The energy problem: a cost/financial approach

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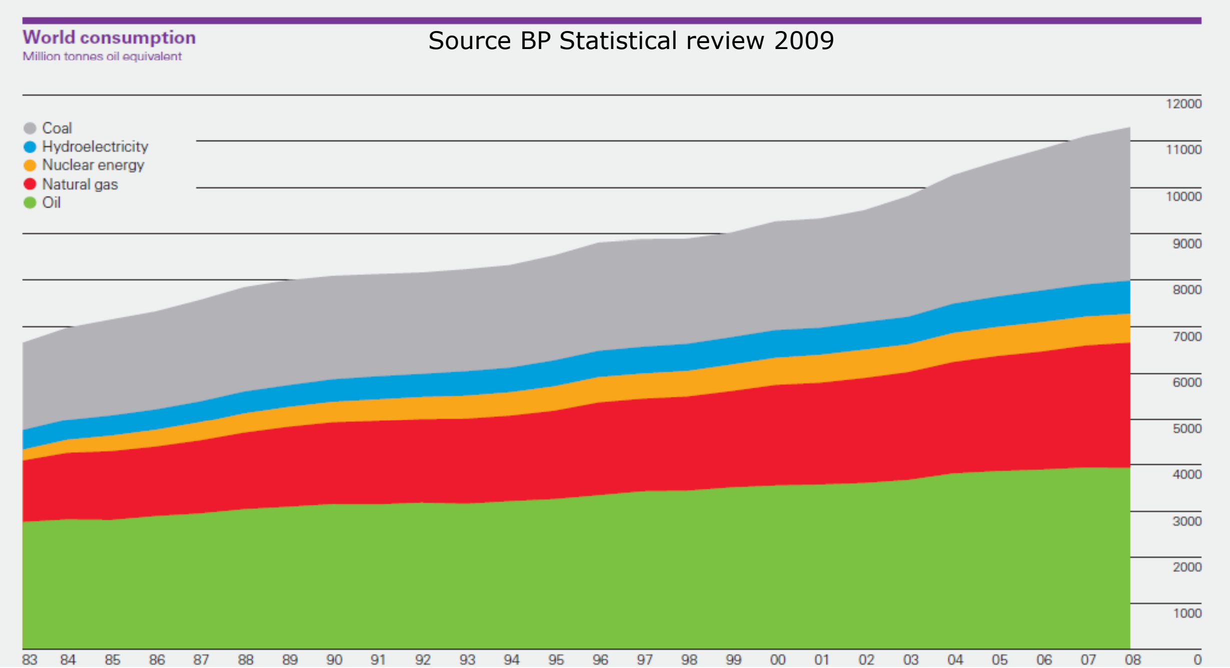
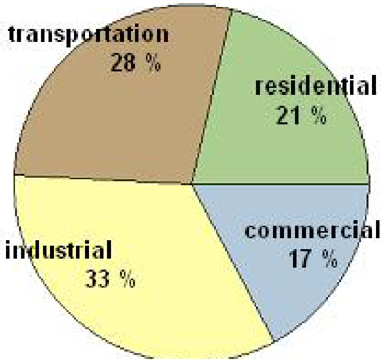
Total energy needs follow GDP (+1.6%/y on average)



In Mton of Oil Equivalent (1tonOE=7.33 barrels = 12 MWh = 4.4 MWh thermoel.)



Actually the **problem is twofold**:

- The "**input**" problem concerns the need of finding enough energy sources to supply the development of humanity
- The "**output**" problem refers to the need of limiting GHG emissions

Need to distinguish between **mobility** and **non-mobility** needs.

We'll concentrate on **costs and pricing**

Non-transportation needs

“Static” (residential, industrial, etc.) consumption is split into baseload and peakload components. All energy sources can be used if distribution infrastructure exists.

Today baseload is coal or nuclear, peakload is mainly gas or hydro

Let’s look at some numbers:

12000 MtOE/y = 150000 TWh/y = 16 TW

This could produce 6 TW electric but taking into account losses in recovertion to heat we get to roughly **10 TW electric**

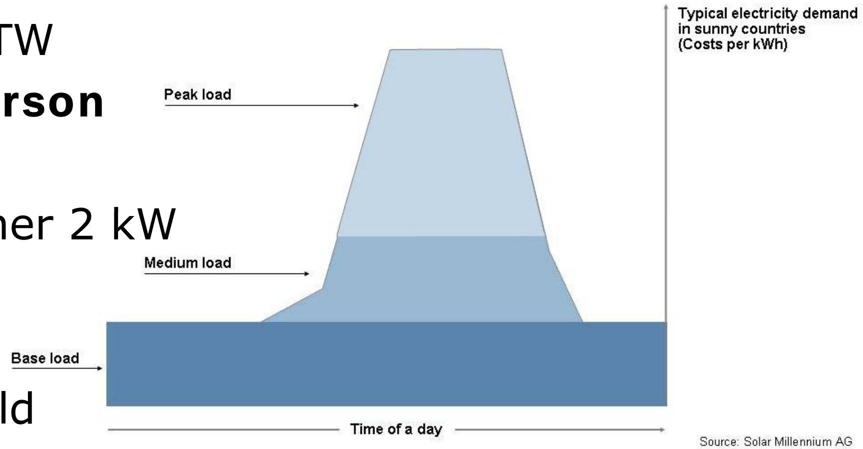
(actual **electric** consumption is 2 TW today)

1/3 is transportation so we remain with 7 TW

There are 7b people on earth -> **1 kW / person**

or 24 kWh/person/d (electric)

In developed countries consumption is rather 2 kW



Today baseload is 3 TW, peakload can be additional 10 TW (but these numbers would double if all countries were developed as Europe)

Commodities are *useful (=needed) goods that have standard features so that price is the only aspect that matters*.

Examples: copper, Brent-type oil, arabica coffee, etc.

Like for most other goods, commodity prices are determined by **supply and demand**

Demand is very stable, directly tied to world GDP

Supply, by its vary nature, can be at the root of wide price fluctuations:

