SustainAbility

Plugging Into Electric Mobility

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- Energy policy hierarchy
- History of oil – and what it means for the future
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- Electricity = energy efficiency & emissions control
- Electricity = energy diversification
- Overcoming barriers to automotive electrification

Energy Policy Hierarchy

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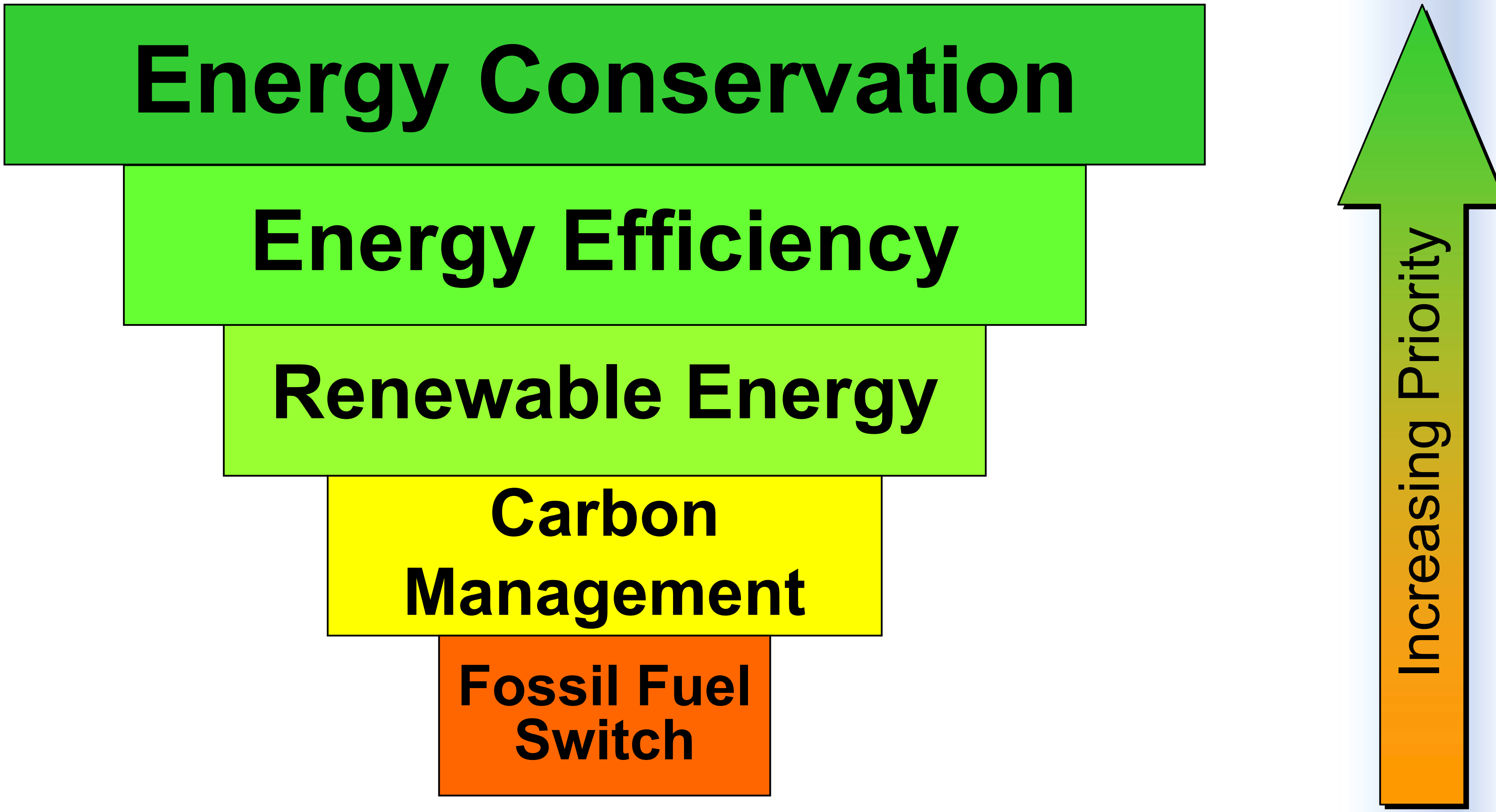

- By 2050: virtually zero-carbon energy system
  - No fossil fuels without CCS → no fossil fuels in mobile applications

Early History of Oil

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- 1859: crude oil discovered in Pennsylvania, USA
- 1863: John D. Rockefeller creates Standard Oil Co.
- Kerosene derived from crude oil displaces whale oil (unsustainable biofuel) from lamps
  - Crude oil dominates the lighting sector
- 1878: Thomas Edison creates Edison Electric Light Co.
  - Electricity displaces oil in lighting, oil price falls sharply
- Late 1800s: “horseless carriages” appear in US, Europe
- 1900: electric cars outsell steam- & gasoline-powered cars
- 1908: Henry Ford introduces “Model T” for US$ 950
- 1912: the electric starter motor is invented
- 1912: peak year of production of electric cars

Today’s Global Primary Energy Mix

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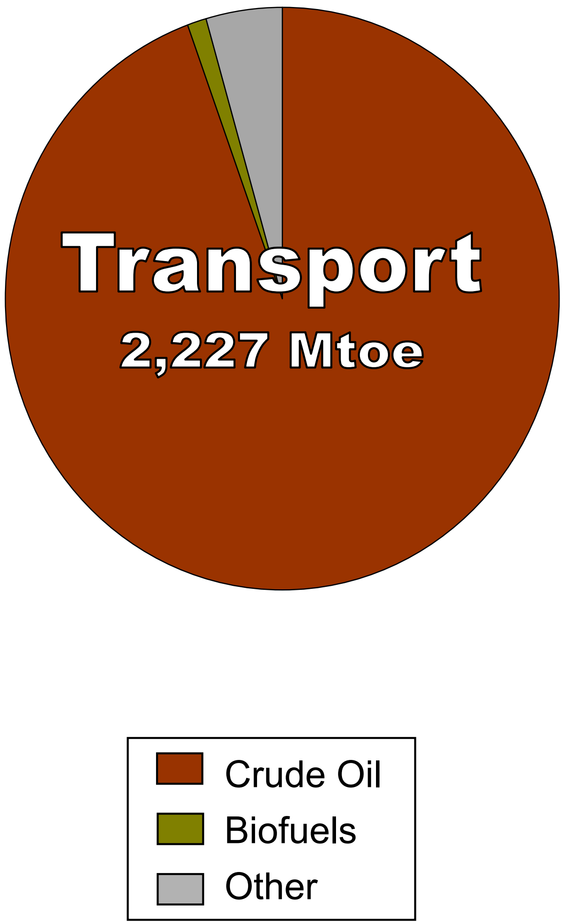

