"It's not all about electricity"

(An overview of "non-traditional" CCS)

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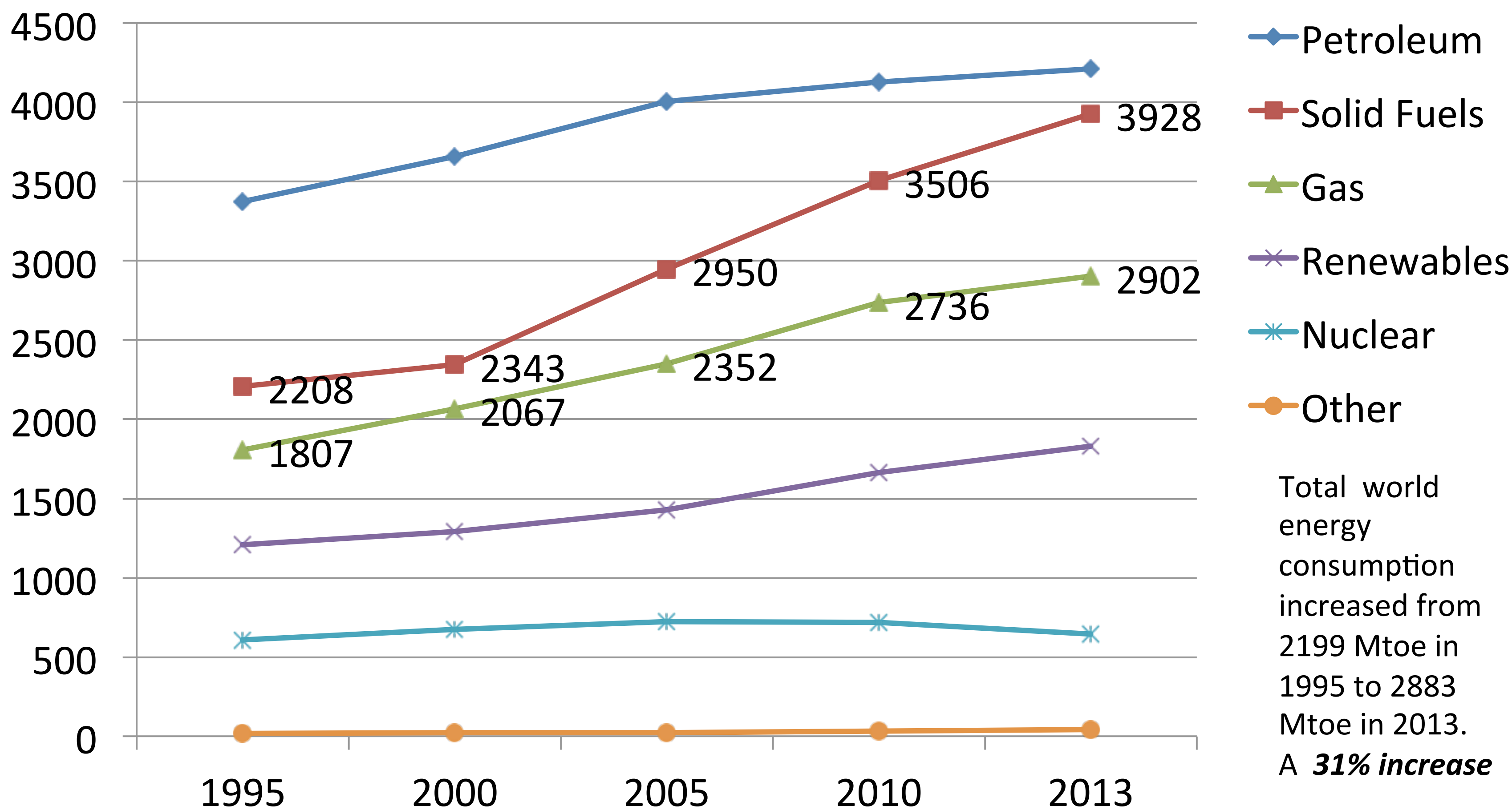
CO2GeoNet, Venice, May 2016

World energy consumption by fuel Mtoe



Total world energy consumption increased from 2199 Mtoe in 1995 to 2883 Mtoe in 2013. A ***31% increase***

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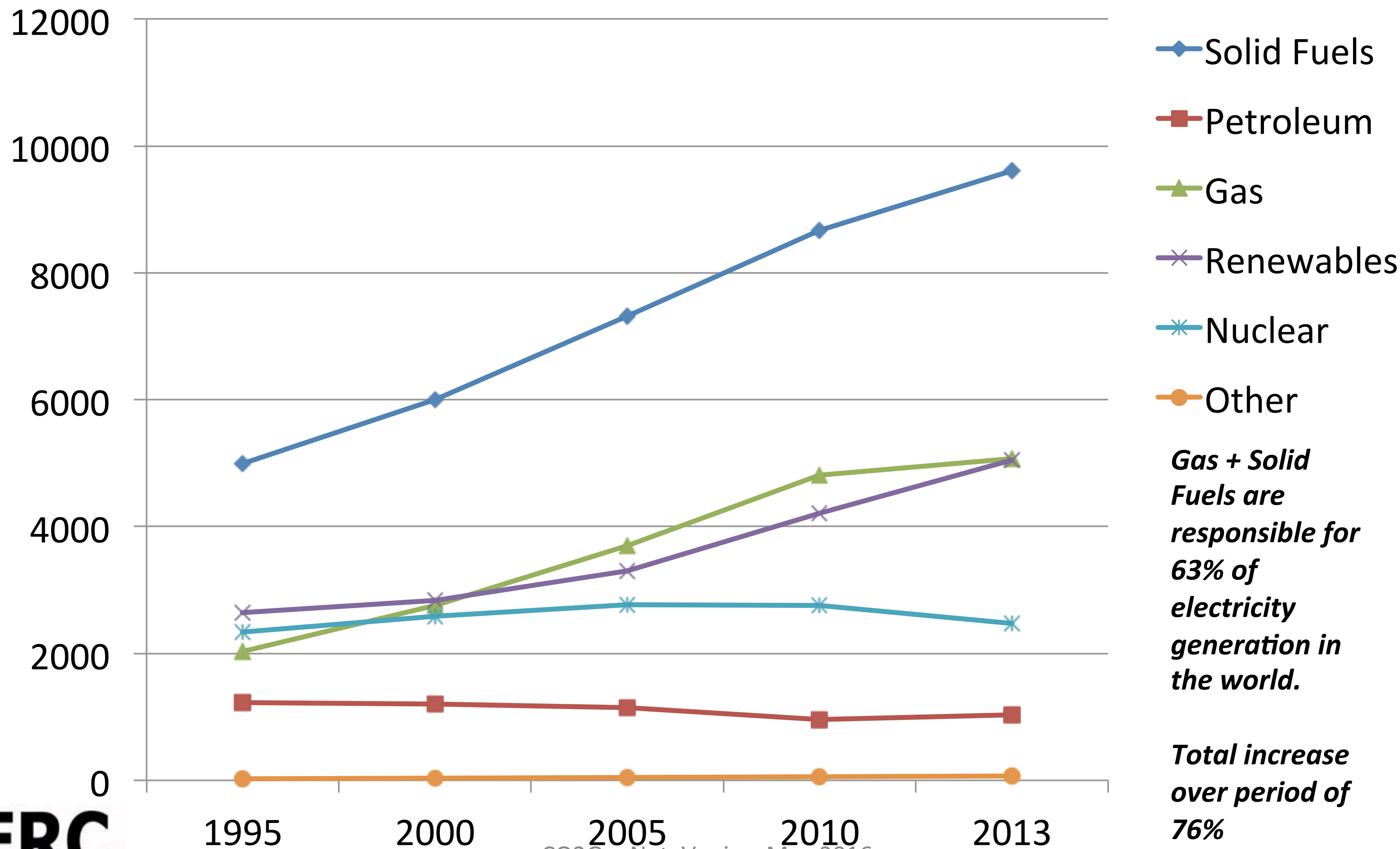
World electricity generation by fuel TWh



Gas + Solid Fuels are responsible for 63% of electricity generation in the world.

