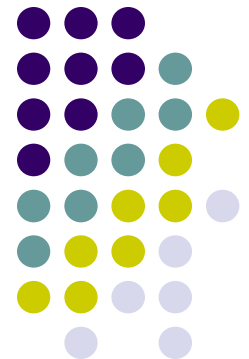


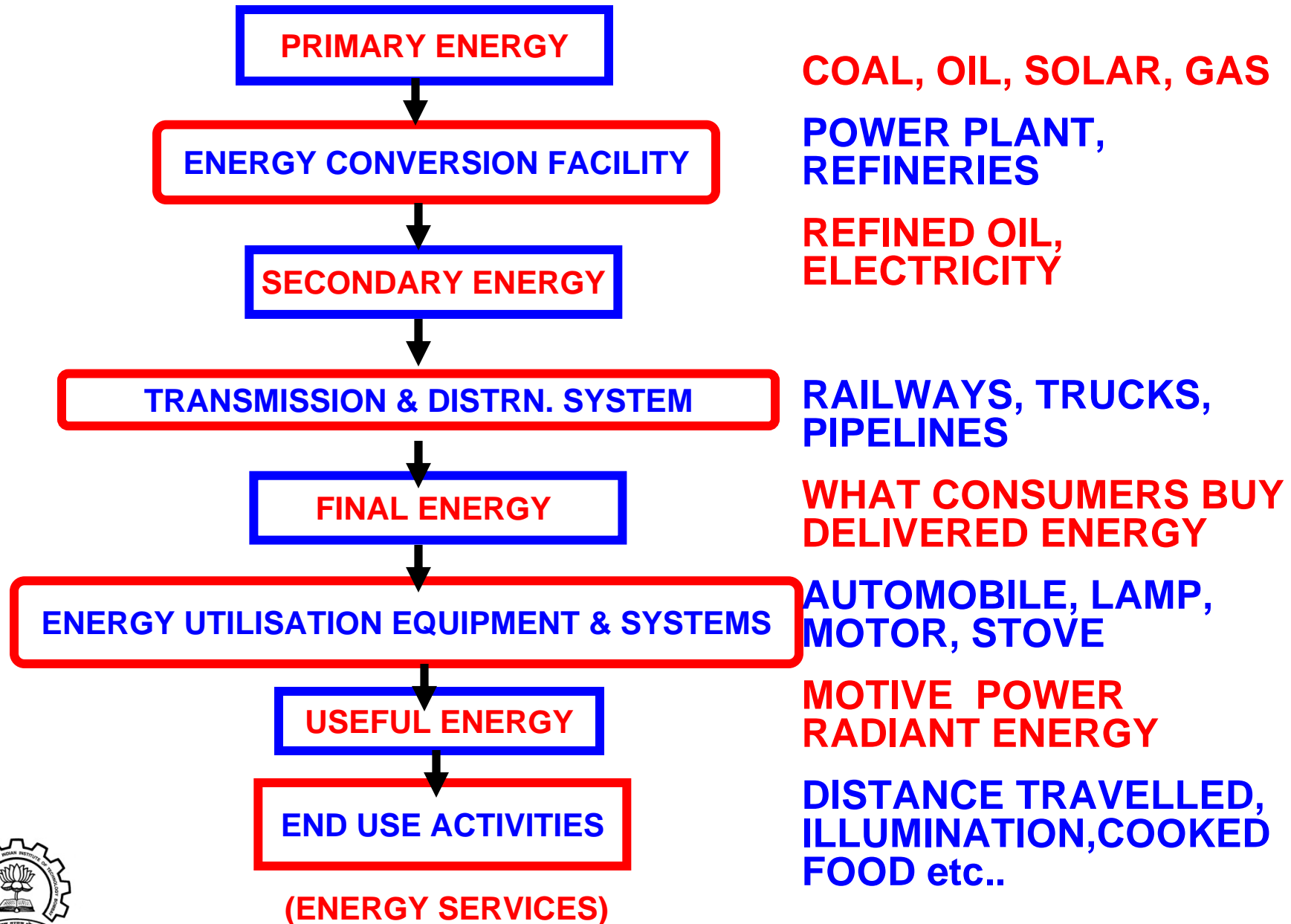
Energy, Materials and Nanotechnology

Rangan Banerjee
Department of Energy Science and Engineering
IIT Bombay

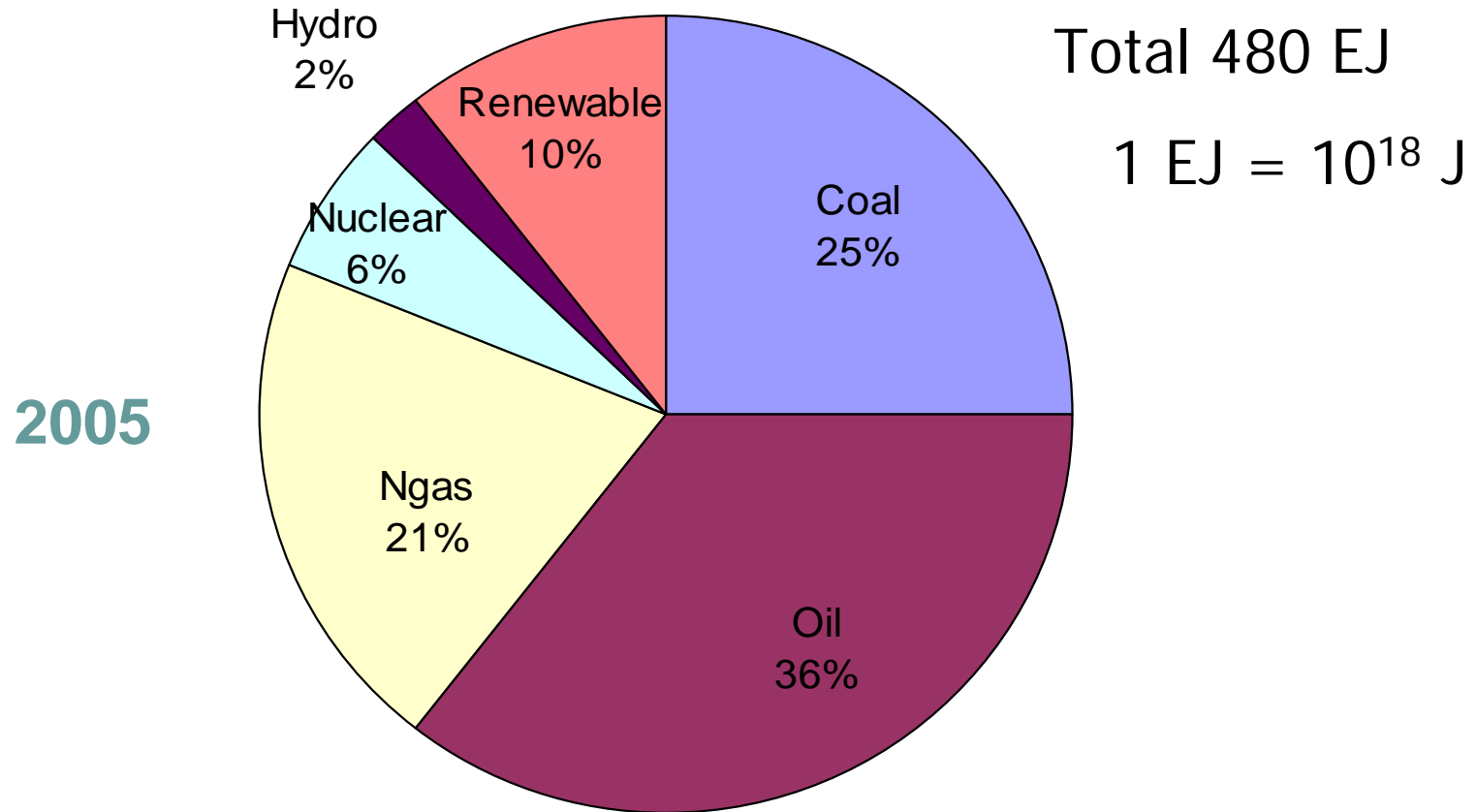


International Workshop on Nanotechnology for Energy Applications 1st December, 2008

ENERGY FLOW DIAGRAM



World Primary Energy Consumption



Data Source: <http://www.iea.org/>



Energy Issues

- Energy system – predominantly based on fossil fuel (~80% +)
- 2 billion people – No access to modern energy services
- Link between energy service and quality of life
- Significant disparity in per capita energy use
- Depletion of fossil fuels (peak oil?)
- Adverse environmental impact- local, regional, global



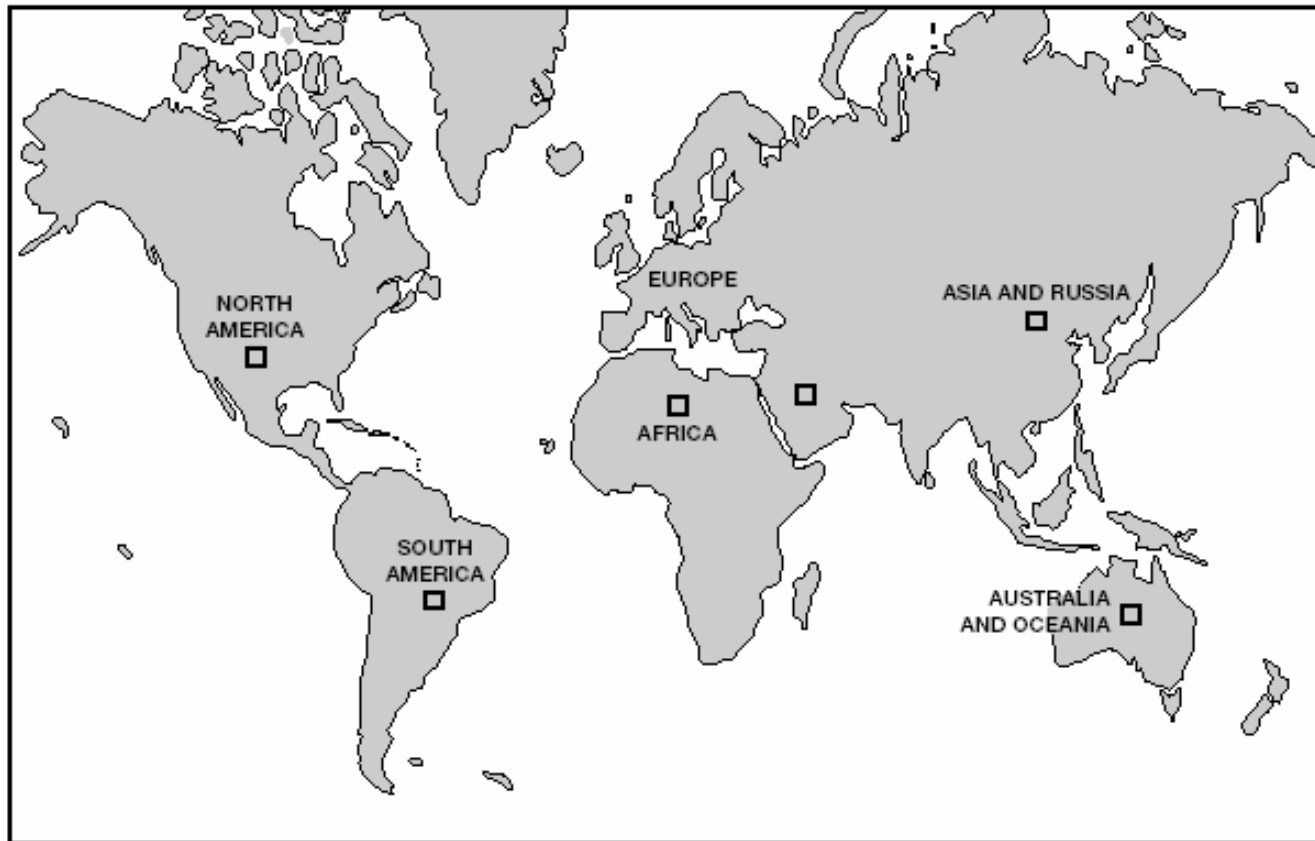


Figure 3. Solar cell land area requirements in which the six boxes (100 km on a side), located in areas of high solar radiation, can each provide 3.3 terawatts of electrical power to a total of ~20 terawatts of electrical power. Courtesy of Nate Lewis of the California Institute of Technology.