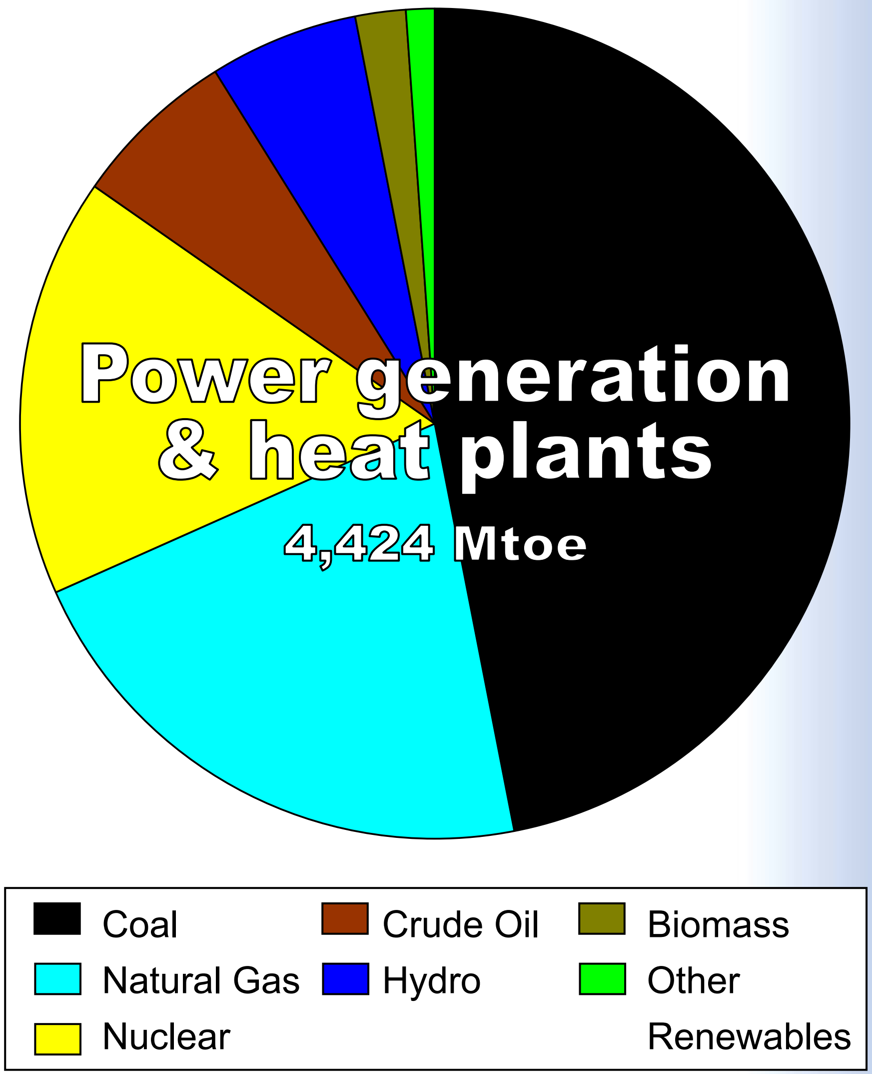

IEA World Energy Outlook 2008 (data for 2006)

Why Crude Oil Matters

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- Transport – the movement of people and stuff – allows economic activity to take place
- And, transport is 95% dependent on a single source of primary energy: crude oil
- Without crude oil, modern societies fail to function
- Example: UK fuel protests of 2000
  - After one week…
    - 90% of filling stations empty
    - Fighting at supermarkets
    - ATMs ran out of cash
    - Hospital operations cancelled
    - Dead bodies left unburied
  - Cost to UK economy ~ $1.5 billion

