Lloyd's Register Educational Trust

University of Southampton

Setting the Context for CCS

by

Dr Simon Reeve

The LRET Research Collegium
Southampton, 11 July – 2 September 2011

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Global Trends in Power Plant Development
Setting the context for CCS

Simon Reeve
Power Sector Director
Energy
July 2011

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Global Trends in Power Plant development

- Lloyd's Register – An overview
- Global Trends in Power Plant development
  - Electricity production 2010 – 2040
- Power Technology Development
  - Nuclear
  - Thermal (Coal, Gas, Carbon Capture & Storage)
  - Renewables (Wind, Marine)
  - Other Power Technologies
- Conclusion
- Appendix

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How we started

- in a 17th Century Coffee house in London owned by Mr. Edward Lloyd
- customers formed the 'Register Society' in 1760 to examine merchant ships and 'classify' them. The first 'Register of Ships' was published in 1764 – "Lloyd's Register"
- other customers formed 'Lloyd's of London' the finance institution – no relation to Lloyd's Register!

Lloyd's Register Group

The Group at a glance

- 7,500 employees of 90 nationalities
- 101 companies

- Celebrating our 250 year anniversary this year
- Four business divisions:
  - Marine
  - Energy
  - Transportation
  - Management Systems (LRQA)
- Anticipated annual turnover $1.0bn

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Marine

- Classification
  - standards of quality and reliability
  - new construction surveys
  - surveys on existing ships

- Statutory certification
  - international conventions and codes (IMO)
  - reference: ship safety and marine pollution
  - on behalf of national administrations

- Technical services
  - specialist advice at all stages:
    design/ construction/ operation/ disposal
  - 24-hours emergency response service

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Transportation

- Services to help improve rail systems safety, quality and asset management

- Strategic and economic management consultancy services to the wider transport sector:
  - Lloyd's Register Rail has technology and assurance focus
  - BSL Management Consultants focuses on the economic, organisational and corporate governance issues

- Recent projects include:
  - Taiwan High Speed Rail Project
  - Palm Jumeirah monorail system in Dubai
  - Metro safety assessment, signal in China
  - ISA for signal system lifecycle on Incheon Maglev, Korea

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Management Systems (LRQA)

- Business Assurance approach

- Assessment and certification
  - quality/ environmental / health and safety standards
  - ISO 9000 and ISO 14001

- Verification
  - EC directives
  - Carbon emissions

- Serve many industries
  - over 35,000 clients in 110 countries
  - food/ telecommunications/ aerospace/ automotive/ pharmaceutical, IT…

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Energy - Upstream

Example applications:

- fixed offshore platforms
- pipelines (offshore / onshore)
- semi-submersibles / drilling ships
- FPSO / FSO / FLNG

Example services:

- verification
- optimising risk-based inspection
- classification guidance
- risks and procedures

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Energy - Downstream

Example applications:

- storage (tank farms, underground gas storage)
- petrochemicals
- bulk chemicals

Example services:

- optimising risk-based inspection
- life extension studies
- risk consultancy

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Energy - Nuclear Power

Example applications:

- first-generation nuclear power plants
- new power plants

Example services:

- design approval
- asset integrity management with bespoke
- software solutions
- regulatory compliance assessment
- risk consultancy
- asset management system certification

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Energy - Thermal Power

Example applications:

- New-build fossil plant
- Rehabilitation of existing plant
- Carbon, capture & storage

Example services:

- asset integrity management with bespoke software solutions
- supply-chain verification
- regulatory compliance assessment
- risk consultancy
- asset management system certification

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Energy - Renewable Power

Example applications:

- Off-shore wind
- On-shore wind
- wave and tidal / marine renewables

Example services:

- project certification (IEC TS 61400 – 22)
- wind turbine design evaluation
- support structure manufacturing surveillance
- PAS 55, HSE and IV&V
- measurement and failure investigation

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Energy - Manufacturing

Example applications:

- pressure systems
- ports and cranes
- containers

Example services:

- advice on ASME, EN standards and
- EU directives
- risk-based vendor inspection
- design appraisal

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Energy - Asset life cycle

We bring added value for our clients at each stage of the asset life cycle.

Concept

Procurement and construction

Operation (in-service)

Decommissioning, removal and disposal

From concept to decommissioning

Design

Commissioning

Life extension and re-use

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Energy - Supply chain

We work with businesses operating at every stage of the energy supply chain.

Recovery:
exploration
and extraction

Logistics:
production and
transportation

Processing:
refining, storage,
conversion and
power generation

Delivery:
transmission
and
distribution

From deep water applications to onshore applications

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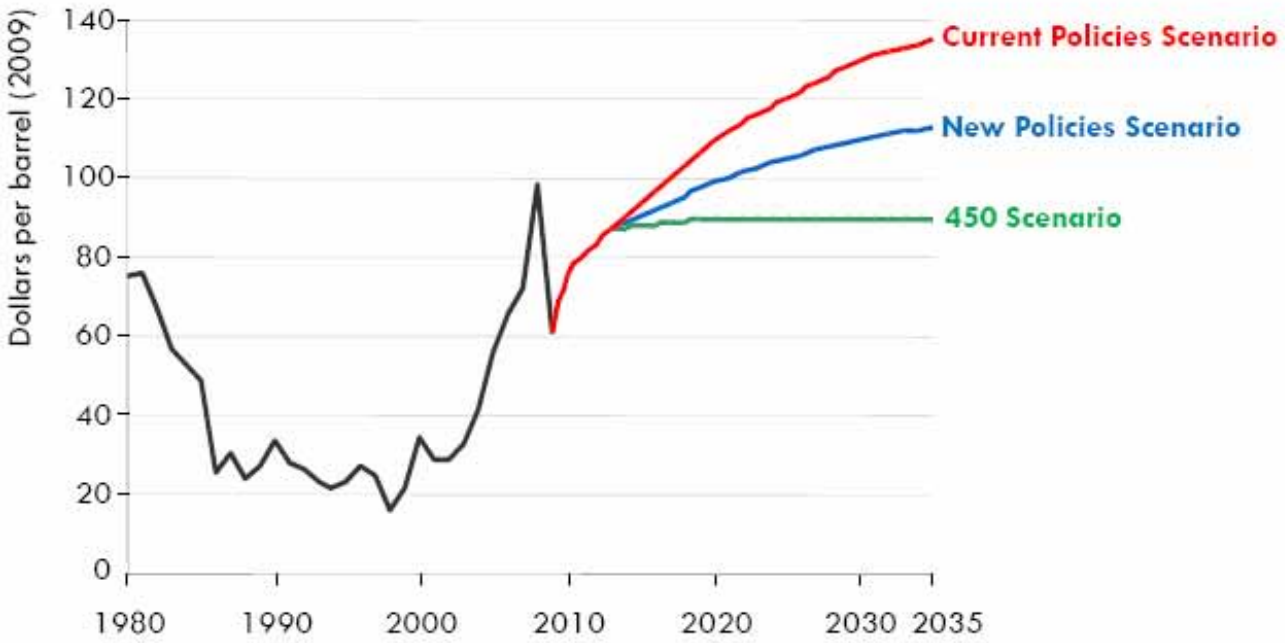
Global Trends

- Oil prices continue to rise though policy action will have a significant effect on the rate & stability.