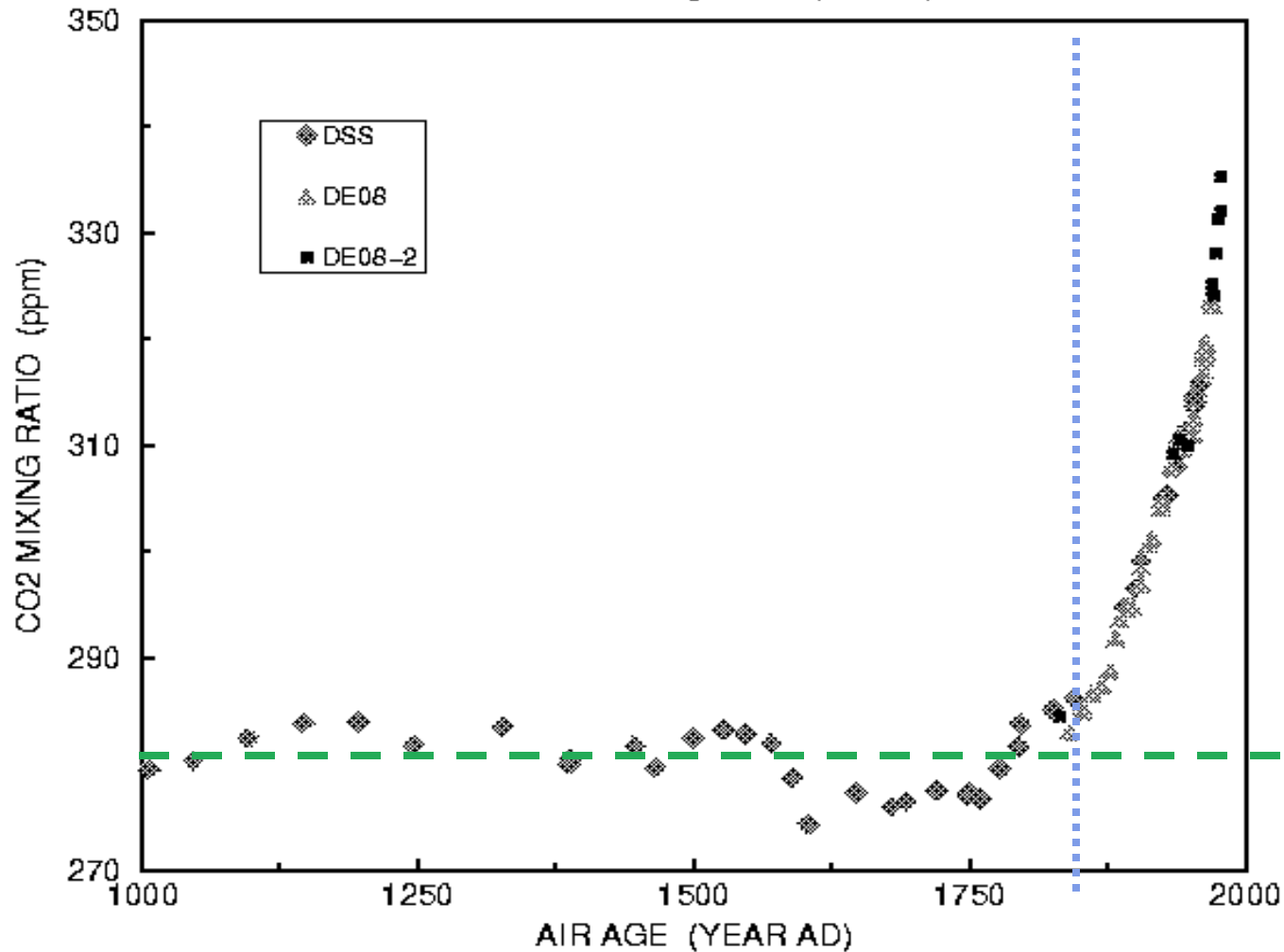
Source: R.Smalley (2005)



Carbon Dioxide Concentrations

LAW DOME, ANTARCTICA ICE CORES

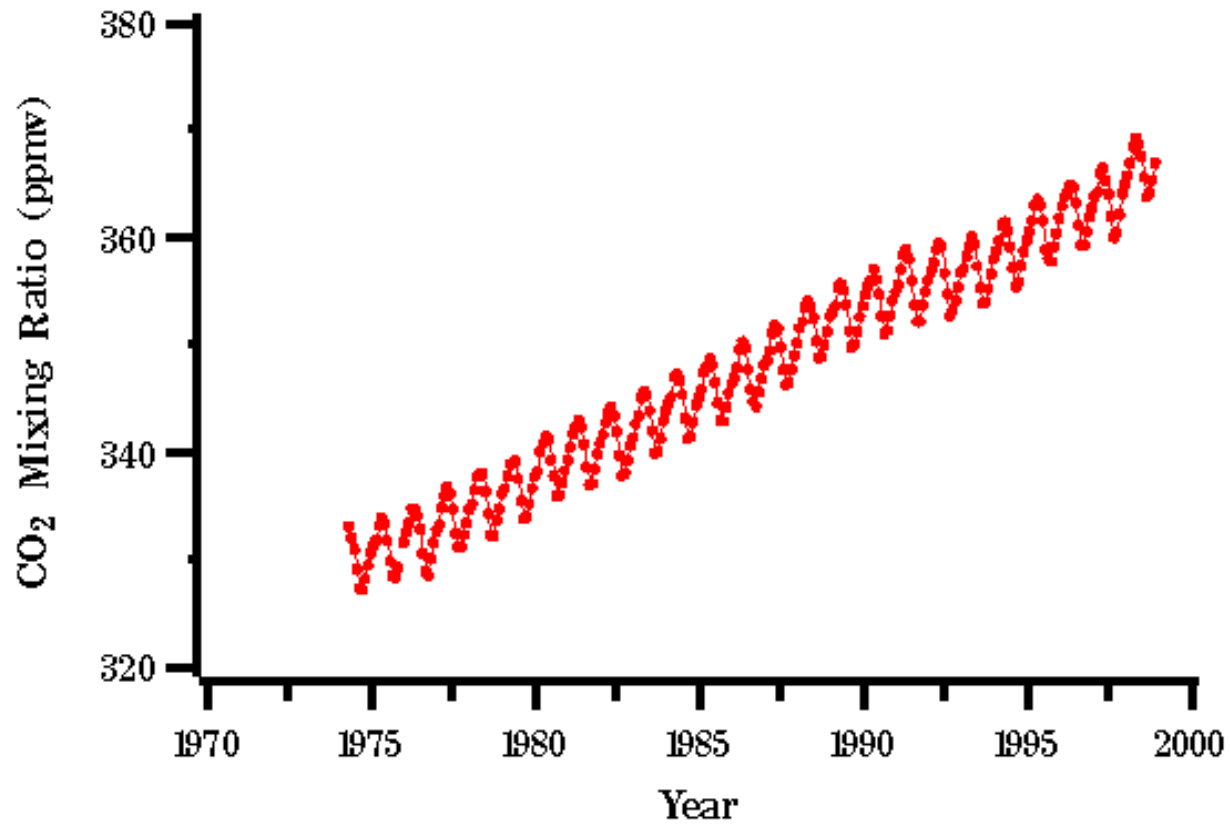
Source: Etheridge et al. (CSIRO)



<http://cdiac.ornl.gov/trends/co2/graphics/lawdome.gif>

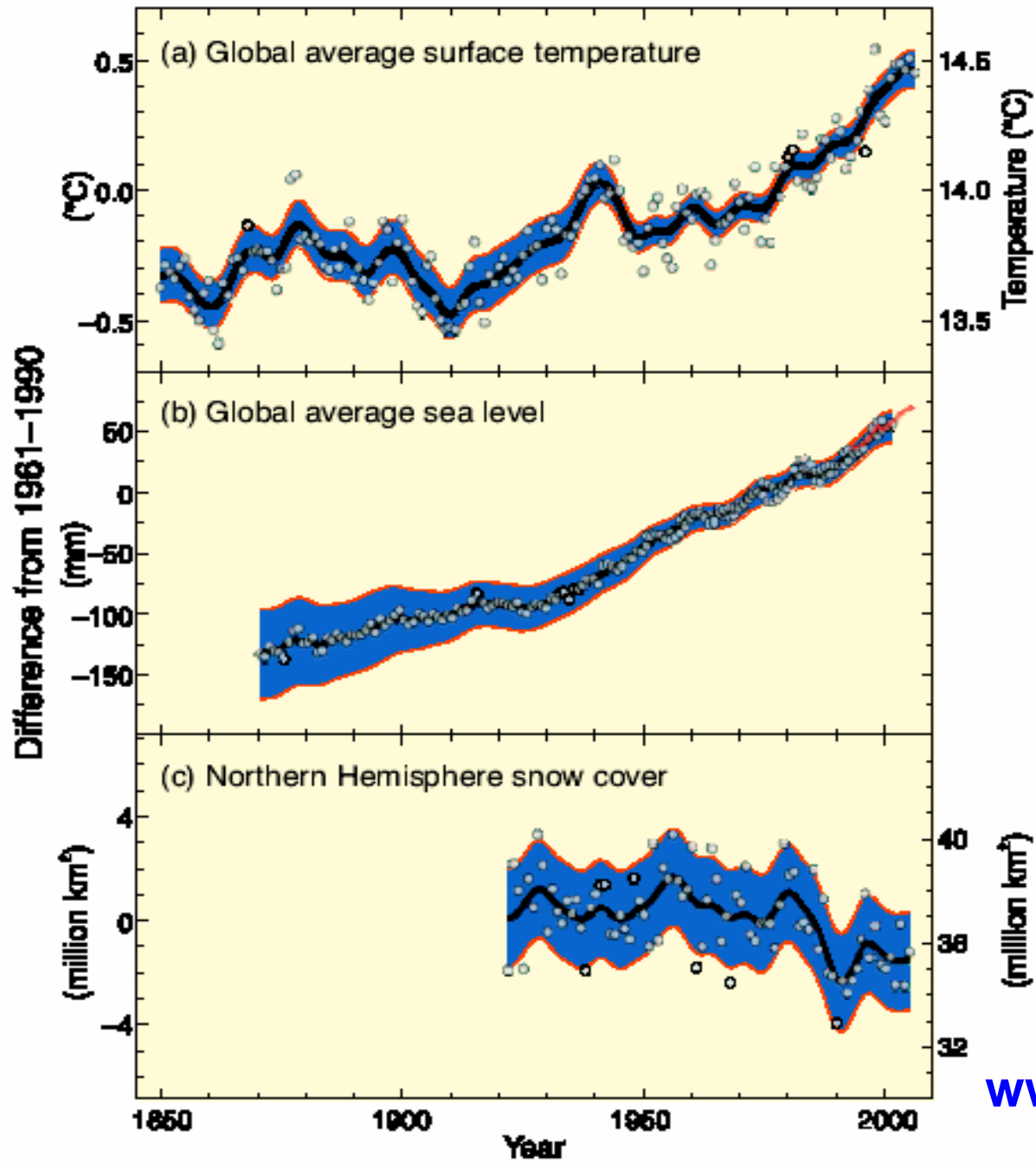
Carbon Dioxide Concentrations

Mauna Loa, Hawaii



Source: Kirk Thoning and Pieter Tans (NOAA/CMDL)

