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Climate Change & Energy

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Power generation is largest source of CO_2 emissions (IEA GHG, 2002)

- Fossil-fuel-based heat & power production, e.g.
  - natural-gas (NG)-fired plants
  - oil- & coal-fired plants
- 2nd largest: manufacturing & construction, e.g.
- 3rd largest: transportation
- **This chapter will concentrate on the strategic directions and opportunities climate change mitigation initiatives through R&D in the energy sector for power generation and for transportation**

Energy & Power Generation: required R&D efforts for CO_2 capture & storage (CCS)—general overview

- Major challenges for R&D in CCS:
  - to portray technology choice in context of entire life-cycles
  - to improve focus on fundamentals of molecules, materials, & naturally-occurring mechanisms (e.g., photosynthesis) for enhanced process design
  - increased exploration & exploitation of hybrid processes, e.g., integrated separation & reaction—combine attractive aspects of conventionally discrete unit operations for improved energy & exergy efficiency
- Most important factor likely to influence CCS implementation: government support, both in terms of size & perceived predictability (Steeneveldt et al., 2006):
  - similar to systems for SO_x removal, cost of building & operating CO2 capture systems should be reduced over time through cumulative learning & technological progress (e.g., Alic et al., 2003; McDonald & Schrattenholzer, 2001; Riahia et al., 2004; Rubin et al., 2004a, b; Rao et al., 2003)
  - numerous technical routes to CO2 capture at different stages of maturity
  - cumulative learning contention rests on assumption that there is effective learning across technology platforms—debatable where there is proliferation of approaches

Steeneveldt, R., B. Berger, and T. A. Torp. CO2 capture and storage: closing the knowing-doing gap. *Trans IChemE* 84 (2006): 739 – 763.

Energy & Power Generation: Required R&D efforts for CO_2 capture & storage (CCS)

- Major R&D initiatives should be concentrated in the following strategies for climate change mitigation that reconcile continued use of fossil fuels with goals to reduce CO2 emission related to meeting global energy needs:
  1. improved energy efficiency
  2. fuel switching, e.g., coal → NG
  3. CO2 capture & storage (CCS)—major components of CCS value chain:
     - capture: separation & compression to supercritical state
     - transport & storage, including measurement, monitoring, & verification of safe operations

     CO2 capture is premised upon safe long-term storage of CO2 in geological formations
- No serious research initiatives in CO2 storage appears to be discernible among Malaysian academics
- Large scale CO2 applications:
  - enhanced oil recovery (EOR)
  - enhanced coal bed methane (ECBM)
- Widespread implementation of fully-integrated CO2 value chains will depend on:
  - achieving public acceptance and regulatory approval for CO2 storage
  - cost reduction for CO2 capture
  - Sufficient economic incentives for key actors involved

Steeneveldt, R., B. Berger, and T. A. Torp.

Energy & Power Generation: main research directions for CO_2 capture & storage (CCS)

Main capture routes
- Post-combustion capture
- Pre-combustion capture
- Oxyfuel capture

Emergent capture routes
- Biomimetic/enzymatic CO_2 fixation
- Electrochemical pumping

CO_2 compression, liquefaction, & transport
- Fundamental properties of CO_2

CO_2 storage in geological formations
- Trapping mechanisms
- CO_2 migration
- Storage integrity
- Monitoring & verification
- Risk assessment

CO_2 emissions policy/regulation
- CO_2 storage regulation

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Energy & Power Generation: required R&D efforts for CO_2 capture & storage (CCS)

Post-combustion CO_2 capture

- Amine scrubbing process: key technology know-how = development of inhibitors and their application to cost-effectively prevent degradation and corrosion
- Important factors for design and cost of CO2 removal plant:
  - CO2 purity at point of use
  - flue gas impurities
- Research directions: improvements with potential to reduce energy requirements for post-combustion capture:

Improved/new solvents | **New sorbents** | **New turbine design** | **New CO2 membranes**

Improved mass transfer (e.g., contacting membranes)

Simplify plant design/remove redundancy

Integrate $CO_2/NO_x/SO_x$ removal

Modify combustion to increase CO2 partial pressure

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Energy & Power Generation: Required R&D efforts for CO_2 capture & storage (CCS)

Integrated Gasification Combined Cycle (IGCC) with CCS

- Integrated Gasification Combined Cycle (IGCC) with CCS
  - despite worldwide commercial use and acceptance of gasification processes and combined cycle power systems, relatively new is integration of coal gasification with combined cycle power block to produce electricity as primary output
  - commercial gasification processes believed most suited for near-term IGCC applications using coal or petroleum coke feedstock: General Electric, ConocoPhillips, & Shell entrained-flow gasifiers—worthwhile to be investigated for potentially feasible Malaysian implementations

Energy & Power Generation: Required R&D efforts for CO_2 capture & storage (CCS)
Improved absorption, membrane, and cryogenic separation

