



The Role of Materials in Creating a Sustainable Economy

Prof. Paul Hogg CEng, CSci, FIMMM, 2004

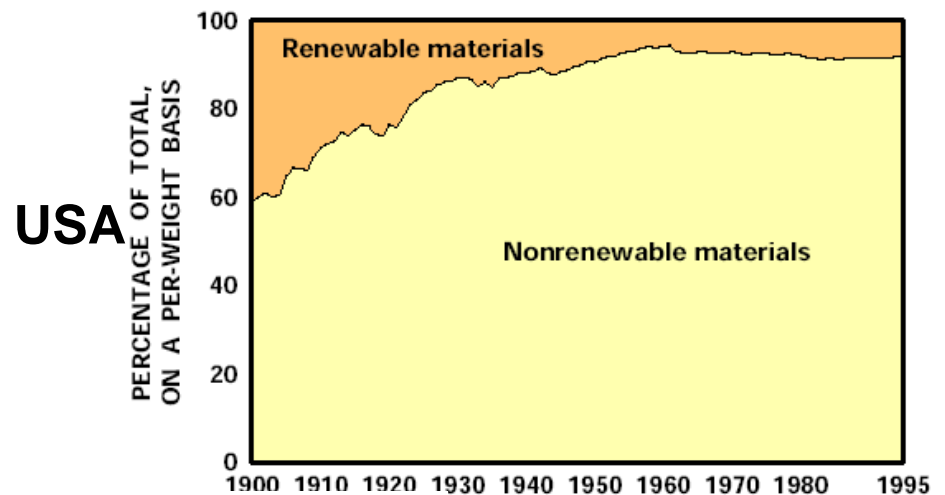
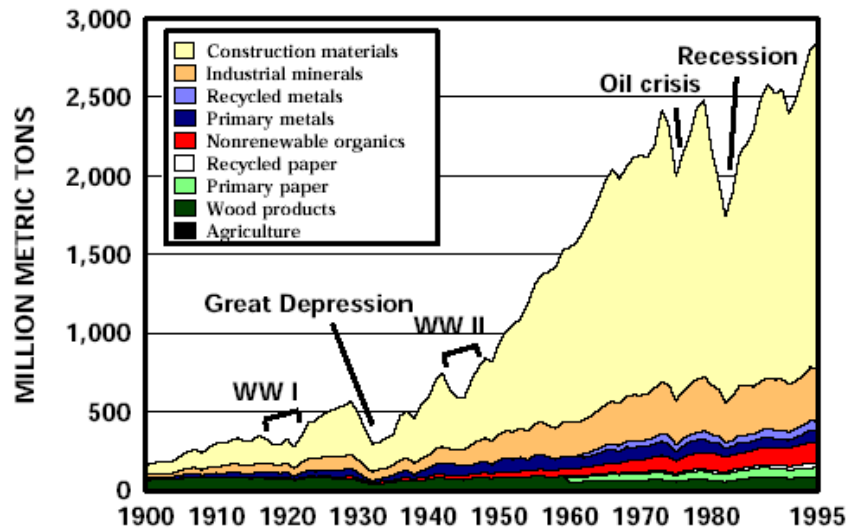


Contents

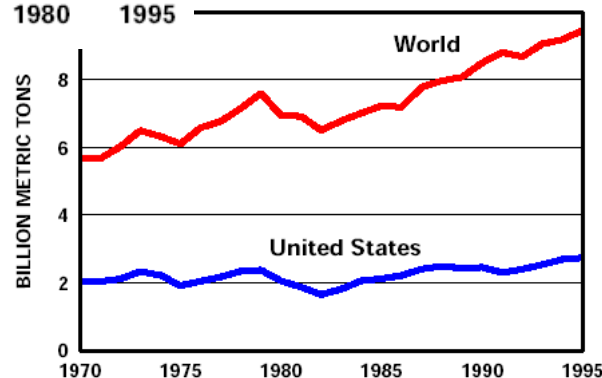
- ▶ Introduction
- ▶ Sustainable Development
- ▶ The Role of Materials
 - ▶ Minimise Pollution
 - ▶ Conservation of Resources
 - ▶ Maximisation of Clean Energy Supply
 - ▶ Reduce Consumption
 - Reduce fuel consumption (reduce weight)
 - Retain/manage heat
 - Reduce power losses
 - ▶ Facilitate Supply & Use of Sustainable Energy
 - Energy capture (PV)
 - Energy conversion (wind and fuel cells)
 - Energy storage (batteries, flywheels)
- ▶ How to Ensure Technology is Exploited
- ▶ Concluding Thoughts

Introduction

- ▶ Materials consumption increases annually and is increasingly non renewable.



USA vs RoW





UNSUSTAINABLE DEVELOPMENT



OUR FUTURE?



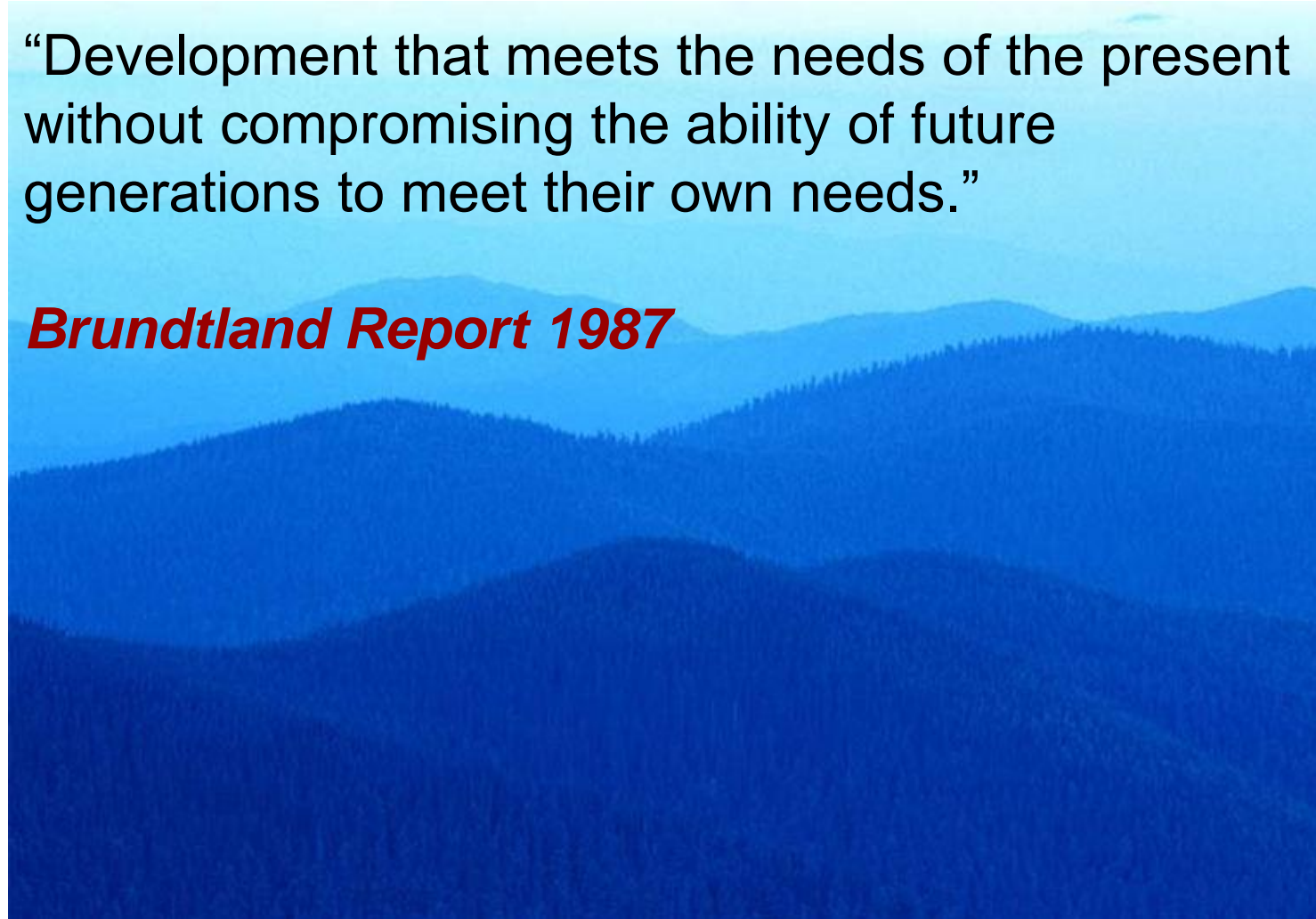


Sustainable Development

Sustainable Development

“Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Brundtland Report 1987





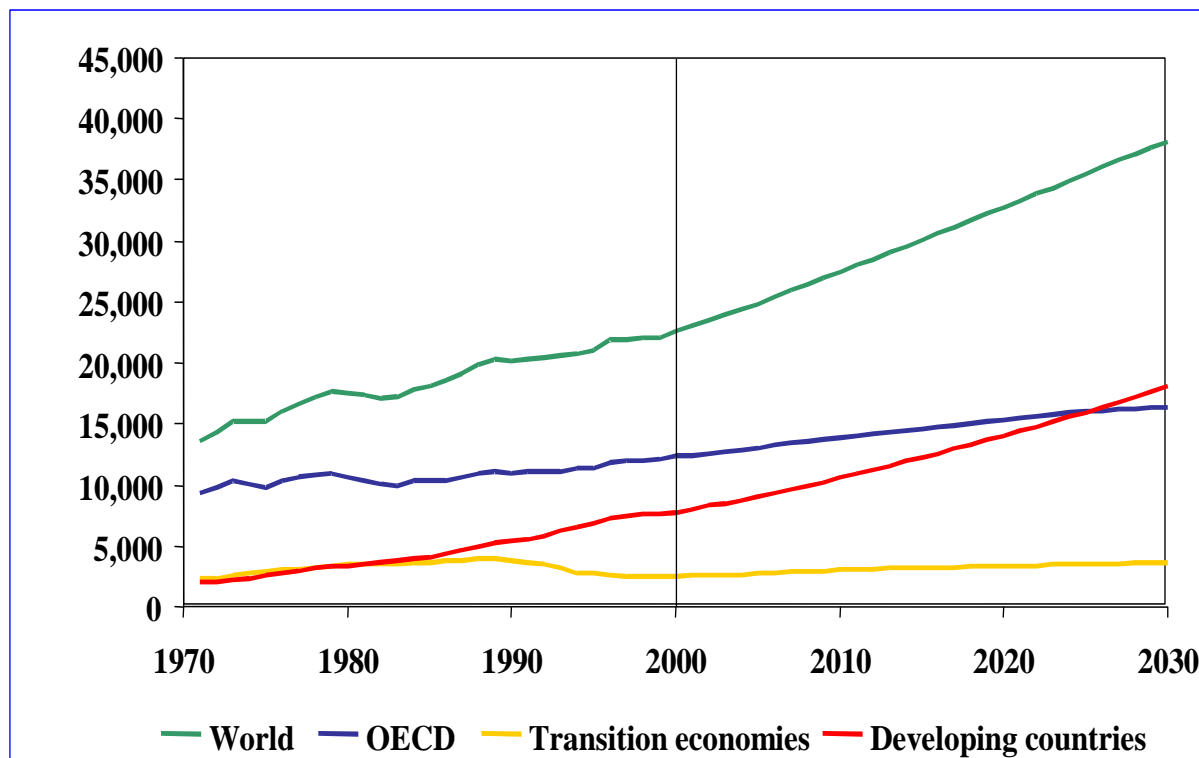
Is the Materials Community Involved?

“Under current conditions, approximately one quarter of the Western European **Green House Gas** emissions can be attributed to the **production and waste handling of materials.**”

These emissions can be reduced through materials strategies, based on changes in the use of materials”.