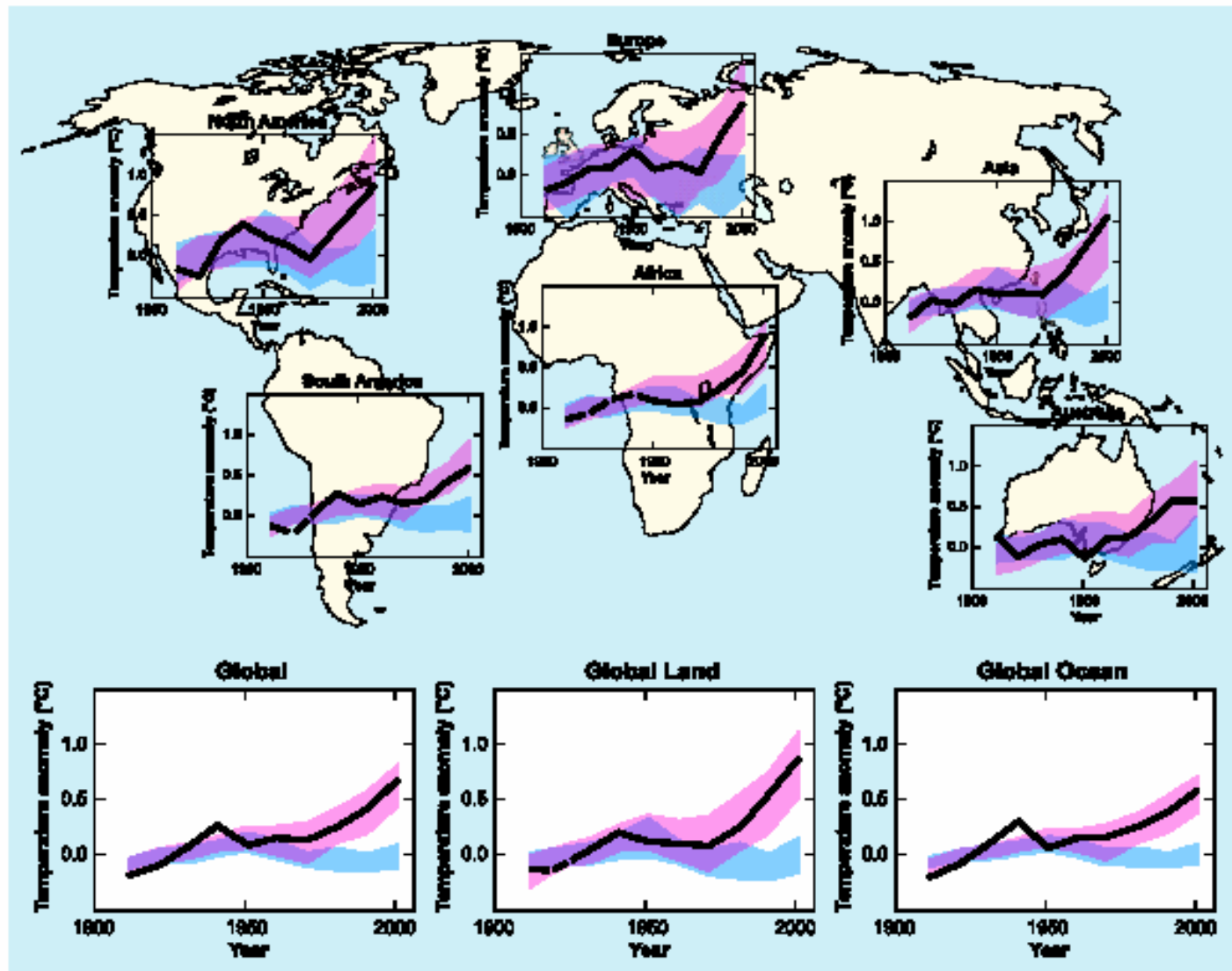




www.ipcc.ch



Global and continental temperature change



models using only natural forcings
 models using both natural and anthropogenic forcings
 observations



Energy and Climate

- Greenhouse gas (GHG) emissions –CO₂– mainly from energy sector
- Existing energy use patterns unsustainable in future
- Alternatives – aforestation (increase sinks), mitigation (renewables, energy efficiency, nuclear), carbon capture and storage
- Solutions costly



Materials and Energy

- How much materials do we use?
- Is this usage pattern sustainable?
- How does material usage impact the energy problem?
- Dematerialisation – key strategy to solve global environmental problems

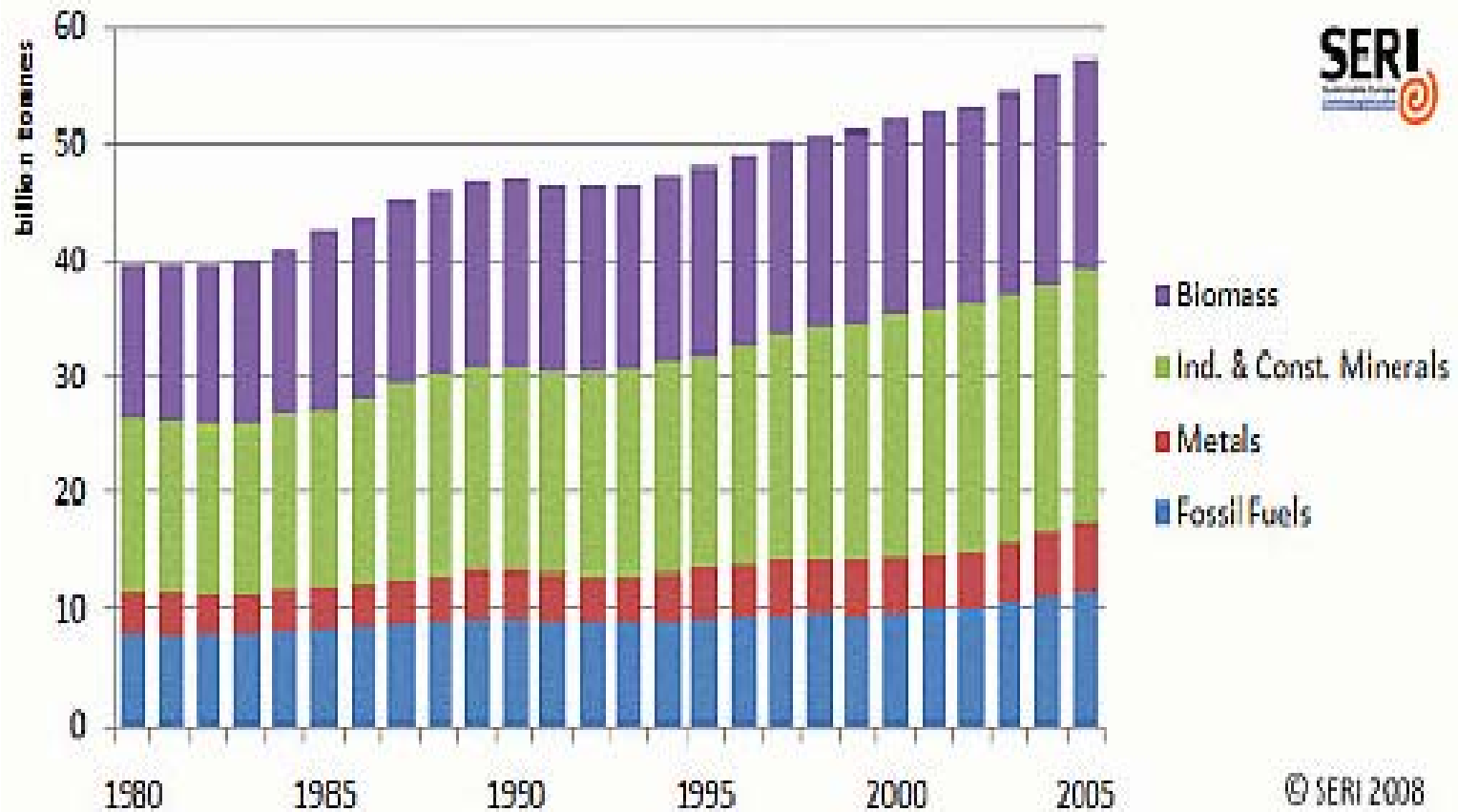


Classification of Materials

- Fossil fuels (coal,oil, gas,peat)
- Metal ores
- Industrial and construction minerals
- Biomass (agriculture, forestry and fishery)



Trends in Global Material Use



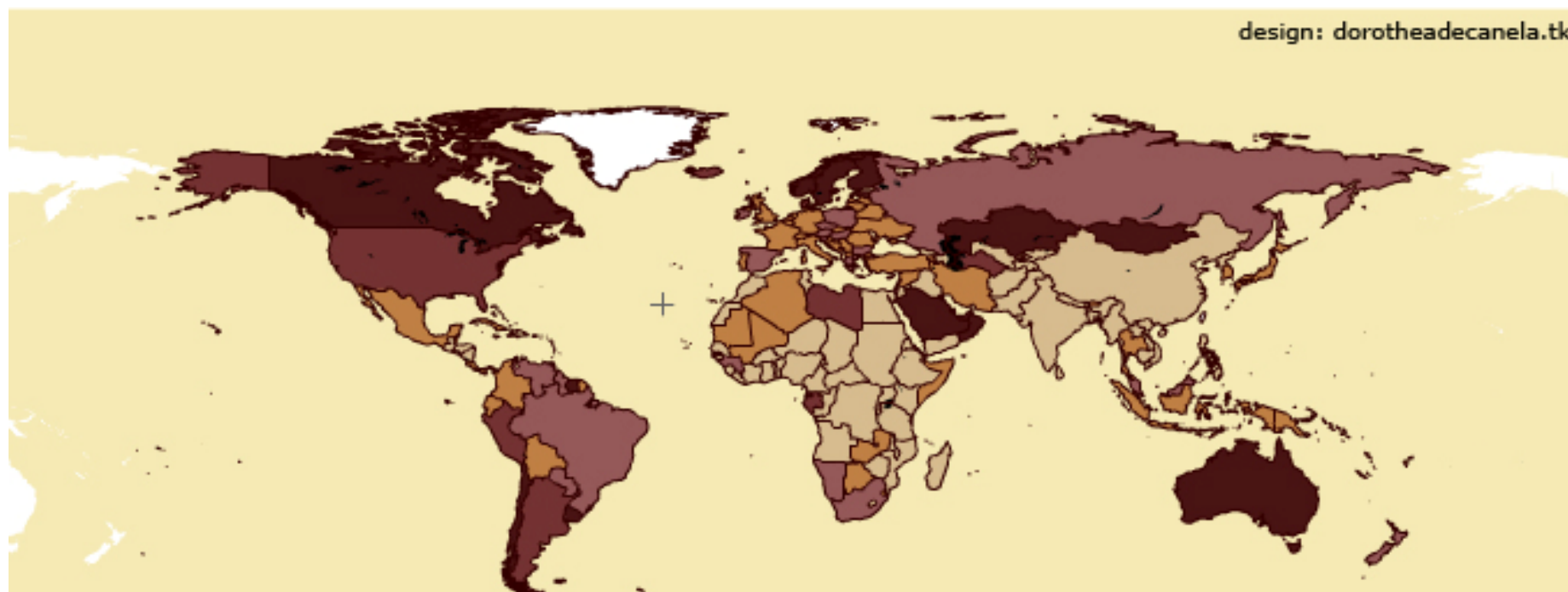
www.seri.at, Behrens et al (2007)

Total Used Extraction per Capita

Year: 2005, Unit: t/cap



design: dorotheadecanela.tk



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□ No reported extraction
■ 13.1 - 19.6

