Options for carbon dioxide emission mitigation from energy generation and the technology challenges

- Alternative centralised low carbon energy generation
- Increased generation efficiency of fossil fuel power stations
- Decentralised electricity generation and grid management
- End-user efficiency and demand management/reduction
- Carbon capture and storage/utilisation
- Carbon capture toolbox

Alternative centralised low carbon energy generation: SOLAR

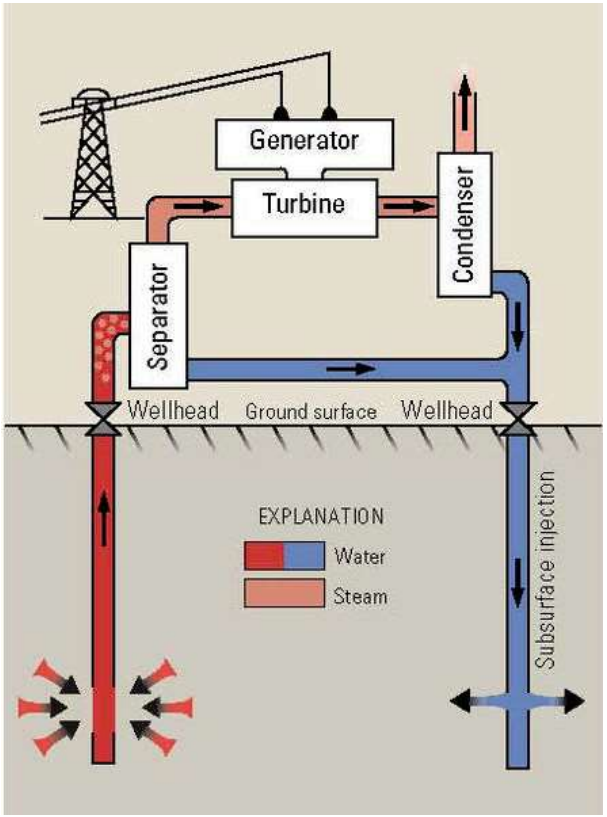
- **Photovoltaics** (solar panels) that directly convert solar radiation to electricity using semiconductors (e.g. crystalline or amorphous silicon, cadmium telluride)
- **Solar thermal** in which mirrors are used to focus and concentrate solar radiation and produce high temperatures to generate hot pressurised gas (to operate a steam/gas turbine) or drive chemical reactions to produce a fuel (e.g. splitting water to produce H_2)

Alternative centralised low carbon energy generation: WIND

- A wind powered turbine is used to drive the generator
- Arrays of wind turbines are called wind farms

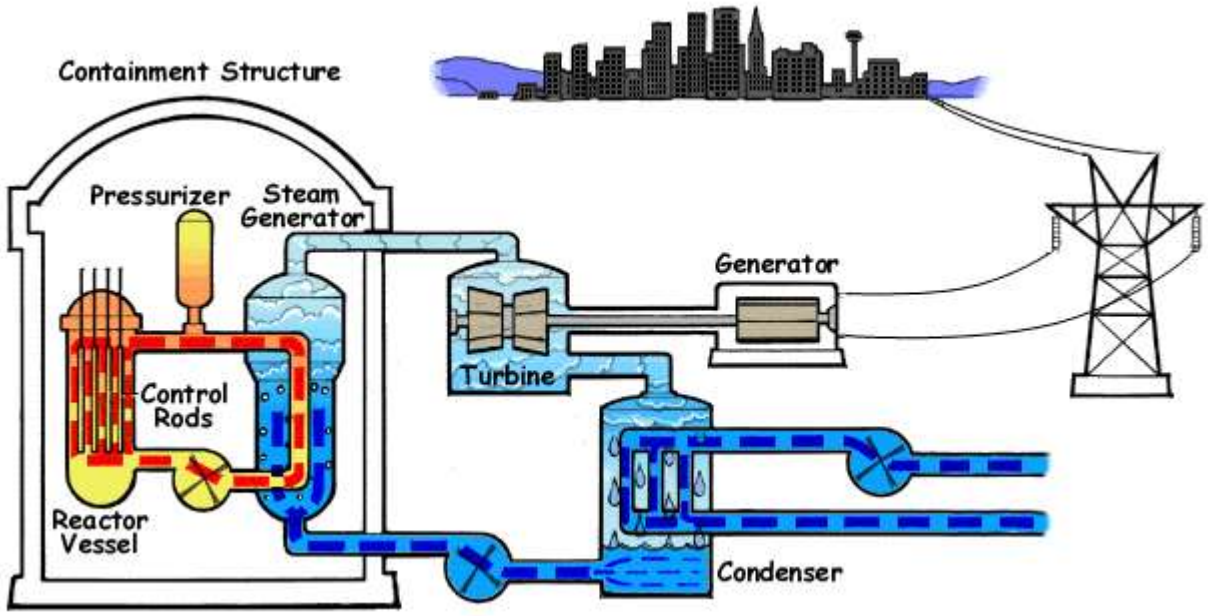
Alternative centralised low carbon energy generation: GEOTHERMAL

- Geothermal energy, heat from below the Earth's surface, is used to generate steam to drive a turbine and generator