Oil price changes in period 2008 - 2035



Source: OECD/IEA 2010. "450 scenario" refers to a scenario where the long-term concentration of greenhouse gases in the Earth's atmosphere is limited to 450 parts per million of carbon-dioxide equivalent

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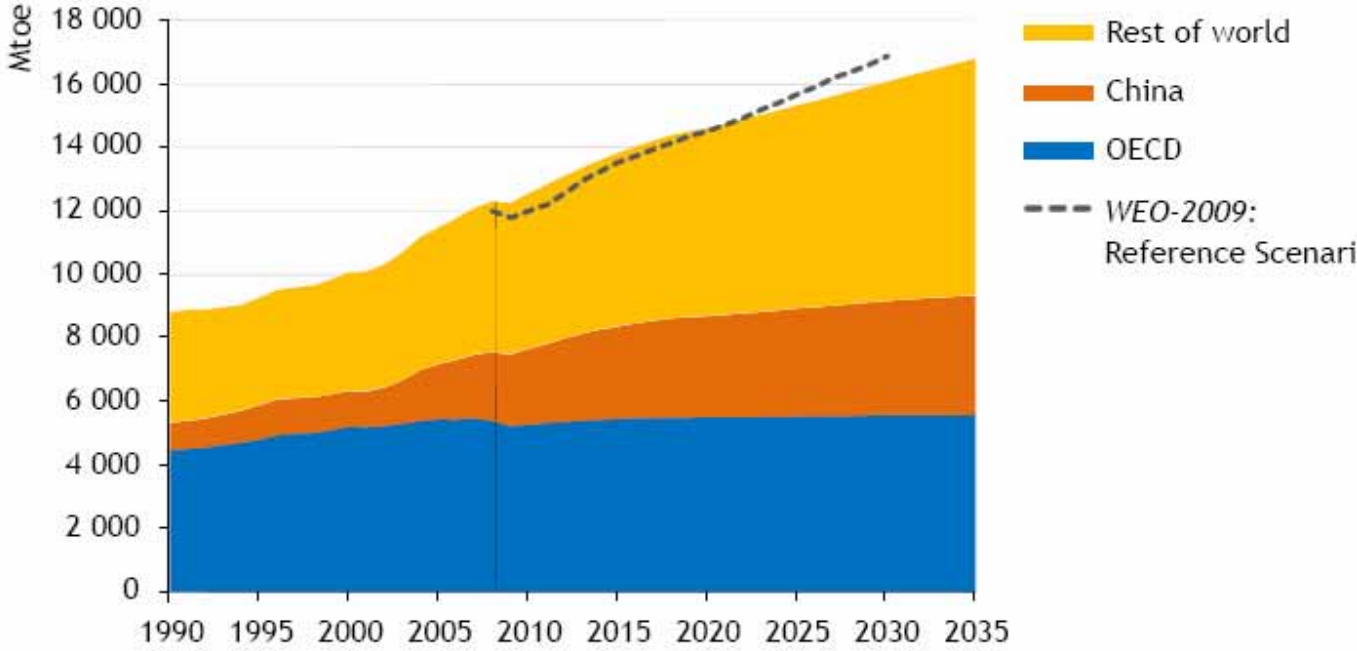
Global Trends

- Global Energy use grows by 36%
- Lead is China with 75% growth

World Primary Energy Demand by region

In New Policies scenario



Source: OECD/IEA 2010

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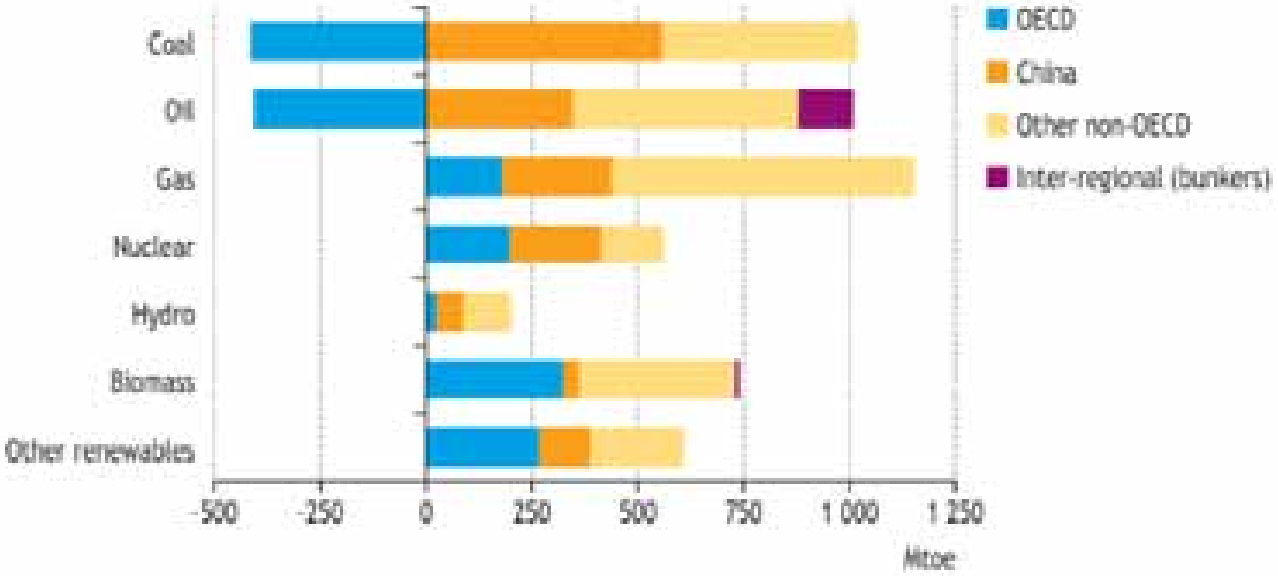
Global Trends

- The change in fuel source for primary energy demand is markedly different for OECD and non OECD countries.
- Thermal fossil power (Coal, Oil & Gas) continue to grow globally
- Nuclear primary growth is strong in OECD, China & other countries
- Renewables growth is similar in both markets.

Change in Primary Energy demand in New Policies Scenario, 2008 - 2035



Source: OECD/IEA 2010

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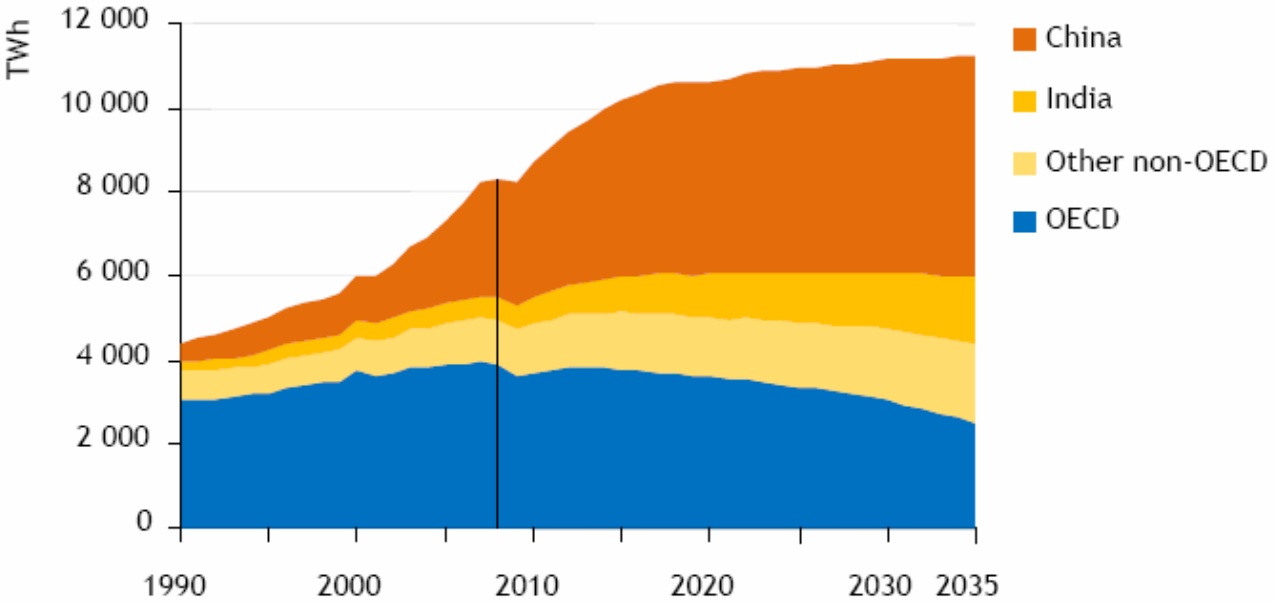
Global Trends

