Materials and Sustainable Development

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This lecture unit is part of a set created by Mike Ashby to help introduce students to materials, processes and rational selection.

The Teaching Resources website aims to support teaching of materials-related courses in Design, Engineering and Science.
Resources come in various formats and are aimed primarily at undergraduate education.
Some of the resources are open access and students can access them. Others are only available to educators using CES EduPack. **www.grantadesign.com/education/resources**

Defining “Sustainable development”

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs”

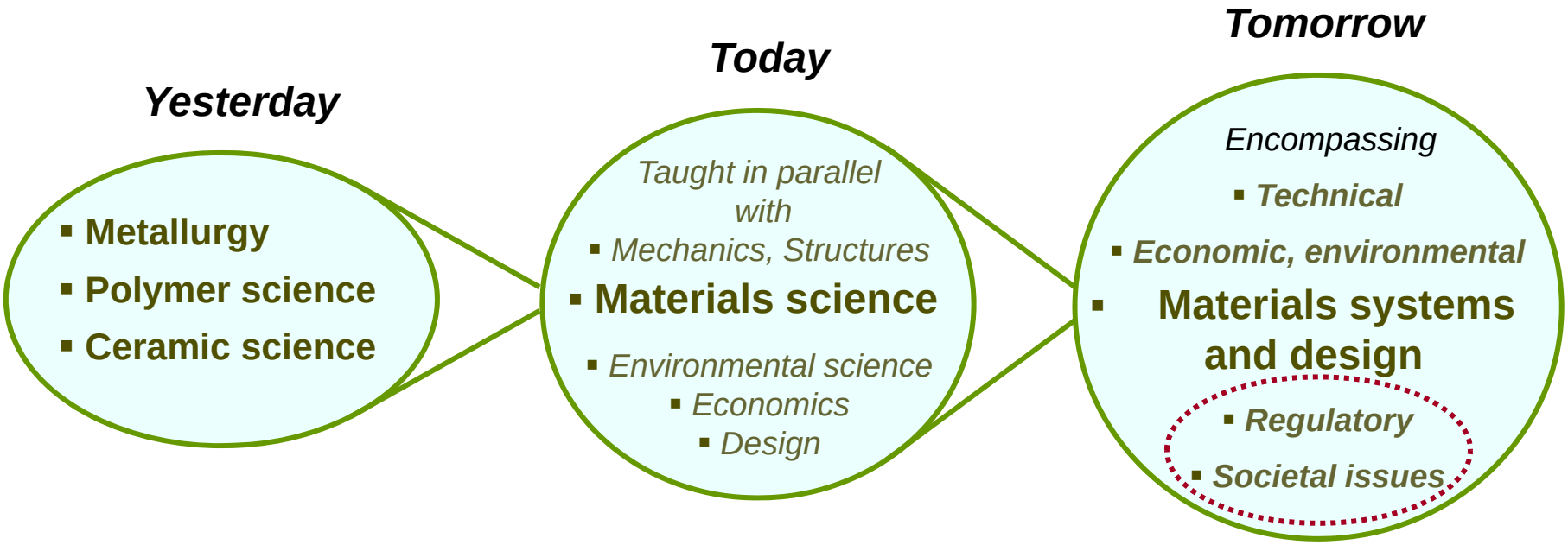
Report of the Brundtland commission of the UN, 1987

- ***But how?***
- ***And where do materials fit in?***
- ***“Sustainability” vs. “Sustainable development”***

SUSTAIN: a database to support sustainable technology

- **Material efficiency** essential to provide needs of present and of future generation
- **Select materials** to maximize functionality with minimum material loss
- **Boundary conditions:** regulations, incentives, voluntary obligations
  social equity, ethical sourcing
- Provide a **tool** to help with this

The evolution of Materials teaching



The need:

A data source that allows material selection technical grounds

And helps with pointers to regulation and societal issues

Sustainable assessment: the method

Step 1: Clarify Objective

Step 2: Stakeholders

Step 3: Fact finding
- *objective*

Step 4: Integration
- *subjective*

Step 5: Reflection

The CES EduPack SUSTAINABILITY DB

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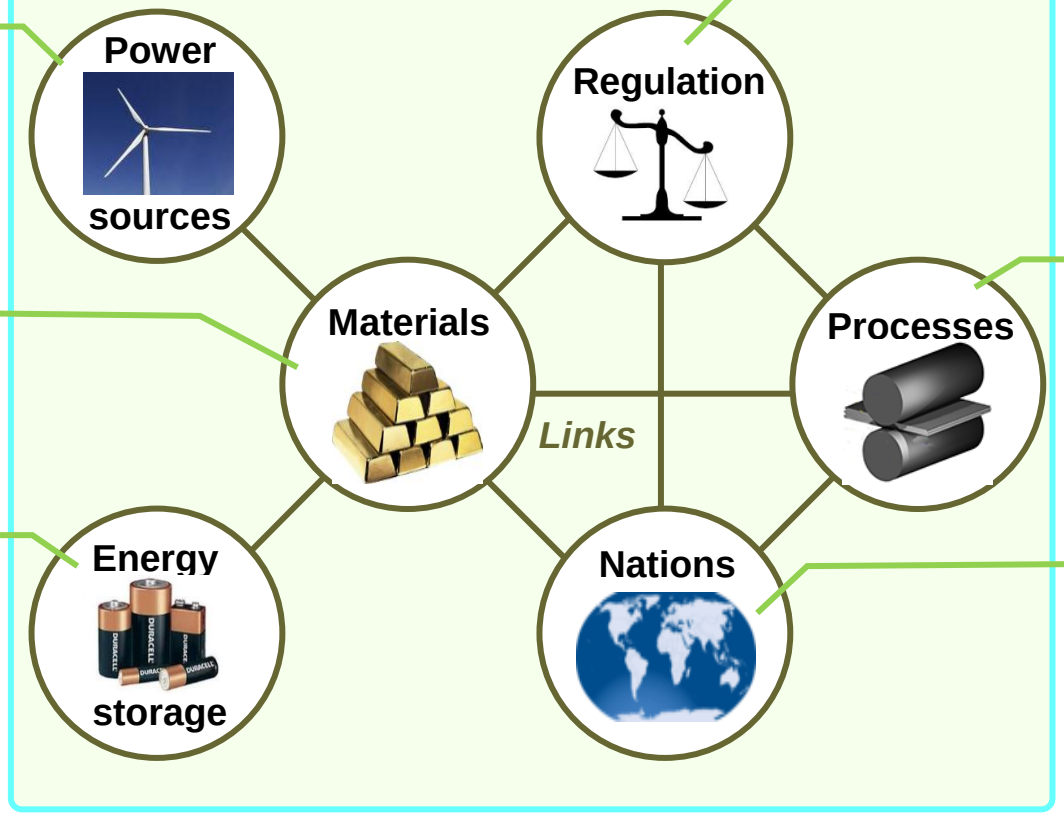
The SUSTAINABILITY database

Data for
- Conventional
- Nuclear
- Renewable

Data for
- Metals
- Polymers
- Ceramics
- Hybrids

Data for
- Chemical
- Kinetic energy
- Pot. energy
- Elec. energy



Information on
- Standards
- EU directives
- US regulation
- Tax legislation
- Trading schemes

Data for
- Joining
- Shaping
- Surface treatment

Data for Nations
- Geography
- People
- Governance
- Human rights
- Economy
- Eco-footprint

Regulation and Legislation

Regulation

End-of-Life Vehicles (ELV)

Relevant sector

Automobile industry.

Summary of legislation

End-of-Life Vehicles (ELV, 2000). The European Community Directive, EC2000/53, establishes norms for recovering materials from dead cars. The initial target, a rate of reuse and recycling of 80% by weight of the vehicle and the safe disposal of hazardous materials, was established in 2006. By 2015 the target is a limit of 5% by weight to landfill and a recycling target of 85%. The motive is to encourage manufacturers to redesign their products to avoid using hazardous materials and to maximise ease of recovery and reuse.

