Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile

Ministero dello Sviluppo Economico

Ricerca di Sistema elettrico

La presenza italiana in campo internazionale per il coordinamento strategico e programmatico nel settore delle Tecnologie di Cattura e Stoccaggio della CO2 (CCS)

Giuseppe Girardi

Report RdS/2013/227

LA PRESENZA ITALIANA IN CAMPO INTERNAZIONALE PER IL COORDINAMENTO STRATEGICO E PROGRAMMATICO NEL SETTORE DELLE TECNOLOGIE DI CATTURA E STOCCAGGIO DELLA CO_2 (CCS)

Giuseppe Girardi (ENEA)

Settembre 2013

Report Ricerca di Sistema Elettrico

Accordo di Programma Ministero dello Sviluppo Economico - ENEA
Piano Annuale di Realizzazione 2012
Area: Cattura e sequestro della CO_2 prodotta dall'utilizzo di combustibili fossili
Progetto: Cattura e sequestro della CO_2 prodotta dall'utilizzo di combustibili fossili
Obiettivo: Tecnologie per la rimozione permanente della CO_2

Responsabile del Progetto:Stefano Giammartini, ENEA

Le attività sono state condotte in stretto raccordo con il Ministero dello Sviluppo Economico, insieme al Ministero dell'istruzione dell'Università e della Ricerca, al Ministero dell'Ambiente e della tutela del Territorio e del Mare, e al Dipartimento Politiche Europee della Presidenza del Consiglio dei Ministri.
Hanno collaborato Istituzioni pubbliche e private, in particolare: OGS, RSE, CNR, INGV, svariate Università, ENEL, Sotacarbo, Carbosulcis, Assocarboni, Osservatorio sulle CCS della Fondazione per lo Sviluppo Sostenibile.

Un grande apprezzamento per il lavoro svolto dai colleghi dell'ENEA impegnati nelle attività di R/S e di divulgazione, e a tecnici e ricercatori di Sotacarbo.

Un ringraziamento particolare ai Dott. Andrea Corleto e Veronica Tomasetti, contrattisti di ricerca rispettivamente presso l'Università di Roma la Sapienza e presso l'ENEA, che hanno operato ad altissimo livello per la diffusione delle informazioni e per la "public acceptance".

ENEA
RICERCA DI SISTEMA ELETTRICO

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Sommario

Nel presente documento sono sinteticamente descritte le attività, ed i risultati più rilevanti, condotte nell'ambito di alcuni organismi internazionali. In particolare si fa riferimento a:

Partecipazione, quale delegato italiano, nel Technical Group del ***CSLF*** *(Carbon Sequestration Leadership Forum)*. Il CSLF è un consesso internazionale, nato su iniziativa governativa, che ha la missione di facilitare lo sviluppo e l'applicazione delle tecnologie CCS attraverso collaborazioni internazionali volte a superare i principali ostacoli di ordine tecnico, economico ed ambientale, promuovendo anche la consapevolezza del pubblico nonché sviluppi normativi e finanziari internazionali.

Partecipazione, quale delegato italiano, a organismi della ***IEA****:*
- *Working Party on Fossil Fuels*
- *Implementing Agreement Clean Coal Centre (CCC)*
- *Implementing Agreement Gas and Oil Technologies (GOT)*

Partecipazione, quale rappresentante ENEA, al ***Global Carbon Capture and Storage Institute*** *(GCCSI).* Il GCCSI è un'organizzazione nata su iniziativa del Governo australiano il cui obiettivo è mobilitare risorse pubbliche e private per diffondere le tecniche CCS. L'impegno immediato è quello di accelerare l'avvio di oltre venti progetti pilota. E' in discussione il piano strategico.

Partecipazione, quale Membro italiano, alla piattaforma tecnologica europea ***ZEP****.* La piattaforma tecnologica ZEP (Zero Emission Fossil Fuels Power Plants) unisce e rappresenta gli operatori industriali europei impegnati nelle tecnologie CCS; partecipano rappresentanti del mondo della ricerca e vari operatori; è diretta dal un "ministerial group" ed è organizzata in task force. La nostra partecipazione ha consentito di discutere delle priorità di politica energetica italiana e degli aspetti tecnici legati alle esigenze di ricerca e sviluppo e di diminuzione dei costi.

Partecipazione, quale delegato italiano, al ***CCS-EII Team****, team della Iniziativa Industriale Europea (EII) per la cattura, trasporto e stoccaggio della CO2 (CCS) del SET Plan (Strategic Energy technologies)*. Opera, in particolare, per l'individuazione di strategie europee e sui finanziamenti europei, specialmente quelli per attività di sviluppo e dimostrative. Particolare attenzione è stata posta alla definizione dei nuovi indirizzi di politica europea della ricerca (Horizon 2020)

Partecipazione, quale rappresentante ENEA e coordinatore nazionale, a ***EERA*** *(European Energy research Alliance) per le tecnologie CCS*. E' un organismo analogo alla piattaforma ZEP ma riunisce gli operatori del mondo della ricerca. Sono stati lanciati Joint Programmes, fra cui quello sulle CCS di cui ENEA è uno dei partner principali

Iniziative progettuali internazionali. Sono stati presi contatti con gli operatori cinesi, nell'ambito di una collaborazione già avviata fra Cina ed ENEL, ed australiani per la costruzione di progetti comuni finanziabili anche da UE; si è proseguito nella partecipazione al progetto ECCSEL; sono stati avviati contatti per collaborazioni con ALSTOM e FOSTER WHEELER.

Summer School sulle CCS. E' stata avviata la prima edizione di una iniziativa che continuerà in maniera stabile per i prossimi anni, con l'obiettivo di diventare un punto di riferimento internazionale anche attraverso il coinvolgimento diretto di IEA.

1 Introduzione

Le attività sono inserite nel complesso contesto internazionale nel quale operano governi, istituzioni pubbliche e operatori privati, con l'obiettivo di accelerare lo sviluppo e l'ingegnerizzazione delle tecnologie per l'impiego sostenibile dei combustibili fossili e, in questo ambito, cercare di rendere competitive le tecnologie di cattura e stoccaggio dell'anidride carbonica (CCS) in grado di consentire l'impiego "dei combustibili fossili, specialmente il carbone, con una drastica riduzione delle emissioni di CO_2.

Le considerazioni che seguono vogliono fornire un quadro, sintetico ma esaustivo, del quadro internazionale ed europeo nel quale si è operato per rafforzare il ruolo e la presenza italiana in un settore nel quale si gioca una delle sfide più difficili dei prossimi anni, che è quella di accelerare il percorso verso una società "low carbon"; due sono le considerazioni a monte: a) nei prossimi decenni continuerà l'impiego massiccio di combustibili fossili; b) essenziale, per limitare i danni, è riuscire a sviluppare e rendere competitive le tecnologie CCS. E' una sfida che si gioca a livello globale, che richiede una sempre maggiore e più efficace cooperazione internazionale.

Di quanto detto vi è consapevolezza diffusa in Italia, e ciò ha sostenuto il ruolo svolto di coordinamento a livello nazionale che la presenza in Europa e su scala più ampia ha richiesto: per questo un grande ringraziamento va ai vari operatori industriali e della ricerca, ed ai rappresentanti dei Ministeri coinvolti.

1.1 Le scelte energetiche per uno sviluppo sostenibile

Per fronteggiare efficacemente le modificazioni climatiche è necessario un approccio mirato su efficienza e rinnovabili; tuttavia permarrà per i prossimi decenni un ricorso massiccio alle fonti fossili, tendenzialmente il gas nei Paesi sviluppati ed il carbone nei Paesi ad economie emergenti, anche se il quadro è in rapida evoluzione.

La transizione verso una economia "decarbonizzata" è un processo complesso e non breve, che vede l'impegno per lo sviluppo e diffusione delle tecnologie "green" ma allo stesso tempo richiede grandi sforzi per rendere l'impiego dei fossili sempre meno dannoso, accompagnandone la riduzione senza traumi occupazionali e sociali.

Gli obiettivi climatici, insieme alla necessità di ridurre ulteriormente le emissioni inquinanti, sono strettamente intrecciati con l'obiettivo di uscire dalla crisi economica puntando ad un delta positivo in termini di razionale impiego delle risorse, di lavoro qualificato e stabile, e di aumento della qualità della vita dei cittadini.

E' il senso che diamo al concetto di sviluppo sostenibile, troppo spesso usato in maniera settoriale o settaria, distorta o strumentale: ricerca e innovazione per la competitività del sistema industriale e dell'intero "sistema paese" sono il perno per guardare al futuro, anche prossimo, con ottimismo.

Su questo, come in Europa e nei Paesi più forti, dobbiamo investire anche in Italia, operando finalmente quel salto culturale da tempo atteso.

Lo sviluppo sostenibile, introdotto nel rapporto "Our Common Future" del 1987, e definitivamente lanciato al*la Conferenza di Rio su ambiente e sviluppo del 1992,* mettendo in stretta relazione **tre aspetti** di fondamentale importanza - quello **economico**, quello **ambientale** e quello **sociale** - evoca un **approccio multidisciplinare** la cui ultima finalità prevede, fra l'altro, di interrompere il degrado del patrimonio e delle risorse naturali (che di fatto sono esauribili) ed un loro utilizzo più efficiente anche per meglio controllare e ridurre sempre più il carico verso l'ambiente in termini di emissioni in atmosfera.

Se prendiamo in considerazione il fattore umano, il traguardo da raggiungere è l'aumento equo del tenore di vita dell'intera popolazione del Pianeta che, guardando al tema energetico, vuol dire sia sicurezza di approvvigionamento delle fonti e disponibilità di elettricità, sia solidità dei sistemi industriali, salvaguardando le risorse naturali e l'ambiente.

Focalizzando l'attenzione sul tema energetico, un importante documento europeo al quale fare riferimento è il noto **Libro Verde-Un quadro per le politiche dell'energia e del clima all'orizzonte 2030**, presentato lo scorso marzo al Parlamento Europeo e sul quale si sta ancora discutendo.

In esso si affronta il tema della sostenibilità vista come la sintesi tra sostenibilità ambientale, sicurezza degli approvvigionamenti energetici e competitività economico-industriale.

Nello specifico, il tema ambientale ha a che fare con la riduzione delle emissioni in atmosfera, sia di inquinanti che – principalmente - di anidride carbonica, la riduzione del consumo di energia e quindi l'efficienza energetica, ed ovviamente lo sviluppo delle rinnovabili.

Parlando invece di sicurezza degli approvvigionamenti energetici, bisogna guardare alla diversificazione delle fonti di energia, sia per quanto riguarda le regioni d'origine che la logistica.
Un altro aspetto da non sottovalutare riguarda la stabilità delle reti e la risoluzione degli attuali problemi legati all'intermittenza e alla variabilità dell'energia elettrica prodotta dalle fonti rinnovabili. Questo richiama quindi l'esigenza di adeguare le infrastrutture.

Infine, la competitività comporta ad esempio l'abbassamento dei prezzi dell'energia, lo sviluppo di nuove tecnologie, la creazione di nuovi posti di lavoro, il sostegno alle politiche industriali ovvero l'aumento dell'efficienza tecnologica.

Negli ultimi decenni il concetto di sviluppo sostenibile è stato spesso strumentalizzato e divulgato in maniera parziale, e ancora oggi vi sono diverse interpretazioni che non rispecchiano appieno il suo senso vero ed il significato che ne danno gli economisti: le reali finalità sono quelle di governare in maniera equilibrata e sinergica le tre complessità del sistema prima citate.

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L'Europa ha assunto lo sviluppo sostenibile come riferimento essenziale anche per le politiche energetiche. La **Roadmap dell'energia al 2050** pone come target europeo la riduzione entro il 2030 delle emissioni di gas serra del 40% rispetto ai valori del 1990 per poter conseguire una riduzione dell'80-95% entro il 2050, in linea con l'obiettivo concordato a livello internazionale di limitare il riscaldamento globale a 2°C. Ciò a partire dai ben noti **Obiettivi 20-20-20** da conseguire entro il 2020:

- riduzione del 20% delle **emissioni di CO_2;**
- aumento al 20% della quota di **fonti rinnovabili** nella copertura dei consumi finali ;
- riduzione del 20% dell'utilizzo dell'energia / incremento in termini di **efficienza**.

Elementi essenziali sono da un lato la progressiva diffusione delle rinnovabili e dell'efficienza energetica, dall'altro la gestione ottimale dell'impiego dei fossili – che continueranno ad essere diffusamente utilizzati nel mondo – riducendo drasticamente le emissioni di CO_2 ad essi dovute.

Esemplari sono due recenti importanti discorsi del **Presidente Obama**.
Nel primo viene ribadita la volontà degli Stati Uniti di puntare sul **gas naturale** - ed in particolare sulle enormi riserve del cosiddetto *shale gas* - dal momento che tale fonte, negli USA, costa molto poco (ad esempio circa un quarto di quanto costa in Europa); non è un caso che già nel 2012 una progressiva sostituzione del carbone con tale fonte decisamente molto meno onerosa, ha consentito un incremento (valutato in un punto) del PIL della Nazione. Parallelamente gli USA si propongono di puntare fortemente anche su efficienza energetica e rinnovabili. Questa politica consentirà all'industria americana di essere più competitiva sul mercato globale dell'impiantistica energetica – basata su fossili e rinnovabili - dei prossimi anni e decenni.
Nel secondo intervento è stato lanciato il cosiddetto progetto **Africa Power**, tramite il quale verranno messi a disposizione del continente africano 14 miliardi di dollari - tra fondi pubblici ed investimenti privati - allo scopo di adeguarne le infrastrutture ed impedire al Paese di seguire le stesse traiettorie inquinanti seguite dall'Occidente. Ne consegue la promozione dello sviluppo di tecnologie USA vendibili sul mercato internazionale, in preparazione di eventuali inasprimenti futuri delle normative internazionali sulle emissioni. Anche in questo caso le scelte effettuate sono dettate da ragioni di competitività sul mercato.

L'aspetto **competitività** non va quindi sottovalutato né nel settore dei combustibili **fossili** né in quello delle **rinnovabili**, in particolare guardando al mercato globale. A tal fine sono indispensabili politiche industriali forti, con anche incentivi per l'innovazione, che possono svolgere una funzione essenziale purché il processo sia ben governato nella sua complessità.

Per quanto riguarda l'Italia, un aspetto della complessità è rappresentato dalla inadeguatezza della nostra rete a gestire un carico così importante di energia intermittente: è un problema enorme, che non può essere sottovalutato. Questo si lega alla articolazione del nostro parco di centrali termoelettriche e alla necessità di tenerlo in considerazione per gestire il processo di transizione ad un nuovo assetto della produzione verso una società sempre meno basata sul carbonio: in sintesi, non si può pensare solo alle FER senza tener conto del contesto.

Nel nostro Paese, l'inattesa penetrazione delle rinnovabili nella rete, per effetto delle priorità di dispacciamento, ha infatti condotto ad una crisi di diversi impianti termoelettrici, con una sensibile riduzione del loro funzionamento medio annuo. Basti pensare che i parchi termoelettrici a gas di Enel si attestano in media al di sotto delle 2.000 ore annue. Ciò sta comportando una profonda crisi di quel settore, anche occupazionale.

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Per effetto della politica americana che si è rivolta alle riserve di *shale gas*, si sono resi disponibili sul mercato internazionale quantitativi di carbone elevatissimi. Conseguenza diretta è stata la diminuzione del costo del carbone in Europa (specialmente in relazione al gas naturale), tant'è che nel 2012 vi è stato un vero e proprio boom nella realizzazione di tali impianti. Considerando inoltre l'attuale andamento di mercato (che dovrebbe mantenersi similare anche nei prossimi anni), è ragionevole pensare che sul piano economico gli impianti a carbone potranno competere con quelli alimentati a gas naturale.

Naturalmente da ciò non discende che il nostro Paese debba puntare maggiormente sul carbone, ma piuttosto è utile mantenere stabile la quota – quasi residuale - di elettricità proveniente da esso, come previsto dalla **SEN** (Strategia Energetica nazionale). In sintesi, non ha senso pensare ad aumentare il parco impianti a carbone, ma bensì a un retrofitting o sostituzione di quelli vecchi.

Per sostenere tale settore bisognerebbe pensare ad interventi di miglioramento tecnologico utili ad abbassare i costi ed ottenere energia più pulita.

Due le vie da perseguire: la prima è quella dello sviluppo di tecnologie che siano allo stesso tempo più efficienti e meno inquinanti, le cosiddette HELE – High-Efficiency, Low-Emissions; l'altra è quella costituita dalle CCS – Carbon Capture Storage. Entrambe rappresentano un'opportunità enorme.

Se una delle priorità a livello globale è quella di produrre energia elettrica"pulita" e a basso costo, è necessario puntare – specialmente per noi italiani – alla innovazione degli impianti guardando ai costi di generazione, e alle emissioni (tecnologie HELE e CCS) per mantenere la competitività complessiva del nostro sistema industriale nell' ambito internazionale: non possiamo permetterci il lusso di perdere anche il settore dell'impiantistica energetica, destinato ad essere profondamente mutato sotto la spinta, appunto, delle tendenze internazionali e delle politiche energetiche praticate da aree strategiche (Cine e India in primis) che continueranno ad impiegare per svariati decenni combustibili fossili ed in particolare carbone.

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Riguardo alle tecnologie CCS, al loro impiego in relazione alla generazione elettrica ed alle prospettive di applicazioni industriali, è bene riferirsi ancora allo scenario internazionale.

In primis va detto che l'obiettivo che ci si pone è quello di rendere utilizzabili industrialmente le **CCS a partire dal 2030.** Per questo occorrono non solo molta ricerca e sviluppo, ma anche impianti dimostrativi di scala significativa, dotati di queste tecnologie, affiancati ovviamente da un'opportuna normativa ed interventi politici: da quest'ultimo punto di vista sono d'esempio la **Carbon Tax norvegese** sulle emissioni di carbonio piuttosto che l'**ETS** europeo, ma ovviamente è necessaria una normazione internazionale abbastanza omogenea.

E' necessario ribadire che in un'ottica di raggiungimento dei citati target europei di riduzione delle emissioni al 2050, occorrono comunque interventi "a ventaglio", che consentano in primo luogo di incrementare le rinnovabili e l'efficienza energetica ma anche di introdurre la tecnologia delle CCS che può contribuire per almeno il 20% al conseguimento dell'obiettivo. Occorre, però, superare gli attuali limiti, ovvero quello dei **costi** e quello dell'**accettabilità sociale**.

Rispetto al primo limite, come emerso da un recente studio effettuato dalla piattaforma tecnologica europea **ZEP (Zero Emissions Fossil Fuel Power Plants)**, il costo medio per catturare e stoccare l'anidride carbonica, varia dai 60-70$ agli oltre 100$ a tonnellata di CO_2. L'obiettivo è quello di ridurlo a 40$. Questo sarà possibile solo grazie allo sviluppo di sistemi più efficienti, attraverso attività di ricerca e sviluppo e attraverso la realizzazione di impianti industriali pilota e dimostrativi di grande taglia.

Sul fronte invece dell'accettazione sociale le maggiori preoccupazioni riguardano le possibili conseguenze di eventuali fuoriuscite incontrollate della CO_2 iniettata nel sottosuolo.

Va detto in tal senso che molte sono le conoscenze già acquisite sia da un punto di vista tecnologico (messa a punto di sistemi di monitoraggio) che geologico.
Già da tempo si utilizza infatti l'anidride carbonica per aumentare la produttività dei pozzi di petrolio avvalendosi della nota tecnologia **EOR - Enhanced Oil Recovery**, e sono in corso nel mondo moltissime iniziative industriali volte a dimostrare la fattibilità di tali applicazioni in giacimenti acquiferi salini e pozzi depleti.

Il punto centrale è avviare una vera ed efficace politica di "partecipazione", che coinvolga i cittadini e le Istituzioni locali, basata su una azione di informazione seria ed autorevole sulle tecnologie e tutte le relative implicazioni; occorre riuscire a comunicare e a dialogare con la popolazione e gli amministratori, senza reticenze, senza negare i problemi e allo stesso tempo dando conto delle garanzie di sicurezza basate sulle conoscenze e sulle precauzioni che si possono e si devono adottare: è l'unica strada, non solo in questo settore specifico, per poter dare vita a nuovi investimenti e ad un numero maggiore di applicazioni dimostrative.

Nel nostro Paese è comunque già in essere un'importante iniziativa in questo settore, che spazia dalla ricerca e sviluppo, alla dimostrazione su scala industriale, fino alla formazione-informazione e crescita dell'accettabilità sociale.
E' un'iniziativa lanciata nell'area del **Sulcis**, nel territorio Sud Ovest della Sardegna, che tra l'altro si presta molto bene allo stoccaggio dell'anidride carbonica in quanto è una zona non sismica e presenta formazioni acquifere saline, considerate le più idonee per lo stoccaggio della CO_2, sovrastate da strati di carbone non utilizzabili. Tutte queste condizioni consentono di sperimentare simultaneamente due differenti tecnologie di stoccaggio: l'iniezione in acquiferi salini e lo stoccaggio in giacimenti non sfruttabili di carbone – ECBM: Enhanced Coal Bed Methane – tramite il quale si pompa CO_2 negli strati di carbone liberando il metano lì presente.
Elemento non trascurabile è l'assenza di forti ostilità sociali e politiche, trovandoci in un'area che storicamente ha impostato la sua attività economica sul carbone e che attualmente è affetta da una clamorosa deindustrializzazione, e la cui popolazione è pertanto maggiormente aperta ad accettare – addirittura a promuovere - impianti di questo tipo.

Su tale base il Governo ha stipulato un accordo con la Regione Sardegna, per la realizzazione di un **polo tecnologico per il carbone pulito**. Caratteristica essenziale del piano è di operare sui tre pilastri che portano alla innovazione industriale: studi e sperimentazione su attrezzature da laboratorio, sviluppo delle tecnologie con attività su apparati pilota di taglia rilevante, e qualificazione e trasferimento mediante realizzazione ed esercizio di impianti industriali dimostrativi.
Tale piano si basa sull'esperienza e le infrastrutture già presenti presso Sotacarbo e sugli studi in corso relativi a svariate tecnologie di cattura e di stoccaggio della CO_2, sulla produzione di nuovi combustibili liquidi e gassosi a partire da carbone, e su sistemi integrati di "poligenerazione".
L'obiettivo è valorizzare e promuovere l'industria italiana e lo sviluppo delle tecnologie per consentire al settore manifatturiero termoelettrico di competere sul mercato internazionale: anche per questo si pensa alla realizzazione di un impianto pilota di **50 MWth** basato sulla tecnologia di **ossicombustione** in pressione sviluppata nel nostro Paese. Nel campo dello stoccaggio, poi, è previsto un ampio programma volto alla sperimentazione e caratterizzazione del sito Sulcis per l'iniezione di CO_2 in "acquiferi salini" e in strati di carbone con possibile estrazione di metano (la citata tecnologia ECBM). E' un'opportunità enorme quella di

poter sperimentare due soluzioni tecnologiche nello stesso sito, che peraltro ha caratteristiche geologiche di grande pregio essendo anche in zona non sismica ed è di sicuro interesse in ambito comunitario.
L'ultimo step consiste nella realizzazione di un dimostrativo industriale di taglia medio-piccola (potenza intorno a 300 MWe) dotato di sistemi CCS di taglia intorno a 70 MWe.
Infine, per chiudere la catena dell'innovazione, si andrà ad aggiungere alle attività di ricerca, sviluppo e dimostrazione anche la formazione, con la nascita di un polo di riferimento tecnico scientifico. Già da fine luglio di quest'anno si è svolta la prima edizione dell'**International Summer School** sulle CCS, che proseguirà nel 2014 ed in maniera stabile negli anni futuri su scala internazionale sempre più vasta. L'idea è quella di trasformare l'area del Sulcis in un centro internazionale di riferimento tecnico scientifico e allo stesso tempo in una meta per un turismo d'élite a carattere scientifico.

1.2 Impieghi del carbone in sistemi integrati di poligenerazione

Il carbone ha svolto finora, nel contesto internazionale, un ruolo chiave nelle politiche energetiche dei vari Paesi, quasi esclusivamente per la produzione di energia elettrica.
La situazione si avvia ad un sostanziale cambiamento nei prossimi anni e decenni per l'esigenza di abbattere drasticamente le emissioni di anidride carbonica per contenere e controllare le alterazioni climatiche: in Europa, dopo la strategia al 2020, la UE ha adottato nel 2011 una strategia al 2050, che prevede la riduzione di emissioni di gas serra da 80 a 90% rispetto al 1990 e si appresta ad approvare una roadmap al 2030 indicata nel "Libro verde **-** quadro per le politiche dell'energia e del clima al 2030" di Marzo 2013.

La transizione verso una economia non più basata sul carbonio non sarà breve, e comunque impone di affrontare il tema dell'Impiego sostenibile dei fossili, che verranno ancora ampiamente utilizzati nei prossimi decenni. L'impiego di carbone, imputato principale in quanto caratterizzato dal più elevato indice tCO_2/MWh, è destinato a diminuire globalmente, anche se alcuni Paesi – India e Cina in primis – continueranno a ricorrere massicciamente a questa fonte.

Per il conseguimento degli obiettivi climatici, sempre più condivisi a livello globale, la UE punta a una quasi totale decarbonizzazione dei processi di generazione elettrica, con il ricorso massiccio a efficienza energetica e fonti rinnovabili, in parte minore al nucleare, e l'adozione di tecnologie di cattura e stoccaggio della CO_2 per gli impianti a fossili. E' una strategia complessa, che raccoglie la sfida della sostenibilità puntando sulle opportunità per accrescere competitività e sicurezza energetica a livello europeo. Questo percorso è tanto più importante in funzione dei grandi cambiamenti in corso nel mondo: in USA i più bassi prezzi di gas ed elettricità conferiscono all'industria americana un vantaggio competitivo, ed hanno già comportato la riduzione di consumo di carbone: la conseguenza è una sua maggiore disponibilità a prezzi ancora più bassi in Europa, tanto che nel 2012 vi è stato il boom nella realizzazione di impianti a carbone nel nostro continente.

