SAND2009-5688C

Energy Planning Workshop

Carbon Capture & Storage

Basic Concepts

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Outline of Presentation

- **My background and professional experience**
- **Carbon Capture Key Technical Elements**
- **Operations** ***(focus on Capture & Storage)***
- **Opportunities & Challenges**
  - **Economics**
  - **Industry**
  - **Risks**
  - **Policy**

My Background and Experience

- Immigrant grandparents: Dominica & Haiti
- Undergraduate, double major: Mathematics- Physics & History
- Lived primarily along east coast USA, mostly New York
- Technical Training, major: B.S.E.E., M.S.E.E.
- Experience Sandia National Laboratories
  - Telemetry/ Aircraft Compatibility
  - Radiation Protection: Sources & Device Control
  - Environment Safety & Health : Renewable Energy Sector
  - Arctic Radiation Measurements
  - Satellites / Payload
  - Energy Policy, Markets
  - Projects in Alaska, Papua New Guinea, mainland USA and Hawaii , West Africa, Caribbean

Carbon Capture – Key Technical Elements

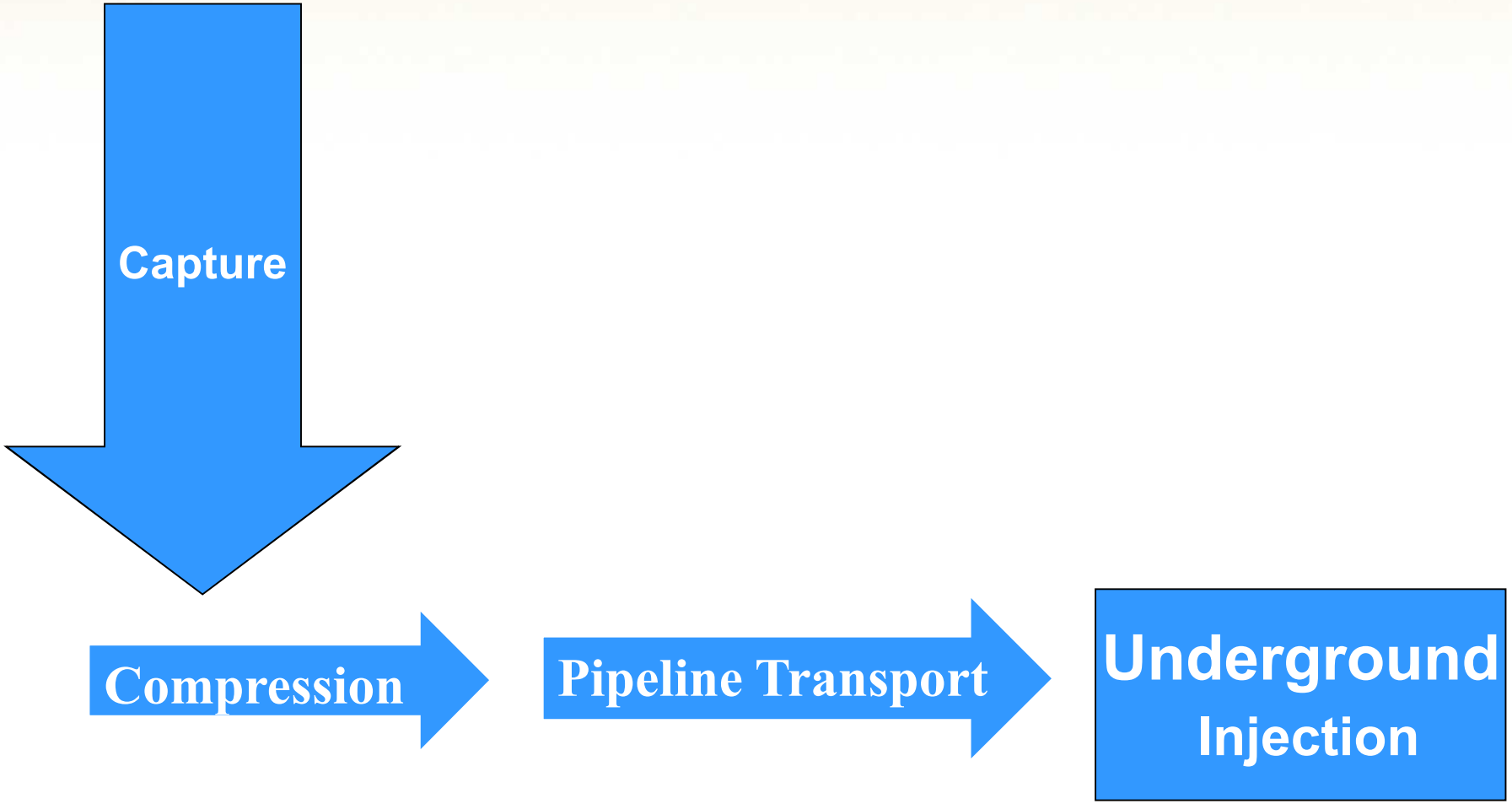
Warwick Sweeney/Photographer RR/ Getty Images
Steam and smoke are emitted from a coal-fired power station in England.

Carbon Capture Defined

- CCS is a broad term that encompasses a number of technologies that can be used to capture carbon dioxide from point sources, such as power plants and other industrial facilities; compress it; transport it mainly by pipeline to suitable locations; and inject it into deep subsurface geological formations for long-term isolation from the atmosphere.
- Key Elements

1. Capture of CO2 from power plants/industrial sources
2. Transport of the CO2 via pipeline
3. Storage of the CO2 in geological sites *(saline formations or oil & gas fields)*

