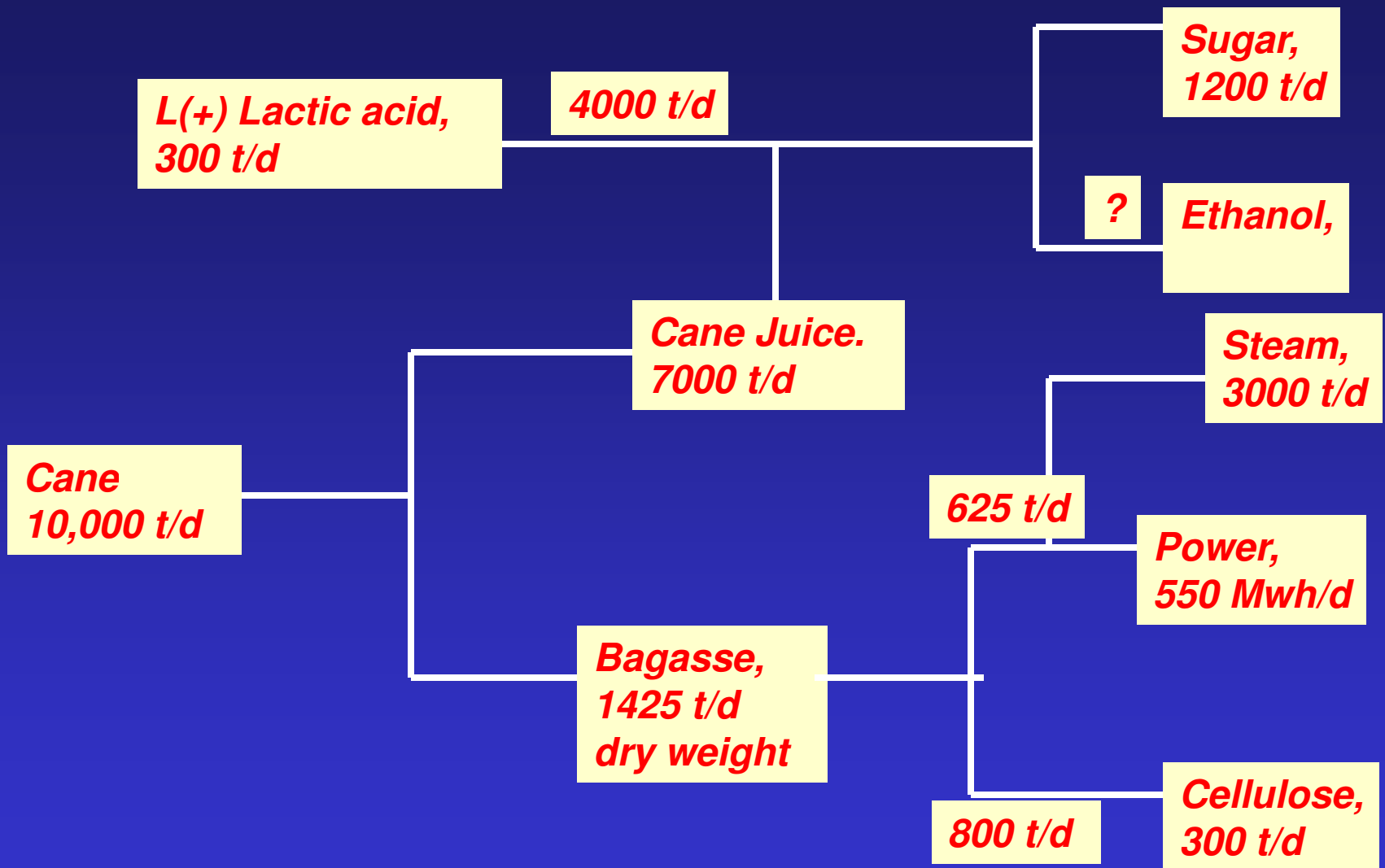


Deployment of a combination of bio- and chemical technologies

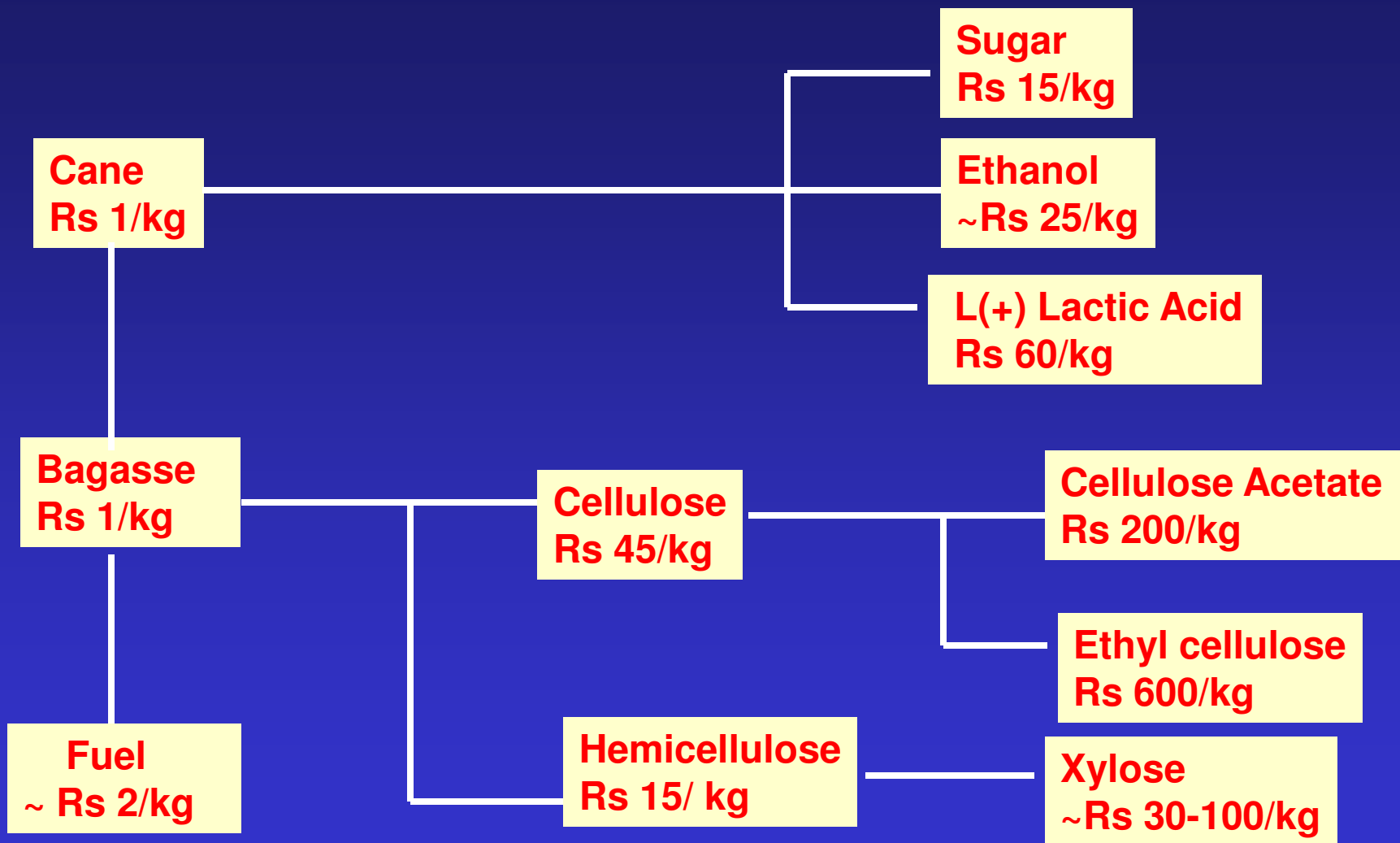
BIOMASS PATHWAYS