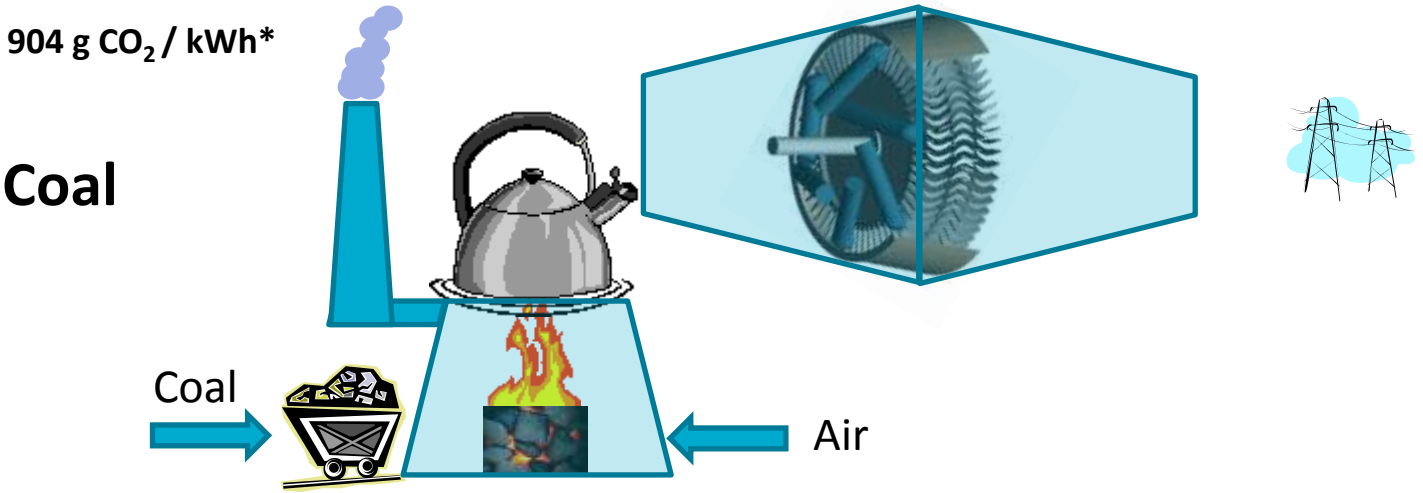


Alternative centralised low carbon energy generation: NUCLEAR

- The energy released by nuclear fission, the splitting apart of the nucleus of a heavy atom (e.g. uranium-235, plutonium-239), is used to generate steam to drive a steam turbine and generator

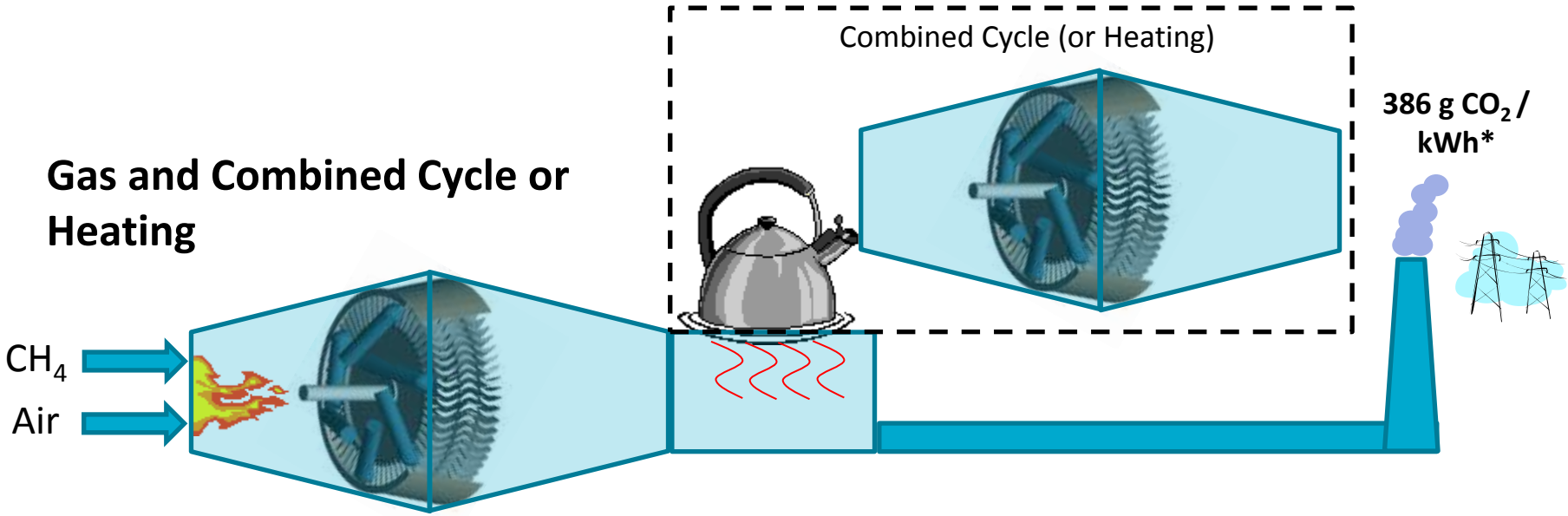


Increased generation efficiency: SWITCHING FROM COAL TO GAS



*OECD/IEA, *CO_2 Emissions from Fuel Combustion - Highlights*. IEA, Paris, France, 2010, pgs 110-118.

