Clean Coal Technologies: Moving to 21st Century

San Shwe Hla

Senior Research Scientist | CSIRO Energy Technology

ASEAN ++ 2013: MOVING FORWARD, Chiang Mai, Thailand
11 November 2013
- Global Energy Trend

- Efficiency and Emissions
  - Improving efficiency to underpin emissions reduction and CO$_2$ capture
  - Clean Coal technology strategies
  - Gasification: a flexible enabling technology

- R&D Challenges
  - Australian demonstration projects
  - IGCC-CCS case study
  - CSIRO Gasification and Syngas Researches

- Summary & Remark
CSIRO
Commonwealth Scientific and Industrial Research Organisation

People  6500

Divisions  13

Locations  58

Flagships  11

Budget  $1B+

Top 1% of global research institutions in 14 of 22 research fields
Top 0.1% in 4 research fields

62% of our people hold university degrees
2000 doctorates
500 masters

With our university partners, we develop 650 postgraduate research students
Global connections: impact partnerships

China Australia Alliance for New Energy Vehicle Innovation

80+ countries
Global Energy Trends
World electricity production

World net electricity generation by fuel, 2010-2040 (trillion kilowatthours)

- Coal expected to continue to fuel the largest share of world electricity beyond 2040

World electricity production

Coal remains the core fuel in future scenarios

- OECD nations reduce their reliance on coal-fired electricity generation
- Strong growth in China and India
  - China to add nearly 500GW new coal capacity
    - exceeds US, EU and Japan capacity
    - 36% of world coal power generation by 2040

Source: IEA World Energy Outlook, 2012
Efficiency and Emissions
High efficiency technologies underpin future deployment
CO₂ emission in a typical coal fired power plant using a typical coal

- 1 kg of Coal
- 0.8 kg of C
- 30 MJ of Energy Input

≈1.0 kg of CO₂ / 1 kWh

35% efficiency

Boiler

Generator

Electricity

10.5 MJ of Energy Output
≈ 2.92 kWh

CO₂ in flue gas

2.93 kg of CO₂
Technology efficiency impact on CO$_2$ emissions

- Brown coal pulverised fuel
- Black coal pulverised fuel
- Brown coal Integrated Drying Gasification Combined Cycle
- Super/ultra critical pulverised fuel
- Black coal Integrated Gasification Combined Cycle
- Integrated gasification fuel cell
- Current Australian technology
- DICE
- DCFC
High Efficiency is an essential requirement for effective CO$_2$ capture

Increasing efficiency has many virtues:
- reduced fuel use
- smaller plant size (& cost)
- reduced emissions
- more amenable to CO$_2$ capture and storage (CCS)
  - less CO$_2$ for capture processes to deal with

CO$_2$ capture increases costs and reduces efficiency and capacity!
- ~30 % capacity reduction for pf
Clean Coal Research and Technology Strategies
Low Emissions Power Generation

*Post-combustion capture*

1. Energy Conversion
2. Capture of CO₂
3. Storage/Use of CO₂

*Pre-combustion decarbonisation*

1. Coal → ASU → Gasification
2. Syngas (CO + H₂) → CO Shift
3. CO₂/H₂ separation

*Oxy-fuel combustion*

Source: adapted from IEA Clean Coal Centre
Post Combustion Capture Technology

Coal → Boiler → Flue gas pretreatment → Flue gas → Generator → Electricity → Low CO\(_2\) flue gas → Absorber → Liquid CO\(_2\) → Reboiler → Stripper → Flue Gas → Reboiler → C.W.

Clean Coal Technologies: Moving to 21st Century | ASEAN ++ 2013 | San Shwe Hla | Page 14
More about PCC

Only practical option for existing plants to substantially reduce GHG intensity

The technology of CO$_2$ capture is well understood and is currently used in other industrial applications.

There are important issues in applying the technology to coal fired boilers for the purpose of capture for storage

- Capturing and compressing CO$_2$ may increase the fuel needs of a coal-fired CCS plant by 25–40% 
- high cost (presently around $35/t CO$_2$ captured and compressed, equivalent to around $33$/MWh for an 85% reduction in GHG) 
- small scale (presently around 850 tpd/unit (suitable for 50 MWe))

One of the practical issue with existing plants is how far it might be from a potential sequestration site.
## Economics and Efficiency of PCC

<table>
<thead>
<tr>
<th>Efficiency or Cost</th>
<th>Range</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation efficiency without PCC</td>
<td>35 – 41 %</td>
<td>Efficiency range determined by type of steam cycle and type of cooling</td>
</tr>
<tr>
<td>Generation efficiency with PCC</td>
<td>25 – 29 %</td>
<td></td>
</tr>
<tr>
<td>Capital costs without PCC</td>
<td>$ 2300 – 3000/kW</td>
<td>Cost range determined by type of steam cycle and type of cooling</td>
</tr>
<tr>
<td>Capital costs with PCC</td>
<td>$ 4900 – 5900/kW</td>
<td></td>
</tr>
<tr>
<td>Cost of generation without PCC</td>
<td>$ 21 – 66/MWh</td>
<td>Lower costs refer to the fully amortised power plant; higher costs refer to newly built power plant</td>
</tr>
<tr>
<td>Cost of generation with PCC</td>
<td>$ 75 – 129/MWh</td>
<td></td>
</tr>
<tr>
<td>Avoided CO\textsubscript{2} emissions cost</td>
<td>$ 68 – 92/t CO\textsubscript{2}</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Feron and Paterson (2011)*
Post-Combustion CO$_2$ Capture Pilot Plants
CSIRO and partners