D Gielen, T Kram and H Brezet “Integrated energy and materials scenarios for greenhouse gas emission mitigation”

The other major source of CO₂ emissions is energy related activities (in which materials plays another major role)



Source: World Energy, Technology and Climate Policy Outlook, 2003



The Role of Materials

- ▶ Minimise Pollution
- ▶ Conservation of Resources
- ▶ Maximisation of (Clean) Energy Supply



The Role of Materials

- ▶ Minimise Pollution

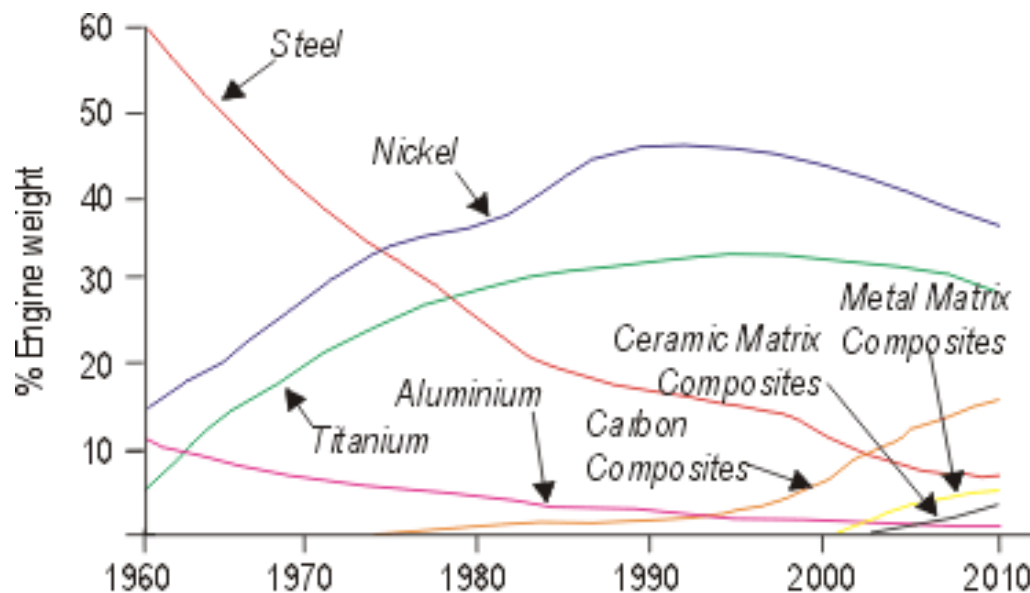


Pollution

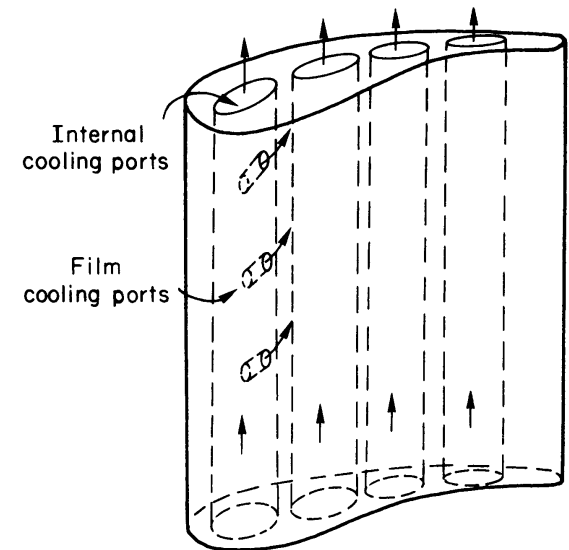
- the contamination of the environment by the by-products of industry, farming or other forms of human endeavour. In most cases this can be envisaged as the build up of chemicals in the air, in the water and in the ground.
- ▶ *Stop it happening*
- ▶ *Reduce the consequences*
- ▶ *Clean-up the mess.*

Stop it happening

- ▶ Improve process efficiency by raising temperatures, changing pH etc.



Materials usage in aero engines



Clever design can extend the operating window of a material

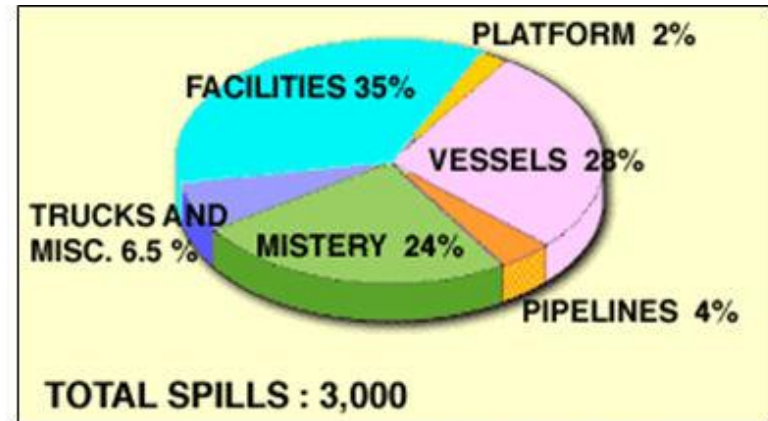
Aero engine emissions reduce as efficiency increases. Aero engine efficiency increases with combustion temperature

Stop it happening

- ▶ Stop leaks, spills, seepage by better containment.



Tougher, more corrosion resistant

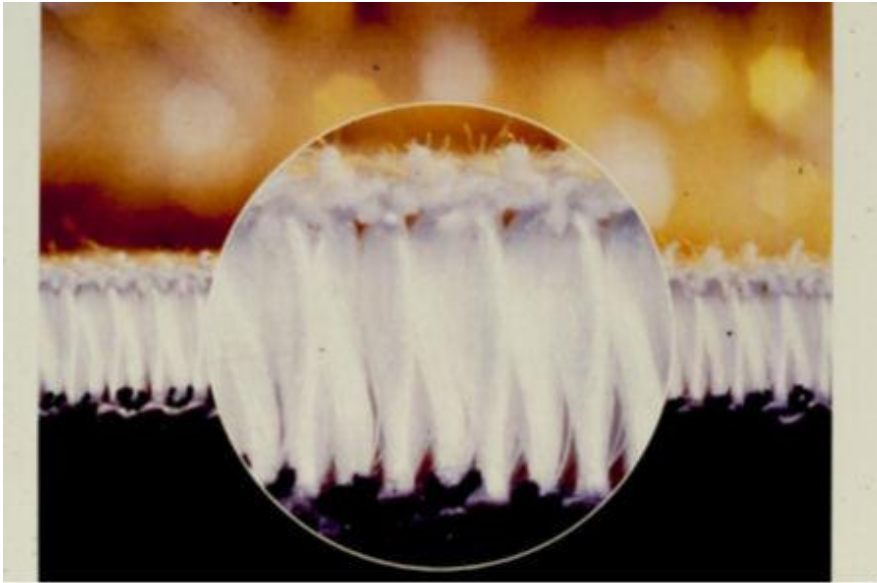


Texan coastal oil spills 91-93



Stop it happening

► By design



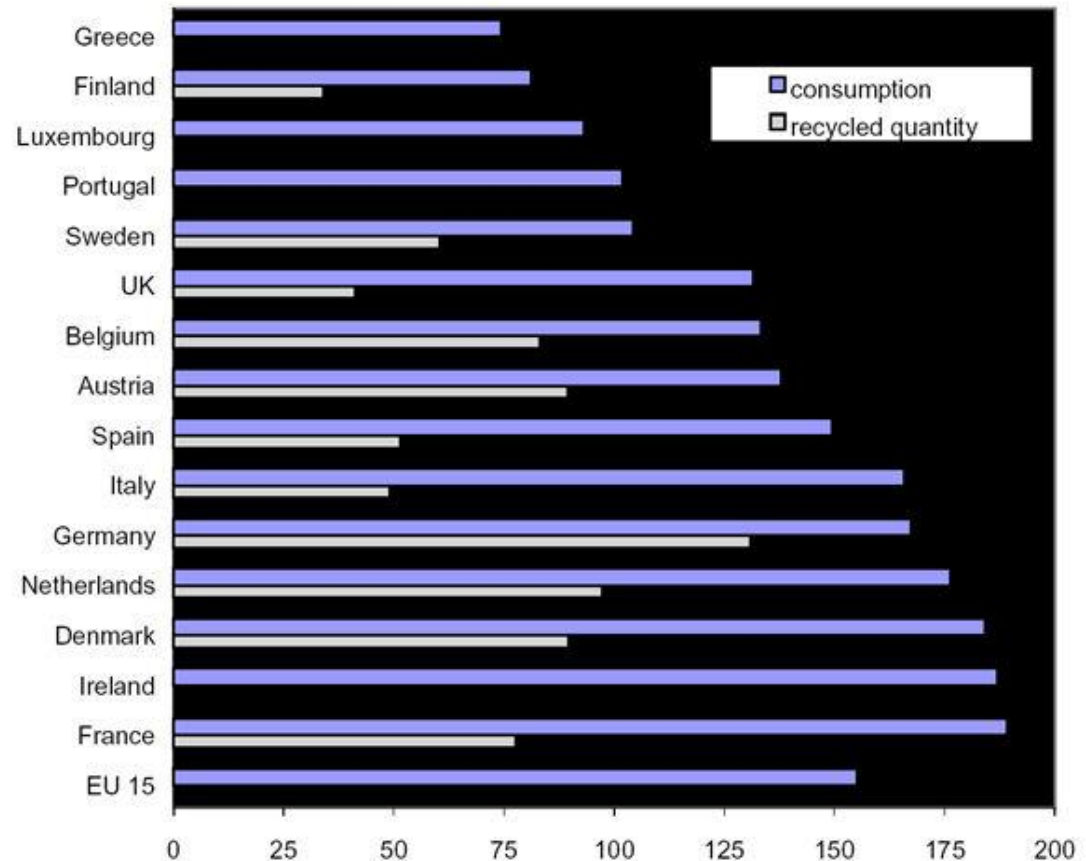
Use of novel fabrics makes a fail-safe design cost effective- double skinned tanks

Leaking underground fuel tanks can pollute the water supply (reports cite one tank in Australia that leaked 15,000 gallons of fuel before discovery)

Packaging



- ▶ Reduce it.
- ▶ Make products more durable so less packaging is required.
- ▶ Make packaging biodegradable so it disappears after use.



European per capita consumption of packaging waste, kgs, 1995 (source EU)



Reduce the consequences

- ▶ Get rid of unnecessary or undesirable components in a material system....eliminate lead from solders, carcinogenic curing agents from thermosets etc.
- ▶ Make liquid systems (primers, release agents, paints) based on water not volatile organic solvents.



Clean up the mess!

▶ RE-USE

- ▶ Directly. e.g. containers
- ▶ Re-condition, components

▶ RE-CYCLE

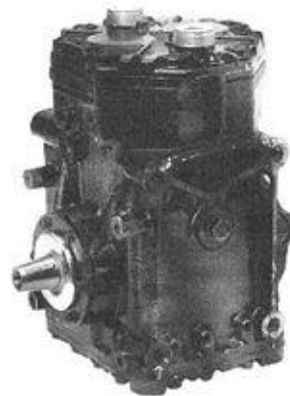
- ▶ Primary , in house
- ▶ Post industrial
- ▶ Post consumer

Re-use

- ▶ Bottles, containers etc.
 - ▶ Beer, milk bottles, chemical drums.
 - ▶ Environmental impact affected by costs of cleaning.



- ▶ Re conditioning.
 - ▶ Machines, equipment.
 - ▶ Components in auto industry...driven by insurance companies.