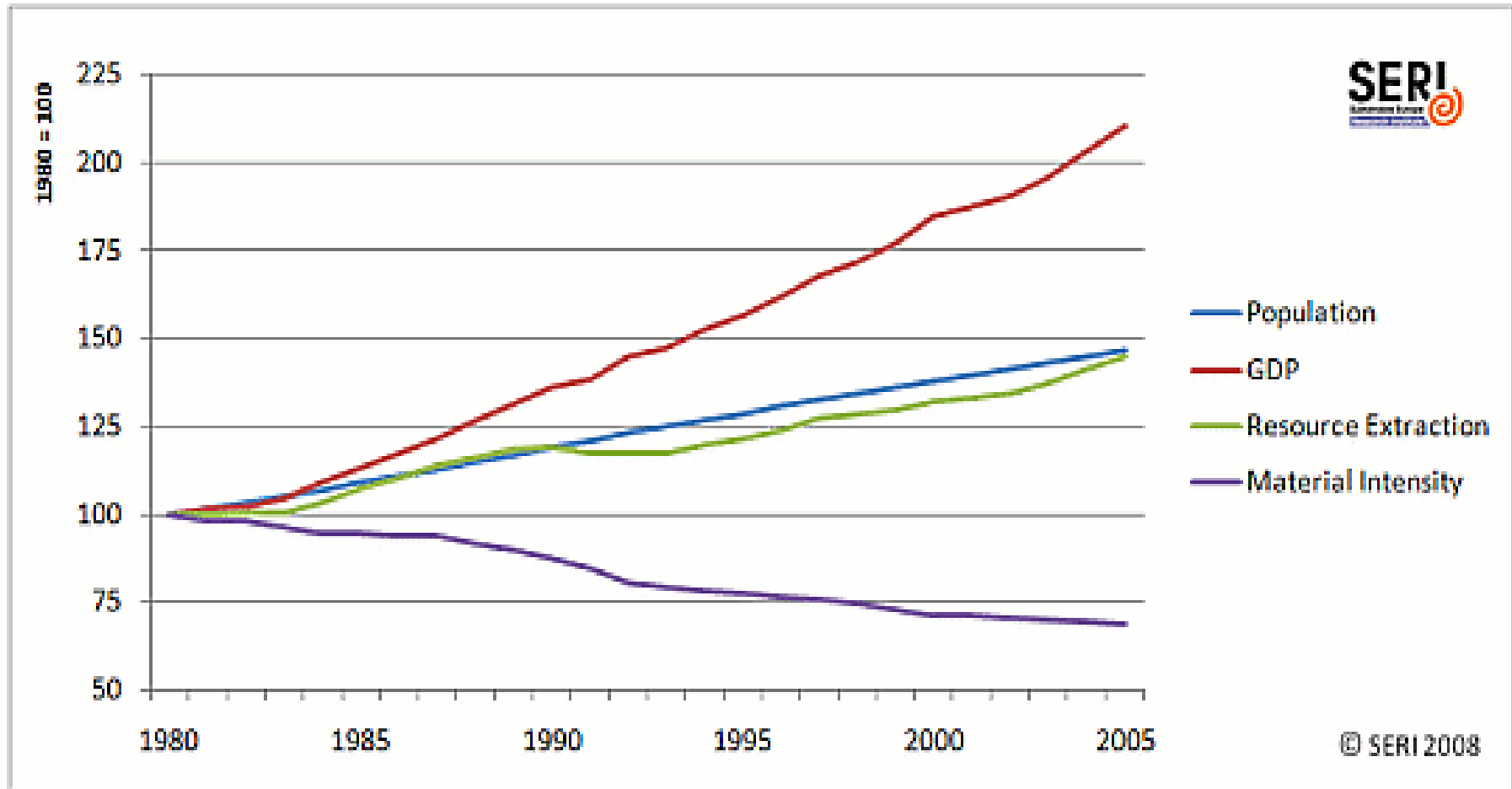
■ >0 - 6.51
■ 19.6 - 26.1

■ 6.51 - 13.1
■ >=26.1

www.materialflows.net

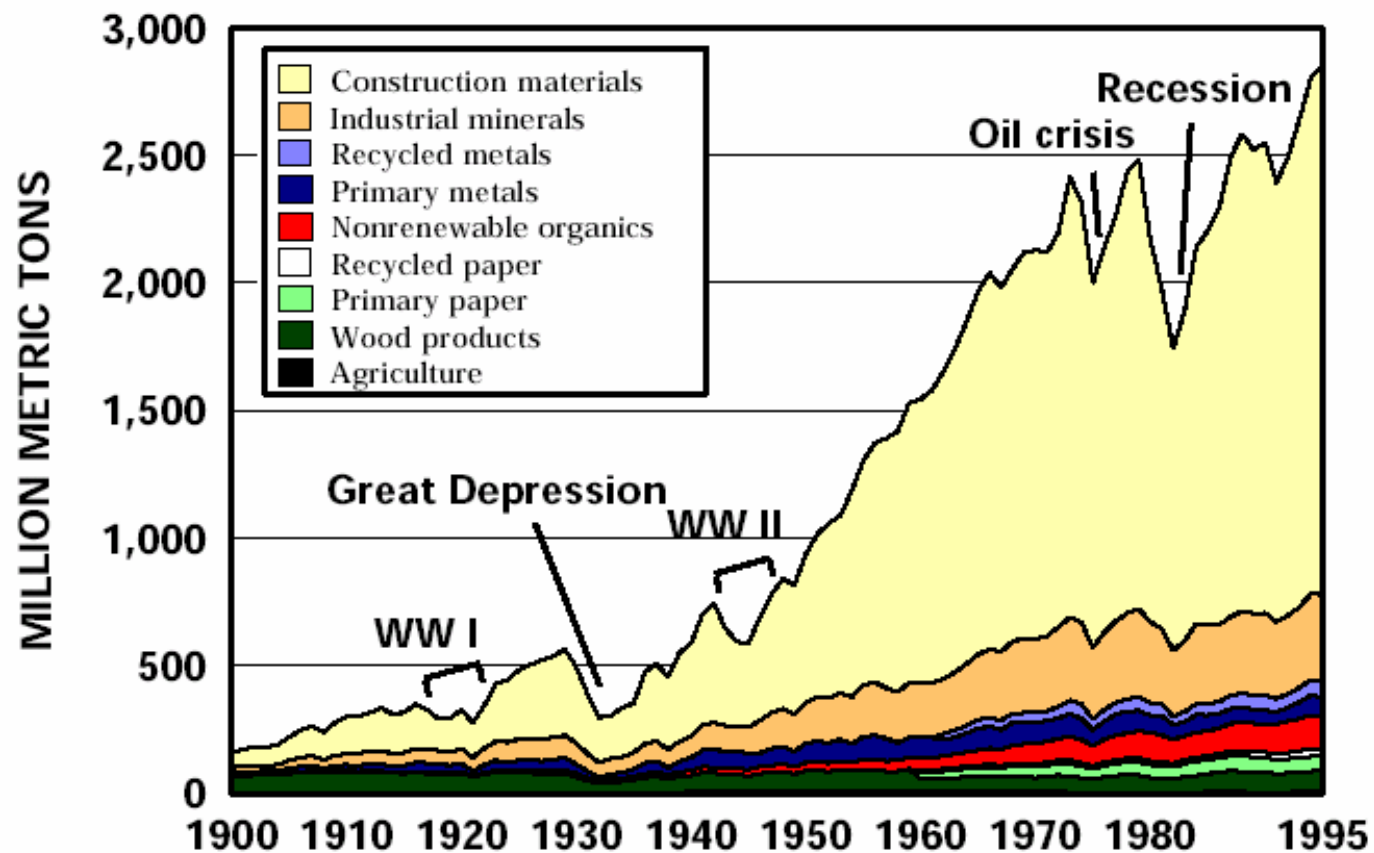


Trends in Growth rates



US Material Usage trend

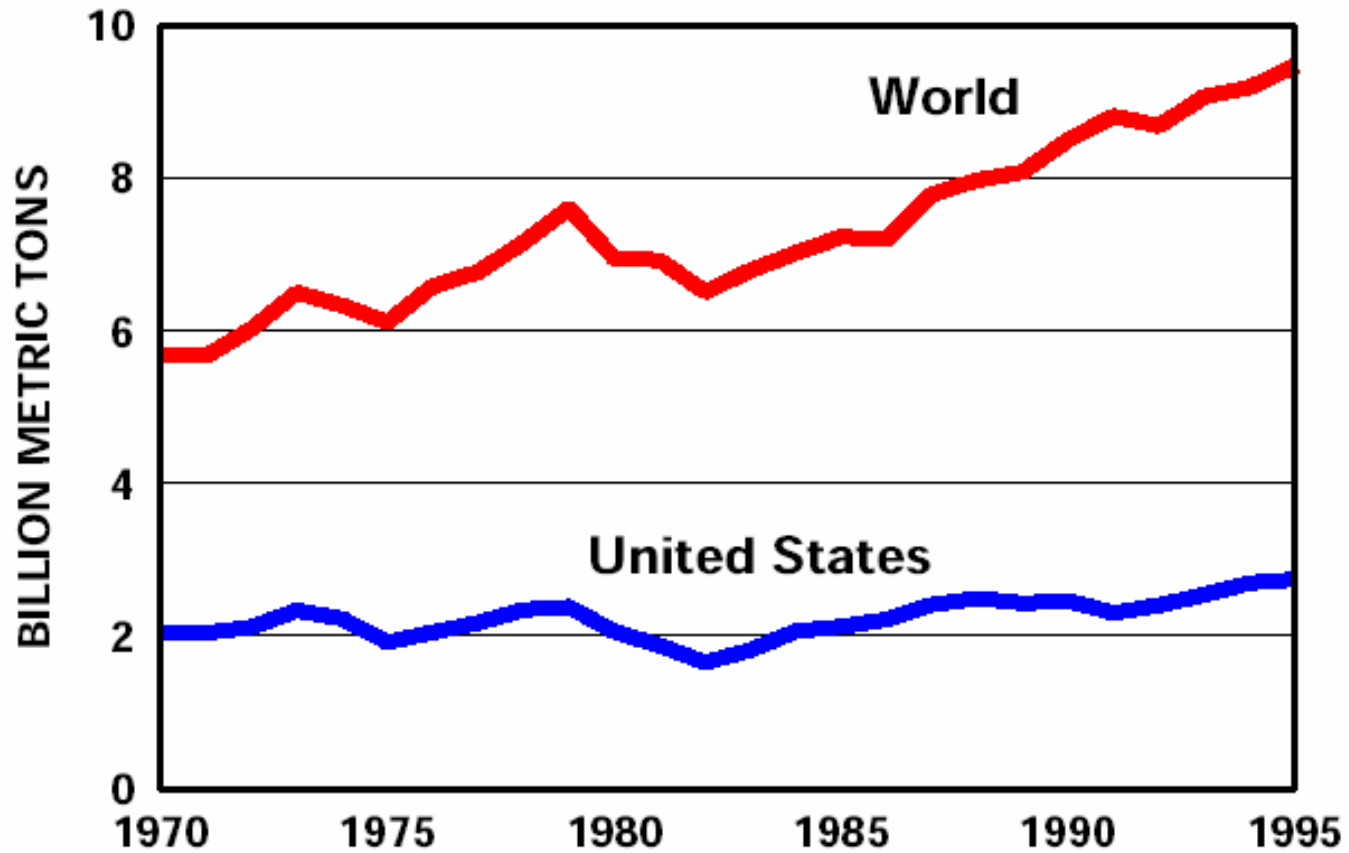
Excluding fuel and food



Matos and Wagner

World and US comparison

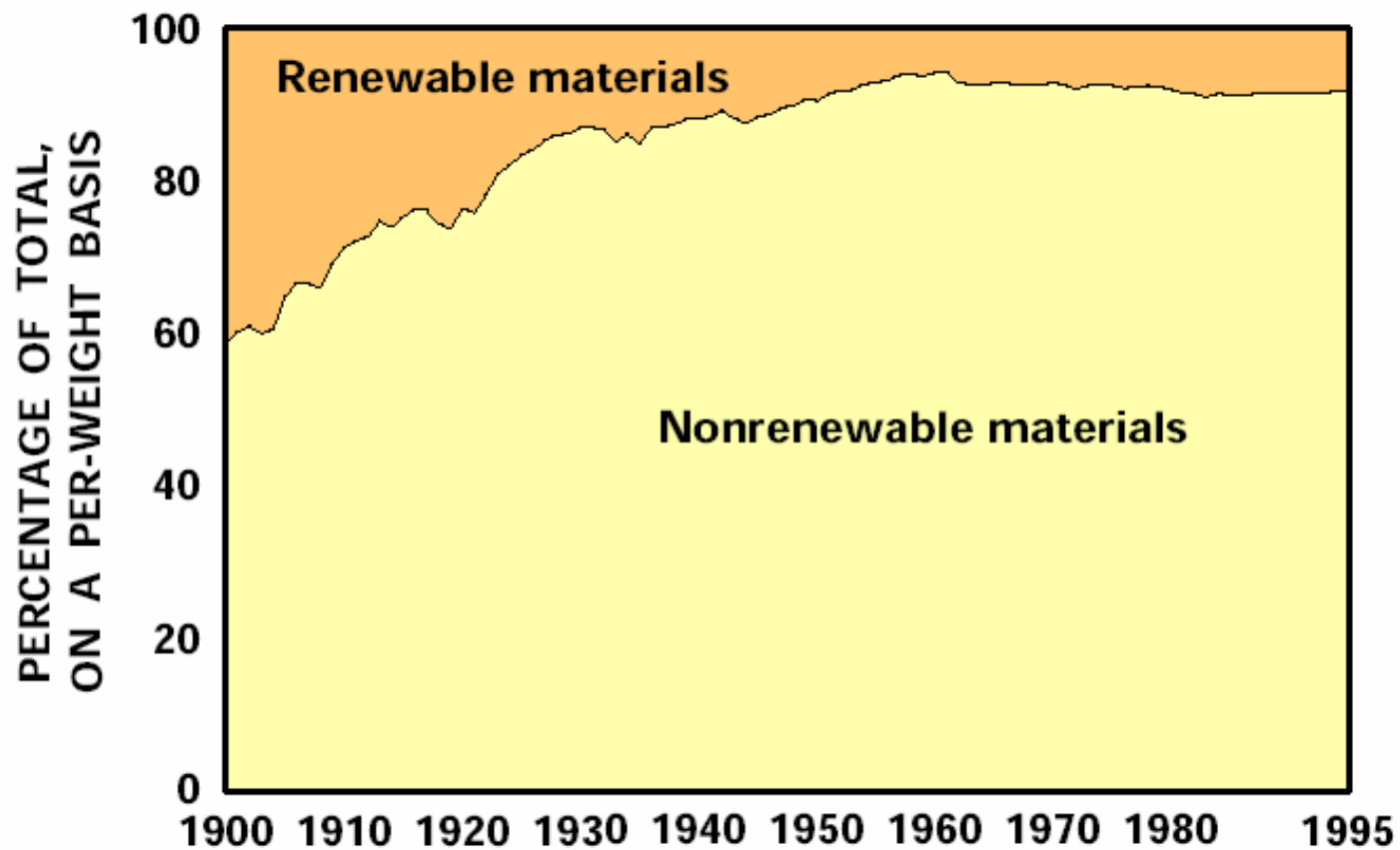
Excluding fuel and food



Matos and Wagner

US- Share of Non-Renewable Materials

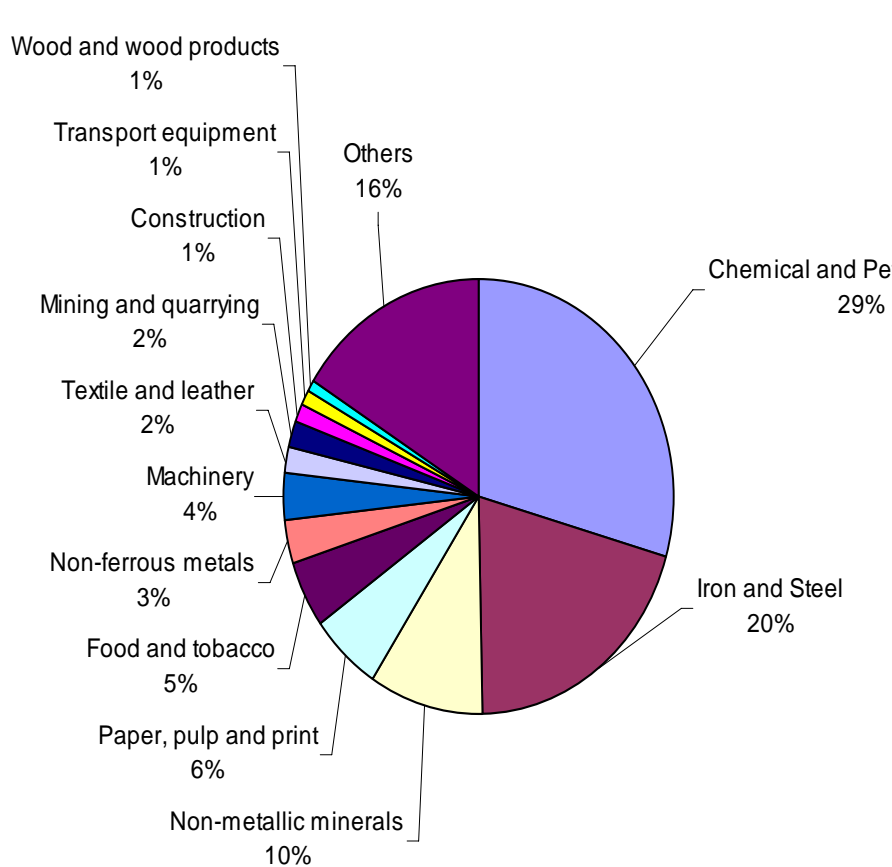
