Carbon Dioxide Capture and Storage: The Science and some questions related to materials. Energy Materials Conference

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R&D
RWE npower

Coal produces more than twice as much carbon dioxide per unit of electricity compared to natural gas. (1kg per kWhr)

- **I will concentrate on coal for this presentation.**

- **However we are also considering similar issues for gas fired power generation.**

Technology options

Post combustion capture (often amine)

Oxyfuel

Pre combustion (gasification)

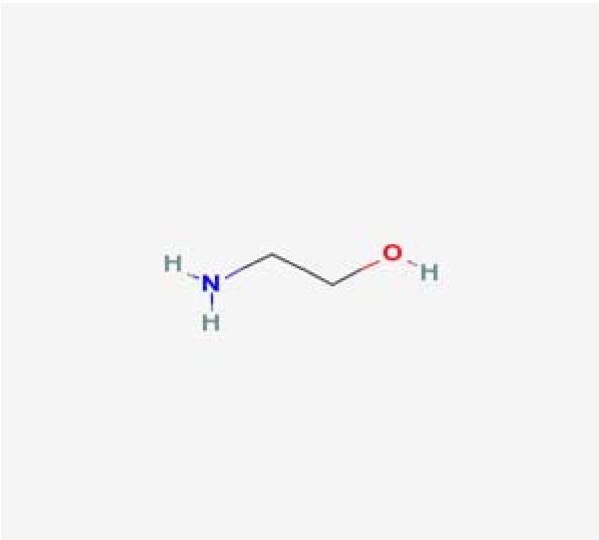
Amine absorber.

What is an amine?

Ammonia (NH_3) in which one or more hydrogen atoms have been replaced by organic groups.

Monoethanolamine

MEA or 2-aminoethanol C_2H_7NO or $NH_2.CH_2.CH_2OH$



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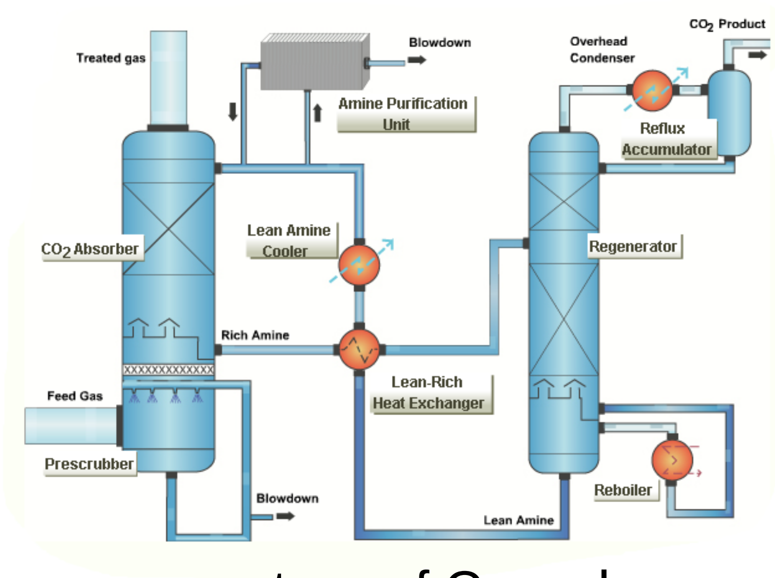


courtesy of Cansolv

Amine absorber.

Acidic gases like CO_2 dissolve in amine solution (aqueous) at atmospheric pressure and around 60C. (exothermic process)

CO_2 is driven out from the amines by reducing pressure, increasing temperature or steam desorption at 120 to 130C. Amines then recycled.

Widely used under reducing conditions and at high partial pressures, e.g. for H_2S and/or CO_2 removal from oil refinery gases, natural gas or coal gas.

Under oxidising conditions, SO_2, NO_x and especially oxygen react with amines causing solvent loss. The products can be acidic and/or toxic.

Proprietary additives protect amines from oxidation and materials from corrosion, but still sensitive to SO_2 and NO_x. Little public information on how well additives protect amines from flue gas oxygen.