Oil Price, Consumption, Growth

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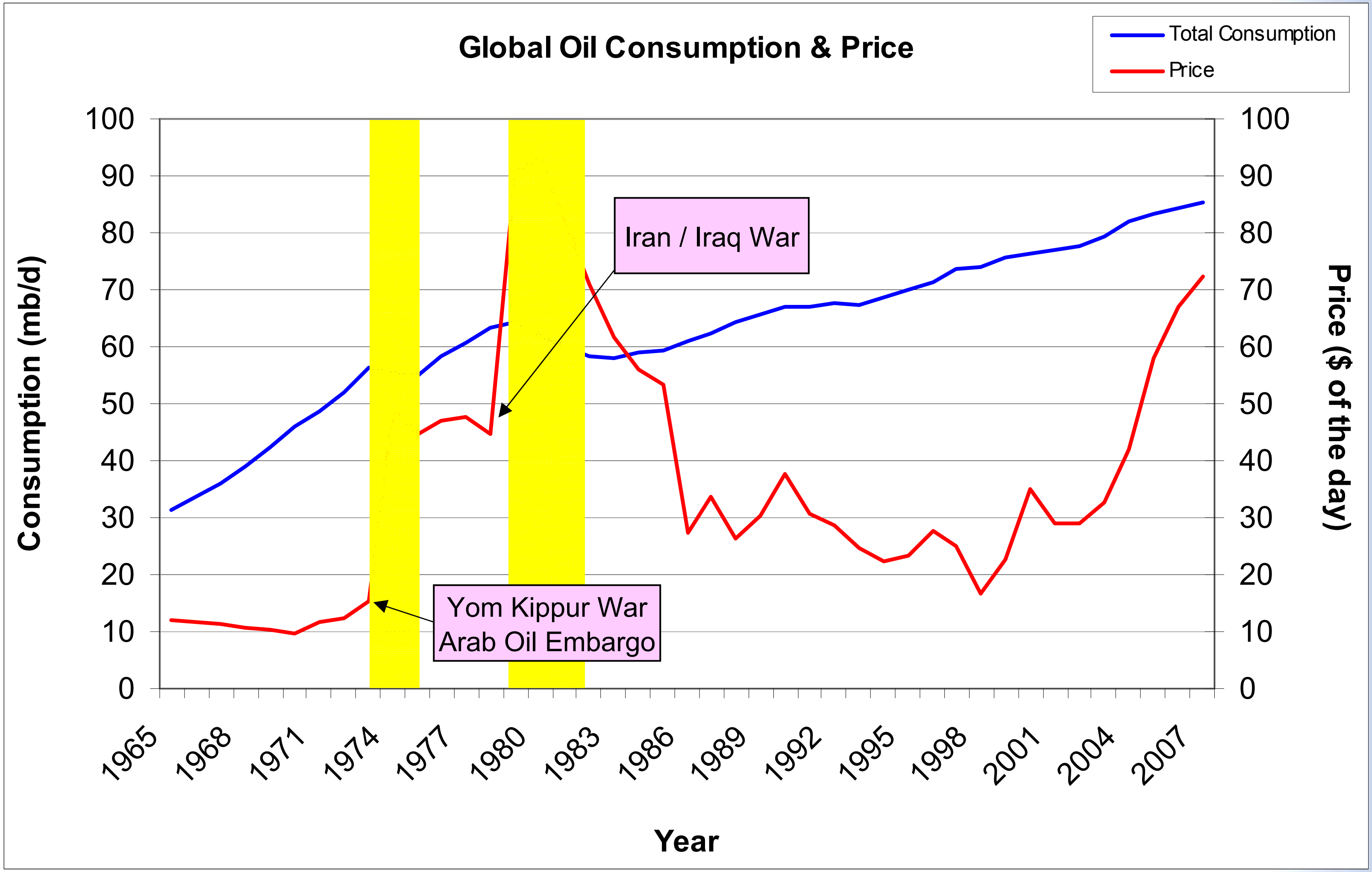

Periods of falling demand (recession)

After the 1970s Oil Shocks

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- Four deliberate responses (+ economic recession!):

1. State-sponsored **energy efficiency** drives
   – US imposed nationwide 55mph maximum speed limit
2. Renewed efforts in **exploration** and production
   – And OPEC subsequently opened the taps
3. Investment in **oil substitutes**
   – Brazil's biofuel industry born in 1980
   – Synthetic Fuels Corporation formed in the US (coal-to-liquids)
4. Crucially, crude oil **displaced** from certain applications
   – Gas, coal, nukes into heat, power, chemicals etc.