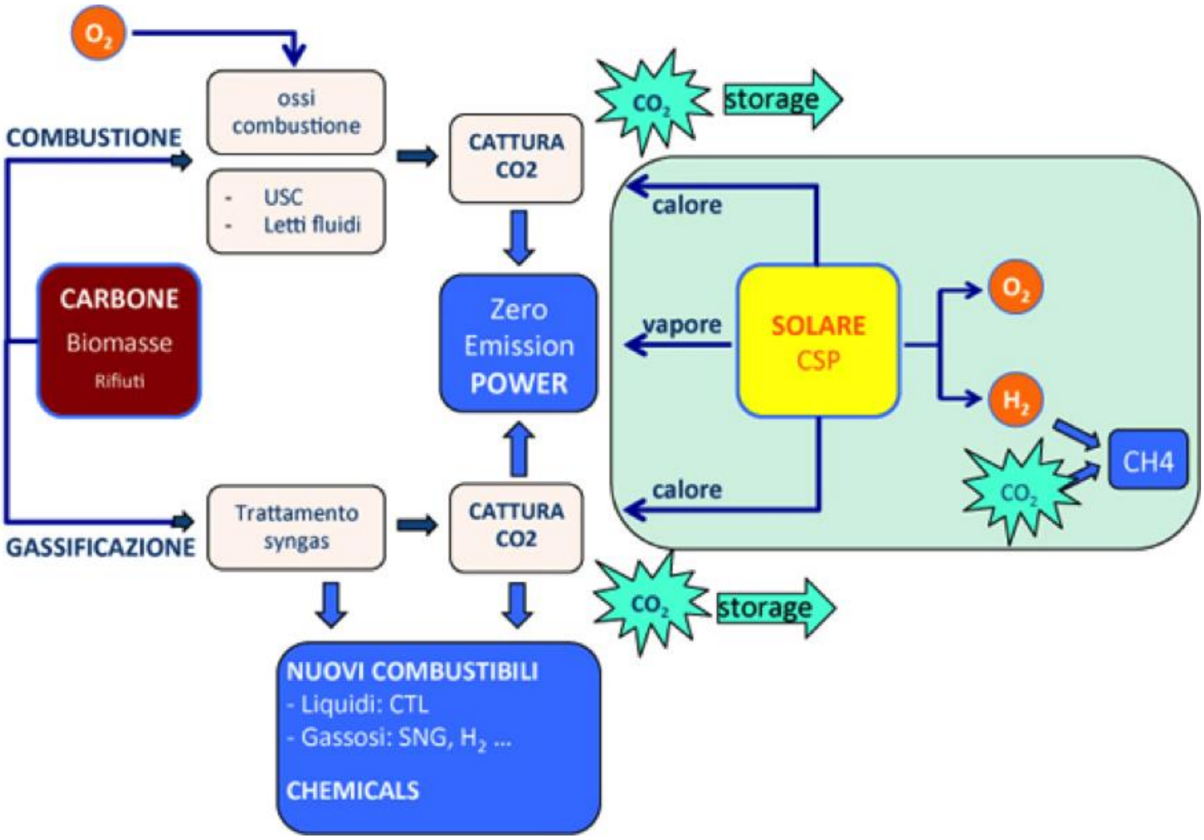
In questo quadro, nonostante tutto, il carbone continuerà a giocare un ruolo non secondario, e molti - specialmente i detentori di riserve di carbone - stanno valutando e proponendo processi e soluzioni tecnologiche volte ad allargare lo spettro di impiego di questa fonte: si pensa essenzialmente alla produzione di combustibili di vario tipo - molto utili, ad esempio, a Paesi detentori di riserve di carbone ma forti importatori di petrolio da destinare alla autotrazione - e a prodotti chimici pregiati già oggi prodotti a partire da idrocarburi.

Altro elemento importante è costituito dall'integrazione fra tecnologie diverse che si riferiscono ai settori dei fossili e delle rinnovabili: infatti Il sistema energetico si caratterizza sempre più come un sistema integrato, dove si fa strada la logica della "poligenerazione" – generazione combinata di elettricità, nuovi combustibili e chemicals – e l'impiego sinergico di fonti primarie diverse. L'obiettivo è valorizzare le rispettive peculiarità ma in un'ottica di complementarità/integrazione finalizzata ad aumentare l'efficienza complessiva dei sistemi impiantistici.

Ad esempio - si veda lo schema seguente - è possibile impiegare il carbone in combustori oppure provvedere alla sua preventiva gassificazione per ottenere un gas di sintesi da inviare alla combustione; insieme al carbone è possibile utilizzare anche biomasse in co-combustione oppure co-gassificazione; si possono adottare tecnologie di cattura e separazione della CO_2 in entrambi i casi, per ottenere la produzione di energia elettrica a emissioni (quasi) zero.

E' possibile anche produrre nuovi combustibili, sia passando attraverso la gassificazione (esempio tipico è il Coal to Liquid) oppure attraverso processi "one step" studiati in particolare dai cinesi; si possono produrre combustibili liquidi ma anche gassosi – principalmente SNG (Substitute Natural Gas), idrogeno, metano – così come altri prodotti chimici (chemicals).

E' particolarmente interessante l'integrazione con sistemi solari del tipo a concentrazione (CSP), che possono fornire calore ad alta temperatura necessario ad alcuni sottoprocessi (tipicamente legati alla cattura della CO_2) oppure vapore per la generazione di potenza. Tali sistemi possono poi integrarsi con la catena della CO_2 catturata utilizzata per la produzione di metano impiegando idrogeno ottenuto per elettrolisi dell'acqua, col che realizzando un sistema per lo storage chimico dell'energia; l'ossigeno prodotto, infine, può essere riciclato in sistemi di ossi-combustione, di particolare interesse in quanto basati su una tecnologia ad altissima efficienza sviluppata dall'industria nazionale.



Su questa grande tematica – fossili/carbone/nuovi combustibili e chemicals/integrazione – si riscontra un grande interesse a livello europeo e internazionale: si cita soltanto il Working Party sui Fossil Fuels della IEA che ha recentemente avviato una task force a cui attualmente partecipano USA, Germania, Polonia, Italia, Sud Africa e India e che verrà estesa anche ad altri Paesi fra cui la Cina.

ENEA opera nel campo da tempo, già nell'ambito del precedente piano triennale dell'Accordo di Programma con il MiSE, e sta intensificando l'impegno con attività teoriche e sperimentali presso i propri laboratori di Casaccia e presso il Centro Ricerche di Sotacarbo. Tali attività, infine, rientrano nell'ambito del programma del "polo tecnologico sul carbone pulito" da realizzare in Sardegna - nell'area del Sulcis iglesiente - recentemente deciso nel quadro dell'accordo fra MiSE e Regione Autonoma Sardegna

2 Descrizione delle attività svolte e risultati

2.1 Partecipazione al CSLF (carbon Sequestration Leadership Forum)

Il CSLF è un consesso internazionale, istituito a livello ministeriale, che attualmente coinvolge 24 nazioni più l'Unione Europea, che rappresentano oltre 3.5 miliardi di persone, pari a circa il 60% della intera popolazione mondiale. La missione del CSLF consiste nel facilitare lo sviluppo e l'applicazione delle tecnologie CCS attraverso collaborazioni internazionali volte a superare i principali ostacoli di ordine tecnico, economico ed ambientale, promuovendo anche la consapevolezza del pubblico nonché sviluppi normativi e finanziari internazionali.

Il CSLF ha ormai assunto un ruolo fondamentale nel panorama internazionale, ed ha operato in stretta sinergia con l'Agenzia Internazionale per l'Energia (IEA) nella stesura di documenti strategici per vari incontri, quali il G8-Energia di Roma dove, si ricorda, il nostro Paese ha sottoscritto importanti accordi di collaborazione anche con il governo USA.

La partecipazione assidua dell'Italia a tutte le riunioni del CSLF ha consentito al nostro Paese di mantenere uno stretto contatto con tutti i principali attori internazionali e di promuovere le iniziative italiane.

In particolare è stato ospitato in Italia il meeting annuale del CSLF, organizzato a Roma da ENEA. Sono stati affrontati e discussi gli sviluppi delle politiche energetiche nei vari Paesi, e si è proceduto ad un aggiornamento della road-map sulle CCS.

Si è, poi, partecipato ad un importante meeting internazionale organizzato da "CGS Europe" che associa i principali organismi di ricerca e industriali operanti nel settore dello stoccaggio della CO2: in tale ambito abbiamo partecipato in rappresentanza del CSLF, presentando i principali progetti sostenuti da CSLF

2.2 Partecipazione alla IEA (International Energy Agency)

Di particolare rilievo è stata la partecipazione al Working Party on Fossil Fuels (WPFF), organismo di vertice al quale, fra l'altro, si riferiscono I vari Implementing Agreement. In questo ambito ci è stato chiesto di presentare la situazione energetica in Italia, con riferimento al gas, al carbone e alle CCS. In questo ambito, ancora, è stato lanciato un nuovo Implementing Agreement sulle Tecnologie del gas e olio (GOT), a cui l'Italia partecipa per ora come osservatore in attesa di una adesione formale.

E' proseguito il lavoro all'interno dell'Implementing Agreement CCC (Clean Coal Center), nel quale ha assunto un ruolo primario la tematica delle CCS: ciò è dovuto alla consapevolezza – unanimemente condivisa – che nei prossimi decennia il ricorso ai fossili sarà ancora massiccio e determinante, e l'unica via per un loro impiego il più possibile sostenibile sta nell'applicazione delle tecnologie CCS.

Quello di IEA è, dunque, un consesso cruciale al quale l'italia ha partecipato presentando le iniziative nazionali e confrontandole con quelle degli altri paesi. Il progetto SULCIS, recentemente lanciato dal MISE, rappresenta un importante riferimento anche in questo prestigioso consesso.

2.3 Partecipazione al Global CCS Institute (GCCSI)

Al G8 Ambiente, tenutosi nell'aprile 2008 a Siracusa, è stato sottoscritto, nell'ambito dell'Intesa italo-australiana per la cooperazione nello sviluppo delle tecnologie CCS, un "Memorandum of Understanding" tra ENEL e il ministro australiano dell'Agricoltura, della Pesca e delle Foreste, che prevede l'adesione di ENEL come socio fondatore al Global Carbon Capture and Storage Institute (GCCSI). Il GCCSI è un'organizzazione nata su iniziativa del Governo australiano il cui obiettivo è mobilitare risorse pubbliche e private per diffondere le tecniche CCS; l'impegno immediato è quello di accelerare l'avvio progetti pilota e dimostrativi. Hanno aderito al GCCSI tutti i Paesi dell'Europa maggiormente impegnati nello sviluppo delle tecnologie CCS, oltre a Stati Uniti, Canada, Messico, Sud-Africa ed altri Paesi dell'Oceania e dell'Asia. L'adesione al GCCSI ci ha consentito di entrare in un circuito internazionale che sta assumento un ruolo di leadership assoluta quale stakeholder "indipendente", di acquisire informazioni anche su progetti extra-europei; sono state acquisite le condizioni per partecipare a pieno titolo alla rete di alleanze tecnologiche e industriali che nasceranno nell'ambito dell'organizzazione, di essere costantemente aggiornata sugli sviluppi normativi e regolamentari del CCS nel mondo e, infine, di valutare i risultati delle varie iniziative di comunicazione attivate dagli altri membri.

Si è partecipato alla elaborazione del nuovo piano strategico, che vede un ulteriore sviluppo del GCCSI.

2.4 Partecipazione alla Piattaforma Zero Emission Fossil Fuel Power Plants (ZEP)

La piattaforma tecnologica ZEP (fondata nel 2005, unisce e rappresenta gli operatori industriali europei impegnati nelle tecnologie CCS; partecipano rappresentanti dei Governi nazionali, del mondo della ricerca e di organizzazioni terze. Svolge un ruolo essenziale per la definizione delle strategie europee. I membri della Task Force Tecnology (TFT), oltre a incontrarsi periodicamente per la messa a punto degli indirizzi da suggerire alla Commissione – in funzione delle attività di finanziamento di progetti di ricerca e dimostrazione - hanno operato, usando ampiamente lo strumento delle riunioni via Skype, per l'aggiornamento di documenti quali la **road-map** e il nuovo piano strategico sulle CCS: In particolare si è partecipato ai lavori di elaborazione del documento su <recommendations for research to support CCS deployment in Europe beyond 2020 – update on CO2 capture>.

la partecipazione al Ministerial Group di ZEP ci ha consentito di cionfrontare, anche in questo ambito, politiche e priorità del nostro Paese.

Ci è stato chiesto di ospitare la seconda riunione annuale del ministerial meeting, ciò che avverrà a novembre di quest'anno presso la sede ENEA di Brussels.

2.5 Partecipazione a CCS EII Team (Iniziativa industriale Europea) del SET Plan (Strategic Energy Technologies)

E' un gruppo costituito da un rappresentante per ciascuno Stato membro, da alcuni rappresentanti della piattaforma ZEP e di EERA, e da alcuni stakeholder. Svolge un ruolo cruciale per la definizione degli indirizzi attuativi delle varie iniziative previste in ambito SET Plan, cercando di armonizzare le attività di ricerca, pilota e dimostrative, e allo stesso tempo allargando occasioni di cooperazione fra gli Stati. In particolare sono state concordate e trasmesse alla Commissione gli indirtizzi consigliati per il prossimo programma in ambito Horizon 2020. L'Italia, che di fatto ha abbandonato il progetto ENEL di Porto Tolle, è comunque in campo con il nuovo progetto SULCIS.

2.6 Partecipazione a EERA (European Energy Research Alleance)

EERA E' un organismo per molti aspetti analogo alla piattaforma ZEP ma riunisce gli operatori del mondo della ricerca sulle tematiche ritenute cruciali, e fra esse le CCS. Il lavoro svolto si è concentrato sulla definizione del Joint Programme (JP), un ampio programma di ricerca con obiettivi nel medio-lungo periodo costruito con il concorso di un numero rilevante di organismi dei vari Paesi che hanno concordato di armonizzare programmi in corso e già finanziati. L'ENEA, insieme ai suoi associati (varie Università) ha proposto il pacchetto delle attività svolte nell'ambito dell'ADP MISE-ENEA, con ciò valorizzando tali attività e creando opportunità per future collaborazioni. E' da rilevare che il ruolo di EERA sarà cruciale nei prossimi anni in quanto si prevede che, in ambito Horizon 2020, i finanziamenti comunitari verranno assegnati non più a singoli progetti ma a programmi complessivi, come appunto i JPs: è stato, dunque, essenziale essere fra i promotori dell'iniziativa, caratterizzando l'ENEA come uno fra i principali partner del JP. Nell'assemblea generale di Giugno 2012 si è concordato di aggiornare il JP entro l'anno, anche a seguito della adesione di altri membri. I lavori sono proseguiti con l'aggiornamento del programma congiunto, e con l'interazione con UE per le priorità di Horizon 2020.

La prossima riunione dall'assemblea dei membri del Joint programme si terrà a Dicembre presso la sede ENEA di Roma.

2.7 *Iniziative progettuali internazionali (ENEL, ALSTOM, FOSTER WHEELER)*

Sono stati presi contatti con gli operatori cinesi, nell'ambito di una collaborazione già avviata fra Cina ed ENEL, ed australiani per la costruzione di progetti comuni finanziabili anche da UE.

Si è proseguito nella partecipazione al progetto ECCSEL, un programma (FP7-Research Infrastructures) volto alla realizzazione di grandi infrastrutture di ricerca europee in vari settori, contando su quanto di rilevante già esiste ed è operativo e che, però, va ampliato ed integrato a fronte di finanziamenti comunitari e nazionali. Il progetto riunisce i Centri di Eccellenza europei sulle tematiche CCS ed è coordinato dall'istituto norvegese NTNU con la partecipazione di organismi da Polonia, Francia, Germania, Spagna, UK, Grecia, Olanda, Svizzera e Italia**.** Per l'Italia partecipano OGS (per la tematica dello stoccaggio di CO_2) ed ENEA (relativamente alle tecnologie impiantistiche di cattura, integrazione ed analisi energetico-ambientali). Importanti ricadute consistono nell'opportunità di valorizzare – utilizzando fondi comunitari - le infrastrutture esistenti sia presso il Centro ENEA-Casaccia che presso l'area sperimentale di Sotacarbo, e l'inserimento a pieno titolo nel network europeo sulle CCS.

Sono stati avviati contatti per collaborazioni con ALSTOM e FOSTER WHEELER relative alla produzione di combustibili liquidi e gassosi in processi innovativi legati anche alla cattura ed impiego della CO2.

E' stato organizzato il *meeting internazionale Tecnologie Zero Emission per la competitività, lo sviluppo industriale e l'ambiente - Il progetto CCS Sulcis: prospettive, realizzazione, ricadute produttive e territoriali;* si è svolto il 21 novembre 2012 presso il Centro Ricerche Sotacarbo, Grande Miniera Serbariu—Carbonia (CI) con l'obiettivo di rilanciare il "progetto Sulcis" sulla base di considerazioni unanimemente condivise che si riportano sinteticamente.

- Obiettivi della politica energetica europea sono la riduzione delle emissioni di gas con effetto serra, la sicurezza degli approvvigionamenti e la competitività delle imprese. Il Pacchetto clima-energia del 2009 e la Road Map per l'anno 2050 definiscono le linee guida e gli strumenti per l'attuazione. La nuova Strategia Energetica Nazionale confermando le scelte europee, propone azioni per un'energia più competitiva e sostenibile.
- In questo quadro hanno un ruolo fondamentale le tecnologie di cattura e stoccaggio dell'anidride carbonica (CCS), che permettono di separare l'anidride carbonica (CO_2) generata dai processi industriali e di confinarla attraverso lo stoccaggio nel sottosuolo in formazioni geologiche profonde, oppure mediante altri metodi di natura biologica e chimica.
- Le tecnologie CCS sono essenziali su scala mondiale per la stabilizzazione e la riduzione delle emissioni di gas serra al fine di evitare il surriscaldamento dell'atmosfera del pianeta.
- Le tecnologie CCS modificano in modo radicale la costruzione dei futuri impianti termoelettrici (a carbone e a gas naturale) e potranno trovare impiego anche in altri settori caratterizzati da processi industriali che producono grandi emissioni di CO_2, come la fabbricazione del cemento, la siderurgia, e la petrolchimica.
- Tuttavia le tecnologie CCS oggi disponibili devono essere dimostrate su scala significativa in vista di una loro estesa commercializzazione e impiego.
- Lo sviluppo delle tecnologie CCS può offrire, all'industria nazionale, l'opportunità di svilupparsi e di competere nel settore delle grandi infrastrutture energetiche e dei processi industriali fortemente emettitori di CO_2.

- Per il nostro paese è essenziale puntare sull'innovazione in un settore importante come quello energetico, uno fra i pochissimi sui quali si può costruire una filiera tecnologica italiana.

Il Convegno ha inteso offrire un'occasione di incontro e di proposta sul progetto **CCS Sulcis**, sulle opportunità e occasioni per nuove collaborazioni tecnologiche e industriali, sulle ricadute produttive del Progetto e sulle opportunità di investimento.

Hanno partecipato, fra gli altri, rappresentanti di IEA, Global CCS Institute, WEC, Foster Wheeler, oltre a rappresentanti delle Istituzioni (in primis MiSE) e di organismi di ricerca.

2.8 Summer School sulle CCS

ENEA, insieme a Università di Cagliari-Dipartimento di Ingegneria Meccanica, Chimica e dei Materiali e Sotacarbo, ha organizzato la prima edizione della “Sulcis Summer School on CCS Technologies” che si è svolta presso il centro sperimentale di Sotacarbo dal 23 al 26 Luglio 2013.

E’ una iniziativa di valenza internazionale che si pone l’obiettivo di attivare una sede stabile di approfondimento degli argomenti e delle problematiche relative al campo delle tecnologie di cattura e stoccaggio della CO_2 (CCS), e si rivolge a studenti universitari della laurea magistrale (o corsi equipollenti) e del dottorato di ricerca provenienti da diversi percorsi formativi, oltre che a operatori ed esperti di impiantistica energetica, al fine di promuovere la loro partecipazione attiva in questo settore.

La cattura e lo stoccaggio dell’anidride carbonica sono unanimemente considerati essenziali per poter conseguire l’obiettivo della drastica riduzione delle emissioni di CO_2 in atmosfera nei prossimi anni e decenni. Attualmente, il potenziale delle tecnologie CCS è in fase di studio in tutto il mondo con più di 100 progetti e conferenze internazionali che servono come piattaforme per lo scambio dei risultati di tali attività tra gli esperti. Per la diffusione di applicazioni su larga scala è tuttavia necessario ampliare la base di conoscenze nei paesi industrializzati e in via di sviluppo, in particolare a livello accademico. I corsi di formazione o scuole estive sono un modo di contribuire a questo obbiettivo, promuovendo e sostenendo la diffusione delle conoscenze sul potenziale di CCS a studenti ed operatori di tutto il mondo.

Questa “prima edizione” della scuola estiva ha una durata di tre giorni, più un quarto destinato alla visita della miniera, e prevede lo svolgimento di seminari e di attività formative e la costituzione di gruppi di discussione guidati da esperti nel campo delle CCS. Al termine del percorso formativo gli studenti hanno acquisito un'ampia panoramica delle tematiche e delle inerenti problematiche che circondano lo sviluppo tecnologico e l'implementazione delle tecnologie CCS e avranno contribuito alla realizzazione di una rete di contatti utili per lo sviluppo di attività nel settore. Il percorso formativo si concluderà con la redazione, da parte di ciascuno “studente”, di un elaborato finale per l’accertamento delle conoscenze acquisite. L’Università di Cagliari, infine, riconoscerà crediti formativi agli studenti che avranno frequentato con profitto l’intero pacchetto di lezioni.

L’iscrizione alla scuola è gratuita. La docenza è stata affidata a professori universitari ed esperti provenienti dal mondo della ricerca e dal settore industriale, con una presenza significativa in particolare di esponenti dell’ENEA, dell’Università di Cagliari e di Sotacarbo.

L’iniziativa proseguirà - in maniera più vasta e con un forte connotato internazionale - con cadenza annuale a partire dal 2014, e si pone l’obiettivo di attivare una sede stabile di formazione/informazione rivolta anche agli amministratori locali e agli stakeholder, locali e nazionali, per favorire il dialogo, accrescere la fiducia in tali tecnologie, e contribuire quindi alla accettabilità sociale.

Tale iniziativa, infine, comporta implicazioni più generali volte anche ad attivare un “turismo scientifico” di qualità nell’area del Sulcis.

E’ stato attivato il sito http://www.sulcisccssummerschool.it da parte degli esperti ENEA, con importanti funzionalità da sviluppare immediatamente come quella di attivare un programma di e-learning su piattaforma ENEA.

Partner coinvolti

L' Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS è un ente pubblico di ricerca che svolge, promuove, coordina studi e ricerche rivolti alla conoscenza della Terra e delle sue risorse, allo sviluppo di nuove tecnologie applicative ed interpretative nei campi delle scienze del mare, dell'ambiente, della sismicità , delle risorse minerarie ed alla migliore utilizzazione del territorio. La natura e la missione dell´OGS sono definite nella legge n.399/1989 di riordino dell´Osservatorio Geofisico Sperimentale e nel decreto legislativo n.381/1999 con cui esso è stato trasformato in istituto nazionale.

UNIVERSITA' DI ROMA LA SAPIENZA - C.E.R.I. - Il Laboratorio di Chimica dei Fluidi diretto dal professor Salvatore Lombardi e afferente al CERI, Centro di Ricerca Previsione, Prevenzione e Controllo dei Rischi Geologici presso l'Università di Roma La Sapienza, rappresenta nel contesto sia nazionale che internazionale una delle realtà più avanzate della ricerca sulla migrazione dei gas e sul loro monitoraggio. Partner in numerosi progetti europei, Membro del Network di Eccellenza Europeo CO2GeoNet, costituisce un punto di riferimento nazionale, oltre che per l'attualità delle sue ricerche, anche per la conoscenza derivata da una banca dati sui gas del suolo in Italia, che è unica nel suo genere.

Osservatorio CCS - Costituisce una sede esperta e indipendente per la promozione della tecnologia della cattura e del sequestro della CO2 (CCS) con la partecipazione degli stakeholder, con incontri pubblici, seminari di approfondimento, attività di comunicazione, formazione e informazione. Raccoglie informazioni e documentazione sugli aspetti tecnologici della CCS, sullo sviluppo della ricerca e delle sue applicazioni, sullo sviluppo dei progetti in corso a livello europeo e internazionale.

Itea Spa è uno dei protagonisti più dinamici in Europa nel settore dell'energia pulita e del rispetto ambientale. Nell'ambito del gruppo Sofinter, che è uno dei pochi protagonisti mondiali nel settore dell'energia con marchi prestigiosi (Ansaldo Caldaie, Macchi) è la società dedicata allo sviluppo ed alla commercializzazione di impianti basati sulla tecnologia di ossi combustione "flameless" ISOTHERM Pwr°.

CENTRO SVILUPPO MATERIALI S.p.A. è un centro di ricerca privato, di preminenza a livello europeo nel campo dei materiali anche innovativi, che intrattiene una intensa cooperazione con Industrie, Università e Centri di Ricerca nazionali ed esteri. Oltre alle attività di ricerca, sviluppo ed innovazione, il CSM è in grado di offrire servizi tecnologici e consulenza (testing, qualificazione materiali e componenti, ecc) e servizi ausiliari (project financing, alta formazione, brevetti, ecc.).