Excluding fuel and food



Matos and Wagner



Status of World Industrial Energy Use



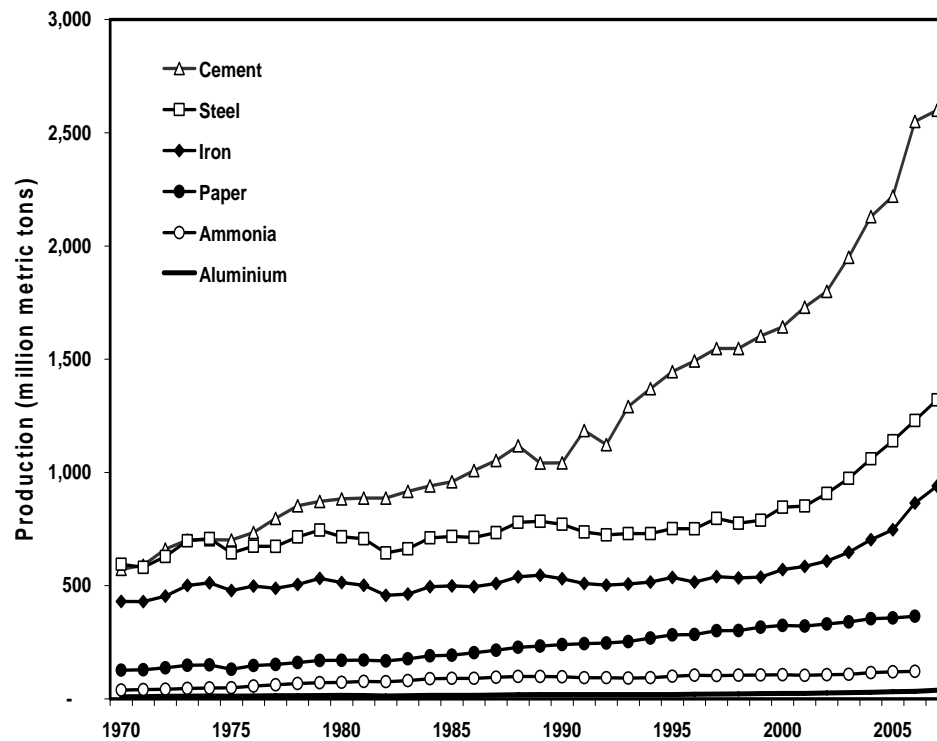
115-132 EJ in 2005

30% of Total World Energy use



Source:ETP, 2008

Trends in Material Usage



Energy intensive materials
50% of industrial energy use

Cement, Steel, Paper,
Chemicals and fertilisers etc.

Substitution

Higher growth rate in
developing countries



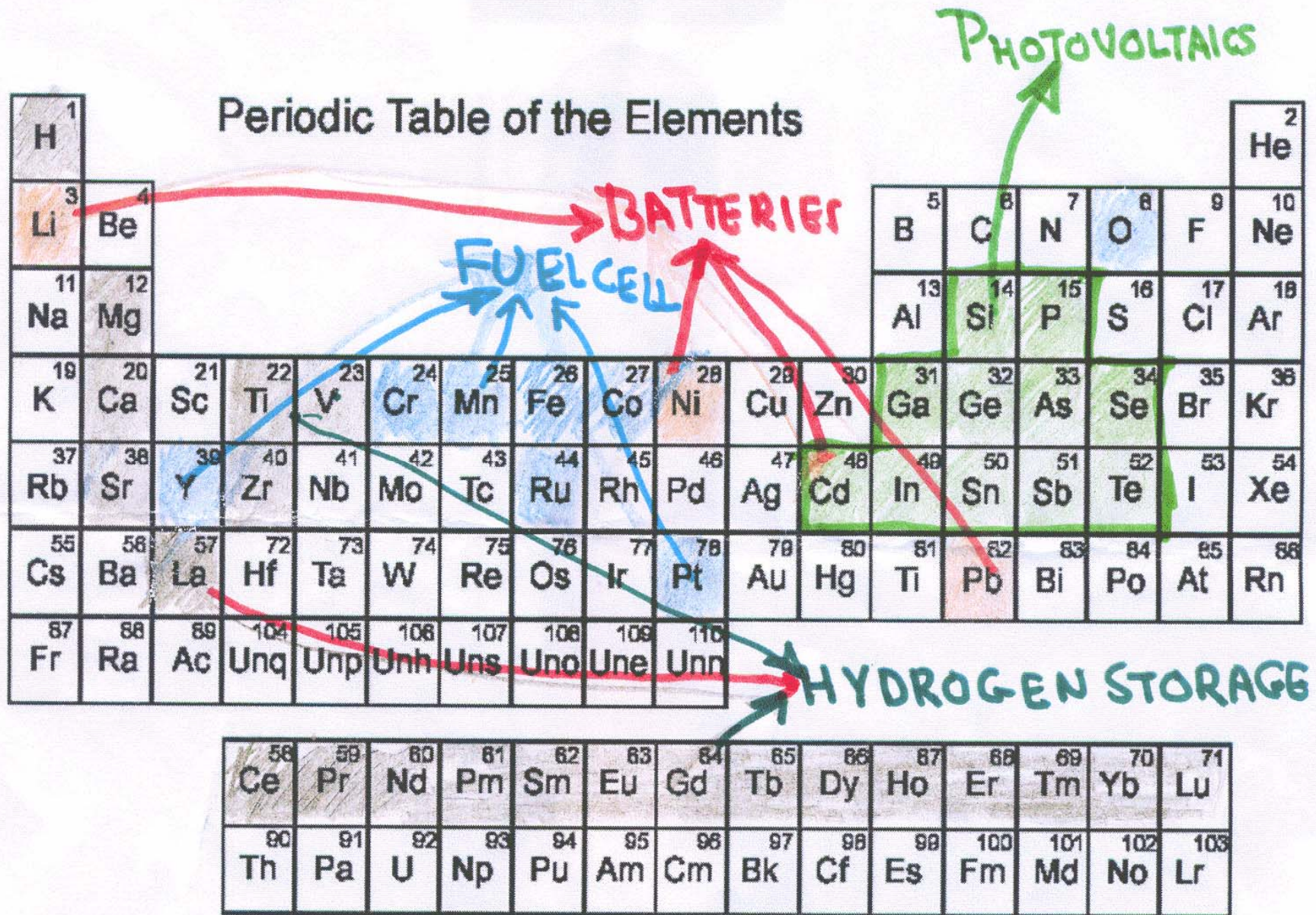
Source: GEA, KM8, Industrial End Use Efficiency(ongoing) 20