Oil Concentrates into Transport

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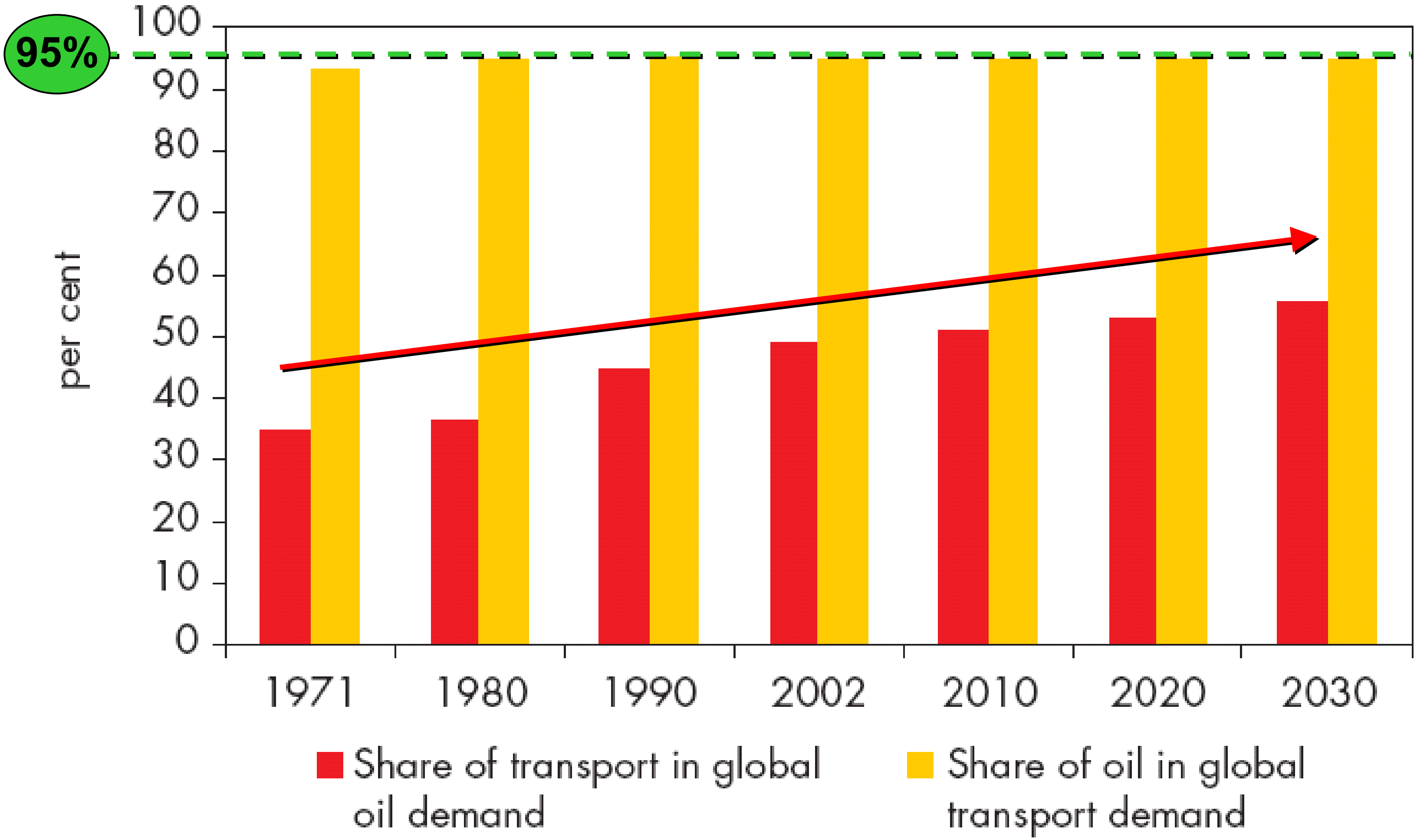
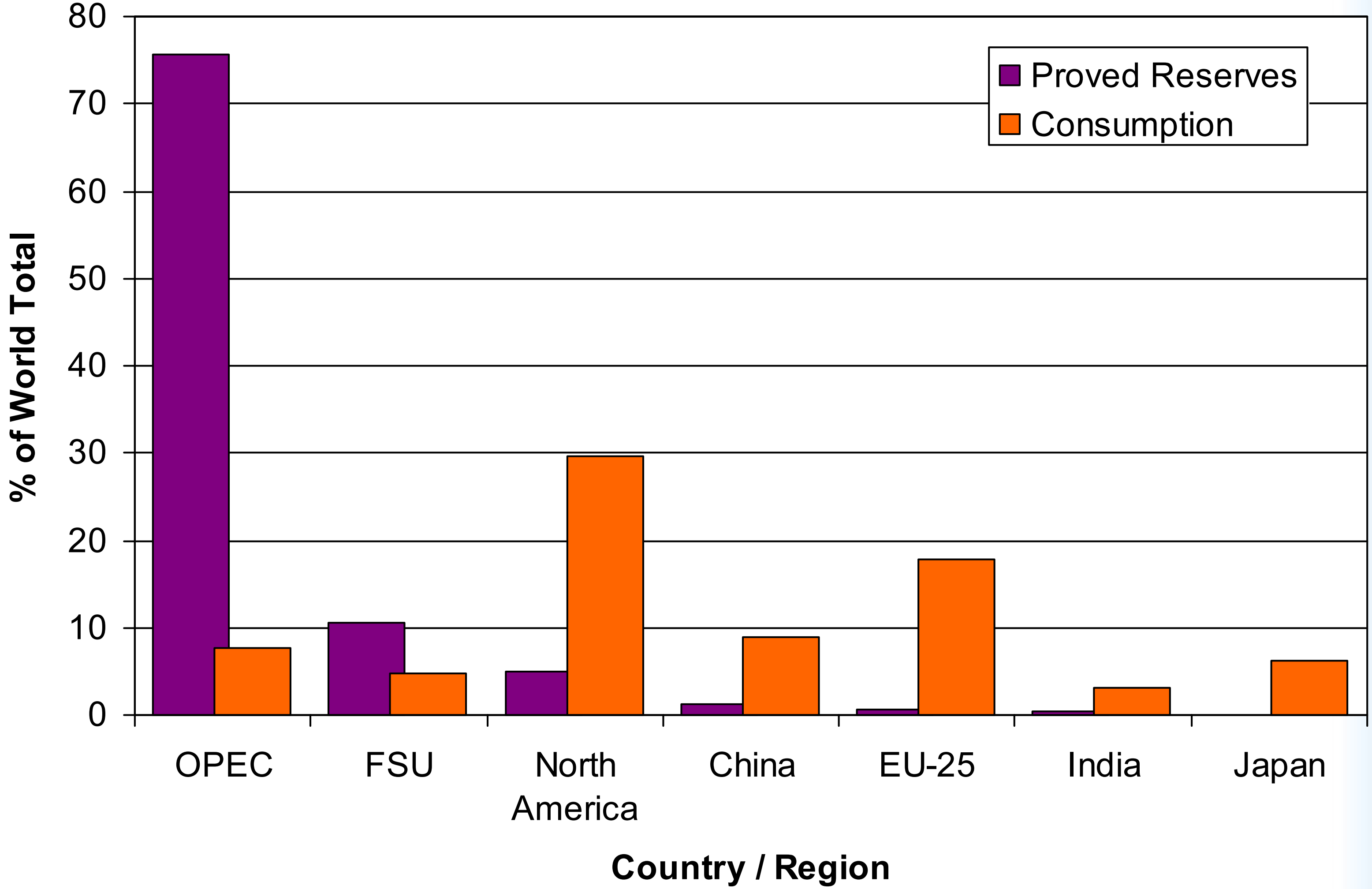