A Diagram of the CCS Process



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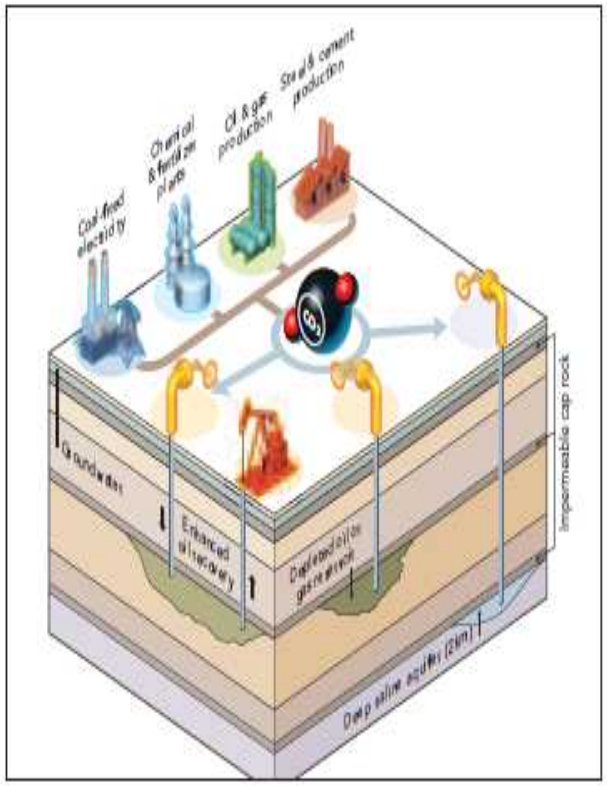
Carbon Capture Implications

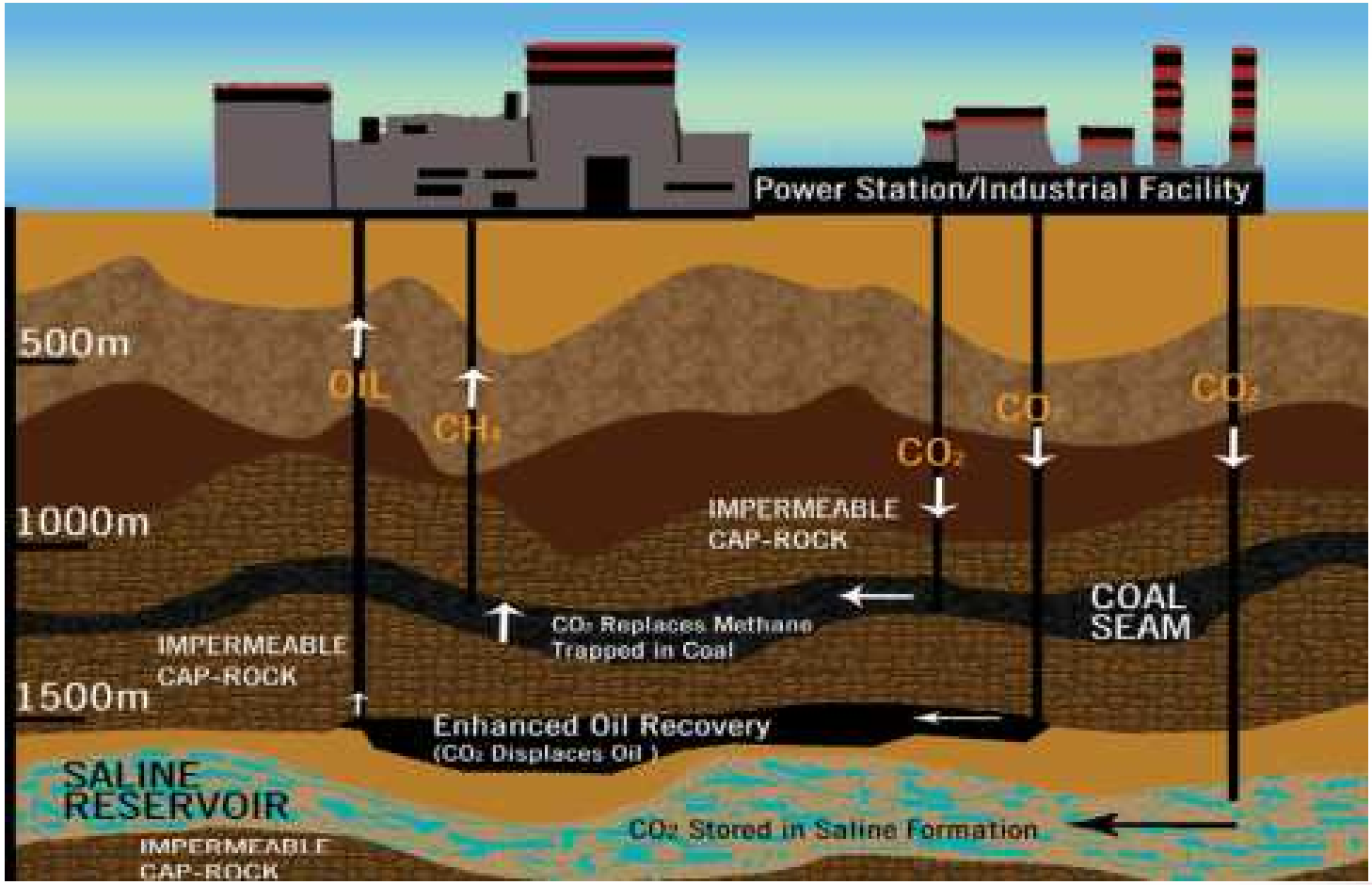


CO_2 capture and storage has potential across multiple industries. Various end use applications can provide economic benefits and safe storage.

This technology is a critical option in the portfolio of solutions available to combat climate challenges, because it allows for significant reductions in CO2 emissions from fossil-based systems, enabling it to be used it as a bridge to a sustainable energy future and can affect several industrial applications: coal-fired electricity, chemical and fertilizer plants, oil and gas production, and steel and cement production.

Carbon Capture Technology Application

Illustration by World Resources Institute (WRI)



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Three Capture Techniques

- **Post Combustion**
- **Pre-Combustion**
- **Oxy- Combustion**

The following six images are provided by Bellona

Post Combustion Capture

Image from Bellona Industries

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Post Combustion Carbon Capture