Reference

ELV (2000) The Directive EC 2000/53 Directive on End-of-life vehicles (ELV) Journal of the European Communities L269, 21/10/2000, pp. 34 - 42.

http://rod.eionet.europa.eu/instruments/526

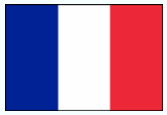
Nations of the World

Nations

Human Capital

Manufact'd Capital

Natural Capital



France

Geography

Area (Land Only)	6.4 e5	km^2

People

Population	6.4 e7	
Median Age	39	yrs
Satisfaction with life	220	points

Human Rights & Education

Press freedom index	0.13
Rule of Law index	91
Public spend on education, % GDP	5.6%

Economy & Development

GDP per capita	21,000	USD
Life expectancy	81.5	yrs
UN Human Development Index	0.95	points

Environment, energy and carbon

Ecological footprint	4.9	Global hectares (gha)
Oil consumption	1.9 e6	bbl/day
Annual Greenhouse Gas Emission	4.2 e8	Tonnes $CO_{2\ eqiv}$/year

Material efficiency: the wind turbine

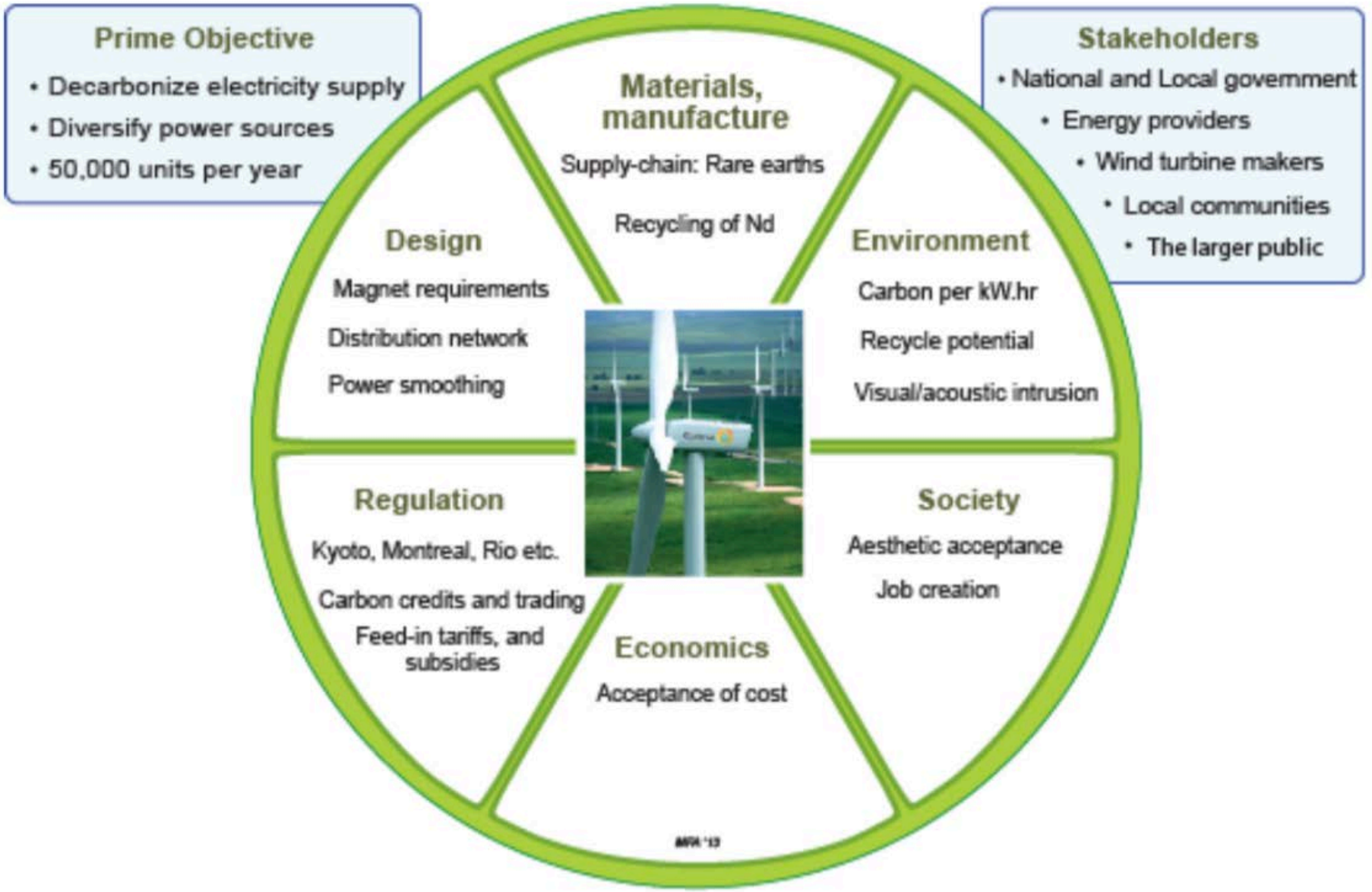


Figure 18 *Fact-finding for Wind farms*

Wind turbine – notional poster

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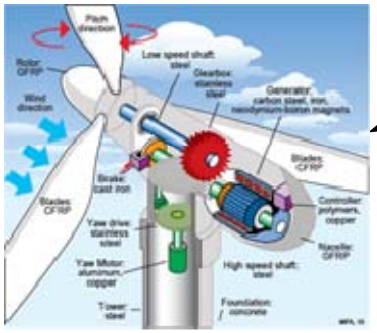
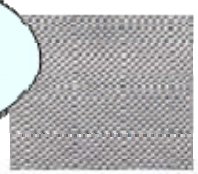
Materials



Blades
- Wood
- E-glass - PVC
- E-glass - epoxy
- Carbon - epoxy



Generator
- Nd-Fe-B magnets

(Critical materials)

Enclosure and support
- GFRP, steel, concrete

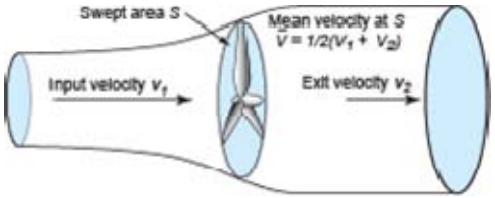
Transmission network
- Copper, Aluminum

Design

When wind comes into contact with the rotor of a wind turbine, some of its kinetic energy is imparted to the blades, driving their rotation. This rotation is transmitted through a gearbox to a generator, creating electric power. Wind speed v increases with height h above ground level:

$$v(h) \approx v_{10}\left(\frac{h}{10}\right)^{0.14}$$

where v_{10} is the wind speed at a height $h = 10m$.



The peak power of a turbine (the Betz limit) varies as the swept area S times the cube of the incoming wind speed v_1 $\quad Power = 0.3\ \rho\ S\ v_1^3$ ..

(ρ is the density of air).

The tip speed ratio is the ratio of the blade tip speed and the speed of the wind. High efficiency 3-blade-turbines have tip-speed ratios of 6 to 7. Composite blades gives low rotational inertia so the turbine accelerates quickly if the winds change, keeping the tip speed ratio constant. The lighter blades reduce gravitational fatigue loading.

Regulations, incentives

Kyoto Protocol

The Kyoto Protocol (1997) is an international treaty to reduce the emissions of gases that, through the greenhouse effect, cause climate change.

Carbon commitment

The UK is committed to reducing its greenhouse gas emissions by at least 80% by 2050, relative to 1990 levels.

Renewable energy subsidies

Many countries offer a feed-in tariff that amounts to a subsidy for renewable energy..

Planning permission

Planning permission may require a public enquiry and can take years.

Stakeholder acceptance

Government

Wind power contributes to carbon commitment

Energy providers

Subsidised wind power is profitable for energy companies

Energy consumers

Clean energy. But expensive

Anti wind lobby

Citizen's groups opposed to wind turbines because of visual and acoustic intrusion.