Goals for Materials

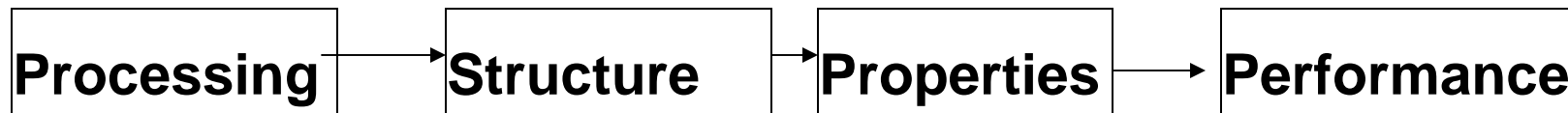
- Dematerialisation
- Energy Efficiency
- Reduced emissions
- ‘Sustainable’, renewable materials
- Cost Effectiveness



Examples of Energy Materials



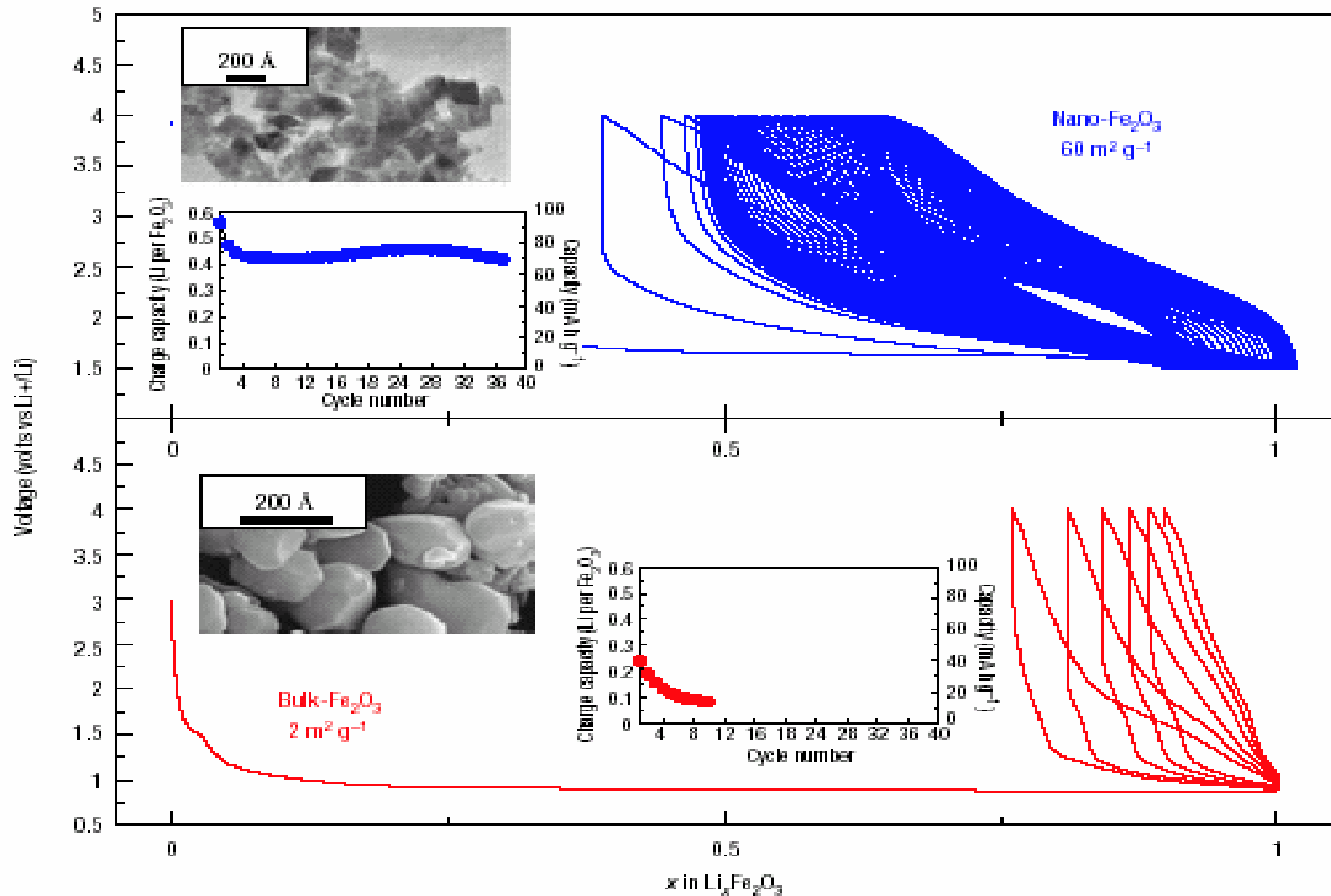
Nanotechnology



- **Macroscopic behaviour –often different from nanoscale/ quantum behaviour**
- **Synthesis of Materials with desired quantum behaviour**



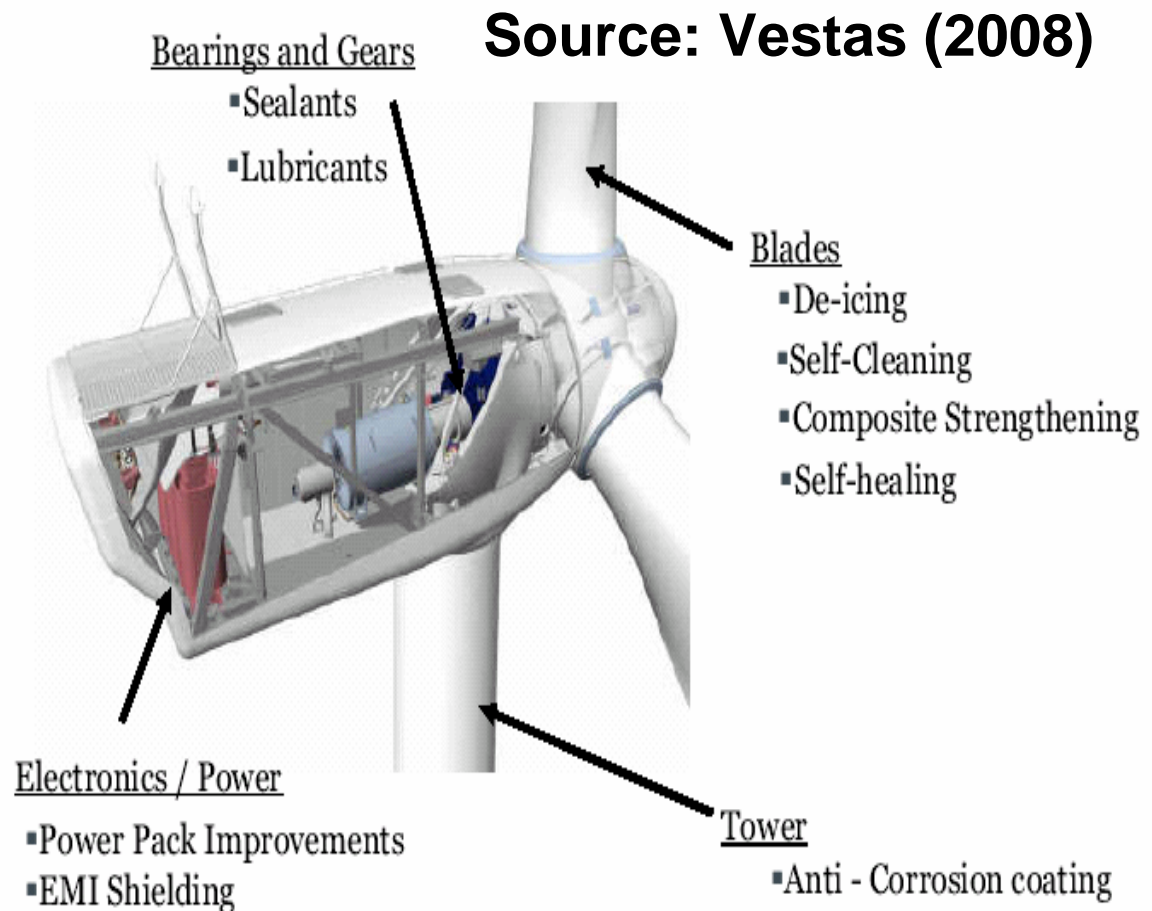
Example: Bulk and Nanostructured properties



Source: Arico et al, Nature Materials (2005)

Wind Energy

- Nano-coatings for blade structures
- Self-Lubricating surfaces for bearings and gears
- Sensors for Structural Health monitoring



Real Time Sensing

- Nano –Sensors- Real time sensing
- Injecting magnetic nano-particles into reservoirs
- Distributed wireless sensors ‘smart dust’
- ‘Resbots’ – Reservoir robots –‘EXPEC ARC’ – first trial claimed in Ghawar field – ARAMCO Saudi Arabia (crealis, 2008)
- Chevron- use of miniaturised flow sensors and fibre-optic thermocouples- 20% saving (Gillett,2002)
- Applications in Geothermal resource, Nuclear mining



Electrosynthesis

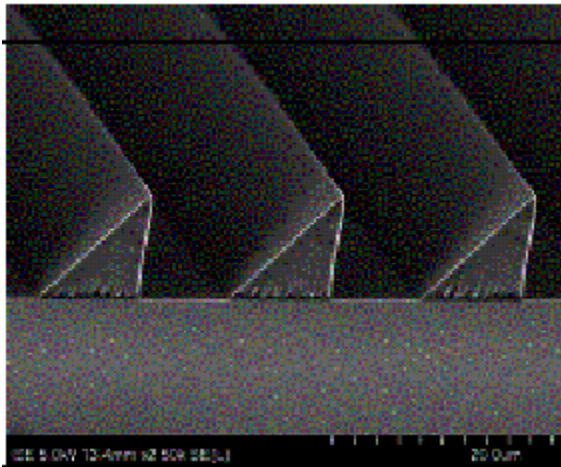
- Synthesis of chemical compounds in an electrochemical cell
- Ambient pressure electrosynthesis of Ammonia (Marnellos and Stoukides. 1998), Kordali et al (2000)
Conventional Haber process – 480° C, 100 atm, energy intensive
- Solid Polymer Electrolytes
- Electrocatalysts
- Nanotechnology – to engineer catalyst, electrolyte combinations – for viable conversion processes