PROGRAMMA

Martedì 23 Luglio 2013 h 9.00 – 16.00

h 09.00	Introduzione	Prof.Cau/Girardi/Porcu	UniCA/ENEA
h 09.30	Inquadramento generale delle tecnologie CCS	Prof. Cau / Ing. Girardi	Unica/ENEA
h 10.00	Fonti di CO2 e bilancio delle emissioni	Prof. Cau	Unica
h 11.00	break		
h 11.15	Cattura della CO2: le diverse tecnologie precomb, post comb e oxyfuel	Prof. Cocco/Ing. Tola	Unica
h 12.00	Storage della CO2: il contributo del progetto Sulcis	Ing. Porcu	Sota/Carbosulcis
h 13.00	lunch		
h 14.30	Lo studio e lo sviluppo di tecnologie CCS nell'esperienza e nelle attività ENEA	Ing. Deiana	ENEA
h 15.00	La tecnologia ITEA: ossicombustione pressurizzata flameless	Ing.Bassignano/Malavasi	ITEA
h 15.30	Le attività della Piattaforma Pilota Sotacarbo	Ing. Maggio	Sotacarbo
h 16.00	break		
h 16.15	Visita agli impianti Sotacarbo	Ing. Calì	Sotacarbo

Mercoledì 24 Luglio 2013 h 9.00 – 16.00

h 09.00	Le tecnologie di stoccaggio della CO2	Ing. Persoglia	OGS
h 09.30	Valutazione del potenziale di stoccaggio nei siti idonei allo storage della CO2	Dott. Donda	OGS
h 10.00	Normativa europea e nazionale: lo stato di attuazione del DLgs162/2011	Dott. Panei	MiSE
h 11.00	break		
h 11.15	Linee guida per monitoraggio geochimico dei siti idonei allo storage della CO2	Prof. Lombardi	UniRoma1
h 12.00	Caratterizzazione reservoir carbonatico per lo stoccaggio della CO2 nel Sulcis	Prof. Fais	Unica
h 13.00	lunch		
h 14.30	L'esperienza Carbosulcis	Ing. Podda	Carbosulcis
h 15.00	Sistemi innovativi di cattura della CO2	Ing. De Angelis	UniBO
h 15.30	Le attività di monitoraggio della CO2 c/o l'area del Sulcis	Prof. Lombardi	UniRoma1

h 16.00	break		
h 16.15	Visita e laboratorio in campo nei siti di monitoraggio	Ing. Graziani	CERI

Giovedì 25 Luglio 2013 h 9.00 – 16.00

h 09.00	Introduzione		
h 09.30	La modellazione integrata dei sistemi cattura pre e post combustione	Ing. Tola	Unica
h 10.00	La modellazione ed il controllo dei processi di cattura della CO2 con ammine	Prof. Baratti	Unica
h 11.00	break		
h 11.15	Il trasporto della CO2	Ing. Demofonti	CSM
h 12.00	Costi e potenziale economico delle tecnologie CCS nel settore elettrico	Ing. Bassano	ENEA
h 13.00	lunch		
h 14.30	Aspetti di sicurezza e percezione pubblica	Ing. Federico	Oss. CCS
h 14.50	Usi industriali della CO2	Ing. Deiana	ENEA
h 15.10	break		
h 15.30	Rapporto finale per la verifica dell'apprendimento	Comitato Scientifico	Unica/Altri
h 16.00	Le attività dei laboratori Sotacarbo/Visita ai laboratori Sotacarbo	Ing. Pettinau/Plaisant	Sotacarbo

Venerdì 26 Luglio 2013 h 9.00 – 13.00

Visita alla miniera CARBOSULCIS di Nuraxi-Figus

3 Conclusioni

Si valuta che, senza CCS, i costi del conseguimento di una riduzione in Europa del 30% dei gas serra nel 2030 potrebbero essere del 40% superiori. Il mancato avvio della CCS avrebbe notevoli impatti negativi sulla capacità dell'Europa di soddisfare il limite dei 2 °C, sulla competitività, ma anche sull'occupazione e avrebbe un impatto negativo anche sulla sicurezza dell'approvvigionamento.
Per l'applicazione delle tecnologie CCS occorre affrontare e risolvere un insieme di problematiche legate a:

- sviluppo e qualificazione delle tecnologie
- economicità del processo di CCS che allo stato attuale è caratterizzato ancora da costi elevati;
- aspetti legali e autorizzativi, dovuti al fatto che l'attuale regolamentazione ambientale e mineraria non contempla, di fatto, l'opzione delle CCS;
- la percezione da parte dell'opinione pubblica del rischio associato ad una attività poco nota e non sempre di facile comprensione a livello di rischi e benefici, soprattutto in termini di possibili perdite di CO_2 dai serbatoi di confinamento.

Per quanto riguarda lo ***sviluppo delle tecnologie***, sono abbastanza chiare le esigenze e svariati attori hanno prodotto road-map che sostanzialmente concordano nella impostazione generale pur differendo rispetto a specifici obiettivi delle differenti aree geografiche.

Il ***fattore economico*** è, ovviamente, determinante e rappresenta uno dei principali ostacoli verso la diffusione di queste tecnologie: proprio per queste ragioni la UE sta finanziando i grandi progetti dimostrativi con fondi utili a coprire gli extra costi imputabili alle CCS.
I programmi dimostrativi - seppure ridimensionati rispetto alle iniziali aspettative e puntati molto su esperienze pilota di grande scala - dovranno fornire le prime indicazioni utili alla riduzione dei costi, mentre il successivo programma dovrà consentire il passaggio definitivo alla competitività per il 2030. È necessario, poi, affrontare gli ostacoli commerciali per la diffusione delle tecnologie CCS, in quanto lasciarla al libero gioco degli investimenti sul mercato può essere insufficiente, anche se le CCS sono state recentemente inserite nei meccanismi flessibili.

In conclusione, gli obiettivi delle attività nei prossimi anni si possono così sintetizzare:

- abbassare il costo della CO_2 evitata a valori intorno a 40 €/tCO_2;
- ridurre i costi di investimento degli impianti CCS;
- ridurre i costi di esercizio degli impianti CCS;
- ridurre l'energia aggiuntiva richiesta per l'applicazione delle tecnologie CCS;
- ottenere elevata disponibilità in termini di ore/anno di esercizio.

Gli ***aspetti legali e autorizzativi*** hanno assunto una rilevanza particolare, e sono determinanti per lo sviluppo dei progetti dimostrativi, soprattutto nelle fasi di trasporto e stoccaggio geologico della CO_2 e anche rispetto alle problematiche di accettabilità sociale dell'intero processo di CCS.
La UE ha definito un quadro chiaro con la citata direttiva, e l'Italia sta concludendo la fase di recepimento: rimangono aperti tutti gli aspetti applicativi che incontrano sempre grandi difficoltà nel nostro Paese.

Il problema dell'***accettabilità pubblica*** è il secondo grande ostacolo - insieme a quello economico – per la diffusione delle CCS. L'adozione di nuovi sistemi di produzione e gestione dell'energia comporta l'acuirsi di conflitti nel territorio; da un lato si rendono necessari adeguamenti e innovazioni nell'ambito amministrativo-legislativo, dall'altro è indispensabile far conoscere e accettare le nuove tecnologie e i vantaggi che esse procurano, per assicurarsi la collaborazione dei cittadini e delle istituzioni territoriali: occorre dunque attivare una strategia di preventiva e corretta comunicazione che coinvolga fin dall'inizio ogni stakeholder. Ciò vale in modo particolare per le CCS.

In Italia esistono le condizioni per proseguire e ampliare il programma di ricerca e sviluppo e costruire rapidamente un piano industriale centrato su impianti pilota per la fase dimostrativa; possiamo, infatti, contare su alcuni importanti punti di forza:

- la capacità degli enti di ricerca e di molti istituti universitari di mettere a sistema specifiche competenze e partecipare a progetti nazionali, europei e internazionali; e, in questo quadro, le grandi potenzialità offerte dalle infrastrutture sperimentali su scala pilota realizzate presso ENEA e Sotacarbo;
- il credito che a livello europeo tali centri hanno saputo guadagnarsi, e la presenza – assicurata in particolare da ENEA – nei più importanti contesti internazionali (quali CSLF, ZEP, EERA, IEA, SET Plan, Global Institute) e la stipula di accordi bilaterali con USA, UK, Cina, e accordi tecnologici con organismi di altri Paesi;
- la presenza sul territorio italiano e nei mari circostanti di numerosi "laboratori naturali", cioè di siti in cui la CO_2 fuoriesce naturalmente, e di siti potenzialmente idonei allo stoccaggio, offrendo opportunità uniche per valutare gli impatti sui sistemi vegetali e animali, e la possibilità di studiare le varie opzioni tecnologiche di stoccaggio affinando anche le tecniche di monitoraggio della CO_2;
- le iniziative avviate di recente dai due maggiori stakeholders italiani, ENEL ed ENI, e da altre realtà industriali quale Carbosulcis, Techint ecc…

Tali opportunità e risorse si concentreranno nella grande iniziativa lanciata dal MISE e dalla Regione Sardegna per la costituzione del **Polo tecnologico Carbone Pulito**, volto a sviluppare e dimostrare una tecnologia tutta italiana di ossi-combustione in pressione nell'ambito di un ampio programma di ricerca e sviluppo sull'uso sostenibile del carbone.

Abbreviazioni ed acronimi

CCS	Carbon Capture and Storage
CSLF	Carbon Sequestration Leadership Forum
ECCSEL	European Carbon Dioxide Capture and Storage Laboratory Infrastructure
EERA	European Energy Research Alleance
EII	European Industrial Initiative
GCCSI	Global CCS Institute
IEA	International Energy Agency
IA	Implementing Agreement
KPI	Key Performance Indicator
SET Plan	Strategic Energy Technology Plan
TFT	Task Force Tecnology (di ZEP)
WPFF	Working Party on Fossil Fuels
ZEP	Zero Emission fossil fuels power Plants
ZEPT	Zero Emission Porto Tolle

Allegati

Per la bibliografia si faccia riferimento all'ampia bibliografia presente sui siti della UE, CSLF, IEA.
Si allegano i seguenti documenti:

1. Transizione del sistema elettrico: sviluppo e sostenibilità
2. Current status of Italian Energy Strategy, with focus on natural gas, coal and CCS
3. Recommendations for research to support CCS deployment in Europe beyond 2020 – update on CO2 capture.
4. Carbon Sequestration Leadership Forum (CSLF) recognized projects and Task Forces on storage

Allegato 1 - *Transizione del sistema elettrico: sviluppo e sostenibilità*

ALLEGATO 1

ITALIAN NATIONAL AGENCY
FOR NEW TECHNOLOGIES, ENERGY AND
SUSTAINABLE ECONOMIC DEVELOPMENT

Transizione del sistema elettrico sviluppo e sostenibilità

Giuseppe Girardi
ENEA
Impiego sostenibile dei combustibili fossili
SOTACARBO
vicePresidente
giuseppe.girardi@enea.it

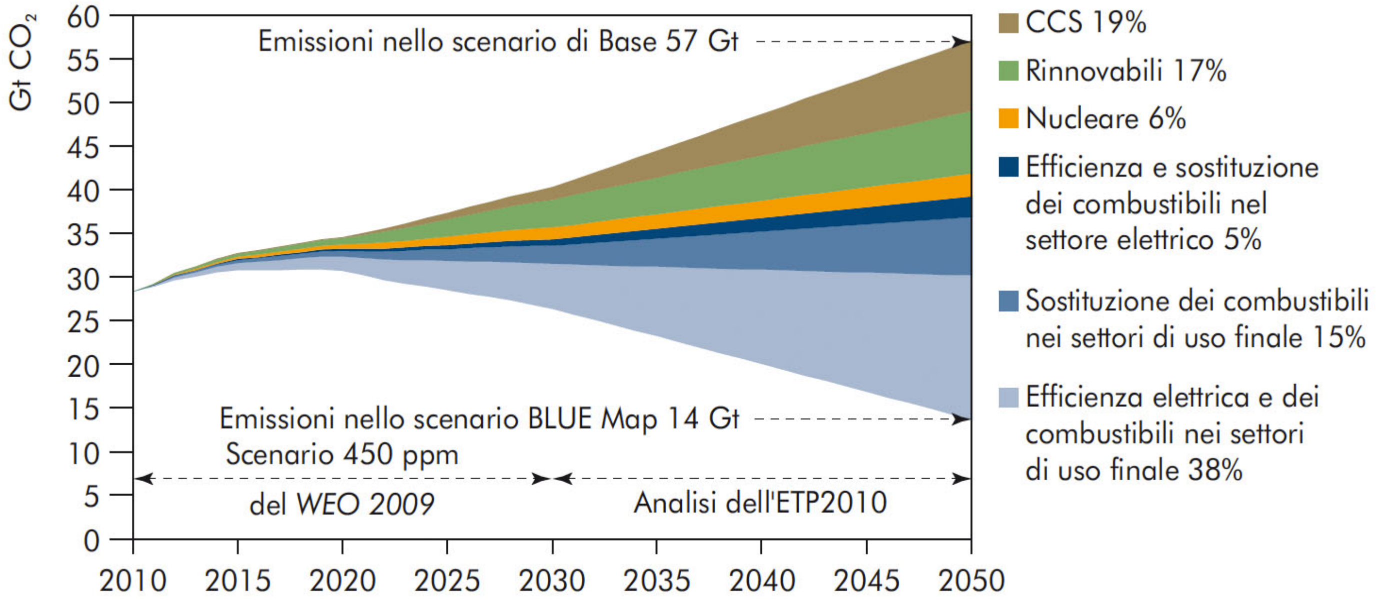
SICUREZZA DI APPROVVIGIONAMENTO

SVILUPPO

COMPETITIVITA’

SOSTENIBILITA’ AMBIENTALE

IEA – opzioni tecnologiche per la riduzione delle emissiomni di CO2



IEA: WEO 2012

SE SI VUOLE RAGGIUNGERE L’OBIETTIVO DEI 2 °C, MENO DI UN TERZO DELLE RISERVE PROVATE DI COMBUSTIBILI FOSSILI PUÒ ESSERE CONSUMATO PRIMA DEL 2050, A MENO DI UN UTILIZZO DIFFUSO DELLA TECNOLOGIA DI CATTURA E STOCCAGGIO DELLA CO2 (CCS)

- Scenario 450: circa i quattro quinti delle emissioni di CO2 consentite all’orizzonte 2035 sono già allocate dallo stock di capitale esistente (centrali elettriche, stabilimenti industriali, edifici, ecc.).
- Se entro il **2017** non verrà intrapresa alcuna azione per ridurre le emissioni, le infrastrutture connesse al settore energetico esistenti in quel momento produrranno l’intero volume di emissioni di CO2 consentite nello Scenario 450.
- Una rapida diffusione delle tecnologie per l’efficienza energetica posticiperebbe la completa allocazione delle emissioni al 2022, consentendo di guadagnare tempo per conseguire un accordo globale sulla riduzione delle emissioni

IL 9 MAGGIO, PER LA PRIMA VOLTA NELLA STORIA DELL’UMANITÀ, LA **CONCENTRAZIONE IN ATMOSFERA DI CO2** SUPERATO LE 400 PPM

IEA: WEO 2012 – il gas naturale

GOLDEN AGE OF GAS:
NEI PROSSIMI DECENNI GRANDE CRESCITA NEL MONDO

- USA: il **prezzo del gas naturale**, che nel 2012 ha toccato il suo livello minimo, è circa un quinto dei prezzi di importazione europei e un ottavo di quelli del Giappone. In futuro tale squilibrio rimarrà, anche se mitigato da una maggiore interdipendenza dei mercati e dalla maggiore flessibilità del commercio di **gas naturale liquefatto**.
- Al 2035 il gas sarà la componente dominante del mix energetico USA
- L’aumento di produzione di petrolio e gas (**light tight oil e shale gas**) sta sostenendo l’attività economica
  - più **bassi prezzi di gas ed elettricità** conferiscono all’industria americana un vantaggio competitivo
- I bassi prezzi del gas naturale stanno riducendo il consumo di **carbone in USA**
  - maggiore disponibilità di carbone a prezzi ancora più bassi in Europa
  - 2012: boom nella realizzazione di impianti a carbone in Europa

IEA: WEO 2012

LO SCORSO DECENNIO, IL CARBONE HA CONTATO PER QUASI LA METÀ DELL'AUMENTO DELLA DOMANDA MONDIALE DI ENERGIA, CRESCENDO AD UNA VELOCITÀ ADDIRITTURA SUPERIORE A QUELLA DELL'INSIEME DELLE FONTI RINNOVABILI

- La domanda di carbone dipenderà da:
  - misure politiche che favoriscono le fonti di energia a basse emissioni
  - implementazione di tecnologie di combustione del carbone più efficienti
  - Implementazione di tecnologie CCS: NEL MEDIO- LUNGO TERMINE
- Decisioni politiche di **maggior peso**: saranno quelle assunte da **CINA** e **INDIA** a cui si devono circa i tre quarti dell'attesa crescita della domanda di carbone dell'area non OCSE (mentre il consumo nell'area OCSE diminuisce).

EUROPA: si parte dalla roadmap al 2050

Comunicazione Energy Roadmap 2050 (COM(2011) 885/2

ENERGY ROADMAP 2050

2030 GREEN PAPER

Proposals for the 2030 framework for climate and energy policies

2011

Marzo 2013

Entro la fine del 2013

- Il passaggio a una economia europea a basse emissioni di carbonio entro il 2050 (riduzione da 80 a 85% di gas serra rispetto al 1990) è un obiettivo tecnicamente ed economicamente fattibile: richiede una quasi totale decarbonizzazione dei processi di generazione elettrica.
- Diversi scenari - diversa combinazione degli elementi chiave :
  - efficienza energetica
  - fonti rinnovabili
  - nucleare,
  - cattura e stoccaggio della CO2
- Opportunità per accrescere competitività e sicurezza energetica a livello europeo.
- Gli investimenti saranno ampiamente ripagati: crescita economica, occupazione, certezza degli approvvigionamenti energetici e minori costi dei combustibili

➠ **RICERCA E INNOVAZIONE: SET Plan e Horizon 2020**

Comunicazione (2011) Energy Roadmap 2050

- Sostituzione di olio e carbone con **gas** nel breve/medio periodo
- Mercato del gas: **shale** gas e **LNG**
- Impianti termoelettrici a gas: minori costi di investimento e più flessibilità
- Se le tecnologie **CCS** saranno disponibili ed applicate su larga scala, potranno essere applicate anche agli impianti a gas ➡ GAS = "low carbon technology"

- Le tecnologie **CCS** devono poter essere **applicabili a partire dal 2030 nel settore termoelettrico** per poter raggiungere i target di emissioni.
- Sono cruciali per altri settori industriali (cemento, siderurgia, petrolchimica). Il futuro delle CCS dipende fortemente da due fattori:
  - Accettazione
  - Prezzi del carbonio adeguati

  ➡ Dimostrare le CCS su scala industriale per iniziare ad impiegarle dal 2030

- **Nucleare**: rimane importante per la UE, anche se con posizioni diversificate
  - I costi crescono (sicurezza, decommissioning, gestione dei rifiuti)
  - Guardando al 2050, sarà più chiaro il ruolo della fusione

OBAMA: politica energetica in USA

- **Riduzione dei gas serra**: serve nuova strategia ed un accordo globale

  ➡ Non uccidiamo l'economia, anzi le diamo impulso
- **EPA**: definire limiti alle emissioni delle centrali elettriche (entro il 2013)
- **Trivellazioni** (shale gas and oil…): vincoli e standard pensando al clima
- **Oleodotto** Keystone XL che collega Canada e Texas: sarà costruito solo se gli effetti negativi sull'ambiente saranno limitati
- **Efficienza**: nuovi standard in case e per veicoli
- Piu' **solare** ed **eolico**

- **PVS**: livello di inquinamento più alto nel mondo – grande richiesta di energia

  ➡ subito energia pulita

  ➡ mettere a punto tecnologie che permettano loro di saltare la fase in cui inquinano, passando direttamente all'energia pulita

MERCATO ENORME: NUOVI STANDARD FISSATI QUANDO LE TECNOLOGIE SONO DISPONIBILI: CHI AVRA' INNOVATO PER TEMPO SARA' PIU' COMPETITIVO (es.: emissioni di NOx e Nuovo Pignone)

OBAMA: Power Africa

- grande piano di investimenti da **sette miliardi in 5 anni** per **raddoppiare la rete elettrica nell'Africa sub-sahariana** e garantire accesso alla corrente in un continente dove due terzi della popolazione vive senza elettricità:
  Etiopia, Ghana, Kenya, Liberia, Nigeria e Tanzania.
- Sfruttare l'enorme potenziale energetico dell'Africa:
  - ➡ nuove scoperte di vaste riserve di **gas** e **petrolio**,
  - ➡ potenziale sviluppo delle **rinnovabili**: geotermia, eolica, idraulica, solare
- il piano americano coinvolge diversi enti governativi e dovrebbe portare ad almeno **9 miliardi di dollari di investimenti privati**.
  Il progetto quindi è anche in parte una risposta alle critiche della poca attenzione data dall'amministrazione Obama all'Africa, mentre la Cina sta 'colonizzando' economicamente il continente, con molti investimenti e accordi con i governi
- IEA: Africa sub-sahariana avrà bisogno di investimenti per oltre 300 miliardi di dollari per raggiungere entro il 2030 un accesso universale all'energia elettrica

UE: LIBRO VERDE

quadro per le politiche dell’energia e del clima al 2030

Occorre confermare e perseguire i 3 obiettivi strategici già definiti al 2020:

- ➢ riduzione delle **emissioni** di gas serra,
- ➢ **sicurezza** dell’approvvigionamento energetico e
- ➢ **sostegno** alla crescita, alla competitività e all’occupazione

UN NUOVO QUADRO PER IL 2030 È IMPORTANTE PER TRE RAGIONI

- cicli di investimento lunghi (impianti in vita anche dopo il 2030):
  - ➡ gli investitori hanno bisogno di certezza e di meno rischi regolamentari;
- Favoriti i progressi verso un’economia competitiva e un sistema energetico sicuro, **incentivando lavori di ricerca, sviluppo e innovazione che possono creare nuove opportunità di lavoro e di crescita**. Ciò a sua volta riduce i costi economici
- Un accordo internazionale vincolante sulla mitigazione dei cambiamenti climatici è previsto per il 2015. La UE dovrà arrivarci con un accordo su una serie di questioni, compreso il *“livello della sua ambizione”*

UE: LIBRO VERDE

quadro per le politiche dell’energia e del clima al 2030

Sfide nel conseguimento degli obiettivi 2020: da considerare nel “quadro 2030”

- Increasing concern about energy import dependency and rising energy prices
- Stability and costs of renewables support schemes, impacts on the internal energy market, on grid stability and on capital allocation
- Need for massive investments in energy transmission and distribution infrastructure, e.g. due to renewables expansion
- Current large surplus of ETS allowances, resulting in a low carbon price and low investment incentives

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UE: LIBRO VERDE

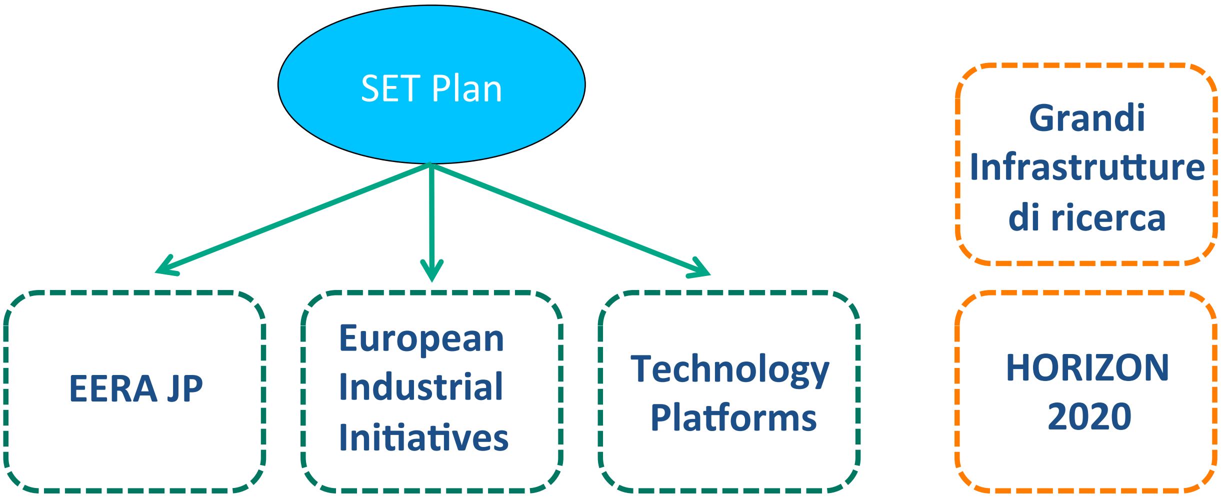
Assicurare il progresso al 2030 dei 3 obiettivi

Sustainability	**Security of energy supply**	**Competitiveness**
Reduction of emissions	Diversification of energy sources, supply countries and routes	Affordable and competitive prices
Reduction of energy consumption	Grid Stability	Promotion of new technologies, growth and jobs
Development of alternative energy sources	Adequate energy infrastructures	Improved energy efficiency

OCCORRE CONSIDERARE:

- ➠ conseguenze della crisi economica attuale: difficoltà per investimenti a lungo termine
- ➠ evoluzione dei mercati energetici UE e mondiali: rinnovabili, gas e petrolio non convenzionali, nucleare

SET Plan: Strategic Energy technologies Plan



SET Plan

EERA JP

European Industrial Initiatives

Technology Platforms

Grandi Infrastrutture di ricerca

HORIZON 2020

Organismi e network internazionali

IEA
IPCC (Intergovernmental Panel on Climate Change

ETN (European Turbine Network)
CSLF (Carbon Sequestration Leadership Forum)
Global CCS Institute

IFRF (Int. Flame Research Foundation)

EIIs: European Industrial Initiatives

- Rafforzare la ricerca e l'innovazione industriale nel settore dell'energia
- Ridurre i costi e/o migliorare le prestazioni

Iniziative avviate:

- Eolico
- Solare (sia fotovoltaico che a concentrazione)
- Elettricità (smart) grids
- CO2: cattura, trasporto e stoccaggio
- Fissione nucleare sostenibile (IV generazione)
- Bio Energia
- Smart Cities
- Fuel cells e idrogeno
- Fusione nucleare

UE: Technology challanges per il 2020

- fare dei biocarburanti di seconda generazione un'alternativa competitiva ai combustibili fossili, assicurando la sostenibilità della produzione;
- consentire l'uso commerciale delle tecnologie per la cattura, il trasporto e lo stoccaggio di CO2 mediante attività di dimostrazione su scala industriale, anche in materia di efficienza di sistemi completi e di ricerca avanzata;
- raddoppiare la capacità di generazione di energia delle turbine eoliche più grandi, concentrandosi sugli impianti eolici in mare;
- dimostrare la commerciabilità dei grandi impianti fotovoltaici (PV) e dell'energia solare a concentrazione;
- permettere la costituzione di un'unica rete europea intelligente dell'elettricità capace di integrare le fonti energetiche rinnovabili e decentrate;
- introdurre sul mercato di massa dispositivi e sistemi più efficienti di conversione dell'energia e per gli usi finali, come la poligenerazione e le celle a combustibile, nell'edilizia, nei trasporti e nell'industria;
- preservare la competitività nelle tecnologie della fissione, insieme a soluzioni a lungo termine per la gestione delle scorie;

Fondamentale l'innovazione industriale

- Individuazione delle priorita' di ricerca, creando luoghi di confronto e concertazione fra mondo della **ricerca e sviluppo** e dell'**industria**

- **RICERCA SVILUPPO INGEGNERIZZAZIONE**: una catena essenziale

  ⇨ Integrazione fra politiche industriali (energia/ambiente) e della ricerca

- La SEN rappresenta un importante elemento di discontinuita'

  ⇨ Occorre guardare al trend europeo: roadmap al 2030 e 2050

- Integrare indissolubilmente le scelte di politica energetica ad una nuova politica industriale, che guardi alle sfide della transizione del sistema energetico, e termoelettrico

- Andare vero la produzione di manufatti, componenti, impianti avanzati e che troveranno spazi sul mercato globale dell'energia, mantenendo e rafforzando la nostra presenza

In Italia

- E’ in corso una colossale competizione sulle tecnologie energetiche, che condizionerà il sistema industriale dei principali Paesi
- Guardare i trend internazionali considerando punti di forza e debolezza del nostro sistema industriale, individuando i settori strategici, e dotandoci di “strumenti”

Domanda1

➡ possiamo permetterci che – dopo la decrescita (infelice) di molti settori industriali - chimico, automobilistico, siderurgico, ecc.. - anche quello dell’**impiantistica energetica** segua la stessa fine? No!