**Learning by doing**
- 4 operating Pilot plants
- 1-3 kt pa CO$_2$ capture
- Combinations of:
  - Coal type
  - Solvents
  - Flue gas properties
Oxy-pf with Flue Gas Liquefaction
More of Oxy-fired pulverised coal technology

Advantages
- PF fuel burned in high-purity oxygen atmosphere with flue gas recycling
  - The mass and volume of the flue gas are reduced by approximately 75%.
  - Less heat is lost in the flue gas, reduce the size of the flue gas treatment equipment
  - Less NOx
- Greatly increases CO$_2$ concentration in flue gas, compression separation possible
- Only physical (not chemical) separation required to remove CO$_2$ for storage

Issues
- Challenging to retrofit
  - Air leaks add non-condensable contaminants (Ar, O$_2$, N$_2$)
- High-purity O$_2$ expensive and energy intensive
  - New air separation technologies can help here
- Similar total energy cost as PCC (theoretical min. 104 kWh/tonne CO$_2$)

Demonstration project
- CS Energy (with CCSD) 30MW demonstration in Central Qld
IGCC Technology

FEEDS

Alternatives:
• Asphalt
• Coal
• Heavy Oil
• Petroleum Coke
• Orimulsion
• Natural Gas
• Wastes
• Clean Fuels

GASIFICATION

Gasifier

Oxygen

Byproducts:
Solids (slag)

GAS CLEANUP

Syngas

Gas & Steam Turbines

Sulfur Removal

Combined Cycle Power Block

Marketable Byproducts:
Sulfur

END PRODUCTS

Electricity Steam

Alternatives:
• Hydrogen
• Ammonia
• Chemicals
• Methanol

Source: ChevronTexaco-2003
## Coal-fired IGCC plants around the world

<table>
<thead>
<tr>
<th>PLANT NAME</th>
<th>LOCATION</th>
<th>OUTPUT (MWe)</th>
<th>FEEDSTOCK</th>
<th>GASIFIER</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUON/Demkolec Willem-Alexander</td>
<td>Buggenum, The Netherlands</td>
<td>253</td>
<td>Bituminous Coal and Biomass</td>
<td>Shell</td>
<td>1994 -Present</td>
</tr>
<tr>
<td>ConocoPhillips Wabash River Plant</td>
<td>West Terre Haute, IN USA</td>
<td>262</td>
<td>Bituminous Coal and Pet Coke (2544 tpd)</td>
<td>E-Gas®</td>
<td>1995 -Present</td>
</tr>
<tr>
<td>Tampa Electric Polk Plant</td>
<td>Polk County, FL USA</td>
<td>250</td>
<td>Bituminous Coal (2200 tpd), Pet Coke</td>
<td>GE</td>
<td>1996 -Present</td>
</tr>
<tr>
<td>ELCOGAS/ Puertollano</td>
<td>Puertollano, Spain</td>
<td>318</td>
<td>Coal and Petroleum Coke (2500 tpd)</td>
<td>Prenflo *</td>
<td>1998 -Present</td>
</tr>
<tr>
<td>Vresova</td>
<td>Czech Republic</td>
<td>350</td>
<td>Coal/lignite</td>
<td>Lurgi, Siemens</td>
<td>1996-Lurgi 2008-Siemens</td>
</tr>
<tr>
<td>Nakoso</td>
<td>Nakoso, Japan</td>
<td>220</td>
<td>Bituminous Coal</td>
<td>MHI</td>
<td>2007- Present</td>
</tr>
<tr>
<td>Duke Energy Edwardsport</td>
<td>Knox County, Indiana</td>
<td>630</td>
<td>Coal</td>
<td>GE</td>
<td>2013 - Present</td>
</tr>
</tbody>
</table>
**IGCC Demonstration Programs**

**Emissions and Environment**
- NOx and SOx remarkably low without extra scrubbing units
- Slagging gasifiers lead to reduction in fine particles and solid wastes
- Less Water: IGCC units use 20%-50% less water than conventional coal plants

**Efficiency**
- Current IGCC match state of the art pf units

**Flexibility**
- Feedstock flexibility is high, especially entrained flow gasifiers
- Product flexibility: ‘polygen’: power, fuel, SNG, H₂ ...