- A drop in coal-fired generation in the OECD is offset by big increases elsewhere, especially China, where 600 GW of new capacity exceeds the current capacity of the US, EU & Japan

Coal-fired electricity generation by region

In the New Policies scenario



Source: OECD/IEA 2010

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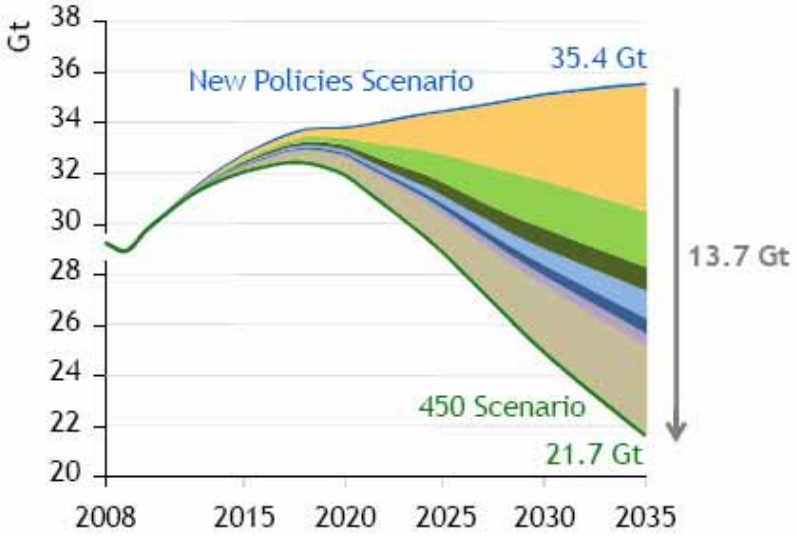
Global Trends

- CO_2 abatement technologies will have a significant impact on the balance of power technologies employed.
- Progress in adopting these technologies will accelerate in the period up to 2020.
- EMEA and Americas are likely to adopt in parallel. Asia will follow within a 5–10 year period.

World energy-related CO2 emission savings in 450 scenario, 2008 - 2035



Share of cumulative abatement between 2010-2035	
China	32%
United States	18%
European Union	8%
India	7%
Middle East	4%
Russia	4%
Rest of world	27%

Source: OECD/IEA 2010.

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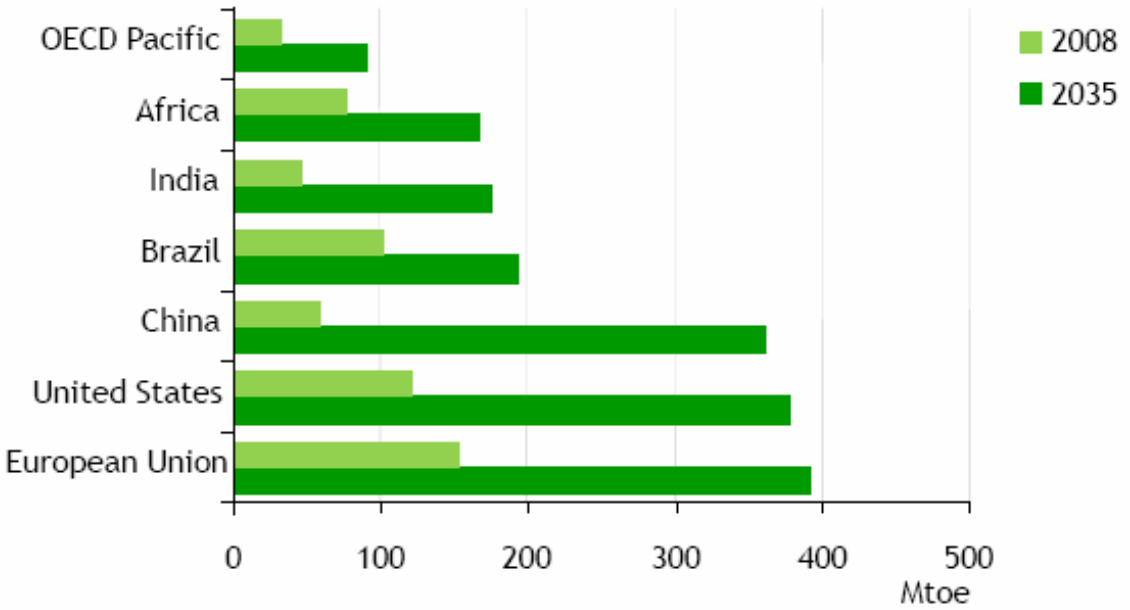
Global Trends

- Tripling of renewable energy driven by electricity supply rising from 19% in 2008 to 32% in 2035
- Largest growth in EU, US & China

Renewable primary energy demand

New Policies Scenario 2008 - 2035



Source: OECD/IEA 2010

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Nuclear Power

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Nuclear Power Drivers

Benefits

- Fuel availability
- Low emissions
- Advanced technology

Challenges

- Cost
- Safety

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Nuclear Technology

Current reactor technology is Generation III+ Pressurised Water Reactors. (PWR)

Leading designs: EPR (Areva)
AP1000 (Westinghouse)

Currently under construction:

EPR	Olkiluoto (Finland)
	Flaminville (France)
	Taishan 1 & 2 (China)
AP1000	Sanmen (China)
	Haiyang (China)

UK: Major programme to replace end-of-life Magnox & AGR plant.