MATERIAL FLOWS :SUGAR BIOREFINERY



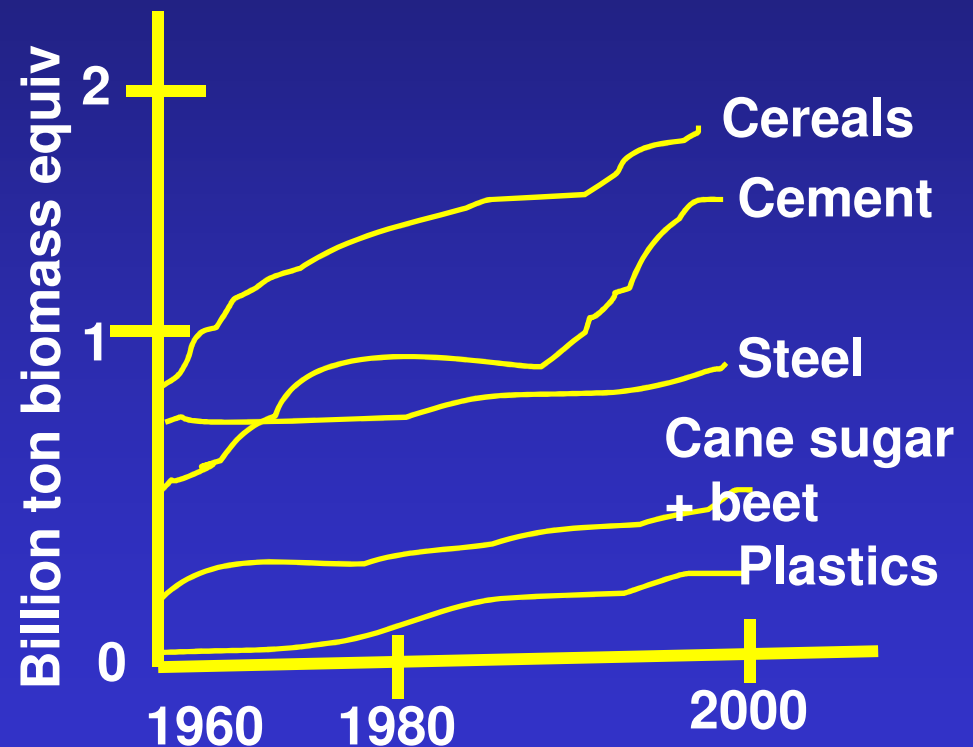
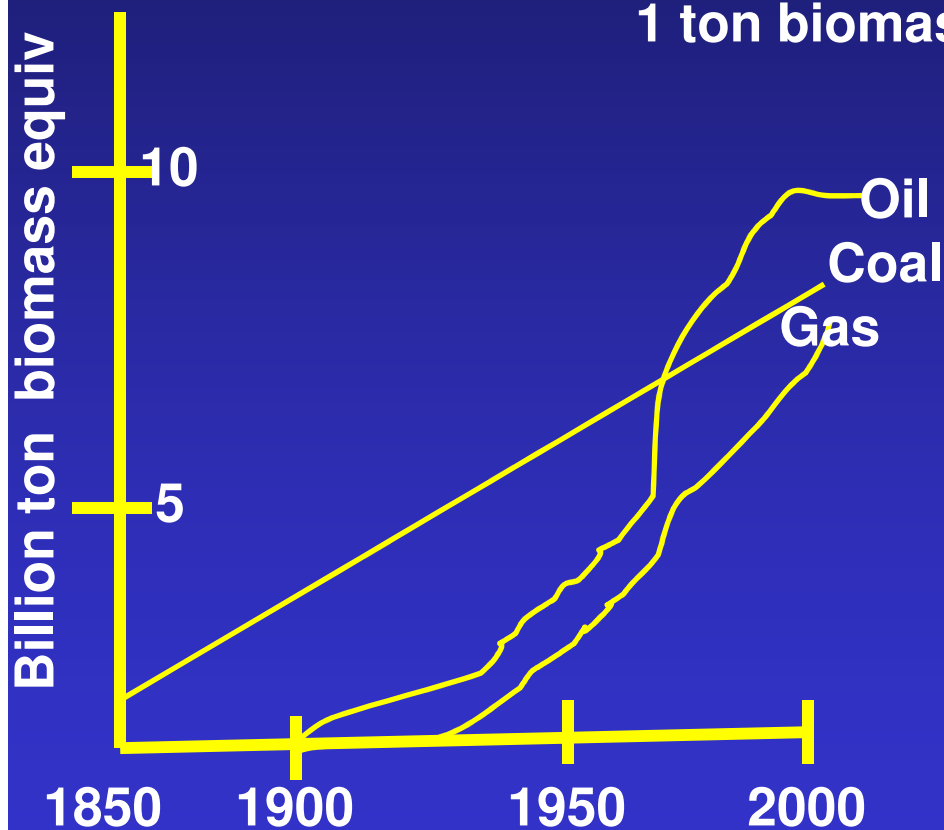
LIGNO-CELLULOSIC BIO-REFINERY : VALUE CHAIN