Post-combustion capture presents fewer risks to boiler operation

Oxy-fuel.

Liquefaction plant separates oxygen from air (80% nitrogen)

Fuel is burnt in oxygen + recycled flue gas to control temperature.

Flue gas is mainly water + CO_2 which should be a relatively easy mixture to separate.

Applicable to boilers and to GTs but the latter need more extensive design modifications.

Air separation plants use a lot of power.

Novel proposals using near-flame membranes to provide combustion oxygen are a long way from commercial demonstration. (e.g. AZEP)

Manufacturers offering oxy-fuel plant on "commercial terms", i.e. cost-plus with government or buyer accepting delivery and performance risk.

What are the flame stability and radiative properties of combustion with the high CO2 (and perhaps water) partial pressures?

Recycling increases SOx partial pressures.
Nitrogen inleakage?

CO_2 capture techniques – pre combustion

IGCC itself 50%+ higher capital cost than pf boiler power plants and availability is lower.

Gasification produces CO_2, CO, H_2 and H_20.

Water gas shift to CO_2 and hydrogen well proven in other industries.

$CO + H_20 = CO_2 + H_2$

Shift and CO_2 removal carried out at high pressures, high partial pressures and under reducing conditions.

Hydrogen turbine unproven and many developers suggest some methane fired in the GT.

So IGCC is expensive and complex but the marginal cost of adding CO_2 capture is less than combustion.

CO_2 capture techniques – Novel

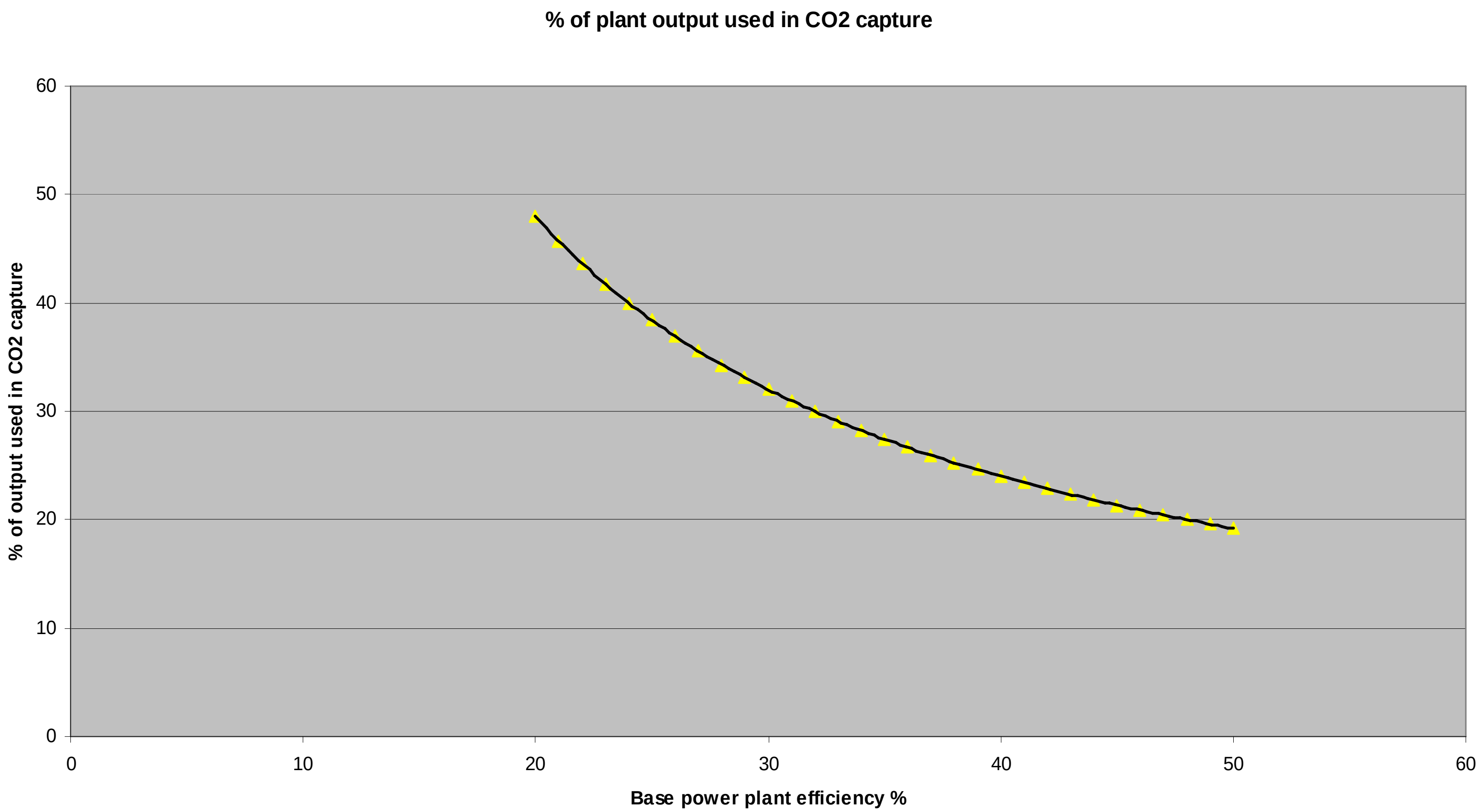
The range of processes from normal gas treatments. Alkalis, glycols?