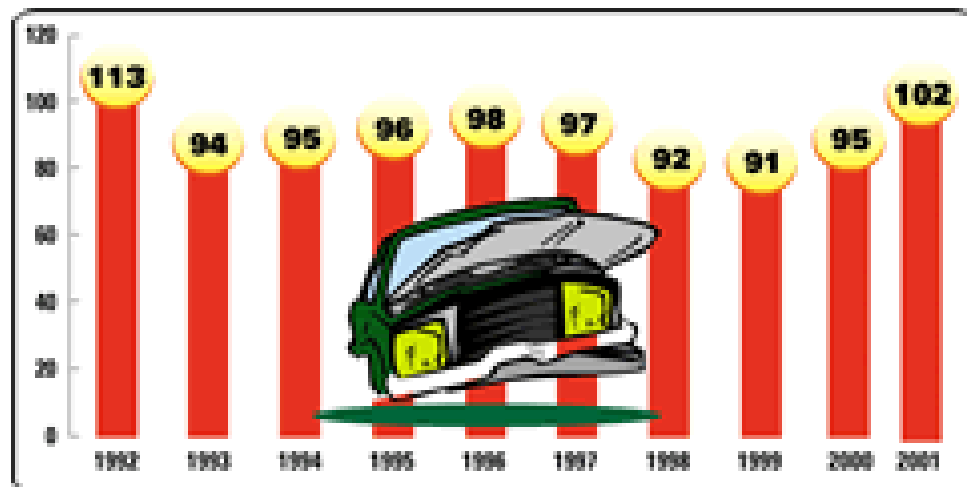
Steel recycling

- ▶ Scrap steel vital for production of new steel.
- ▶ US recycles 64% of steel output (1999 figures).
- ▶ Each metric tonnes recycled saves 1.3 tonnes of iron ore, 700 kg of coal and 60 kg of limestone.



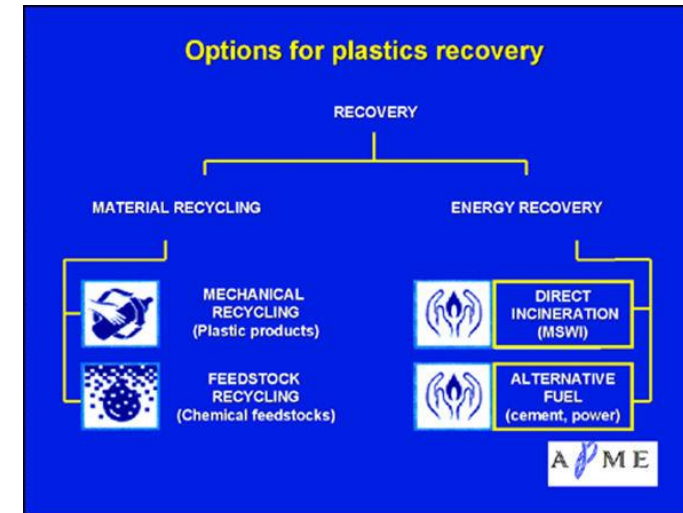
Auto steel (US)

- ▶ Auto industry recycles about 91-92% of scrap steel (often more is recycled in a year than is consumed)
- ▶ The car dismantling industry consists of 16000 dismantling businesses with 3000 scrap processors



Plastics recycling

- ▶ In-house- direct use of runners/sprues, out of spec parts back into the injection moulder.
- ▶ Post consumer- problems of identification and separation.
- ▶ Domestic waste needs plastics as fuel in incineration plant.
- ▶ Problems with mixed materials- electronics.



Completing the recovery picture 1994-1998 (x 1 000 tonnes)

	1994	1995	1996	1997	1998
Total plastics waste	17 505	16 056	16 871	16 975	17 570
Mechanical recycling	1 057	1 222	1 320	1 455	1 614
Feedstock recycling	51	99	251	334	361
Energy recovery	2 348	2 698	2 496	2 575	3 348
Total plastics waste recovered	20%	26%	25%	25%	30%

Composites: Design for Recycling

- ▶ Problems with lightweight composites based on glass fibre – fibres cannot be recycled.
- ▶ Thermoplastic composites can be melted and re-used but fibres are broken.
- ▶ Ultimately composite can be burnt – but fibres are left.
- ▶ Alternatives now “designed” for re-cycling.
- ▶ Based on highly oriented PP fibres.

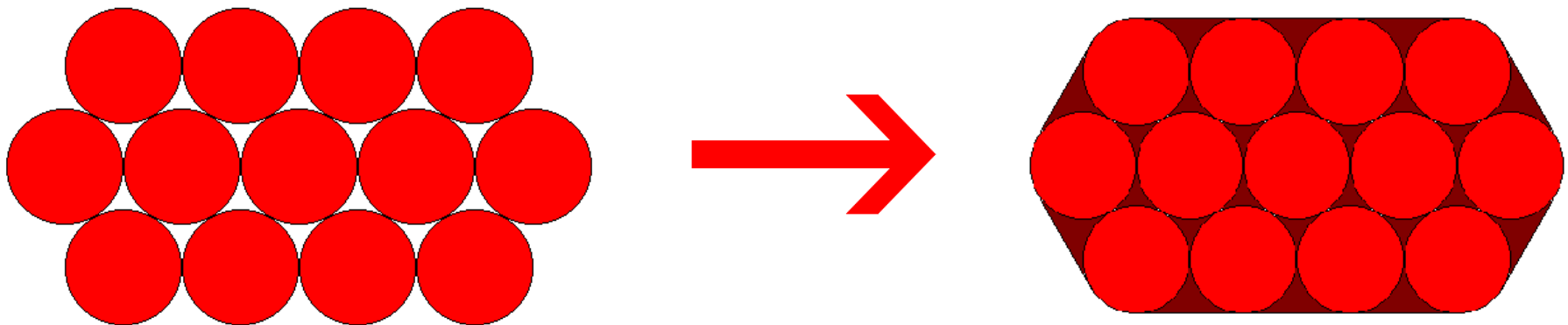


Single Polymer Composites
“All-PP”



Examples of single polymer composite

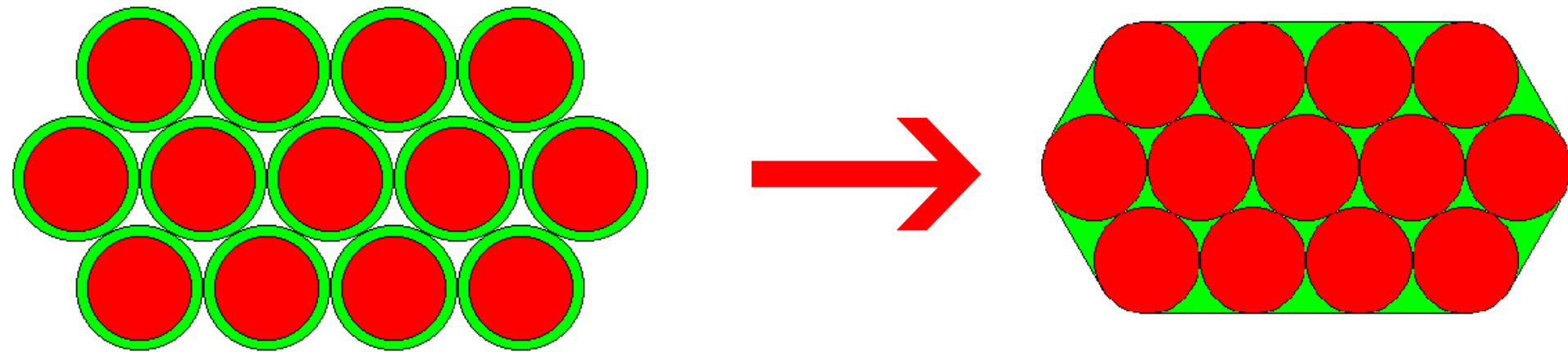
Hot Compaction of oriented PP fibres developed at IRC, University of Leeds.



- ▶ No impregnation but welding.
- ▶ Selective melting.
- ▶ Recyclable.
- ▶ Very small processing window.

Examples of single polymer composite

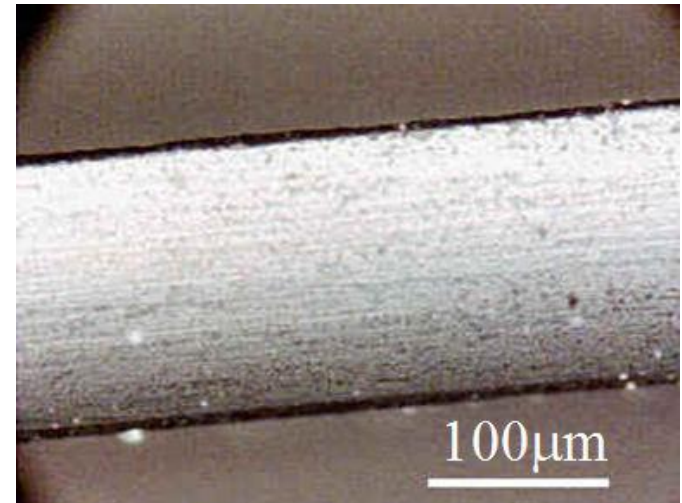
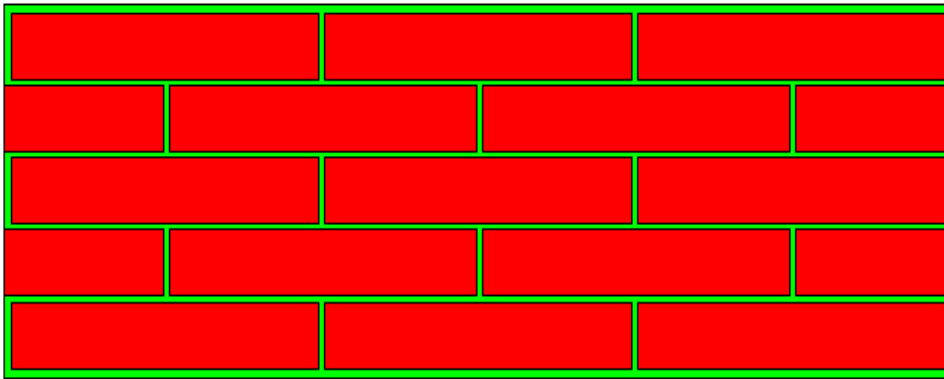
Hot Compaction of Coextruded Fibres



- ▶ Oriented 'B' coextruded with lower T_m 'A'.
- ▶ Original V_f retained.
- ▶ Recycling possible.
- ▶ Much larger processing window.

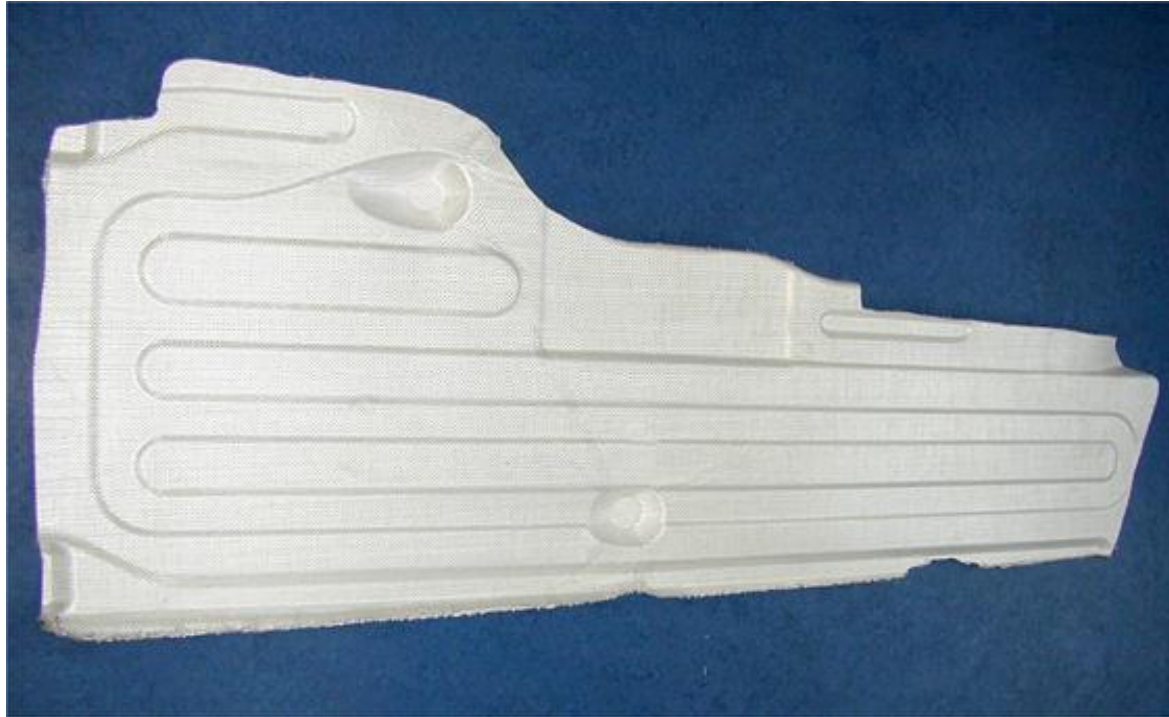
Examples of single polymer composite

Tapes - Reinforcement Geometry



- ▶ Welding instead of impregnation.
- ▶ Smaller amount of copolymer needed.
- ▶ Improved load transfer.
- ▶ Reduced drapability of fabric.