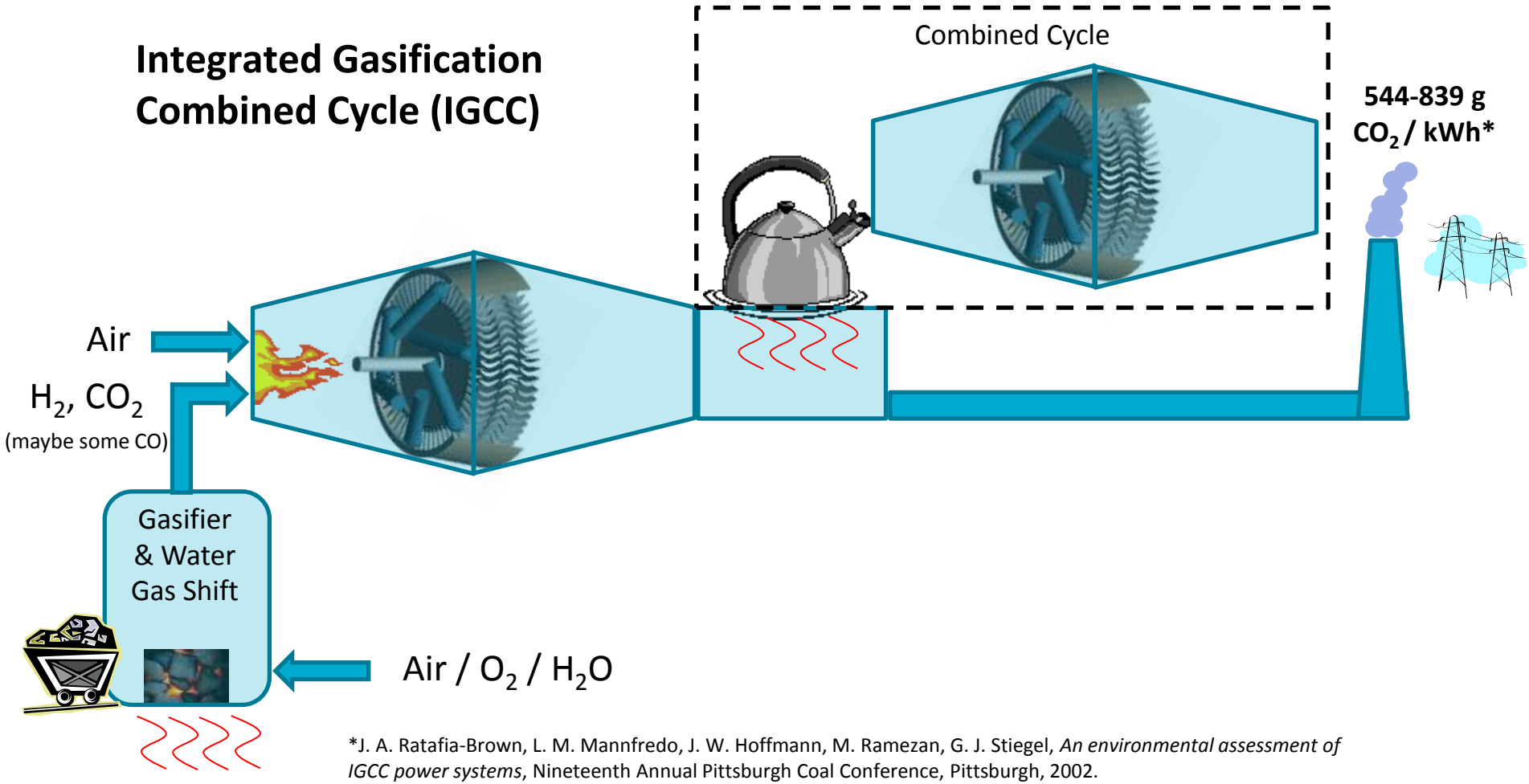
Increased generation efficiency: SWITCHING FROM COAL TO GAS



*OECD/IEA, *CO_2 *Emissions from Fuel Combustion - Highlights*. IEA, Paris, France, 2010, pgs 110-118.

Increased generation efficiency: COAL GASIFICATION

Integrated Gasification Combined Cycle (IGCC)



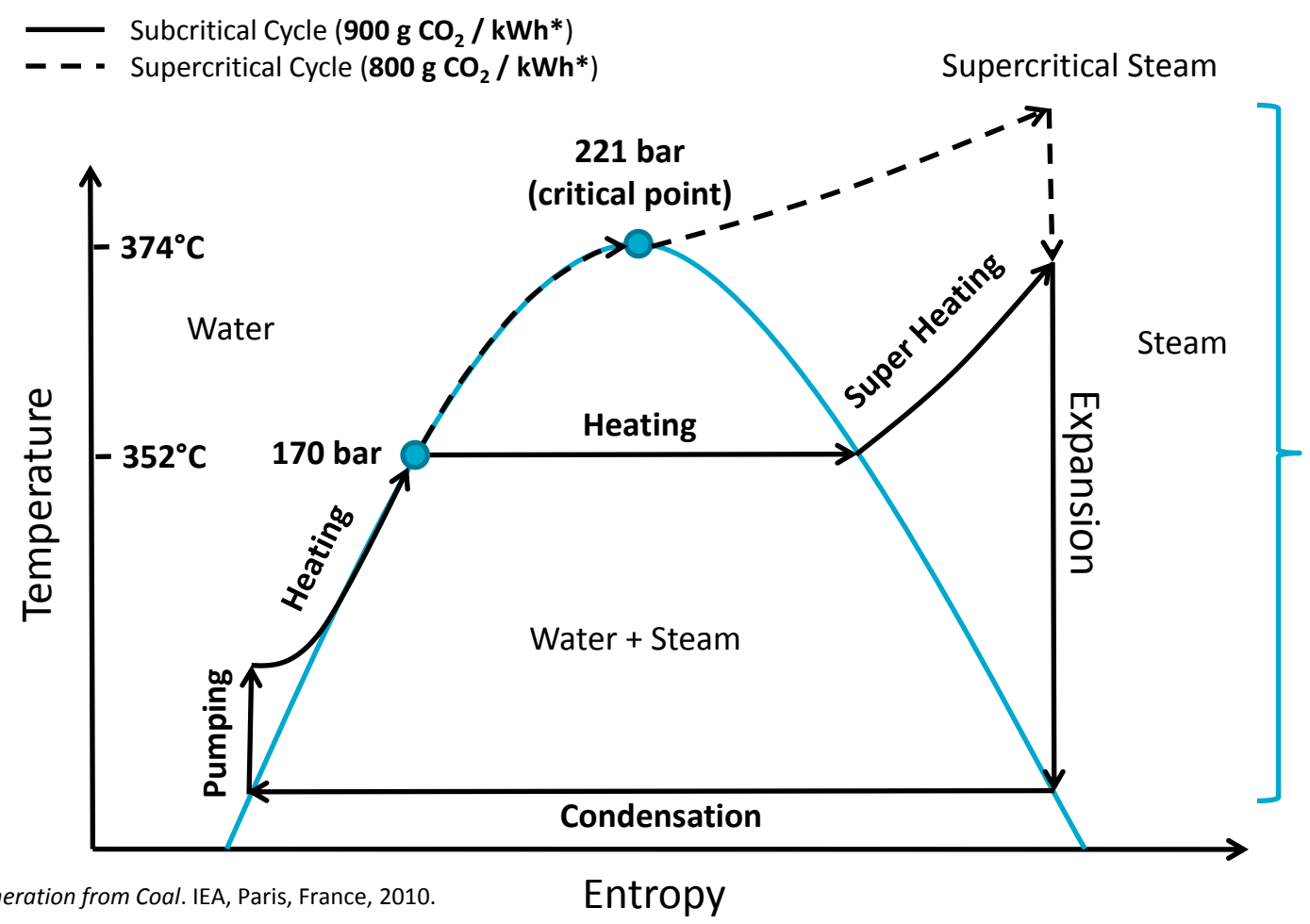
*J. A. Ratafia-Brown, L. M. Mannfredo, J. W. Hoffmann, M. Ramezan, G. J. Stiegel, *An environmental assessment of IGCC power systems*, Nineteenth Annual Pittsburgh Coal Conference, Pittsburgh, 2002.