Nature conservancy groups

Groups with mission to conserve habitat, bio-diversity, countryside

Ethical sourcing

Civil rights
Gender equity
Child protection

Mike Ashby, 2012

The electric car – Prime objective

15 % of global fossil fuel CO_2 release comes from cars

Europe: Carbon Reduction Commitments (CRCs)
60 – 80 % reductions in carbon emissions by 2050

70 % of oil production is used for transport

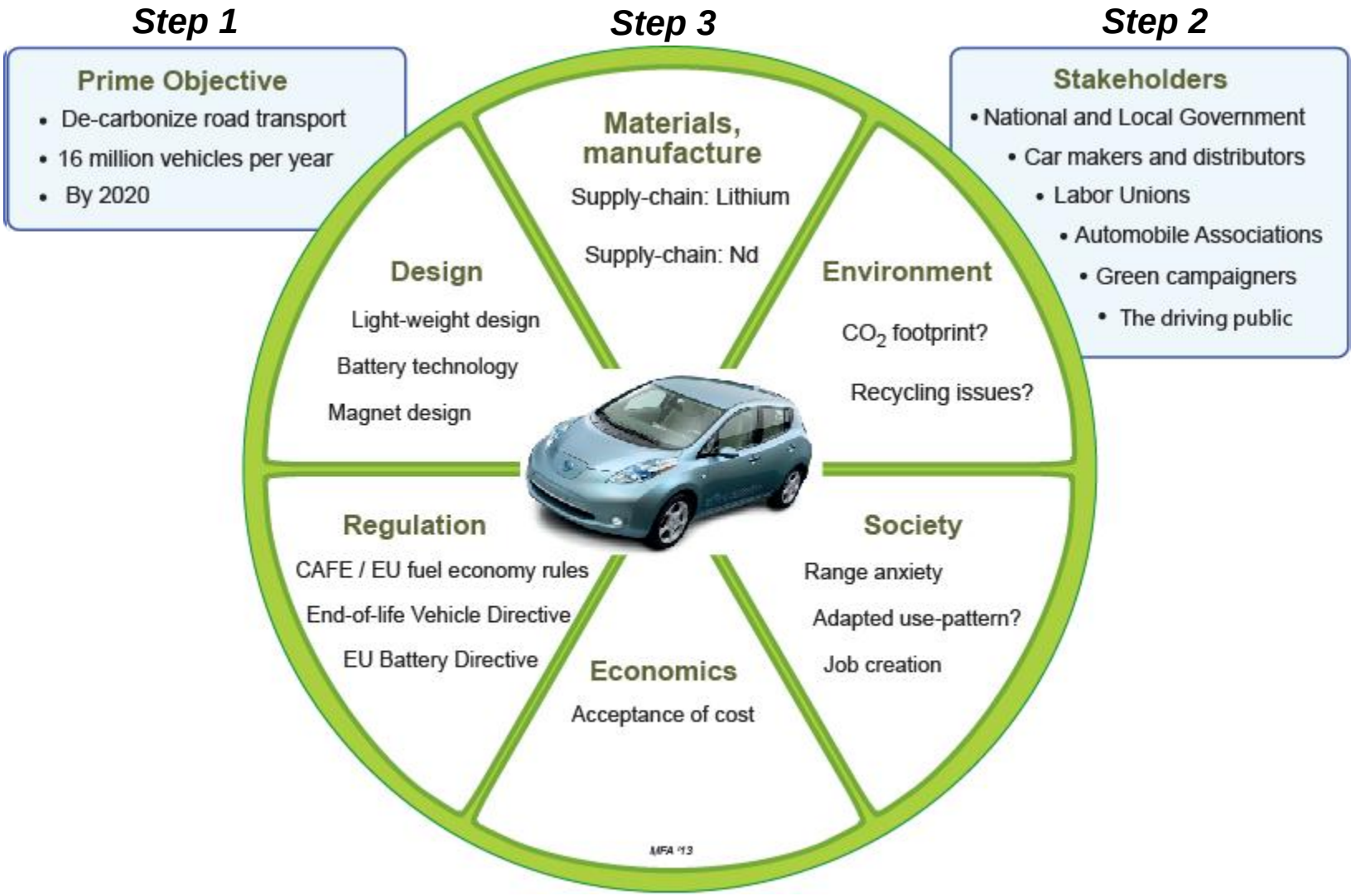
President Obama aims to put one million electric vehicles on the road by 2015 to reduce US dependence on oil