BIOMASS PRODUCTION FOR FOOD, ENERGY AND MATERIALS

1 ton oil equiv = 42 GJ

1 ton biomass equiv = 18 GJ

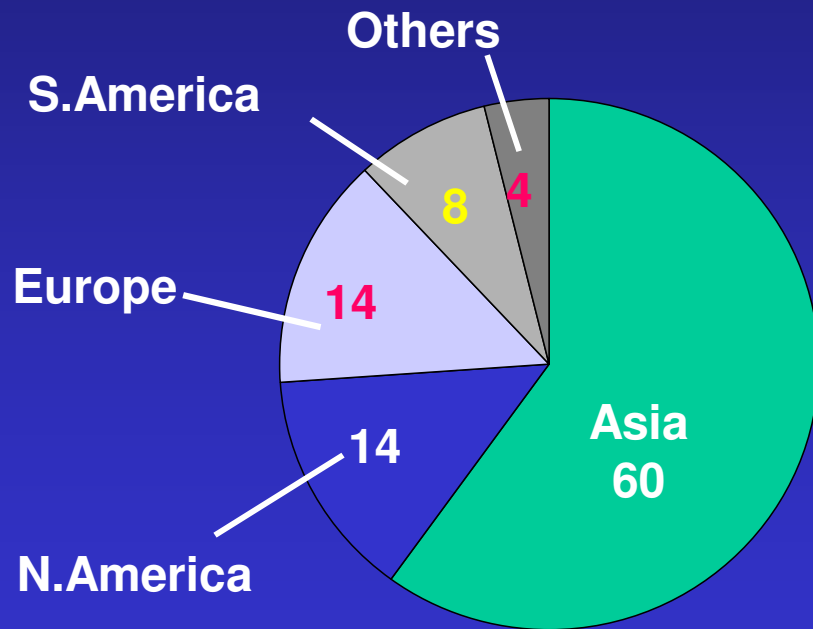


Clearly using food crops for fuels is not sustainable

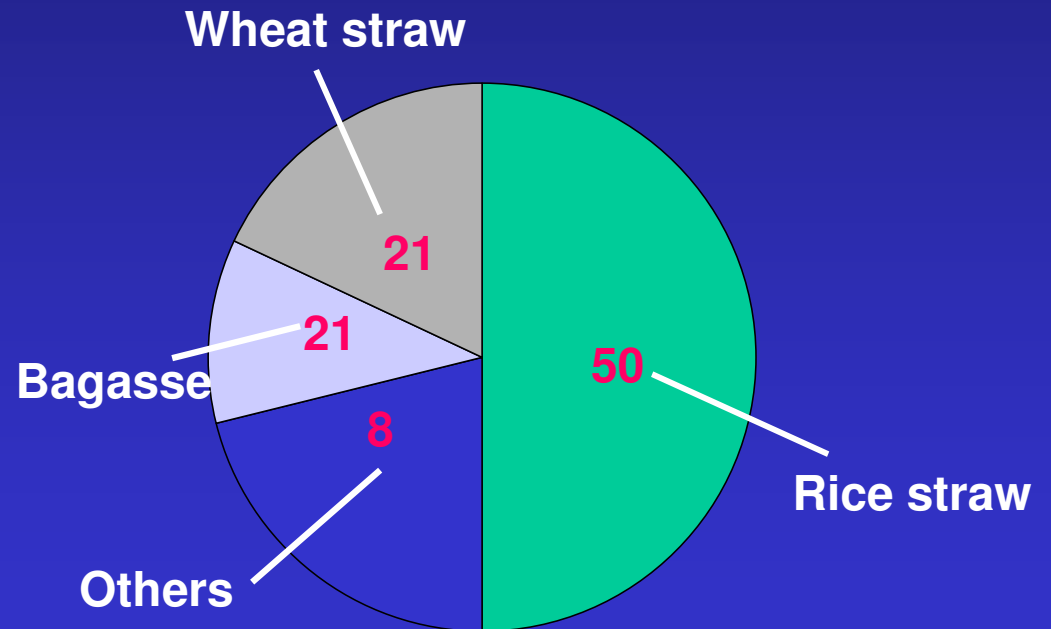
WORLD - WIDE AVAILABILITY OF AGRICULTURAL RESIDUES

Crop residues : > 2 billion tons

An unique Indian advantage ?

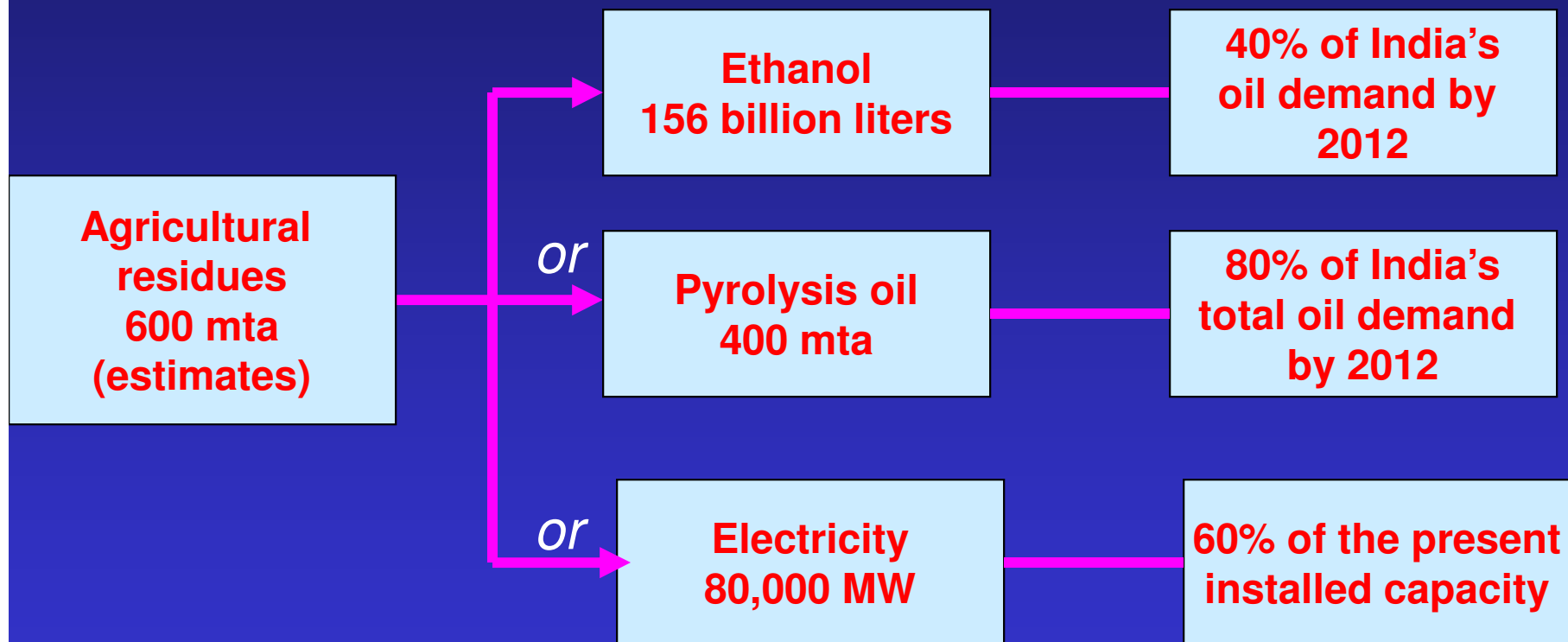


By Geography



By type

AGRICULTURAL RESIDUES : INDIAN PERSPECTIVE



COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH (CSIR)



**CSIR Network on
Solar Energy
*TAP-SUN***

SOLAR ENERGY : INDIAN SCENE

- For the first time India has set for itself a clear set of goals in the area of Solar Energy
 - Current PV Manufacturers : 9; Module Manufacturers : 20; Total capacity : 700 mW
 - Current Global solar cell capacity : 11 gW targeted growing to 25 gW by 2015
 - 40% of global capacity in China and Taiwan
 - India does not have domestic Silicon capacity
-
- ***India has set for itself an impossible challenge for Silicon – PV. Global Solar Cell capacity will be a constraint for India`s plans***
 - ***Can we depend on a critical resource such as Silicon Wafers for fuelling our energy needs on a few nations of the world ?***

NATIONAL SOLAR ENERGY MISSION

(Source : Financial Express, August 17, 2009)

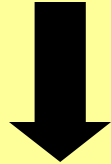
Launch	November 14, 2009
Outlay	<ul style="list-style-type: none"> ▪ 91,684 crores (US \$ 19 billion) <li style="padding-left: 20px;">-- Investment incentives 70,000 crore <li style="padding-left: 20px;">-- Subsidies 7,000 crore
Target	<ul style="list-style-type: none"> ▪ 20 GW by 2020 <li style="padding-left: 20px;">-- 1.5 GW (2012) <li style="padding-left: 20px;">-- 6 GW (2017) <li style="padding-left: 20px;">-- 20 GW (2020) ▪ Rs. 18/Kwh (2009) – Rs. 6 Kw h (2020) – Rs. 2 Kw h (2030 (Grid parity with coal)) ▪ Light 3 billion house holds by 2030 ▪ CO₂ reduction by 42 million tons ▪ 50 million sq.ft.area for solar thermal power
System	<ul style="list-style-type: none"> ▪ Statutory Solar Authority <li style="padding-left: 20px;">-- Finance <li style="padding-left: 20px;">-- Tariff <li style="padding-left: 20px;">-- Technology <li style="padding-left: 20px;">-- Special projects

SILICON COST FACTORS

- **Expensive high purity materials**
- **Multi-step, high temperature processing**
- **30% Material utilization**
- **30% Theoretical efficiency**

THE CHALLENGE OF SOLAR CELL FABRICATION

- 10 TW of solar power generation



***15% efficiency
250 w/sq m***

- 500,000 sq km



30 year replacement

- 50 sq km of cells per day



- 2 billion cells (15x15 cm) each day

The current method of fabrication of silicon wafers from ingots irrelevant for large scale deployment ; clearly, there is a technology gap