Data source: IEA World Energy Outlook 2004

Geographical Distribution of Reserves



Data source: BP Statistical Review 2007

Oil Substitutes ≠ Alternative Fuels

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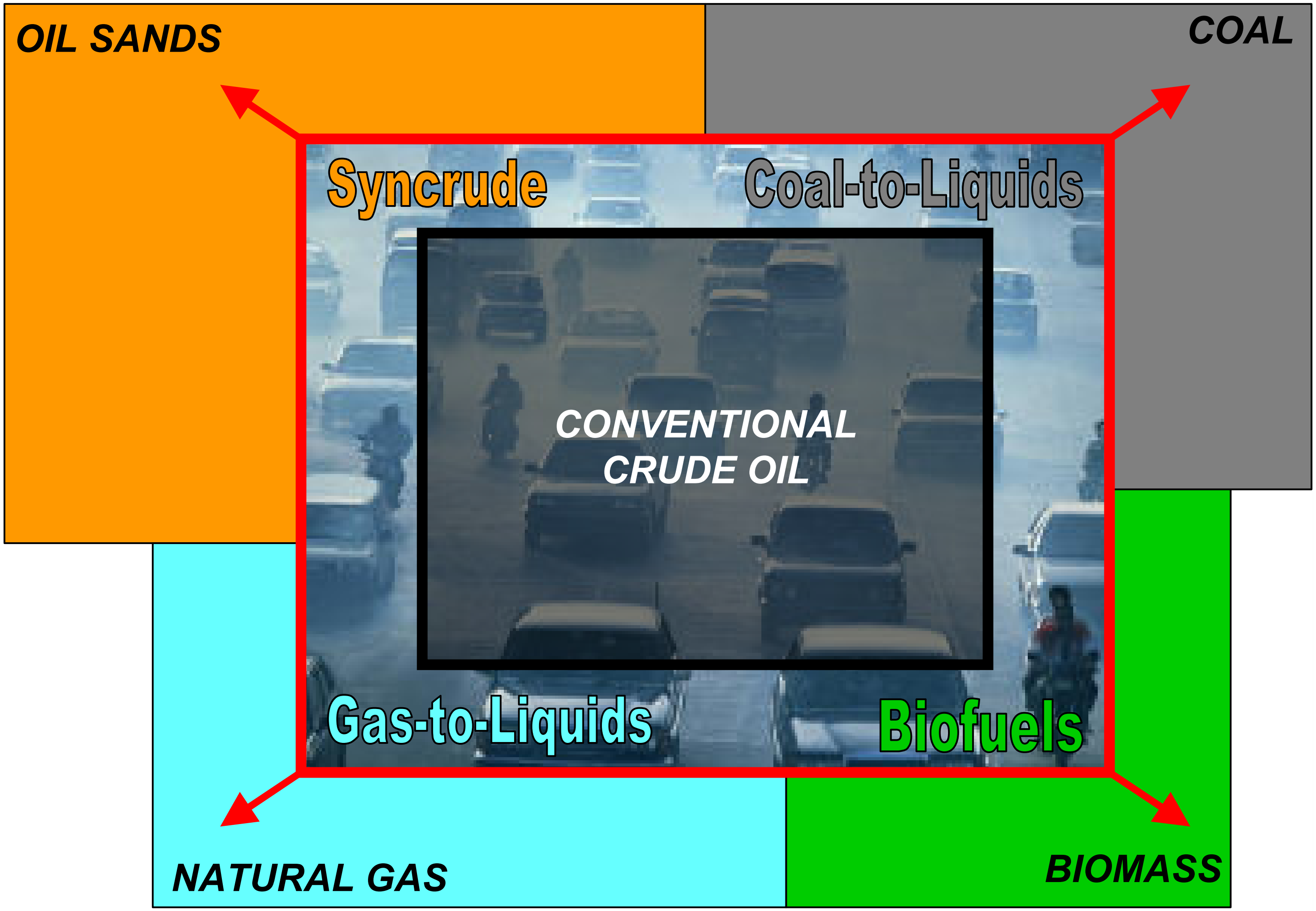

- All these oil substitutes are **liquid hydrocarbon fuels** that are burned on board in (relatively) low efficiency internal combustion engines

Energy Efficiency & Emissions Control

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- When we burn carbonaceous fuels in a carbon-constrained world, these are the **four truths that we can hold to be self-evident**:

1. ***Large*** *is better than small*
   - MW-scale plants run hotter ∴ more efficiently than kW-scale plants
2. ***Constant load*** *is better than variable load*
   - Optimal thermal operating efficiency may be maintained ~continuously
3. ***Few*** *is better than many*
   - Fewer sources of emissions are easier to control (e.g. capture and store)
4. ***Stationary*** *is better than mobile*
   - CCS is technically impractical from mobile emissions sources

- So, to maximise efficiency and facilitate emissions control:
  - Few, large, stationary plants running at constant load (e.g. power plants)
  - Directionally superior to: many, small, mobile plants running at variable load (e.g. vehicular internal combustion engines)

Energy Efficiency – Using Less

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- For any given hydrocarbon resource (coal, crude oil, natural gas, or biomass) electricity beats liquids on an energy efficiency basis

Primary Energy	Fuel Technology	Transmission Losses	Powertrain	% Energy @ Wheels	Carbon Factor	Relative CO_2 Emissions	CCS Potential
COAL	CTL ~50%		Diesel ICEV ~23%	12	2.00	17	
COAL	Power ~45%	T&D ~92%	Battery EV ~70%	29	2.00	7	CCS
CRUDE OIL	Refinery ~85%		Petrol ICEV ~18%	15	1.33	9	
CRUDE OIL	Refinery ~85%		Diesel ICEV ~23%	20	1.33	7	
CRUDE OIL	Power ~45%	T&D ~92%	Battery EV ~70%	29	1.33	5	CCS
NAT. GAS	GTL ~66%		Diesel ICEV ~23%	15	1.00	7	
NAT. GAS	Power ~60%	T&D ~92%	Battery EV ~70%	39	1.00	3	CCS

NOTE: percentages in boxes represent primary energy efficiency of conversion step (T&D = Transmission & Distribution)

Electrons Always Beat Liquids

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- In energy efficiency terms, the notion that "crude oil is too valuable to 'waste' in power generation" is a paradox …
  - … not to mention a missed opportunity for CCS
- Very difficult to justify investments in GTL and CTL
- And biofuels?
  - http://www.sciencemag.org/cgi/content/abstract/1168885

Greater Transportation Energy and GHG Offsets from Bioelectricity Than Ethanol

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The quantity of land available to grow biofuel crops without impacting food prices or greenhouse gas emissions from land conversion is limited. Therefore, bioenergy should maximize land-use efficiency when addressing transportation and climate change goals. Biomass could power either internal combustion or electric vehicles, but the relative land-use efficiency of these two energy pathways is not well quantified. Here, we show that