Chilled ammonia for the ammonium carbonate to ammonium bicarbonate transition.

Chemical looping – getting the oxygen from a metal oxide. Regenerate the reduced metal oxide in air. Family of lab bench processes.

Chemical looping – more complex…. Sulphide, sulphite, sulphate transitions.

Efficiency and cost implications of most CO_2 capture options.



Start with an efficient power plant!

CCS issues for generators and investors

Who owns which part of the problem?

- **Generators need to consider CCS options for new power plant**
  - capture and storage technologies
  - impact of key technologies on operations
  - timescales for carbon capture ready and carbon capture
  - influence of CCS on plant development decisions
  - obtaining permissions and consents

Generators want to buy from others, intelligently.

Feasibility study – CCS economics

Carbon capture and storage currently uneconomic at large scale even without complex integration with a power plant

- most of the CO_2 separated from natural gas at wellheads or landing sites is vented to atmosphere

CCS economics are highly uncertain and very sensitive to assumed commodity prices

- capex/kW and through-life generation costs may increase greatly- increasing costs by between 50 and 150%. Materials influence area?
- need investment in a CO_2 transport infrastructure – onshore pipelines expensive in the UK where built-up areas make routing difficult but UK and Norwegian Governments looking at offshore infrastructure

Costs and risks may change greatly and quickly with technology improvements (YOUR CHALLENGE) and better treatment in the EU ETS

RWE Npower low carbon investments

- RWE npower opted Tilbury and Didcot A (coal) plus Littlebrook and Fawley (oil) out of LCPD
- To replace these, and contribute to meeting the UK energy gap, the following low-carbon investments are planned (subject to scoping, consenting and market conditions)
- Further projects are under consideration

Clean Coal

- Tilbury (1600 MW) developing
  - Capex around GBP 1bn
  - Efficiency – around 46%
- Blyth (2400 MW) developing
  - Capex around GBP 1.5bn
  - Efficiency – around 46%
- R&D program on CO_2 capture

CCGT

- Pembroke (2000 MW – developing)
  - Capex around GBP 800m
  - Efficiency – around 59%
- Staythorpe (1650 MW)
  - Capex around GBP 600m
  - Efficiency – around 58%
- Didcot B - efficiency upgrade
  - Capex around GBP 60m