Examples of single polymer composite



Automotive undertray manufactured from polypropylene reinforced polypropylene (PURE)



The Role of Materials

- ▶ Minimise Pollution
- ▶ Conservation of Resources



The Conservation of Resources.

- ▶ Use materials that are re-formed naturally by the Sun!
- ▶ Plants harness the energy from the Sun to combine elements to form useful polymers and composites (e.g. wood).
- ▶ Most of these materials are naturally biodegradable and return to the feedstock materials required by plants.

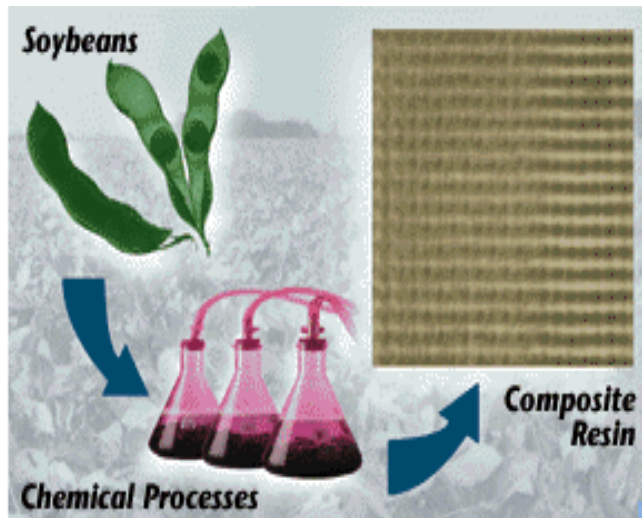
Bio-fibres



Fibre	1996	1999
Flax	2.000	15.900
Hemp	-	1.700
Jute	1.000	2.100
Sisal	1.000	500
Kenaf	-	1.100
<i>Total</i>	4.000	21.300

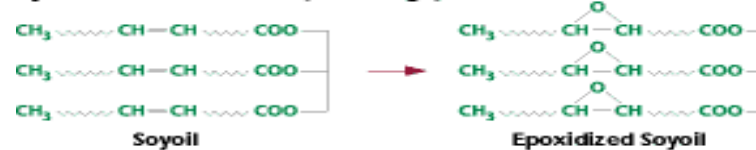
Green Thermosetting Resins

- Composites based on Green Thermosetting Resins, ACRES (University of Delaware) / ENIVIREZ® (Ashland Inc.)

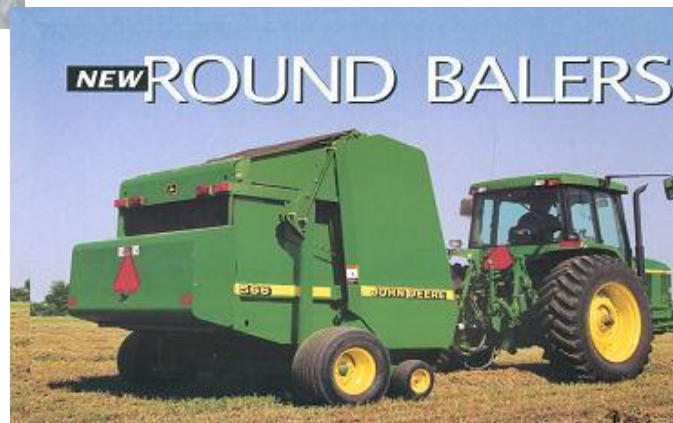


Soybean oil triglycerides as raw materials in the synthesis of new polymers suitable for liquid composite moulding processes like RTM

Epoxidization of Soyoil Triglycerides



- Epoxidised vegetable oils
- Maleinated triglycerides
- Aminated fats
- Polyoles



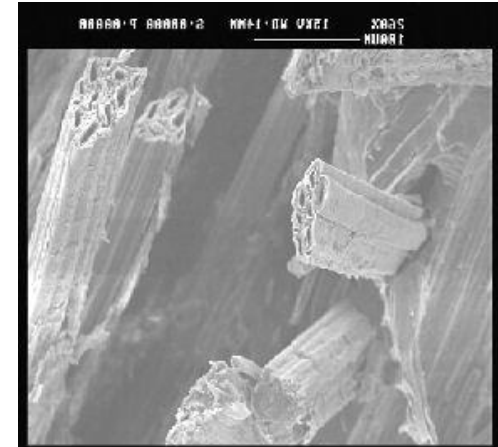
Hay baler side panel from soy-based resin developed for for John Deere Co.

Biodegradable Plastics

► Biocomposites based on Biodegradable Plastics:

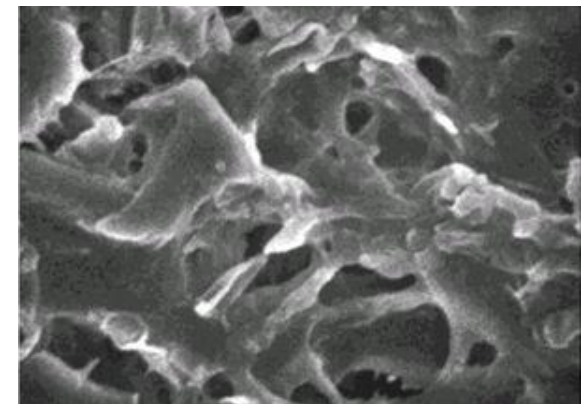


Improvement of
toughness and
reduction of
material **cost**



- Cellulose ester (Bioceta)
- PHB (Biopol)
- Polyesteramide (BAK)
- Polylactic Acid (PLA)

Biodegradation in
Soil is **accelerated**
by cellulosic fibres.





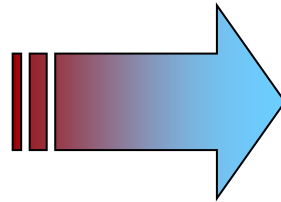
Early example of Road Rage? – no, Henry Ford
“testing” soy derived auto panel in 1938



The Role of Materials

- ▶ Minimise Pollution
- ▶ Conservation of Resources
- ▶ Maximisation of (Clean) Energy Supply

Maximisation of the (Clean) Energy Supply





Maximisation of the (clean) energy supply

► Role of materials:

- Reduce energy consumption.
 - Reduce fuel consumption by weight (transport/moving parts) and design.
 - Retain/manage heat.
 - Reduce power losses using superconductors.
- Facilitate supply and use of sustainable energy.
 - Energy Capture.
 - Energy conversion.
 - Energy storage.



Reducing Fuel

- ▶ Materials can reduce weight – lightweight structural materials in cars and planes and moving parts in machinery in general.
- ▶ They can improve aerodynamics by enhancing design capabilities.



-
- ▶ Most material driven weight changes in autos are incremental and modest.
 - ▶ But radical changes can produce major benefits.
 - ▶ (Cascade effects)



Anatomy of Hypercar, Inc.'s *Revolution* concept vehicle

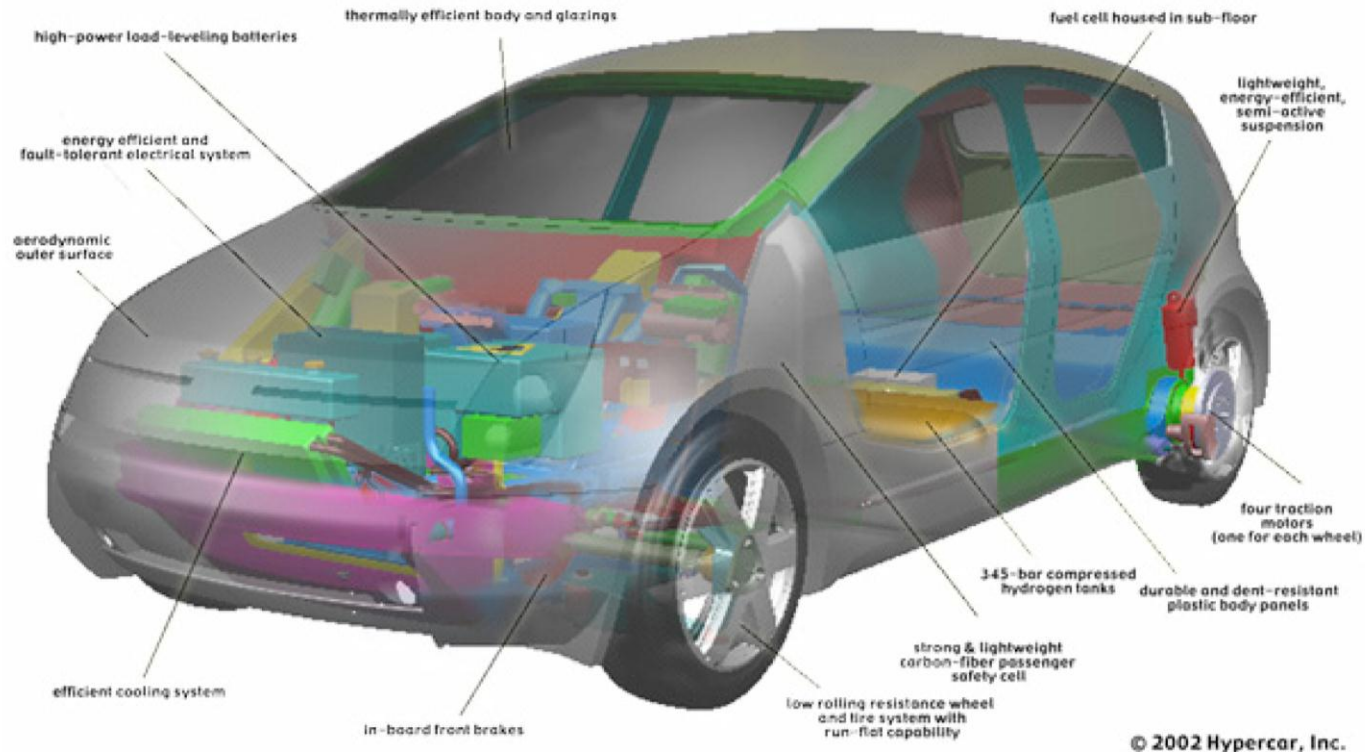
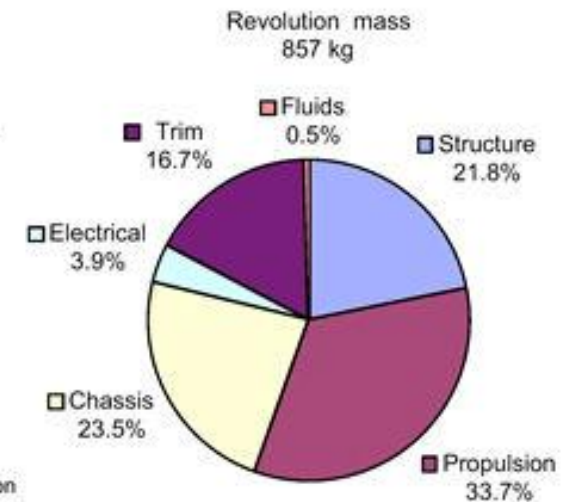
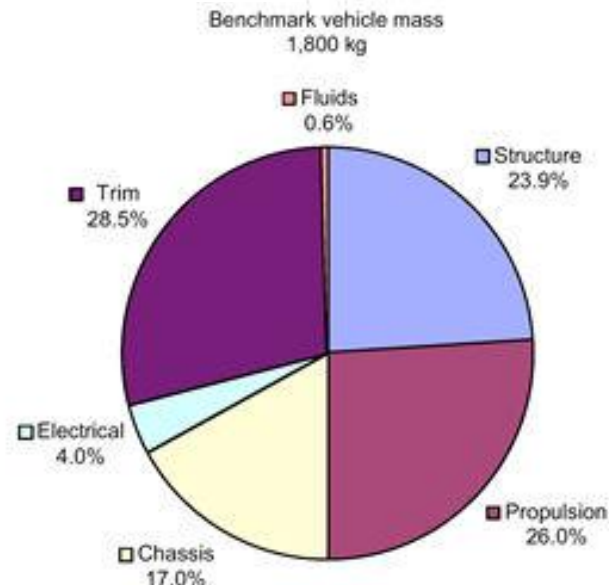


Figure 3: Technologies within the *Revolution*

Design and Manufacture of an Affordable Advanced-Composite Automotive Body Structure
David R. Cramer, David F. Taggart, Hypercar, Inc.

