

# Removal of CO<sub>2</sub> from the Atmosphere

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## Institution fully engaged in the public debate:

**ENERGY**

**UK 2050 ENERGY MAKING COMMITMENT A REALITY**

Institution of MECHANICAL ENGINEERS

**ENVIRONMENT**

**CLIMATE CHANGE HAVE WE THE BATTLE?**

Institution of MECHANICAL ENGINEERS

**ENVIRONMENT**

**GEO-ENGINEERING GIVING US TIME TO...**

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**ENVIRONMENT**

**BECCS FOR ELECTRICITY LAND-USE TENSION**

Institution of MECHANICAL ENGINEERS

Bioenergy is widely expected to make a contribution to global electricity production in the coming decades, because of its potential to be a cost-effective source of non-intermittent power generation with low carbon emissions<sup>1,2,3</sup>. The combination of carbon capture and storage (CCS) with bioenergy power plant, a technique known as bioenergy with CCS (BECCS), offers the additional prospect of removing carbon dioxide (CO<sub>2</sub>) from the atmosphere and thereby provides further opportunities for climate change mitigation<sup>4</sup>.

However, the possibility of a widespread adoption of electricity production from bioenergy has raised concerns in some that increased biomass may compete for land use<sup>5,6</sup>. These would arise because biomass cultivated for power generation might compete for land use with other human needs, such as food supply, transport fuels and the desire to maintain global ecosystems.

The analysis presented in this statement suggests that current global emissions electricity from biomass, tensions with food production may not be. Given that the inclusion energy risk would equal cost of reducing the CO<sub>2</sub> energy systems<sup>7</sup>, the Institution of Mechanical Engineers urges Government following recommendations:

1. Undertake a thorough into the potential use technologies for UK oil sources of future inter-annual, ecosystem price climate change mitigation
2. Take an international fully integrated global ecosystem generated electricity from biomass scope for related impact and help ensure biomass to undervalued land-use
3. Support UK research a demonstration of BECCS biomass-based electricity simultaneously pursuit of 'negative emissions climate change mitigation

**ENERGY**

**ENERGY POLICY STATEMENT: 10/02**

**CARBON CAPTURE AND STORAGE NATURAL GAS POWER PLANTS**

Institution of MECHANICAL ENGINEERS

With ambitious targets set by the 2008 Climate Change Act<sup>1</sup> to reduce Greenhouse Gas (GHG) emissions by 80% in the UK by 2050, the electricity generation sector is being forced to address its emissions and, in particular, to rapidly decrease emissions of CO<sub>2</sub> (i.e. 'decarbonise'). To achieve this, the Committee on Climate Change has suggested that for the entire UK fleet of electricity generating equipment the overall intensity of CO<sub>2</sub> emissions should be under 100gCO<sub>2</sub>/kWh by 2030 (Figure 1) and even lower thereafter.

If the emissions reduction targets are to be met, fossil-fuel generating equipment operating generation equipment that includes renewables will be required in future to average somewhere between 150-200gCO<sub>2</sub>. Currently new coal fired power stations CCS would emit in the region of 70gCO<sub>2</sub> whereas electricity generation using coal gas plants emits a lower figure of around 100gCO<sub>2</sub> when the machine is working at full (full load). But given the intermittent that many renewable sources of energy, such as wind power, gas plants deployed as generating mix will not always be optimal load. This part load generation is considered efficient, which means average emissions use in the power sector would be above 100gCO<sub>2</sub>. Open cycle gas plants used to meet electricity demand and to provide a quick for intermittency are even less efficient at higher emissions rates.

**ENVIRONMENT**

**NEGATIVE EMISSIONS AND CARBON RECYCLING AIR CAPTURE**

Institution of MECHANICAL ENGINEERS

Reducing emissions of greenhouse gases (GHGs), while maintaining momentum on economic growth, is a major challenge for industrialised and industrialising nations alike. In recent years, governments across the world have become increasingly aware of the technical, social and economic difficulties in meeting the emissions targets required to avoid dangerous climate change, and struggled to develop effective mitigation policies to address the issue. Policymakers have largely ignored the potential contribution that can be made from the implementation of methods that can directly extract GHGs, particularly carbon dioxide (CO<sub>2</sub>), from the atmosphere.

This policy statement examines the role that such an approach, known as air capture, could play in tackling the challenge of global warming and makes recommendations for climate change policy developments in this area.