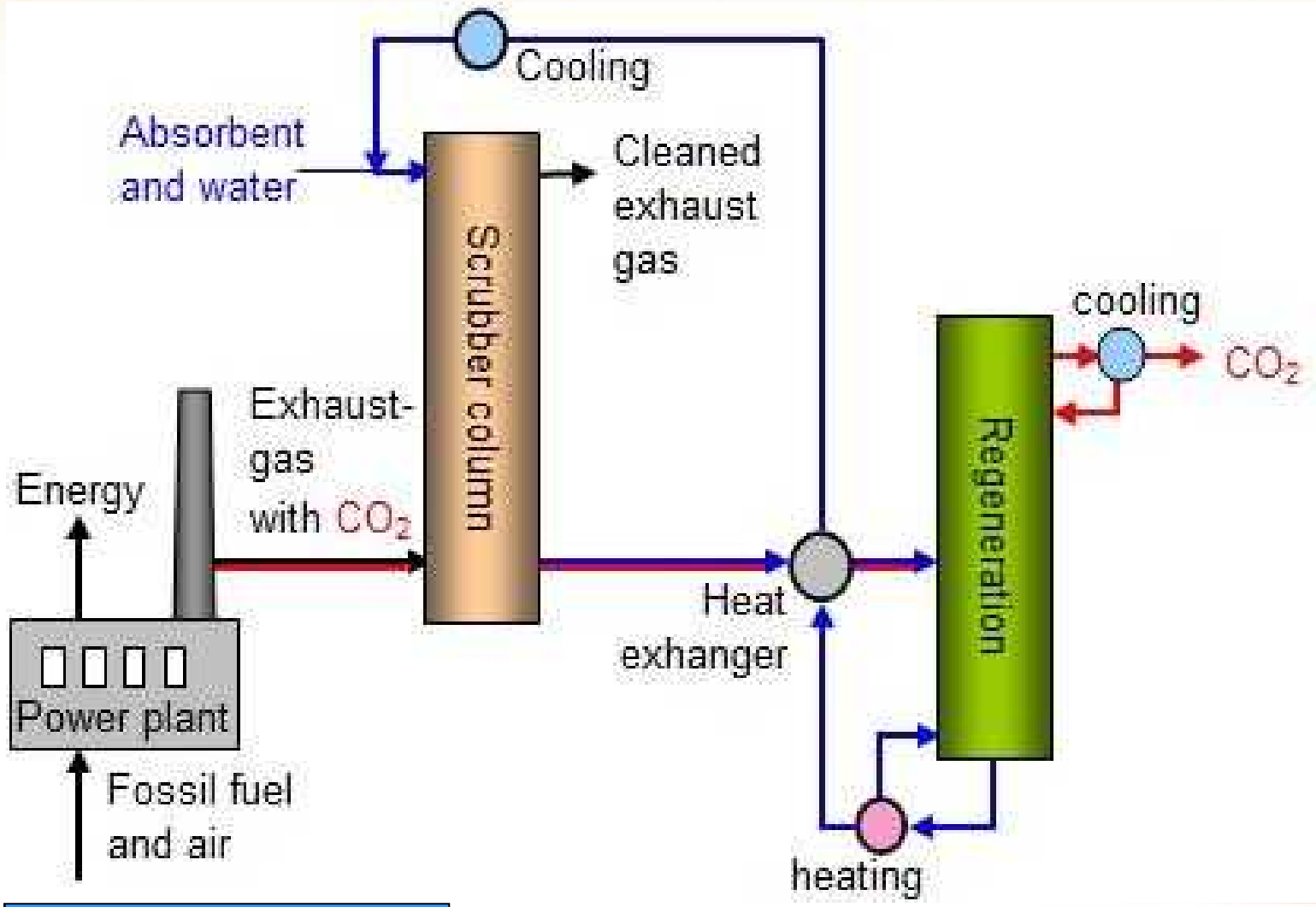

Image from Bellona Industries

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Pre Combustion Capture

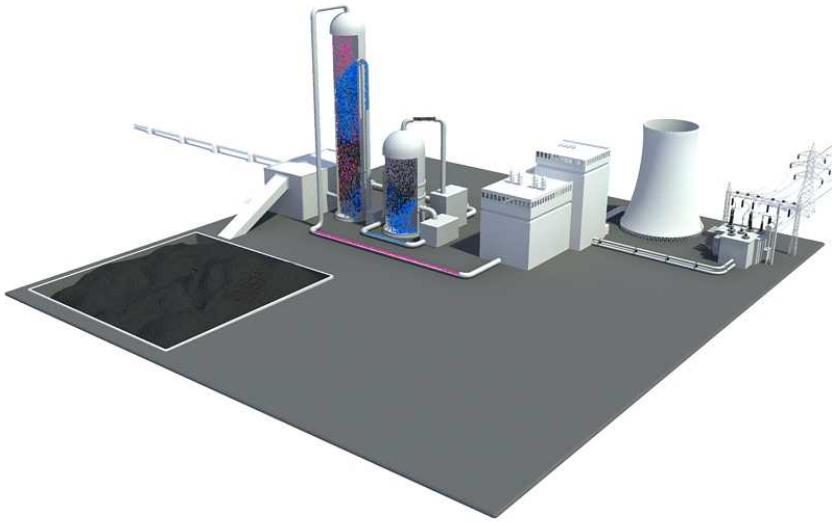

Image from Bellona Industries

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Pre-Combustion Carbon Capture