Smart Materials



Glass characteristics



Microstructured glazing

**Electrochromic windows -
Active Material – Tungsten
oxide**

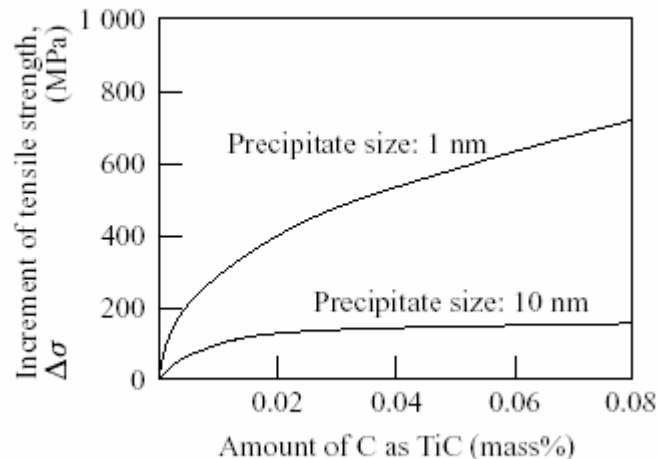
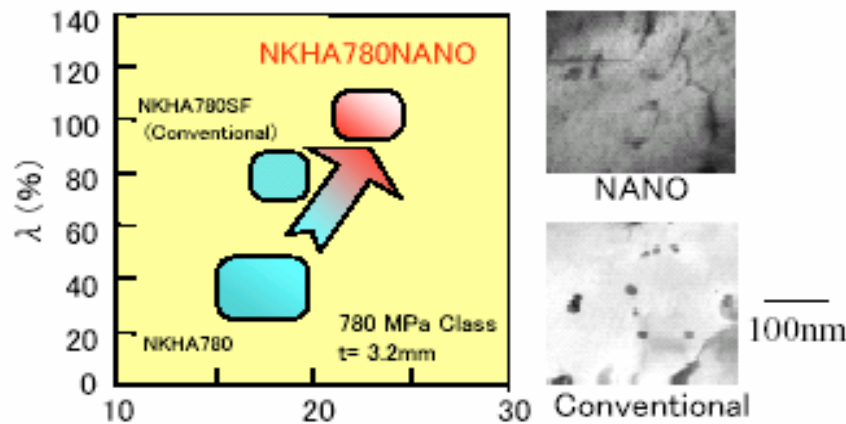
**Reversibly darken – Voltage
applied by nanostructured
electrodes – Normally Indium
Tin Oxide – Substitution by
nanostructured ZnO**

Photochromic windows

Source: EU Nanotech report, 2003



Improved Material properties

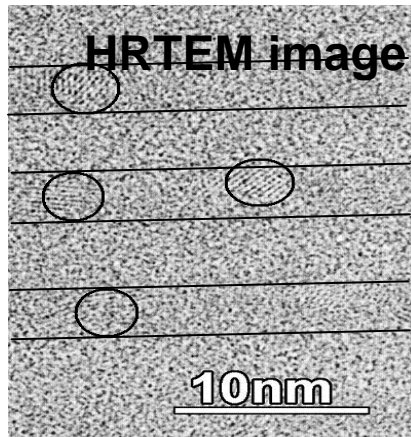


- Example – NANOHITEN (JFE) Steel (780 MPa)
- Precipitates of Ti, Mo C ~3 nm
- Higher strength with increased hole expansion ability and elongation
- 10% reduction in weight

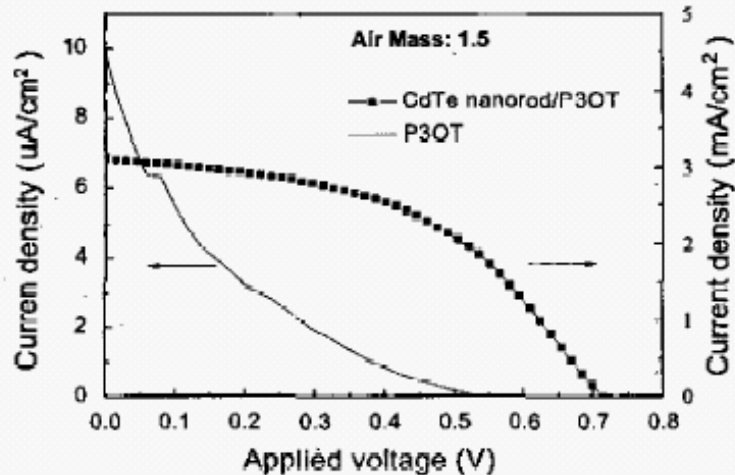


Source: JFE Tech report (2007)

Solar Photovoltaics



Source: Solanki et al

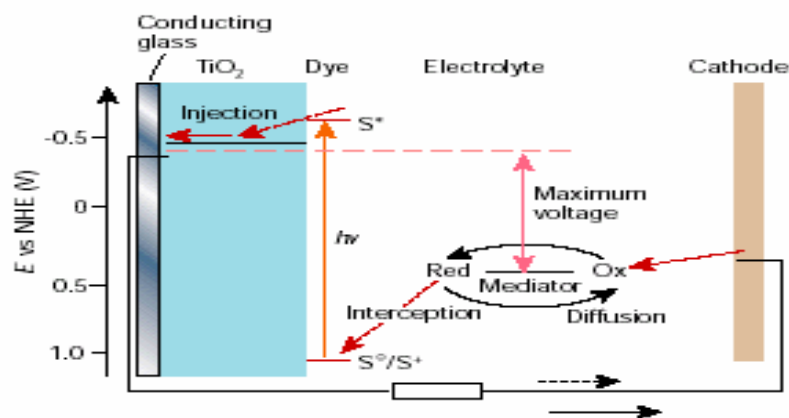


Source: Kang and Kim (2005)

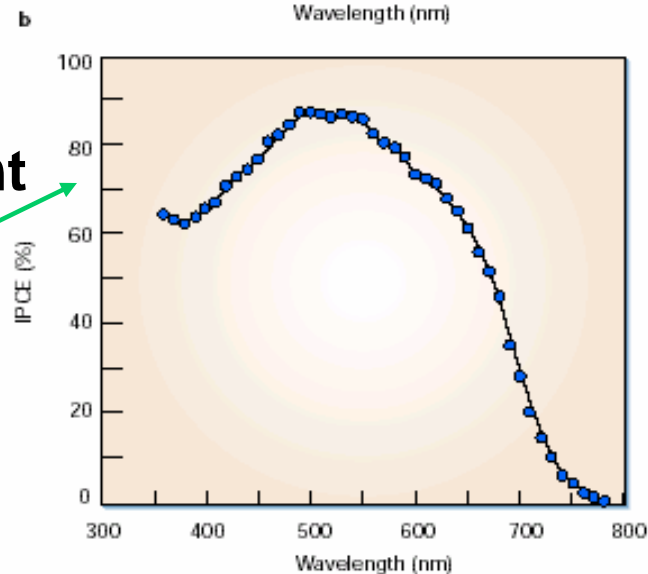
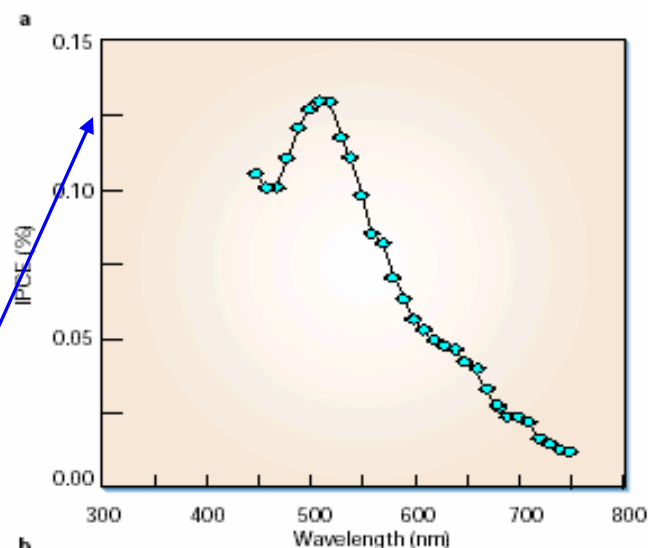
- Porous Silicon
- Quantum dots
- Band gap engineering
- Nanomaterials for high efficiency, low cost CIS cell
- Polymer PV –conjugate polymers and carbon nanotubes
- Nanorods of CdTe (Nansys)
- CdTe/conjugate polymer hybrid



Photoelectrochemical Cells



- Dye Sensitised TiO₂ electrodes
- Comparison of photon to current conversion efficiency – **single crystal electrode (A)** with **Nanocrystalline electrode (B)**



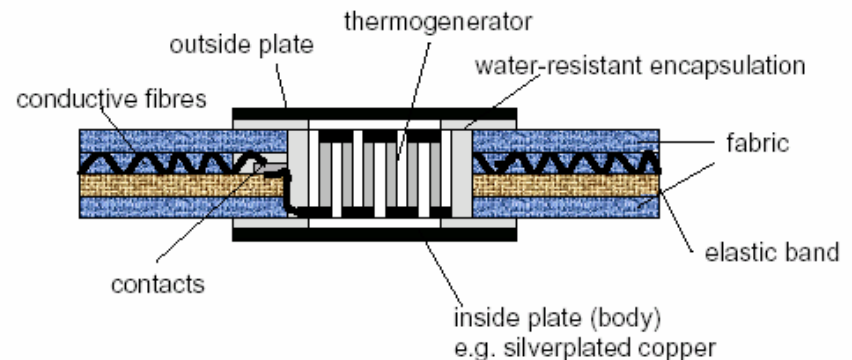
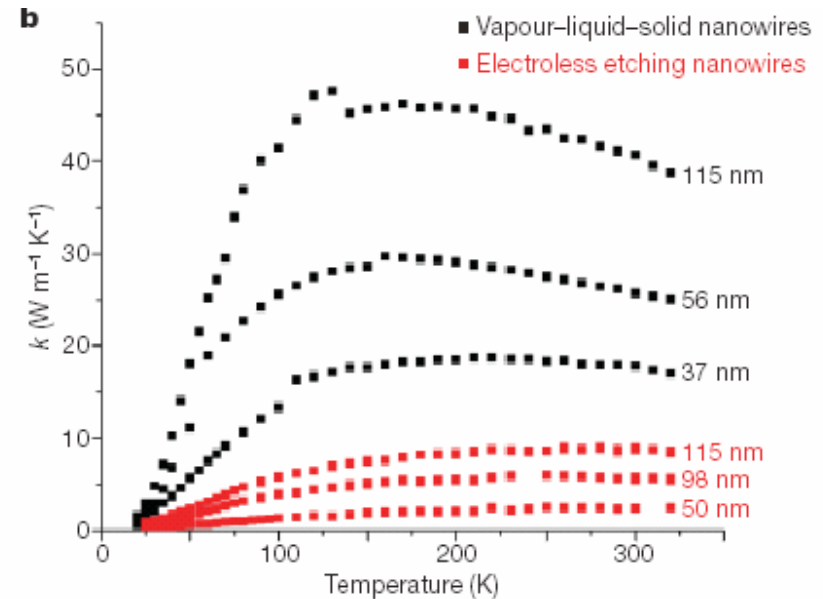
Source: Graetzel (2001)

Thermoelectrics

- Thermoelectric generators and coolers
- Figure of merit $ZT = S^2T/\rho k$
- Bi_2Te_3 , $(\text{Bi Sb})_2\text{Te}_3$ (ZT 1-2)
- Silicon nanowires 50 nm ZT 0.6 room temp
- Berkeley, 7nm Bi wires- ZT 6
- Michigan
- Smart clothes – powered by body heat