Hypercar weight savings

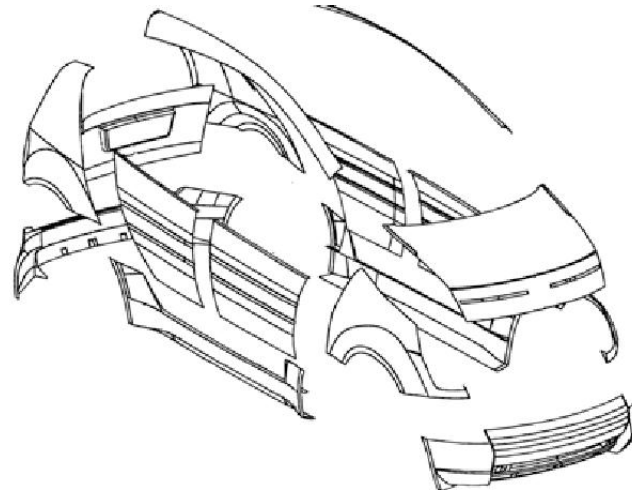
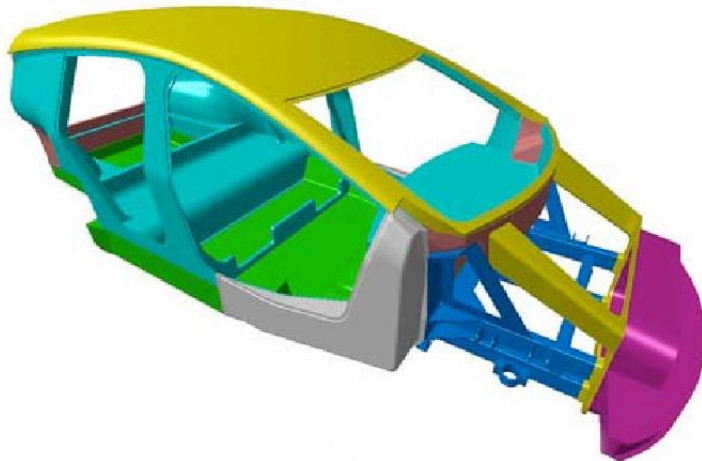
System	Benchmark mass (kg)	Revolution mass (kg)	Difference (%)
Structure	430	186.5	-57 %
Propulsion	468	288.3	-38 %
Chassis	306	201.2	-34 %
Electrical	72	33.4	-54 %
Trim	513	143.2	-72 %
Fluids	11	4.1	-63 %
Total	1,800	856.6	-52 %



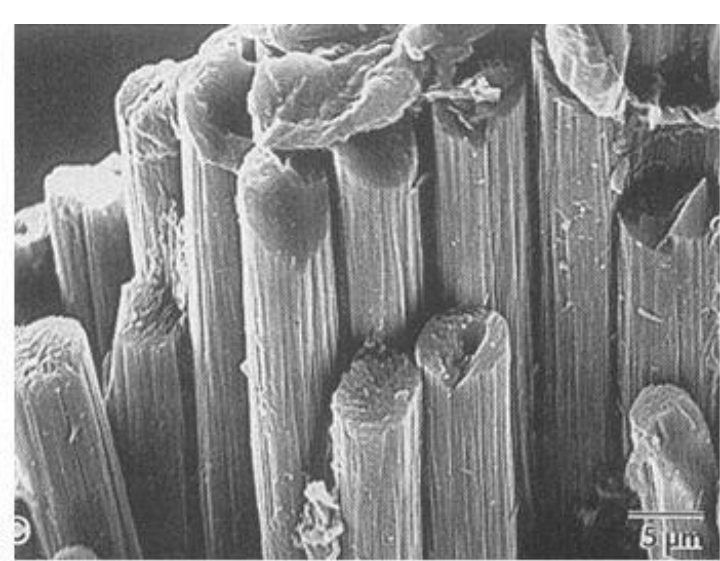
Hypercar: design

- ▶ The primary structure is composed of fourteen major parts and 62 total parts—65% and 77% fewer parts than in the equivalent portion of a conventional stamped steel BIW, respectively.
- ▶ Each major part in the composite safety cell is joined using a patent-pending blade and clevis fully bonded joining technique that is strong, robust, and self-fixturing. Together, the small number of parts and the joint design simplify assembly, as just a few parts must be held together until the adhesive bond sets up, without the need for complex fixtures.

Parts Consolidation



Design and Manufacture of an Affordable Advanced-Composite Automotive Body Structure
David R. Cramer, David F. Taggart, Hypercar, Inc.



Carbon fibre composites used to reduce weight in aircraft – initially military, for performance, then civil for payload.....and now for fuel economy!





New Boeing 787 to Be Made Largely of Composites

20% Fuel Savings

Boeing's new 787 will become the first commercial jet to be made with most of its primary structure consisting of composite materials.

Some of the composite materials that will be used include graphite and toughened epoxy resin, and TiGr, a titanium/graphite composite. The graphite/epoxy material will make up the bulk of the composite materials used in the 787, while the titanium/graphite composite will be used for the wings.

(Source Azcom)

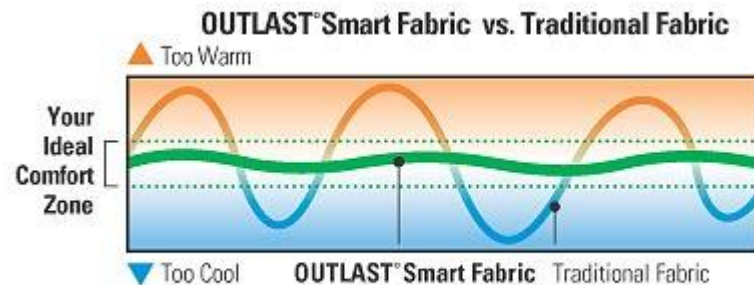
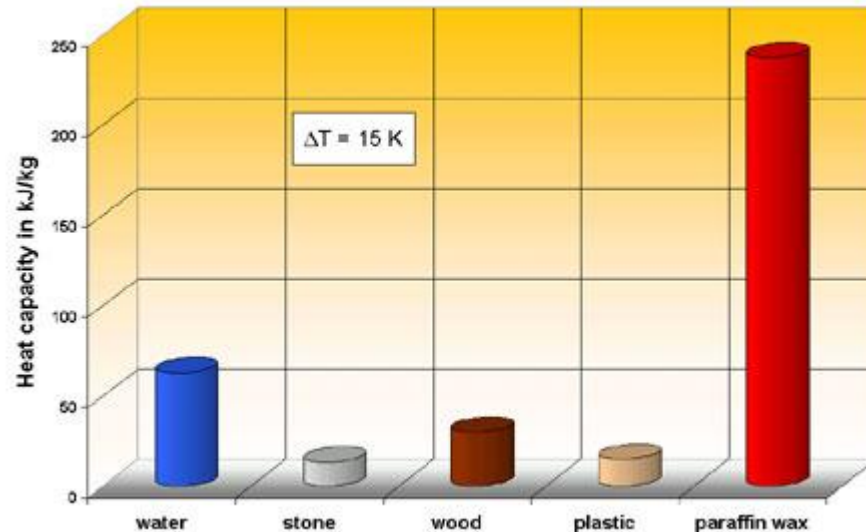
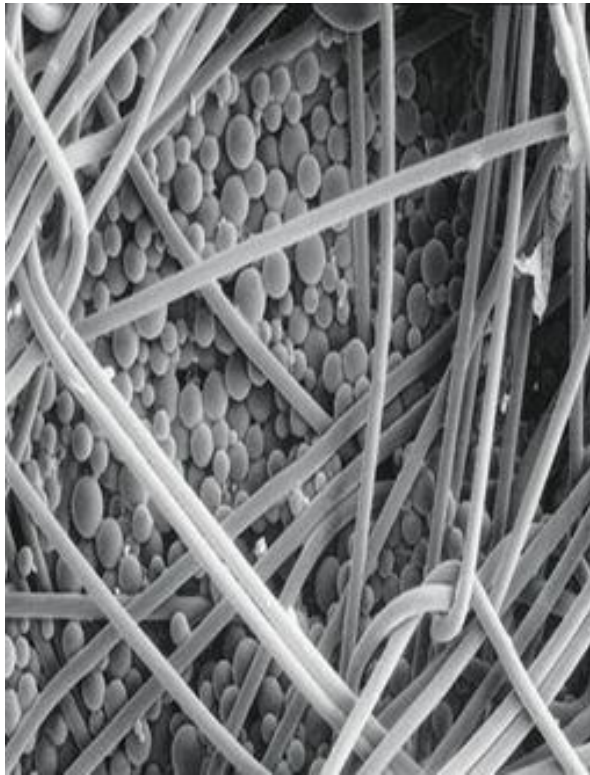
Randy Baseler, Boeing's vice president of marketing, said the company expects the world's airlines to purchase 2,520 small widebodies over the next 20 years.

Boeing could capture the bulk of those sales if cost-obsessed airlines embrace a plane that can burn 20 percent less fuel than the A330-200, currently the best-selling small widebody.



Thermal Management – save energy

- ▶ Outlast fibres – contain microcapsules of paraffin wax



Reduce Power Needs: Superconductors

- ▶ Maglev trains use 30% less energy than a highspeed train traveling at the same speed. (1/3 more power for the same amount of energy).
- ▶ In Germany, engineers have developed an electromagnetic suspension (EMS) system, called Transrapid. In this system, the bottom of the train wraps around a steel guideway. Electromagnets attached to the train's undercarriage are directed up toward the guideway, which levitates the train about 1/3 of an inch (1 cm) above the guideway and keeps the train levitated even when it's not moving.
- ▶ Japanese engineers are developing a competing version of maglev trains that use an **electrodynamic suspension (EDS)** system, which is based on the repelling force of magnets. The key difference between Japanese and German maglev trains is that the Japanese trains use **super-cooled, superconducting electromagnets**. Japan's system saves energy.