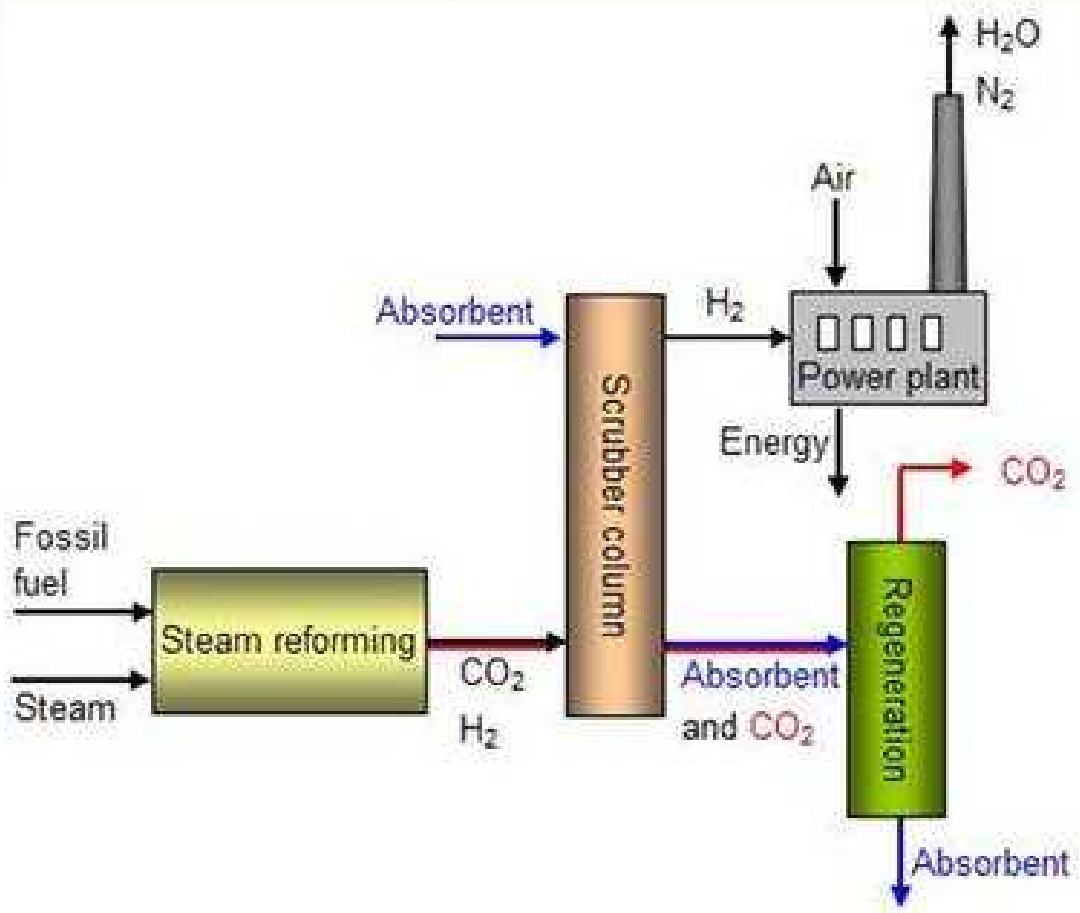

Image from Bellona Industries

Oxy-Combustion Capture

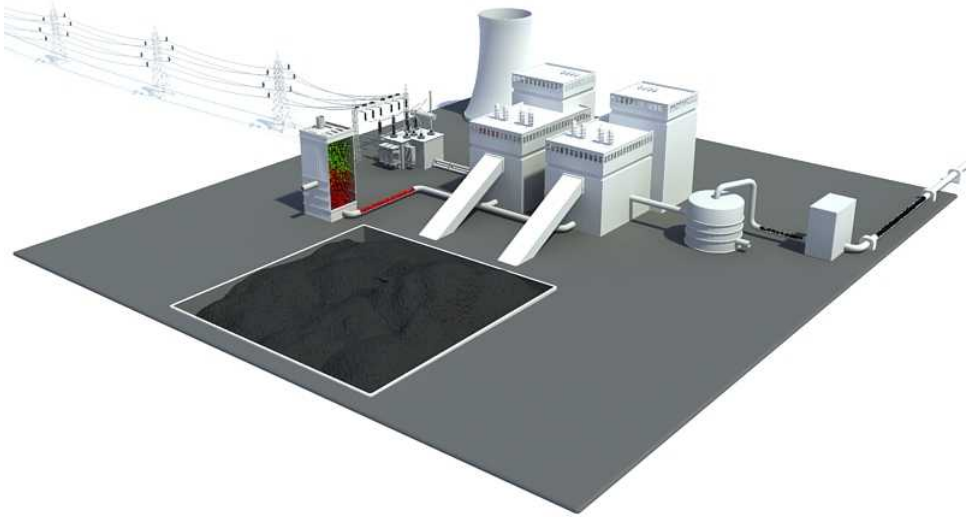

Image from Bellona Industries

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Oxy-Combustion Carbon Capture

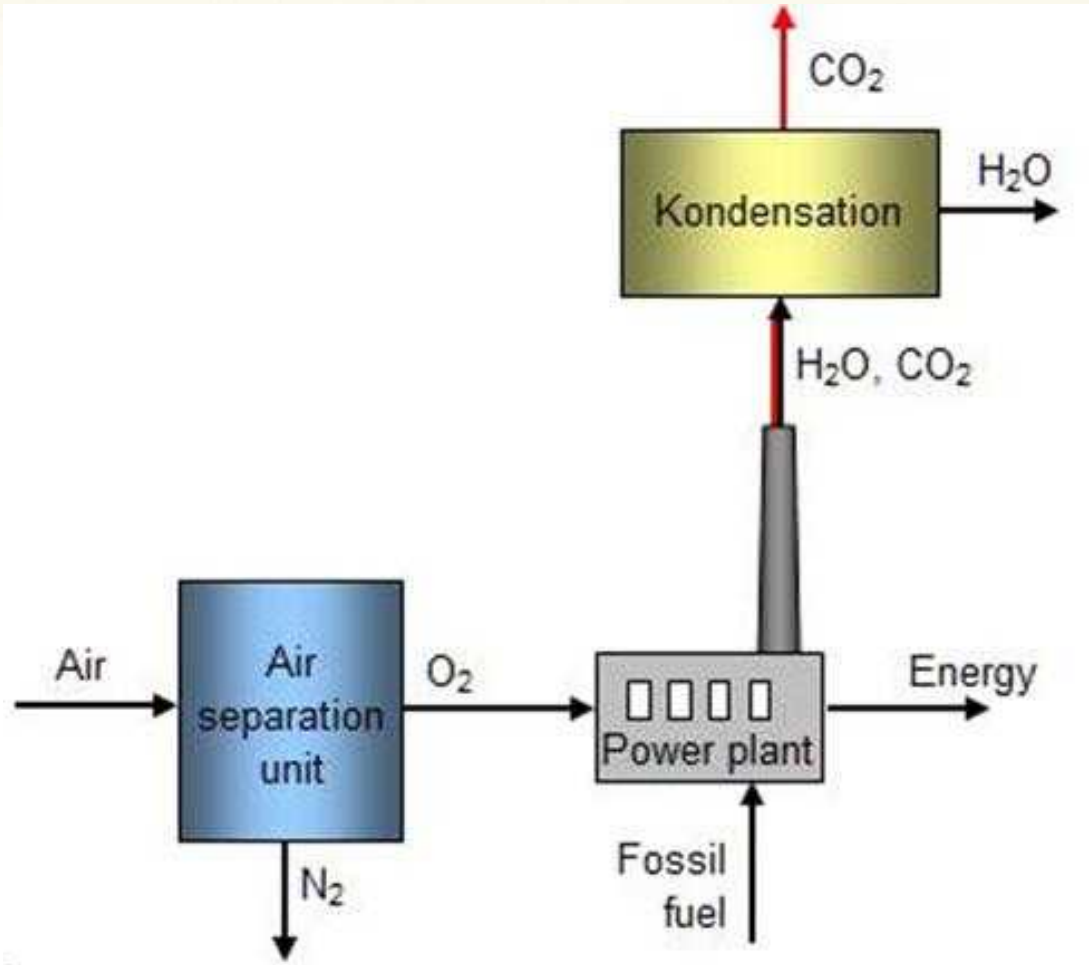

Image from Bellona Industries

Examples of CCS Projects

- **Vattenfall Schwarze Pumpe Plant**
- **In Salah Gas Plant in Algeria**

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Why Capture?