Una tale concentrazione di conoscenze, capacità di progettazione e ingegneria, e capacità di esercizio accumulate in decenni si può perdere in pochissimo tempo, se si perde il treno dell’innovazione (che passa ora)

Domanda2

➡ Esistono priorità comuni a settori andati in crisi e da sostenere e rilanciare?

C’e’ una priorita’ comune al settore della produzione di **elettricita**’ e a quelli **siderurgico**, **petrolchimico**, del **cemento**: la limitazione delle emissioni di CO2

Accordo Ministero dello Sviluppo Economico e Regione Sardegna: costituzione del POLO TECNOLOGICO CARBONE PULITO

POLO TECNOLOGICO CARBONE PULITO

R/D - Pilota	Sviluppo tecnologie "zero emission"	◆ Generazione elettrica da carbone e fossili ◆ Produzione di nuovi combustibili ◆ Integrazione – Rinnovabili (es.: CSP e Biomasse)
Pilota - Demo	Impianto pilota oxycomb (50 MWth)	◆ Sviluppo e dimostrazione tecnologia italiana ◆ Realizzare in Sardegna le infrastrutture per la realizzazione dei componenti dei nuovi impianti
Pilota - Demo	Stoccaggio geologico della CO_2	◆ Caratterizzazione del sito per lo stoccaggio ◆ Iniezione in acquiferi salini ◆ Iniezione in starti di carbone con estrazione CH_4
Demo: Tecnologia oxycomb	Impianto a carbone 300 MWe con sitema dimostrativo per CCS da 80 MWe (equivalenti)	
Formazione e Accettazione pubblica	Summer School Prima edizione: Luglio 2013	◆ Formazione specialistica - master ◆ Turismo scientifico ◆ Apertura alla socità: informazione e dialogo

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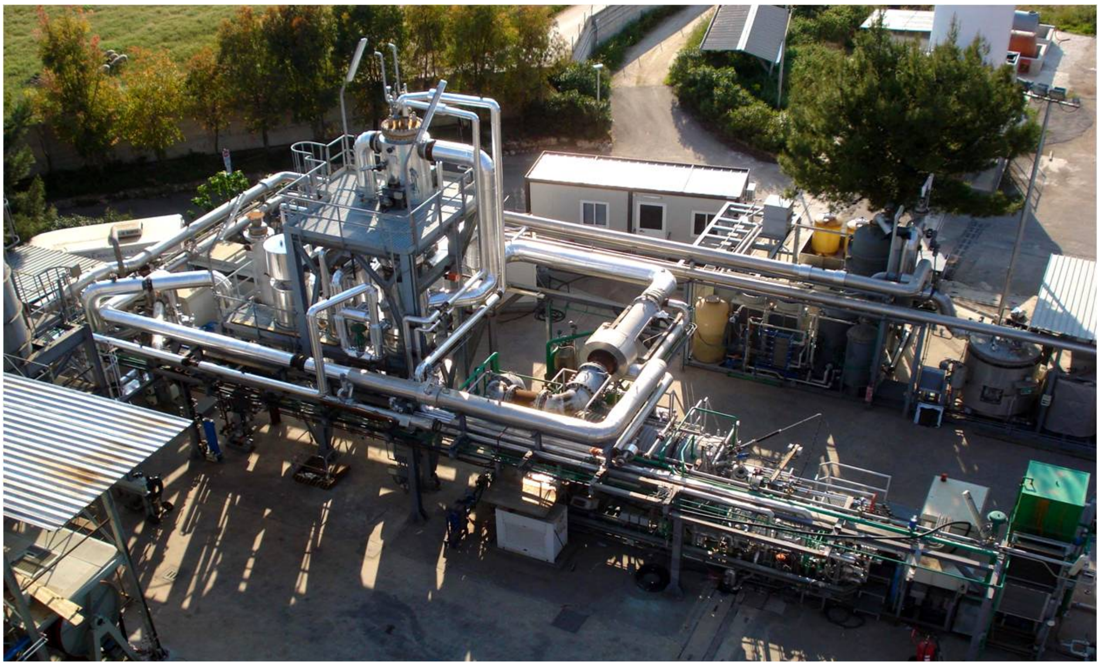
POLO TECNOLOGICO CARBONE PULITO

Oxycombustion

5 MW_{th} ISOTHERM® pilot unit by ITEA (Gioia del Colle, Italy)



Build-up, in Sulcis area, of a 50 MW_{th} demonstration oxycombustion unit working ant 10 bar pressure

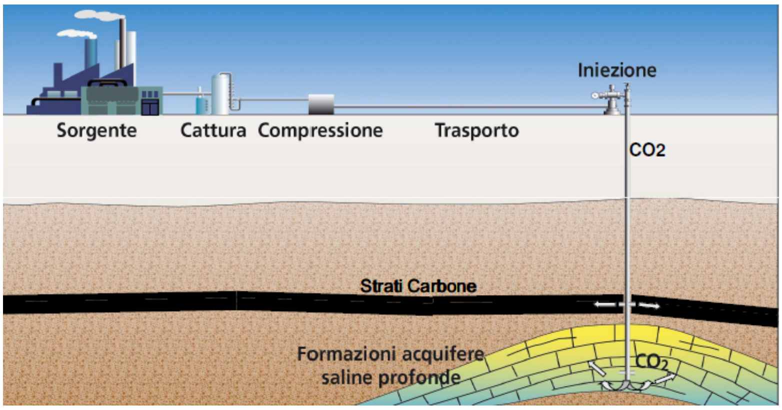
POLO TECNOLOGICO CARBONE PULITO

CO_2 geological storage

- CO_2 injection and CH_4 extraction wells
- pilot-scale tests on ECBM (enhanced coal-bed methane) technique
- pilot scale tests on CO2 storage in saline aquifers
- development of advanced monitoring systems

SUMMER SCHOOL

DIDACTIC LABORATORY on CO_2 storage techniques



Allegato 2 - *Current status of Italian Energy Strategy, with focus on natural gas, coal and CCS*

ALLEGATO 2

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SOCIETÀ TECNOLOGIE AVANZATE CARBONE S.P.A.

ENEA
ITALIAN NATIONAL AGENCY
FOR NEW TECHNOLOGIES, ENERGY AND
SUSTAINABLE ECONOMIC DEVELOPMENT

Working Party on Fossil Fuels:
Sixty-fourth meeting

Current status of Italian Energy Strategy, with focus on natural gas, coal and CCS

Giuseppe Girardi

ENEA
Sustainable fossil fuels and CCS

SOTACARBO
vicePresident

giuseppe.girardi@enea.it

19 – 21 June 2013, Warsaw

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NATIONAL ENERGY STRATEGY (SEN)

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AGENZIA NAZIONALE
PER LE NUOVE TECNOLOGIE, L'ENERGIA
E LO SVILUPPO ECONOMICO SOSTENIBILE

The new government confirmed the SEN approved by the previous government

4 MAIN GOALS

1. **Competitiveness**: **Reduce the gap of the energy cost**, with a gradual alignment to European prices and costs of energy
2. **Environment and Quality**: **Meet and exceed the 20-20-20 environmental objectives**
3. **Security**: Continue to improve our **security of supply**, especially in the gas sector, and **reduce our dependence** on import
4. **Growth**: Promote sustainable economic growth through the **development of the energy sector**

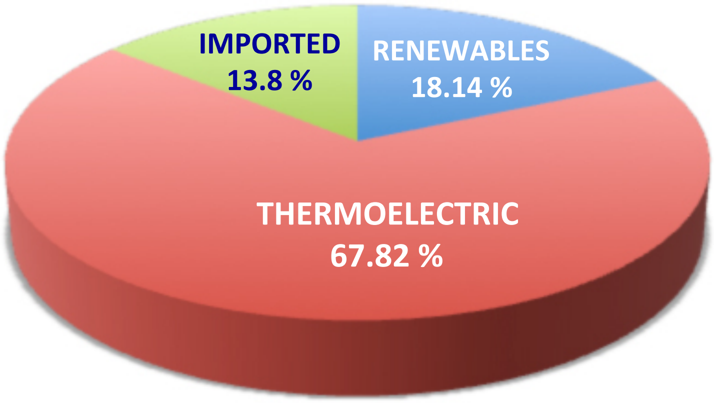
Challange, not only for Italy: Green paper - a strategy to 2030
innovation, development, employment

ELECTRICITY GENERATION IN ITALY

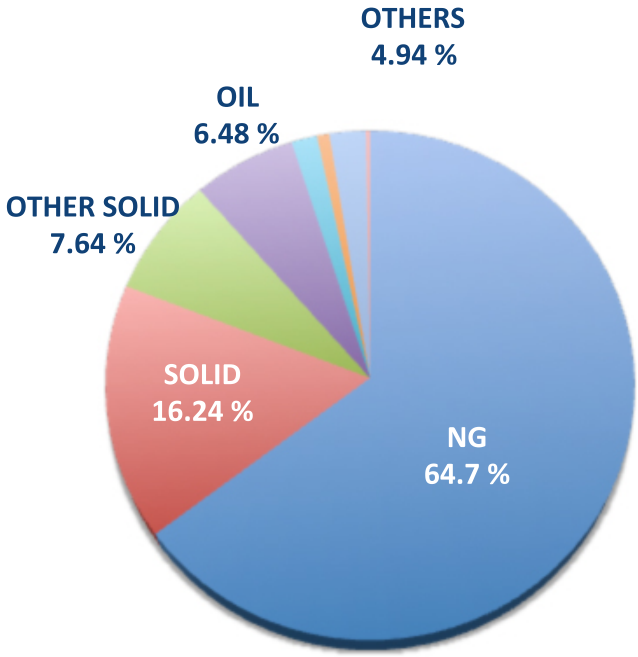
ENERGY REQUESTED:326,000 GWh

THERMOELECTRIC:	221,100 GWh
RENEWABLES:	59,150 GWh
IMPORTED:	45,000 GWh

HYDRO: 52,000 GWh (15.95 %)
WIND + PV: 7,150 GWh (2.19 %)



THERMOELECTRIC ENERGY GENERATION: 221,100 GWh



7 PRIORITIES IN THE MIDDLE PERIOD

1 Energy Efficiency

2 Development of competitive market and South-European gas Hub

3 Sustainable Development of Renewables energy

4 Development of Infrastructures and electric market

5 Restructuring of refining and fuel distribution network

6 Sustainable production of national hydrocarbons

7 Improvement and modernization of governance

Research and Development in Energy sector
↓
-
CCS

FULL USE OF THE EXISTING TRANSPORT CAPACITY

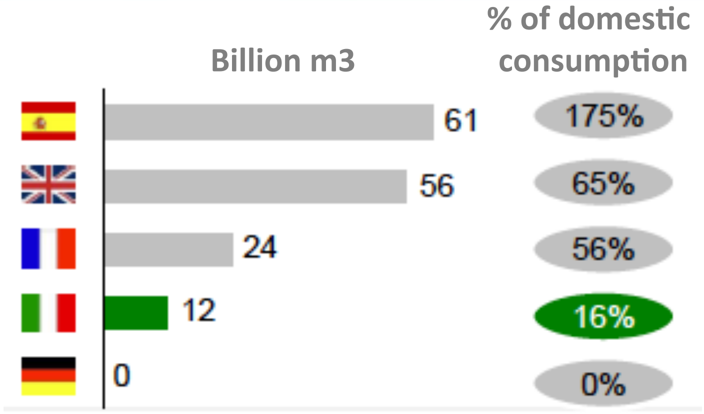
- Promote cooperation for **full integration of the common market**
- Liberalize the allocation and access to the **storage capacity**
- **Separation of SNAM from ENI**: create an independent company, able to invest in new infrastructures (transport, storage and regasification

STRATEGIC INFRASTRUCTURES

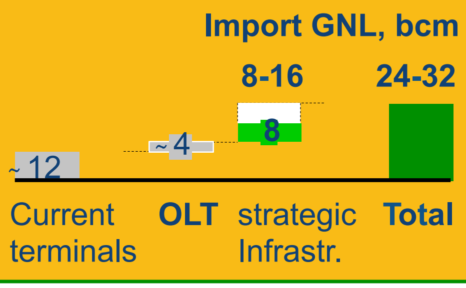
- Build the strategic infrastructures (mainly **LNG** terminals and **storage**)
- Support the implementation of other import infrastructure - pipelines and terminals, in particular the **TAP** pipeline)
- Promote the availability of capacity for **counter-flow towards the markets of Northern and Central Europe**

LNG TERMINALS

The ability to import LNG in Italy is lower than other European countries



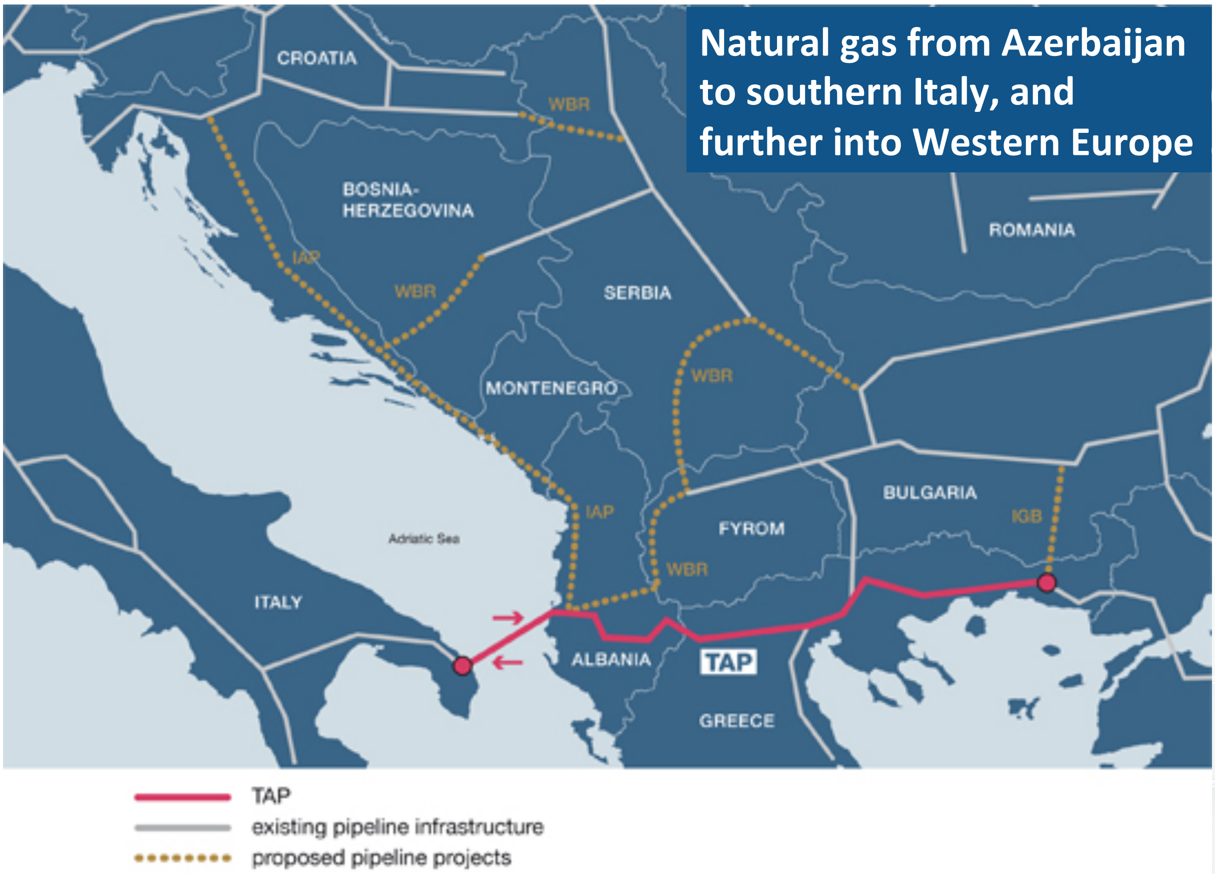
Increase of GNL import capacity from the current 12 bcm to 24-32 bcm



'FRSU TOSCANA', the floating regasification terminal of **OLT** (**O**ffshore **L**ng **T**oscana), is sailing from Dubai, (Drydocks World shipyard) To Livorno

\+ **other 'merchant' plants in addition**

TRANS ADRIATIC PIPELINE



Natural gas from Azerbaijan to southern Italy, and further into Western Europe

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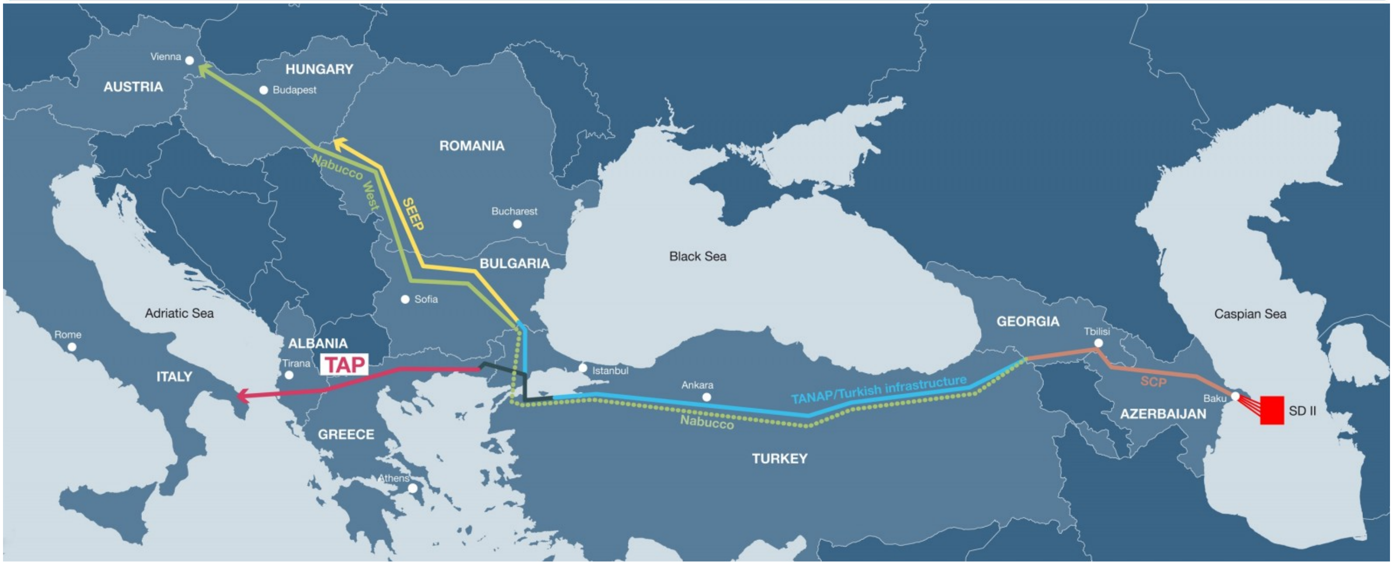
TRANS ADRIATIC PIPELINE



- 10 – 20 bcm of natural gas from Azerbaijan to southern Italy and to Europe
- Final decision of the Azerbaijan government: next weeks
- **Shah Deniz II** field in Azerbaijan will start production in 2017/2018)

- ITALIAN NEW GOVERNMENT HAS APPROVED A LAW CONCERNING TAP PIPELINE: now it has to be approved by parliament

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DEVELOPMENT OF NATIONAL HYDROCARBONS

Increase production of hydrocarbon and support the industry

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SAFETY

- Strengthen safety measures in plants and infrastructures operation
- No projects – in particular those on shale gas – in prized and protected areas
- Shale gas: it isn't a current option

AUTHORIZATION PROCEDURES – Reduce Bureaucracy

- New procedures for authorization, and full license for exploration and production
- Public consultation in order to achieve acceptance and reduce time
- **Compression station at SULMONA** for adriatic pipeline (but some public opposition)
    - Ministry of development is approving procedures for public consultation, as for CO2 storage (EU derective already adopted)

OFF SHORE – increase production, mainly natural gas

- **Gas and oil well at OMBRINA** (but some public opposition)

DEVELOPMENT OF REGIONS AND INDUSTRIAL POLES

- Support the strengthening of technological/industrial poles in Emilia Romagna, Lombardia, Abruzzo, Basilicata, Sicily

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RESEARCH

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PRIORITIES

- Innovative renewable technologies, as concentrating solar power and second-generation biofuels
- Intelligent networks (smart grids, also to facilitate distributed generation), and storage systems, also with a view to sustainable mobility
- Materials and energy efficiency solutions and their technology transfer

- Development of projects on **CCS**, in accordance with European strategy and programmes, aimed at accelerate innovation in power plants as opportunity for Industry to compete on the international market
    - Medium time

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COAL ad CCS in Italy

COAL

- No increase in coal share
- No new plants in the short time
  - Possible: 350 MWe in Sulcis (Sardinia), with 80 MWe CCS
- Porto Tolle: in stand by

CCS

- R&D funded by Ministry of development
- Technology Centre in Sardinia

NER300

- Probably no proposals for CCS

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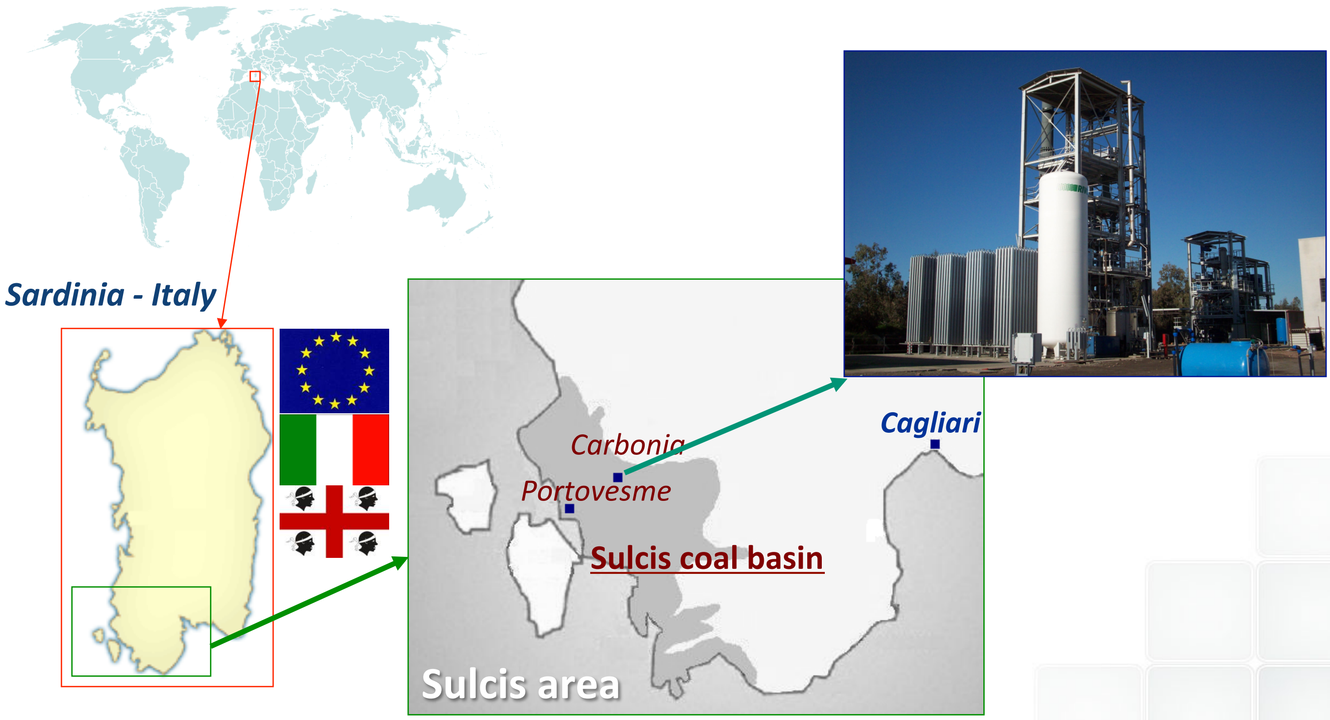
NATIONAL CENTER ON ZERO EMISSION ENERGY