State of the Union Address, 2011

Prime objective and scale

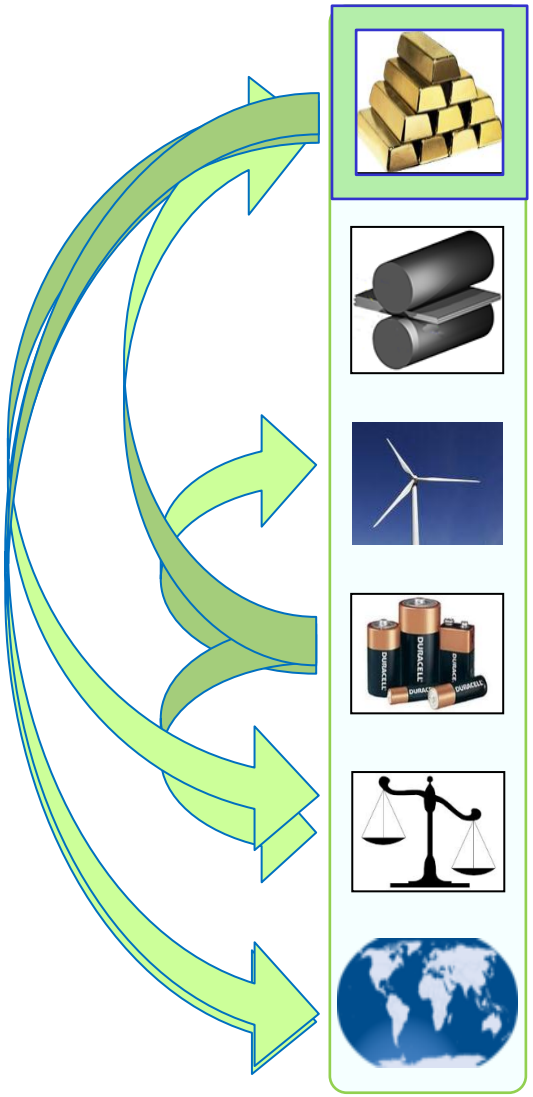
- ***Decarbonize road transport***
- ***16 million cars/year by 2020***

Electric cars: the first three steps



Use of the database for fact-finding

Electric car



Six linked data-tables

Materials with source-nation

Processes

Power generation systems

Energy storage systems

Regulation and legislation

Nations: people, governance, human rights, economy, development

Materials (1)

Neodymium-boron magnet motors

Lithium-ion batteries

Bill of materials	kg
Carbon steel	790
Cast iron	151
Wrought aluminum (10% recycle)	30
Cast aluminum (35% recycle)	64
Copper / Brass	26
Magnesium	0.3
Glass	39
Thermoplastic polymers (PU, PVC)	94
Thermosetting polymers (Polyester)	55
Rubber	33
Platinum, exhaust catalyst	0.007
Electronics, emission control	0.27
Rare earth magnets (0.5 kg Neodymium)	**1.5**
Batteries (4.8 kg Lithium)	**100**
Total weight	1385

Nd-B magnets for motors

Lithium for lithium-ion batteries

Materials (2)

Material supply chain

16 million cars per year

- *0.5 kg Neodymium per car*
- *4.8 kg Li per car MINIMUM*

Neodymium

Producing Nation	Tonnes/year 2011
China	*22,100*
India	*510*
Brazil	*93*
Malaysia	*5*
World	**22,710**

***Nd** demand =*
***40%** present world production*

Lithium

Producing Nation	Tonnes/year 2011
Chile	*12,600*
Australia	*11,300*
China	*5,200*
Bolivia	*5,000*
Argentina	*3,200*
Portugal	*820*
Zimbabwe	*470*
Brazil	*160*
World	**34,000**