Increased generation efficiency: SUPERCRITICAL STEAM

- Higher steam temperatures and pressures leads to greater power output from the turbine and greater efficiency
- Steam temperatures are limited by materials used in the boiler and turbine

Increased generation efficiency: SUPERCRITICAL STEAM

Rankine Cycle



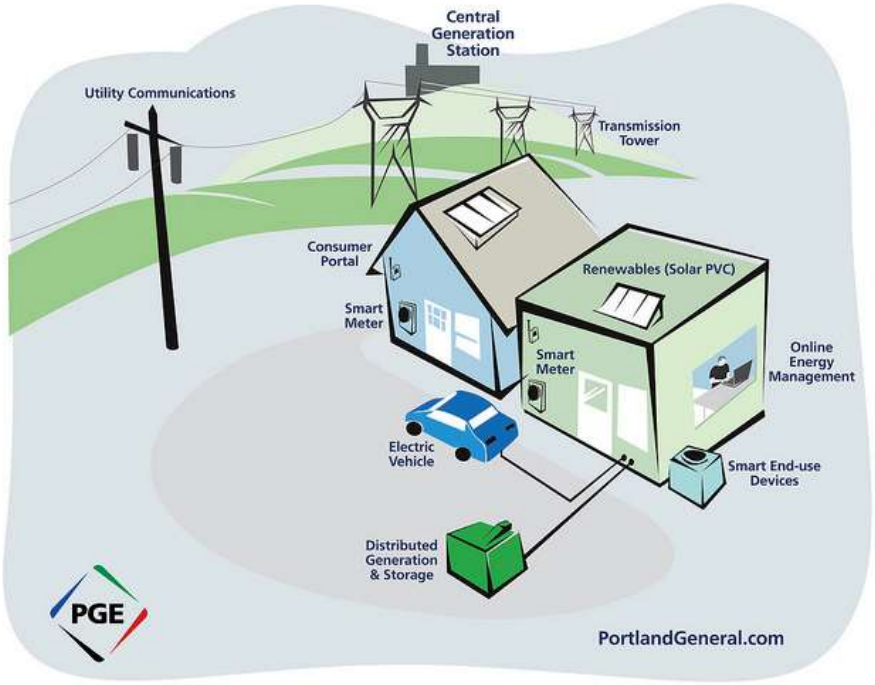
*OECD/IEA, *Power Generation from Coal*. IEA, Paris, France, 2010.

Increased generation efficiency: SUMMARY

Technology	Emissions Intensity ($g\ CO_2$ / kWh)
Subcritical Coal Power Plant	900
Supercritical Coal Power Plant	800
Integrated Gasification Combined Cycle	544-839
Gas Combined Cycle Power Plant	386 ✓