Sustainable fossil fuels and renewables vs Global warming

NATIONAL CENTER ON ZERO EMISSION ENERGY

SOTACARBO RESEARCH CENTRE



NATIONAL CENTER ON ZERO EMISSION ENERGY

R/D - Pilot	Development of "zero emissions" technologies for Power generation and New Fuels production	
Pilot - Demo	Pilot oxycomb. unit (50 MW)	Agreement Sotacarbo-Sofinter-ITEA to build up in Sulcis area the infrastructure for the production of oxycombustion plant components
Pilot - Demo	Test field on CO_2 geological storage	Large scale basin for CO_2 geological storage (injection wells in deep coal seams and aquifers, CH_4 extraction wells)
Demo	350 MW power generation plant with a demonstration 80 MW (equivalent) CCS system	
Education & Public accept.	Summer School	First edition: July 2014 Starting July 2013

NATIONAL CENTER ON ZERO EMISSION ENERGY

Development of zero emissions technologies

Power generation – coal, biomass, wastes

- ❑ Pre combustion CO_2 capture - *(post combustion)*
- ❑ Oxy combustion CO_2 capture
- ❑ CO2 storage (ECBM, aquifers)
- ❑ Advanced combustion
- ❑ pollutant compounds removal

New Fuels

- ❑ Liquid – Coal to Liquid
- ❑ SNG
- ❑ Hydrogen

Experimental tests on pilot platform, properly modified

Integration with renewables

- ❑ CSP for heat and pover
- ❑ Biomass

NATIONAL CENTER ON ZERO EMISSION ENERGY

Technologies for production of fuels from coal

(low rank Sulcis coal)

Coal to liquid

- ❑ simulations
- ❑ Small scale tests
- ❑ Small scale pilot design

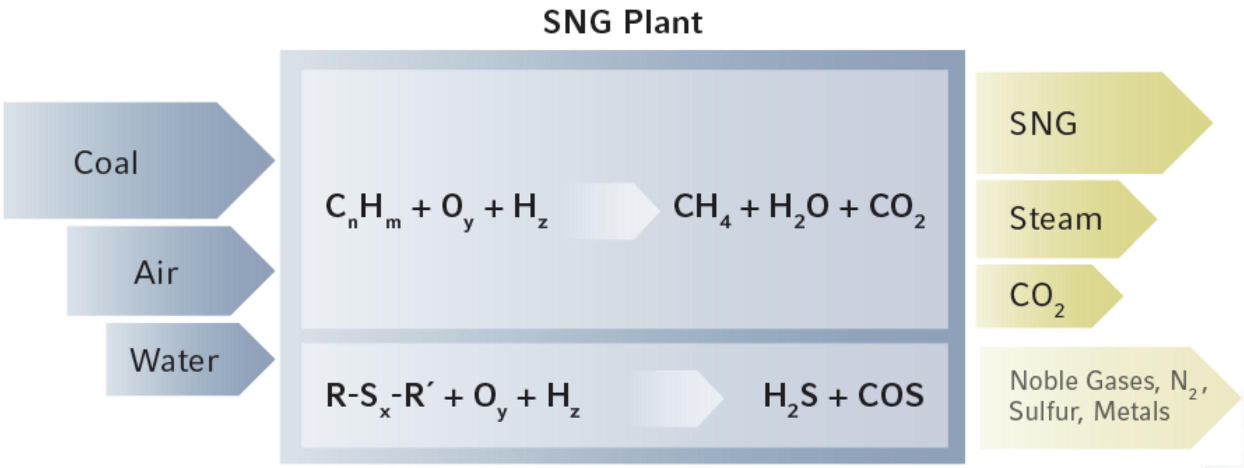
Coal to gas (with CO2 capture)

- ❑ Substitute Natural Gas
- ❑ Methane from CO2 and H2
- ❑ Hydrogen (gasification - CO2 captutre

THE SNG (SOBSTITUTE NG) PLANT CONCEPT

Coal-to-SNG process includes coal gasification, CO shift, Syngas cleanup and methanation, which featured as mature technologies, but high investment

Methanation Black Box Concept



SNG Plant

Coal
Air
Water

$C_nH_m + O_y + H_z \rightarrow CH_4 + H_2O + CO_2$

$R\text{-}S_x\text{-}R' + O_y + H_z \rightarrow H_2S + COS$

SNG
Steam
CO_2
Noble Gases, N_2, Sulfur, Metals

The methanation reactions are highly exothermic

$CO + 3\,H_2 \longleftrightarrow CH_4 + H_2O$ DH = - 205 kJ/mole

$CO_2 + 4\,H_2 \longleftrightarrow CH_4 + 2\,H_2O$ DH = - 165 kJ/mole

---

ADVANCED “VESTA” PROCESS

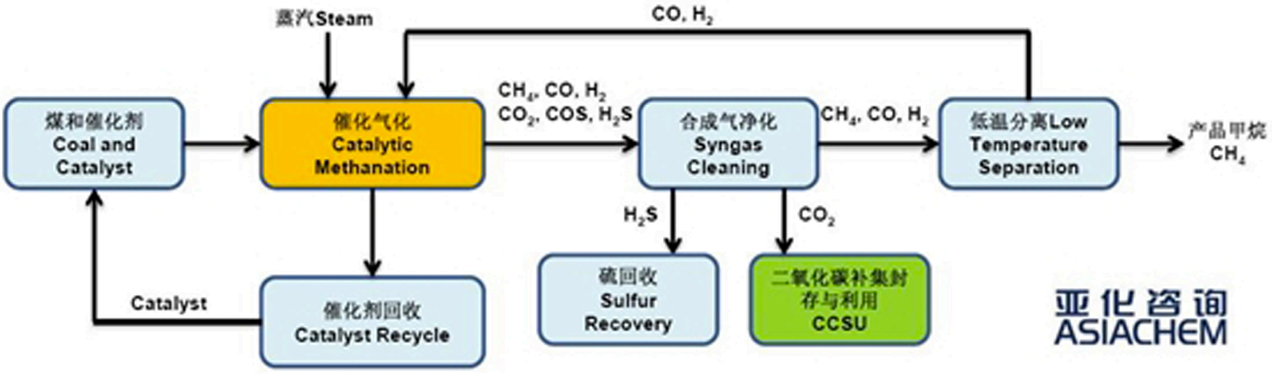
The VESTA SNG Process

- Process to produce **SNG from any syngas**
- **Efficiency to recover heat of reaction**
  - Flexibility in steam production
- **Production of export steam**
- **Full flexibility of gasification technology**
  - Utilization of low quality coal, as Sulcis coal

ONE STEP COAL TO SNG PROCESS

GPE (Great Point Energy Company) has developed a **one-step coal to SNG** process that realizes catalytic reaction in one pressurized fluid reactor:

- three reactions: gasification, water gas shift, and methanation
- coal (or other carbon-containing substances), steam and catalyst in a single reactor to produce SNG



INTEGRATION: GASIFICATION WITH MCFC

H_2S + COS < 1 ppm

clean syngas suitable to feed a MCFC system

1500 hours of experimental tests

\+

MCFC mathematical model
+
tests at ENEA labs

24.0 kg/h
of coal
~ 120 kW_{th}

85.2 kg/h
of clean syngas
113.2 kW_{th}

36.7 kW (electrical energy)
\+
30.2 kW (sensible heat)

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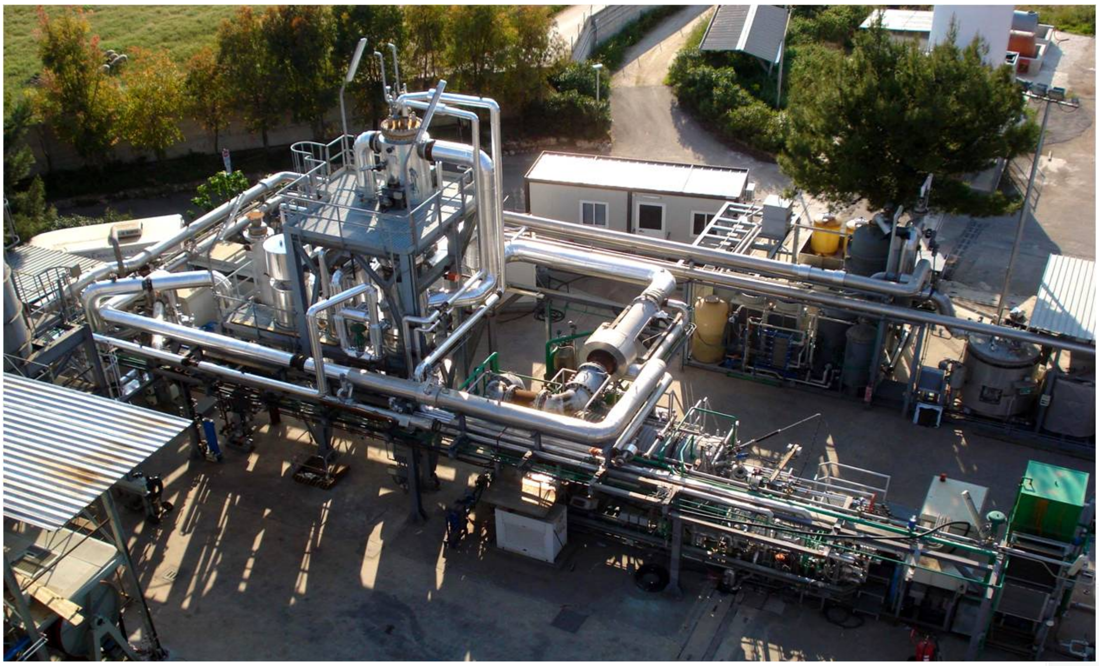
Oxycombustion

5 MW_{th} ISOTHERM® pilot unit by ITEA (Gioia del Colle, Italy)



Build-up, in Sulcis area, of a 50 MW_{th} demonstration oxycombustion unit working ant 10 bar pressure

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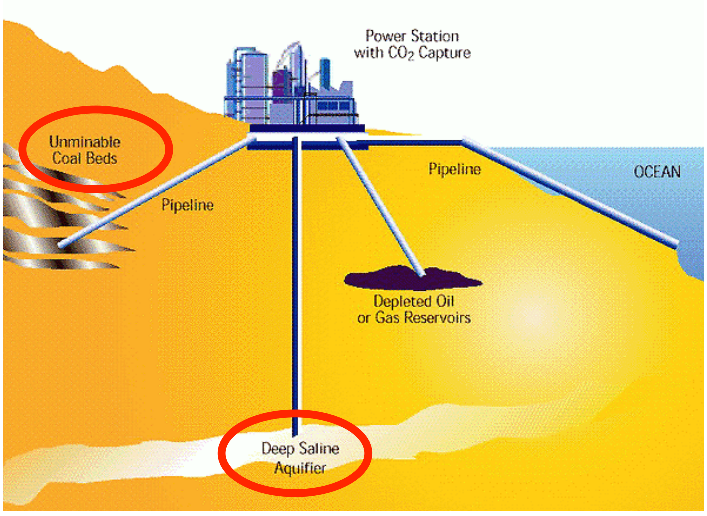
NATIONAL CENTER ON ZERO EMISSION ENERGY

CO_2 geological storage

- pilot-scale tests on ECBM (enhanced coal-bed methane) technique
- pilot scale tests on CO2 storage in saline aquifers
- development of advanced monitoring systems
- Qualification: site for CO2 storage in Italy

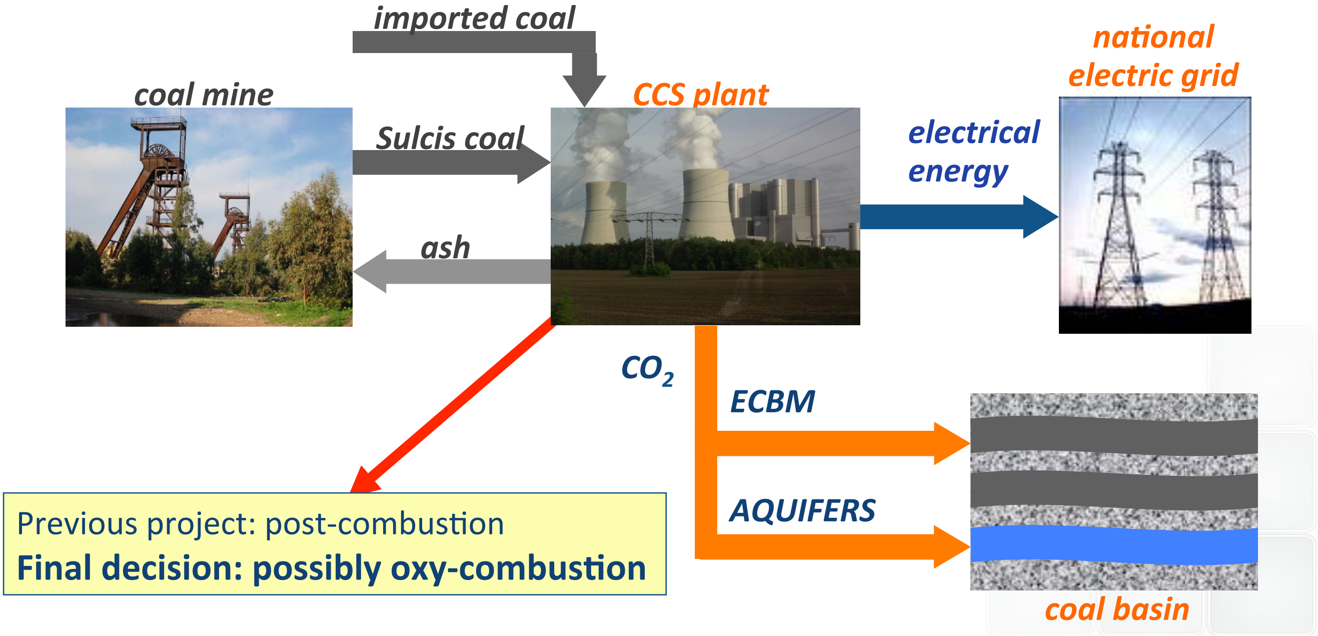
SUMMER SCHOOL

DIDACTIC LABORATORY
on CO_2 storage
techniques



Industrial-scale CCS demonstration plant

- CO_2 capture: oxy or post combustion)
- Two CO2 storage techniques: ECBM and injection in saline aquifers



imported coal

coal mine

Sulcis coal

ash

CCS plant

electrical energy

national electric grid

CO_2

ECBM

AQUIFERS

coal basin

Previous project: post-combustion
Final decision: possibly oxy-combustion

THANK YOU FOR YOUR ATTENTION

Giuseppe Girardi
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Allegato 3 - *Recommendations for research to support CCS deployment in Europe beyond 2020 – update on CO2 capture*

ALLEGATO 3

Zero emissions platform

Recommendations for research to support CCS deployment in Europe beyond 2020

Update on CO_2 Capture

European Technology Platform for Zero Emission Fossil Fuel Power Plants

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1 Introduction

The critical role of CO_2 Capture and Storage (CCS) in meeting the EU's energy, climate and societal goals is now indisputable: the European Commission's Communication[1] *on CCS has confirmed that is not only "vital for meeting the Union's greenhouse gas reduction targets", it provides a "very visible link between jobs in local communities and continued industrial production". Indeed, CCS must account for 19-32% of total emissions reductions in the power sector by 2050, which means that "For all fossil fuels, Carbon Capture and Storage will have to be applied from around 2030 onwards".* [2]

In 2010, ZEP published its ground-breaking report, "Recommendations for research to support the deployment of CCS in Europe beyond 2020"[3] which identified the main R&D areas for driving down costs through well-targeted R&D programmes. FP7-ENERGY calls have taken into account several of the recommended priorities, developing various key components of the CCS value chain.

Ongoing R&D for CCS is essential in order to drive down costs – and deliver EU climate targets

In the power sector, first-generation technologies for all three capture pathways (post-combustion, pre-combustion and oxy-fuel) have already been tested at large pilot-scale facilities and are now ready for the demonstration phase. However, CO_2 capture is an emerging technology and historical experience with comparable processes suggests that significant improvements are achievable through futher well-targeted R&D. The optimisation of current and next-generation technologies is therefore essential to further drive down costs, enable rapid deployment post 2020 – and deliver EU climate targets.

R&D is also needed to validate capture technologies for use in industries *beyond* power – expected to deliver half of the global emissions reductions required by 2050 from CCS.[4] Indeed, in some industries, such as steel and cement, it is the only means of achieving deep emission cuts. As several have almost pure CO_2 streams, this also dramatically reduces the cost of CO_2 capture, while clustering different CO_2 sources to a transport network will result in significant economies of scale for both industrial *and* power projects.

Combined with sustainable biomass, CCS can even remove CO_2 from the atmosphere (Bio-CCS[5]) – the only large-scale technology that can deliver net *negative* emissions (in addition to any emissions reductions achieved by replacing fossil fuels with biomass). Certain biofuels production routes could provide 'low-hanging fruits' for early, low-cost CCS deployment and in the US, Bio-CCS is already being deployed at industrial scale.[6]

This report therefore prioritises immediate R&D needs of CO_2 capture, focusing mainly on the power sector, while identifying the need to verify industrial applications – taking into account advances achieved to date and future requirements to drive down costs.

Future R&D programmes must also allow for new, breakthrough technologies

While long-term R&D needs have been identified for CO_2 capture technologies known today, novel technologies – or the novel use of known technologies – are likely to be presented in the years to come. It is therefore vital that future R&D programmes are formulated in such a way that breakthrough technologies can be incorporated and given a fair evaluation.

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[1] http://ec.europa.eu/energy/coal/ccs_en.htm
[2] http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf
[3] www.zeroemissionsplatform.eu/zep-long-tem-r-d-ccs
[4] International Energy Agency (IEA). See also ZEP's report, "CO_2 Capture and Storage (CCS) in energy-intensive industries: an indispensable route to an EU low-carbon economy": www.zeroemissionsplatform.eu/library/publication/222-ccsotherind.html
[5] See ZEP's report, "Biomass with CO_2 Capture and Storage (Bio-CCS) – The way forward for Europe": www.zeroemissionsplatform.eu/library/publication/206-biomass-with-co2-capture-and-storage-bio-ccs- the-way-forward-for-europe.html
[6] The ADM bioethanol-CCS project

Such technologies must not only be advanced and innovative, but have the potential to effect improvements compared to first-generation technologies – mainly in terms of cost and efficiency. They will then have to undergo the full development product cycle (laboratory – small/large pilot – demonstration – pre-commercial (first-of-a-kind) – commercial). Finally, it is essential to recognise the need for large-scale pilots, which are risky and costly to carry out and therefore a limiting factor for new developments.

ZEP will also publish an update on research priorities for CO_2 *transport and storage in due course.*

The Zero Emissions Platform (ZEP)

Founded in 2005, the Zero Emissions Platform (ZEP) is focused on CCS as a critical technology for achieving Europe's energy, climate and societal goals. A coalition of over 200 members from 19 countries – representing academics, scientists, European utilities, petroleum companies, equipment suppliers and environmental NGOs – ZEP serves as an advisor to the European Commission on the research, demonstration and deployment of CCS.

This report has been developed by CO_2 capture experts within ZEP's Taskforce Technology (Working Group (WG) 'Long-term R&D Plan for Capture Technology', with additional contributions from WG 'Other Industries').

www.zeroemissionsplatform.eu

2 Recommendations for research on CO_2 capture

2.1 Technology structure and evaluation methodology

Sections 2.2-2.5 contain an overview of technologies that could be applicable to CO_2 capture from power plants, or enable the potential of CO_2 capture to be fully realised. The technologies have been structured according to the technology blocks in section 2.1.2. Development of technology maturity over time has been estimated for three periods (see section 2.1.1, Definition of timeframe) and maturity levels defined (see section 2.1.3, Definition of validation status). It must be emphasised that the estimated development of technology maturity depends on continuous R&D in the identified areas.

However, a multitude of R&D topics has been identified in this report and pursuing R&D in all areas would be very costly. Research carried out over the past decade has enabled a tremendous increase in knowledge of CO_2 capture from power plants, which enables the identification of some technologies as more promising than others. It is also recognised that there are many technologies where it is still too early to quantify what kind of impact they will have on CO_2 capture, since more R&D is still required.

Based on experience within ZEP, an evaluation has therefore been made of whether the R&D topics listed could have a positive impact on investment decisions by power plant operators. The methodology applied is described in section 2.1.4 and the resulting recommendations for further research on CO_2 capture provided in section 2.6. It should be noted that some of the technologies listed in sections 2.2-2.5 are not explicitly recommended for further R&D by ZEP, but are still included for the sake of completeness.

2.1.1 Definition of timeframe

The timeframe for long-term R&D has been categorised for the following intervals, corresponding to periods where R&D efforts performed now and in the years to come will result in commercially available technologies:

- *Period I, up to 2020*: short term – not the subject of this report, but provided in order to establish a baseline and likely development. Investment decisions made in the early 2020s will need some proof of concept and must therefore be based on technologies that are fully validated (green in summary tables – see section 2.1.3) during Period I or early in Period II.
- *Period II, 2020-2030*: technologies brought to commercial operation within this period are likely to be based on improvements and refinements of technologies employed in Period I. Some new technologies, today in the R&D phase, should reach the demonstration or even the commercial phase.
- *Period III, 2030 and beyond*: long-term technologies – technologies brought to commercial operation within this period are likely to be based on optimised and refined technologies from Periods I and II. In particular, demonstration phase technologies from Period II should become commercial. New technologies, which today could be in R&D infancy, should reach the demonstration phase and then become commercially available.

2.1.2 Capture routes and technology blocks

Table 1 below gives an overview of the "technology blocks" within each of the three main capture routes, in accordance with ZEP's "Matrix of Technologies[7]" (October 2008), although the structure has been slightly rearranged. Technology blocks that are specific to CO_2 capture are in **bold** and the long-term R&D needs for these blocks are further described in chapters 2.2 to 2.4. Technology blocks that are not directly linked to only one CO_2 capture technology (e.g. 'CO_2 compression') are not in bold in Table 1 and are addressed in chapter 2.5. This is also the case for technology blocks that are not CO_2 capture specific but more generally related to power plant improvements (e.g. 700°C steam cycle).

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[7] www.zero-emissionplatform.eu/website/docs/ETP%20ZEP/ZEP%20Technology%20Matrix.pdf

Table 1: CO_2 capture technology blocks (according to ZEP's document: "CO_2 Capture and Storage (CCS) – Matrix of Technologies"[6]):

Post-combustion		**Oxy-fuel**		**Pre-combustion**
		Oxygen separation		**Oxygen separation**
Fuel preparation Lignite drying		Fuel preparation Lignite drying		Fuel handling Lignite drying
Combustion (NG GT, Coal PC, Lignite PC, CFB, Biomass)		**Oxy-combustion (Oxy-PC/ CFB, Oxy-gas, Biomass)**		**Gasification/reforming (NG, Coal, Lignite, Biomass)**
Boiler	Gas turbine	**Boiler**	**Gas turbine**	Dust removal
Steam cycle		Steam cycle		**Water-gas shift**
700°C cycle.		700°C cycle.		
	CO_2 enrichment in flue gas	**Flue gas recycling and O_2 mixing**		Desulphurisation
Flue gas treatment and heat recovery		**Flue gas treatment and cooling**		**CO_2 capture/H_2 separation**
CO_2 capture				**H_2 gas turbine**
CO_2 purification*		**CO_2 purification**		CO_2 purification*
CO_2 compression		CO_2 compression		CO_2 compression
		Integrated components **		**Integrated components ****
Overall process development and integration		**Overall process development and integration**		**Overall process development and integration**

* For processes where the CO_2 stream formed contains co-adsorbates and/or other impurities that cannot be sequestrated with the CO_2, further processing will be necessary. Specific separation steps addressing this may therefore give rise to R&D activities where the aim is to modify existing processes or develop new specific separation processes.

** Two or more components/sub-processes integrated into one unit. Examples are CLC in the oxy-fuel route combining oxygen separation and combustion, and sorption enhanced reforming/gasification in the pre-combustion route combining gasification/reforming, water-gas shift and CO_2 removal.

2.1.3 Definition of validation status

In the following chapters, summary tables are provided where colour coding defines the validation status of the different technologies under each technology block. As in ZEP's "Matrix of Technologies"[6], validation status is divided into three levels:

- **Red** Not validated: not tested/less advanced than pilot scale
- **Yellow** Partly validated: ready for a demonstration plant (a few 100s of MW_{el}, depending on the technology)
- **Green** Fully validated: commercially available for application in large power plants.

2.1.4 Methodology for evaluating the importance of R&D topics

In order to evaluate the importance of R&D topics listed, an estimate was made of the impact of each R&D topic on various investment decision parameters *if/when the technology researched becomes fully validated and ready for commercial applications* (validation status Green, as defined in section 2.1.3). As far as possible, this has been assessed with reference to appropriate base cases consisting of present commercially available technology.

Seven investment decision parameters were defined (Table 2) for which different weighting factors were assigned in order to rank them according to typical power plant operator priorities when making investment decisions. The weighting factors therefore also provide guidance on the relative importance of areas in the search for improvements in CO_2 capture-related technologies.

Table 2: Definitions and weighting factors for investment decision parameters used to assess the impact of R&D topics on commercialised CO_2 capture.

Investment decision parameter	Weighting factor	Definition
Efficiency	2	Impact of the technology on the electric efficiency of the power plant
CAPEX	2	Capital expenditures, i.e. impact of the technology on investment costs for the power plant
O&M (excluding fuel)	1.5	Impact of the technology on operational and maintenance costs of the power plant, excluding fuel costs which are covered by the efficiency parameter. This can include costs incurred by (e.g.) solvent replacement or membrane replacement.
Availability	1.5	Impact of the technology on the availability of the power plant. The availability of a power plant is the percentage of time over one year that the plant is capable of producing electricity and includes both planned and unplanned stops.
Operability	1.5	Impact of the technology on the operability of the plant, i.e. on flexibility (acceptable steady-state operation over a range of conditions), controllability (ability to move to new steady-state set-points and to handle process disturbances), start-up/shutdown characteristics and the ability to handle equipment failures in a safe manner.[8]
HSE	1	Impact of the technology on health, safety and environment (HSE) related to the power plant operation
Capture rate	1	The fraction of the CO_2 generated by the power plant that is captured (90% CO_2 capture is the base case).