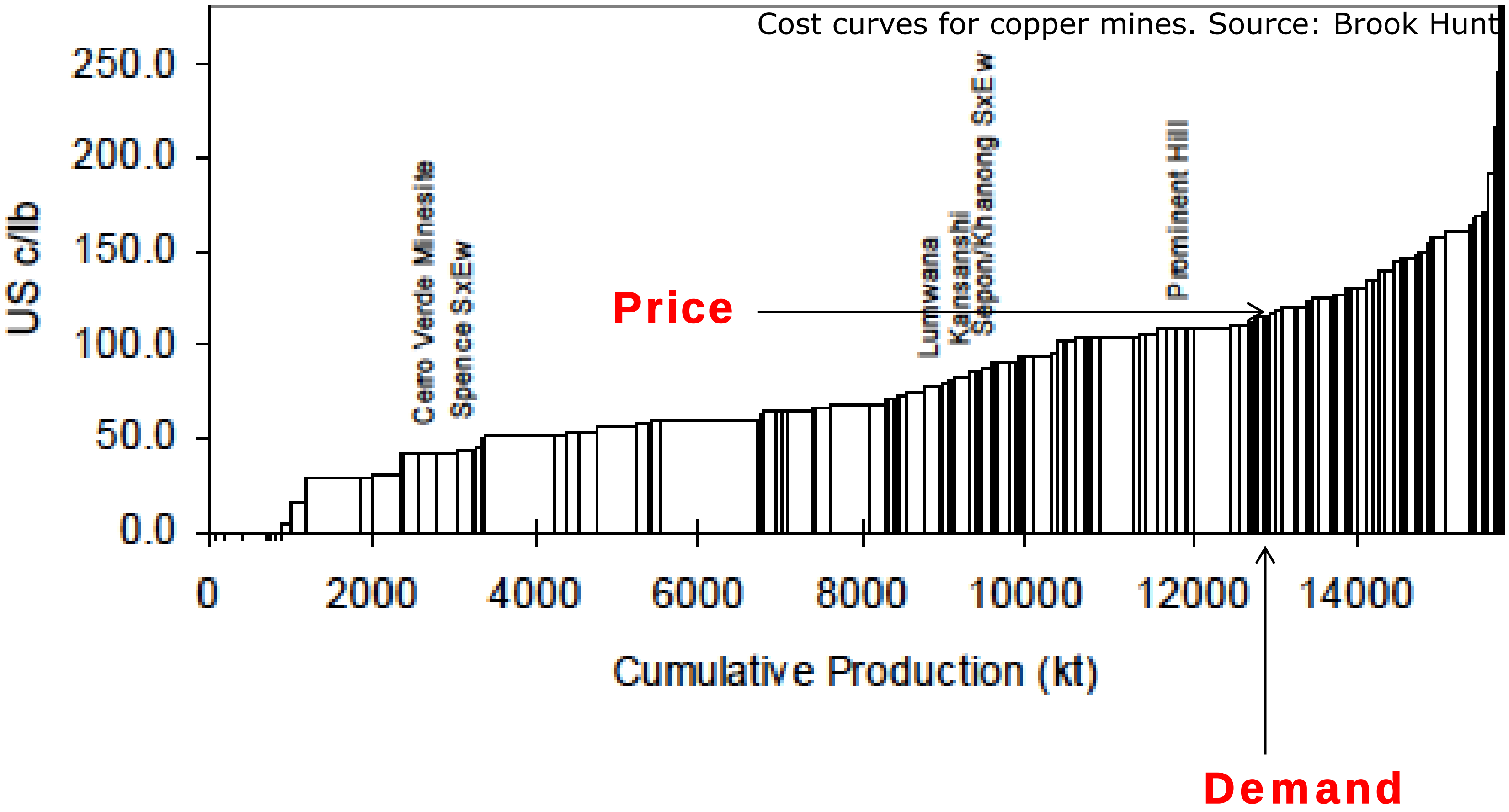
- Very long lead (production) times
- Very high sunk (fixed) costs
- In some case, very large single increases

Both supply and demand are very inelastic: any disruption in supply creates strong jumps in prices

Prices are determined in a straightforward way, but there are three very different regimes:

1. **excess capacity** (oversupplied market)
2. **incentive pricing** (normal market)
3. **auctioning market** (undersupplied market)

With **excess capacity** prices are determined by the **cash cost** of the marginal producer. Example: copper mining cash cost



In a **normal (balanced) environment**, prices are just below the level that would encourage newcomers, i.e. current producers maximize their profit up to a level that would incentivize new capacity addition

Figure 19. ROIC of new copper mining projects

	Old	New
Return target	15%	20%
Cost of Capital	7%	9%
Capital cost (US$/t)	7500	12750
Cash Cost (USc/lb)	70	100
Price (USc/lb)	160	160
ROIC = return on invested capital	19%	7%

Source: Citi Investment Research and Analysis

Source: Citi

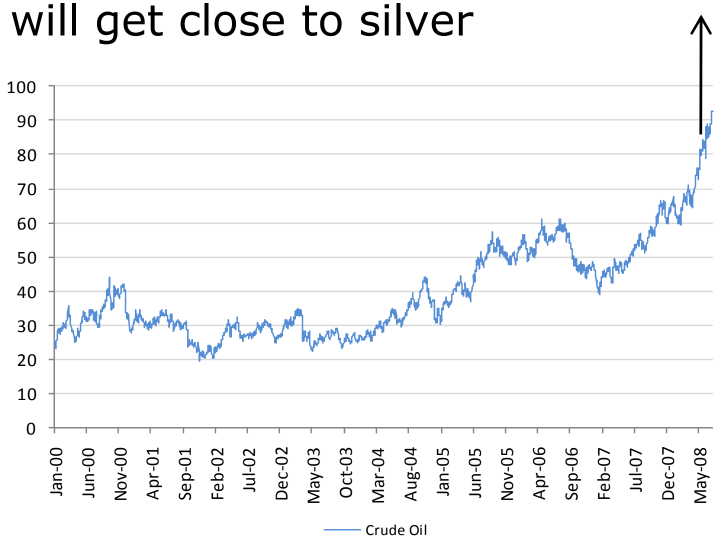
At 160 $c/lb a newcomer would make a return of 7%

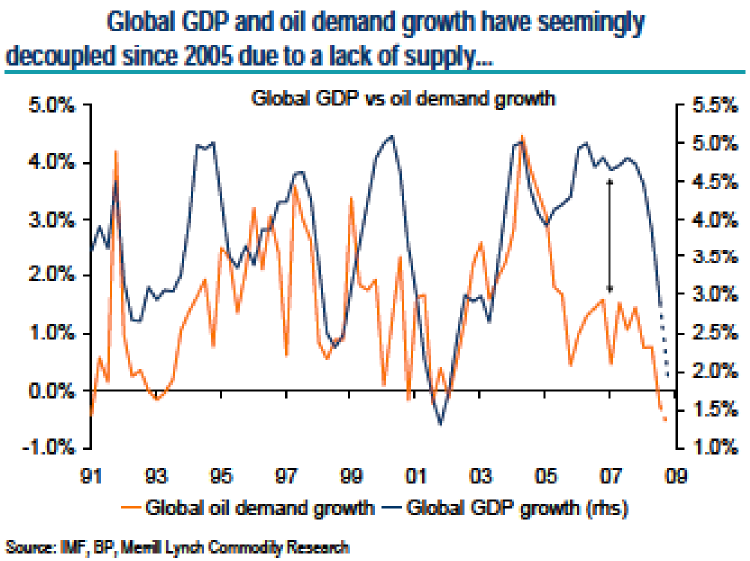
Sometimes, supply cannot meet demand, over the short/medium term, at any price. Then, an **auction** starts

In an auctioning regime, prices are limited by demand destruction, conservation and substitution

For truly inelastic applications, price becomes the **marginal cost of substitutive products**