***Li** demand =*
***230%** present world production*

Facts

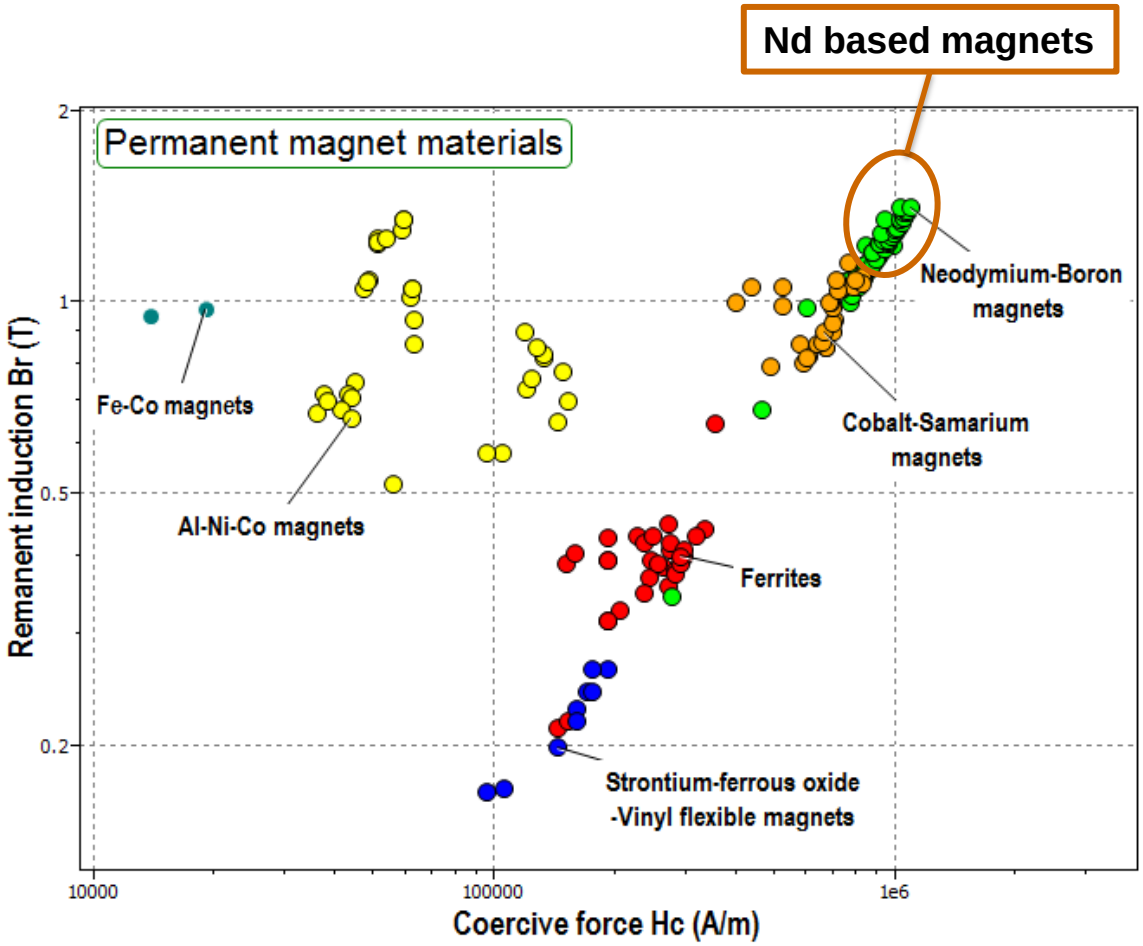
Materials

- ***Nd: Severe supply-chain concentration***
- ***Li: Current world production inadequate***

Design (1)

Alternative magnets?

Need high remanence and high coercive force



Facts

Design

- ***No better magnet than Nd-B***

Materials

- ***Nd, Li: Supply-chain issues***

Design (2)

Alternative batteries?