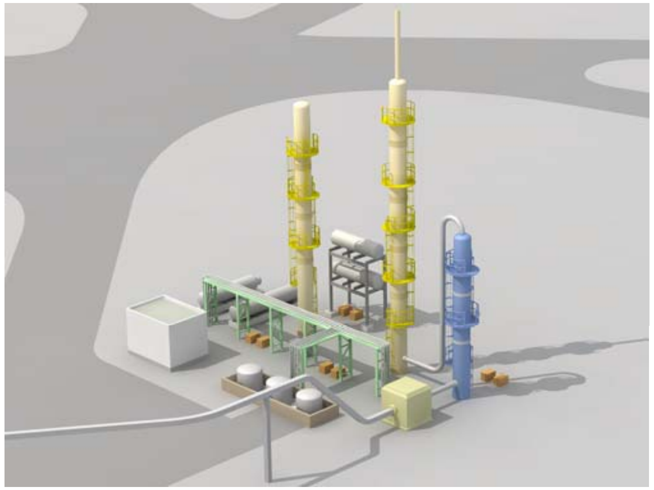
Wind

Onshore
- Little Cheyne Court (Kent, 60 MW)
- Knabs Ridge Yorkshire, 16 MW)
- The Hollies (Lincolnshire, 2.6 MW)
- Bilbster (High Lands, 3.9 MW)

Offshore developing
- Rhyl Flats (North Wales, 90 MW)
- Gwynt-y-mor (North Wales, 750 MW – still requires consenting)

Combustion test facility CO_2 capture programme

- **£650k Oxyfuel combustion programme including coal and biomass co firing**
  - Simulation using bought-in carbon dioxide instead of flue gas recirculation
- **£650k Amine absorption programme, including CO_2 recovery by steam desorption**
- **Both the oxyfuel and the amine absorber projects are multi-partner with DTI funding.**



Next stage(s) -

1 MWe or thereabouts at Aberthaw.
Capture but no storage

Oxyfuel R&D on the 0.5 MWt combustion test facility.

- BOC Installation Of Tanks, Evaporators, control systems complete
- BOC OXY Fuel Equipment Commissioning Complete
- CE Marking and Pressure systems Certification Complete
- Test Programme for DTI Oxy Coal Programme in place
- Hot Commissioning of the rig with Oxy fuel on gas underway

RWE Group

Amine process Carbon Dioxide Capture at the 0.5 MWt combustion test facility.

Note, this is only taking about 1/3 of the test facility flue gas.

ECO-Scrub Concept

- **Project**

  42 month project funded by the European Commission under the Research Fund for Coal and Steel, co-ordinated by RWE npower in collaboration with three universities, two research institutes and three power companies from five EU member states

- **Enhanced combustion with oxygen and scrubbing**
  - either no recirculation or partial recirculation of flue gas with replacement of some air by oxygen
    - reduces volume of flue gas
    - enhances CO_2 concentration of flue gas
- **Several potential benefits**
  - potential for net reduction of operating cost due to increased capture efficiency (opex)
  - potential for slight reduction in size of post-combustion capture plant (capex)
  - reduced-cost retrofit option or potential for savings in new plant through advanced combustion optimisation and reduced boiler size
  - may also be able to reduce size of SCR plant
  - no issues with air in-leakage

RWE npower facilities at Didcot, UK

Pilot scale amine test facility

0.5 MW_{th} Combustion Test Facility

Oxyfuel gas mixing equipment

Some international projects being considered or pursued

- Schwarze Pumpe, Germany – Oxyfuel
- Carson, USA – IGCC
- SaskPower, Canada – Oxyfuel
- Callide A, Australia – Oxyfuel

Futuregen, USA
Castor, Denmark
Zerogen, Australia
ZEP, EU

- Brindisi, Italy – PCC
- Cooperation agreement – Oxyfuel

- Hazelwood, Australia – PCC

- PCC
- IGCC

- Lacq basin, France – Oxyfuel

Tilbury ready for CO_2 capture

When considering sizes, remember that the boilers shown are tower boilers.

Other options being considered, e.g. different numbers of stacks and different orientations.

Land requirement for CO2 capture is comparable to non-CCS parts of power plants.