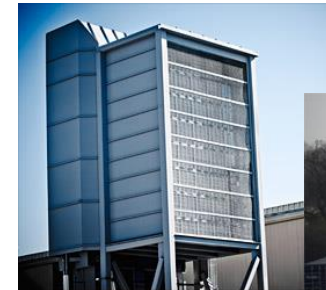
The Institution of Mechanical Engineers recommends:

1. Support more detailed work to establish the cost of air capture technology and to demonstrate its feasibility.
2. Develop policy frameworks that enable the adoption of negative emissions and carbon recycling approaches to mitigate.
3. Provide international leadership in mitigation policy and communicate the important contribution that air capture can make.

**Improving the world through engineering**

- **Presentation overview**

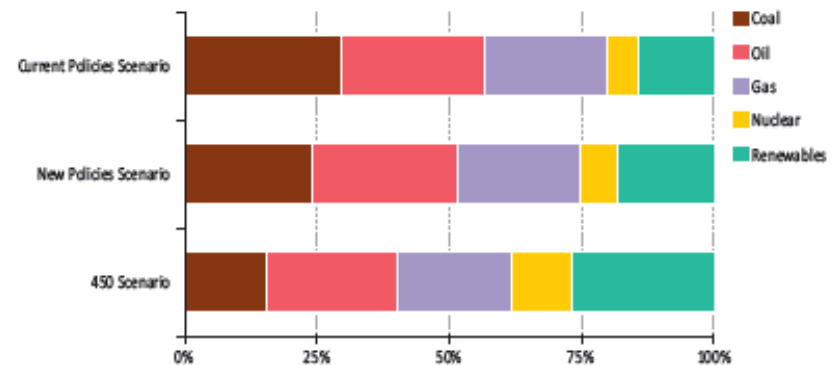
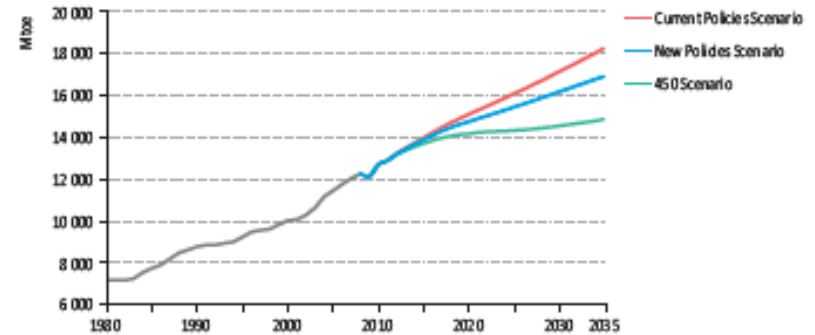
- Removing CO<sub>2</sub> from Air
- Removal techniques
- Air capture machines
- State of play
- CO<sub>2</sub> recycling
- Carbon pricing
- Unlocking innovation
- Conclusions



# More energy – mainly fossil

## • Global growth

- IEA predicts 40% increase in primary energy demand by 2035, with 90% of growth in non-OECD.
- Possible doubling of today's demand by 2050, tripling over 21<sup>st</sup> century.
- 81% of primary energy currently from fossil fuels (coal, oil, gas), potentially still 75% in 2035 [IEA].



- On-track for mean global temperature rise of 3.5°C by 2100.

# Removing CO<sub>2</sub> from air

- **Principal advantages**

- Removes CO<sub>2</sub> regardless of location.
- Tackles difficult sources (transport, domestic, dispersed industry; circa 50% of global emissions).
- Enables 'carbon recycling' through 'closed' carbon loops.
- Puts a credible 'ceiling price' on CO<sub>2</sub> emissions.
- Can address past emissions (and enable geo-engineering?).