**Carbon Capture and Storage**
- IGCC well-suited for CO₂ capture
- Incremental cost < pf technology

**Challenges**
- Demonstrated reliability (integrated system) and availability
- Cost
- Acceptance by power industry
IGCC with Integrated CO₂ Capture

- Pulverised coal, oxygen / steam, recycle char
- Hot gas cleaning (540 - 1000°C)
- S & N compounds removal
- Water gas shift
- CO₂ separation
- CO₂ to sequestration
- Gasifier output: gas
- Combustor: H₂, H₂O
- Gas turbine: electricity
- Boiler: steam turbine, electricity
- Boiler feed water
- Boiler feed water
- Quenched slag frit
- Fly slag, char for recycle
Coal gasification and capture of CO$_2$ from syngas is commercially mature in chemicals & refinery industries
- cost and scale issues less significant

CO$_2$ capture adds approx 30% to cost of electricity
- and 6% points reduction in efficiency
- these cost and efficiency penalties are less than those for pf with PCC

Costs will be reduced with increased IGCC commercial deployment.

Strong interest in gasification of low rank coals & pet coke blends
- Eg: Powder River Basin and lignite coals are an important resource in the USA
- Australian brown coal gasification and CTL projects
Gasification (Now & Future)
Gasification: a flexible enabling technology

Fuel Flexibility


Gasification

Syngas CO, H₂

Shift Reaction

- CO₂

EOR and CO₂ storage opportunities

- Hydrogen
  - FC Vehicles
  - Heavy Oil Upgrading

- Electricity
  - Syngas for Power Generation

- Chemicals
  - Methanol & Ammonia Applications

- Fischer-Tropsch
  - Liquid Fuels
  - Coal to Liquids Opportunities

Source: Shell 2007
World gasification capacity projected to grow 70% by 2015

~140 plants operating (>400 gasifiers)

Strongest activity:
- coal gasification
- Asia & North America

Power, chemicals & synfuels products

Source: Gasification Technologies Council (2010)
Coal gasification capacity and planned growth

- World coal gasification capacity projected to grow 120% in 2013-2016.
- Plans for 250% growth by 2020.

Data source: Gasification Technologies Council (2013)
Major expansion of plans in China
- 140,000 MW\(_{th}\) syngas planned in China alone

Strong emphasis on chemicals and gaseous fuels (SNG, fuel gas)
Australian Demonstration projects
Clean Coal projects in Australia

Source: Geoscience Australia
Australian Demonstration Projects

PCC demonstration projects
- **Brown Coal PCC** demonstration project- Loy Yang Power – TRUenergy (~50ktpa)
- **Black Coal PCC** demonstration- Delta Energy (~300ktpa)
- **Black Coal PCC** demonstration- Tarong Energy (~100ktpa)

**Callide Oxy-firing Project (30MW)**

**CO2CRC Otway Sequestration Demonstration**

**CCS Flagships Program**
- Proposals for two black coal IGCC-CCS projects (Qld)
  - ZeroGen (~400MW, Stanwell Corp, MHI)
  - Wandoan (~400MW, GE, Stanwell Corp, Xstrata Coal)
- Two CO2 storage proposals (Vic, WA)
  - CarbonNet (CSS Hub Victoria)
  - South West Hub (CCS Hub WA)

**Brown coal IDGCC project in Victoria**
- HRL IDGCC (Dual Gas) Project
CSIRO Gasification & Syngas Research
CSIRO Research Approach

Improve the understanding of coal performance in gasification technologies, supporting:

- Use of Australian coals in new technologies
- Implementation of advanced coal technologies in Australia
- Development of high efficiency IGCC-CCS systems

Pilot scale performance studies
Slipstream testing in coal-derived syngas
Gasification research

Mineral matter in gasification

Development of H2 membrane

Gasifier modelling

Entrained flow reactor

Devolutilisation, char formation

Heated grid reactor

Char reactivity

Fixed-bed and TGA

Development of CMR

Synthesis Gas...

High Pressure CO₂

Gas Analysis

H₂
Barriers to new technology

Barriers to widely adopting high efficient coal fired power plant

• higher investment cost than conventional technology
  – Capital cost seen as critical barrier

• no commercial value on CO₂ reductions (carbon tax, carbon trading policies under discussion)
  – Cost and capacity of CO₂ storage uncertain
  – ‘value’ of increasing efficiencies not clear in technology debates

• public acceptance for coal fired power plant
  – confusion in discussion of ‘clean’ coal technologies
    – CBM, UCG, IGCC, PCC, Oxyfuel, CCS
High efficiency coal technologies will play a key role in achieving long term greenhouse abatement targets

- Increasing efficiency is a prerequisite for effective CO₂ capture and storage

Coal properties and performance issues affect many aspects of technology development, deployment and optimisation

- Advanced coal science capabilities needed to support improved coal characterisation, preparation and utilisation

R&D challenges to increase efficiency, improve reliability, reduce costs

- Gasification provides a high efficiency technology platform for low emissions power systems
  - Development pathway for power, hydrogen & polygeneration systems
  - New research in key areas where breakthroughs will improve cost and reliability

Novel high efficiency systems developing on the horizon

National and international partnerships are needed to facilitate research, development, demonstration and deployment

- Coordination and ‘critical mass’ are essential
Thank You

Contact: San Shwe Hla
Phone: +61 7 3327 4125
Email: San.Hla@csiro.au