Total increase over period of 76%

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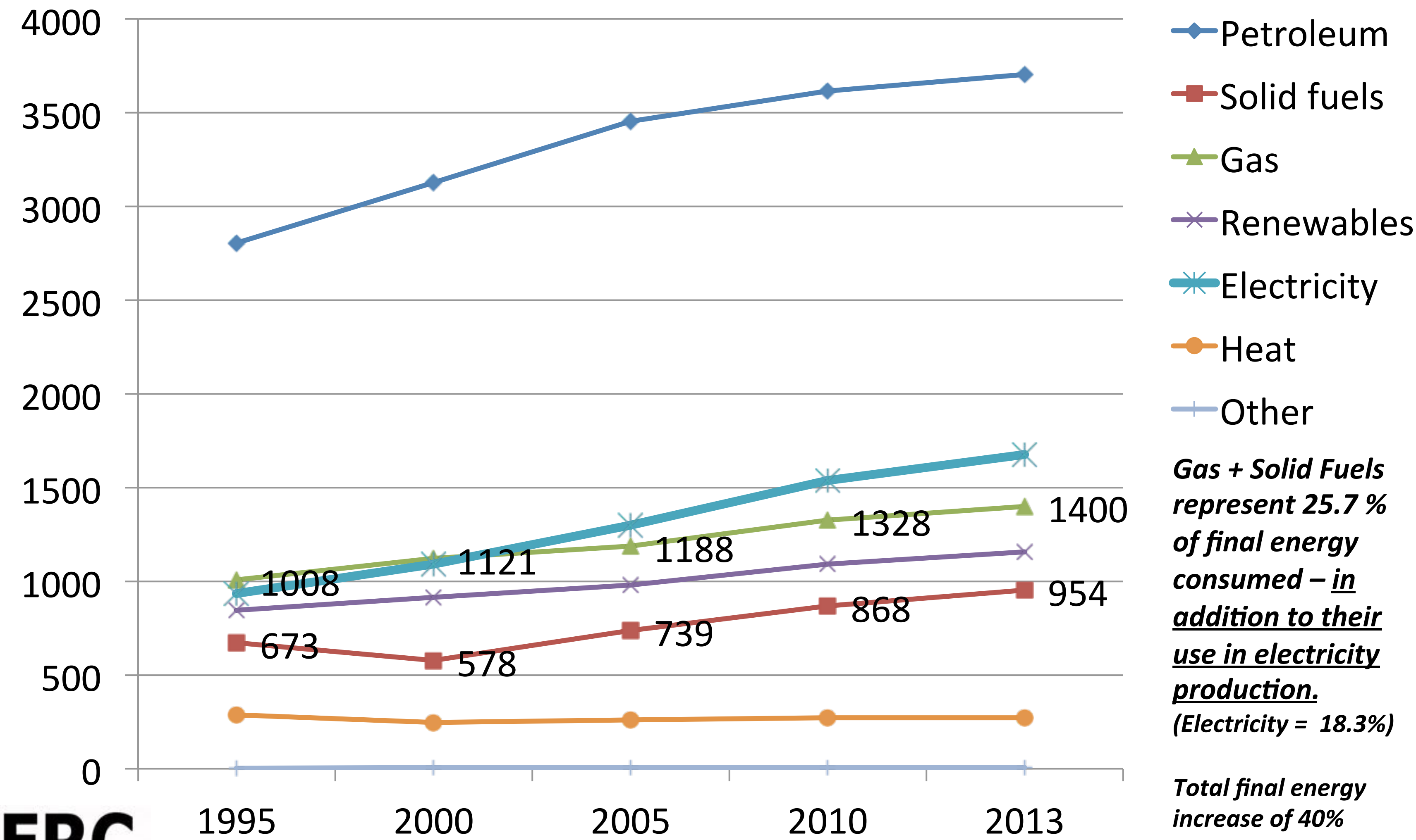
World *final* energy consumption by fuel Mtoe



Gas + Solid Fuels represent 25.7 % of final energy consumed – <u>in addition to their use in electricity production.</u>
(Electricity = 18.3%)

Total final energy increase of 40%

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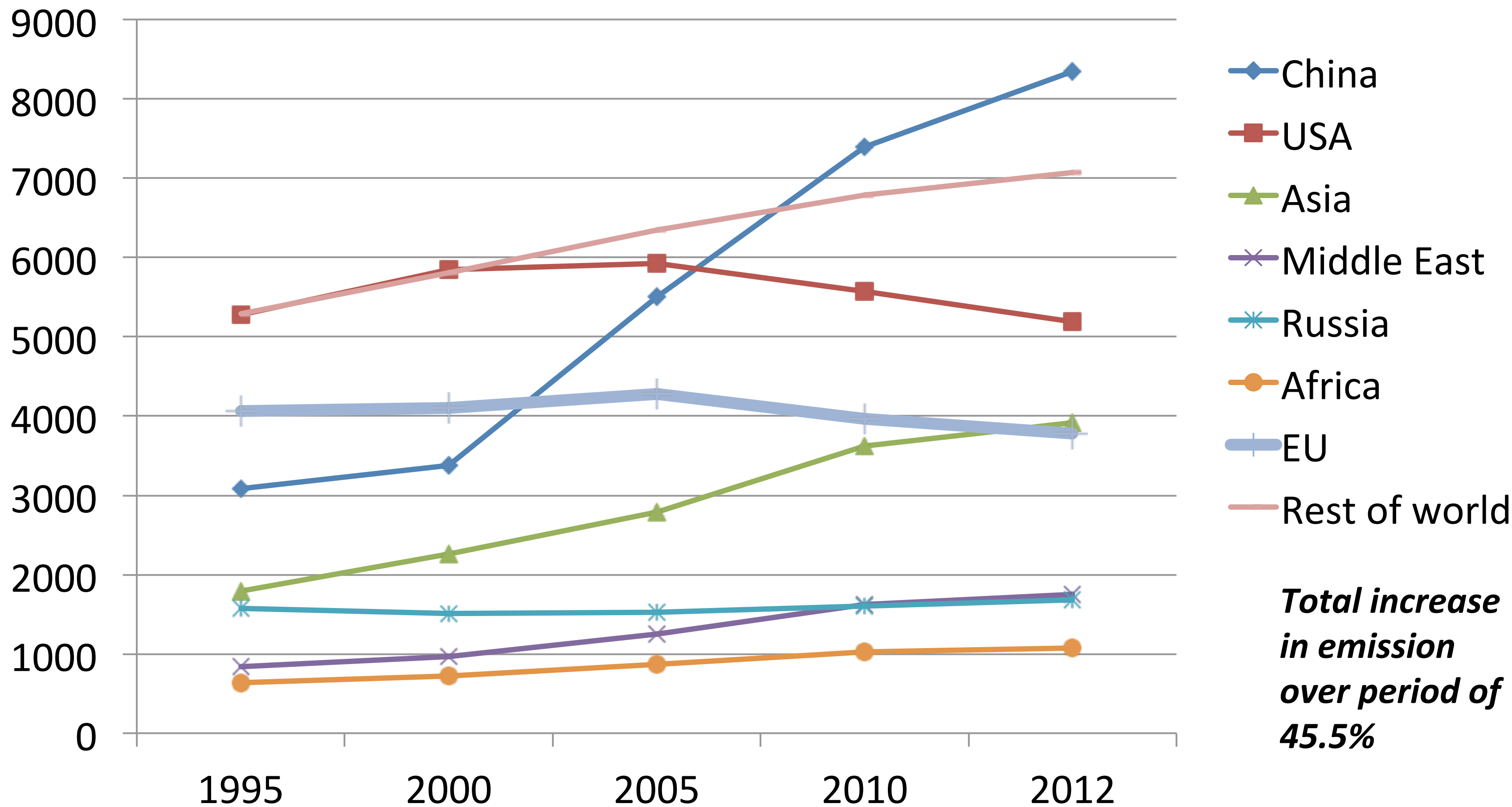
World CO_2 emissions by region
Mio ton CO_2