TECHNOLOGY COMPARISON

	Silicon	Quantum Dots	Copper Indium Gallium Diselenide (CIGS)	Conventional Organic Polymer Cells	Nanopatterned Cells
Efficiency (%)	12-24	16	11-19	2-5	10-12 <i>(Projected)</i>
Cost (\$/Watt)	~4	2.4	4	~1	~0.5
Flexibility	No	No	Some	Yes	Yes

Silicon and QD only commercially available technology

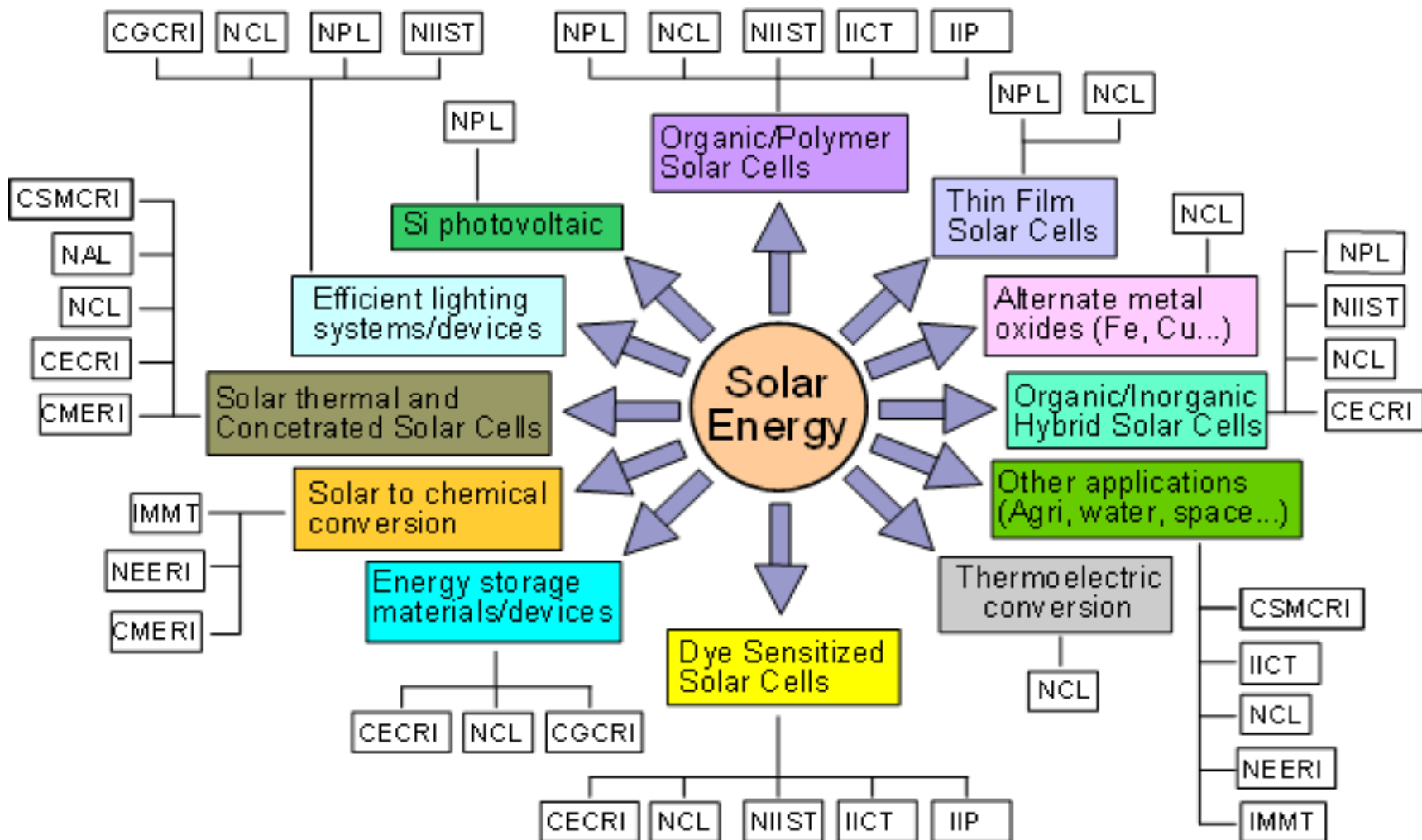
ORGANIC POLYMER DEVICES

- **Abundant, Inexpensive starting materials**
- **Ease of processing (Roll to Roll)**
- **High theoretical efficiency (60%)**
- **Flexible**
- **Efficiency challenges**

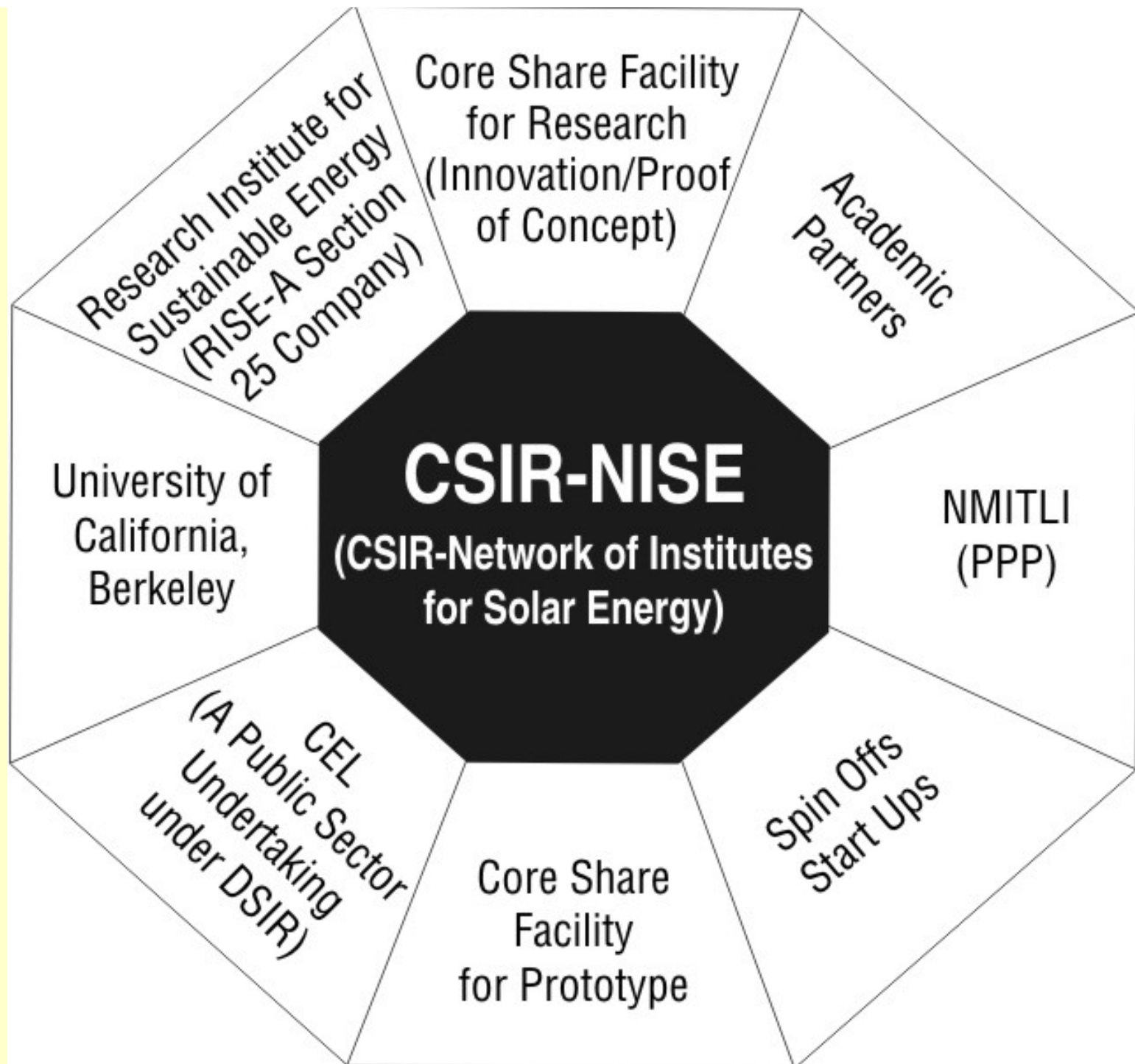
NEW FABRICATION TECHNIQUES

- **Clearly, solution lies in newer fabrication techniques**
- **Greater applicability of flexible organic solar cells for India, since this has a scalable manufacturing process**
- **Soft lithography, inkjet printing are areas that may have greater relevance to India**
- **Efficiencies/ durability may be lower, but given India's lower energy use intensity, they may still offer viable solutions in terms of cost per kw**