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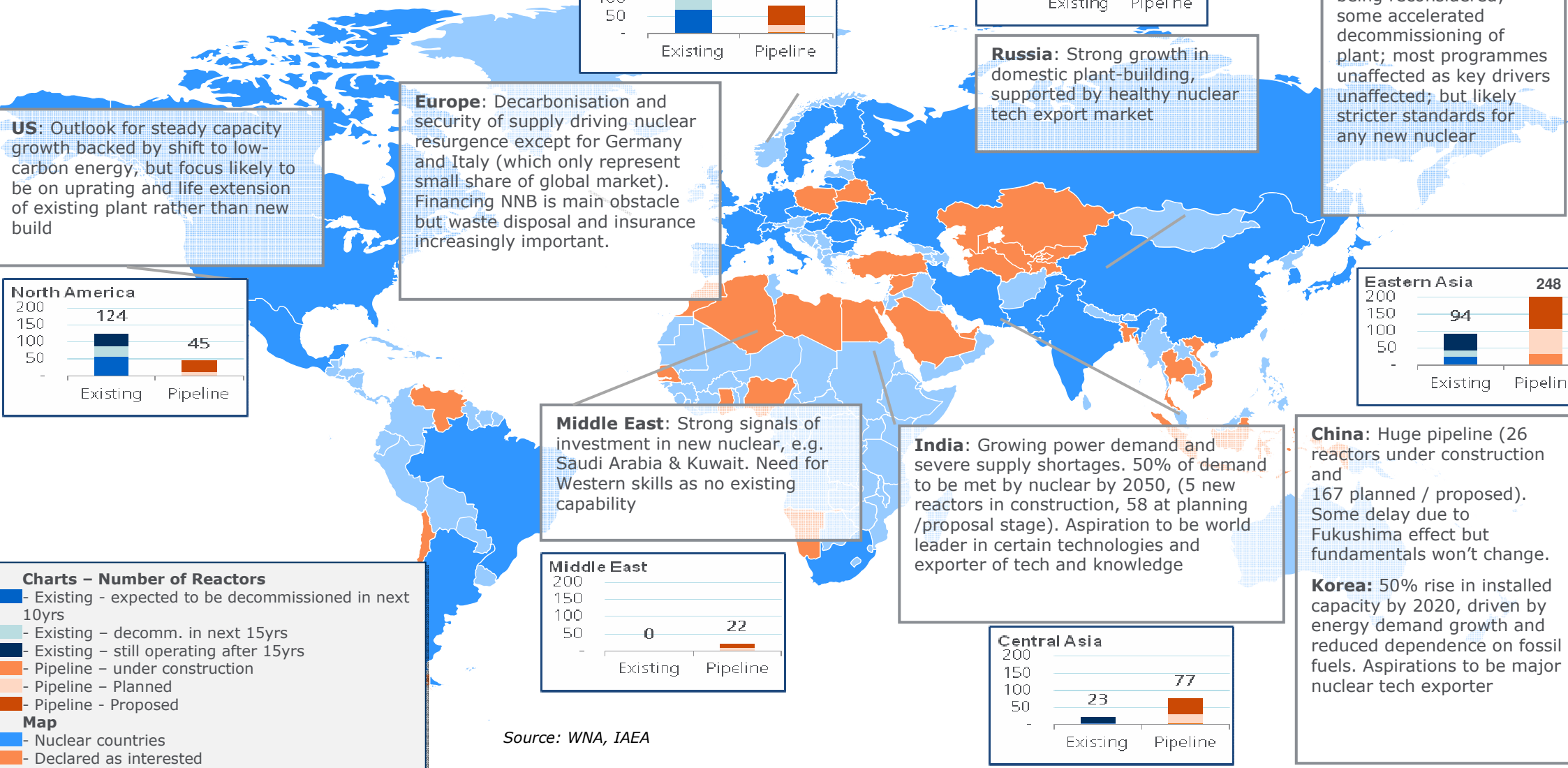
Nuclear landscape & trends



US: Outlook for steady capacity growth backed by shift to low-carbon energy, but focus likely to be on uprating and life extension of existing plant rather than new build

Europe: Decarbonisation and security of supply driving nuclear resurgence except for Germany and Italy (which only represent small share of global market). Financing NNB is main obstacle but waste disposal and insurance increasingly important.

Russia: Strong growth in domestic plant-building, supported by healthy nuclear tech export market

Japan: Wide-ranging domestic & global implications from Fukushima - Some nuclear programmes being reconsidered; some accelerated decommissioning of plant; most programmes unaffected as key drivers unaffected; but likely stricter standards for any new nuclear

Middle East: Strong signals of investment in new nuclear, e.g. Saudi Arabia & Kuwait. Need for Western skills as no existing capability

India: Growing power demand and severe supply shortages. 50% of demand to be met by nuclear by 2050, (5 new reactors in construction, 58 at planning /proposal stage). Aspiration to be world leader in certain technologies and exporter of tech and knowledge

China: Huge pipeline (26 reactors under construction and 167 planned / proposed). Some delay due to Fukushima effect but fundamentals won't change.

Korea: 50% rise in installed capacity by 2020, driven by energy demand growth and reduced dependence on fossil fuels. Aspirations to be major nuclear tech exporter

Charts – Number of Reactors
- Existing - expected to be decommissioned in next 10yrs
- Existing – decomm. in next 15yrs
- Existing – still operating after 15yrs
- Pipeline – under construction
- Pipeline – Planned
- Pipeline - Proposed

Map
- Nuclear countries
- Declared as interested

Source: WNA, IAEA

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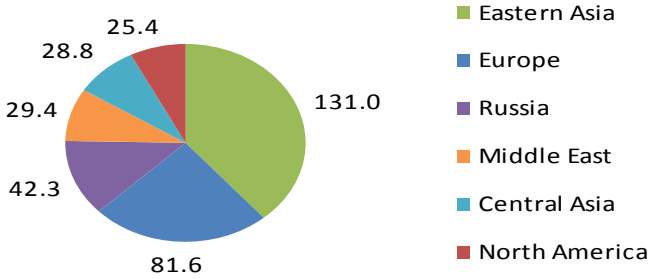
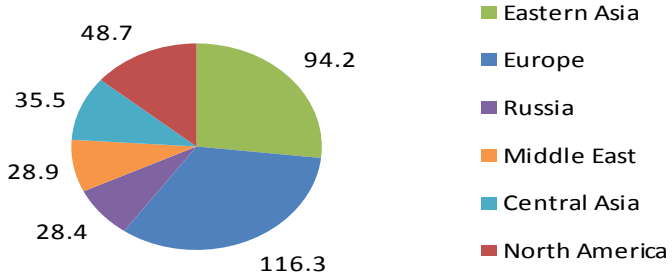
Nuclear Market value*

Construction

New build construction costs in period 2011-2021 (total: £338.5bn)



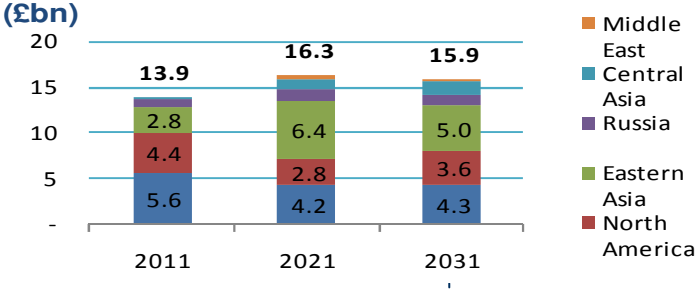
New build construction costs in period 2022-2031 (total: £352.0bn)



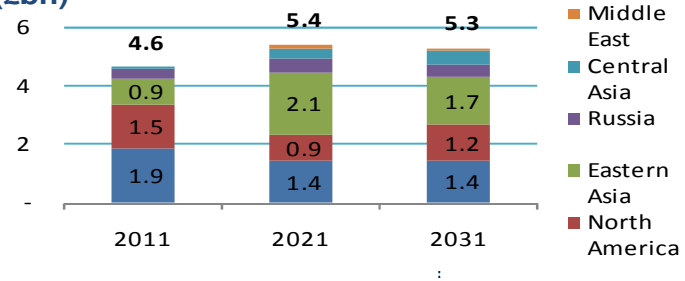
New build costs: *includes pre-construction, construction engineering, procurement and construction) and contingency costs, excludes interest during construction*

Fuelling & Operation

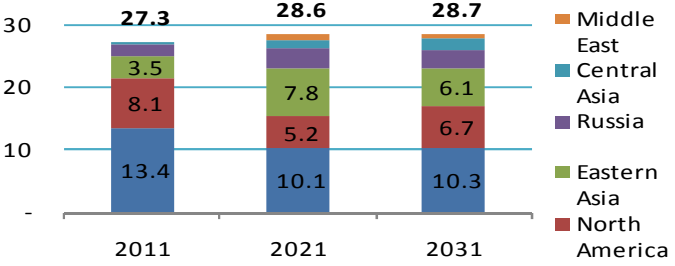
Front-end fuel cycle annual cost (£bn)



Back-end fuel cycle annual cost (£bn)



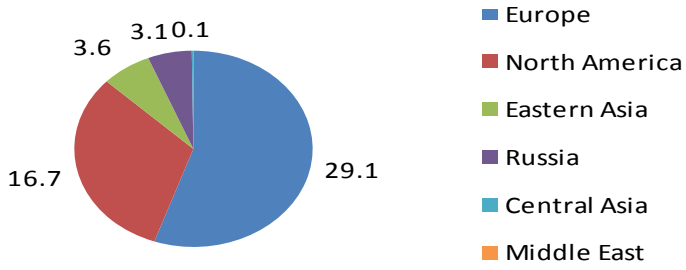
O&M annual cost (£bn)