Total increase in emission over period of 45.5%

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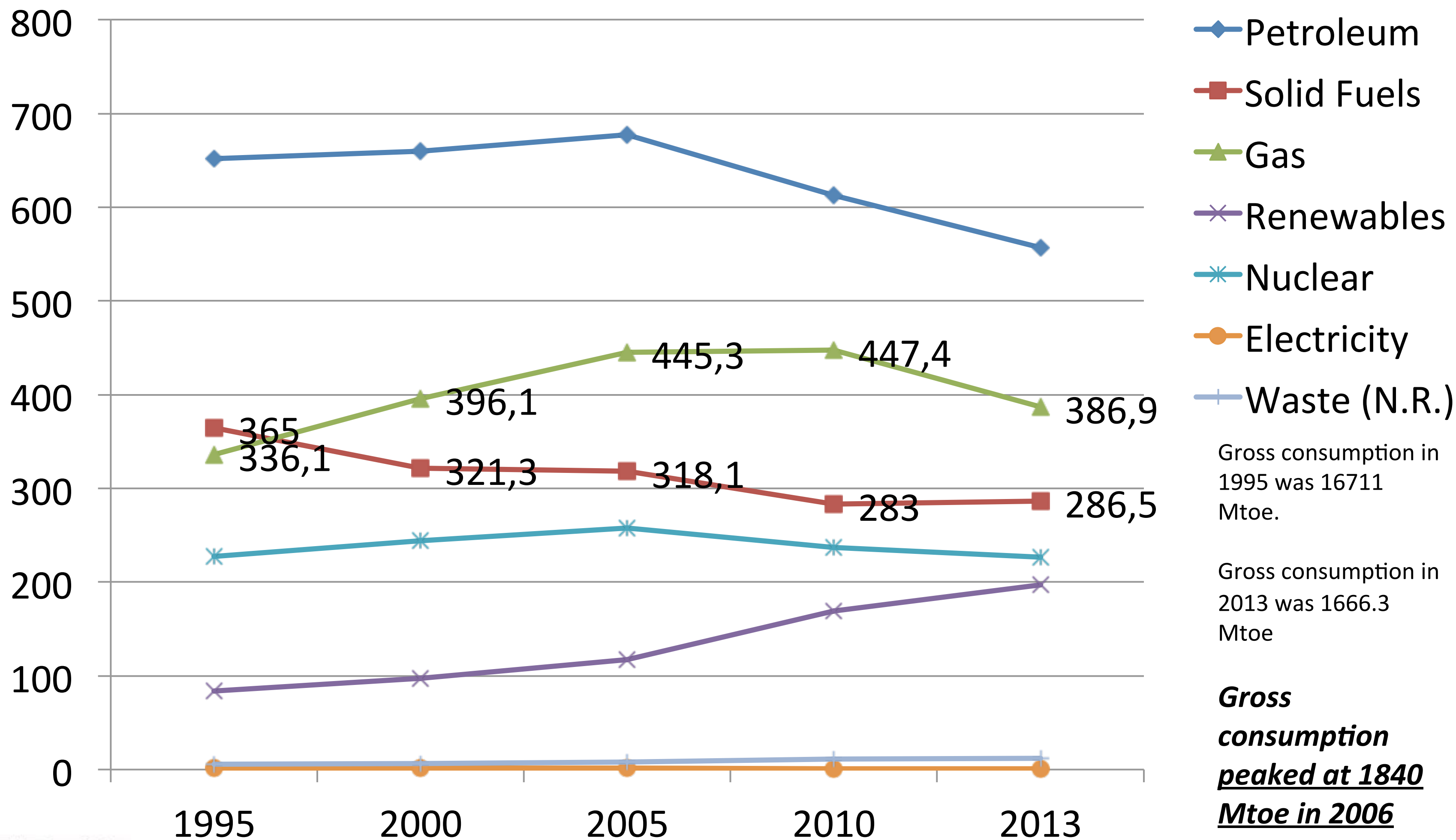
World energy – some conclusions

- Energy consumption is increasing
- Electricity is making a growing contribution
- Solid fuels are the main beneficiary
- Solid fuels and gas, together, provide ***more final energy*** than does electricity
- In fact, nearly 25% of all coal – and close to 50% of all gas – are used ***outside*** of the electricity generation sector. That is a lot of carbon dioxide.

EU gross inland consumption by fuel

Mtoe



Gross consumption in 1995 was 16711 Mtoe.