- Improved absorption:
  - improved solvents to improve CO2 loading
  - reduced energy requirement for solvent circulation & regeneration & to overcome solvent degradation
  - design of improved contacting equipment that additionally overcomes known operational problems with packed columns (e.g., of problems: flooding, channelling, entrainment, and foaming)
  - improved packing
  - use of contacting membranes
  - combination of chemical absorption and selective membranes so as to perform absorption & desorption in a single unit
  - combination of polymeric microporous membranes and diethyl amine (DEA) solvents
  - increased solvent concentration so as to reduce circulation rates and thus energy requirements for regeneration and removal of O2, in order to enable use of solvents that are intolerant of oxygen
    - ammonia has been proposed as an alternative to amines and can be employed to capture all three major acid gases (SO2, NOx, CO2) besides only flue gas of coal combustors
  - CO2 capture for fertilizer production

- Membrane: major disadvantage = high hydrocarbon lost

- Cryogenic separation:
  - robust: applicable to wider range of conditions than membrane
  - reported only 2 companies in the world working on this

Energy & Power Generation: Required R&D efforts for CO_2 capture & storage (CCS)

- Power block/capture integration: energy integration between CO2 capture plant and power plant to reduce energy requirements
  - recirculation of flue gas (most studied configuration option) (Bolland and Sæther, 1992)
  - combination of new solvent technology and integration of steam requirements for CO2 stripper with power plant—potential lowering of energy penalty for CO2 capture and compression (Mimura et al, 1997)
  - potential improvements to amine-based CO2 capture from flue gas:
    - depressurization of lean solvent and vapor compression
    - elimination of contact coolers before absorber
    - using structured packing
    - direct integration of stripper and heat recovery steam generator
    - recycle of portion of flue gas to increase CO2 feed concentration to absorber (Chinn et al., 2004)

Energy & Power Generation: Required R&D efforts for CO_2 capture & storage (CCS)—additional remarks

- Large scale CO2 applications:
  - enhanced oil recovery (EOR)
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- Widespread implementation of fully-integrated CO2 value chains will depend on:
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Energy & Power Generation: R&D in renewable energy (RE) as an alternative cleaner carbon-neutral energy source—some remarks on current status

- Technology development for energy generation from renewable resources is still not properly established
  - Commercialization of research findings has not been fully undertaken on a large scale despite reported research and studies pointing to its technical feasibility
- High investment costs and final energy costs of RE generation faces stiff competitions from cheaper conventional energy (fossil fuels), thus renders it economically unattractive
  - electricity costs:
    - from biomass, geothermal and solar sources = US$ 7–25 cents/kWh
    - from conventional (coal, natural gas, etc.) = US$ 4–6 cents/kWh (Hitam, 1999)
  - The relatively higher costs of energy generation from renewable resources, both in terms of investment costs and final energy costs, make the generation of energy from renewable resources economically unattractive

Energy & Power Generation: R&D in RE to address GHG emissions via photovoltaic (PV) solar energy

- R&D on viability of enforcing mandatory installations of photovoltaic solar energy systems (panel) in all governmental, commercial, and residential buildings (Lee et al., 2009)
- the PV system could eventually reduce peak demand for electricity from the national grid/supplement the national grid for the requirement of peak demand for electricity
- reduce consumption of fossil fuels in power plants
- in imitating some of the successful measures in Japan for reducing carbon footprint, perform R&D investigating viability/feasibility of providing incentives (e.g., capital incentives) to promote members of the public to install PV panels in residential homes

Source: Lee, Chung Lau, Kok Tat Tan, Keat Teong Lee, and Abdul Rahman Mohamed. A comparative study on the energy policies in Japan and Malaysia in fulfilling their nations' obligations towards the Kyoto Protocol. Energy Policy (2009), doi:10.1016/j.enpol.2009.06.034.

Energy & Transportation: R&D initiatives to address GHG emissions

- Vehicle design for greater fuel efficiency
- 2nd generation biofuels as alternative energy source
- More efficient road and traffic infrastructure
- Improved public transportation systems
- Driver education to capture benefits of more fuel-efficient eco-driving

Source: Lee, Chung Lau, Kok Tat Tan, Keat Teong Lee, and Abdul Rahman Mohamed. A comparative study on the energy policies in Japan and Malaysia in fulfilling their nations' obligations towards the Kyoto Protocol. Energy Policy (2009), doi:10.1016/j.enpol.2009.06.034.

Energy & Petroleum Industry/Oil & Gas: R&D initiatives to address GHG emissions

- Reduce use of flaring/venting (burning unwanted gases/byproduct) at oil and gas fields and plants (refineries, petrochemicals)
- Send otherwise flared gases back to offshore for reinjection into reservoir (as EOR agent)
- Cogeneration facilities in refineries & petrochemical plants:
  - simultaneous production of heat & power: excess heat captured from refineries or power-generation processes can be used as substitute for carbon-intensive activities by:
    - converting into steam for industrial use
    - using it directly to hear nearby houses or business premises

Thank you

… discussion