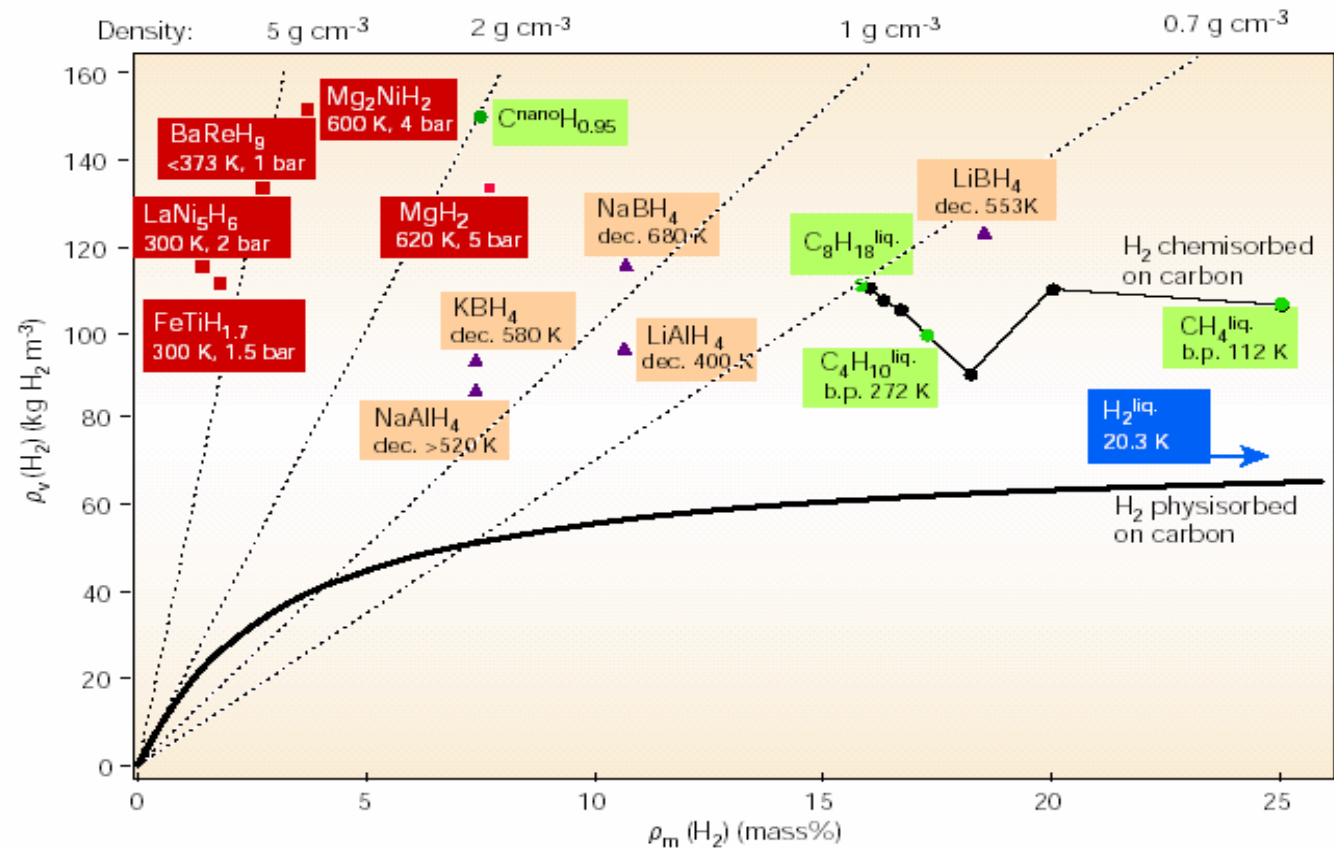
Sources: Hochbaum et al (2008),

Lauterbach et al (Infineon) 2002



Hydrogen Storage

- BASF – Nanocubes – 3D organometallic networks
- Metal hydrides
- Alanates, light hydrides

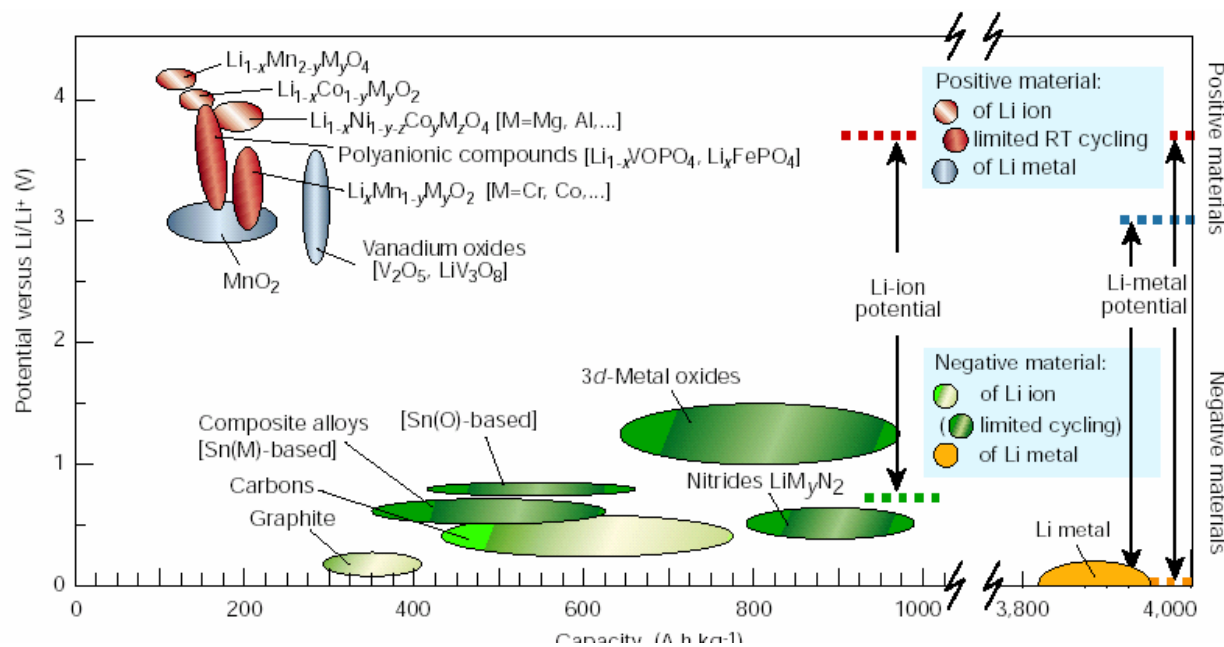
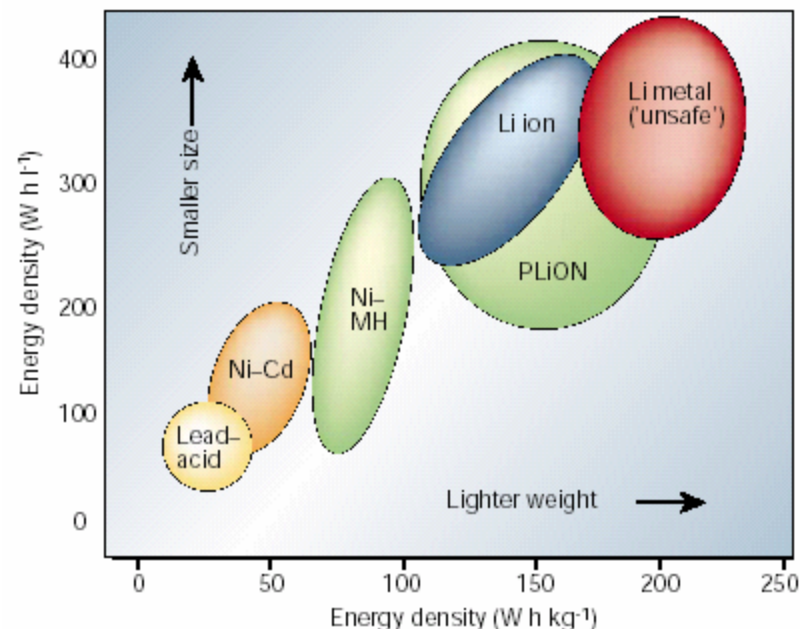


Source: Slapbach and Zuttel, 2001



Batteries

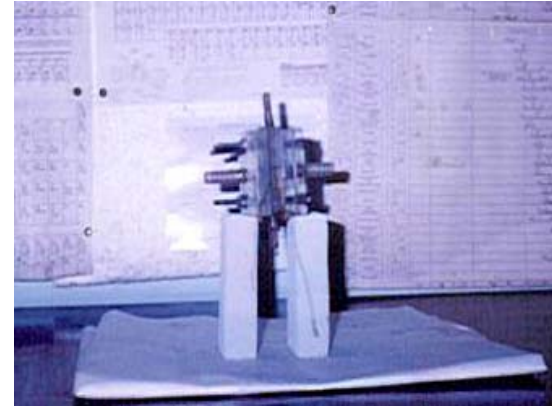
- Li-ion, Ni-MetalHydride
- Nanoparticle fillers
Al₂O₃, TiO₂ to polyethylene Oxide (electrolyte)
- Metal intercalated electrodes
- Supercapacitors-High power, long cycle life – Nanostructured carbon



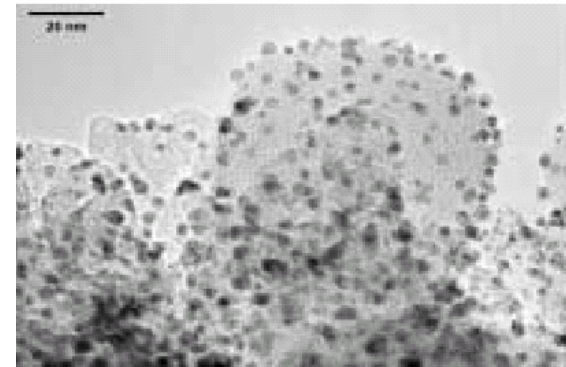
Source: Tarascon and Armand (2001), Arico et al (2005)

Fuel Cells

- Nanoscale catalysts for PEM – reduce costs of metal
- Nanocrystalline zirconia films- electrolyte for SOFC
- Ceramic nanopowders for SOFC (ItN Nanovation, Nextechmaterials)
- SONY- fullerenes – electrodes for DMFC



Alkaline fuel cell



Carbon supported metal catalyst



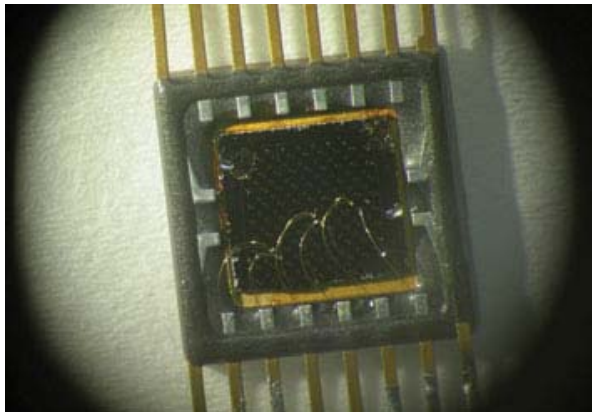
Source: EU Nanotech report, 2003

Efficient Lighting



Blue LED

- Quantum Caged Atoms (QCA) – efficient Solid State Lighting (few nm) – GE, Phillips, Siemens



Q- dot based device

- QCA based nanophosphors- five times as efficient as conventional – FTL (UV to white)

- Kopin – nanopockets – blue LED

- Night vision systems based on quantum dots



Nano BioTechnology



Molecular model -artificial reaction center

- Combination of nanoparticles, surfaces and biomaterials – Artificial photosynthesis systems
- Microbial fuel cell – Nanomaterials for electrodes, catalysts



Summing Up

- Energy – shortages, disparity, fossil fuel depletion
- Climate change- GHG – ‘Unsustainable’
- Linkage material use and energy
- Nanotechnology –potential to modify/ obtain desired material properties
- Materials improved properties, real time sensing, electrosynthesis, energy efficiency, improved energy conversion devices, energy storage
- Challenge -Lab-scale – to products



Thank you

References

www.seri.at

Matos and Wagner

<http://cdiac.ornl.gov/trends/co2/graphics/lawdome.gif>

www.nanoforum.org, Nanotechnology helps solve the worlds energy problems, August 2003

www.materialflows.org

<http://www.iea.org/>

G. Marnellos and M. Stoukides, *Science*, 1998, **282**, 95.

Kordalli et al,2000

<http://crealis.es/2008/10/saudi-arabia-using-nano-agents-to-test.html>

www.ipcc.ch

R.Smalley, 2005

ETP, 2008

Gillett,2000

Slapbach and Zuttel, 2001, *Nature*, Vol 414, p 353-358

J.M.Tarascon, M.Armand,2001, *Nature*, Vol 414, p 359-367

B.C.H.Steele, A.Heinzel, *Nature*, Vol 414, p 359-367

M.Graetzel, *Nature*, Vol 414, p 338--344

Arico et al, *Nature Materials*, Vol 4, May 2005, p 366 -377

Behrens et al (2007)

Kazuhiro et al,JFE Technical report, Dec 2007

Vestas (2008)