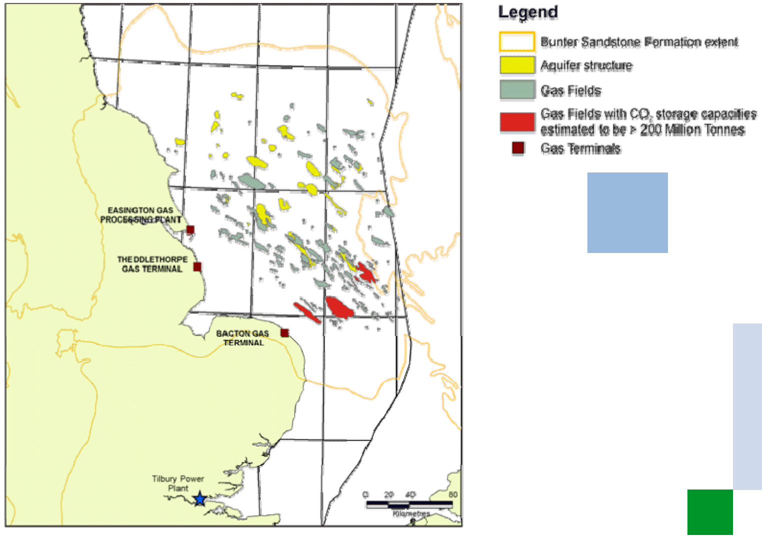
Oxyfuel land requirements are comparable.

Tilbury transport and storage

Transport

High pressure pipeline

- No infrastructure currently available
- 250 miles pipeline required
- large capital cost



Ship

- Specialist vessels
- Transportation conditions – purity, pressure, temperature etc.

Storage

Storage options

- Southern North Sea most likely option
- No practical gas or oil recovery prospects
- Knowledge of storage conditions and monitoring requirements for deep saline aquifers is limited

Some carbon dioxide storage demonstrations

Sleipner

STATOIL

- Field on stream since 1996
- Contains 4 to 9.5% CO_2
- Need to reduce to 2.5%
- Elf - amine technology
- CO_2 - saline aquifer injection

In Salah

bp

- Field on stream since 2004
- Largest dry gas field in Algeria
- Jointly operated with Statoil
- 1,200 Km south of Algiers
- 1 m/t CO_2 injected/year

Weyburn

- Project launched in 1999
- Enhanced oil recovery
- Expected - 22 m/t of CO_2
- Dakota Gasification Company
- 320 Km pipeline

There are natural CO_2 stores and some leak.

CO2 driven geyser in the Eifel, Germany.

http://ortsgemeinde-wallenborn.online.de/joomla/index.php?option=com_content&task=category&sectionid=8&id=25&Itemid=46

Materials questions – post combustion capture

- **Large structures – steel, concrete or even GRP?**
- **Lined or unlined.**
- **Oxidising conditions plus amines / alkalis and amine breakdown products**
- **Residual acidic species in flue gas (SOx and NOx)**
- **Higher temperature boilers and steam turbines (for efficiency, regardless of CCS)**
- **Improved solvents. (Balancing propensity to absorption and ease of desorption)**
- **Costs – initial and through life**
- **Constructing, commissioning and operating pilot plants for maximum learning. (Regulatory regimes have changed a lot over the last 2 decades)**

Materials questions - oxyfuel

- Cryogenic materials at 10 x world's largest scale.
- Safety
- CO_2 has very different spectral absorption properties to nitrogen, changing heat release patterns.
- Boiler metallurgy.
- Carburising / decarburising?
- High SOx content.
- Gas cooled nuclear reactor chemistry / metallurgy?

Materials questions, pre-combustion capture / gasification.

- **Hydrogen combustion in gas turbine – usual GT materials issues plus…..**
- **Gasifier materials, reducing conditions, H2S etc**
- **Process plant structural materials and catalysts**
- **Hot gas filters**

Materials questions for currently unfavoured processes.