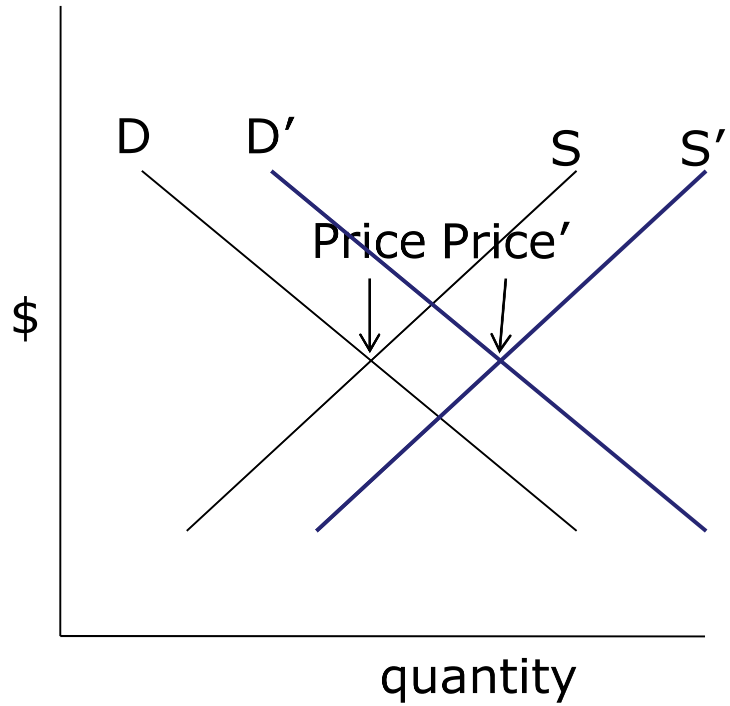
Example: if there's not enough copper and silver has to be used, copper price will get close to silver

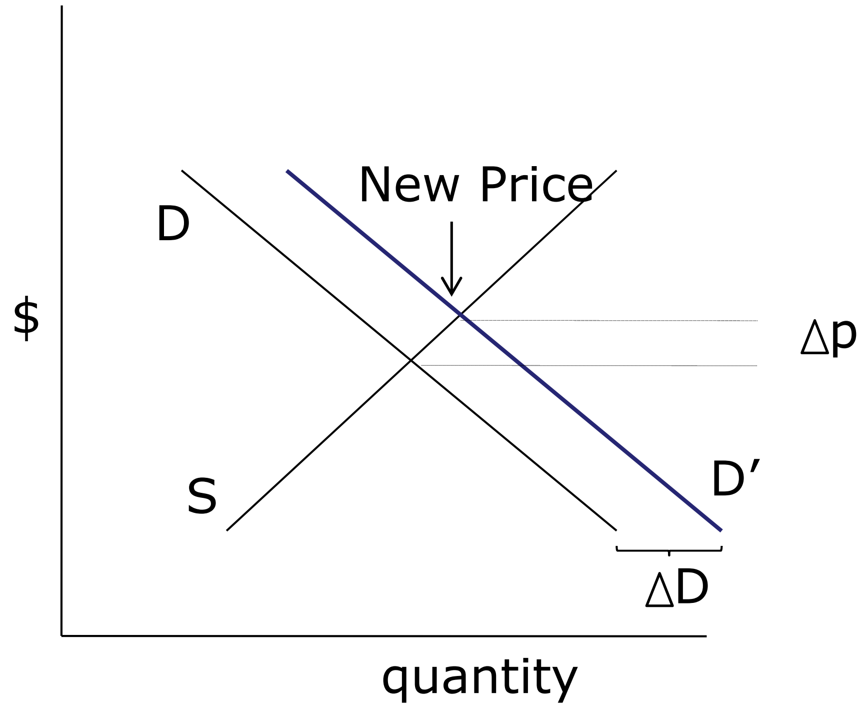




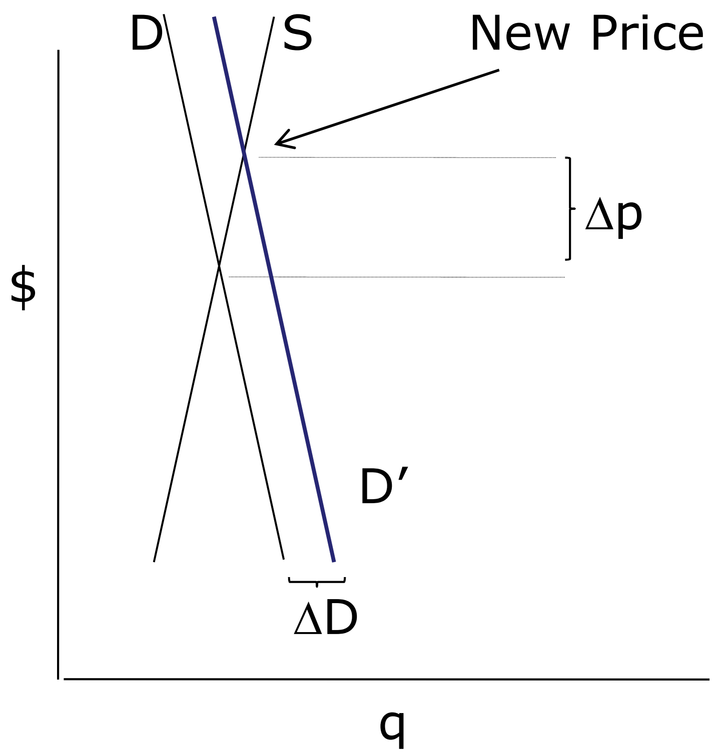
In 2008 oil typically behaved as a price-inelastic commodity in an undersupplied market. **Oil as no close substitute** (see below)

If, for any commodity, an increase in demand can be met by an equivalent increase in supply, price does not change

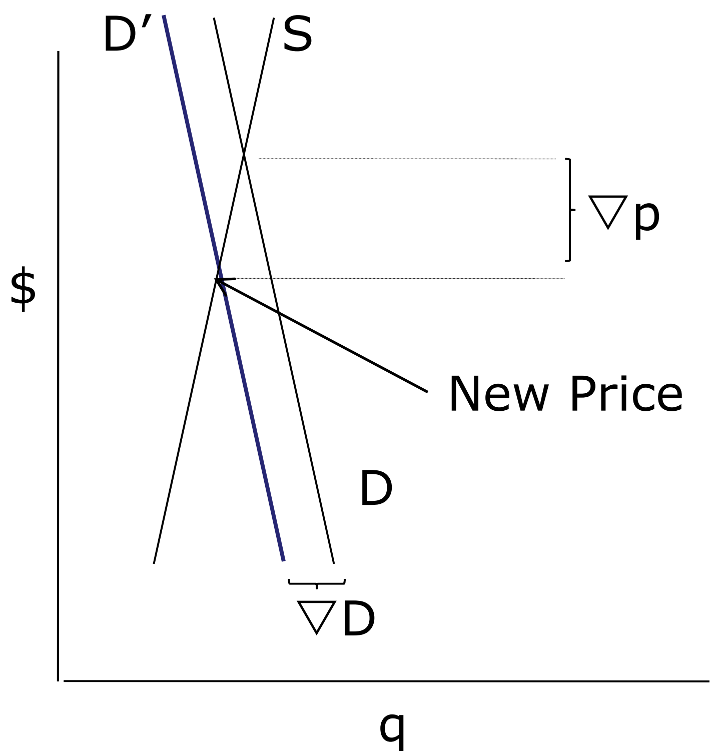




Otherwise, it does. Price will be set by new marginal supplier



If both supply and demand are **very inelastic**, a small increase in demand that cannot be met by supply implies a *huge* increase in price to balance the market