Speed	ICE Train	Maglev Train
200 km/hr	32 Wh/km	32 Wh/km
250 km/hr	44 Wh/km	37 Wh/km
300 km/hr	71 Wh/km	47 Wh/km
400 km/hr	-	71 Wh/km



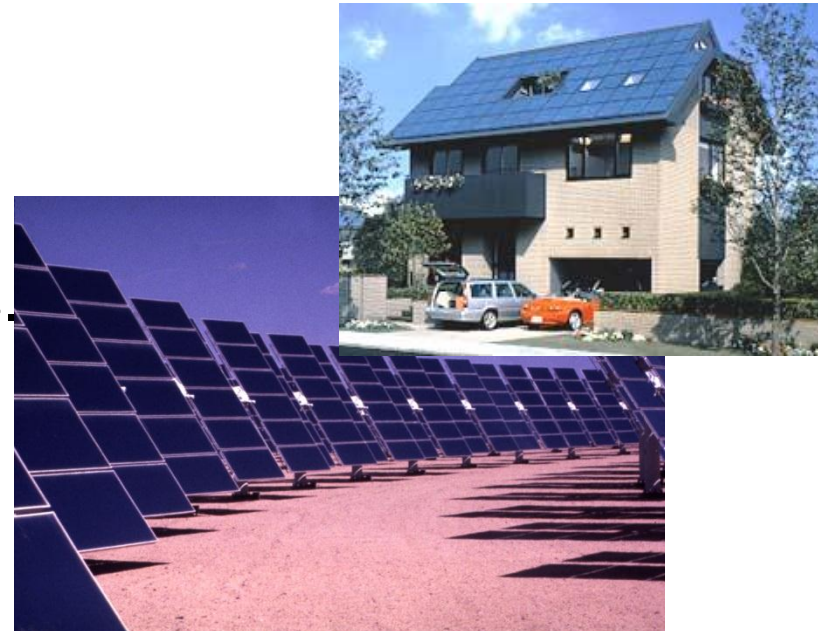


Clean Energy Supply & Use

- ▶ The total energy demand will increase more than 50% between 2000 and 2030, and the related CO₂ emissions will increase more than 60% compared to current levels. Industrialized countries are projected to account for 42% of global emissions, while China, India and other developing countries for about 50%.
- ▶ The trends of CO₂ emissions:
 - ▶ Will not allow industrialized countries to achieve the Kyoto targets by 2008-2012.
 - ▶ Are not consistent with the IPCC long-term scenario of stabilization of CO₂ concentration (550ppm) and the related global emissions reduction target of around 50-60%.

Energy Capture - Solar Photovoltaics (PV)

- ▶ It is an industry that is doubling every two years
- ▶ Worth \$3.5 billion in 2002, it can grow to \$27.5 billion per year by 2012.
- ▶ Materials – mainly based on silicon 54.6% market share. Multicrystalline silicon, then Single crystalline silicon, then amorphous.
- ▶ Materials are expensive.
- ▶ Potential for dye sensitised and polymeric organic materials.





World Photovoltaic Cell/Module Production - MW

Country	1999	2000	2001	2002	2003
USA	60.8	74.97	100.32	120.6	127.0
Japan	80.0	128.60	171.22	251.07	331.0
Europe	40.0	60.66	86.38	135.05	213.0
ROW	20.5	23.42	32.62	55.05	74.0
TOTAL	201.3	287.65	390.54	561.77	740.0

COMING SOON?

Nanoscale Antennae Solar

Electric Power

Over 80% Efficiency Potential

Potential Cost < 10% of the

Present cost

Paper thin cells with increased efficiency -37 mm from Fraunhofer

D. Yogi Goswami

President, International Solar Energy Society



Clean Energy - Energy Conversion

- ▶ Wind – the conversion of kinetic energy to electrical energy.
 - ▶ On shore/offshore.
- ▶ Fuel cells – the conversion of chemical energy to electrical energy.
 - ▶ For transport, distributed power generation.

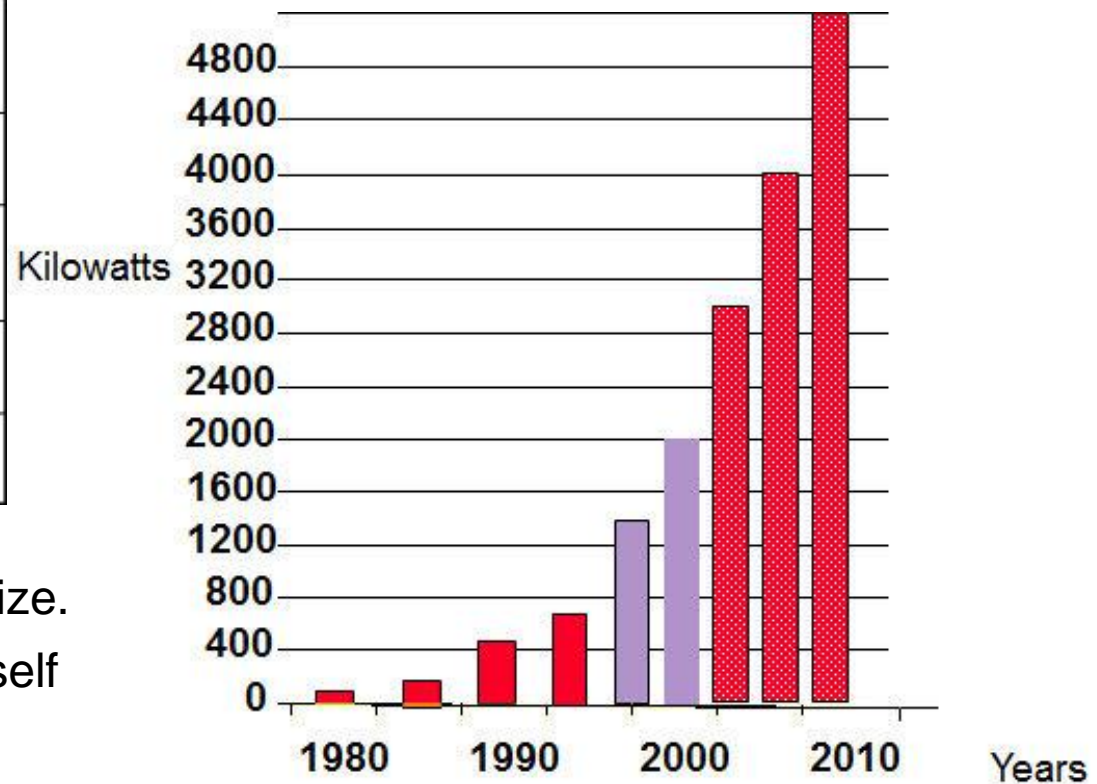
Wind



Wind

COUNTRY	2001 MW	2002 MW	Total Beginning 2003 MW
North America	4473	450	4923
USA	4275	410	4685
EU	17241	5871	23056
Germany	8753	3247	12001
Other Europe	123	112	235
Norway	17	80	97
ROW	2479	435	2914
India	1507	195	1702
WORLD TOTAL	24315	6868	31128

Technology Developments Average Wind Turbine Size



- ▶ Market growth depends on size.
- ▶ Size depends on materials (self fatigue)

Wind blades



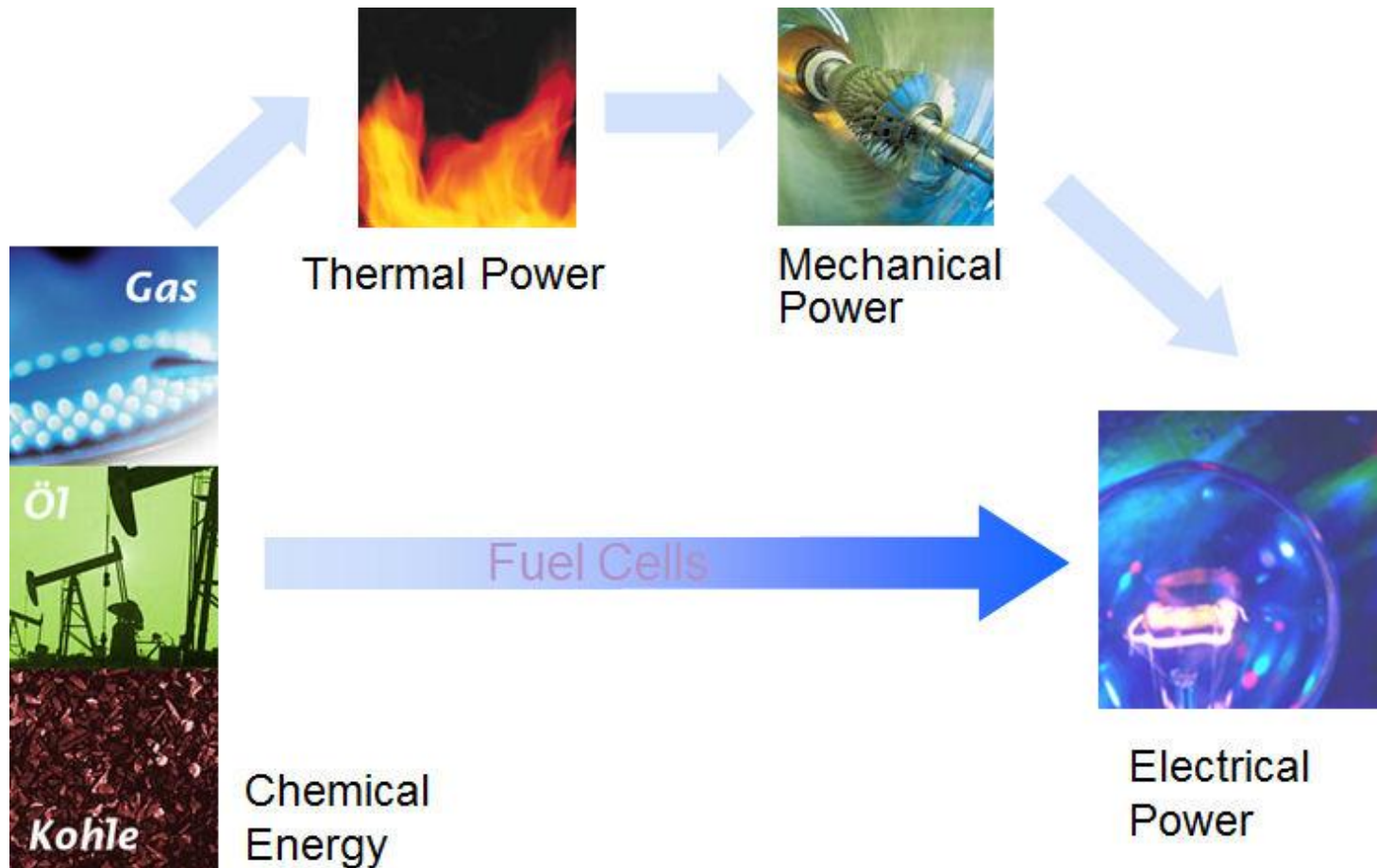
Middlegrunden,
Copenhagen, Denmark,
captures wind energy with 20
of these 2 MW turbines, each
fitted with 36.8m blades
manufactured by LM
Glasfiber. Source: LM
Glasfiber

- ▶ Longer blades, plus advances over 20 years in rotor controls, generators, composite materials and blade design, have boosted wind turbine generating capability from 25 kilowatts (kW) using a 10m/33-ft diameter rotor, to 1.5 MW, with a 72m/236-ft diameter rotor.
- ▶ The cost of generated kilowatt hours (kWh) drops exponentially with increased power, an important element in the economics of wind energy. This is particularly dramatic when small and large wind farms are compared. E.g., the American Wind Energy Assn. estimates the cost per kWh for a 51-MW project is 40 percent less than the cost for a 3-MW project.
- ▶ The economics for wind farm operators and power companies clearly point to bigger blades. Equally clear is the necessity for advanced technology and production economics in the manufacture of big blades.