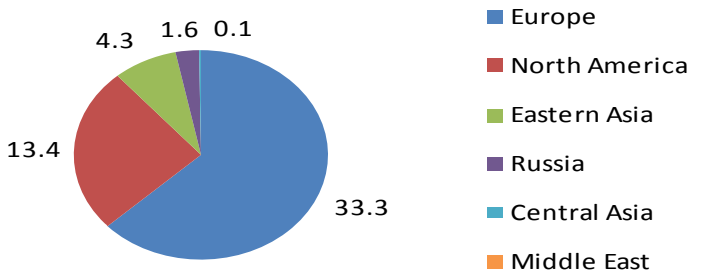
Front-end: *Uranium mining & milling, conversion, enrichment & fuel fabrication*
Back-end*: Spent fuel transport, storage, reprocessing & disposal*

Decommissioning

Decommissioning costs in period 2011-21 (total: £52.6bn)



Decommissioning costs in period 2022-31 (total: £52.7bn)



**Estimate based on forecasts of new nuclear build programmes and remaining operational life of existing*
Source: World Nuclear Association (WNA), OECD NEA, IEA, IAEA, PwC analysis

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Thermal Power

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Thermal Power Drivers

Benefits

Fuel availability & price – gas, coal

Low capital & operating cost

Gas CCGT plant quick to build & commission

Mature technology

Challenges

Emissions – CO2,NOx, SOx

Safety

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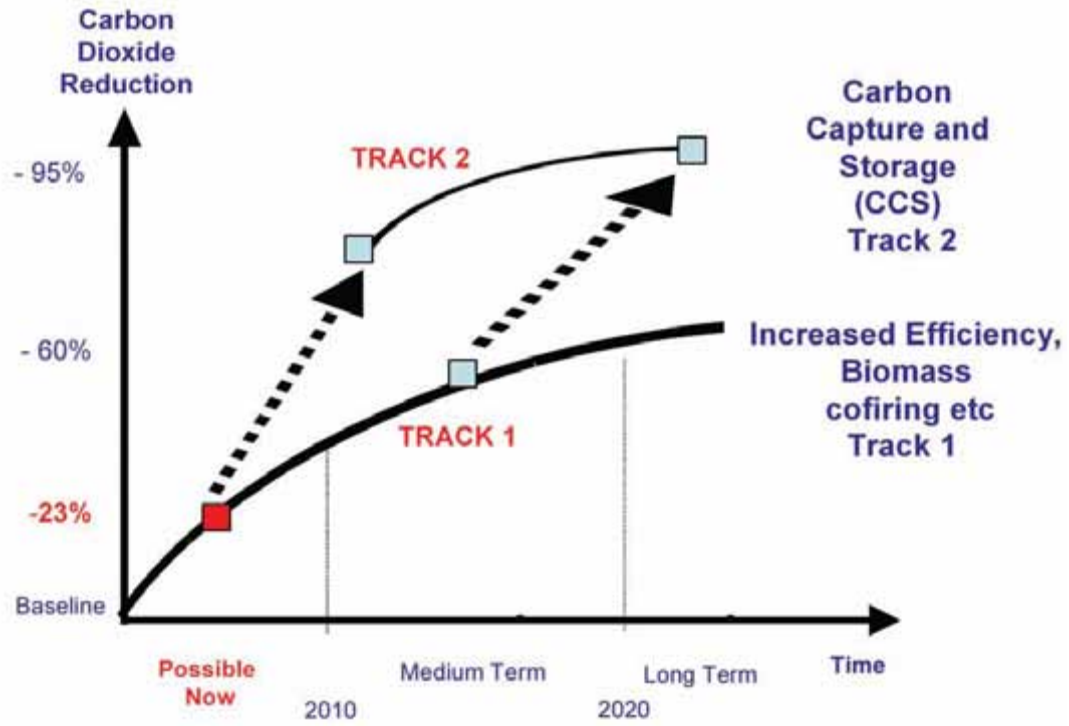
Thermal Technology

Coal-fired Plant



2 aims

1. Increase efficiency (less fuel / MW)
2. Decrease Emissions (NOx, SOx, CO_2)

Boiler Technology

Pulverised Fuel (PF) boilers

- subcritical 30-35% η_{th} (300bar / 600C / 620C)
- current advanced supercritical (ASC) 46-48% η_{th} (300bar / 600C / 620C)
- future ASC 50-55% η_{th} (350bar / 700C / 720C)

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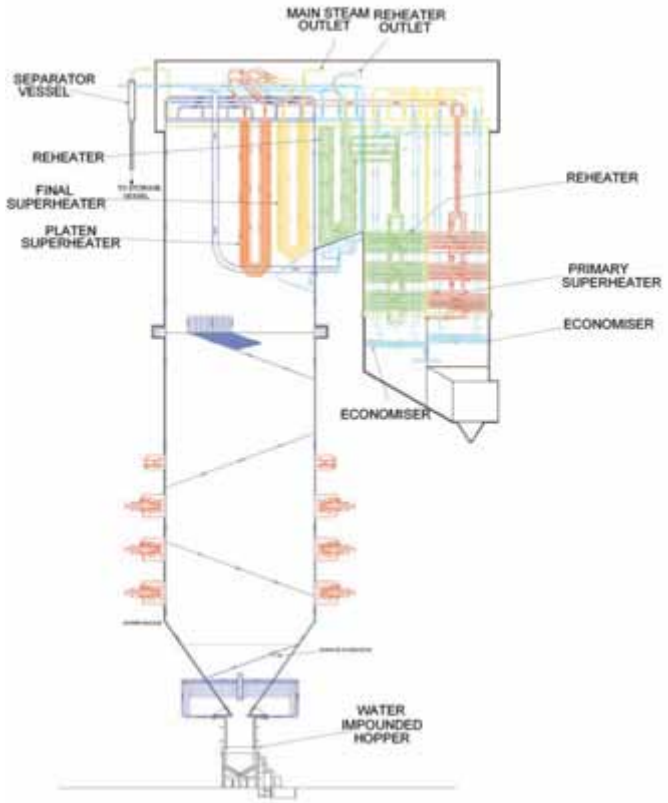
Thermal Technology

Coal-fired Plant



Best Available Technology (BAT)

Steam Conditions: ~300bar / 600C / 620C

Net thermal Efficiency: ~46% η_{th}

Selective Catalytic Reduction (SCR) for NOx emissions

Flue Gas Desulpherisation (FGD) for SO_2 emissions

Electrostatic Precipitator (ESP) for particulate removal

Plant Layout supports space for carbon capture equipment

Retrofit capability for higher temperatures & pressures, biomass co-firing & CCS

Main challenge to 700C technologies: material & cost limitations
(large volumes, high Ni-content alloys)

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Thermal Technology

Natural Gas fired plant

GT26 Gas Turbine (Alstom)

NG preferred technology

1. Availability
2. Price
3. Ease of transport & storage
4. Quick to build/commission
5. Flexible load operation

H2 under development

Back-up to NG but likely 30+ years away from H2 economy

Combined-cycle (CCGT) norm for large-scale power generation η_{th} 57-58%

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Thermal Technology

High efficiency, load flexible, low emission CCGTs

Alstom GT26 upgrade: 61% efficiency claimed
99.55% of full load efficiency at 80% load.
Turn down to 40% load & maintain emission compliance:
NOx <25ppm, CO<5ppm