Gross consumption in 2013 was 1666.3 Mtoe

Gross consumption peaked at 1840 Mtoe in 2006

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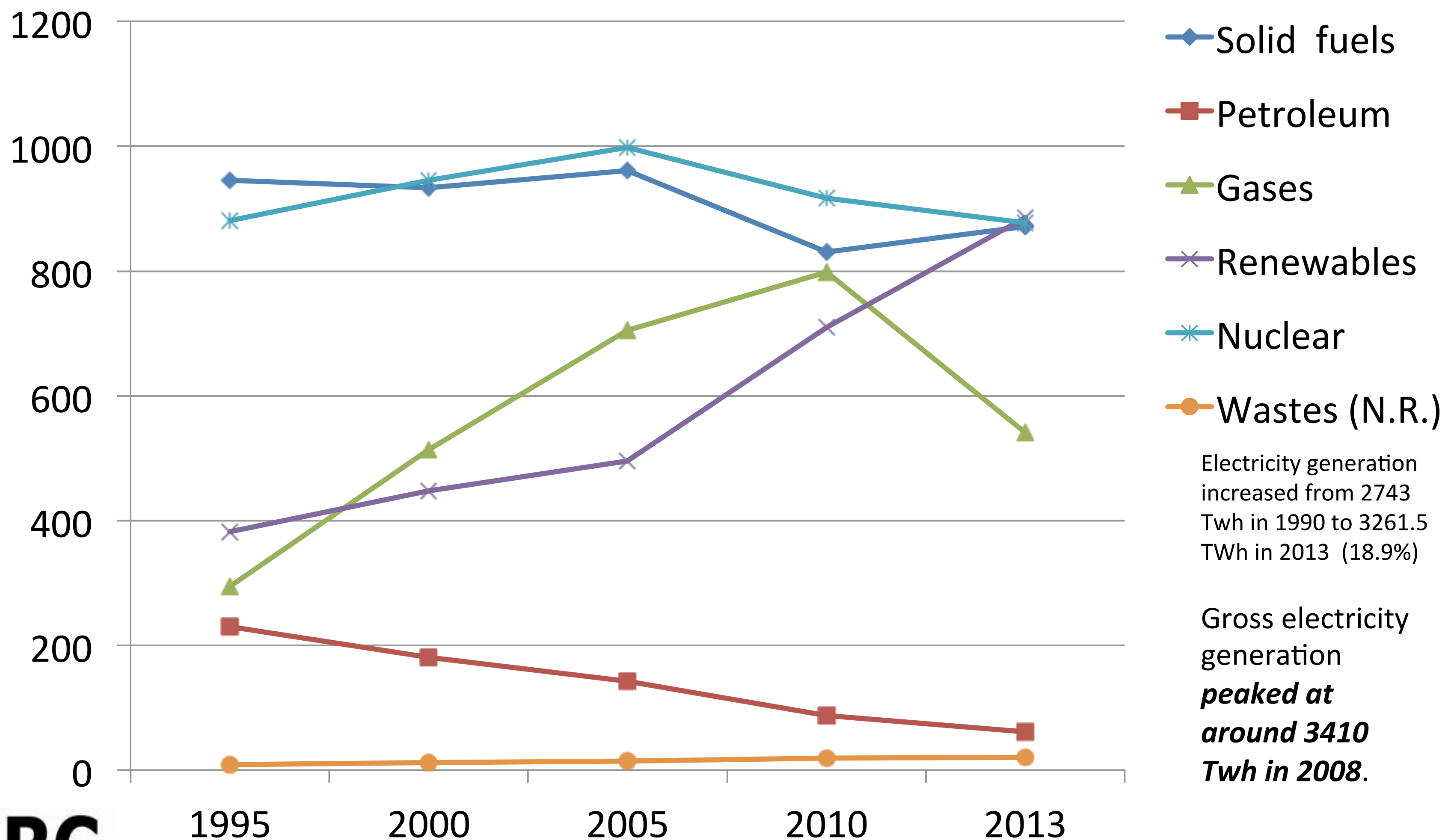
EU electricity generation by fuel TWh



Electricity generation increased from 2743 Twh in 1990 to 3261.5 TWh in 2013 (18.9%)

Gross electricity generation ***peaked at around 3410 Twh in 2008***.

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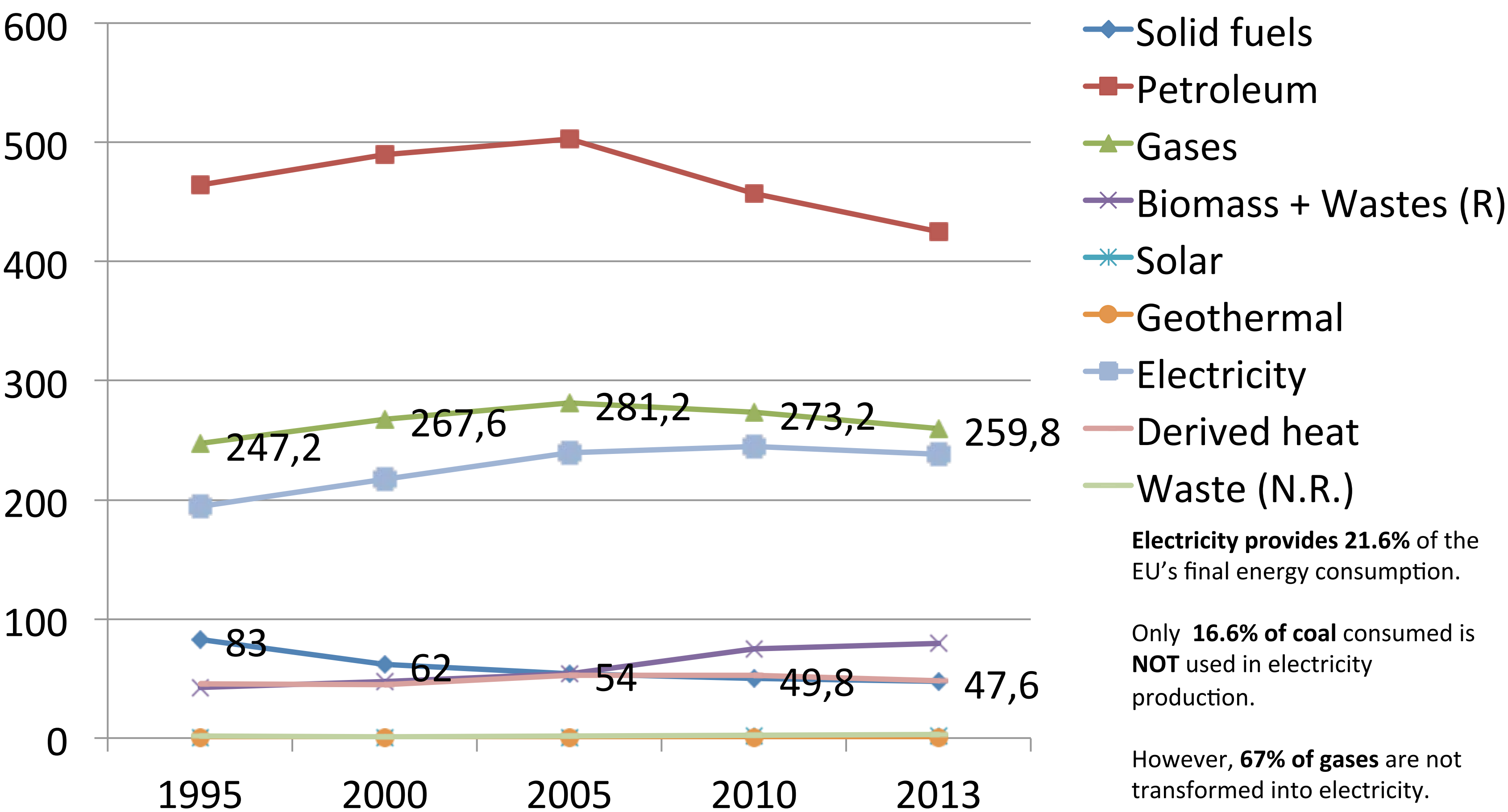
EU final energy consumption by fuel Mtoe



Electricity provides 21.6% of the EU's final energy consumption.

Only **16.6% of coal** consumed is **NOT** used in electricity production.

However, **67% of gases** are not transformed into electricity.