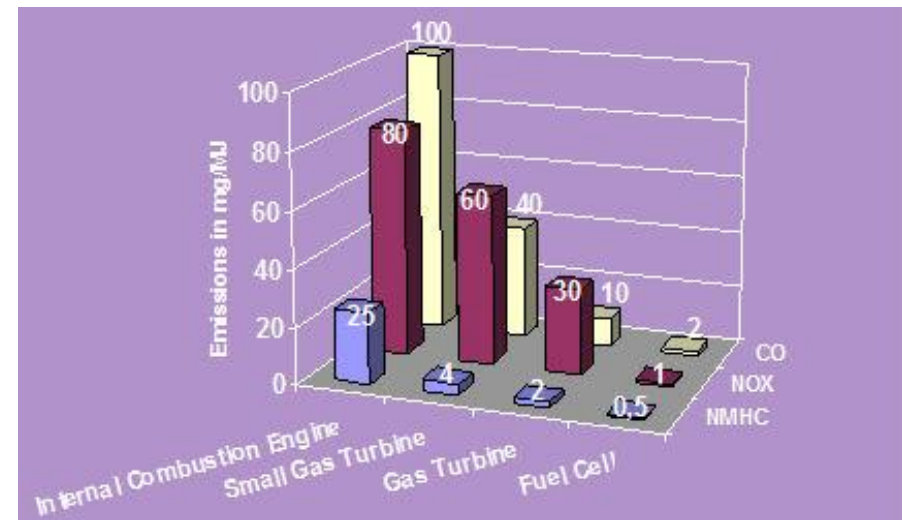
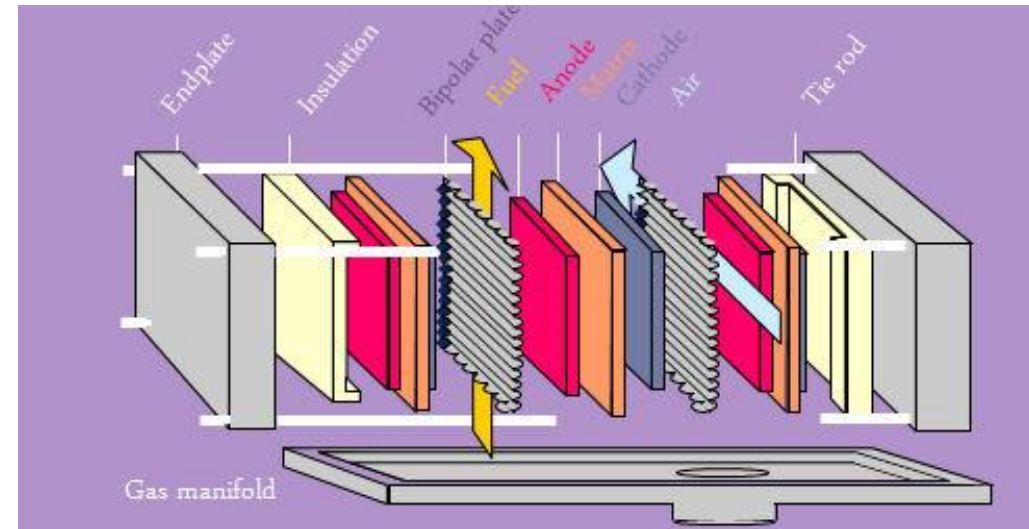
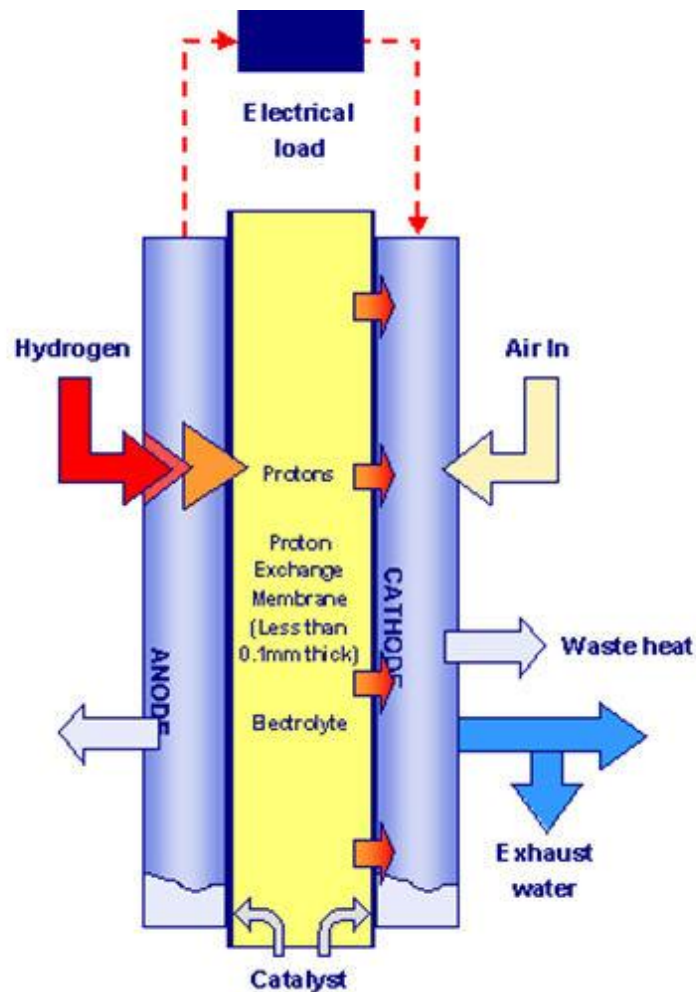
MATERIALS ISSUE – FATIGUE
(and cost!)

Fuel Cells

A New Approach to Power Production



Fuel Cells



Fuel Cell Types



*Low temperature
fuel cells*

Alkaline FC

H₂
H₂O

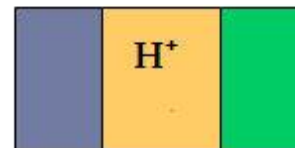


O₂
H₂O

AFC: 20 °C

Phosphoric Acid FC

H₂



O₂

PAFC: 180 °C – 220 °C

Membrane FC

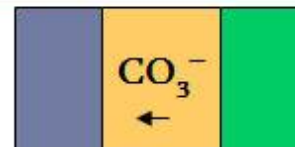
H₂O

PEM: 30 °C – 80 °C

*High temperature
fuel cells*

Carbonate FC

H₂
CO₂
H₂O

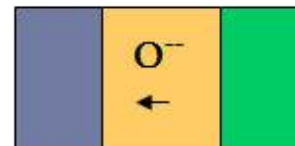


O₂
CO₂

MCFC: 650 °C

Solide Oxide FC

H₂
H₂O



O₂

SOFC: 1000 °C



Materials issues

“Solid Oxide and solid polymer fuel cells are seen as prime candidates for both stationary and mobile applications. However, there a number of important areas to be addressed in any future development” – [Materials Foresight Report, 2003, IoM3](#)

SOFC: Anodes– more resistant to redox, coking problems, tolerant of sulphur to allow broader range of fuels to be used.

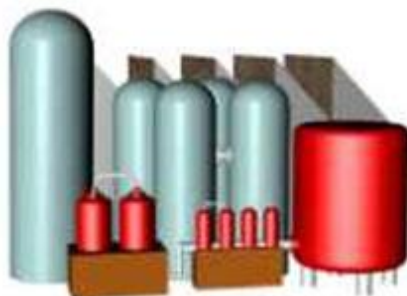
Cathodes: better electrocatalytic stability

Electrolyte: new thin film technology, better oxide ion conducting systems

PEMFCs: higher membrane temperatures, tolerance to CO and other impurities. Low cost systems, membranes and bipolar planes.

Hydrogen Storage: need for solid route to storing hydrogen to achieve energy densities comparable to liquid fossil fuels.

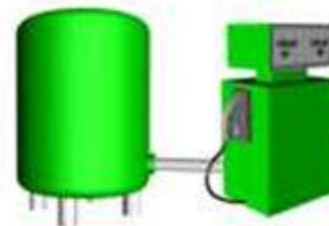
Approaching Reality



Oil refinery



Hydrogen
road transport



Filling Station with pressure
tank, compressor and
dispenser



Fuel Cell Buses

Energy Storage - Batteries

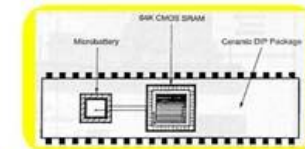
- ▶ Li-composites
- ▶ Thin films
- ▶ Batteries for cars (Evs)
- ▶ Batteries for electronic devices, medical implants

Thin Film Battery

1. Thin Film Battery : Active Power Sources for Microelectronics

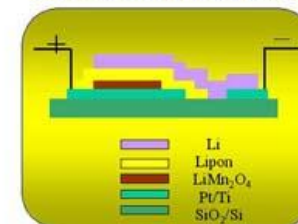
➡ **On chip Battery !!!**

- Remote Sensors, Miniature Transmitters
- 카드 판독기 없이 동작하는 Smart cards의 실현, MEMS Devices
- Implantable Medical Devices (인체내 투입가능한 의료기기를 통한 진료)



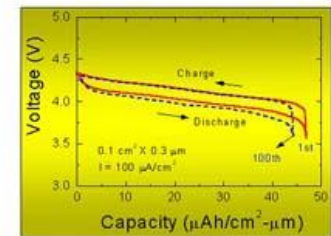
<CMOS-SRAM Memory with Thin Film Battery>

2. Thin Film Battery Fabrication



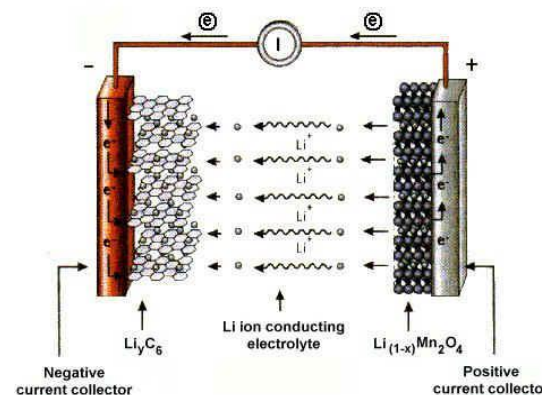
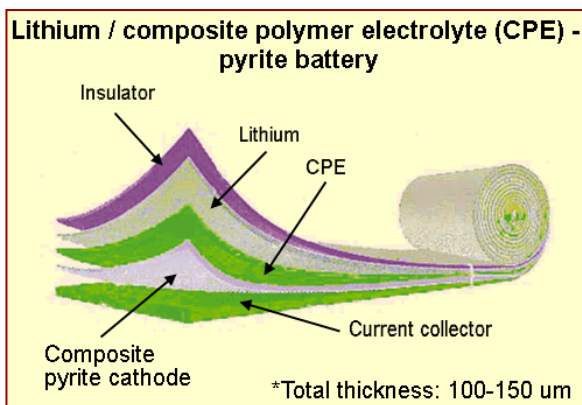
<박막 전지의 적층구조>

양극박막 (LiMn₂O₄) 증착 (0.4 mm)
↓
고체 전해질 (Lipon) 증착 (1 mm)
↓
음극박막 (Li) 진공 열증착
↓
전고성 미세박막전지 제작



<Li/Lipon/LiMn₂O₄ 총방전 특성>

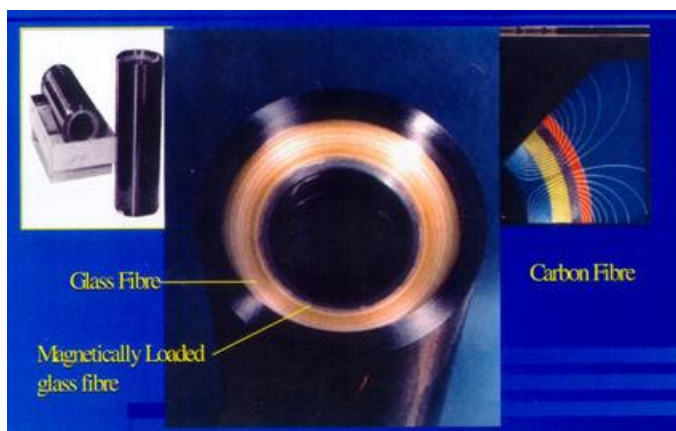
- ➡ 용량감소 <0.05% per cycle
- ➡ Better Coulombic Efficiency Than Liquid Electrolyte



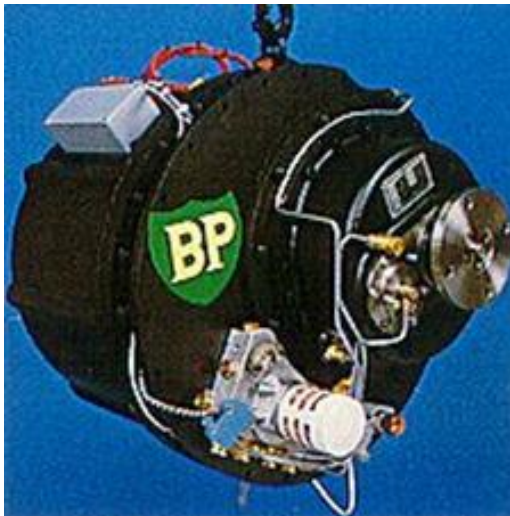
**Manganese oxide (spinel)
positive electrodes**