CSIR in solar energy



An exhaustive mapping of CSIR's competence and facilities in research related to solar energy materials, conversion and applications has been completed



RESEARCH AND TECHNOLOGY CHALLENGES

- **Silicon Photo Voltaic Cell**
- **Non-silicon materials for PV Applications**
- **Dye Sensitized and Quantum Dot Sensitized Solar Cells**
- **New Semi-conducting Materials (Fe/Cu)**
- **Solar Thermal/ systems**
- **New materials & processes for Energy applications**
- **Solar Energy to Chemical Energy Conversion/ Nanoscale Photoelectrochemical Cell (RISE)**
- **Thermoelectric Conversion (RISE)**
- **Energy Storage Materials/ Batteries/ supercapcitors/ Novel approaches to rechargeable batteries (RISE)**
- **Phase change materials for Energy Storage (RISE)**
- **Efficient Lighting Systems/ Devices**
- **Power Electronics for solar power grid connectivity**

S&T CHALLENGES

Activity	Challenge 1	Challenge 2	Challenge 3
Silicon Cells (SC, Poly, a-Si)	Raw Materials, Processing, Purity	Cell Fabrication Costs	Concentrated solar power (CSP) concepts and Designs
Sensitized cells	Nanomaterials and Film architecture design Micro, Nano-porosity Light Harvesting	Dye degradation Efficiency degradation control Dye leaching Broadband Dye design QD-oxide interface engineering	Contacts, sealing Solid State p-layer Lab to production process development
Thin Film Cells	Alternative process tolerant materials	Controlling interfaces Defects, re-combinations	Lab to production process scale up issues
Organic PV	Enhancing efficiency via material property and blend constitution control	Design of new semiconducting polymers	Process methodologies for scale up
Hybrid Cells	Choice of organic and inorganic materials based electronic states	Engineering organic- inorganic interfaces	

S&T CHALLENGES

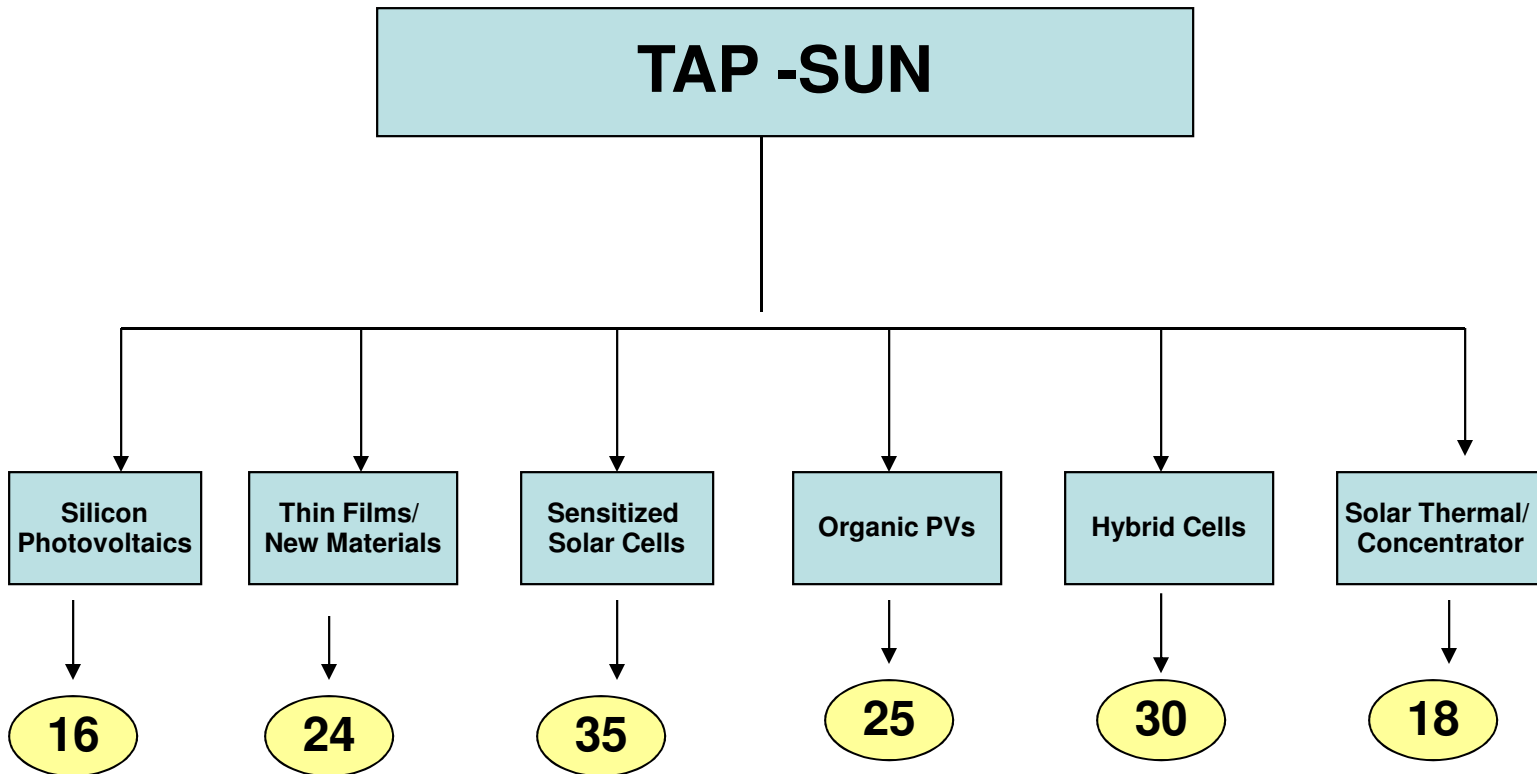
Activity	Challenge 1	Challenge 2	Challenge 3
Photo-electrochemical cells (PEC)	Cheaper nano composite electrodes with enhanced efficiency	More stable(durable) electrolytes with a larger potential window	More facile redox couples on the counter electrode to cause
Thermo-electrics	New Materials with high efficiency (larger thermo-electric coefficient)	Integration with photo-thermal source	
Super-capacitors (Storage)	Cheaper electrode materials based on carbon from waste materials to replace ruthenium oxide	Stable thin film and ionic liquid based hybrid Electrolytes with good Li ion/proton conductivity	Design challenge to solve Lower ESR and regenerative breaking capability to match with EV applications
Battery (Storage)	Robust, yet inexpensive nanowire anodes with good life enhanced capacity	Thin film cathodes based on organo-inorganic hybrids	Thin Film Electrolytes and separators based on polmeric and ionic liquid systems
Solar lighting (Light emitting diodes) Conservation	New Materials Optimization of Material Properties	Optimization of Device Properties	Strong and nimble engineering team for prototype development with strong interaction with industry
Solar Thermal	New multilayered Functional Coatings	Anti reflection coatings	Concentrating Solar Power