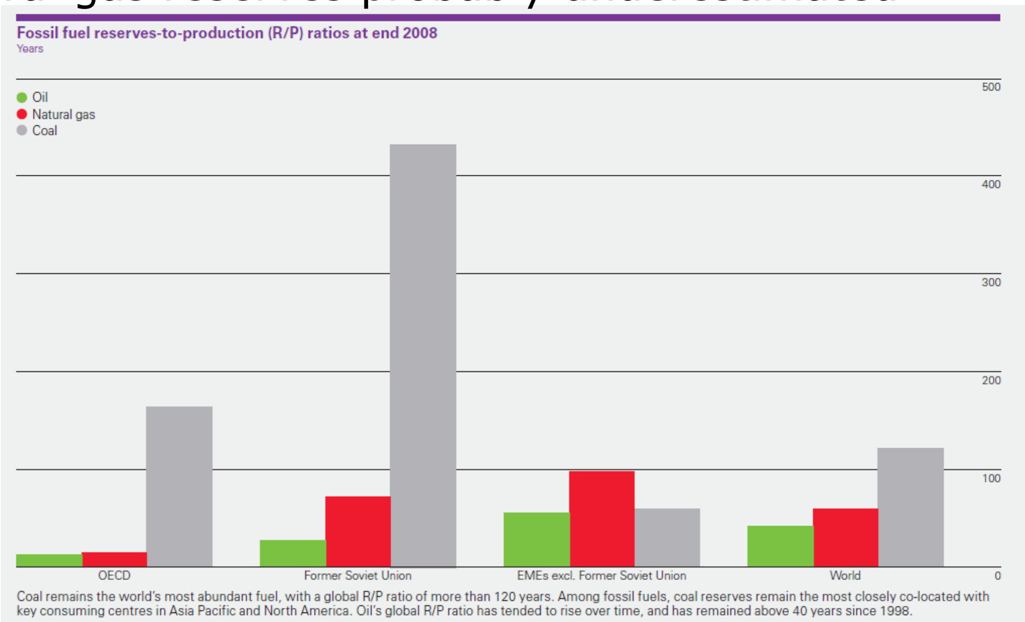


But, if demand drops, so will price **(to the marginal cash cost**). The very limited storage capacity exacerbates the problem.

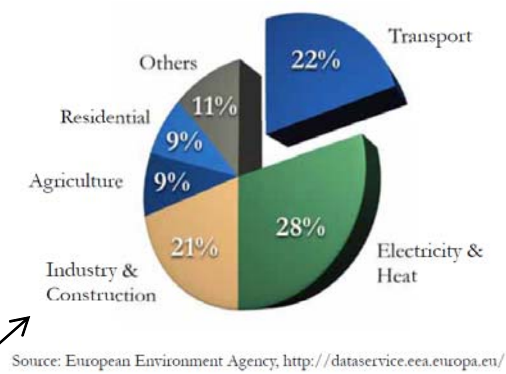
Fossil fuel

Natural gas and coal may be substitutes. Oil relevant for transportation.

Natural gas reserves probably underestimated.



GHG emissions per sector:



These are "proven" (1P) reserves (some 90% probability). There are also "probable" (2P) (50% probability) and "possible" (3P) (20% probability) resources. Urgent problem is **output** (GHG)

Can we avoid using fossil fuels at least for non-transportation neeeds?

Lets' neglect hydro (alraedy exploited wherever possible) ,geothermal (marginal) and biofuel (inefficient).

Non-transportation needs

Nuclear

Uranium reserves: 4.7 Mt (conventional)
+ 22 Mt (phospates) + 4500 Mt (seawater).
1 GW reactor = 160 t/y, so **conventional reserves are 29000 GWy**

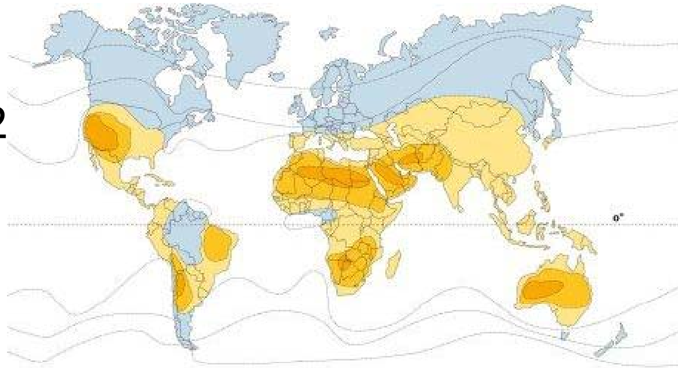
Global nuclear production is 400 GW
Global electric consumption is 2000 GW -> 15y
Global energy need is 7000 GW electric (excluding mobility)
If we cover baseload (3000 GW) with nuclear **we need X10 more power** and conventional reserves would last 10y (cases of **France**, **China**, etc.)

However a fast neutron breeder reactor is X60 more efficient... –> **600y**
And seawater reserves are **X1000** larger...

Dangerous? Maybe, but an average EU citizen consumes 16kg/d of fossil fuel and produces 30kg/d of CO2; with nuclear power it would consume 2g/d of U238 and produce 0.5g/d of waste!
Cost: **40-50 €/MWh** (stable) for existing plants (**double for new plants**)

Solar

In **central Europe** solar heat is 1000W/m2 X 0.7 (angle) X 0.3 (rotation) X 0.4 (clouds) =100W/m2



With photovoltaic (PV) ε=15% ->15W/m2 electric **in phase with peak demand** (peakload supply)

We need 1.5 kW/person during peak hours -> **100m2/person** in central Europe

Better to produce electricity in the Sahara and transport it back (HVDC line) to Europe ("Desertec Project"). At high temperature solar thermal more convenient, provides storage and hybridization. But soil efficiency is lower. One can get 25W/m2.