Demand management: INTELLIGENT GRIDS AND DEVICES

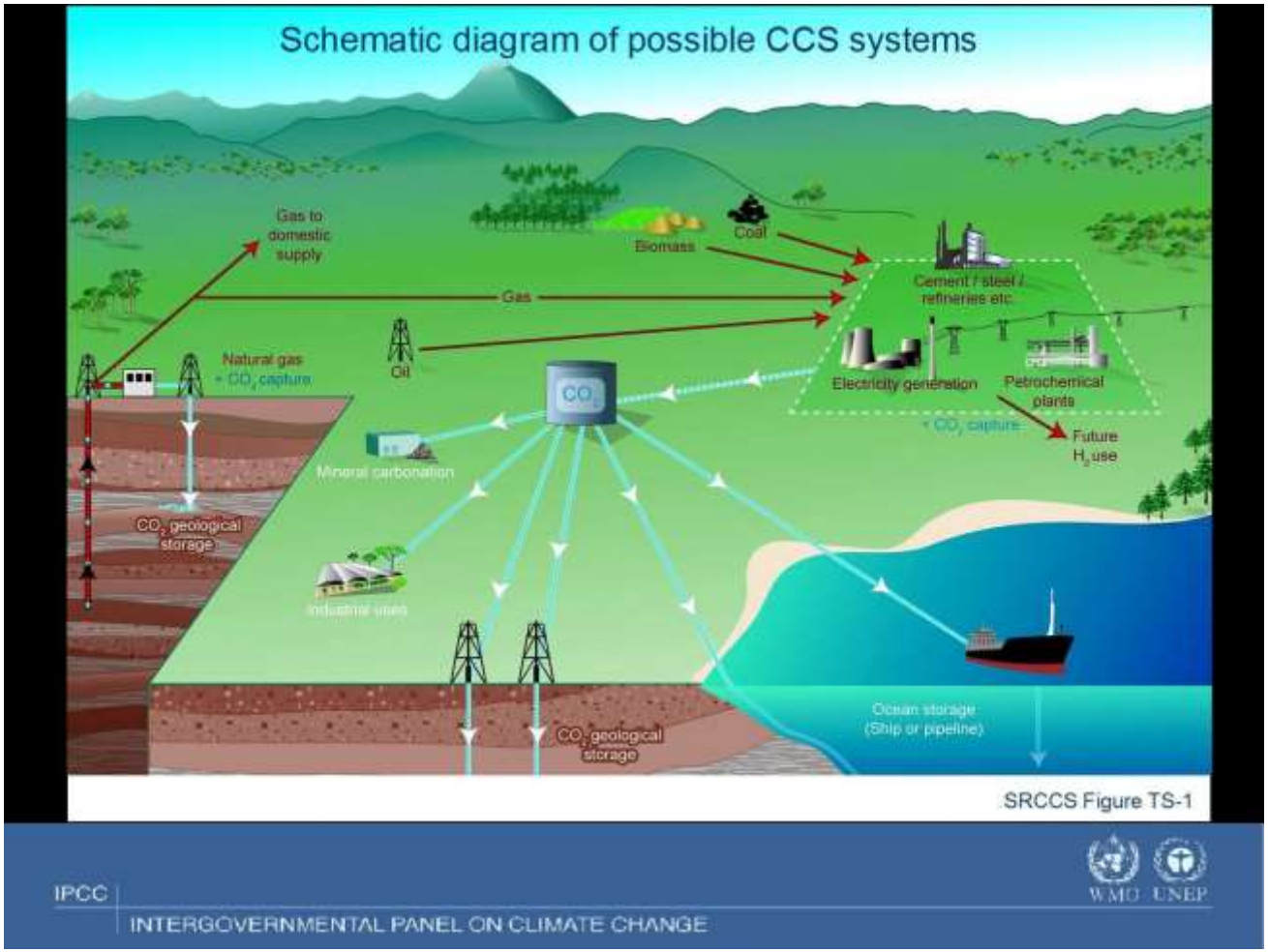
- An electricity grid that intelligently predicts and responds to the behaviour of electricity producers and consumers to optimise efficiency and maintain supply.



End-user efficiency: INCREASED PUBLIC AWARENESS

- Energy efficient appliances
- Low energy lighting and turning lights off
- Turning appliances with a stand-by function off at the wall
- Increasing the temperature set-point during summer and decreasing it during winter for cooling and heating
- Minimising the use of energy hungry appliances (plasma TVs, kettles, …)
- Only boil a kettle with the required amount of water
- And many more

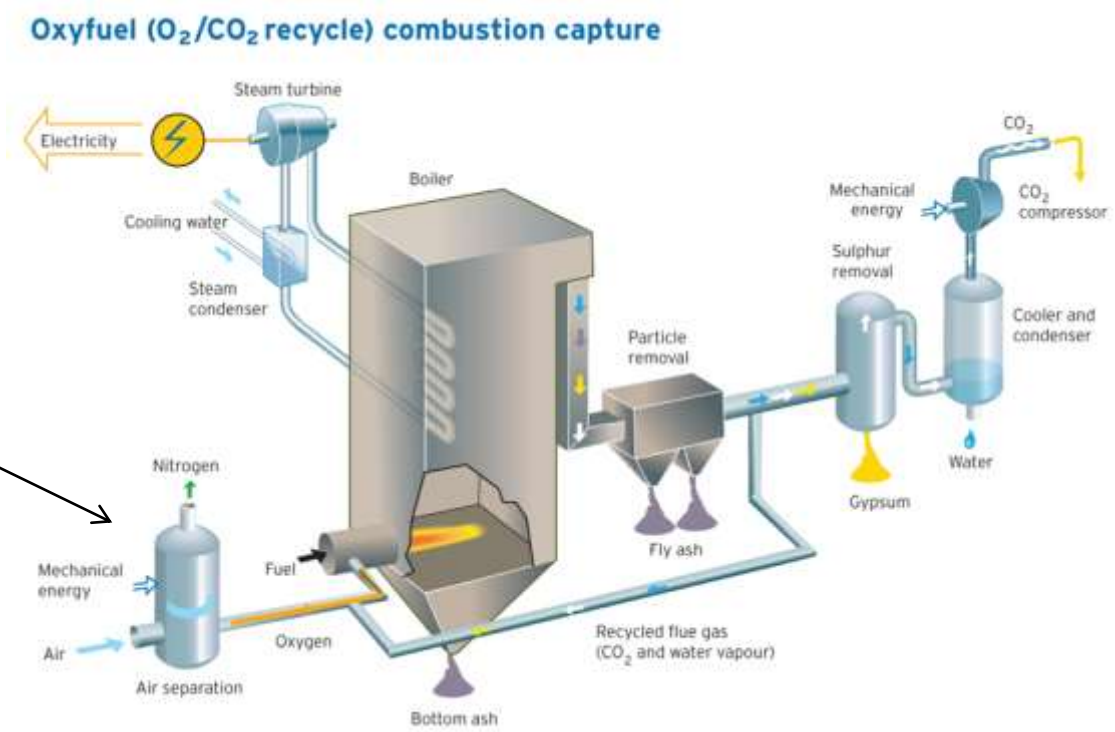
Carbon capture and storage/utilisation: THE CCS CHAIN