# Removal techniques

## • Top candidates

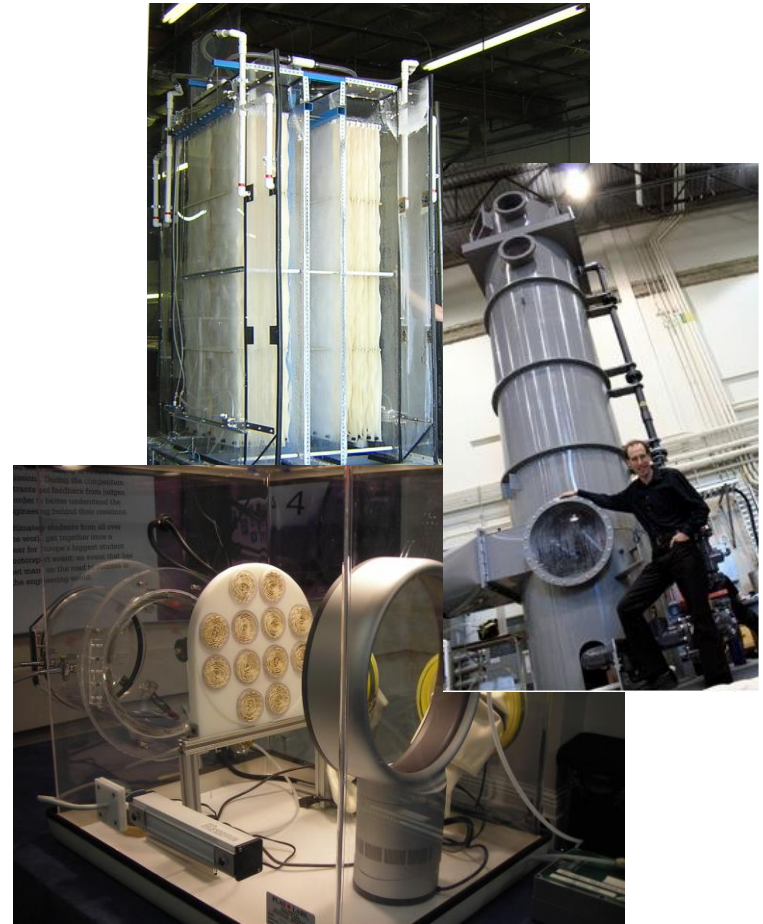
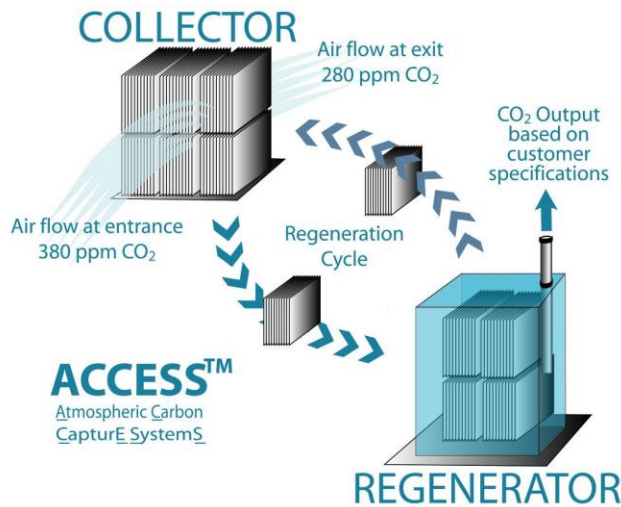
- Air capture machines (Direct Air Capture – DAC).
- Bioenergy with Carbon Capture and Storage (BECCS).
- Augmented ocean sequestration.
- Biochar production through pyrolysis.
- Reforestation and afforestation.
- Enhanced weathering.



# Air capture machines

- Key process steps

- Capture CO<sub>2</sub> to filter medium.
- Remove CO<sub>2</sub> from filter.
- Storage of CO<sub>2</sub> or recycle.



- Early Pioneers

- Klaus Lackner, Peter Eisenberger, David Keith, Aldo Steinfeld

- **Entrepreneurial commercial players**

- Carbon Engineering
- Global Thermostat
- Kilimanjaro Energy
- Sapphire Energy
- Air Fuels Synthesis
- Climeworks

- **CO<sub>2</sub> markets**

- Enhanced Oil Recovery (EOR)
- Algae for Fuel (Aviation)
- Synthetic Fuel (Aviation)
- Chemical processing
- Horticulture
- Military





# CO<sub>2</sub> recycling - 1

## • Challenge of transportation fuels

- High energy densities found in hydrocarbon liquid fuels.
- Replacing enormous global infrastructure for liquid fuels.

## • Carbon recycling for fuel

- Captured CO<sub>2</sub> used as feedstock for a biological or chemical process for production of fuels.
- 'Closed-loop' carbon cycle when CO<sub>2</sub> from air capture.