- **CO2 is too dilute in flue gas of power plants to transport and inject from an economic point of view**
- **CCS is potentially a very cost-effective mitigation technology application for environmental concerns**
- **Rising energy demands will require innovation that includes conventional and renewable energy along with applications like CCS technologies**
- ***CCS can possibly be used as a means of getting more fossil fuel out of the ground – especially in oil wells***

Schwarze Vattenfall CCS in Germany

Functional Diagram of Vattenfall

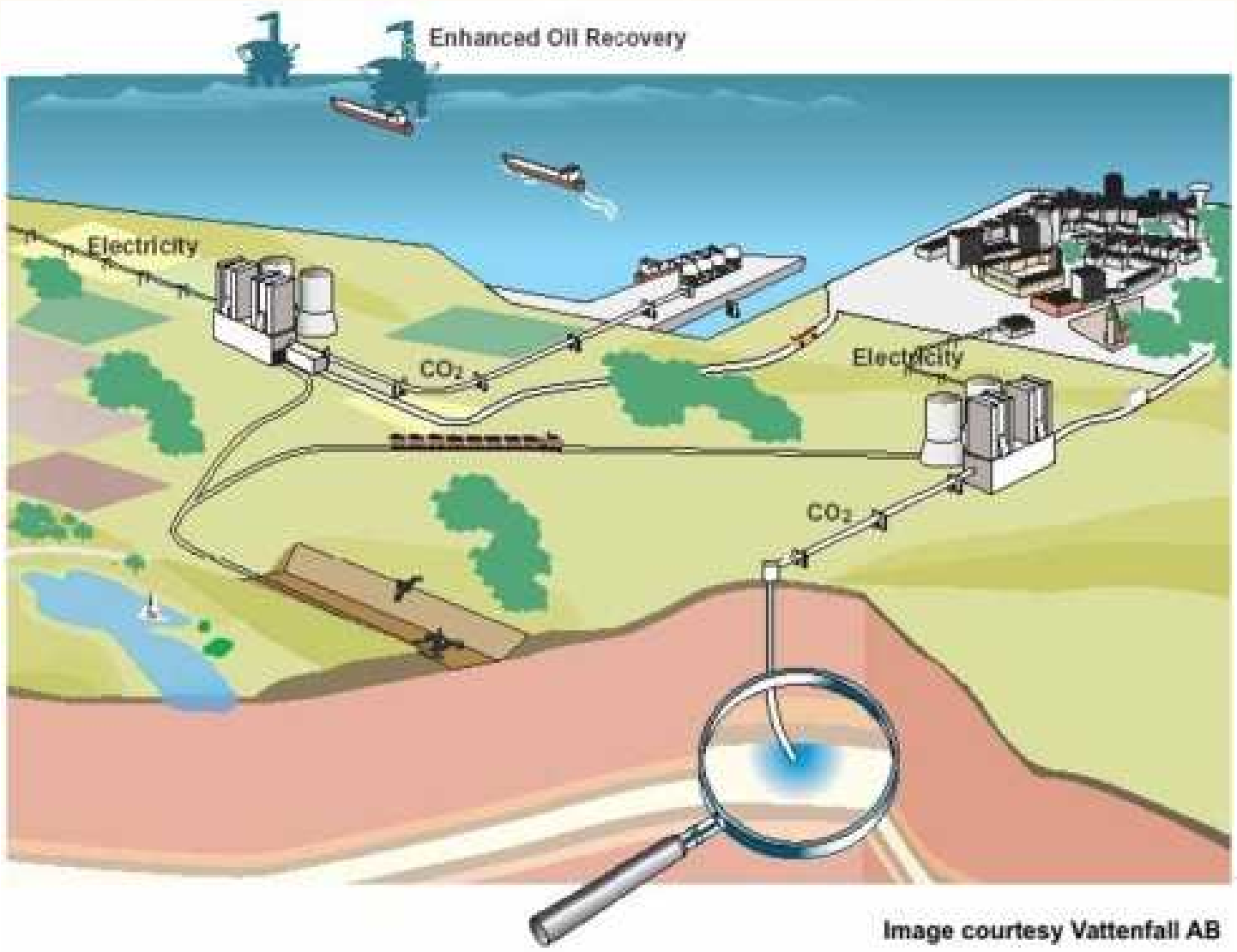

Image courtesy Vattenfall AB

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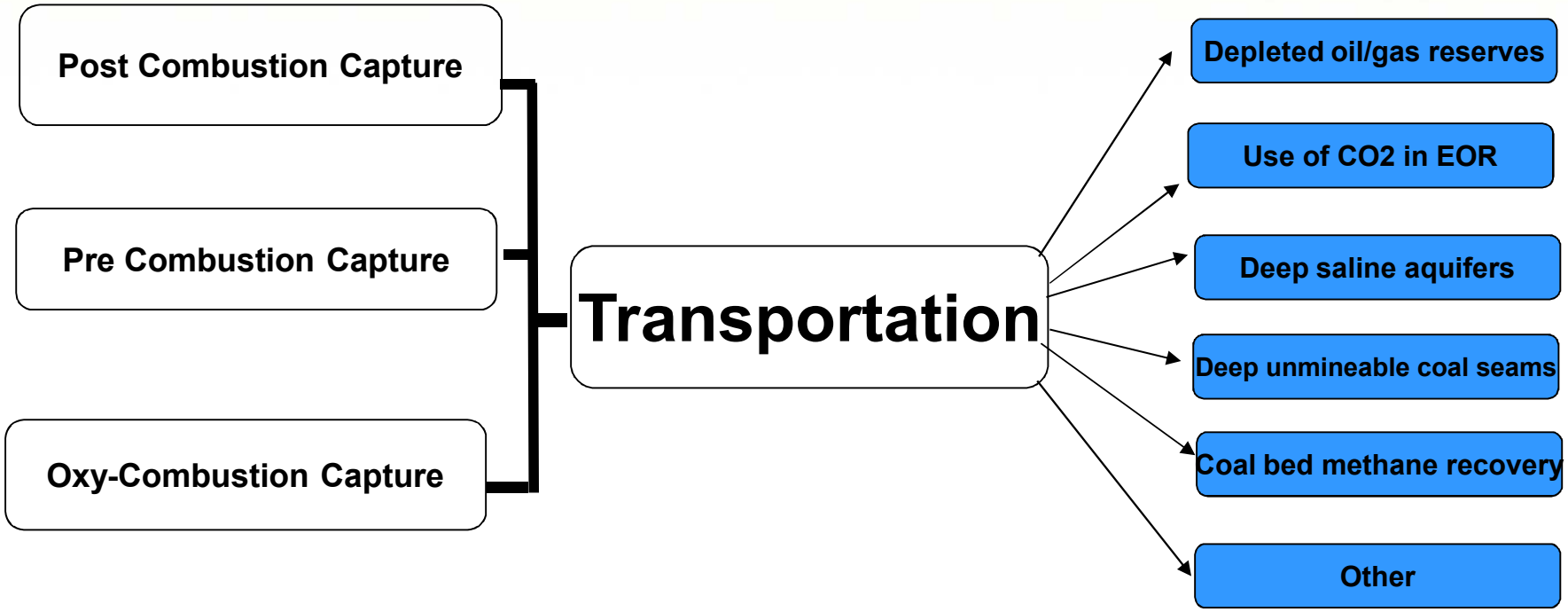
In Salah CCS Project in Algeria