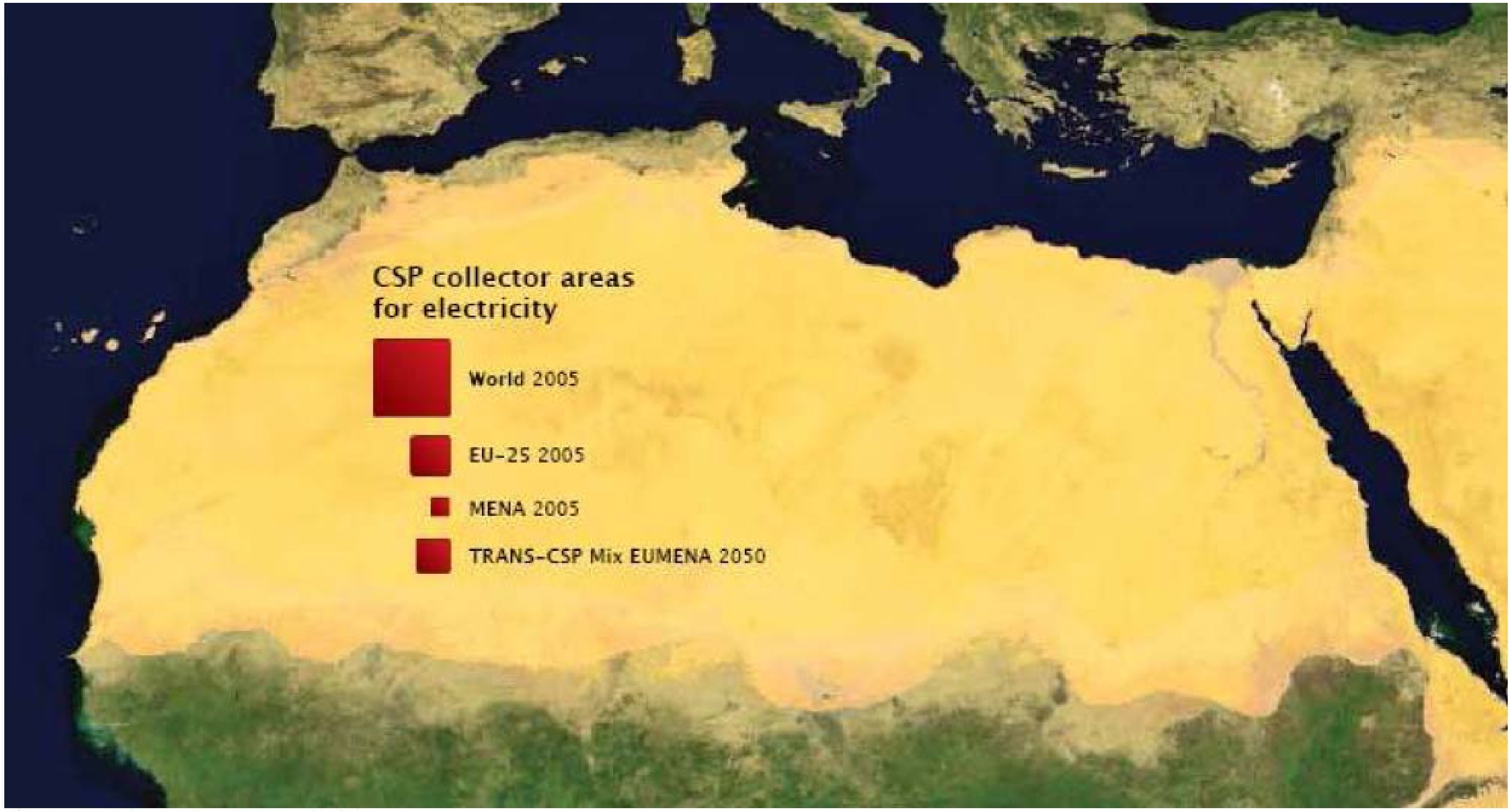
SOLAR TWO - MOJAVE DESERT, CALIFORNIA

For 1b people in Europe and North Africa one would need 1bX60m2 = 250 X 250 km^2

What is the **cost of solar energy**?

Potential of solar thermal

CSP collector areas for electricity



Source: Desertec Foundation

Cost of solar energy

For PV panels you need to account for **panel cost** plus **installation costs.**

Today PV panels cost 0.85$/W (peak power) to companies (thin film) and are sold at 1.5$/W.

Installation costs are 1.5$/W.

This makes 3$/W.In Europe **3€ / W**

In Italy **thermal** irradiation is 150W/m2

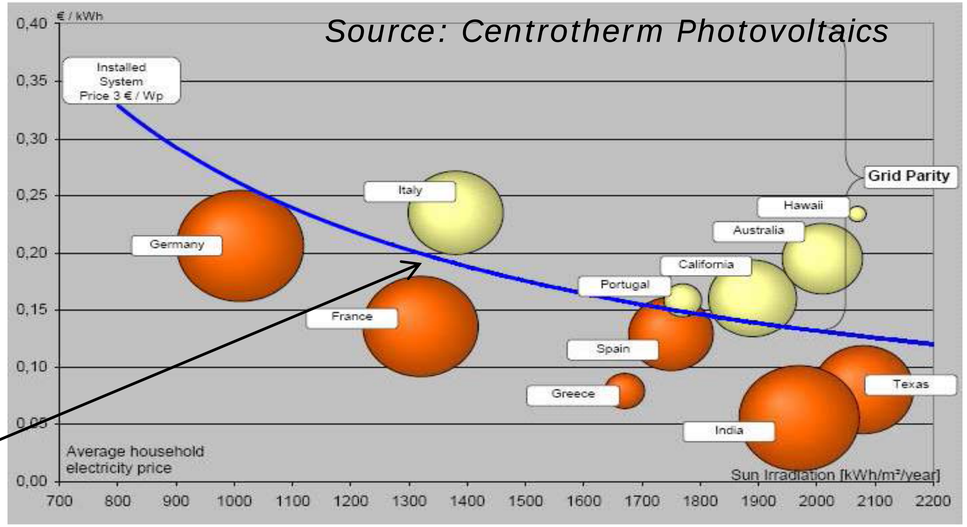
-> 150 X 365 X 24 = 1300 kWh/m2/y

Wholesale price is 70 € /MWh

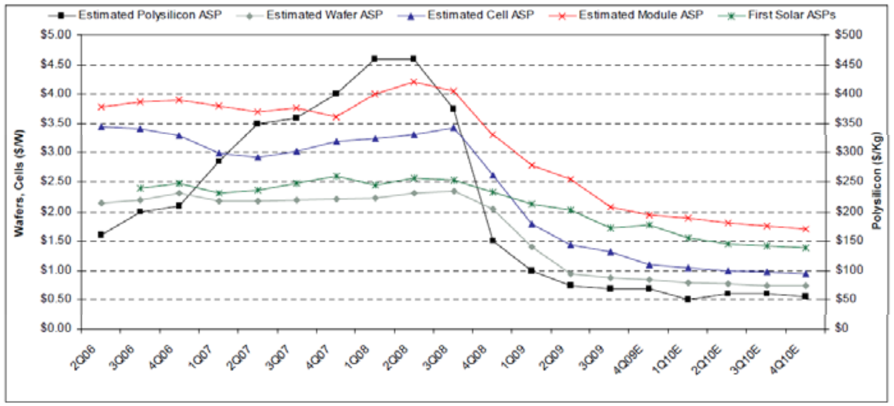
Retail is 200€/MWh (20€c/KWh)

PV market cost is 200 €/MWh

-> **Grid parity is achieved**



Cost of PV solar panels dropping very fast, now at 1/2 the 2008 price...



Source: Company reports and Thomas Weisel Partners LLC estimates

Cost of solar energy

...the reason being that PV panels are a **commodity** and prices fall in oversupply...