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[8] Alie, C., Douglas, P. L., Davison, J. On the operability of power plants with CO_2 capture and storage, Energy Procedia 1 (2009) 1521-1526.

Motivation for assigned weighting factors
When a decision is made whether to invest in a new power plant, efficiency and CAPEX are generally the two most important parameters, since these are decisive for the economy of the power plant over its lifetime. This justifies a weighting factor of 2. The costs of operation and maintenance are also important for investment decisions, although not as important as CAPEX, which justifies a weighting factor of 1.5.

Furthermore, it is predicted in the EU Energy Roadmap 2050 that the share of renewable energy will rise substantially in Europe until 2050. A significant share of renewables in the power system will pose large requirements on balancing power that can be rapidly put into operation when renewables such as wind or solar power are not producing electricity. This, in turn, means that the operability of power plants with CO_2 capture may become an important basis for investment decisions in the future. However, the owner's requirements on load-changing capacities could very well vary for different power plant concepts, e.g. an IGCC is likely to operate in base load, where as an NGCC is more likely to have a load following role. Altogether, the importance of power plant operability justifies a weighting factor of 1.5.

The availability of power plants, i.e. the amount of time during a year that they can actually produce power, is also important when making investment decisions; and the same importance is assigned to operation and maintenance costs, excluding fuel (which is covered by the efficiency parameter). Altogether, these two parameters justify a weighting factor of 1.5.

Hence, the two remaining technology parameters with the lowest weighting factors are HSE and CO_2 capture rate. HSE can be regarded as a binary issue that needs no further weighting. Significantly increased negative impact on HSE from a CO_2 capture technology under development is enough to halt this technology, regardless of potential improvements in efficiency and CAPEX. Improvements in HSE can also be an additional reason for pursuing an R&D topic that appears fairly promising.

Assigning a weighting factor of unity to CO_2 capture rate is justified by the fact that the baseline capture rate considered for the R&D topic evaluation is 90%. There are certainly technologies available which can increase CO_2 capture rate beyond 90%, but it is usually possible to design the overall power plant in such a way that efficiency is increased and/or CAPEX reduced, while targeting 90% CO_2 capture. Technologies that achieve a CO_2 capture rate significantly below 90% will also, in an appropriate economical context, be penalised through increased O&M costs due to high CO_2 emissions.

Enabling activities
It is not relevant to evaluate some of the R&D topics listed in section 2.2-2.5 against the technology parameters listed in Table 2. Typical examples are the development of numerical simulation tools or materials databases. The purpose of this category of R&D topics is to enable an improved capture route, rather than achieve a direct technology improvement. (Enabling activities are marked “EA” in the summary tables in sections 2.2-2.5).

It must be emphasised that the conclusions and recommendations in section 2.6 are based on *estimates* of the impact of different R&D topics, according to the current level of knowledge within ZEP. The level of knowledge is also different for different parameters, with the greatest knowledge available for efficiency, capture rate and CAPEX, which are generally the research areas first explored for a novel technology. Operability and availability are still, to a large extent, unexplored research areas.

2.2 Post-combustion technologies

2.2.1 CO_2 capture in post-combustion applications

Post-combustion capture technologies can, in principle, be applied to flue gases from all kinds of industrial processes, in particular power production from fossil fuels and biomass, cement, steel and aluminium production. Several separation principles are relevant. Absorption based on liquid chemical solvents (amines) is currently the leading and most developed technology. Further along the timeline, high temperature calcium looping cycles, which have undergone a fast development process in recent years, is seen as a potential candidate; also membrane separation and adsorption by low temperature solid sorbents are potential candidates in the longer term.

Key challenges and long-term R&D targets

- Flexible operation of integrated capture and power plants.
  Long-term R&D target: develop processes that enable the integrated plant to respond quickly and efficiently to changes in power and carbon markets.
- The high energy requirement of the separation process; a penalty of ~10% points in efficiency loss with present technology (MEA). A long-term R&D target (beyond 2030) should be to reduce this to below 5% points.
- The low CO_2 partial pressure (especially for NG power plants) and the large flue gas volumes imply very large equipment volumes and contacting surfaces.
  Long-term R&D target: reduce equipment volumes by developing more effective contacting surfaces.
- Flue gas impurities (depending on fuel).
  Long-term R&D target: develop capture processes independent from, or at least very robust with respect to composition of impurities in the flue gas. Develop capture processes which can efficiently co-capture impurities of larger concentration (e.g. SO_2).
- Degradation and environmental aspects.
  Long-term R&D target: develop processes with very low overall emission levels (e.g. degradation products) and in line measurement techniques for very low concentrations.
- Material of construction
  Long-term R&D target: develop lower cost materials for construction of capture plants.

R&D needs

- Liquid absorbents: liquid solvents need to have a lower energy requirement for regeneration than today, be non-toxic and environmentally friendly. They should also be robust against flue gas impurities and have a low degradation rate. In order to decrease CAPEX and OPEX, technological development of gas/liquid contactors is also necessary (including also membrane contactors). Research on this type of solvent is ongoing and progressing, but is likely to continue beyond 2020. Systems using additional effects such as precipitation, pH swing and liquid extraction will probably play an important part in their development. Adaptation of capture and power process configurations is also necessary to make best use of these improved solvents.
- Calcium looping (or carbonate looping) is a chemical looping type of process that uses CaO particles to react with CO_2 in the flue gas. In recent years, this process has reached MW_{th} pilot scale, using existing Circulating Fluidised Bed technology in the carbonator reactor. The subsequent calcination of $CaCO_3$ in an oxyfired CFBC (see 2.3.2) regenerates the CaO and returns CO_2. The overall efficiency penalty can approach 6% points. R&D issues are: scaling up of Circulating Fluidised Bed carbonator and experimental validation at increasing scales, alternative calciner designs, CO_2 sorbent performance issues related to chemical and mechanical stability, integration of purge uses, combined SO_2 capture and low-cost reactivation processes.
- High-temperature solid sorbents other than natural CaO/CaCO3.
- Low-temperature solid sorbent (amines supported on carbon, metal oxide frameworks etc.) are being investigated as alternative functional materials for post-combustion CO_2 capture. High adsorption rates, selectivities and capacities under low partial pressures of CO_2 are needed for these materials to be suitable for large-scale CO_2 capture.
- Membranes: the application of membranes in fossil fuel power plants requires large membranes that can be maintained and repaired. They also have to withstand pollution, fouling, as well as temperature

and pressure changes – properties that cannot be delivered by today's membrane technology. R&D needs: development of low-cost and more robust membrane modules with high permeability and selectivity.

- Cryogenic technologies: cryogenic liquefaction is feasible today, anti-sublimation process for CO_2 separation is in the early demonstration phase.
- Generating hydrates for CO_2 capture: R&D is needed to increase selectivity and kinetics.
- Materials of construction: R&D for lower-cost solutions.

Summary table: post-combustion CO_2 capture

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Liquid solvents, energy requirement < 2.5 GJ/tonne CO_2	🟨	🟩	🟩
Liquid solvents, energy requirement < 1.5 GJ/tonne CO_2	🟥	🟥🟨	🟩
Minimisation of solvent degradation/avoidance 7of emissions*	--	--	--
Calcium looping (a.k.a carbonate looping)	🟨	🟨🟩	🟩
High-temperature solid sorbents other than natural CaO/CaCO3	🟥🟨	🟨	🟩
Low-temperature solid sorbents	🟥🟨	🟨	🟩
Capture processes for liquid and solid sorbents* (EA)	--	--	--
Membranes development and stability	🟥	🟨	🟩
Cryogenics: anti-sublimation	🟨	🟩	🟩
Hydrates	🟥	🟨	🟩

*Maturity will depend on the solvent under consideration. For MEA, the colour code is green from 2020.
**Maturity will depend on the solvent or sorbent under consideration

2.2.2 CO_2 enrichment in flue gas from gas turbines

The basic idea with this concept is to recirculate part of the flue gas from the gas turbine back to the compressor inlet, thereby increasing the CO_2 concentration in the flue gas, which is beneficial to the post-combustion CO_2 capture process. Concepts with oxygen-enriched air are also envisaged for producing flue gases with a further increase in CO_2 concentration.

Key challenges and long-term R&D targets

- Increase CO_2 content in the flue gas in order to facilitate CO_2 capture.
- Stable and complete combustion in CO_2- and/or oxygen-enriched atmosphere

R&D needs

- Process configuration optimisation with recirculation of (part of) the flue gas prior to the CO_2 capture unit
- Adaptation of gas turbines for operation with new CO_2- and/or oxygen-enriched media, in particular to ensure stable and complete combustion

Summary table: CO_2 enrichment in flue gas

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Process configuration optimisation	🟨	🟩	🟩
Gas turbine development for CO_2 and/or O_2 enrichment	🟥	🟨🟩	🟩

2.2.3 *Overall process development and integration*

Integration of the post-combustion capture process with the power generation process and CO_2 compression is a key issue for reducing the energy penalty of post-combustion capture and therefore requires further attention. Overall environmentally-friendly integration of the power plant with respect to water consumption and pollutants is also vital.

Key challenges and long-term R&D targets

- Development of gas and solid fuel power processes with integrated post-combustion CO_2 capture process, with maximised power output and minimum loss of waste heat, also taking into account good part-load performance.

R&D needs

- Minimisation of overall energy penalty for flue gas cleaning and CO_2 compression and intercooling
- Minimisation of overall energy penalty for the steam cycle configuration with respect to CO_2 capture and compression, and good part-load performance
- Impact of integration on system reliability and availability
- Environmental integration of the power plant with respect to (e.g.) cooling water requirements, liquid effluents and their purifications
- Development and implementation of dynamic models to study transients in the power process, as well as in the capture unit

Summary table: overall process development and integration

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Energy efficient flue gas cleaning and CO_2 compression	🟨	🟩	🟩
Optimisation of steam power cycle to match capture process*	--	--	--
Integration impact on reliability and availability *	--	--	--
Environmental integration of power plant*	--	--	--
Dynamic modelling, simulations and analysis*	--	--	--

*Maturity depends on the capture process under consideration

2.3 Oxy-fuel technologies

2.3.1 *Oxygen production for oxy-fuel applications*

For the first large-scale demonstrations (100s of MW_{th}) of oxy-fuel power plants and the first commercial generations, cryogenic air separation will be the only viable air separation technology at large scale. In the longer term, other air separation technologies based on membranes or adsorbents are seen as potential candidates.

Key challenges and long-term R&D targets

- Reduced energy consumption for oxygen production. Specific energy consumption of current cryogenic processes is in the range of 160-220 kWh/tonne at ISO conditions.[9] A long-term R&D target is to reduce this to 120-140 kWh/tonne for improved cryogenic processes and to 90-120 for membrane or sorbent-based technologies.
- Standardisation to reduce investment costs for cryogenic ASUs
- Adaption and optimisation of cryogenic air separation for specific oxy-fuel boiler requirements.

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[9] Air at 101325 Pa, 15°C, 60%RH and oxygen at atmospheric pressure; for oxygen at 140 kPa abs, it adds 10 kWh/tonne

R&D needs

- Advanced cryogenic air separation technology, heat integration with other parts of the power plant or other adjacent 'cold industries' (e.g. LNG regasification)
- Flexible cryogenic air separation with improved turndown and load following capabilities with minimised impact on O_2 purity and specific power consumption
- High-temperature oxygen-separating membranes and adsorbents which may have the potential for efficiency improvement in oxy-fuel operation, compared to cryogenic ASU
  - Further materials development (flux, improved performance at lower temperatures (below 700°C), industrial fabrication methods)
  - Materials stability at sour conditions (enables use of recycled CO_2 for sweep/regeneration)
  - Further component development (membrane scale-up and manufacturing and adsorbent reactor design) and integration into the power process
  - Pilot and full-scale demonstration.

Summary table: oxygen production for oxy-fuel applications

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Advanced cryogenic air separation	🟨 🟩	🟩 🟩	🟩 🟩
Flexible cryogenic air separation	🟨 🟨	🟩 🟩	🟩 🟩
Oxygen separating membranes (flux, stability, manufacturing)	🟨 🟨	🟨 🟩	🟩 🟩
Oxygen separating adsorbents (O2 capacity, stability)	🟨 🟨	🟨 🟩	🟩 🟩
Membrane and adsorbent material stability at sour conditions	🟥 🟨	🟨 🟩	🟩 🟩
Membrane unit manufacturing, development and process integration	🟥 🟥	🟨 🟨	🟩 🟩
Adsorbent unit development and process integration	🟨 🟨	🟨 🟩	🟩 🟩

2.3.2 Oxy-fuel boilers

In Period I, extensive R&D is ongoing to create a strong, validated basis for the design of oxy-fuel boilers for use in large-scale demonstrations of oxy-fuel power plants (100s of MW_{th}). Validations and R&D are also expected to continue beyond the first demonstration plants. These first generation(s) of oxy-fuel boilers will operate at conditions similar to air-fired boilers. Selecting a higher O_2 concentration for PF, as well as CFB boilers, provides the potential for cost savings and efficiency improvements, but also requires completely new boiler designs.

Key challenges and long-term R&D targets

- In Period I, R&D on corrosion, slagging and fouling in solid fuel oxy-fuel PF and CFB boilers is ongoing and expected to continue beyond the first demonstration plants.
- Exploit the inherent potential for boiler size and cost reduction for PF and CFBs by enabling higher O_2 concentrations and thus reduced flue gas recirculation.
- Improved knowledge of sulphur chemistry for solid fuels
- Enhanced knowledge of the use of lean fuels (low-volatile coals, anthracite, petcoke)
- In Period I, improved CFD modelling is ongoing and expected to continue beyond the first demonstration plants.

R&D needs

- Boiler heat exchanger and refractory materials: issues regarding slagging, fouling and corrosion related to specific oxy-fuel flue gas conditions need further investigation; tests are ongoing and expected to continue beyond the first demonstration plants.

- Formation of various (gaseous) sulphur species (capturing in fly ash, SO_3 formation, reduction of recycled SO_2/SO_3) and direct desulphurisation without the intermediate calcination step to be further investigated.
- Lean fuels (low-volatile coals, anthracite, petcoke) require special furnaces (down-shot, slag-tap) and/or special combustion technologies (indirect firing) for air combustion. Oxygen enrichment may offer the application of conventional direct PF combustion in conventionally shaped furnaces.
- CFD modelling (chemistry, interaction with CO_2, radiation) is being adapted for oxy-combustion and validated in Period I, and expected to continue beyond the first demonstration plants.
- CFB bed material behaviour: heat extraction from solid loop, in-situ sulphur removal is being investigated in Period I.
- PF and CFB boiler design for size and cost reduction with increased O_2 concentration (i.e. less flue gas recycled). The development and tests in laboratory and pilot plants of:
  - Combustion characteristics in high O_2 concentration
  - Design and heat managing schemes for high O_2 concentration boilers
- Novel pressurised combustion concepts (with dry or wet coal feed) able to produce a concentrated, pressurised CO_2 stream
- Slagging oxy-fuel boilers
- Operation with multiple/'dirty' fuels/biomass in oxy-fuel CFB and co-fired in oxy-fuel PF
- Development and optimisation of boilers that can switch between air-firing mode and oxy-fuel mode
- Development and optimisation of burners for oxy-fuel operation in boilers.

Summary table: oxy-fuel boilers

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020		2020-2030		2030-
Boiler refractories and heat exchanger materials (EA)	🟨	🟩	🟩	🟩	🟩
Sulphur chemistry (EA)	🟨	🟩	🟩	🟩	🟩
Lean fuels (low-volatile coals, anthracite, petcoke)	🟨	🟨	🟩	🟩	🟩
CFD Modelling (EA)	🟨	🟨	🟩	🟩	🟩
CFB bed material behaviour	🟨	🟩	🟩	🟩	🟩
High O_2 concentration combustion, heat management	🟨	🟨	🟨	🟩	🟩
Pressurised oxy-fuel combustion concepts	🟨	🟨	🟨	🟩	🟩
Slagging oxy-fuel boilers	🟨	🟨	🟨	🟩	🟩
Multiple/dirty fuels/biomass in CFB	🟥	🟥	🟨	🟨	🟩
Boilers designed for both air-firing and oxy-fuel mode	🟨	🟨	🟩	🟩	🟩
Oxy-fuel burners	🟨	🟨	🟩	🟩	🟩

2.3.3 Oxy-fuel gas turbine

The natural gas-fired oxy-fuel gas turbine, operating with a CO_2/H_2O mixture as the working medium, and with recirculation of the main part of the working medium, can be designed from an aerodynamic point of view within current engineering practice. R&D is still needed in terms of structural analysis and materials to be used for construction, also taking the altered heat transfer conditions into account.

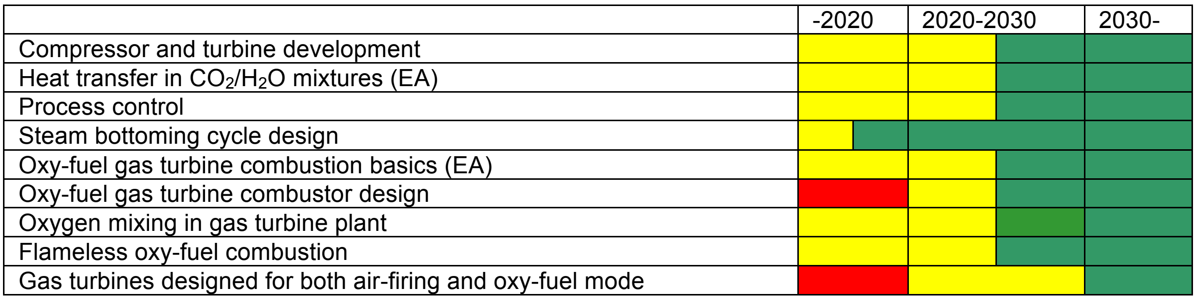
Key challenges and long-term R&D targets
- Turbomachinery development, taking into account the altered heat transfer conditions in the hot parts
- Overall process design and control
- Oxy-fuel gas turbine combustors: combustion and heat transfer

R&D needs

- Design of compressor and turbine for operation with a CO_2/H_2O mixture as the working medium
- Improved knowledge of heat transfer in turbines operating with a CO_2/H_2O mixture, for the design of new cooling schemes
- Design of control system for the semi-closed CO_2/H_2O gas turbine, with massive recirculation of the working medium
- Development of steam bottoming cycle to match the gas turbine operating parameters
- Oxy-fuel gas turbine combustors:
  - Basic investigation of combustion of gaseous fuel with O_2 in a CO_2 and H_2O environment under high pressure
  - Combustor design to enable complete and stable combustion of the fuel under altered (compared to air) heat transfer conditions
- Investigation of oxygen mixing in the gas turbine process
- Flameless oxy-fuel combustion
- Gas turbine design with the flexibility to switch between air-firing and oxy-fuel mode

Summary table: oxy-fuel gas turbine

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)



	-2020	2020-2030	2030-
Compressor and turbine development	🟨	🟨🟩	🟩
Heat transfer in CO_2/H_2O mixtures (EA)	🟨	🟨🟩	🟩
Process control	🟨	🟨🟩	🟩
Steam bottoming cycle design	🟨🟩	🟩	🟩
Oxy-fuel gas turbine combustion basics (EA)	🟨	🟨🟩	🟩
Oxy-fuel gas turbine combustor design	🟥	🟨🟩	🟩
Oxygen mixing in gas turbine plant	🟨	🟨🟩	🟩
Flameless oxy-fuel combustion	🟨	🟨🟩	🟩
Gas turbines designed for both air-firing and oxy-fuel mode	🟥	🟨	🟩

2.3.4 Flue gas recycling and O_2 mixing

Systems for mixing oxygen and recycled flue gases are being investigated and tested in Period I. Further improvements can be beneficial for combustion process control.

Key challenges and long-term R&D targets

- Technologies and approved construction materials for the safe mixing of oxygen and recycled flue gases that may contain dust and unburnt carbon
- Individual mixing points for O_2 and recirculated flue gas (in burner, overfire, pulveriser)

R&D needs

- Research and validation of technologies and approved construction materials for safe mixing of recycled flue gases and oxygen is ongoing in Period I and expected to continue.
- Individual mixing of O_2 and recirculated flue gas may offer further possibilities to steer the ignition/ pyrolysis/combustion process.

Summary table: flue gas recycling and O_2 mixing

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Safe mixing of recycled flue gases and oxygen (EA)	🟨🟩	🟩	🟩
Individual mixing of O_2 and recirculated flue gas	🟨	🟨🟩	🟩

2.3.5 *Flue gas treatment and cooling*

R&D to adapt and validate by-product handling for specific oxy-fuel flue gas conditions is ongoing in Period I and further improvements are expected beyond this period.

Key challenges and long-term R&D targets

- Improved handling of by-products in the oxy-fuel generated CO_2 stream

R&D needs

- Overall optimisation of NOx removal in the entire capture chain is necessary to consider overall removal efficiency and costs from upstream flue gas cleaning or downstream CO_2 compression processes, or a combination of both options.
- Emission control from air-firing to oxy-fuel combustion could be a topic for flue gas cleaning design and operation.
- Selective Catalytic Reduction (SCR), Selective Non-Catalytic Reduction (SNCR) for DeNOx: due to specific oxy-fuel flue gas conditions, high-dust arrangements of SCR or SNCR-DeNOx plants need investigation of deactivation and S-conversion. NH_3 and S related fouling and corrosion downstream of the DeNOx plant may also be an issue. These issues are being investigated in Period I and continued R&D on improvements is expected. Optimal locations for de-NOx from a system point of view and technical and economically optimal de-NOx concepts for specific fuels may also include tail-end (authothermal) catalytic de-NOx concepts that should be further investigated.
- The removal of trace components in FGD and FGC for FGD and experience from air-fired wet FGD applications can be transferred to oxy-fuel conditions.
- Technologies for the removal of SO_3 and mercury for lignite-fired plants, including the applicability of SDA concepts with fabric filters.
- Waste-water treatment and minimisation

Summary table: flue gas treatment and cooling

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
SCR, SNCR, DeNOx, improvements beyond Period I (EA)	🟨	🟩	🟩
Removal of trace components in FGD and FGC (EA)	🟨🟩	🟩	🟩
Technologies for removal of SO3 and mercury (EA)	🟨🟩	🟩	🟩
Waste water treatment and minimisation (EA)	🟨🟩	🟩	🟩

2.3.6 *CO_2 purification and compression*

For oxy-fuel, the CO_2 stream at the entrance of the compression and conditioning train can have high concentrations of components other than CO_2. R&D to develop and adapt purification technologies for such conditions is ongoing in Period I and further improvements are expected beyond this period. Improved compressor performance at such conditions, and throughout the entire load range, would contribute to reduced energy consumption. In this context, it is noteworthy that exact demands on CO_2 purity requirements imposed by transport and storage are currently unknown.

Key challenges and long-term R&D targets

- Refined handling of by-products in the oxy-fuel generated CO_2 stream remaining after the upstream cleaning steps
- Reduced compression energy consumption throughout the entire load range

R&D needs

- SOx and NOx removal in CO_2 compression train under pressurised conditions is being researched and validated in Period I and continued improvements are expected.
- Technologies for the recovery of O_2 and CO_2 from vent gas are under development and continued improvements are expected.
- Improved CO_2 compressor efficiencies at full load, as well as part load and extended load range.
- Investigations of compressor materials to verify if they can withstand the composition of the oxy-fuel generated stream
- Removal of trace components in FGD and FGC
- Technologies for the removal of SO_3 and mercury
- CO_2 dehydration: material selection, behaviour of impurities (especially NOx and SOx) in dehydration process and the treatment of regeneration gas
- Waste water treatment

Summary table: CO_2 purification and compression

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020		2020-2030	2030-
SOx and NOx removal in CO_2 compression train under pressurised conditions, improvements after period I	🟨	🟩	🟩	🟩
Technologies for recovery of O_2 and CO_2 from vent gas, improvements after period I	🟨	🟩	🟩	🟩
Improved compressor efficiencies throughout load range	🟨	🟨	🟩	🟩
Compressor design with materials that can withstand oxy-fuel generated streams	🟨	🟩	🟩	🟩
Technologies for removal of SO3 and mercury	🟨	🟩	🟩	🟩
CO_2 dehydration	🟨	🟩	🟩	🟩
Waste water treatment	🟨	🟩	🟩	🟩

2.3.7 Integrated components (including CLC)

In this section, oxygen membrane reactors and chemical looping combustion (CLC) reactors are addressed. In both cases, the separation of oxygen from air is integrated with fuel oxidation. CLC is under investigation at lab and pilot scales. There is significant cost benefit due to (nearly) complete avoidance of the air separation unit. The fuel does not meet the air directly. The oxygen needed for combustion is supplied by an oxygen carrier material which meets the fuel in the fuel reactor. This material is in a solid form and recirculated from fuel to the air reactor. The reduced oxygen carrier is oxidised in the air reactor.