THREE TIER APPROACH

(Foreseen/ Emerging/ Next Generation)

- **Identify available technologies for efficiency improvement and cost reduction; sourcing technologies, deploy, improve and validate.**
- **Develop improved materials for second generation technologies**
- **Discovery research on newer concepts and lead identification**

HUMAN RESOURCES @ CSIR

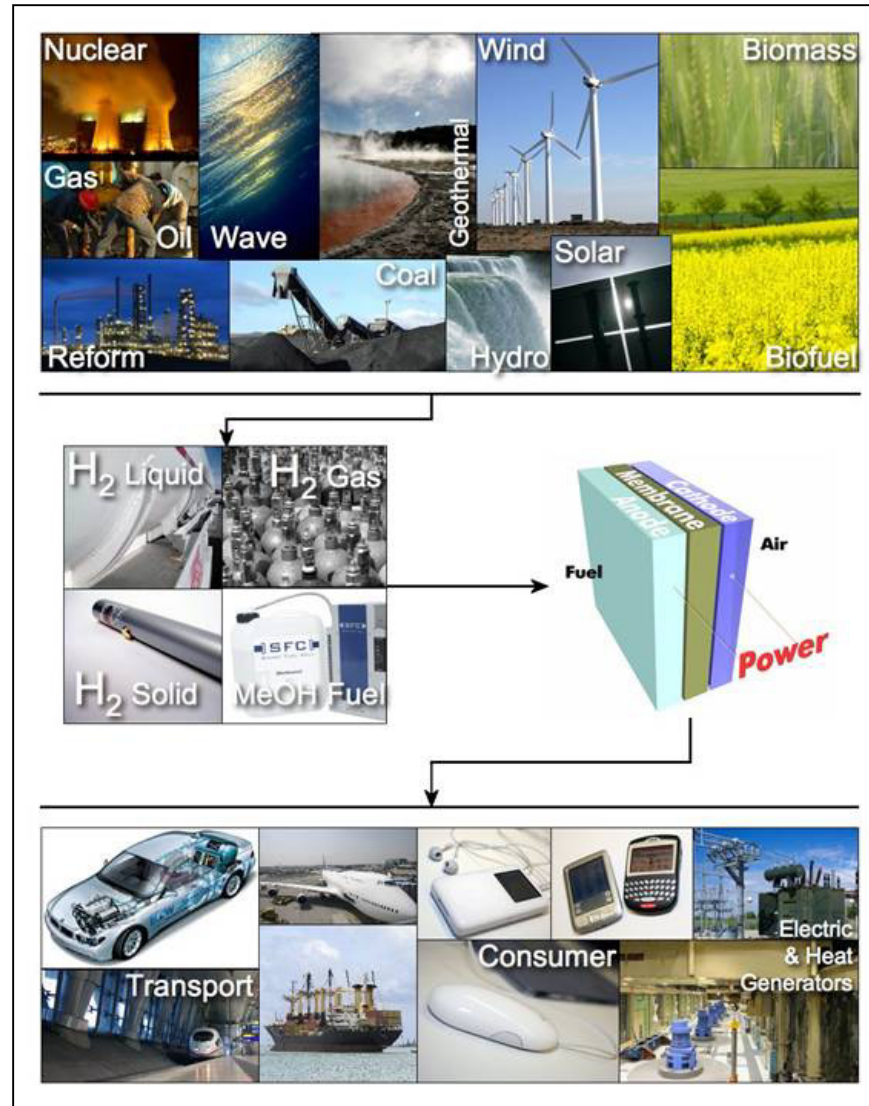


150 full time scientists and engineers Project Staff and Research Scholars: ~ 200

I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait till oil and coal run out before we tackle that

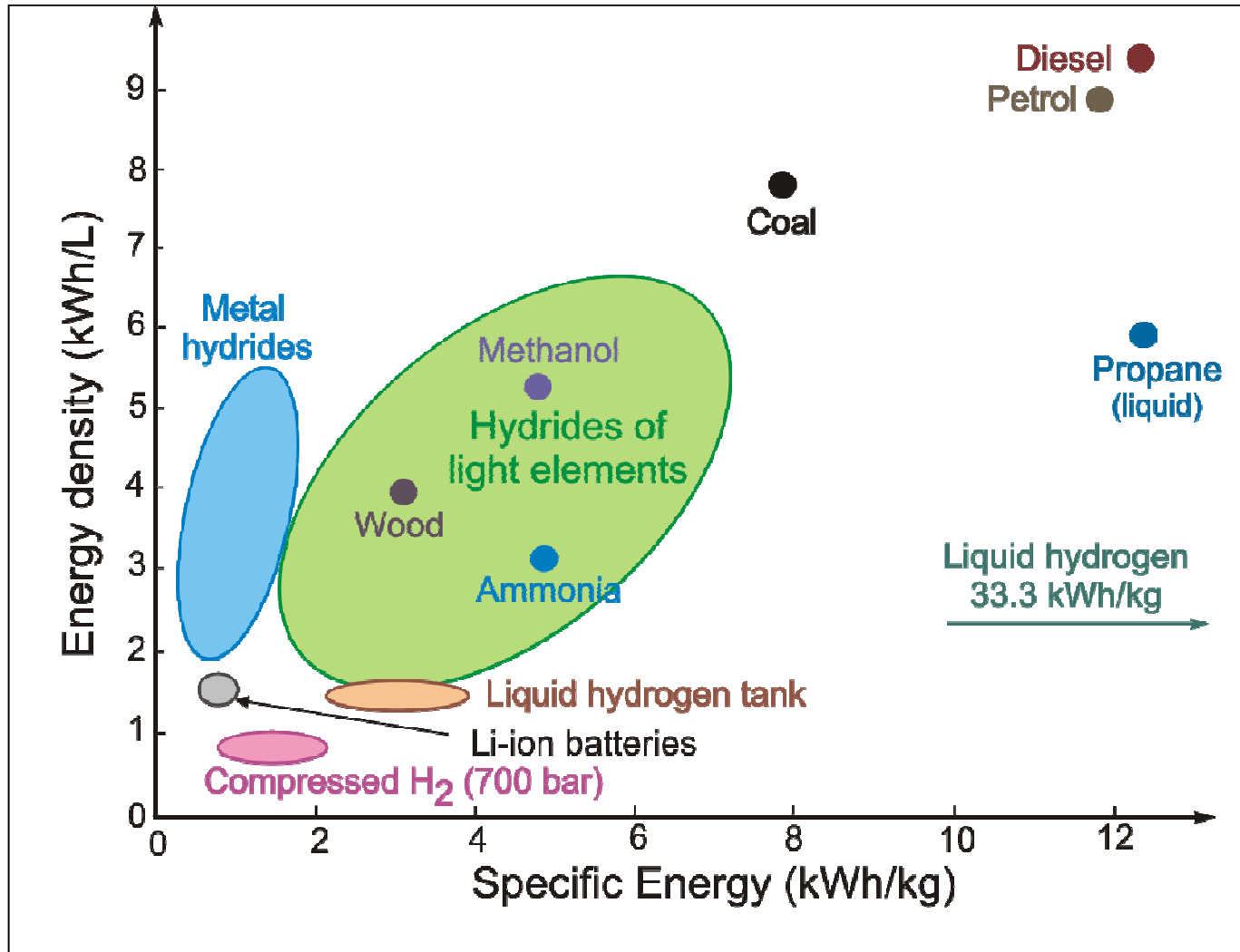
- Thomas Alva Edison (1847-1931)