Non-carbon Energy Sources

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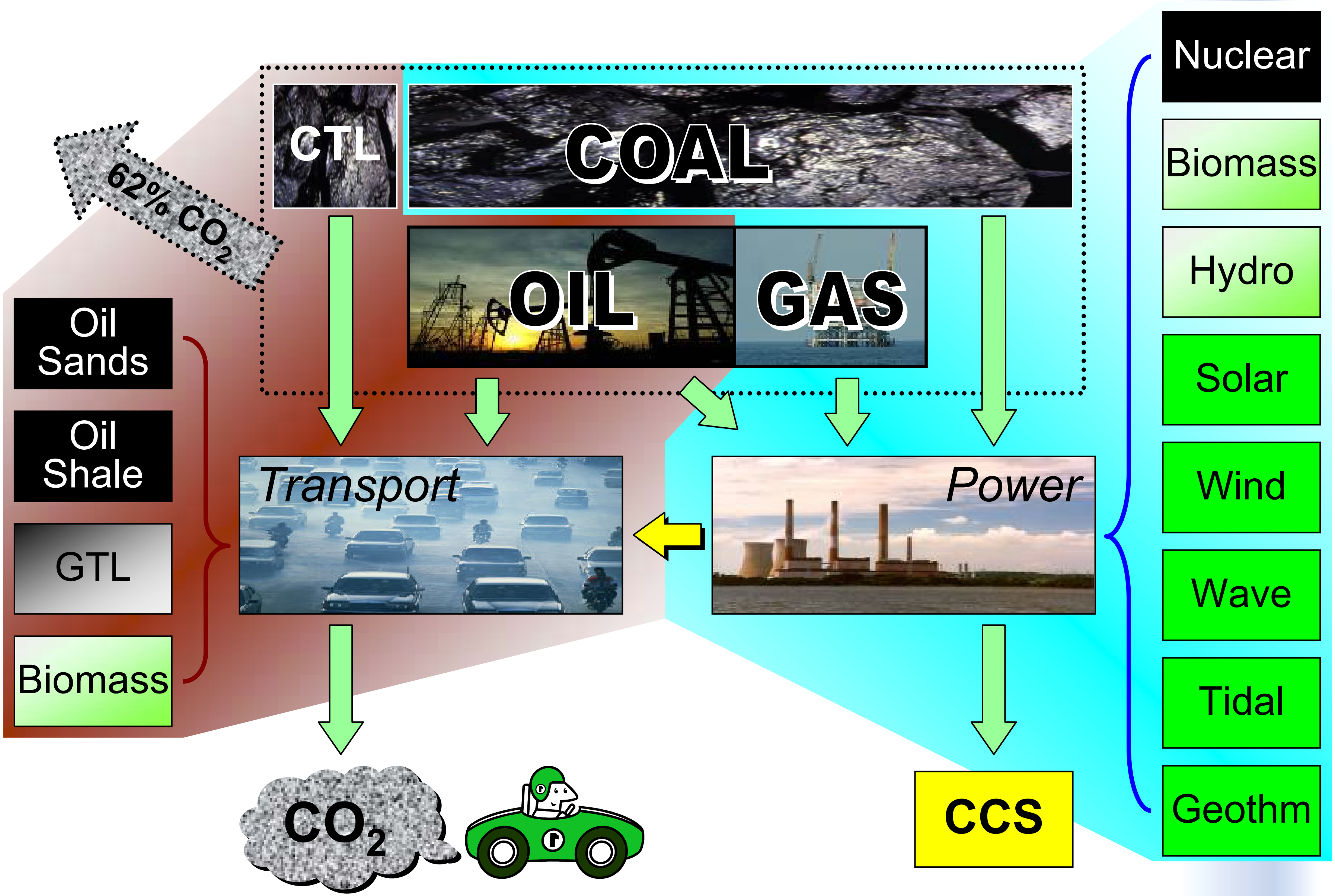
- For a given chemical energy resource (i.e. fossil fuels and biomass), electricity is a more energy efficient carrier than liquid fuels
  - See previous slides
- For physical energy resources (e.g. wind, solar, geothermal, hydro, wave, tidal) electricity is the best option
  - Can’t make diesel, gasoline, kerosene from wind, solar, tidal etc.
- Potential exists for *hydrogen* as an energy storage medium where renewable energy is generated in excess
  - Bidirectional losses (electrolyser / fuel cell) seriously harm energy efficiency of H_2 pathway versus electricity
  - Given what we know today, H_2 doesn’t make energetic sense

Sustainable Diversification



The Case for EVs is Compelling

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- Highly energy efficient
- Energy secure (full primary energy diversification)
- Zero tailpipe emissions = improved air quality
- Cleaner over time as grid decarbonises
- Virtually silent
- Infrastructure is largely available or can be installed / adapted easily
- Can assist with grid management (V2G)
- Multiple new business opportunities
- … and tremendous fun to drive!

Mitsubishi iMiEV vs i (2010)

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- Battery electric vehicle
- Range: 160 km (100 miles)
- Battery size: 16 kWh

- Energy efficiency
  = 16 kWh / 160 km
  = **0.10 kWh/km**

- 658cc petrol
- Fuel consumption: 5.2 l/100km
- 1 litre diesel = 9.6 kWh

- Energy efficiency
  = 5.2 l x 9.6 kWh / 100 km
  = **0.50 kWh/km**

Energy Efficiency Ratio = 5.0

Mini-E vs Mini Cooper D (2009)

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- Battery electric vehicle
- Range: 240 km (150 miles)
- Battery size: 35 kWh

- Energy efficiency
  = 35 kWh / 240 km
  = **0.15 kWh/km**

- 1.6l diesel
- Fuel consumption: 3.9 l/100km
- 1 litre diesel = 10.7 kWh

- Energy efficiency
  = 3.9 l x 10.7 kWh / 100 km
  = **0.42 kWh/km**

Energy Efficiency Ratio = 2.9

Tesla Roadster vs Lotus Elise (2008)

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- Battery electric vehicle
- Range: 386 km (240 miles)
- Battery size: 52.8 kWh

- Energy efficiency
  = 52.8 kWh / 386 km
  = **0.14 kWh/km**

- 2 litre petrol (gasoline)
- Fuel consumption: 8.8 l/100km
- 1 litre petrol = 9.6 kWh

- Energy efficiency
  = 8.8 l x 9.6 kWh / 100 km
  = **0.84 kWh/km**

Energy Efficiency Ratio = 6.2

Barriers to Mass Adoption of EVs

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- Historically, three intrinsic limitations holding back EVs:

1. Cost
   - Batteries are expensive
2. Range
   - Limited to ~100-150 km
3. Refuelling time
   - Several hours to recharge battery

- Fourth barrier: behavioural lock in?