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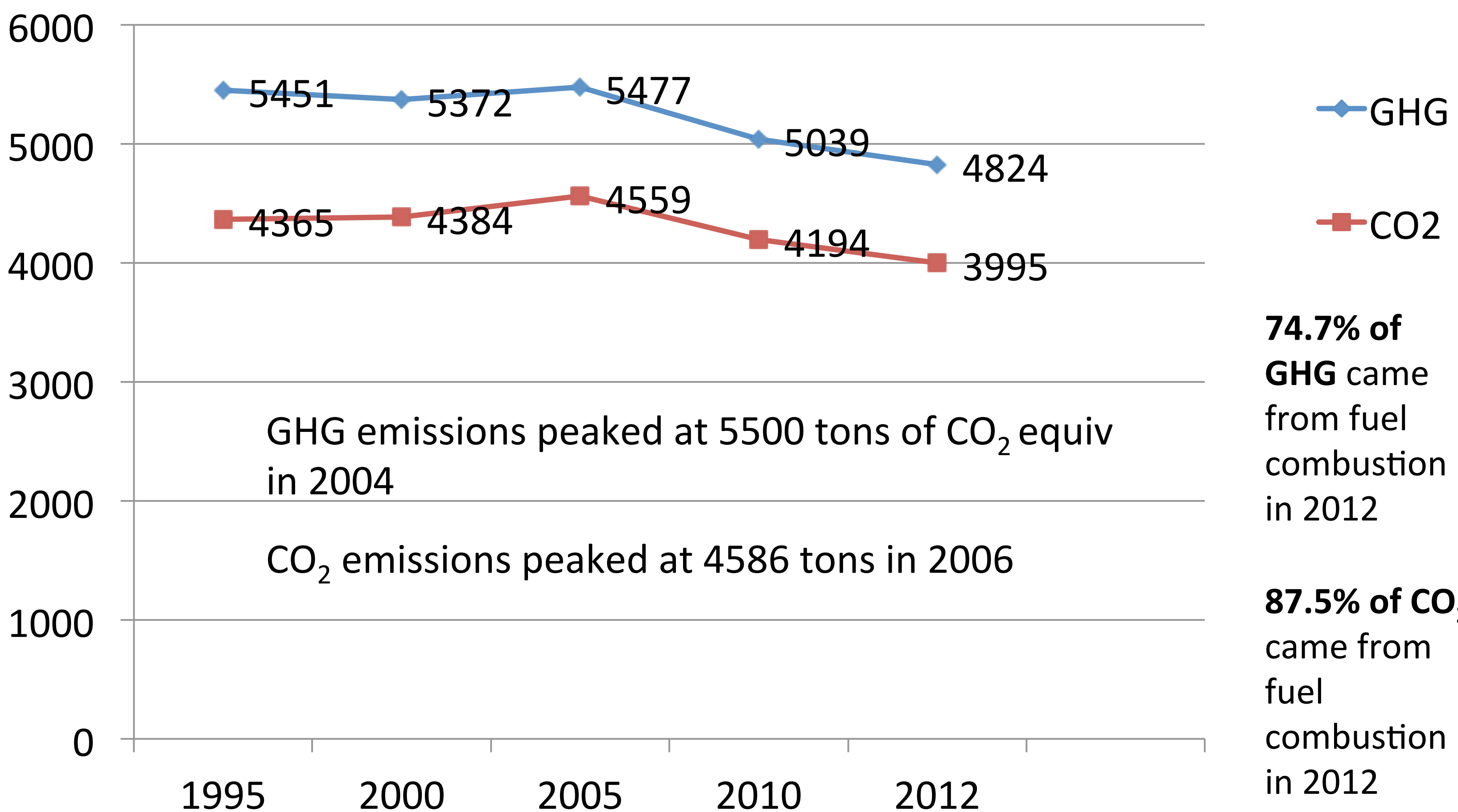
EU – GHG and CO_2 emissions

(GHG in tons CO_2 equiv)



74.7% of GHG came from fuel combustion in 2012

87.5% of CO_2 came from fuel combustion in 2012

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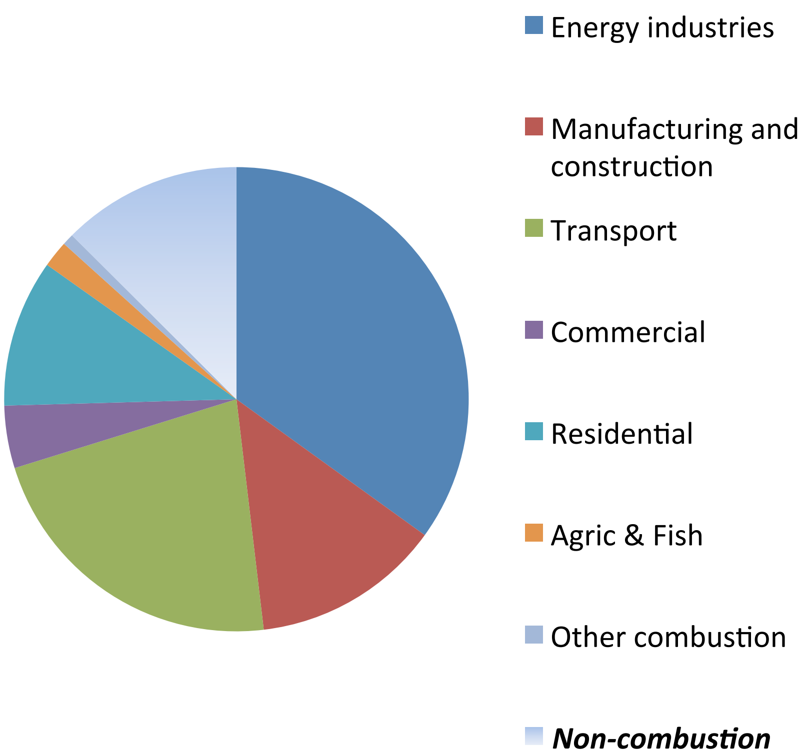
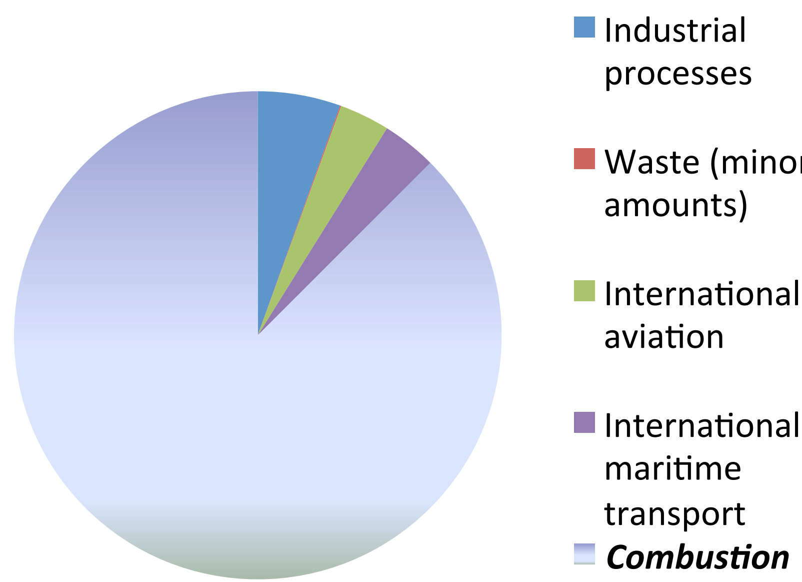
EU CO_2 emissions by sector in 2012

Fuel combustion by sector



Non-fuel combustion by sector



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EU CO_2 emissions by sectors – trends - ***Fuel Combustion*** -

- Since 1990 (to 2012)
- Emissions from fuel combustion have declined (over 15%)
- Energy industries emissions declined (16%)
- Manufacturing* industry emissions declined (38%)
- ***Transport emissions increased (15%)***
- Commercial/institutional declined (13%)
- Residential declined (19%)
- Agriculture, forestry & fisheries declined (20%)

* Includes construction industry

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EU CO_2 emissions by sectors – trends - ***Non-fuel combustion*** -

Since 1990 (to 2012) emissions for:

- Industrial processes and solvent use declined (26%)
- Waste and other declined (41%)
- ***International aviation increased (93%)***
- ***International maritime transport increased (33%)***

Most of the decreases in both fuel and non-fuel combustion occurred ***after 2006/7/8***. Before that date, several sectors (not including transport in all forms) showed strong declines in the early 90s, but little change from then to 2006 or 2007.