Energy Storage – Kinetic energy

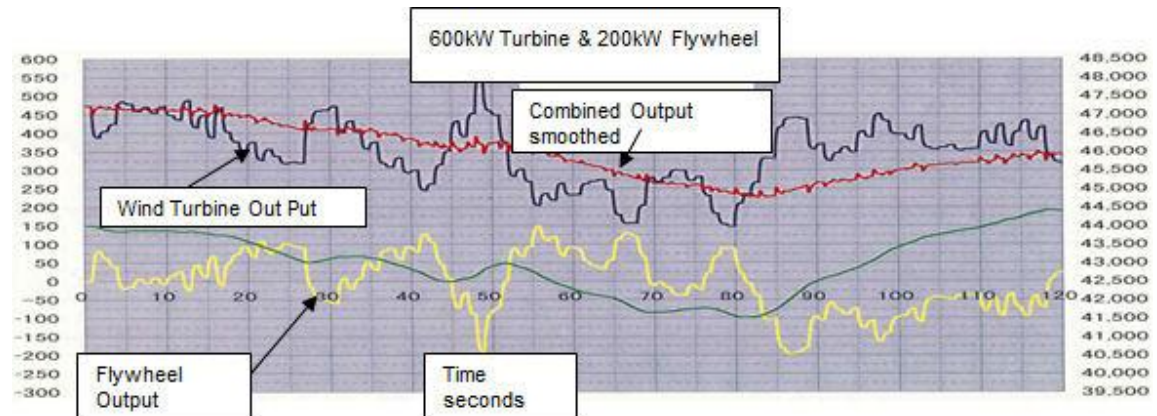
- ▶ Flywheels – high strength composites.
- ▶ More energy stored per Kg – high speed.
- ▶ Magnetic bearings – high energy density, low power losses.
- ▶ Rapid response times.



Energy Storage – Kinetic energy



- ▶ Flywheels also have a role in hybrid power systems, storing energy when vehicles slow down and supplying it when they start again.
- ▶ Some worries about containment – another role of advanced materials
- ▶ And power smoothing e.g with wind turbines...





How to Ensure Technology is Exploited



How to ensure technology is exploited?

- ▶ Many technologies for recycling are developed – but expensive. Recycled plastics often cost more than \$12/kg – much more than virgin feedstock.
- ▶ Replacing organic solvents with aqueous solvents – cost.
- ▶ Encouraging the use of biodegradable materials – cost.



Government intervention is needed to make market corrections that provide a cost incentive, provide assistance in creating infrastructure.



Are all government initiatives helpful?



EU Directive on End-of-Life Vehicles



2002	cost-free take-back of all vehicles produced from this date when they get at end-of-life.
2005	vehicles to be homologated to 85% reuse/recycling and 95% recovery (=10% energy recovery).
2006	all received vehicles to be reused/recycled to 80% and recovered to 85%.
2015	all received vehicles to be reused/recycled to 85% and recovered to 95% .



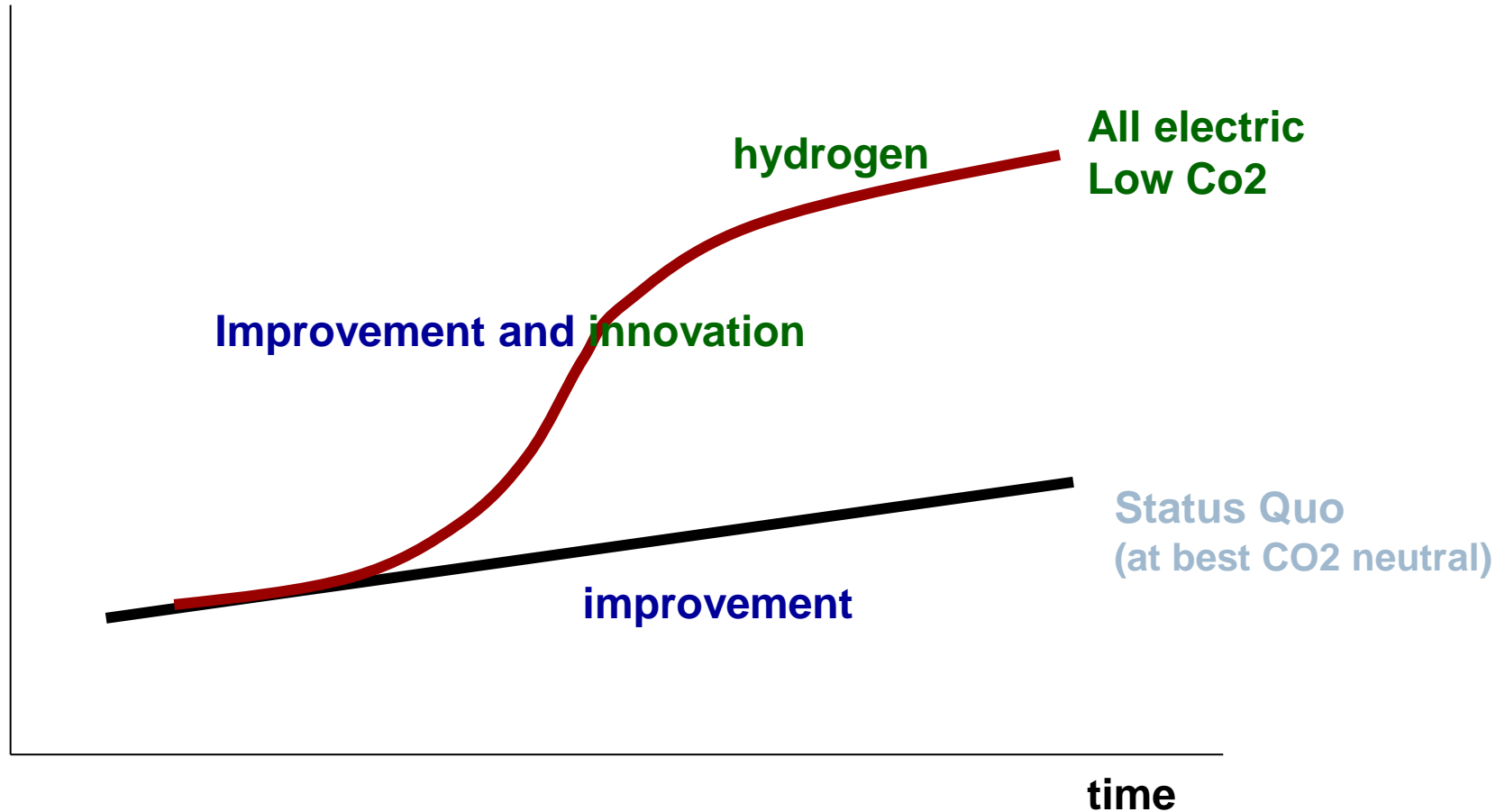
Most governments...

- ▶ Are committed to sustainability.
- ▶ Think short term.
- ▶ Implement legislation to optimise existing systems.
- ▶ Act on limited information.



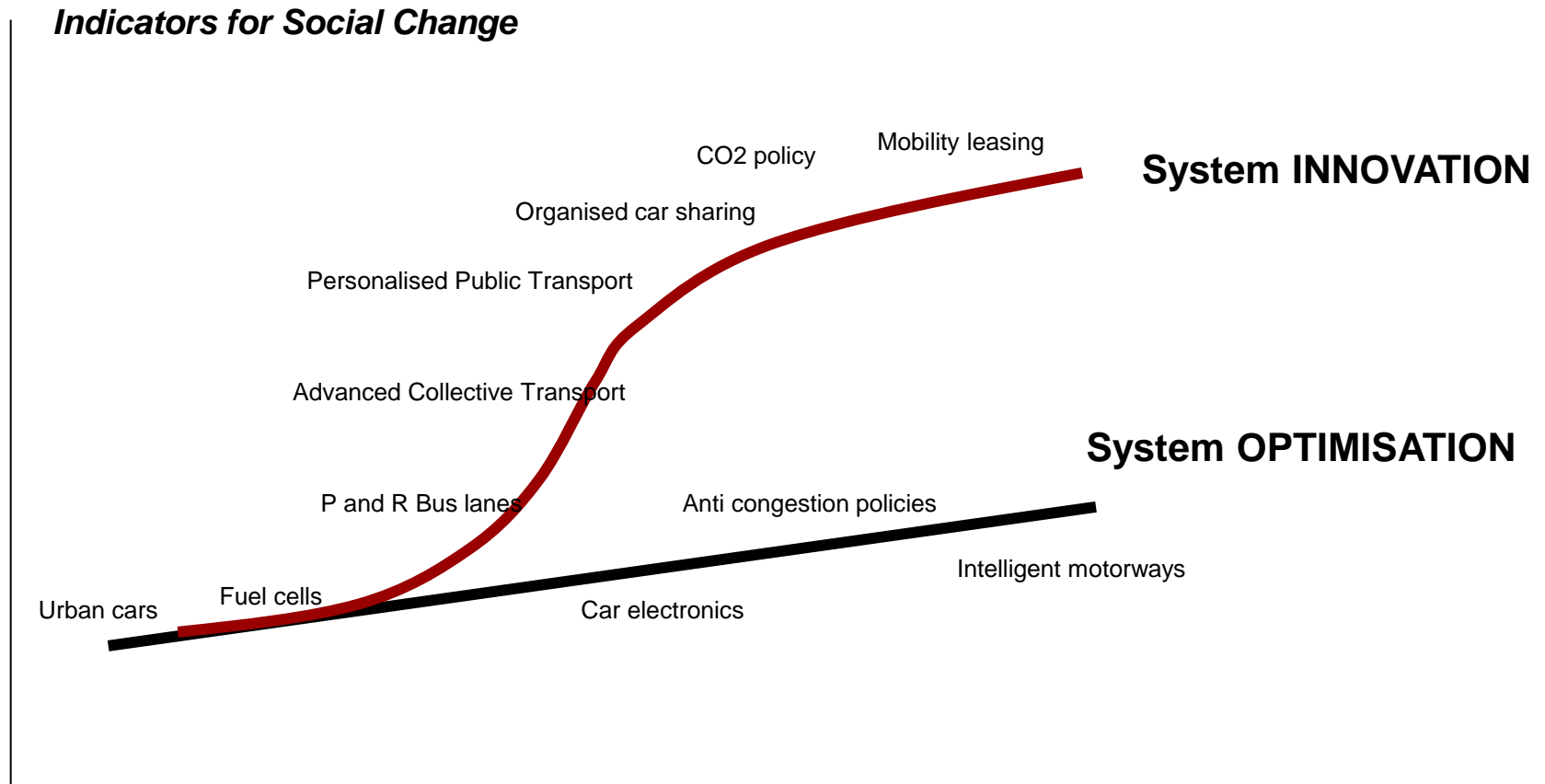
Improvement/optimisation is not enough.....

System change



The Kyoto process and system innovation – after Rotmans et al 2000. 2001

System Transitions required for significant change



System optimisation versus system innovation for land-based passenger transport (Kemp and Rotmans 2001)

Transitions in Systems

- ▶ “Transitions involve structural change but not everything changes. What changes most fundamentally are the assumptions, practices and rules. Technological changes may be secondary, which is a different way of looking at transitions than most people do:
- ▶ especially **engineers** are inclined to view technology changes are primary, and institutional changes as secondary, which are often seen as being forced by technology, overlooking the fact that the technologies are made by people guided by new ideas, a new outlook and a new set of assumptions.”
- ▶ Kemp and Rotmans 2001



Concluding Thoughts



Concluding Thoughts

- ▶ Materials Technology is a major enabling technology for sustainable development.
- ▶ Non technical factors may be just as important in implementation.





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