This field is jointly operated by Sonatrach, BP, and StatoilHydro. It is a gas processing and CO2 separation facility w/ Amine extraction, 1 Mt//year CO2 injection, in operation since 2004, located in Krechba, Algeria

Image Courtesy of SatoilHydro & BP

CCS Infrastructure Review



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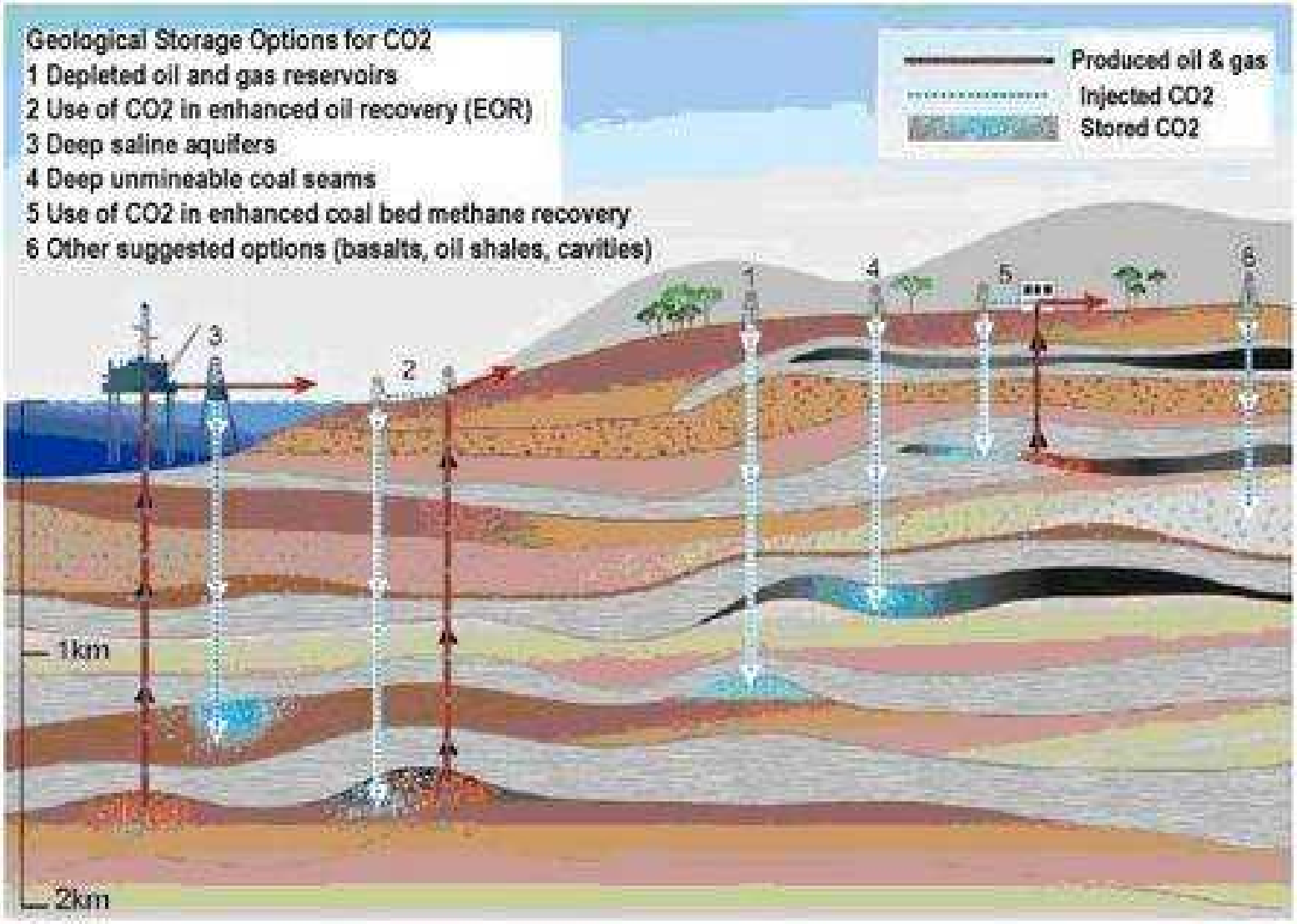
Options for CO2 Storage



CCS Storage Requirements

The geological storage site should have:

- **Adequate capacity and injectivity**
- **Satisfactory sealing cap rock (or confining unit)**
- **Sufficiently stable geologic composition/environment to avoid compromising integrity of storage site**