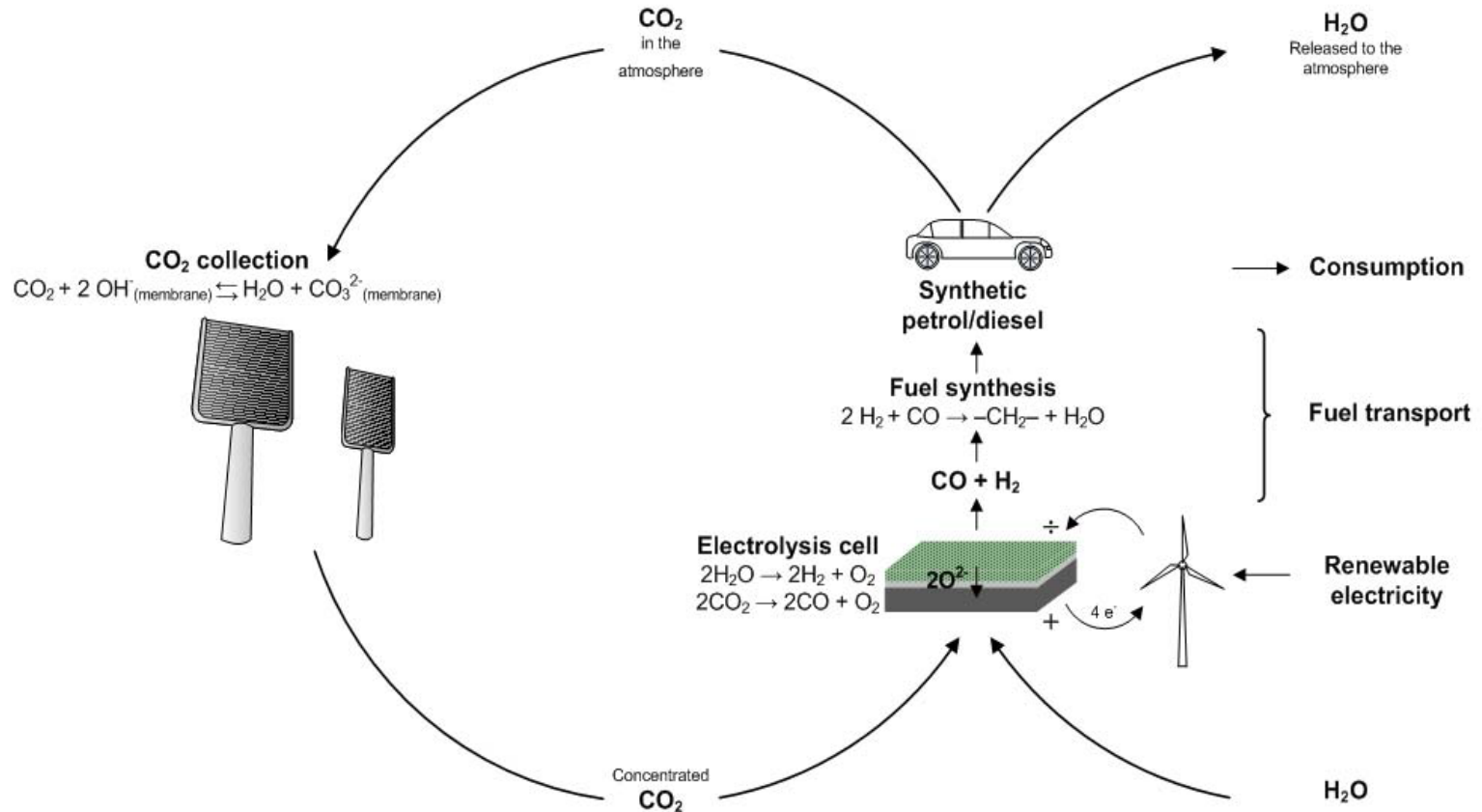
## • Algae based production

- CO<sub>2</sub> and H<sub>2</sub>O as feedstock to algae cultivated in sunlight.