Barrier Removal: Technology

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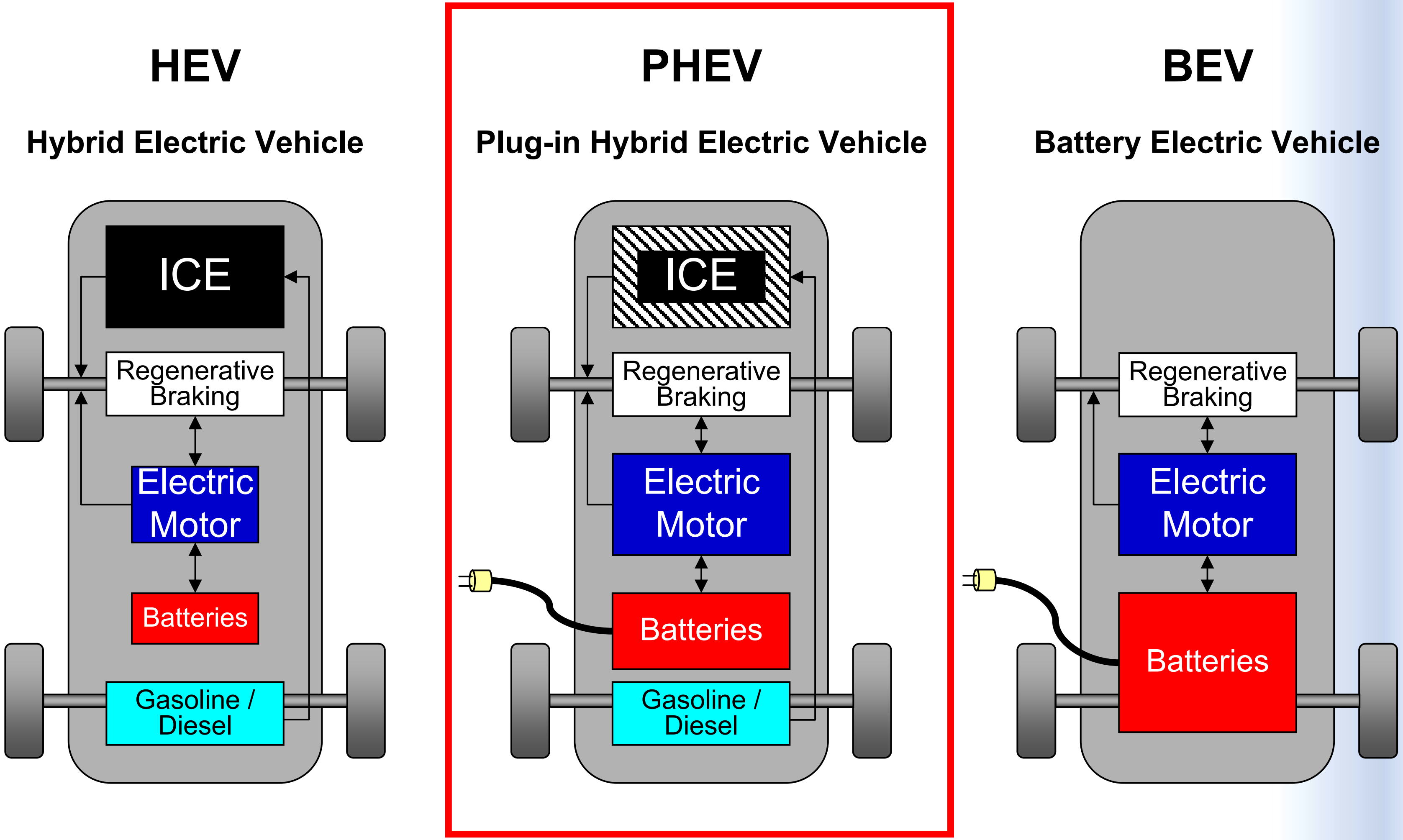