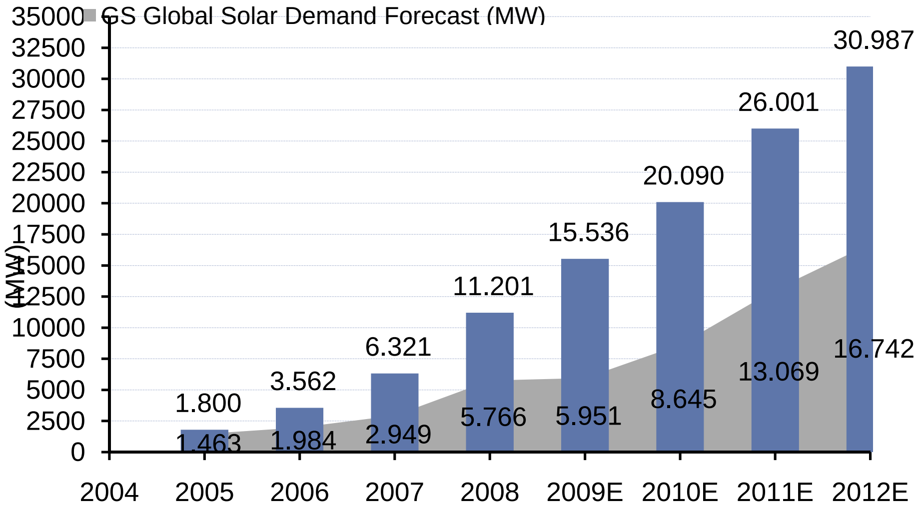
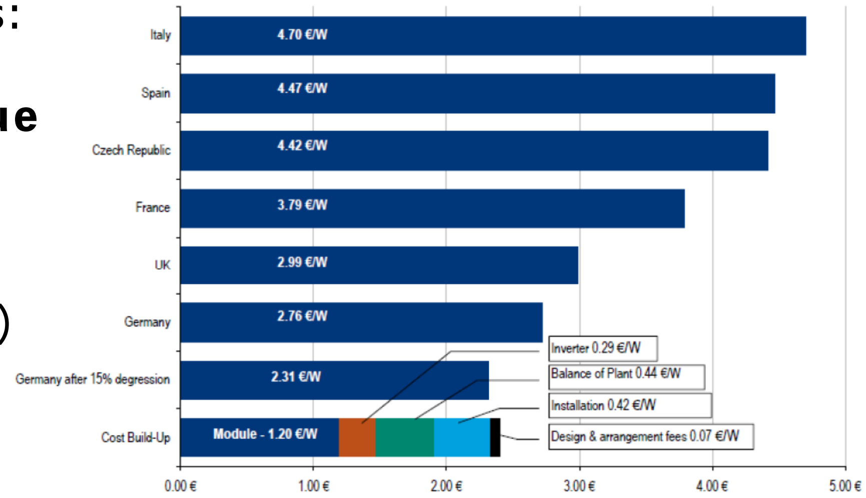


Chart 1: Present value of ground-mounted PV feed-in-tariffs (7% cost of capital, best international system price build-up, €/W)



Source: Bloomberg New Energy Finance, BofA Merrill Lynch Global Research
Notes: Assumes 24/kW/year O&M, various insolation assumptions

Incentives are needed for two reasons:

- **Upfront investment**
- **Economic value < financial value** (unpredictable, no storage)

Incentives:

- feed-in-tariff 300 € /MWh (EU)
- 30% grant on invested capital (US)

Cost of wind energy

Today wind is **cheaper than solar**, dropping -10%/y (vs -30%/y of PV):

a) it requires **less investments** per power capacity: 1.3 €/W (vs 3€/W)

b) has **higher capacity factor** (25-35% vs 20-25%)

Opposite to PV rooftop applications reference electricity price is wholesale price and not retail price

Average power density is lower (2W/m2 vs 15W/m2) but **concentrated** on coast regions,

Current incentives:

- feed-in-tariff 70€/MWh
- 30% grant on invested capital

Example: Spain. 20GW installed. 15% of electricity production in 2009

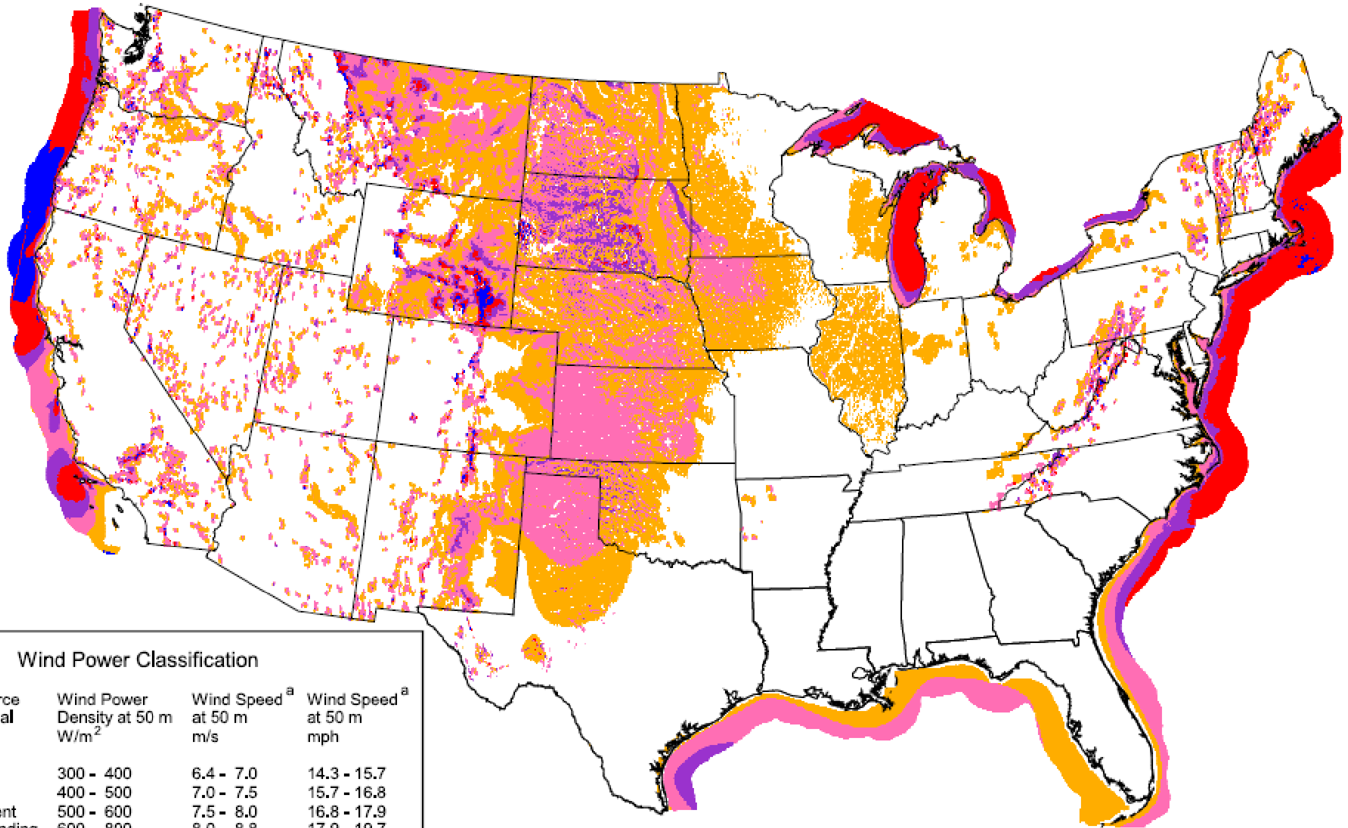
As for solar PV, the **economic** value reduced by unpredictability and no storage