## Carbon recycling and synthetic fuels

Long term realisation - CO<sub>2</sub> capture from the atmosphere



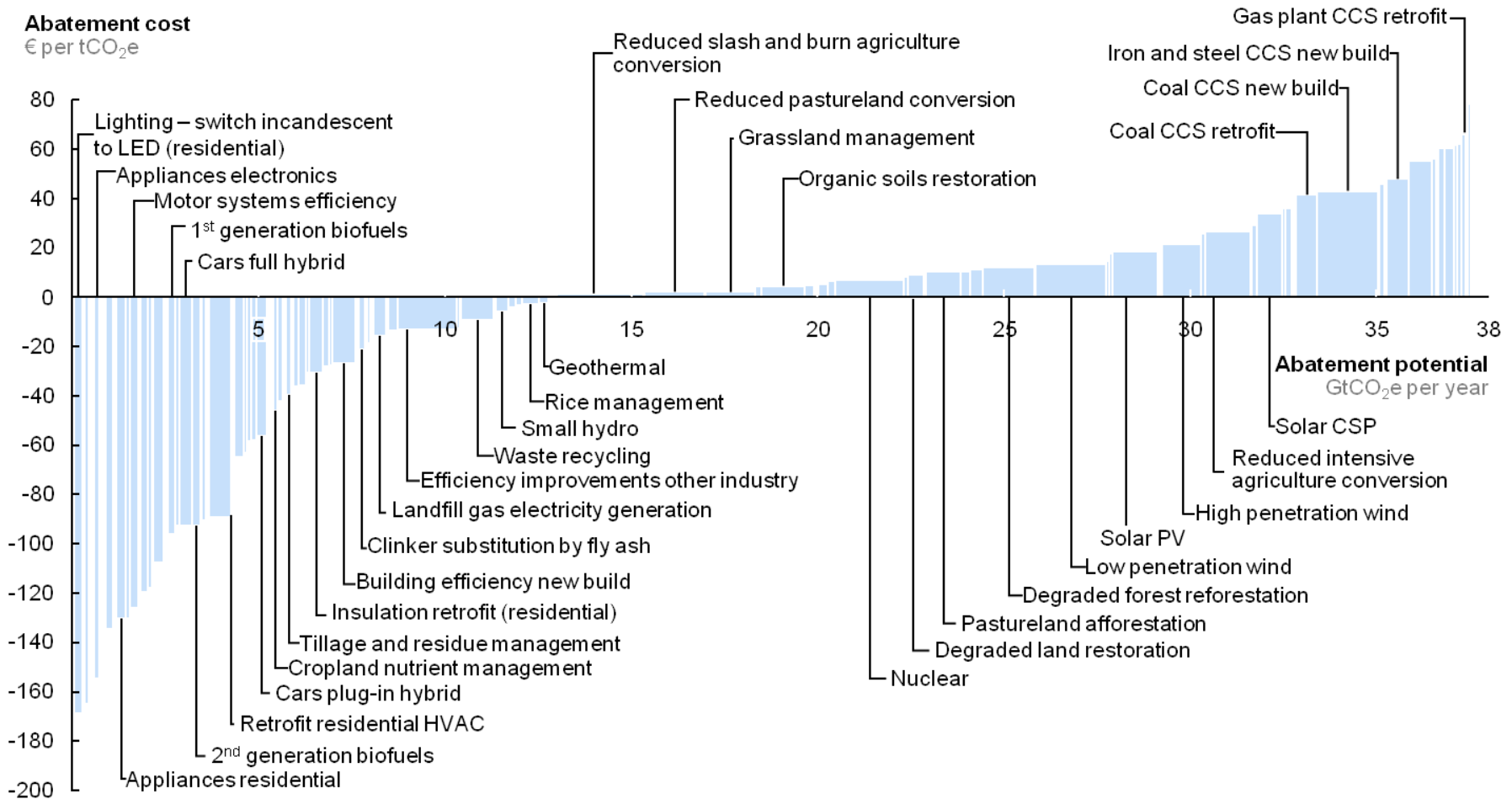
From Mogen Morgensen, DTU Energy Conversion, Technical University of Denmark

# Carbon price challenge

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- **Emitting greenhouse gases is largely cost-free**
  - Challenge is setting a credible, meaningful penalty and creating a mechanism to apply it.
- **Two choices**
  - Regulate for outright global emissions ban; eg HFCs, CFCs.
  - Economic instruments that create a cost for emitting.
- **Challenge for economic instruments**
  - Direct carbon tax or tradable permits scheme?
  - Price setting clear for tax, opaque for tradable permits.
  - Setting the price is highly problematic; future energy price sensitivity, unforeseen consequences, hypothecation.
  - Need credible, logical, tenable, justifiable price applied through transparent, legitimate mechanisms.

# Setting the carbon price



McKinsey & Co., 2010, Impact of the financial crisis on carbon economics:  
Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve.