The Hydrogen Economy


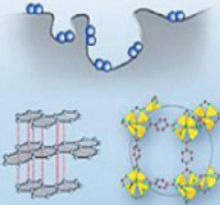
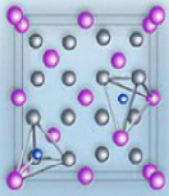

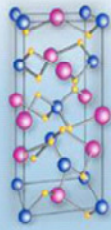
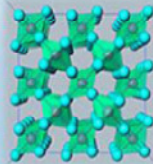



P.P.Edwards, V.L.Kuznetsov, W.I.F.David, N.P.Brandon, *Energy Policy*, 36, (2008), p.4356

Energy Densities of Fuels



Hydrogen Storage: *The Options*

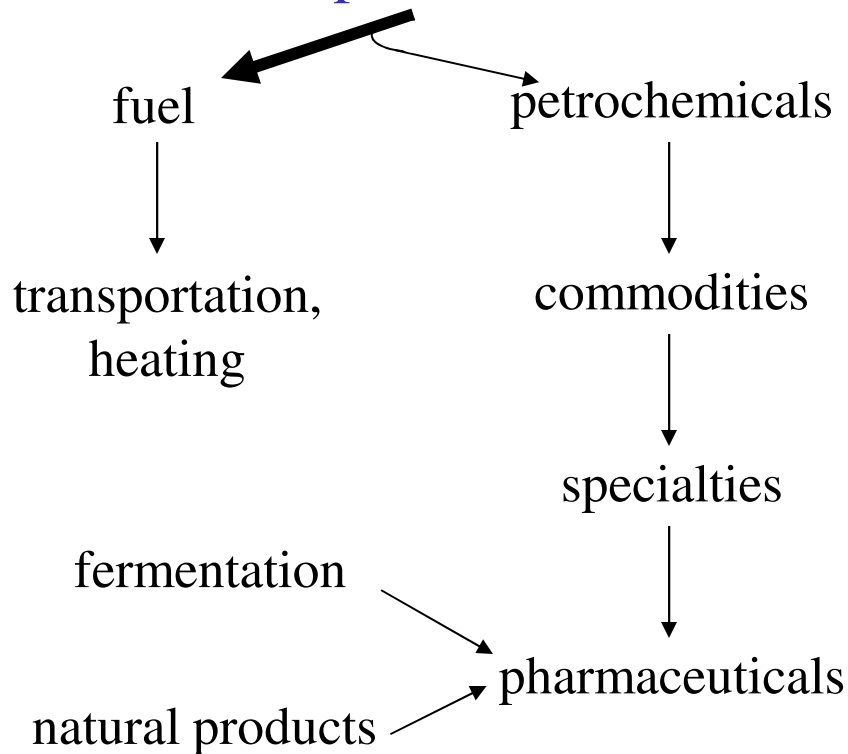
						
Liquid hydrogen	Cryo-adsorption	Interstitial metal hydride	Compressed hydrogen	Aluminate	Salt-like metal hydride	Water
LH ₂	Activated carbon	Laves Phase Comp. / FeTiH _x / LaNi ₅ H _x	CGH ₂	NaAlH ₄	MgH ₂	H ₂ O
100 mat.wt.%	6.5 mat.wt.%	2 mat.wt.%	100 mat.wt.%	5.5 mat.wt.%	7.5 mat.wt.%	11 mat.wt.%
Operating temperature						
-253°C	> -200°C	0 - 30°C	25°C	70 - 170°C	330°C	>> 1000°C
Corresponding energy to release hydrogen in MJ per kg H ₂						
0.45	3.5	15	n/a	23	37	142

R.Helmolt, U.Eberle (General Motors), *J. Power Sources*, 2007, 165, p.833

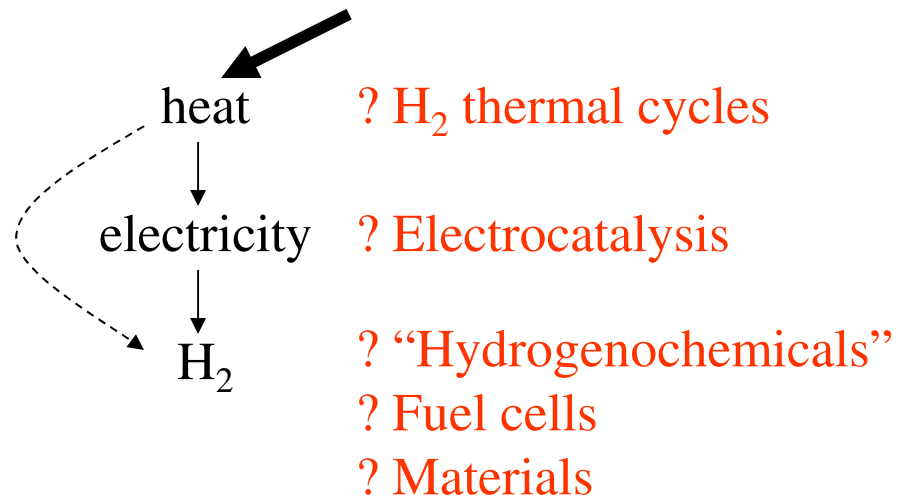
Reinventing the Chain: The chemical economies