CCS Risks

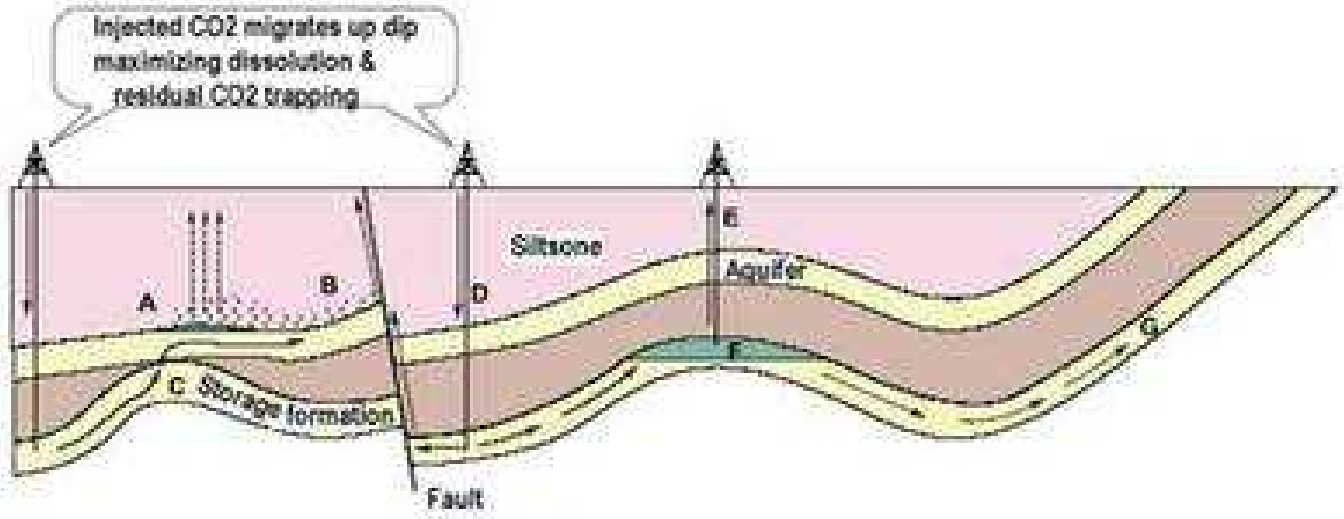
What could go wrong with CCS Technology?

- **There are potential release pathways:**
  - **Well leakage (injection and abandoned wells)**
  - **Poor site characterization (undetected faults)**
  - **Excessive pressure buildup damages seal**
- **Worker and / or public safety**

CO2 Well Failures

- **Wyoming** — **100 million cubic feet/day**
- **Sheep Mountain, Co** — **200x10exp 6 scf/day**
- **Torre Alfina, Italy** — **300 tons/ hours**
- **Crystal Geyser, UT** — **2.6 to 5.8 kg/sec**

CCS Risk Mitigation Scheme



Potential Escape Mechanisms

A. CO2 gas pressure exceeds capillary & passes through siltstone	B. Free CO2 leaks from A into upper aquifer up fault	C. CO2 escapes through 'gap' in cap rock into higher aquifer	D. Injected CO2 migrates up dip, increases reservoir pressure & permeability of fault	E. CO2 escapes via poorly pluged old abandoned well	F. Natural flow dissolves CO2 at CO2 / water interface and transports it out of closure	G. Dissolved CO2 escapes to the atmosphere or ocean

Remedial Measures

A. Extract and purify groundwater	B. Extract & purify ground-water	C. Remove CO2 & reinject elsewhere	D. Lower injection rates or pressures	E. Replug well with cement	F. Intercept & reinject CO2	G. Intercep & reinject CO2

Carbon Economics

- **Estimated CCS Costs for coal**
  - **additional $40 per MWh to cost of generation**
  - **$60-65/tonne CO2 avoided**
- **Estimated CCS Costs for gas**
  - **additional $30 per MWh to cost of generation**
  - **$85/tonne CO2 avoided**
- **Estimated CCS Costs for processes w/ pure CO2 stream**
  - **$20-30/tonne CO2 avoided**
- **EOR credit can offset about $20/tonne CO2**

CCS & Cost Considerations

- **Most of the CCS costs are associated with CO2 Capture**
  - **Improve the capture process**
  - **Modify power plants to enhance capture**
- **CO2 Capture: $60-$100/Tonne CO2**
- **Transportation depends on the distance**
  - **Pipeline**
  - **Ship**
- **Storage: $4 - $20/ t CO2**
- **CCS is cost effective when applied to large stationary sources like power stations**

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Economics & Environmental CCS Issues

- **Quality and Quantity**

  of the CO2 Source
- **Proximity of Sources to Sinks**
- **Existing vs. New Sources**

CCS Policy Considerations

- **Safety of the Workers**
- **Environmental Impact including the cultural component**
- **Storage capacity (especially for aquifers)**
  - Site Characterization
  - Site Selection
- **Monitoring**
- **Costs**
- **Regulation & Liability**

CCS Q&A: Technical Challenges

- **Performance Prediction**
- **Monitoring & Measurements**
- **Storage Security**
- **Knowledge Gaps**

Evidence to support CCS

- Performance of industrial analogs
  - 30+ years experience with CO2 EOR
  - 100 years experience with natural gas storage

- 25+ years of cumulative performance of CO2 storage projects
  - Sleipner, off-shore Norway, 1996
  - Weyburn, Canada, 2000
  - In Salah, Algeria, 2004
  - Snovhit, Norway, 2008