Seek high energy density (MJ/kg)

Facts

Design

- ***Energy density of batteries << gasoline***
- ***No better magnet than Nd-B***

Materials

- ***Nd, Li: Supply-chain issues***

Legislation and commitments

- Corporate fleet fuel-economy penalties –
  Fleet mileage > 35 mpg

- EU Battery Directive –
  None to landfill

- Plug-in electric vehicle subsidy –

USA			*$ 7,500*
China	*¥ 60,000*	–	*$ 9,700*
UK	*£ 5000*	–	*$ 7,000*
France	*€ 7000*	–	*$ 8,500*

Facts

Legislation

- ***Need recycle facilities for Nd and Li***

Design

- ***E-density of battery << gas***
- ***No better magnets than Nd-B***

Materials

- ***Nd, Li: Supply-chain issues***

Society and Stakeholder concerns

Range and Cost anxiety

Energy density of energy-source

- Li-ion battery: ≈ 0.6 MJ / kg
- Conversion efficiency to axel ≈ 0.85

Energy required at axel

- Small car ≈ 0.5 MJ / km

Battery weight ≈ 1 kg per km of range

- 500 km range requires > half-tonne Li-ion battery
- Cost at todays prices $42,000

Facts

Society

- ***Range limited by battery weight and cost***

Legislation

- ***Must recycle Nd and Li***

Design

- ***E-density of battery << gas***
- ***No better magnets than Nd-B***

Materials

- ***Nd, Li: Supply-chain issues***

Environment - Can Prime Objective be met?

Environment

Decarbonize road transport

Charge vehicle from the National Grid, gas / coal fired.

- CO_2 footprint, gas fired power ≈ 140 g / MJ
- Delivered energy to propel small car ≈ 0.6 MJ / km
- Efficiency of battery – electric motor set ≈ 85%

Carbon footprint of electric car ≈ 140 x 0.6 / 0.85

≈ 100 g / km

Facts

Environment

- ***CO_2 footprint ≈ 100 g/km***

Society

- ***Range limited by battery weight and cost***

Legislation

- ***Need recycle facilities for Nd and Li***

Design

- ***E-density of battery << gas***
- ***No better magnets than Nd-B***

Materials

- ***Nd, Li: Supply-chain issues***

What have we got?

Step 1

Prime objective and scale

- Decarbonize road transport
- 20% of global production by 2020

Step 3 – Facts

Environment

- *CO_2 footprint ≈ 100 g/km*

Society

- *Range limited by battery weight and cost*

Legislation

- *Need recycle facilities for Nd and Li*

Design

- *E-density of battery << gas*
- *No better magnets than Nd-B*

Materials

- *Nd, Li: Supply-chain issues*

Step 2

Stakeholders

- National, local government
- Car makers and retailers
- Labor unions
- Green campaigners
- Automobile associations
- Car buying public

Step 4 – Integration

Students (in groups) debate impact on 3 capitals

Step 4 – Integration

Prime Objective

Stakeholders

Facts

Environment

- *CO_2 footprint ≈ 100 g/km*

Society

- *Range limited by battery weight and cost*

Legislation

- *Need recycle facilities for Nd and Li*

Design

- *E-density of batteries << gas*
- *Dependent on Nd-B magnets*

Materials

- *Nd, Li: Supply-chain issues*

Integration

Natural Capital

- **Prime objective -** *not met until grid decarbonized*

Manuf'td Capital

- **Missing infrastructure –** *Lithium, Neodymium production / recycling*
- **Subsidies** - *Poor use of taxes?*

Human Capital

- **Satisfaction?** *Expectations not (at present) met*

Step 5 – Reflection

Prime Objective

Stakeholders

Facts

Environment

- *CO_2 footprint ≈ 100 g/km*

Society

- *Range limited by battery weight and cost*

Legislation

- *Need recycle facilities for Nd and Li*

Design

- *E-density of batteries << gas*
- *Dependent on Nd-B magnets*

Materials

- *Nd, Li: Supply-chain issues*

Reflection

- **Short term – not sustainable**
- **Long term – rethink (redefine?) the way cars are used**
  – rethink use of electrical power for cars