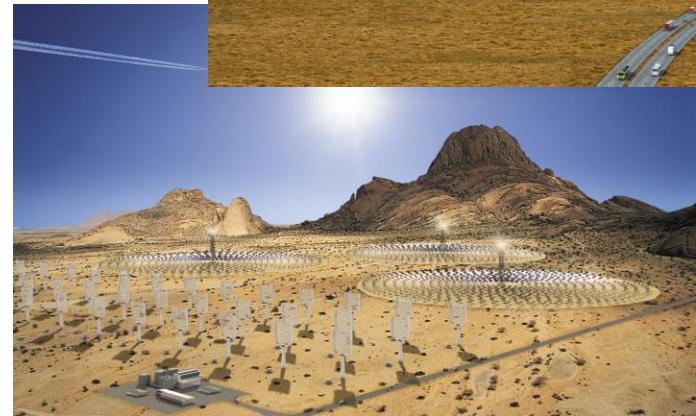
# Unlocking innovation

- **How to levy price and drive innovation?**

- Requirement to abate emissions, or undertake air capture and CO<sub>2</sub> sequestration through own machines, or pay third party machine fleet operators to create 'negative emissions'.
- Requirement could be applied initially to the G20 nations, who collectively account for 80% of global emissions.

- **Price competition**

- Competition amongst fleet operators would innovate the costs out and drive the 'ceiling price' down.
- Drive Cleantech innovation.



# Chances of success?

- Using air capture to set carbon price satisfies three rules for successful technology fixes to social problems.
  - Embodies cause-effect relationship connecting problem to solution.
  - Effects of fix are assessable using relatively unambiguous criteria.
  - R&D necessary to realise the technology improves an established core that already exists.



PHOTO: CHRIS SCHULTZ

- **Access to secure and affordable energy crucial**
  - Essential to human progress and increased well-being.
  - Demand expected to increase substantially in 21<sup>st</sup> century.
  - Continued fossil fuel usage threatened by environmental risk.
- **Removal of CO<sub>2</sub> from the atmosphere**
  - Removal can take place anywhere independent of source.
  - Several technologies available and in development.
  - Enables negative emissions and carbon recycling.
- **Direction of travel**
  - Entrepreneurs stepping into niche markets
  - Potential to fix market failures and drive innovation to reduce costs of clean technologies.
  - Secures continued exploitation of affordable fossil fuels and embedded infrastructure while reducing environmental risk.

- Air capture technology

- Several machines in (commercial) development.
- Enables negative emissions and carbon recycling.
- Potentially helps secure continued exploitation of embedded infrastructure while reducing environmental risk.
- Potential to fix market failures and drive innovation to reduce costs of clean technologies.

- Direction of travel

- Entrepreneurs stepping into niche markets.



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However, the possibility of a widespread adoption of electricity production from bioenergy has raised concerns in some that increased tensions may emerge over land use<sup>(5)</sup>. These would arise because biomass cultivated for power generation might compete for land use with other human needs, such as food supply, transport fuels and the desire to maintain global ecosystems.

The analysis presented in this statement suggests that the current global reliance on biomass for energy may not be sustainable. Given that the exclusion of biomass from the energy mix would significantly increase the cost of reducing the CO<sub>2</sub> emissions of the energy system<sup>(6)</sup>, the Institution of Mechanical Engineers urges Governments to consider the following recommendations:

1. Undertake a thorough assessment of the potential for bioenergy in the UK, taking account of future land needs, ecosystem services and climate change mitigation.
2. Take an internationally integrated approach to bioenergy production, ensuring that electricity production from bioenergy does not lead to land use tensions.
3. Support UK research into the potential for bioenergy in the UK, taking account of future land needs, ecosystem services and climate change mitigation.

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With the average emissions intensity from current equipment fixed at around 500gCO<sub>2</sub>/kWh, this will mean reducing overall emissions of electricity sector at least fivefold over the next 40 years. Some of this reduction can be achieved by the increased use of electricity generating equipment based on low-carbon energy sources such as nuclear and renewables. But a significant amount of fossil fuel-based generation capacity will likely be needed both to meet demand and to provide flexibility to supply, particularly plants which will likely be required to cope with the intermittency that is characteristic of renewable sources.

If the emissions reduction targets are to be met, then the electricity generating equipment operating in the future will need to be based on low-carbon energy sources. Currently, new coal-fired power stations (CCFs) would emit in the region of 750 gCO<sub>2</sub>/kWh whereas electricity generation using combined cycle gas turbine (CCGT) plants emits a lower figure of around 400 gCO<sub>2</sub>/kWh when the machine is working at full (full) load. But given the intermittency of many renewable sources of energy, such as wind and wave power, gas plants deployed as peaking plants will not always be operating at full load. This part load operation is considerably less efficient, which means average emissions from gas plants would be above 400 gCO<sub>2</sub>/kWh. Open cycle gas plants used to meet electricity demand and to provide a quick response to intermittency are even less efficient at higher emissions rates.

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