Data from Sally Benson of Global Climate & Energy Project

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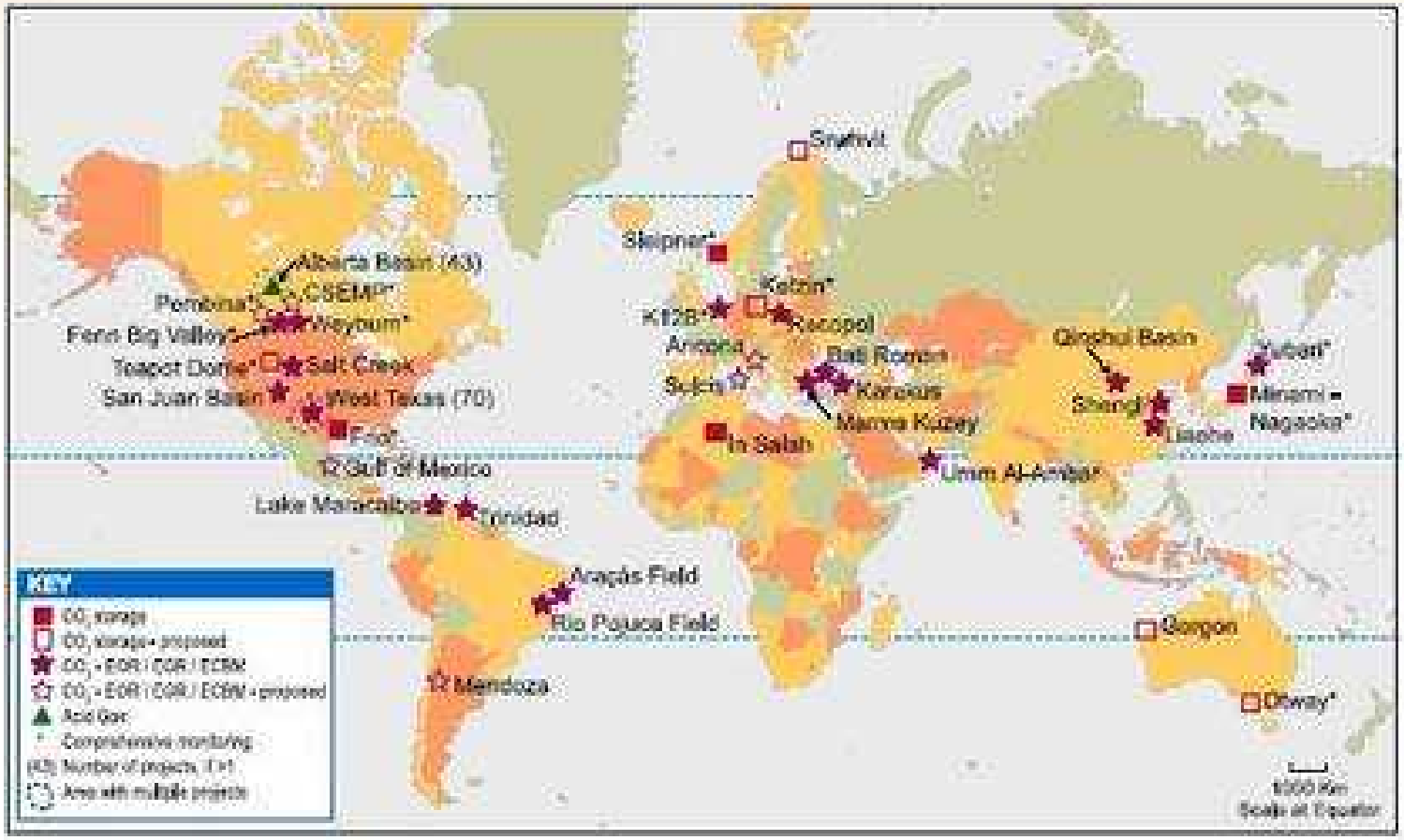
Opportunities - Future Plans for CCS



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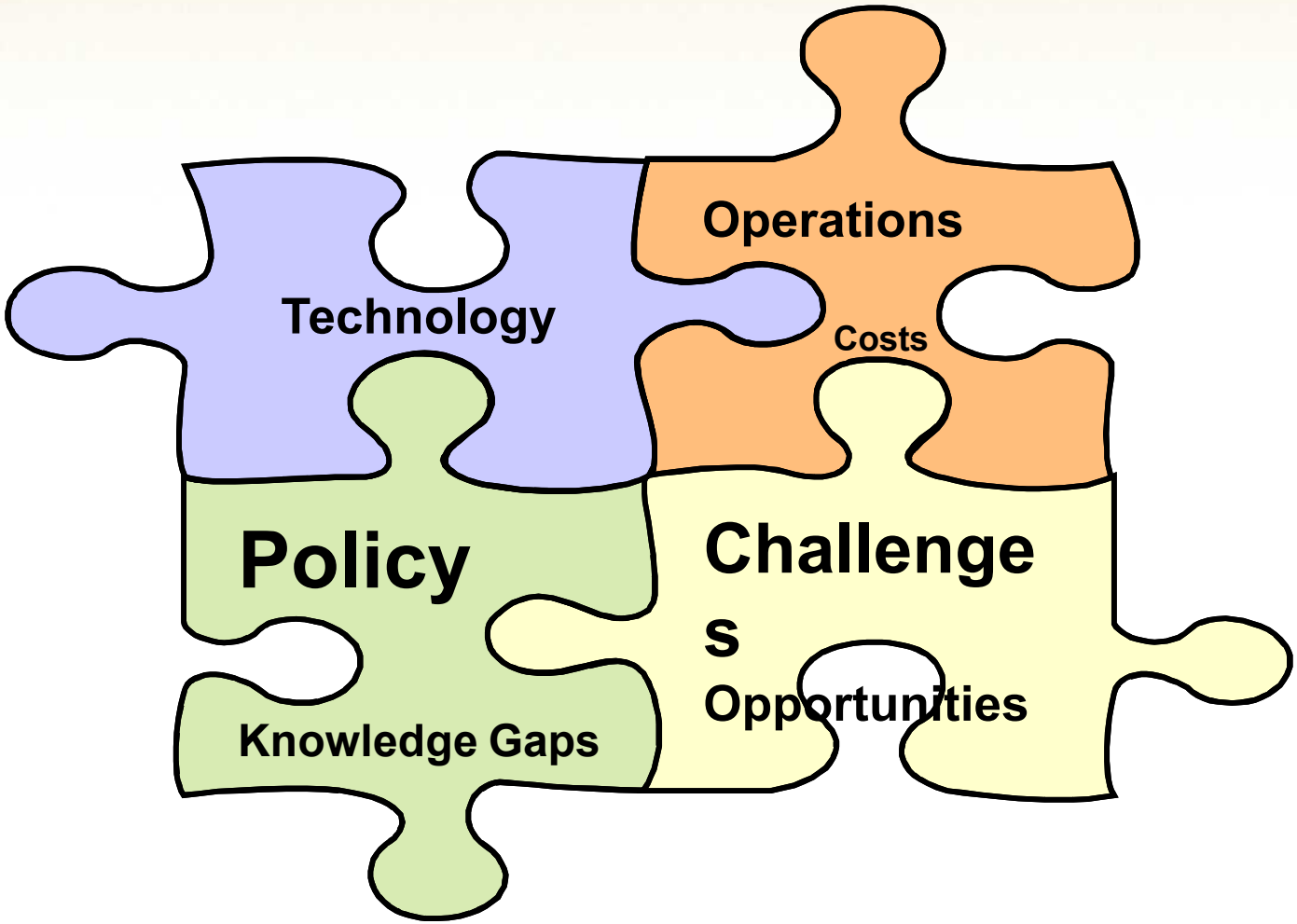
THANK YOU!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