Carbon capture and storage/utilisation: OXYFIRING

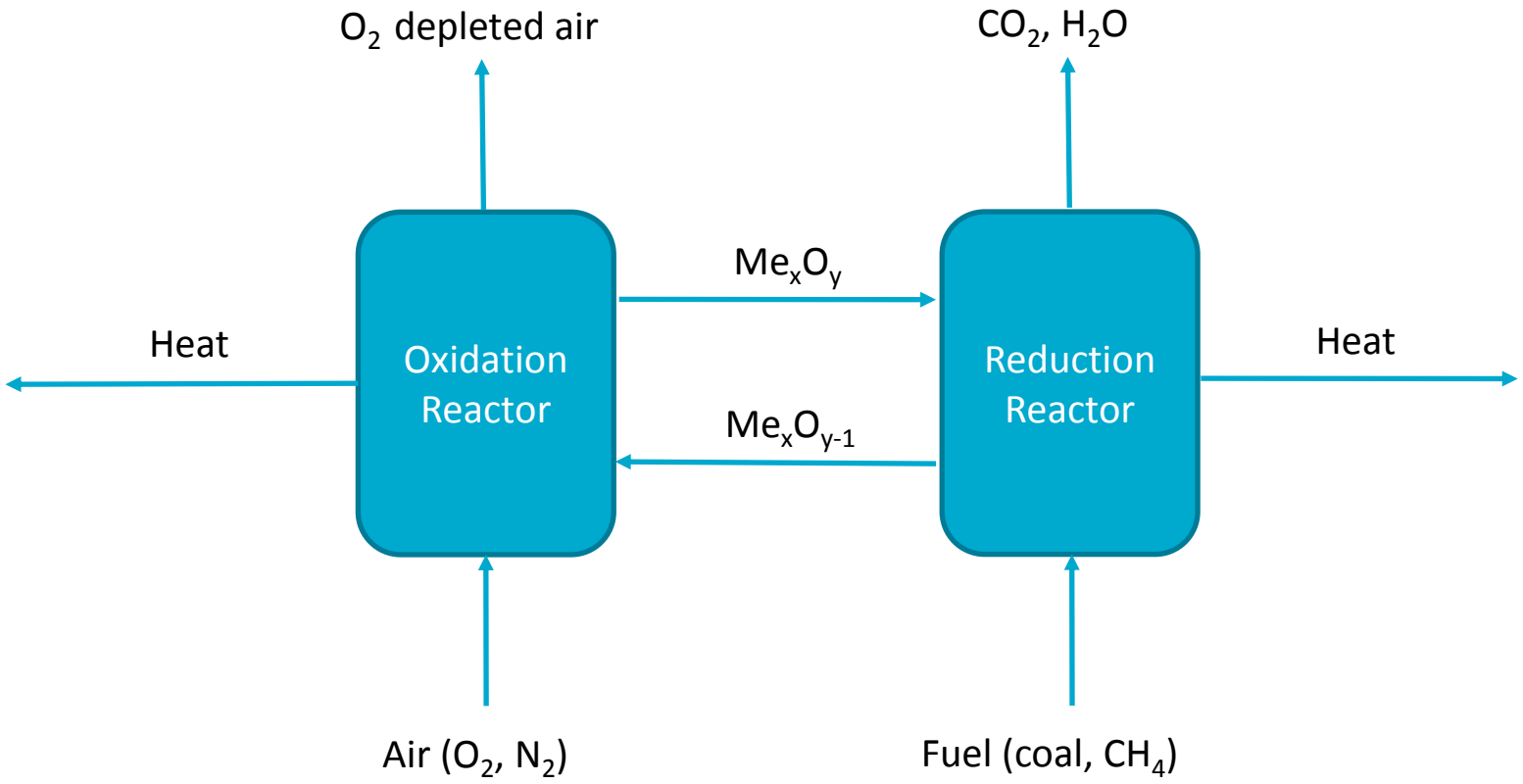
- Use an air separation unit (ASU) to separate O_2 from air (mostly N_2) and carry out combustion in an O_2/CO_2 atmosphere
- Produces a concentrated CO_2 flue gas