Potential of wind energy in US

2.5 GW in 2000, 25 GW in 2008, 35 GW in 2009 (2% of total electricity)

Potential estimated at **10000 TWh/y, i.e. twice total electricity needs**

Bottleneck is in **transmission costs**



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

Source: Department of Energy, National Renewable Energy Laboratory

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Economics of alternative sources

	Nuclear	Solar	Wind	Gas CCGT	Coal
capital cost $/W	8	3.5	1.8	0.8	5
capacity factor	90%	20%	30%	40%	85%
lifetime y	40	20	20	20	20
yearly production kWh/y	8	2	3	4	7
lifetime production kWh	315	35	53	70	149
capex $/MWh (depreciation)	**25**	**100**	**34**	**11**	**34**
opex $/W/y	0.15	0.01	0.045	0.19	0.22
opex $/MWh (cash)	**19**	**6**	**17**	**55**	**30**
Total cost $/MWh	**44**	**106**	**51**	**66**	**64**
capex remuneration 5%/y	**51**	**100**	**34**	**11**	**34**
Total market price $/MWh	**95**	**205**	**86**	**78**	**97**

Current **wholesale** prices:

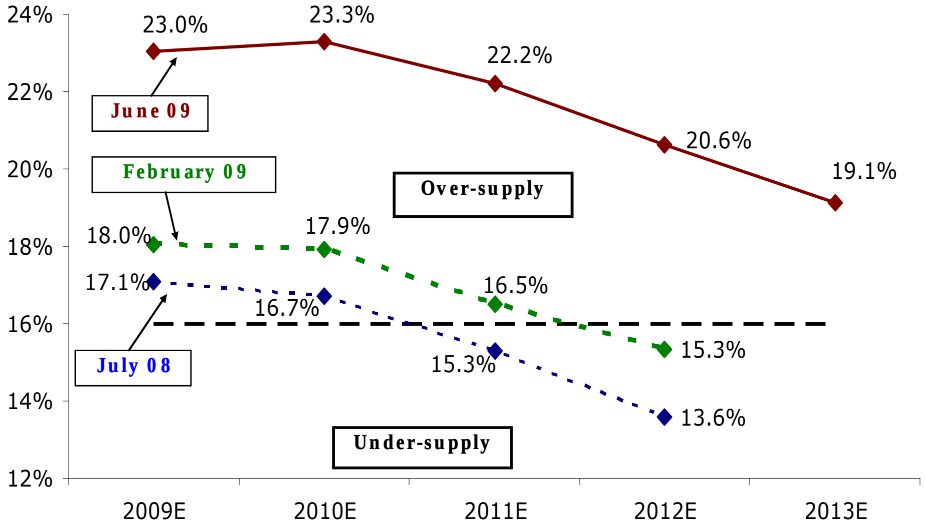
- 70€/MWh in Italy
- 50€/MWh in Germany
- 35€/MWh in Spain
- 35€/MWh in Nordic countries

← Prices in oversupplied market (include CO2) [opex $/MWh (cash)]

← Prices in balanced market [Total market price $/MWh]

Solar PV on rooftop compares to **retail** price (X2 wholesale price)

Currently nearly all energy markets in the world are oversupplied...
Example: US energy reserve margin ->



*Includes 100% of Construction Begun and 0% of Advanced Development and Announced

US reserve margin – Source Wells Fargo

Transportation needs

Key to transportation are **energy (and power) density** of fuel

To drive a car for 500 km you need to store 400 kWh for a IC engine (100 kWh for an electric engine) in the tank.

Energy source	Energy per kg (kWh/kg)	Fuel weight (kg) for 500 km drive	In practice:
Nuclear fission	24513889	0.00004	This is 40 mg of Uranium-235
Gasoline (or LPG or Nat gas)	13	30	This is 50 liters of gasoline, a typical car tank
Coal	8	50	This is 50 kg of coal in your tank
Lithium ion batteries (Chevy Volt type)	0.15	667	This is 700 kg of batteries
NiMH batteries (Toyota Prius type)	0.06	1667	This is 1.6 tons of batteries
Ultracapacitors	0.006	16667	This is 16 tons of capacitors

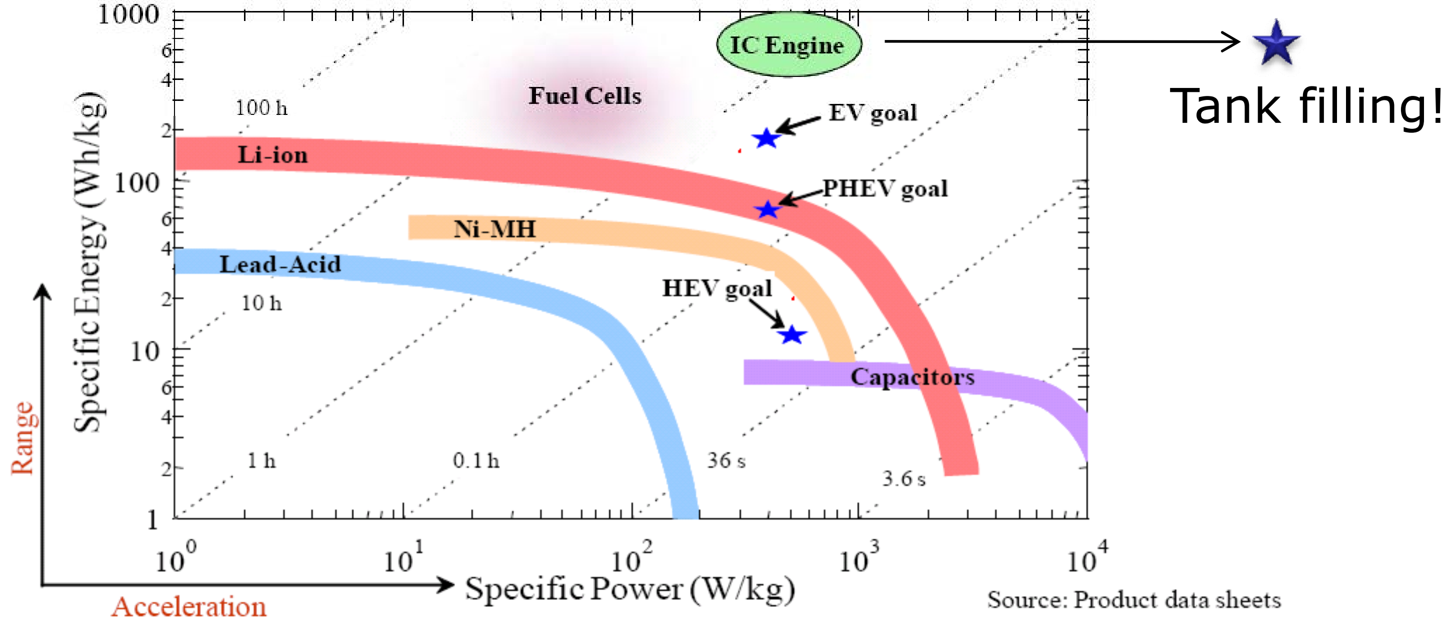
The closest substitutes for oil/gasoline are Li-ion batteries! No technology can replace liquid hydrocarbons as an energy storage device: **oil has no close substitute**.