Key challenges and long-term R&D targets

- Materials development (oxygen carrier material development for CLC, oxygen transport membranes)
- Reactor development with efficient fuel conversion
- Integration of the interconnected oxidising and reducing reactors to achieve reliable operation

R&D needs

- Chemical Looping Combustion:
  - Oxygen carriers (synthetically generated, naturally existing, oxygen capacity and kinetics, mechanical and chemical stability, toxicity).
  - Development of various oxygen carriers for variable fuels (coal, gas, biomass, multiple fuels)
  - Fuel conversion, including avoidance of not fully converted compounds (CO, H_2, CH_4, H_2S)
  - Validation and scale-up of oxygen carrier and ash separation
  - Reactor design, structural optimisation and scale-up
  - Use of advanced materials (e.g. ceramics, composites etc.) in reactor design
  - Scale-up
  - Integration into the power process
  - Pressurised reactors dedicated to gas-turbine operation
  - Pressurised reactors for coal, for improved kinetics
- Oxygen transport membrane (OTM) reactors: materials development, reactor development, reactor temperature control
- Integration of new oxygen separation technologies (i.e. membranes and/or adsorbent processes) with oxy-fuel boilers

Summary table: integrated components

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
CLC Oxygen carrier materials development for gas, coal, biomass or multiple fuels	🟥🟨	🟨🟨	🟩🟩
O_2 carrier material stability at high T, sour and wet environment	🟥🟨	🟨🟩	🟩🟩
CLC Fuel conversion	🟨🟨	🟨🟩	🟩🟩
CLC Oxygen carrier/ash separation	🟨🟨	🟨🟩	🟩🟩
CLC Reactor design, optimisation and scale-up	🟨🟨	🟨🟩	🟩🟩
CLC pressurised reactors for gas turbine operation	🟥🟥	🟥🟨	🟩🟩
CLC pressurised reactors for coal	🟥🟥	🟥🟨	🟩🟩
CLC reactor power process integration	🟨🟩	🟩🟩	🟩🟩
OTM materials and reactor development	🟨🟨	🟨🟩	🟩🟩
Integration of new oxygen separation technologies with oxy-fuel boilers	🟥🟥	🟨🟨	🟨🟩

2.3.8 Overall process development and integration

For pilot, demonstration/full-scale testing of PF and CFB oxy-fuel power plants (10s to 100s of MW), the design of larger-size plants is based on research findings from smaller-scale plants, combined with findings from the sections listed above. As the knowledge of oxy-fuel operation increases with the number of plants, new possibilities for process integration will be easier to identify.

Key challenges and long-term R&D targets

- Scale-up and validations of oxy-fuel power plants with minimum energy penalty. This covers optimisation of heat integration and heat recovery of the entire system, including ASU and compression.

R&D needs

- Validations in pilot plants followed by demonstration plants with associated R&D programmes
- Impact of integration on system reliability and availability
- New/improved technology blocks will require subsequent validations of integration issues in pilots and demonstration plants.
- Plant integration and optimisation for efficiency and cost, including part-load performance

- Environmental integration of the power plant with respect to (e.g.) limiting the increased water usage, recovery of cooling water and low temperature heat, and waste water treatment.

- Development and implementation of dynamic models to study load change capability and control system design in the power process, as well as in specific components.

Summary table: overall process development and integration

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Pilot and demo validation*	--	--	--
Impact of integration on reliability and availability	--	--	--
Validation and integration of improved or new technology blocks*	--	--	--
Plant integration and optimisation*	--	--	--
Environmental integration*	--	--	--
Dynamic modelling, simulations and analysis*	--	--	--

* Maturity level will depend on maturity of technology blocks

2.4 Pre-combustion technologies

2.4.1 Oxygen production for pre-combustion applications

Currently for IGCC power plants, cryogenic air separation is the only viable air separation technology due to the large scale. In the longer term, other air separation technologies based on membranes or adsorbents are seen as potential candidates.

Key challenges and long-term R&D targets

- Reduced energy consumption for oxygen production. Specific energy consumption of current cryogenic processes is dependent on oxygen pressure and nitrogen integration (use of nitrogen in the gas turbine). For oxygen at 4 MPa abs, the current range is 250-310 kWh/tonne (at ISO conditions[10]) with nitrogen integration. Without integration it is 270-330 kWh/tonne. A long-term R&D target should be to reduce this specific energy by 40 kWh/tonne for improved cryogenic processes.

- Further development of adsorbents and membranes for more energy- and cost-efficient oxygen production.

R&D needs

- Advanced cryogenic distillation, integration with other parts of the power plant or other adjacent ’cold industries’ (e.g. LNG plant)

- Flexible cryogenic air separation with improved turndown and load following capabilities with minimised impact on O_2 purity and specific power consumption

- High-temperature – up to 300°C - oxygen separating membranes and adsorbents which may have the potential for efficiency improvements in IGCC (or IRCC) operation, compared to cryogenic ASU
  - Membranes for O_2 production: membrane development (flux, stability, manufacturing),
  - Membrane unit development and manufacturing for integration in the IGCC power plant
  - Adsorbent based O_2 production: adsorbent development (O_2 capacity, stability) and manufacturing methods
  - Adsorbent unit development for integration in IGCC power plant

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[10] Air at 101325 Pa, 15°C, 60%RH

Summary table: oxygen production for pre-combustion applications

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Advanced cryogenic distillation, integration with other parts of the power plant	🟨 🟩	🟩	🟩
Flexible cryogenic air separation	🟨	🟩	🟩
Oxygen separating membranes (flux, stability, manufacturing)	🟨	🟨 🟩	🟩 🟩
Oxygen separating adsorbents (O_2 capacity, stability, manufacturing)	🟨	🟨 🟩	🟩
Membrane unit manufacturing, development and process integration	🟥	🟨	🟩
Adsorbent unit development and process integration	🟨	🟨 🟩	🟩

2.4.2 *Gasification/reforming*

Through the gasification of solid fuels or reforming of natural gas, a syngas consisting to a large extent of CO and H_2 is obtained.

For solid fuels – coal, lignite as well as co-gasification with biomass – the R&D priority is to improve the availability and efficiency of the basic processes of synthesis gas production (gasification, gas treatment and conditioning, heat integration). Further objectives are to develop an optimal overall concept which does justice to the different operational requirements for commercial operation. The optimised adaption of the subsequent gas treatment to the gasification system requires additional, detailed R&D activities.

Reforming of natural gas is basically a mature technology. However, more compact and improved design with improved materials (catalysts etc.), together with material and process integration, will be possible with further developments (see section 2.4.6).

Key challenges and long-term R&D targets

- Upscaling to large gasifiers (1200-1500 MW_{th}) for single-train configuration with effective heat recovery/quench system and with low metal corrosion
- Improved gasifier slag and fly ash removal
- Increasing the efficiency in converting the chemically bound energy of the coal into that of the flue gas (cold gas efficiency)

R&D needs

- Improved coal feeding (e.g. Stamet pump for pulverised coal pressurisation)
- Improved gasifier slag and fly ash removal
- Increasing carbon conversion and the efficiency of converting the chemically bound energy of the coal into that of the fuel gas (cold gas efficiency)
- Reducing the amount of the gasification agent required (especially oxygen requirements)
- Further development of the raw gas cooling system (efficient energy use)
- Understanding material-related consequences in gasification processes
- Modelling of reactive multiphase flows for developing reaction compartments and reactor geometries
- Establishing databases as a basis for material and process modelling
- Modelling the dynamic behaviour of gasifiers for optimising process control of individual plant components

Summary table: gasification/reforming

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Improved coal feeding	🟨	🟨🟩	🟩
Improved slag and fly ash removal	🟨	🟨🟩	🟩
Increasing the efficiency in converting the chemically bound energy of the coal into that of the flue gas (cold gas efficiency)	🟨	🟨	🟨
Reducing the amount of the required gasification agent (especially oxygen requirements)	🟨🟩	🟩	🟩
Further development of the raw gas cooling system (efficient energy use)	🟨	🟨	🟨
Understanding of material-related consequences in gasification processes (EA)	🟨	🟩	🟩
Modelling of reactive multiphase flows for developing reaction compartments and reactor geometries (EA)	🟨	🟩	🟩
Establishing databases as a basis for material and process modelling (EA)	🟨	🟨🟩	🟩
Modelling the dynamic behaviour of gasifiers for optimising process control of the individual plant components (EA)	🟨	🟨🟩	🟩

2.4.3 Water-gas shift

Water-gas shift (WGS) reactors are central to most pre-combustion capture power production schemes. Simplified process schemes can be developed if highly active WGS catalysts, working in the presence of significant amount of acid gases (e.g. H_2S, COS), are developed. Process schemes where CO_2 separation is carried out in the WGS reactors, either through the use of sorbents or membranes, can also be efficient alternatives to conventional schemes. These are further addressed under “Integrated components” (2.4.6).

Key challenges and long-term R&D targets

- Develop improved WGS catalysts, including sour WGS catalysts.

R&D needs

- Further development of sweet shift catalysts (improve activity and stability, reduce required steam demand)
- Development of sour shift catalysts (high activity and stability, low steam demand)
- Improved WGS reactor design (e.g. isothermal reactors)

Summary table: water-gas shift

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Further development of shift catalysts	🟨	🟩	🟩
Development of sour shift catalyst	🟥	🟨	🟩
Improved WGS reactor design	🟨	🟩	🟩

2.4.4 CO_2 capture in pre-combustion applications

In the common scheme, CO_2 is captured at high pressure in a separate step after the low temperature water-gas shift reactor. Physical solvents are the state-of-art technology for this step. Alternatives are pressure swing adsorption (PSA) processes or membranes that separate H_2 or CO_2. Process concepts based on solid sorption or membranes *integrated* into equilibrium-limited processes are addressed under “Integrated components” (2.4.6).

Key challenges and long-term R&D targets

- Reduce the energy requirement of alternative, physical solvent-based separation processes.

- Development of PSA processes based on solid adsorbents. The challenge is to find good adsorbents with high cyclic capacity in the actual pressure range. Another challenge is to find adsorbents with high selectivity for CO_2 in order to avoid the accumulation of impurities that necessitate extra thermal regeneration of the adsorbent.
- Capture of CO_2 at higher temperature to avoid the cooling down step before the combustion step
- Stability of adsorbent in the presence of contaminants such as H_2S etc.

R&D needs

- Develop solvents optimised for simultaneous separation of CO_2 and H_2S.
- Develop solid adsorbents that will adsorb CO_2 with higher selectivity than H_2S.
- Develop solid adsorbents that can separate both CO_2 and H_2S in one step.
- Low-temperature separation of CO_2 and H_2
- Hydrate-based CO_2 separation
- Membrane-based CO_2 separation
- Membrane-based H_2 separation

Summary table: CO_2 capture in pre-combustion applications

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Optimised solvents for CO_2 and H_2S separation	🟨	🟩	🟩
High cyclic capacity adsorbents with higher selectivity for CO_2 than H_2S	🟨	🟨🟩	🟩
High capacity adsorbents for co-separation of CO_2 and H_2S	🟥🟨	🟨	🟨🟩
Low-temperature separation of CO_2 and H_2	🟨	🟨🟩	🟩
Hydrate-based CO_2 separation	🟥	🟨	🟨
Membrane-based CO_2 separation	🟥	🟥🟨	🟨
Membrane-based H_2 separation	🟥🟨	🟨	🟨🟩

2.4.5 H_2 gas turbine

In pre-combustion capture technologies, there is a need for gas turbines that can operate on hydrogen-rich fuel gas with performance and emission levels that can match today's modern gas turbines for natural gas. Currently, gas turbines for hydrogen-rich fuels employ non-premixed burner technology using diluents such as N_2 and H_2O in order to keep flame temperature and NOx emissions down. Reduced turbine inlet temperature in order to compensate for higher moisture content and increased heat transfer is also used. These drawbacks could be overcome by some kind of dry low NOx (DLN) for hydrogen-fired gas turbines. R&D is already ongoing on DLN combustors and gas turbines for hydrogen combustion, but greater efforts are required.

Key challenges and long-term R&D targets

- Dry Low NOx burner technology without the need for large amounts of diluents
- Burner concepts for better fuel flexibility and reliability
- Increased turbine inlet temperature for higher efficiency

R&D needs

- Improved or new burner concepts based on a low-emission mode of operation
- Validated numerical design tools, including detailed resolution of fuel/air mixing and combustion, and high-quality laboratory facilities with advanced measurement technologies, to enable reliable validation
- New GT cooling technologies, high temperature materials and hot path coatings
- Component testing and demonstration under relevant conditions
- Testing a large gas turbine within the scope of a demonstration plant

Summary table: H_2 gas turbine

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Improved or new burner concepts	🟨	🟩	🟩
Validated numerical design tools (EA)	🟨	🟩	🟩
New cooling technologies and high temperature materials	🟨	🟩	🟩
Component testing at relevant conditions (EA)	🟨	🟩	🟩

2.4.6 Integrated components

Major simplifications of process schemes may be obtained by the integration of components and/or material development. Typically, by combining a sorbent or membrane and an equilibrium-limited reaction, the equilibrium of the process can be shifted drastically, making subsequent separation and/or purification steps redundant.

Key challenges and long-term R&D targets

- Reducing the size of equipment and increasing the conversion by combining reaction and separation in single units
- Making use of more advanced materials (membranes, sorbents, high temperature CO_2 and O_2 solid carriers) that will be a more integrated part of the process
- Material manufacturing methods and costs
- Cyclic capacity, stability and compatibility of sorbent in reaction conditions
- Flux and stability of membrane in reaction conditions
- Long-term stability and performance of materials in a harsh environment

R&D needs

- Sorption-enhanced reforming/gasification (SER): SER is based on the capture of CO_2 in a gasification (reforming) reactor using sorbent particles or CO_2 carriers to react with CO_2-forming carbonate. Due to the capture of CO_2, the equilibrium is shifted towards H_2. As a result, gasification (reforming) and the shift reaction are undertaken in a single process step, typically at temperatures of 500°C to 700°C and at elevated pressure. The produced carbonate has to be calcined (regenerated) in a separate step. The most commonly used process design is an interconnected fluid bed reactor system. There are several experimental results with biomass published from laboratory-scale prototypes (10-100s of kW) operating in continuous mode. Novel schemes have recently been proposed combining endothermic CO_2 carrier regeneration with exothermic stages in CLC cycles, allowing for more efficient processes operating with large fixed beds at high temperatures and pressures. These are mainly designed for natural gas reforming. The application to solid fuels raises concerns regarding the conversion rate, in-situ sulphur capture, sorbent/carrier/catalyst durability etc.
- Sorption-enhanced water-gas shift: in this high pressure process, a sorbent is used to remove CO_2 from gas streams during the water-gas shift reaction, shifting the equilibrium towards improved H_2 yield and negligible rests of CO and CO_2 in the effluent. The sorbent has to be regenerated in a separate step in a cyclic manner. As a result of the high pressure, PSA processes are most commonly envisaged, but TSA processes can also be considered. Major challenges are to find sorbents with high cyclic capacity and stability under the reaction conditions used (typically 200°C to 450°C, 20-40 bar, high steam pressure) and to handle any H_2S present. High consumption of steam to regenerate the material is one of the challenges.
- Chemical Looping Reforming (CLR) employs an oxygen carrier for the reforming of natural gas to produce a syngas for a natural gas-based, pre-combustion decarbonisation process. The process is similar to CLC (described in section 2.3.7), but sub-stoichiometric.

- Membrane water-gas shift reactors: in a similar manner as for sorbent-enhanced water-gas shift, a hydrogen or CO_2 permeable membrane is used in-situ to remove product gases during reaction, thus shifting the equilibrium towards higher conversions. The most challenging issue is to develop membranes with high flux, selectivity and stability at the relevant reaction conditions – temperatures from 200°C to 450°C and elevated pressure. For Pd alloy membranes, the main challenge is high stability and scaling up the manufacturing of the membranes and modules while reducing the cost.
- Hydrogen membrane reformers: in a similar manner as for sorbent-enhanced reforming, a hydrogen permeable membrane is used in-situ to remove hydrogen during reaction, thus shifting the equilibrium towards higher natural gas conversions. The most challenging issue is to develop membranes with high flux and stability at the relevant reaction conditions – temperatures from 500°C to 800°C and elevated pressure. The focus should be on scaling up the manufacturing of membranes and modules.
- Oxygen transport membrane reactors: OTM may find applications in large-scale processes for oxygen production (air separation unit), for chemical production (syngas produced from autothermal reforming, ATR or partial oxidation, POX) and for energy conversion (coal to liquid, coal to gas, oxycombustion and IGCC processes). These processes require a very large quantity of O_2 at high temperature (above 500°C) and pressure. The main challenges are to improve membrane integration by increasing the surface/volume ratio to increase the membrane lifetime and to scale up the manufacturing of membranes and modules while reducing costs.

Summary table: integrated components
(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Sorption enhanced water-gas-shift	🟥🟨	🟨	🟩
Sorption enhanced reforming/gasification	🟥🟨	🟨	🟩
Chemical looping reforming	🟥🟨	🟨	🟩
Membrane water-gas-shift reactors	🟥	🟨	🟨
Hydrogen membrane reformers	🟥	🟥🟨	🟨
Oxygen transport membrane reactors	🟥	🟥🟨	🟨

2.4.7 Overall process development and integration

If the classical individual components and the overall IGCC concept are further optimised, then electrical efficiencies above 50% without CO_2 separation seem to be possible. A precondition for this improvement is a gasifier adapted to the IGCC concept and the development of gas-cleaning processes that run at elevated temperatures and also, if possible, operate in a dry mode. Further potential for process optimisation lies in the integration of an air separation unit, CO conversion and CO_2 separation within the IGCC process.

In particular, when targeting the integration of novel technologies (see section 2.4.6) with the aim of improving the process performance, new challenges are likely to appear in overall process development. As the knowledge of IGCC operation increases with the increasing number of plants, new possibilities for process integration will be easier to identify.

IRCC plants (pre-combustion capture based on the reforming of natural gas) currently appear to have a high power penalty, but their attractiveness may increase with the development of novel, integrated components (see section 2.4.6). Hence there may also be a need for overall process development and integration for this type of power cycle with CO_2 capture.

Key challenges and long-term R&D targets

- Low availability
- Long start-up time
- Poor part load efficiency of IGCC
- Finding the best integration of novel (integrated) components for performance improvement

R&D needs

- Optimised power plant concepts with reduced auxiliary power consumption
- Overall process integration and optimisation, including start-up and part-load aspects
- New/improved technology blocks will require subsequent validations of integration issues.
- Environmental integration of the power plant with respect to (e.g.) cooling water requirements, liquid effluents and their purifications
- Development and implementation of dynamic models to study transients in the power process, as well as in specific components

Summary table: overall process development and integration
(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Power plant concepts with reduced auxiliary power consumption*	--	--	--
Integration and optimisation including start-up and part-load*	--	--	--
Validation of integration of new/improved technology blocks*	--	--	--
Environmental integration*	--	--	--
Dynamic modelling, simulations and analysis*	--	--	--

* Maturity level will depend on maturity of technology blocks

2.5 Technologies and research areas for improved CO_2 capture performance

This section lists R&D topics connected to the technology blocks in Table 1 that are not marked in bold, plus other areas related to the performance improvement of power plants with CO_2 capture beyond 2020.

2.5.1 Advanced steam cycle technology

CCS technologies have a negative impact on the net efficiency of modern pulverised coal-fired power plants. An intelligent and cost-effective use of CCS technologies therefore requires new strategies to increase the net efficiency of these plants. The most promising include:

- Increase working steam temperature and pressure in new Ultra Super Critical (USC) power plants (up to and maybe beyond 350/370 bar, 700/750°C) and hence increase the severity of fireside operating conditions, as well as potential new internal oxidation damages and higher creep.
- Promote long-term efficiency increase in existing and next-generation USC power plants, reducing/ eliminating out-of-service accidents and introduce maintenance criteria based on provisional material-component evolution models.

Key challenges and long-term R&D targets
All the technologies mentioned above are scientifically viable, but bring severe technological challenges in terms of materials/components reliability, especially increased resistance of metallic components to creep and creep fatigue in complex thermo-mechanical conditions (e.g. non-steady state working conditions).

- Increased resistance of ceramic components (e.g. refractory) to thermal shock and fatigue
- Increased resistance of ceramic and metallic materials to oxidation/hot corrosion, erosion-abrasion and wear under increased operating pressure
- Increased knowledge of microstructure instability during service, as expected in high alloyed metallic materials and ceramic components operating under highly demanding environmental conditions (e.g. atmosphere composition, temperature, pressure, multi-axial strain-stress)

- Improved component design criteria, taking account of material response in service (e.g. thermal cycling stresses, high thermal expansion in austenitic steels and nickel-base alloys, differential behaviour at welds and joints)
- Improved inspection procedures and maintenance strategies through a strong integration of field data from advanced sensor/monitoring systems and output from metallurgical physical-chemical and thermo mechanical models, in order to describe component behaviour during service and provide tools to assist plant operating decisions

R&D needs

- Innovative solutions in material science (e.g. Fe-base and Ni-base materials, ceramics, coatings)
- Improvement in manufacturing techniques (melting, large forging/casting, rolling/extruding, welding etc.)
- Improvements in design criteria of materials and components for application in very demanding environments (e.g. high temperature, hard fume composition, variable multi-axial load) through the integration and development of engineering + metallurgy evolution models and new experimental test procedures and configurations (e.g. creep-fatigue tests on pipes, including welds)
- Improvement in material performance databases through advanced experimental tests at medium- and full-scale test loop(s)/rig(s)
- HT sensoring for improved Process Control
- Definition and promotion of new/improved EN, ISO and National Standards for the application of new engineering solutions, as well as improved, non-destructive testing methods.

Summary table: USC technology (700-750°C).

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020		2020-2030		2030-
Innovative materials solutions	🟨	🟨	🟨	🟩	🟩
Manufacturing techniques improvements (EA)	🟨	🟩	🟨	🟩	🟩
Design criteria for materials and components in demanding environments (EA)	🟨	🟩	🟩	🟩	🟩
Materials performance database improvements (EA)	🟨	🟨	🟨	🟩	🟩
HT sensoring for improved process control	🟨	🟨	🟨	🟩	🟩
New/improved EN, ISO, National Standards as well as better non destructive testing methods (EA)	🟨	🟨	🟨	🟩	🟩

2.5.2 Other technology development

Ensuring cost-effective CO_2 capture processes requires improved knowledge and standards for processes, components and interdisciplinary areas not directly linked to the technology blocks in Table 1.

R&D needs

- Improved fuel handing, in particular fuel feed to pressurised systems, e.g. gasifiers.
- For fuels with high moisture contents (e.g. lignite), atmospheric and pressurised fluidised bed fuel-drying technologies are being developed and expected to be demonstrated in Period I. Further improved and optimised fuel-drying technologies that could be integrated efficiently into power plants could contribute to higher efficiencies.
- Improved CO_2 compressors (robust, high efficiency, part-load capability)
- H_2S removal at high temperatures. Gasification of coal yields a sour syngas. Innovative technologies such as membranes and sorbents will require or benefit from sulphur removal at higher temperatures,

usually prior to the water-gas shift process. Adsorption at high temperatures and membranes are possible candidates for sulphur removal.

- Multi-component removal processes. Simultaneous removal of H_2S/CO_2/-Hg/dioxin etc.
- Improved knowledge of CO_2 properties
- Improved knowledge of heat transfer characteristics for high CO_2 content mixtures
- Design tool improvements: current process design tools are typically based on either chemical engineering or mechanical engineering principles and an interdisciplinary approach is needed.
- Improved heat exchangers
- Oxy-fuel piston engines for power generation
- Evaluation of novel power cycle concepts based on working fluids other than water/steam (e.g. supercritical CO_2 and organic fluids) and how CO_2 capture could be heat integrated with these concepts

Summary table: technology development

(Colour codes: Green – validated, Yellow – partly validated, Red – not validated)

	-2020	2020-2030	2030-
Improved fuel handing (EA)	🟨	🟩	🟩
Improved and optimised fuel-drying technologies	🟨	🟩	🟩
Improved CO_2 compressors	🟨	🟩	🟩
H_2S/sour gas removal at high temperatures	🟨	🟩	🟩
Multi component removal processes.	🟨	🟨🟩	🟩
Improved knowledge of CO_2 properties (EA)	🟨	🟩	🟩
Improved knowledge of heat transfer characteristics for high CO_2 content mixtures	🟨	🟩	🟩
Design tool improvements (EA)	🟨	🟩	🟩
Improved heat exchangers	🟨	🟩	🟩
Oxy-fuel piston engines for power generation.	🟥	🟨	🟩
Processes with other working fluids than water/steam and their heat integration with CO_2 capture*	---	---	---

*Maturity will depend on the considered process

2.5.3 System studies

In addition to process and component related R&D needs described above, there is also a lack of knowledge within overall system related topics.

R&D needs

- Investigation of total environmental footprint from different types of power generation with CO_2 capture
- Research on the operation of fleets of power plants with CO_2 capture (connected to more than one infrastructure, electric power grid, CO_2 network and possibly also H_2 network). Today, power plant operation is optimised with respect to daily power demand variations and what prices can be achieved. CO_2 capture has to become a parameter in this so that the capture is optimised and balanced between short-term power demand variations and yearly CO_2 quota. This kind of system analysis could be based partly on research on CO_2 value chains.
- Research on how to integrate CCS and fuel cells in energy systems: fuel cells represent the most energy efficient power production and the combination of fuel cells and CCS is an option worth investigating for reducing CO_2 emissions. R&D are needed to optimise the integration of fuel cells and CCS.

- Studies on large- vs. small-scale CCS applications: from a long-term perspective, small-scale CCS could be commercially viable. Small-scale power production with small-scale CCS could be a possibility for green power production for all small villages in developing countries that do not have electricity today. Studies are needed to compare the technological and economic aspects of small- and large-scale CCS. Key challenges to be addressed are small-scale transport and storage of CO_2.
- A research framework that enables tight integration between technology development on different scales and research areas, e.g. solvent-capture process-power process and membrane-membrane reactor-power process. The purpose of such R&D should be to obtain good design targets for solvents or materials and the best possible integration in a dedicated power process.

2.6 CO_2 capture from power plants

This section provides general recommendations on how to continue research on CO_2 capture from power plants, as well as recommendations specific to each capture route.

For the latter, a qualitative analysis was made of how the R&D topics described for the three different capture routes in sections 2.2-2.4 would affect the decision-making parameters in Table 2. For each R&D topic, it was assessed whether a success in research would result in a significantly positive or negative impact on any of the seven decision-making parameters, or have no significant impact. The qualitative results obtained were then analysed together with the information in the summary tables in sections 2.2-2.4. The results are presented below following the general recommendations.