Siemens: SGT5-8000H/Irsching 4: 60.75% CC efficiency witnessed at 578MW

Mitsubishi: M701F4: approaching 60% at 478MW

Source: Powergen Europe: 7 June 2011

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Renewable Power

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Renewable Drivers

Benefits

- Free fuel!
- Low emissions

Challenges

- Intermittency
- Technology maturity
- Energy density
- Cost

Renewable Technology

Wind development

Continued development in Onshore wind

Latest development is Offshore wind

- EU North Sea ~100GW to be installed UK, German & Dutch sectors
- East Coast China 21GW
- US
- France

Key issues

- Design for offshore environment
- Shallow, deep water & floating foundations
- Installation & support vessels
- Transmission & Distribution networks

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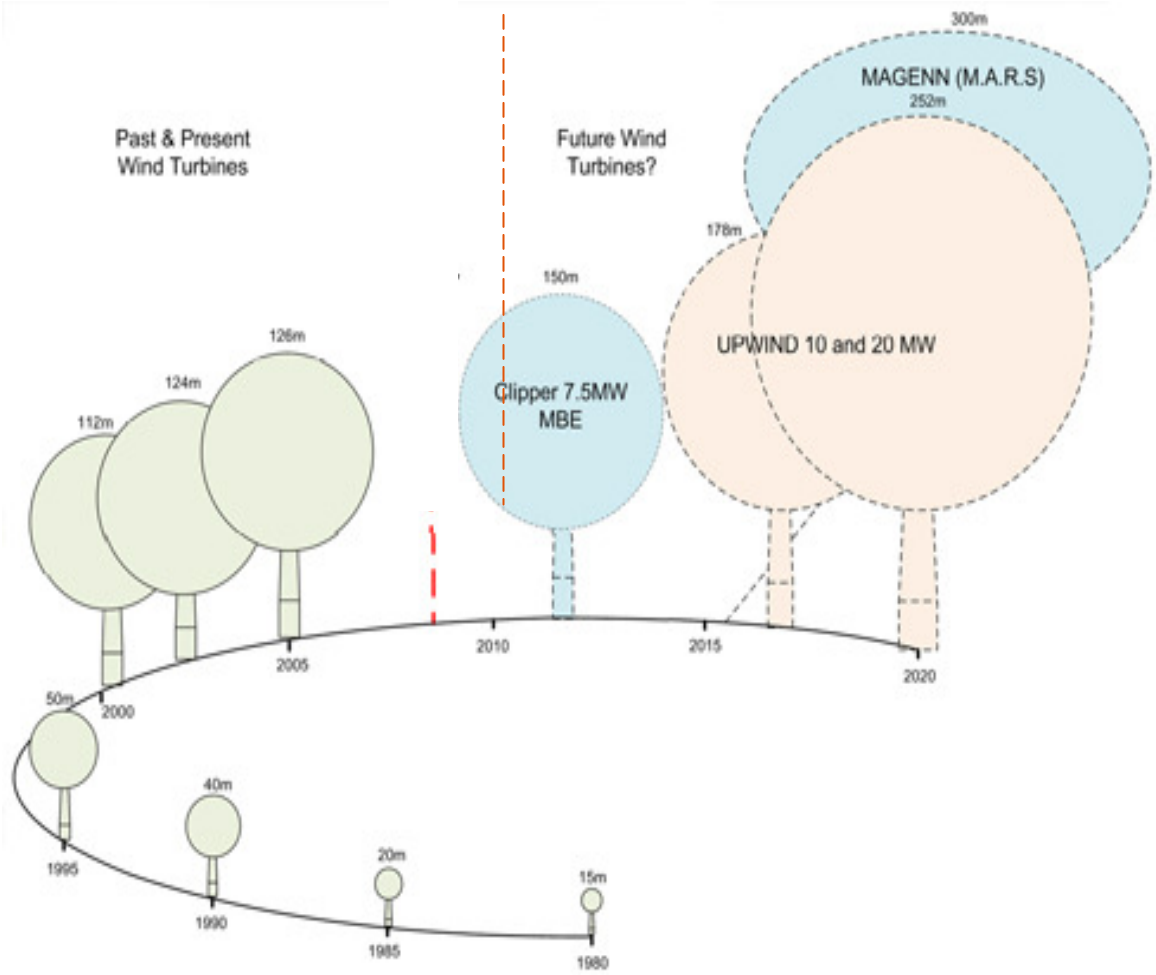
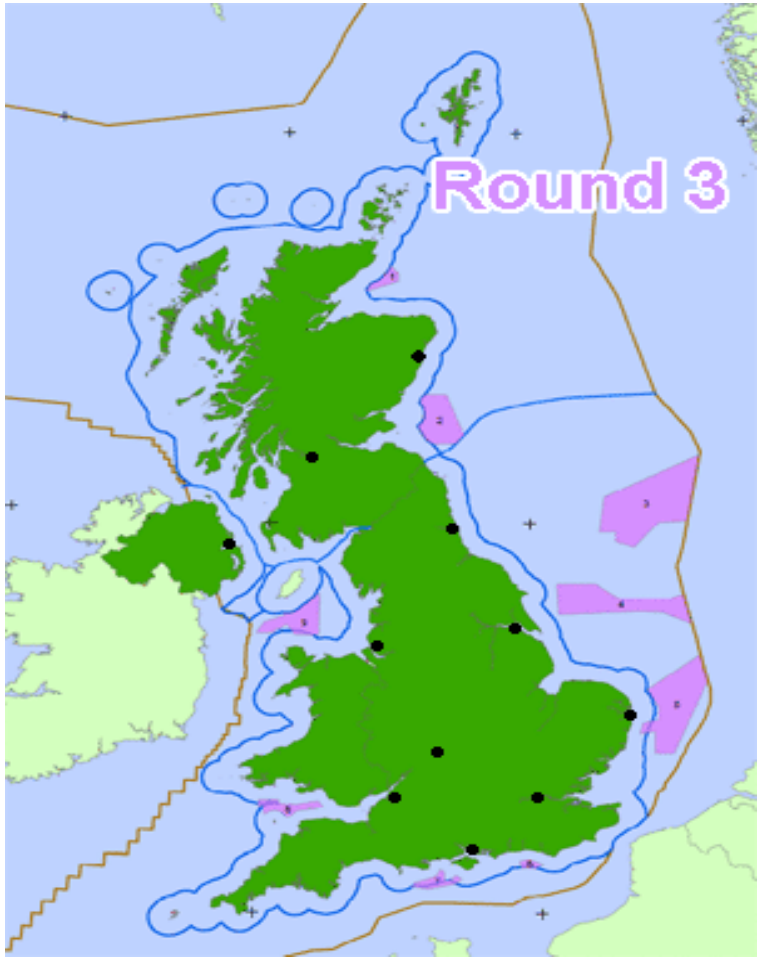
Renewable Technology

Wind development





37GW UK sector – £100bn capex

27GW German sector

5GW Dutch sector

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Renewable Technology

Marine Renewables

Tidal

- Several technologies
- Demonstration projects: Bay of Fundy (Canada) 2012;
  Pentland Firth (Scotland) 2013
- Commercial Operation ~2015?
- Technical challenges:
  - marine environment,
  - civil engineering & power take-off on sea bed,

Atlantis Resources Corporation
Tidal Turbine

Wave

- Earlier in development.
- Many technologies
- Commercial Operation ~2020?

Ocean Power Technologies
Wave Buoy

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Other Power Technologies

- Biomass / co-firing of power plants

  Burning of "biomass" such as wood, waste etc to generate electricity. One of the most attractive and easily implemented biomass energy technologies is cofiring with coal in existing coal-fired boilers. Biomass can substitute for up to 20% of the coal used in the boiler.