In fact, since 2008 transport, international aviation and maritime transport have all *declined* (though are still well above their 1990 levels).

EU energy – Some conclusions

- Consumption has declined from its peak in 2006 to be slightly below that of 1990
- Electricity generation peaked in 2008 before declining, but is still nearly 20% above 1990 levels
- GHG and CO2 emissions peaked in 2004 and 2006 (resp.) but in 2013 were both below their 1990 values (by 11.4 % and 8.5%)
- Only around 17% of coal is used outside the electricity generating sector – but ***67% of gas is used outside this sector***.
- ***<u>The larger part of the emissions from burning gas in Europe come from outside the electricity sector</u>***

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EU emissions of CO_2 - some implications

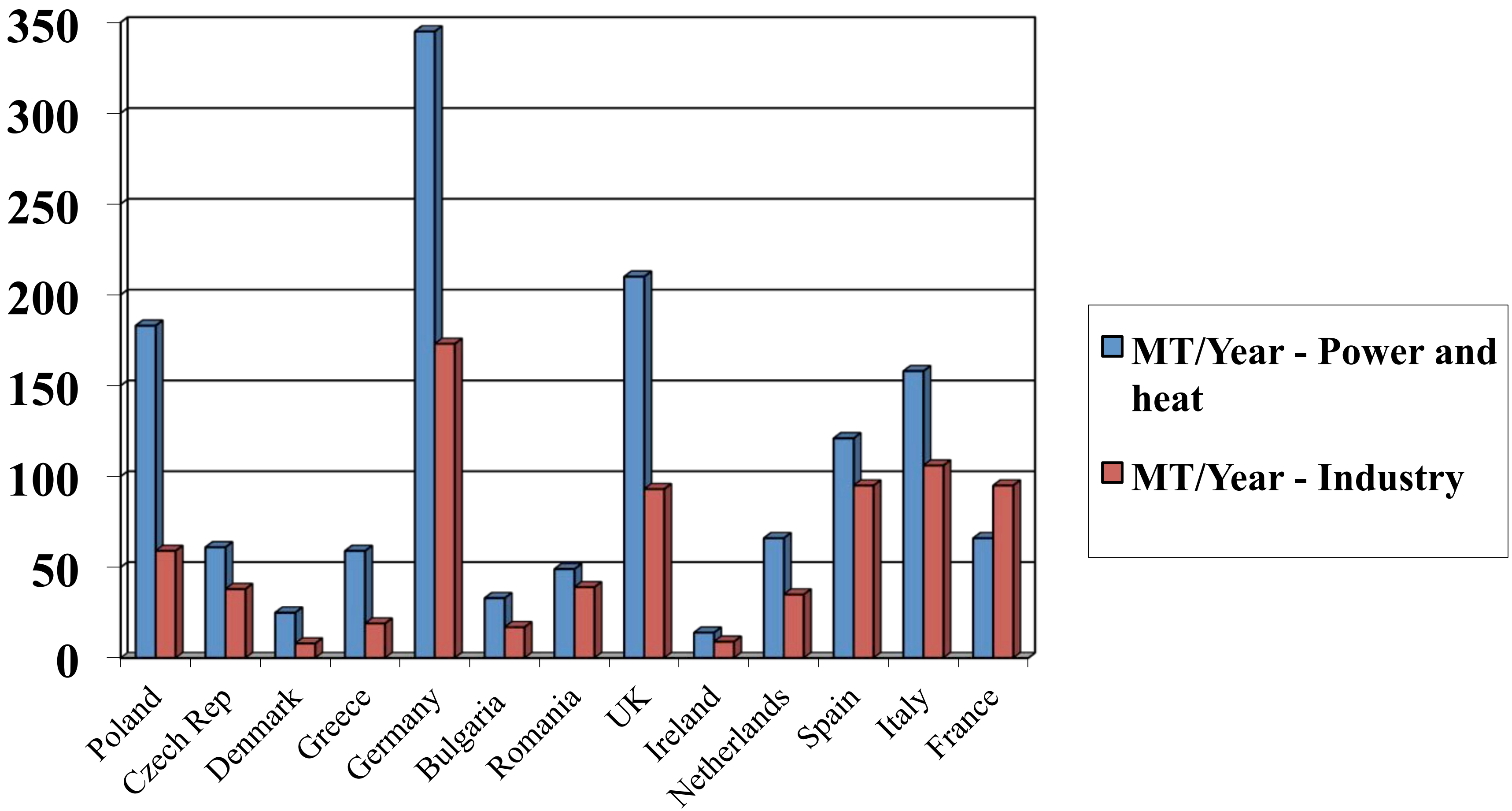
- While close to 90% of CO_2 results from fuel combustion, close to half of this is emitted by equipment from which it cannot be captured (***without great difficulty and/or cost***) – e.g. Most transport, residential, commercial, institutional emissions.
  - We need to further develop and deploy technologies to capture and remove the CO_2 these emissions – ***or, in some way, reduce them***
  - It is also vital that everything possible is done to capture all the other emissions
- In the EU, over 80% of the emissions from coal burn come from the electricity generating sector. So the future of coal is very closely tied to capturing emissions from this sector.
- <u>This is not the case for gas</u>. The majority of gas is burned outside the electricity sector, ***so it is those sectors that consume gas (and/or coal) – especially the larger industrial ones – that need to develop and deploy CCS (or CCUS) as quickly as possible***.
- The same is true in many other regions of the world.

Energy intensive sectors and CO_2

- **Energy intensive industry sectors** – in addition to the power and heat generating industry - **that emit large quantities of CO_2 include**:
- Oil refineries
- Iron production and steel works
- Aluminium and other metal industries
- Cement, lime, glass and ceramic producers
- Pulp and paper
- Acids and bulk organic chemicals

All of these are covered by the EU's Emission Trading System (ETS) – but most have shown little, or no progress towards developing carbon capture for their processes.

The quantities of CO_2 from industry are very significant



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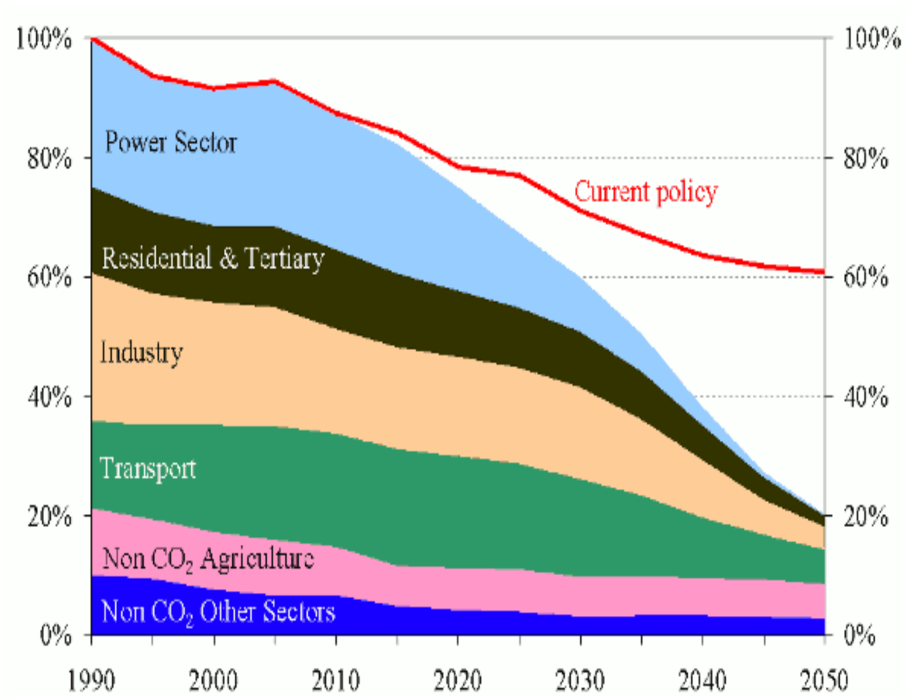
EU Emission targets for 2050