70 kg of batteries provide 50 km range -> plug-in hybrids or « PHEV »

Transportation needs

To recharge 100kWh in 2 minutes (like a gasoline tank!) requires 3MW power (1000X an household plug). Li-ion batteries are limited to 300W/kg.

Need 10 tons of batteries to « fill the tank » in 2 minutes!



Source: Product data sheets

Reference:
http://berc.lbl.gov/venkat/Main_files/Batteries-for-vehicles.pdf

Ultracapacitors have X100 higher power density, but too low energy density.

Battery cost and reliability is another issue: **today 500-1000$/kWh**.

This doubles car price and maintenance cost

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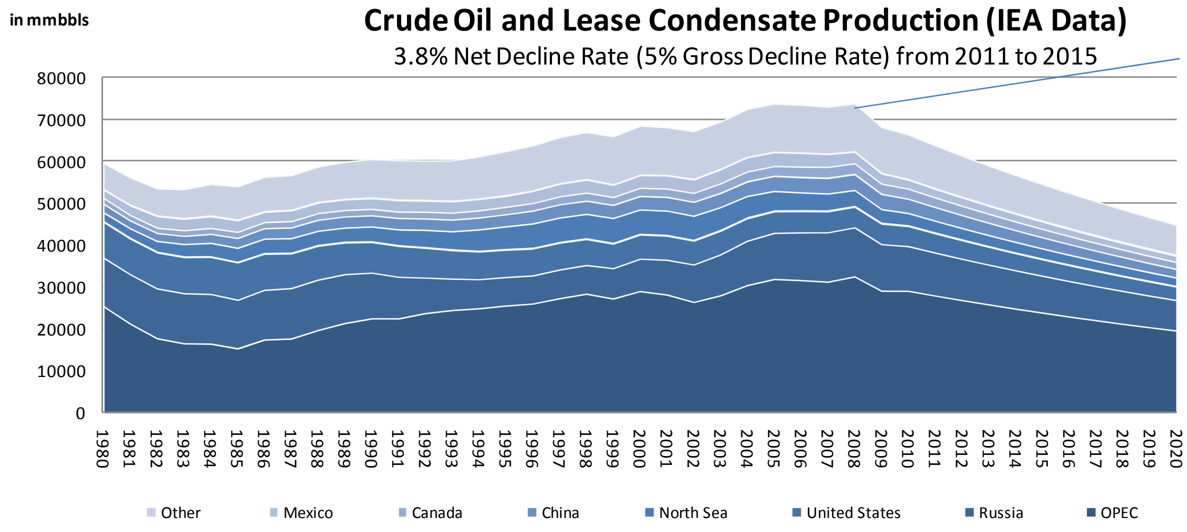
Some thoughts on the oil price



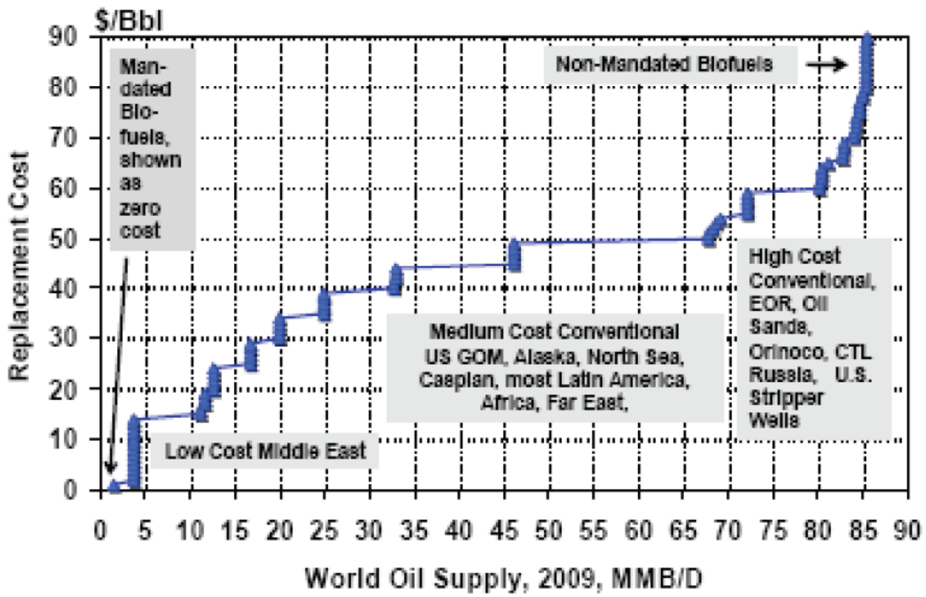
More than 45 mmbbls new supply will be needed to fulfill the demand with an 1.6% p.a. growth which corresponds to 20 times 2008 daily Iraq output

2004-2008 Supply Growth	
OPEC	1.7%
Russia	2.6%
United States	-2.2%
North Sea	-7%
China	2.1%
Canada	2.0%
Mexico	-4.6%
Other	-0.1%
World	0.4%
Demand Trend Growth	1.6%

Source: IEA WEO 2008, EIA Short-Term Outlook April 2009, SIA Estimates

Future supply is known based on **depletion rate** and **investments**. This inelasticity of supply and demand makes short-term prediction totally impossible, but long-term things are very clear. There's only one direction for oil prices.

This has nothing to do with reserves. It's all about supply costs and supply capacity



Conclusions

The supply of energy is characterized by an **input** and an **output** problem.

For "static" needs (industrial, residential, etc.):

- the **input problem is not dramatic nor urgent** (large fossil, nuclear reserves plus renewables potential)
- the output problem is **urgent** but not dramatic: GHG emissions much reduced using **nuclear (baseload) with renewables (peakload).** Cost of renewables still requires incentives, but **prices are dropping fast**. It seems to be more a matter of cost and (political) will

For "mobility" things are different:

- hydrocarbons have **no substitute for energy/power storage**. Demand will increase and **oil supply is constrained**. This makes both input and output problems **urgent and dramatic**

Key is technology to store electric energy (for mobility and renewables)

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Some good readings

- David JC Mackay, ***Sustainable energy – without the hot air***, www.withouthotair.com, 2009
- Oliver Inderwildi et al, ***Future of mobility roadmap***, SSEE, University of Oxford, 2010
- Richard L Garwin and Geoges Charpak, ***Megawatts and megatons***, University of Chicago Press, 2002
- Peter W Huber and Mark P Mills, ***The bottomless well***, Basic Books, 2005

For further questions:

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