petroleum

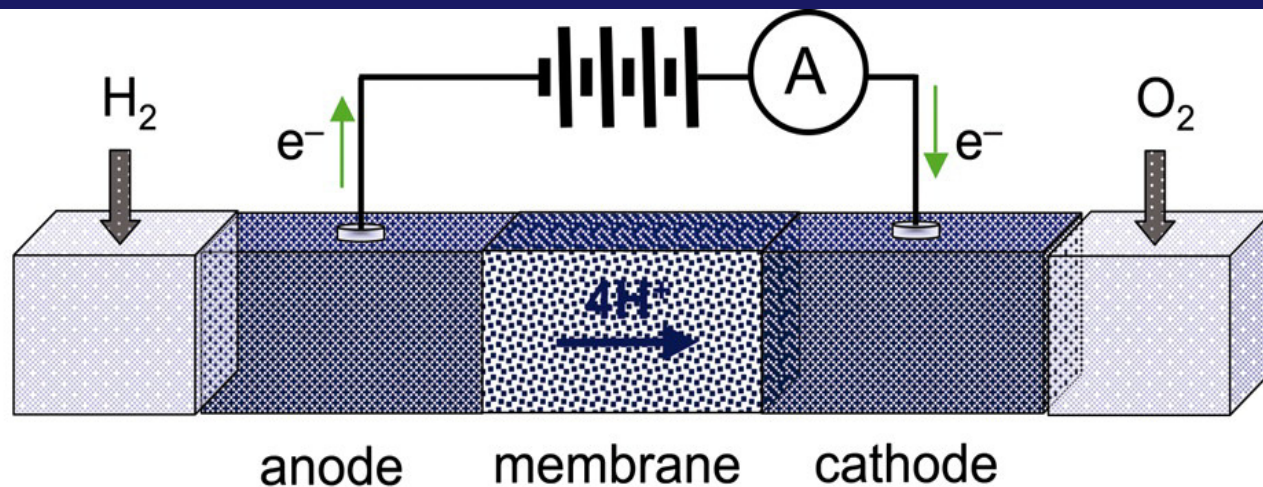


nuclear

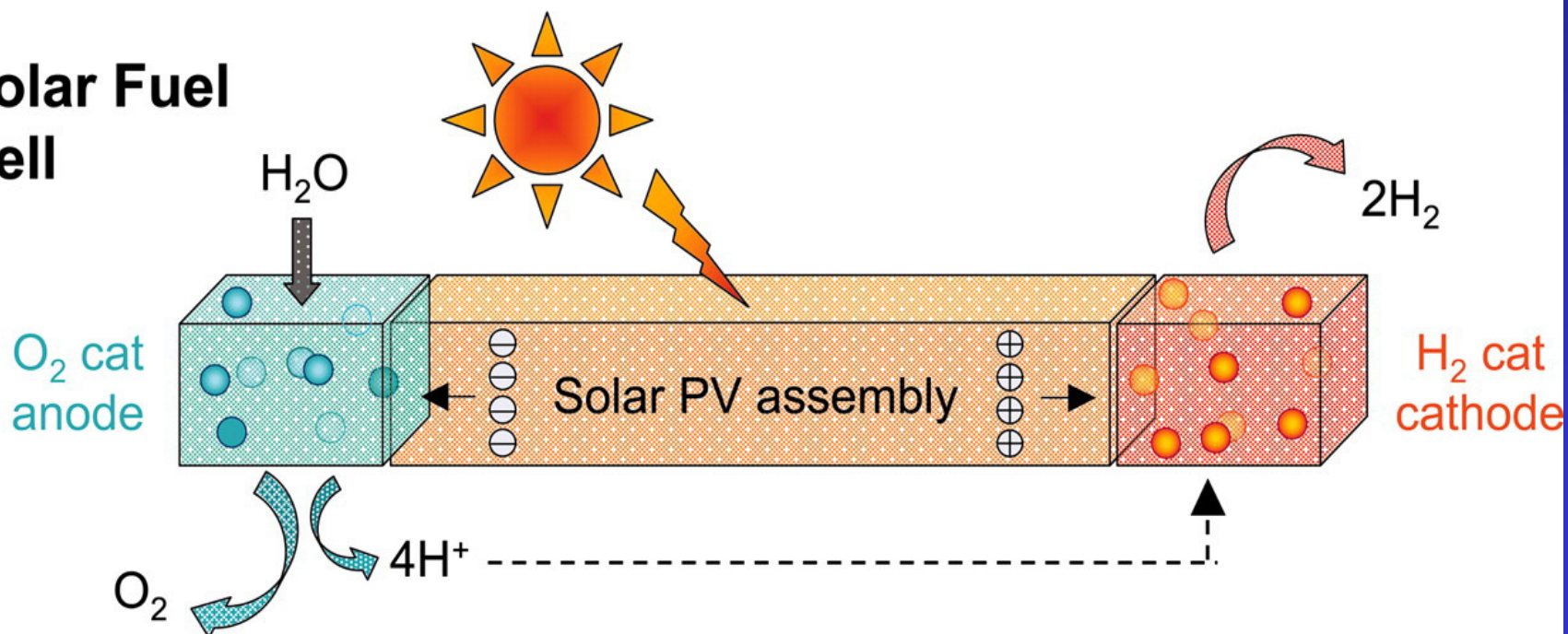


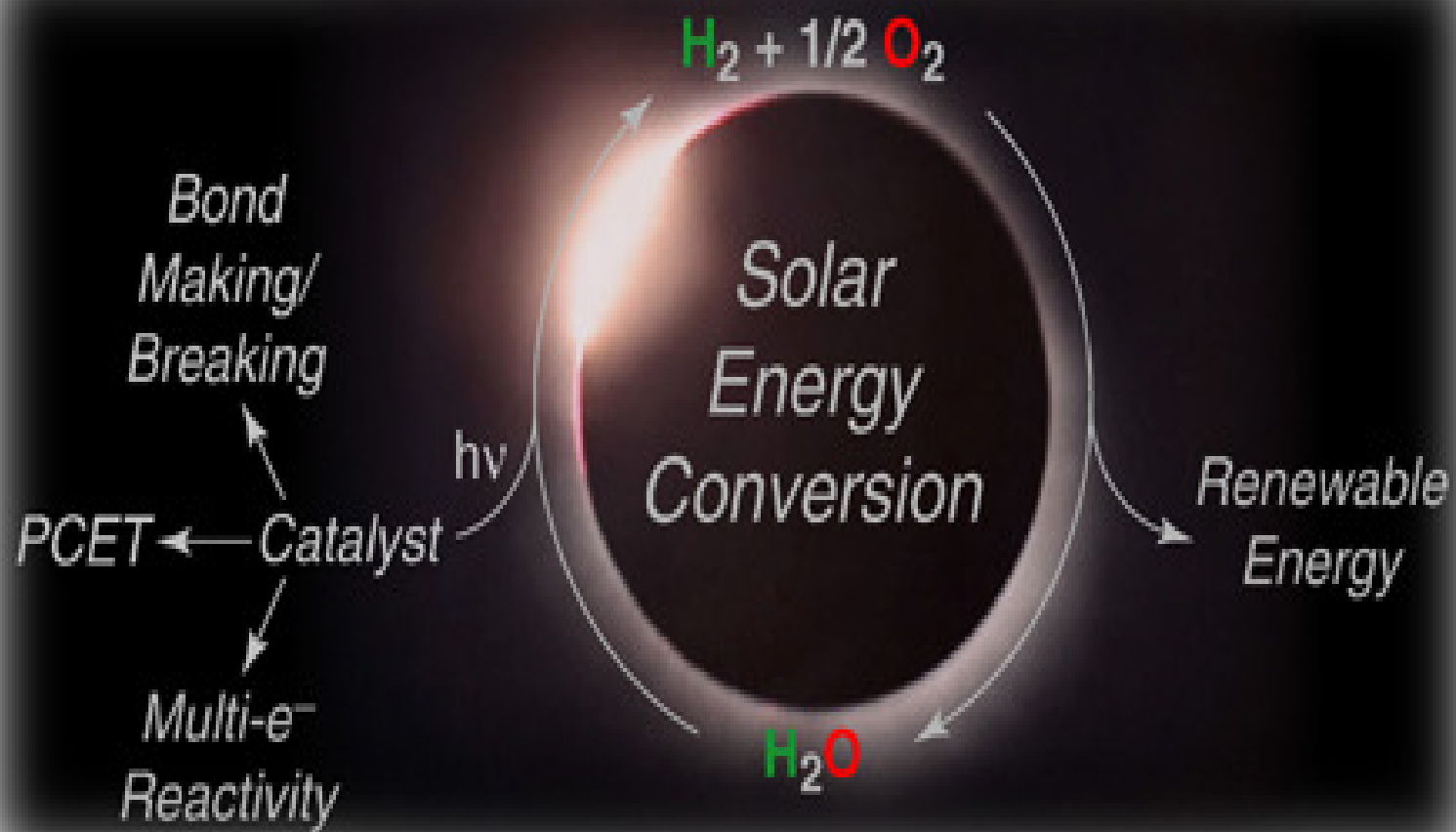
Similarly, what are the chemical economies for: *CH₄*, *coal*, and *biomass*?

Fuel Cell



Solar Fuel Cell





“Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable of..... water will be the coal of the future”

Jules Verne in

The Mysterious Island (1874)

CLEAN ENERGY TECHNOLOGIES

(Report by Pew Charitable Trust, USA, 2010)

- In 2009 \$ 162 billion was invested in CleanTech (energy) globally. 90% was in G 20 nations
- China attracted \$34 billion investments, US \$19 billion and India \$2.3 billion, ranked 10 th in the world.
- Distribution of investments : 60 % asset finance; 9% public equity; 7% Government R&D, 6% Corporate R&D; Private equity 3% and Venture capital 1 %
- Potential investments at current policy (2010-20) for India 118 billion; Enhanced policy: 169 billion
- India's current clean energy capacity 16.5 MW; 9 % of total capacity; 5 year growth rate 31 %. Wind and solar dominates
- Policy framework important. India scores favorably in carbon market, clean energy tax incentives, auto efficiency standards, government procurement and green bonds, but fares poorly in carbon cap, renewable energy standards and feed in tariffs



THANK YOU