The ASU is energy intensive



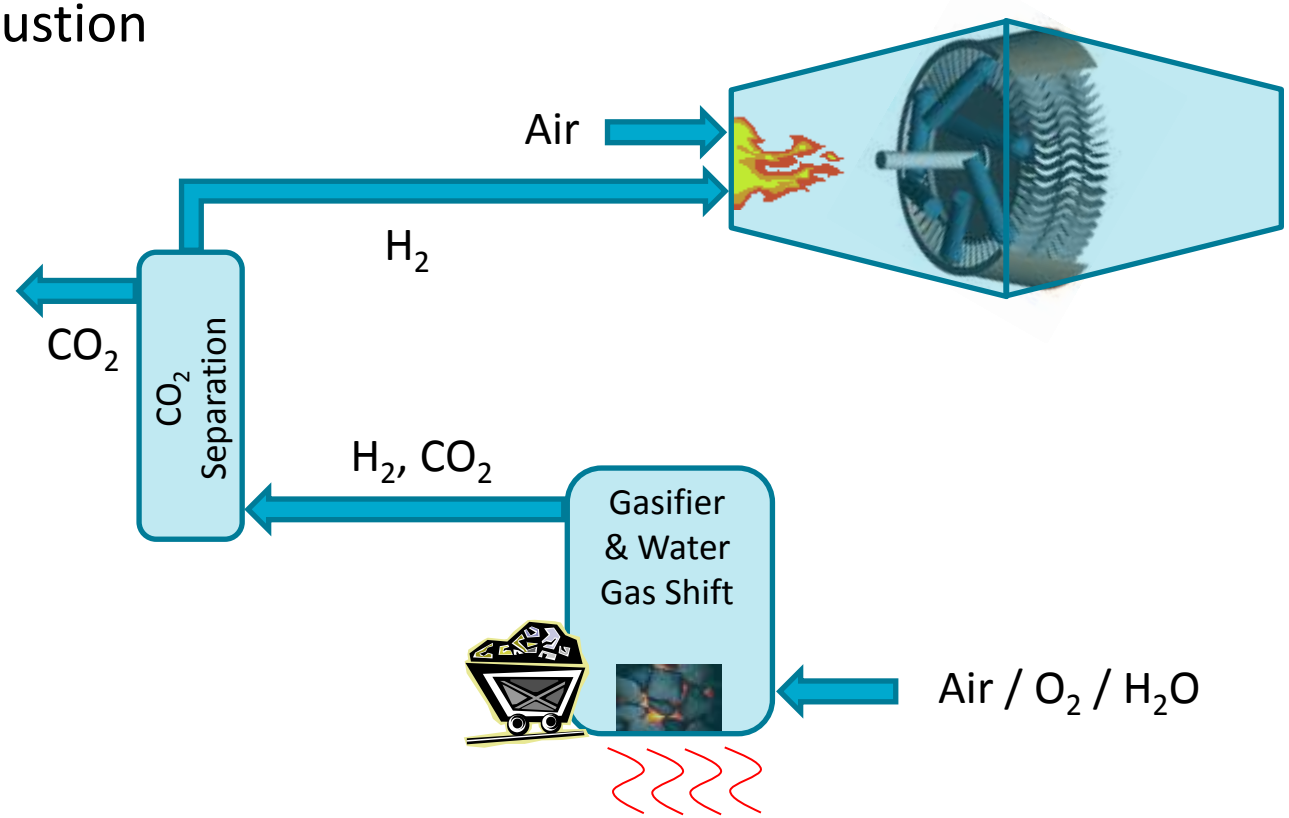
Carbon capture and storage/utilisation: CHEMICAL LOOPING

- Instead of O_2 use a solid metal oxide (e.g. NiO) as an oxygen source



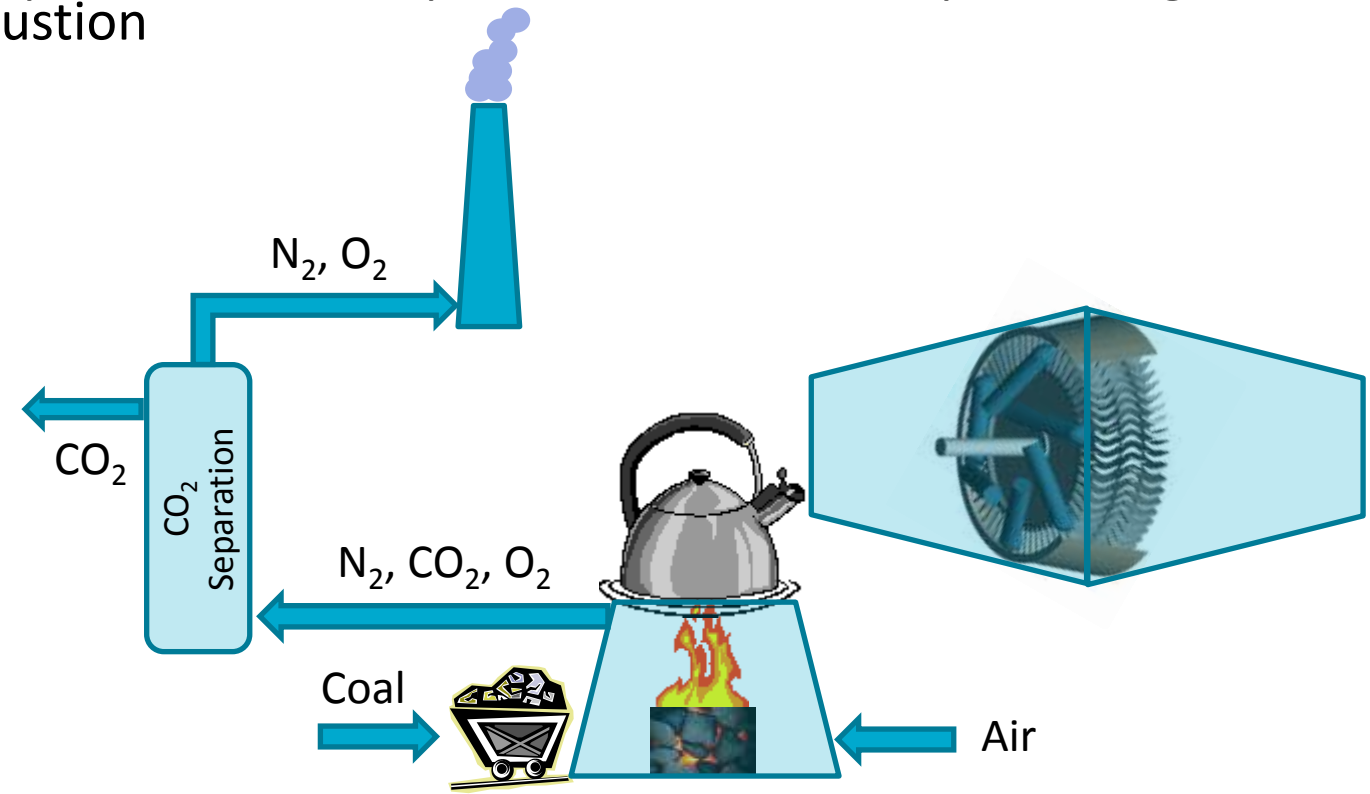
Carbon capture and storage/utilisation: PRE-COMBUSTION CAPTURE