- **Membranes**
- **Amine dosed membranes**
- **Cryogenic flue gas processes.**
- **Centrifugal separation of flue gas components.**
- **Chemical looping – metal oxide to transfer the oxygen for combustion, without accompanying nitrogen. (Metal oxide physical stability)**
- **Large scale mass spectrometry**
- **Very different solvents**

Pipes, ships, wellheads and geological reactions

- **Matching pipe and ship tank materials to carbon dioxide composition.**
- **Expensive materials, coated materials or both?**
- **Monitoring transport and storage.**
- **Sealing wells**
- **Geochemical reactions**

UK

- **The carbon dioxide capture processes are being developed outside the UK, e.g. USA, Canada, Germany.**
- **Worldwide – the skills for constructing and operating really novel pilot plants are in short supply – to the extent that many operational dates and much reported data are dubious.**
- **Petrochemical plant and pipework manufacturing increasingly outside UK**
- **Large scale construction has to be on-site**
- **CCS looks like petrochemical engineering, where the UK has niche strengths in integration and detail engineering.**
- **Is the UK role here just in innovation and education?**
- **We have less operational absorption and regeneration pilot plants than 2 decades ago**

Your chance to answer 2 slides later.

Conclusions

- Climate change is a political reality
- Action is required
- Coal will be part of the fuel mix at least until 2030
- A range of capture options are available for fossil-fired plant but all require further R&D , particularly in scale up, reagents and materials for the oxidising conditions.
- Transport of CO_2 is possible by on-shore or off-shore pipe line or by tankers
- CO_2 storage is possible but a number of technical and legal obstacles need to be overcome
- CCS needs to be recognised in the EU ETS to encourage development
- More confidence in CCS when risks better understood, the regulatory regime is smoothed and requirements for new plant are understood
- Public opinion is a critical issue – and that needs education to form views from knowledge.
- In addition to public education, there is a need for specialist skills to produce the plants at acceptable capital and operating costs.

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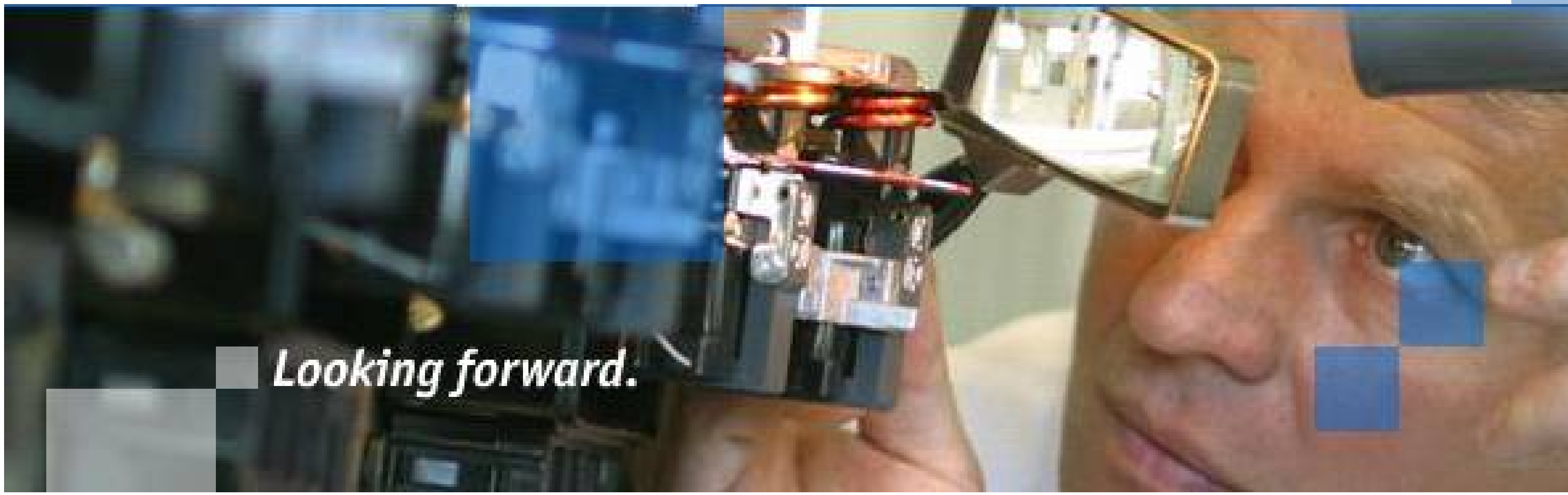

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Questions please