- Solar Thermal

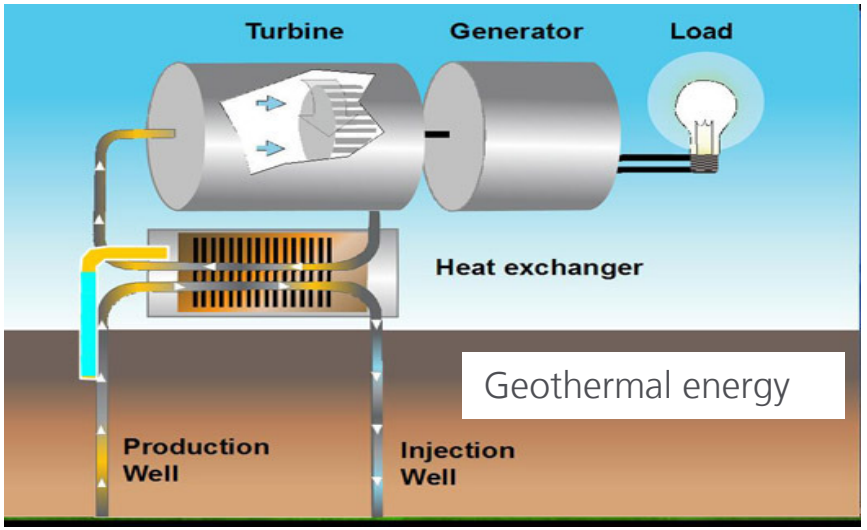
  Solar energy is converted into thermal energy , usually steam, that in turn is converted to electrical energy using a turbine and generator.

- Geothermal

  Thermal heat obtained from the Earth's interior is converted into electricity using a heat exchanger connected to a turbine generator set. Geothermal energy is also used for district heating, for example in Reykjavik where a district heating system provides heat for 95% of the buildings.

Solar thermal plant P10 in Seville, Spain

(11 MW from 624 mirrors, cost €35m)



Geothermal energy

Other Power Technologies

- Hydro

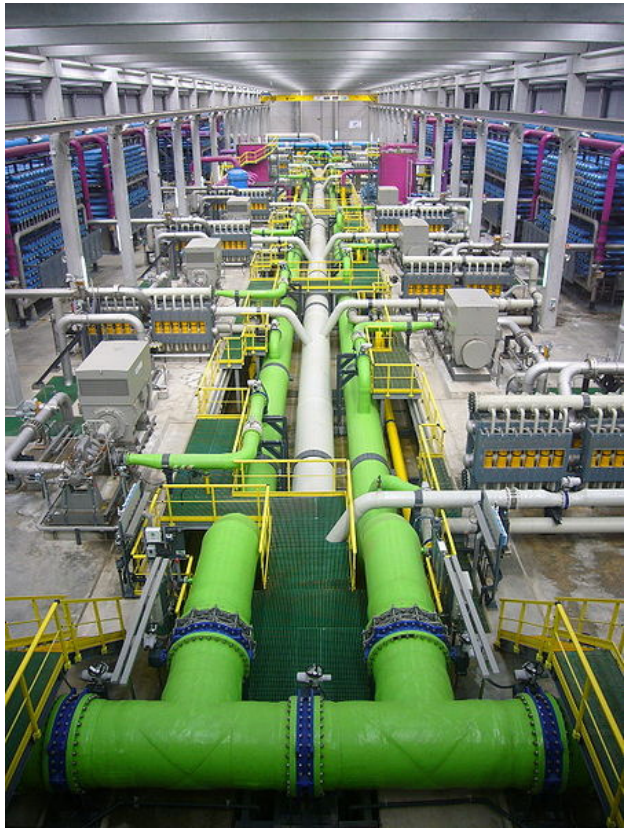
- Solar PV

- Grid Technologies
(Transmission, Distribution & Smart Grids)

- Energy Storage

- Fuel Cells

- Water & Desalination



Reverse Osmosis Desalination
Barcelona, Spain

Challenge:

To link together with traditional plant in smart regional solutions

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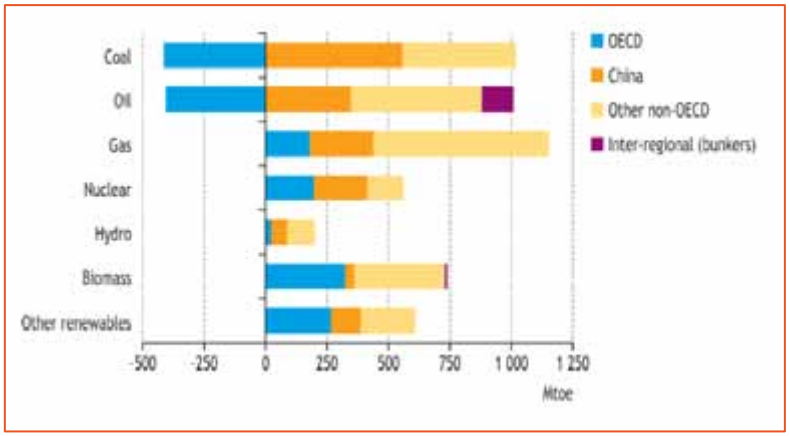
Conclusion

- Energy is essential to life and development
- Key drivers are fuel, cost & environment
- Relative merits of drivers change as technologies develop
- Fossil-fired electricity generation will continue to dominate on the world stage.
- Carbon Capture and Storage is sought as a means to use the fuel we have, in a manner that is acceptable to our environment and at a cost that is sustainable.



Change in Primary Energy demand, 2008 - 2035

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Global Trends in Power Plant development

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Capacity and investment needs in power infrastructure New Policies Scenario

	2010 - 2020					2021 - 2035				
	Capacity (GW)		Investment ($2009 billion)			Capacity (GW)		Investment ($2009 billion)		
	Additions	Retirements	New Plant	Transmission	Distribution	Additions	Retirements	New Plant	Transmission	Distribution
OECD	**777**	**424**	**1490**	**370**	**851**	**1208**	**770**	**2502**	**373**	**892**
North America	322	207	585	169	363	520	324	1039	197	424
United States	*262*	*191*	*498*	*140*	*302*	*411*	*273*	*873*	*160*	*345*
Europe	337	158	694	110	332	498	348	1080	128	386
Pacific	118	59	211	91	156	190	98	383	48	82
Japan	*74*	*50*	*120*	*63*	*105*	*111*	*61*	*211*	*28*	*47*
Non-OECD	**1542**	**232**	**2165**	**617**	**1328**	**2146**	**554**	**3477**	**808**	**1734**
E.Europe/Eurasia	161	123	252	43	144	231	157	413	51	170
Caspian	*29*	*13*	*35*	*10*	*33*	*30*	*18*	*37*	*8*	*28*
Russia	*91*	*62*	*143*	*18*	*60*	*138*	*94*	*254*	*22*	*74*
Asia	1095	74	1526	472	975	1494	244	2347	613	1265
China	*773*	*38*	*1054*	*306*	*632*	*760*	*142*	*1168*	*274*	*566*
India	*200*	*22*	*288*	*102*	*210*	*428*	*58*	*679*	*197*	*407*
Middle East	114	10	129	29	59	144	70	229	49	102
Africa	76	8	109	28	57	138	45	235	42	88
Latin America	95	17	149	45	93	138	38	254	53	110
Brazil	*45*	*7*	*72*	*22*	*46*	*64*	*12*	*126*	*29*	*60*
World	**2319**	**656**	**3655**	**986**	**2179**	**3354**	**1324**	**5979**	**1181**	**2626**
European Union	331	170	685	103	307	469	346	1027	117	348

Source: IEA 2010
New Policies Scenario

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Regional Focus – Europe Summary