- Capture CO_2 from syngas prior to combustion in a gas turbine (IGCC)
- CO_2 captured from high pressure and temperature gas stream before combustion

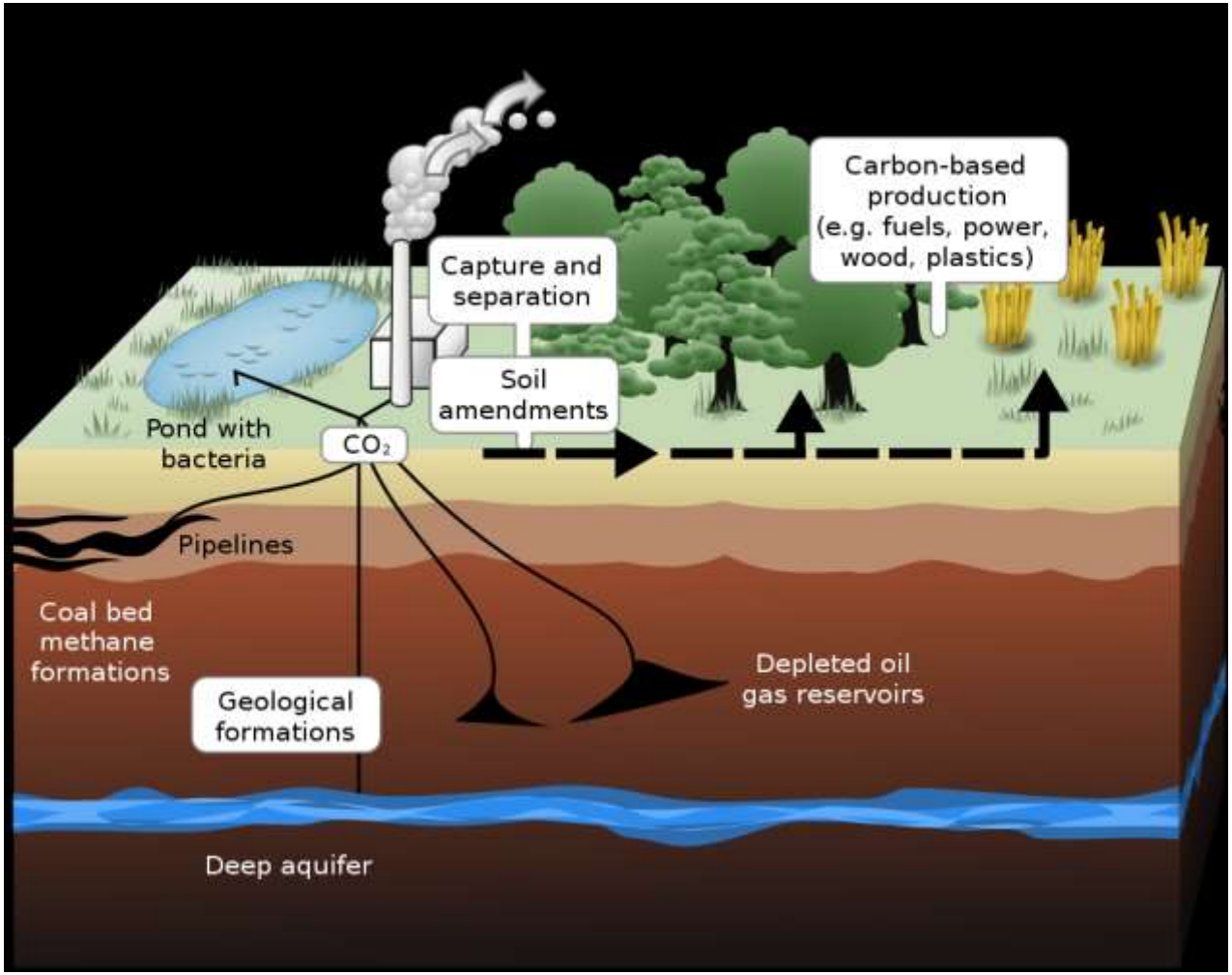


Carbon capture and storage/utilisation: POST-COMBUSTION CAPTURE

- Capture CO_2 from flue gas after combustion in a furnace / turbine
- CO_2 captured from low pressure and low temperature gas stream after combustion



Carbon capture and storage/utilisation: STORAGE/UTILISATION OPTIONS



Carbon capture toolbox

Capture method	Post-combustion capture	Pre-combustion capture	Denitrogenation
Targeted Separations	CO_2 from N_2 / O_2	CO_2 from H_2 / CO / CH_4	O_2 from N_2
Technology Platform			
Membranes	Polymeric membranes Ceramic membranes Facilitated transport membranes Carbon molecular sieve membranes Membrane contactors	Ceramic membranes Polymeric membranes Palladium membranes Membrane contactors	High temperature O_2-conducting membranes Facilitated transport membranes
Adsorption	Lime carbonation/calcinations Carbon based sorbents Amine functionalised sorbents	Dolomite, hydrotalcites and other carbonates Zirconates Carbon based sorbents	Carbon based sorbents High temperature adsorbents e.g. perovskites
Absorption	**Alkanolamine solutions** Amino-acid solutions and other amines Carbonate solutions and slurries Emulsions	**Alkanolamine solutions** **Non-aqueous physical solvents** Amino-acid solutions and other amines Carbonate solutions and slurries Emulsions Water	Absorbents with O_2-carriers (artificial blood)
Cryogenic	Anti-sublimation	CO_2-liquefaction	**Distillation for air separation**

Acknowledgements

The authors wish to acknowledge financial assistance provided through Australian National Low Emissions Coal Research and Development (ANLEC R&D). ANLEC R&D is supported by Australian Coal Association Low Emissions Technology Limited and the Australian Government through the Clean Energy Initiative.