- The energy and climate roadmap to 2050 requires cuts in **all sectors**.
- The **total reduction** in emissions will be between 79% and 82%
- For the **power sector**, emissions must reduce to "near zero" (93%-99%)
- For the **industrial sector** the reductions will be around 87%

Interim targets

- There is already an agreed target for 2030 (40% reduction)
- For 2040, the target is expected to be a 60% reduction

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A word – or two – about CCUS

- CCUS – Carbon Capture ***Use*** and Storage
- The use of captured carbon dioxide – as opposed to its disposal as a waste – can very significantly change the business case for capture and storage.
- ***The prime example is the use of the CO_2 for enhanced oil recovery (EOR).*** (Also EGR - enhanced gas recovery).
- EOR is an important driver of CCS for onshore oilfields in North America and, potentially, in other regions. Offshore it is rather more difficult and costly.
- Unfortunately – at the present time - most other "uses" of CO_2 either require considerable amounts of energy (making them economically unattractive) or on too small a scale to significantly impact on the total emissions.

Iron and Steel

- The iron and steel industry accounts for nearly 20% of final energy use and about one quarter of direct CO_2 emissions from the industry sector
- More than half of these emissions come from four countries: China, India, Ukraine and Russia
- Close to 2 tonnes of CO2 are produced for one tonne of rolled steel
- However, unlike for the power sector, the CO_2 emissions from an integrated steel plant come from several different sources and the waste gases have very different concentrations of CO_2
- So the technology needs to be developed and demonstrated specifically for such plants.

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Projects on iron and steel

- In November 2013 the Abu Dhabi National Oil Company (ADNOC) and Masdar (renewable energy company) created a joint venture for CCUS. CO_2 collected from Emirates Steel plant will be compressed and transported through a 50 km pipeline and pumped into ADNOC's oilfields. The plan is to store 800,000 tons of CO_2 annually. Start up is scheduled for 2016.
- In Europe the "Ultra-Low CO_2 steel making" consortium (ULCOS) is supported by EU funding. The most advanced activity is the HIsarna project at Ijmuiden in the Netherlands.
- There are also projects in Japan, South Korea, Taiwan (the Taiwan CCS Alliance includes the China Steel Corporation) and in Australia.

The Stepwise Project

- The STEPWISE project aims at the demonstration of advanced pre-combustion CO_2 removal technology within the framework of the Iron and Steel industry, aiming at **lowering the CO_2 footprint of steel production**.
- The basis for the project is the Sorption Enhanced Water-Gas Shift (SEWGS) technology. This is a solid adsorption technology for CO2 capture from fuel gases in combination with water-gas shift and acid gas removal.
- The main objectives of the proposed STEPWISE project is to scale up the SEWGS technology for the CO_2 capture from Blast Furnace Gas (BFG) with three overall demonstration goals in comparison to state-of-the-art technologies:
  - Higher carbon capture rate – i.e. lower carbon intensity, 85% reduction
  - Higher energy efficiency – i.e. lower energy consumption for capture, 60% reduction
  - Better economy – i.e. lower cost of CO_2 avoided, 25% reduction
- The STEPWISE project will achieve this by the construction and the operation of a SEWGS pilot test installation (14 t/day CO_2 removal) at a blast furnace site.
- The project is supported by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 640769.

Cement

- Cement (annual production around 3 GT) is thought to be responsible for 2 GT of CO_2/year
- On average, one tonne of cement results in emission of between 600 kg and 800 kg of CO_2
- Sources are normally the fossil fuel used for heat (energy emissions) and gas from both the pre-calciner and the rotary kiln (process emissions)
- China is responsible for nearly half of the world's cement production (India at 6% is next)
- Some estimates are that cement demand could grow to close to - or even over - 5GT/year by 2050

Cement *and the 2050 emission targets*

<u>The World Business Council for Sustainable Development (WBCSD) said:</u>

> ***"In order to achieve an 80% reduction in CO_2 emissions by 2050, taking into account all other measures, and without any other breakthrough technology, 85% of all clinker production would have to be equipped with carbon capture technology, which amounts to 59% of all plants since carbon capture would be deployed at larger plants."***

<u>CEMBUREAU commented on potential costs</u>

- The exact <u>capital expenditure</u> needed per plant is hard to determine at present, but is estimated to be **around €330-360 million to deploy oxyfuel technology at a new 1 million tonne/year plant**, about 100 million for retrofitting oxyfuel technology and €100-300 million to retrofit an existing plant with post-combustion technology
- <u>Operational costs</u> of a plant equipped with post-combustion carbon capture technology are estimated to be **double the cost of a conventional cement pl**ant, while oxyfuel use would incur 25% higher operating costs. Additional costs would then be incurred for compression, transport, injection and storage.
- Carbon capture would **increase production costs by 25 to 100%,** require substantial investments and require the use of additional electricity.

![Leilac]

Project overview

LEILAC aims to apply Direct Separation technology to the cement and lime industry, enabling CO_2 process emissions to be captured without significant operating issues, energy or capital penalty.

Planned pilot plant 10 tph in Lixhe

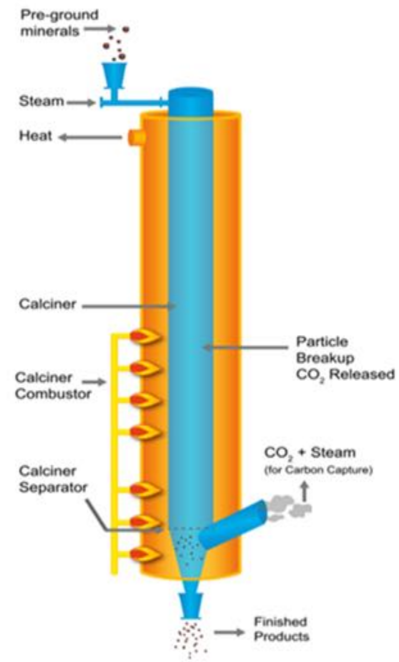
- Lime application
- Cement application

Indirect heating raw meal:

- Direct capture of process-related CO_2
- 99%+ pure CO_2

€12m H2020 grant plus € 9m in-kind

- 5-year project, starting in early 2016



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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654465

Refining – many uncertainties

- There have been few – if any – reliable estimates of the annual CO_2 emissions from refineries – though figures between 800 million and 1,000 million tonnes are frequently quoted (6% of global emissions)
- The rate at which this could grow is very uncertain as it would correlate closely with increasing liquid fossil fuel demand complicated by the higher energy required to recover fuels from less conventional crude sources

Refining – Technology Issues

- Refineries have several complex and varied unit processes – so have numerous point sources of emissions – with different CO_2 concentrations
  - Process heaters produce 30 to 60% of emissions with CO_2 concentrations of 8-10%
  - Utilities (electricity and steam production – using a CHP gas turbine) produces 20 to 50% of emissions with a CO_2 concentration of around 4%
  - Hydrogen Manufacturing produces 5 to 20% of emissions with CO_2 concentrations of 5-20%
  - Fluid Catalytic Cracker produces 20 to 50% of emissions with a CO_2 concentration of 10-20%

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Biomass

- While emissions from biomass use are presently rather low relatively to those from cement and iron and steel, they are projected to grow as more biomass is used to produce transportation fuels and in power generation
- Industries using biomass in some form include:
  - Production of pulp and paper
  - Production of ethanol
  - Generation of power and heat
- Use of various forms of biomass combined with CCS can result in "negative emissions", a lowering of total CO_2 in the atmosphere.