Mix	2008	→ 2035
Electricity demand x 2		
Coal	26%	10%
Gas	24%	24%
Renew.	20%	44%*
Nuclear	26%	21%

*Hydro 15%, Wind 18%, Solar 3%

Utilities/Developers

EDF
Vattenfall
RWE
Iberdrola
EoN
Endesa
EnBW

OEMs

Alstom
Siemens
GE
Mitsubishi
Mitsui Babcock

Source: IEA 2010
New Policies Scenario
Electricity Generation (TWh)

Lloyd's Register
LIFE MATTERS

Lloyd's Register Group

Regional Focus – Middle East Summary

Mix	2008	→ 2035
Electricity demand x 2		
Gas	58%	63%
Renewable	1%	16%*
Nuclear	<1%	2%

*Hydro 3%, Wind 5%, Solar 6%

Utilities/Developers

EDF

Vattenfall

RWE

Iberdrola

EoN

OEMs

Alstom

Siemens

GE

Mitsibushi

Mitsui Babcock

Source: IEA 2010
New Policies Scenario
Electricity Generation (TWh)

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Regional Focus – India Summary

Mix	2008	→ 2035
Electricity demand x 4		
Coal	69%	52%
Gas	10%	14%
Renewable	11%	27%*
Nuclear	2%	6%

*Hydro 13%, Wind 6%, Solar 4%

Utilities/Developers

Examples:

APGENCO

Essar Energy

Larsen & Toubro

NTPC

NPCIL

OEMs

Alstom

GE

Mitsibushi

Mitsui Babcock

Siemens

Source: IEA 2010
New Policies Scenario
Electricity Generation (TWh)

Lloyd's Register Group

Regional Focus – China Summary

Mix	2008	→ 2035
Electricity demand x 3		
Coal	79%	55%
Gas	<1%	9%
Renewable	19%	29%*
Nuclear	2%	5%

*Hydro 14%, Wind 7%, Solar 2%

Utilities/Developers

Big 5:

China Datang Corporation

China Guodian Corporation

China Huadian Group

China Huaneng Group

China Power Investment Corporation

Nuclear:

China Guangdong Nuclear Power Group CGNPG

OEMs

Alstom

GE

Siemens

Shanghai Electric Co.

Harbin Steam Turbine Co.

Dongfang Electric Co.

Source: IEA 2010
New Policies Scenario
Electricity Generation (TWh)

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Regional Focus – United States Summary

Mix	2008	2035
Electricity demand x 1.2		
Coal	49%	33%
Gas	21%	23%
Renewable	16%	27%*
Nuclear	18%	19%

*Hydro 12% & Wind 10%

Utilities/Developers

AES Corporation
Southern Company
American Electric Power
Duke Energy
Luminant
Reliant Energy
Pacific Gas and Electric Co.
Allegheny Energy

OEMs

Alstom
GE
Mitsubishi
Mitsui Babcock
Siemens - Westinghouse

Source: IEA 2010
New Policies Scenario
Electricity Generation (TWh)

Key Organisations & Links for data

International Atomic Energy Association (IAEA):	www.iaea.org
International Energy Agency (IEA):	www.iea.org
IEA World Energy Outlook:	www.worldenergyoutlook.org
IEA World Energy Statistics:	www.iea.org/stats/

Europe

Nuclear Energy Agency:	www.nea.fr/
Europe Energy Portal:	www.energy.eu/
EoN	www.eon.com
EDF	www.edf.com
Endesa	www.endesa.es
Iberdrola	www.Iberdrola.es
RWE	www.rwe.com
Vattenfall	www.vattenfall.com

UK

Nuclear Industries Association	www.niauk.org
Department of Energy & Climate Change	www.decc.gov.uk
UK Energy Statistics (HANDOUT)	www.decc.gov.uk/en/content/cms/statistics/publications/dukes

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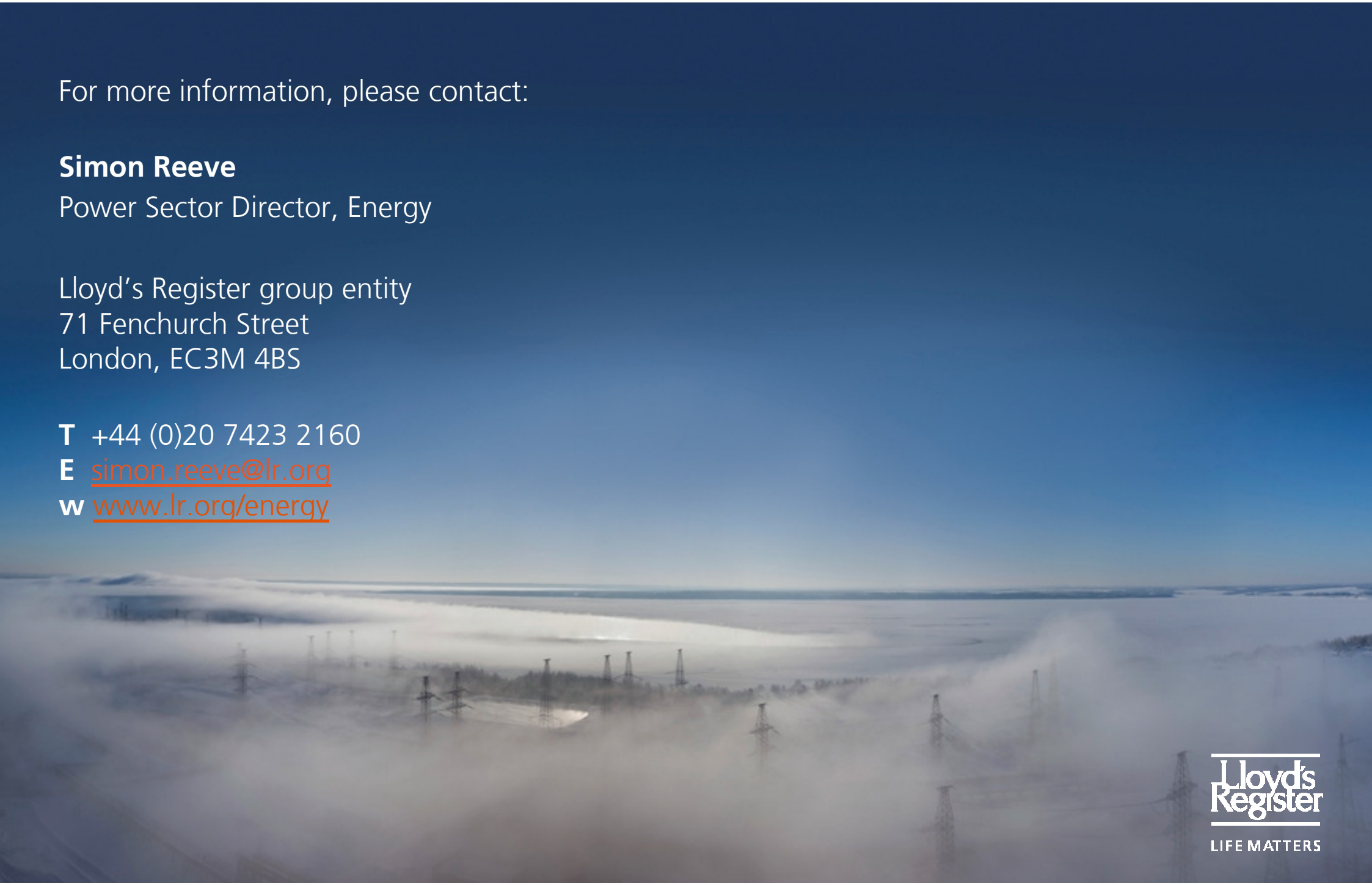

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