Barrier Removal: Business Models

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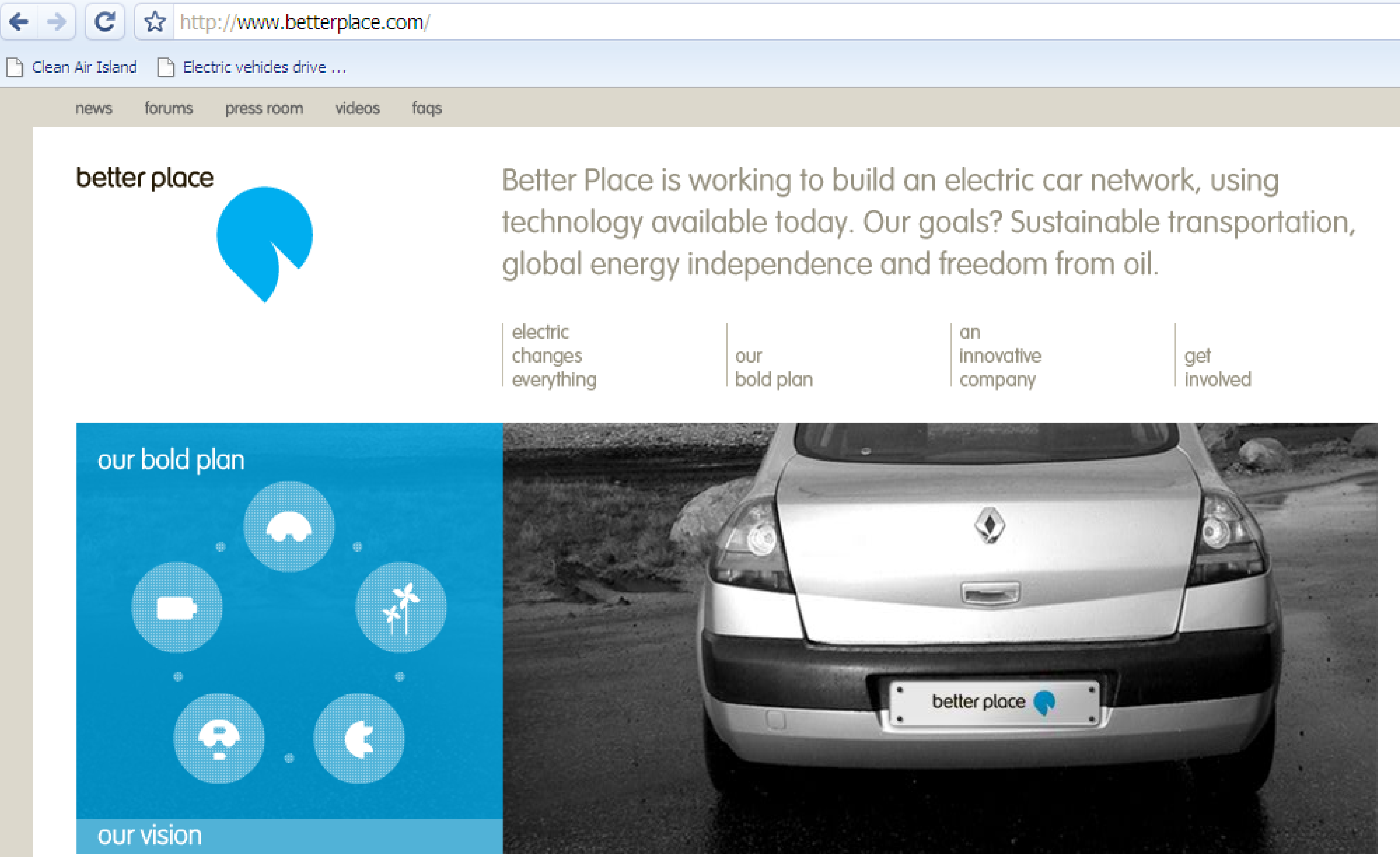

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New Competition for BP, Shell, Exxon…

eDF

i'm lovin' it™

Swiss Context

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- Decarbonised energy supply
  - 28 gCO_2/kWh *
- Highly effective public transport network
  - Opportunity for "last kilometre" network extension
- Well established car clubs at rail hubs
  - Mobility Car Sharing
- Who installs & operates the infrastructure?
  - Highly fragmented electric utility sector a barrier to coordinated roll-out / standardisation?
- Public acceptance?
  - We tried this once before…

* CO_2 emissions per kWh from electricity and heat in 2006, assuming average transmission & distribution efficiency of 92%

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- Available for free download in PDF format:
  www.panda.org/climate
  www.sustainability.com
- For further information, please contact:
  kendall@sustainability.com

Back up

US Utilities Catching On

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REUTERS

Utilities pledge to be ready for plug-in autos

Wed Oct 21, 2009 3:33pm EDT

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By Bernie Woodall

DETROIT (Reuters) - If electric cars plug in at rates hoped for by automakers in the coming years, there will be enough power to serve them, the biggest U.S. electric utilities industry group vowed on Wednesday.

The utilities have pledged to make sure the electricity is there on demand, to work with policy makers on tax rebates and customer financial incentives and to make it easy for consumers to charge up car batteries, according to the Edison Electric Institute.

Convincing Americans of the benefits of plugging in will be a big part of the utilities-automakers efforts, announced at a plug-in conference in Detroit. They will also try to convince consumers to charge up an electric vehicle's batteries at night when power is cheaper and easily available.

Plug-In Hybrids

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- PHEVs are the ultimate flexible fuel vehicle
  - Electrons from any source + liquids from any source
- PHEVs are electric cars with onboard range extenders
  - First 50km on electricity alone (= high % of all journeys)
  - Engine kicks in when battery charge has been depleted
  - Compatible with existing infrastructure, so no range limitations
- Range extender could be running on sustainable biofuels
  - But overall DEMAND for liquid fuels dramatically reduced
- PHEVs forwards and backwards compatible
  - Bridging solution from liquids to electrons
  - Highly efficient
  - Compatible with a sustainable renewable energy future

GHG Emissions of EV vs ICEV

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- Typical energy efficiency ratio of EV vs ICEV ≈ 4.0 / 1
  - Mean average of nine apples-to-apples comparisons
  - (excluding Tesla / Lotus – outlier!)

- CO_2 intensity of gasoline / diesel @ *pump* ≈ **290 gCO_2/kWh**
  - Assuming refining & distribution energy efficiency of 83% [US DOE]

- "Break-even" CO_2 intensity of electricity @ *plug*
  = 290 x 4.0 = **1,173 gCO_2/kWh**

- Grid average electricity* mixes of major economies [IEA, 2008]:
  - CH = 28 gCO_2/kWh ← Best case (CH) = 98% reduction in CO_2
  - EU-27 = 385
  - US = 616
  - China = 857
  - India = 1,026 ← Worst case (India) = 13% reduction in CO_2

- Note: CO_2 intensity of electricity mix will further decline due to climate change policies heavily weighted towards power sector

* CO_2 emissions per kWh from electricity and heat in 2006, assuming average transmission & distribution efficiency of 92%

Reduced Demand for Liquids = Increased Demand for Electricity

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- Typical EV consumes ~0.15 kWh/km
- Estimate 12,000 km per year
- Electricity demand = 0.15 x 12,000
  = 1,800 kWh per vehicle

- Or… one million EVs would consume 1,800 GWh

- Annual electricity demand of Germany is 586 TWh
- So one million EVs in Germany would increase electricity demand by 0.3%

- 1,800 GWh could be supplied by ~230 onshore wind turbines, or one million rooftop solar-PV arrays

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