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Pulp and Paper

- While the contribution to CCS by the pulp and paper sector is expected to be rather limited, it is presently the largest consumer of biomass in industry – 55%
- Pulp and paper plants often emit up to one million tonnes of CO_2/year – with the largest around 2 MT/yr
- One of the most important by-products is “black liquor” which can be burned or gasified and used in the synthesis of transport fuels.
- It could be an “early mover” in combining biomass use with CCS as the costs of the CCS can be at least partly offset by the synthetic fuel production.

Ethanol

- Ethanol is produced by the fermentation of biomass such as sugar cane or corn.
- This fermentation results in a pure or almost pure stream of CO_2
- The purity of the CO_2 means capture costs are very low – which very significantly reduces the cost for applying CCS.
- Plants typically emit 50 000 to 300 000 tonnes annually, with only a few of the larger plants emitting more than one million tonnes per year.
- The Decatur project (IBDP)in the Illinois Basin in the USA collected and stored 300,000 tonnes/year from a corn to ethanol plant (2011-2015). An industrial scale project (1 million tonnes/year of CO_2) is scheduled to start operation.

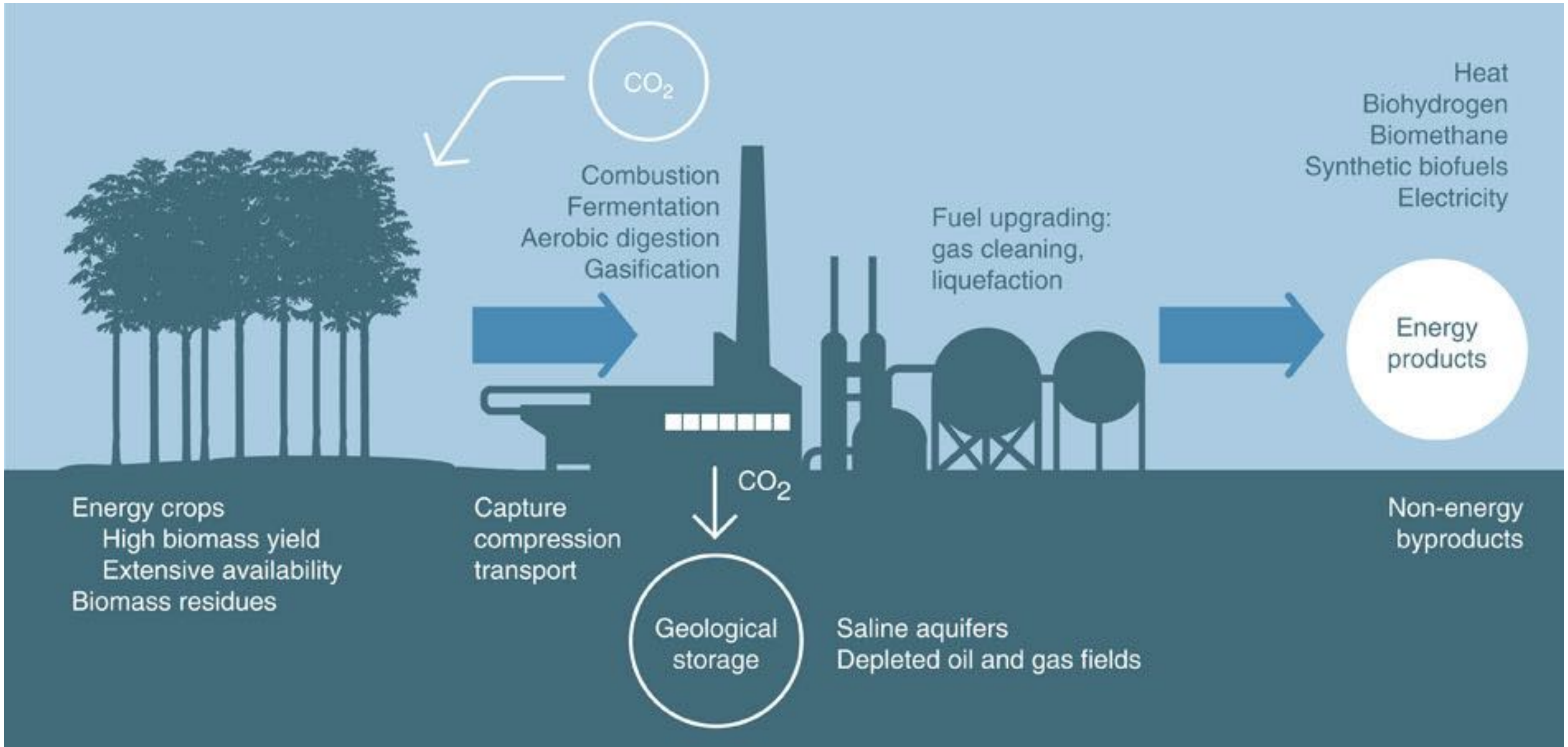
ADM's plant at Decatur, Illinois *(US DOE)*

Power and Heat

- Biomass can be used to generate commercial quantities of both power and heat.
- Many smaller combined heat and power plants (CHP) work on straight biomass or a combination of biomass and a fossil fuel (including lignite).
- Large scale plants can also use a mixture of fossil fuels together with biomass
  - The large **DRAX power station** – the largest in the UK – burns biomass in most of its units. Some are co-fired with biomass while others have been converted to run exclusively on biomass.
  - the most used are wood pellets, sunflower pellets, olive, peanut shell husks and rape meal.

BECCS

- ***Bioenergy and CCS*** (BECCS) is a very exciting prospect.
- It is the only technology by which we can *actually reduce* the level of CO_2 in our atmosphere.
- Nature - in the form of sunlight - provides the energy required to collect and convert the carbon dioxide into a fuel or other material we can use to produce energy or energy products (such as biofuels). Then we can capture and store the CO_2 in geological horizons.
- What sets BECCS apart as a climate mitigation measure is that if it is widely deployed it can result in permanent reduction in in this level of CO_2 - in other words we can produce energy with "***carbon negative***" emissions.


CO_2
Combustion
Fermentation
Aerobic digestion
Gasification
Fuel upgrading:
gas cleaning,
liquefaction
Heat
Biohydrogen
Biomethane
Synthetic biofuels
Electricity
Energy products
Energy crops
High biomass yield
Extensive availability
Biomass residues
Capture
compression
transport
CO_2
Geological storage
Saline aquifers
Depleted oil and gas fields
Non-energy byproducts


Cap Rock
CO_2

Seeing is believing

EGE på Klemetsrud i Oslo

Fangst av **300,000t** CO_2 i året, delvis fra biomateriale?

A few conclusions....

- The challenge of capturing and storing carbon dioxide – in the limited window of opportunity - is a massive one.
- The challenge is even bigger – and more complex - for the industrial sectors.
- Each industrial sector has its own distinct challenges – and costs.
- Things are being done. Projects are starting and the technologies are being developed and tested.
- Some show good promise - but a great deal more is necessary - yesterday!
- Lots of money, effort, enthusiasm and ***clear, strong political support*** are all urgently required.