2.6.1 General recommendations

Overall energy system studies are needed of power plants with CO_2 capture operating as an integral part of energy systems with a high share of renewables. This means studying the interactions with solar and wind power – which must be combined with power plants with a high capability to follow load demands in the power grid – as well as CO_2 capture from biofuels (Bio-CCS). Such studies should also cover CO_2 transport and storage, and recognise the importance of power plant availability and operability. Depending on whether power plants with CCS are intended for base-load operation or as load followers, there will be differences in process design which need further attention. The future development of the electric power market will determine whether there will be any need for base-load power plants.

There is a general recommendation to undertake research on novel – potentially ground-breaking – technologies which could radically improve the performance of CCS, if such technologies emerge. Overall power process development and investigations into the integration of novel CO_2 capture related technologies into power processes and other industrial processes will continue to be important as capture technologies evolve.

Highly efficient retrofittable CO_2 capture solutions should be supported in order to address the urgent issue of locked-in carbon, i.e. CO_2 emissions from newly-built fossil fuel power plants without CO_2 capture.

Ultra Super Critical (USC) steam technology development is highly important for increasing the efficiency of coal-based post-combustion and oxy-fuel technologies. Likewise, the development of advanced gas turbines for achieving higher turbine temperatures is important for natural gas-fired plants and IGCC.

Pilot-scale testing is key to advancing technologies such as novel solvents, sorbents, membranes and CLC on the road to large-scale demonstration. A prerequisite for pilot testing of any technology is that promising performance has been verified both experimentally at lab scale and in studies of full-scale power plant performance. As a follow-up to successful pilot scale testing, an estimation of the potential when scaling up to demonstration- and/or full scale is required.

Finally, it should be noted that the weighting factors assigned to the investment decision-making parameters in Table 2 also provide guidance for R&D on CO_2 capture-related technologies. In particular, it may be observed that there is little knowledge on the availability and operability of many technologies. As they become more mature and show promising performance both technically and economically, it is therefore important to undertake such analyses.

2.6.2 Post-combustion capture technologies

There is an overall recommendation to undertake research on post-combustion capture technologies for coal and other solid fuels, as well as natural gas. Both types of fuels must be able to respond to load changes in the power system due to a high share of renewables such as solar and wind power. Natural gas- fired power must be able to respond more rapidly to load change requirements than coal.

R&D on CO_2 enrichment in flue gas through recycling part of the gas turbine exhaust (often referred to as exhaust gas recirculation, EGR) should be undertaken in order to increase the efficiency of post-combustion capture from natural gas. Impact on CAPEX and OPEX is estimated to be positive, although a negative impact on power plant operability from the gas turbine is possible. That said, the natural gas combined cycle already has a very good operability, so some reduction should be acceptable in this case.

Post-combustion capture power plants are a commercially available technology. It is a fact that commercial amine-based liquid solvents are on the market and that large-scale CO_2 capture units are being built for commercial power plants. However, there is a potential for improvement, requiring further R&D on next-generation technologies, as described below.

R&D on improved liquid solvents based on current commercial technologies, but with reduced energy penalty, should continue. R&D on novel liquid solvents, with a potential to significantly reduce the energy penalty should also be pursued. Examples include (but are not limited to) dual phase liquids, ionic liquids, precipitating solvents, as well as enzymes for catalysing CO_2 absorption/desorption. Energy and cost-efficient capture processes that utilise improved and novel solvents must also be developed.

R&D on solid sorbents should continue since there could be a positive effect on process efficiency compared to (current) liquid solvents and there could also be a positive impact on HSE. The operability and availability of power plants using solid sorbents for CO_2 capture, compared to liquid solvents, should be assessed. There are possible synergies between calcium looping (which is the most mature example of solid sorbent technology) and CO_2 capture in the cement industry that calls for further research.

HSE is the main concern for current solvents and successful R&D on improved/novel solvents, sorbents or membranes is expected to improve the HSE of post-combustion capture, compared to current technology.

There is little support within ZEP to continue research on hydrates as a post-combustion capture technology (particularly due to the estimated low maturity), or pursue anti-sublimation (i.e. freeze-out of CO_2[11]). However, there may be industrial applications for the latter. Recommendations for further R&D in these areas, when related to power plants, should be well-founded to be pursued and there may be advantages that have been omitted by ZEP.

This report does not include any integrated components for post-combustion technologies (section 4.1). However, hybrid technologies, or combinations of technologies, may have been omitted that will prove to have a positive impact on one or several of the investment decision-making parameters, e.g. a combination of first applying CO_2 membranes for CO_2 enrichment of the flue gas, followed by liquefaction of CO_2 to separate it from other exhaust gas components; and possibly other innovative concepts that are either entirely new or combine known technologies in novel ways.

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[11] Not to be confounded with low-temperature capture in the pre-combustion capture route which is based on CO_2 liquefaction technology

2.6.3 Oxy-fuel technologies

The overall recommendation is to pursue R&D for oxy-fuel combustion: much has been undertaken on oxy-fuel for coal to prove that the technology is feasible and can become competitive, but efforts are still needed to make the technology marketable and economical – in particular, system-wide optimisation. However, it should be noted that large demonstrations (100s of MW_{th}) of the entire oxy-fuel and capture route for coal have been planned, including completed FEED studies, and the technology is estimated to become commercially viable as a result. This should be supported by continued validations and R&D as there is also the potential for improvements, as described below.

Advanced (more efficient) and flexible cryogenic air separating unit R&D should be pursued in order to improve oxy-fuel power plant efficiency and operability. Oxygen-separating membranes and solid sorbents are generally expected to have a positive impact on process efficiency, but a negative impact on operability and possibly also availability of the oxy-fuel plant. Time to commercialisation is estimated to be longer for membranes than adsorbents, but the overall estimate is that when realised, membranes will prove to be the preferred alternative to sorbents for efficient oxygen separation in the longer term. The development of most improved oxygen separation methods, including the advanced cryogenic ASU, is estimated to have a small negative impact on power plant CAPEX, which should be balanced by the estimated positive impact on efficiency.

Pursuing the oxy-fuel capture route also means that R&D on oxy-fuel boilers and the overall oxy-fuel process should be continued. There are several opportunities for efficiency increase through boiler R&D, although some high-potential R&D topics (e.g. increased O_2 concentration, pressurised oxy-fuel boilers and oxy-fuel boilers capable of switching to air-firing mode) could have a negative impact on availability and operability, requiring dedicated R&D. CO_2 purification and compression is an important issue for oxy-fuel + coal and some R&D topics (e.g. improved CO_2 compressor efficiency) are also relevant for oxy-fuel + natural gas. Oxygen transport membrane reactors[12] for integration in oxy-fuel boilers are estimated to have a definitive positive impact on process efficiency, but OPEX and CAPEX, as well as operability and availability, are estimated to be worse than for oxy-fuel boilers with conventional cryogenic ASU.

In the case of oxy-fuel combustion for gas turbine-based processes (natural gas-based power production), more R&D is needed before it can be determined whether this CO_2 capture route is competitive when evaluated against the investment decision parameters in Table 2. At the current state of knowledge, no definitive conclusions can be drawn; it can only be observed that the technology has no obvious showstoppers, but there may be operability challenges that require dedicated R&D.

Chemical Looping Combustion (CLC) is a technology that, in the long term, can offer power processes with the potential for high efficiency and potentially also high CO_2 capture rate. For CLC, improved fuel conversion, new oxygen carrier materials, reactor design and power process integration are important R&D topics. Little research has been done on the operability and availability of CLC processes, but should be undertaken in order to evaluate whether they are acceptable in this respect. Pressurised reactors for coal and gas CLC could have significant efficiency advantages, but also face significant challenges and should be regarded as high risk/high gain R&D areas.

2.6.4 Pre-combustion technologies

The overall recommendation is that research related to the Integrated Gasification Combined Cycle (IGCC) should be pursued. IGCC, when implemented with modern technology, has the potential to produce power from coal at a higher efficiency than the conventional pulverised fuel combustion of coal, plus the ability to convert solid fuels of varying quality (including biomass) into electricity.

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[12] Oxygen membranes and oxygen membrane reactors are two slightly different types of technology. In the oxygen membrane reactor, an oxidation or combustion reactor takes place in the same compartment as the oxygen separation from air.

It should be noted that IGCC technology with CO_2 capture is commercially available with both state-of-the-art ASU and existing gas turbines (which show a slight reduction in efficiency since they are manufactured for operation with natural gas). The main R&D needs for improving IGCC performance relate to improved ASU, improved gas turbine efficiency with high H_2-content in the fuel gas and improvements in the syngas cleaning section (at high temperature). This will improve the efficiency of the IGCC plant beyond 2020 and therefore also reduce CO_2 capture costs.

As for oxy-fuel, advanced (more efficient) and flexible cryogenic ASU R&D should be pursued in order to improve power plant efficiency and operability. However, the integration and optimisation of air separation technologies is different for IGCC than for oxy-fuel. Oxygen-separating membranes and solid sorbents are generally estimated to have a positive impact on process efficiency, but a negative impact on operability and possibly also availability of the IGCC. Time to commercialisation is estimated to be longer for membranes than for adsorbents, but the overall estimate is that when realised, membranes will prove to be the preferred alternative to sorbents for efficient oxygen separation in the longer term. The development of most improved oxygen separation methods, including advanced cryogenic ASU, is estimated to have a small negative impact on power plant CAPEX, which should be balanced by a positive impact on efficiency.

Improvements in gasifiers for IGCC should also be pursued, e.g. improved slag and fly ash removal, improved fuel conversion, reduction in the amount of gasification agent required and improved coal feeding.

For H_2 gas turbines, the recommendation is straightforward: as long as R&D is pursued on the IGCC capture route, R&D must also be pursued on efficient, low-emission hydrogen gas turbines. Once this has been realised, improvements will always be necessary to keep track of those in conventional gas turbines.

Positive results are expected from further R&D on water-gas shift (WGS) reactors – in particular, the further development of shift catalysts (including sour shift catalysts) and improvements in WGS reactor design. As it concerns the separation of CO_2 and H_2 in the shifted syngas, it is noted that current commercial solvents for CO_2 separation at conditions typical for IGCC have a rather low energy penalty. Nevertheless, R&D on alternative separation technologies (e.g. H_2-separating membranes, sorbents and low-temperature separation of CO_2, with a focus on availability and operability) should be supported for implementation in the longer term to enable further efficiency improvements.

Integrated components for pre-combustion capture (see section 2.4.6) are generally estimated to have a positive impact on process efficiency and possibly also on CAPEX (due to a reduction in the number of process components), but with an estimated negative impact on availability and operability. It should be emphasised that more research could still be done to assess the impact of integrated components on all investment decision-making parameters.

Technology development related to pre-combustion capture from power plants contains elements (in particular, separation technologies and integrated components) which may prove very useful for H_2 production with CO_2 capture in industrial applications. It is therefore recommended not to focus research on the Integrated Reforming Combined Cycle (IRCC) due to its anticipated poor operability (in particular load-following capacity) compared to a NGCC with post-combustion capture. Natural gas-based pre-combustion technologies should potentially focus on H_2 production with CO_2 capture.

Annex: Bio-CCS and CCS in industries beyond power

This report covers R&D needs for CO_2 capture in the power sector, primarily based on fossil fuels. However, the EU Energy Roadmap 2050 confirms that CCS combined with biomass can deliver "carbon negative" values, while the IEA underlines that CCS in energy-intensive industries must deliver half of the global emissions reductions required by 2050 from CCS.[13] In general, all the CO_2 capture technologies described in this report can have applications beyond fossil fuel-based power.

Bio-CCS: the only large-scale technology that can *remove* CO_2 from the atmosphere

In 2011, the European Biofuels Technology Platform (EBTP) and ZEP set up a joint taskforce (JTF) Bio-CCS to review the various technology routes for combining CCS with biomass conversion. This resulted in a landmark report[14] that covers CCS with the production of biofuels, electricity/heat from biomass (both co-firing and 100% biomass combustion), as well as Bio-CCS options for energy-intensive industries.

The report shows how several biofuel production routes offer a near-pure stream of CO_2 as an integral part of their processes, opening the way for very low-cost CCS deployment where economies of scale can be applied, or where adjacent CO_2 transport and storage infrastructure can be shared. Co-firing biomass with coal or lignite at moderate percentages (at least up to 10%) is also not expected to increase the costs of CCS deployment. (N.B. This refers to the cost of co-firing, not the cost of biomass relative to fossil fuels as this varies highly.) However, for higher co-firing rates and dedicated biomass combustion, higher investment costs and efficiency penalties may be expected.

The composition of biomass fuels is variable, but they generally have a higher alkaline content than fossil fuels which can, for example, lead to ash deposition and corrosion when co-firing with fossil fuels in boilers. The report of the JTF Bio-CCS states that mode data and research is needed on these issues, as well as other potential technological challenges.

Most of the CO_2 capture R&D topics described in this report should be investigated from a biomass point of view and all three capture routes could, in principle, be adapted to biomass power production. Some emerging capture systems (in particular, those operating at high temperatures that can combine biomass gasification and/or combustion with CO_2 sorption in a single step) could be especially suited to power plants with biomass and CCS. This includes both co-firing and 100% biomass applications in order to identify the most feasible technology options. Indeed, if optimised and cost-effective biomass production is achieved, some variants could be ready before 2030, at the latest (i.e. in Period II, as defined in section 2.1.1). It should also be assessed whether there is any transference of alkalines from the biofuel to the captured CO_2 and if this could imply additional corrosion risks or other issues for CO_2 transport and storage.

Realising the significant potential for CCS in industries *beyond* power

According to the IEA, CCS represents the most important new technology option for reducing direct emissions in industry. Indeed, in some industries, such as steel and cement, it is the *only* means of achieving deep emission cuts, with the potential to mitigate 2-2.5 gigatonnes of CO_2 per year globally by 2050.[15] In Europe, several industries are already currently implementing CCS at pilot scale.

In 2012, ZEP therefore created Working Group (WG) Other Industries in order to review technology synergies and options for CCS deployment in energy-industries and seek cooperation with representatives

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[13] IEA: www.iea.org/publications/freepublications/publication/name,38764,en.html

[14] "Biomass with CO_2 Capture and Storage (Bio-CCS) – The way forward for Europe": www.zeroemissionsplatform.eu/library/publication/206-biomass-with-co2-capture-and-storage-bio-ccs- the-way-forward-for-europe.html

[15] IEA Energy Technology Perspectives, 2012

of those sectors. In 2013, ZEP published its report, "*CO_2 Capture and Storage (CCS) in energy-intensive industries: an indispensable route to an EU low-carbon economy*".[16]

Table 3 shows the various energy-intensive industries, the chemical processes involved, relevant separation technologies and their stage of development and deployment. Further modifications could be required to several of the technologies since they are generally optimised for CO_2 capture from power plants, e.g. there may be differences in impurities in the CO_2 captured, or in CO_2 partial pressure.

Apart from technology synergies, cooperating with these industries could enable clustering of activities to achieve economies of scale for CO_2 transport *and* storage infrastructure, plus other synergies such as the (re)use of excess heat. In some cases, joint capture units may even be applicable. It is therefore essential that this is taken into consideration when planning new units.

Table 3: Summary of capture technologies for energy-intensive industries and their maturity in relevant sectors

Separation technology	**Industry**	**Process**	**Process redesign**	**Stage of development and deployment**	**Relative cost per t CO_2 at time of deployment**	**Capture rate**	**Reference**	**Comment**
Chemical or physical absorption (2.2.1/2.4.4)	Fertiliser	Ammonia synthesis (Haber-Bosch)	No	Commercial	Low	>95%	(De Coninck & Mikunda, 2011) (Zakkour & Cook, 2010)	Stream purity depends on design of the process, but can be almost pure. N.B. This is the capture rate of the CO_2 not used in production of urea
	Natural gas extraction	Natural gas upgrading	No	Commercial	Low	>95%	(Zakkour & Cook, 2010)	
	Synthetic fuels	Fischer-Tropsch, methanol-to-gasoline	No	Commercial	Low	50%	(Carbo, 2011)	Not listed explicitly, but assumed to be chemical absorption. Only 5% is lost as flue gas; the remainder is captured in Fischer-Tropsch liquids and char.
		Hydrogen	No	Commercial	Low	>90%	(Carbo, 2011)	
	Ethylene oxide	Direct ethylene oxidation	No	Pilot	Low	>95%	(Zakkour & Cook, 2010)	The process of reactor gas stream clean-up includes removal of the CO_2 using physical sorbents, Hot Potassium Carbonate process (e.g. the Benfield process), or cryogenic separation techniques to give a high purity stream.

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[16] www.zeroemissionsplatform.eu/library/publication/222-ccsotherind.html

	Iron and steel	Direct Reduced Iron (DRI)	No	Pilot	High		(ETSAP, 2010)	
	Cement	Kiln/ Calcination	No	Pilot	High	77 -85%	(De Coninck & Mikunda, 2011) (UNIDO, 2010)	UNIDO assumption for monoethanolamine (MEA) post-combustion absorption
	Refineries	Hydrogen (natural gas reforming or partial oxidation)	No	Commercial	Low	>95%	(UNIDO, 2010)	
		Hydrogen	No	Commercial	Low	>95%	(UNIDO, 2010)	Feed stream often close to 100% CO_2
		Fluidised Catalytic Cracking (FCC)	No	Pilot	Medium		(UNIDO, 2010)	
		Boilers and process heaters	No	Research	High	>95%	(UNIDO, 2010)	
	Aluminium	Electrolysis of aluminium oxide from bauxite	No	Research	High			Cost reduction possible if aluminium plant exhaust can be fed to a gas turbine combined cycle for CO_2 enrichment before capture.
	Offshore	Stand-alone power production from gas turbines	No	Research	High	>95%	(Winden, et al., 2011)	
Membrane separation (2.2.1)	Natural gas extraction	Natural gas upgrading	No	Commercial	Medium	>95%	Zakkour and Cook (2010)	
	Synthetic fuels	Fischer-Tropsch, Methanol-to-Gasoline	No	Research	Medium	>90%	(Richard C. Baliban, 2012)	
		Hydrogen	No	Research	Medium	>90%	(L. Barelli, 2008)	
Pressure swing adsorption (2.2.1/2.4.4)	Synthetic fuels	Hydrogen	No	Research	Medium	80-90%	(Carbo, 2011)	Not used in isolation; also used with other absorption techniques
	Iron and Steel	Direct Reduced Iron (DRI)	Yes	Research	Medium		(ETSAP, 2010)	
		HIsarna	Yes	Research	Medium	70%	(De Coninck & Mikunda, 2011)	

	Refineries	Hydrogen (natural gas reforming or partial oxidation)	No	Research	Low	>90%	(Y Ding, 2000)	
Oxy-fuel (2.3)	Iron and Steel	Oxy-fuel blast furnace	Yes	Pilot	Medium	85-95%	(De Coninck & Mikunda, 2011)	
	Cement	Kiln/Calcination	Yes	Research	Medium	52%	UNIDO (2010)	Assumes partial capture oxy-fuel technology
	Refineries	Fluidised Catalytic Cracking	Yes	Pilot	Medium		(Mark Crombie, 2011)	
		Boilers and process heaters	Yes	Research	Medium	>90%	(Morten Seljeskog, 2005)	
Calcium looping (2.2.1)	Cement	Kiln/Calcination	Yes	Research	Low	>90%	(C.C. Dean, 2011)	Integration synergies possible with CO_2 capture from other large point source (i.e. Coal power plant)
Chemical looping combustion (2.3.7)	Refineries	Boilers and process heaters	Yes	Research	Low	>90%	(María Ortiz, 2012)	Integration synergies possible with cement manufacture
Chemical looping reforming (2.4.7)	Synthetic fuels	Hydrogen	Yes	Research	Low	>95%	(Magnus Rydén, 2006)	
	Refineries	Hydrogen	Yes	Research	Low	>95%	(Magnus Rydén, 2006)	Feed stream is often close to 100% CO_2

Eligible capture source at site: the share of on-site emissions which can be feasibly captured is difficult to quantify even at a high level, owing to plant-specific considerations and limitations in the knowledge available on CCS for industrial applications. The maximum available share may range from 75-80% for iron/steel works and oil refineries, and up to 100% for CHP units.

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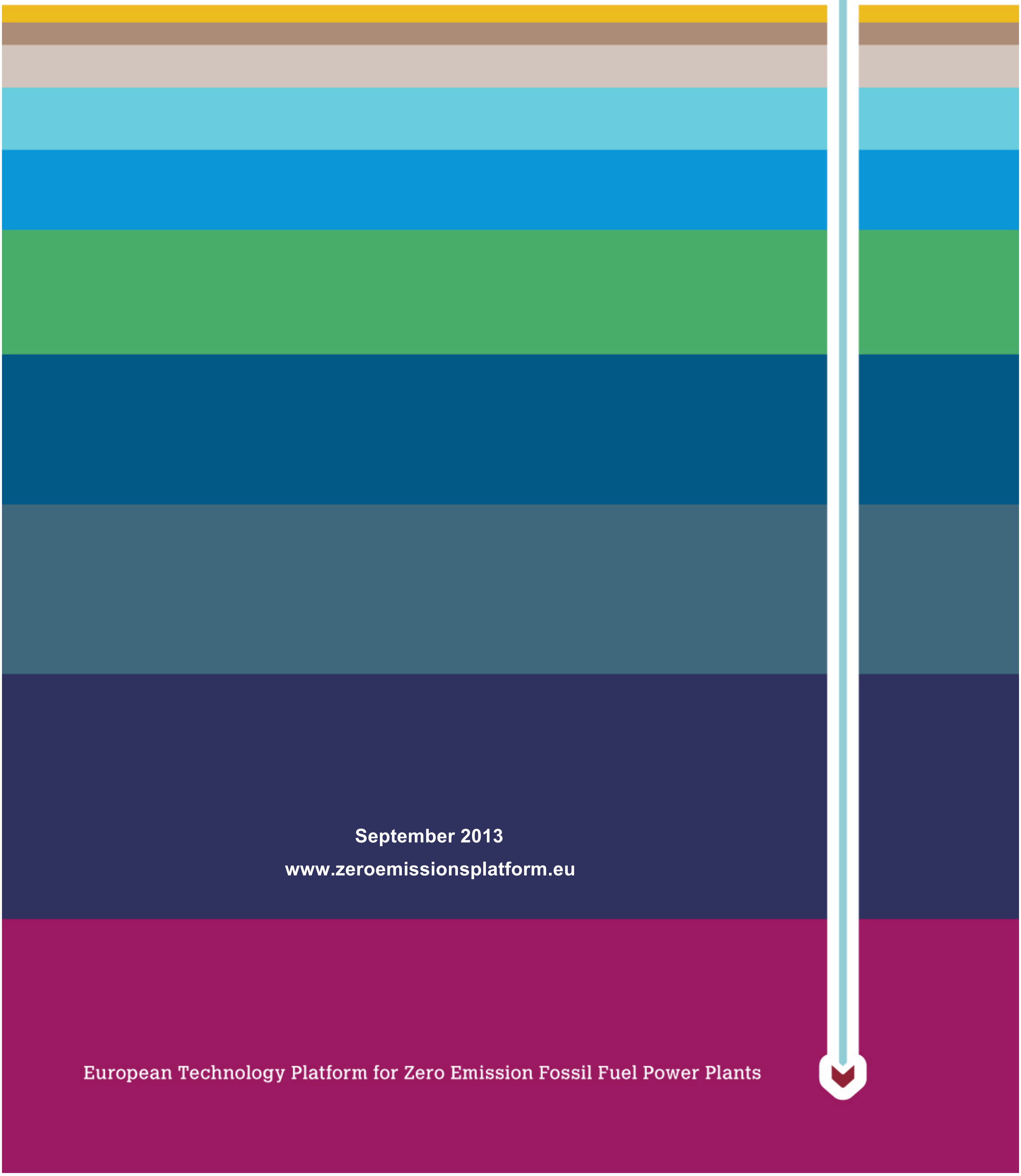

September 2013

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European Technology Platform for Zero Emission Fossil Fuel Power Plants

Allegato 4 - *Carbon Sequestration Leadership Forum (CSLF) recognized projects and Task Forces on storage*

ALLEGATO 4

Carbon Sequestration Leadership Forum (CSLF) recognized projects and Task Forces on storage

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ABOUT THE CSLF

- CSLF is a **Ministerial-level international climate change initiative** that is focused on the development of improved cost-effective CCS technologies.

Mission

- to facilitate the development and deployment of such technologies via collaborative efforts that address key technical, economic, and environmental obstacles
- to promote awareness and champion legal, regulatory, financial, and institutional environments.

CSLF Projects

CSLF promotes collaborative research, development, and demonstration projects that exhibit:

- ❑ Information exchange and networking
- ❑ Planning and road-mapping
- ❑ Facilitation of collaboration
- ❑ Research and development
- ❑ Demonstrations

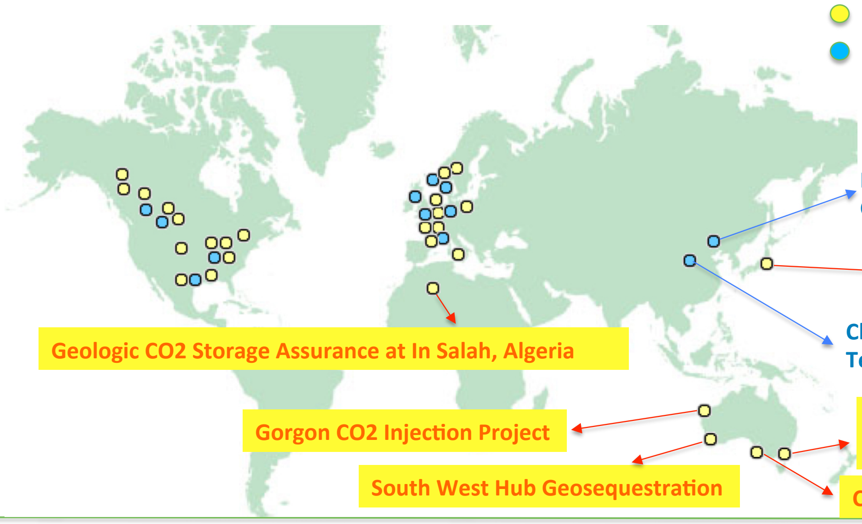
39 projects recognized: 27 active, 12 already completed

6 pilot projects ← → 21 Large Scale or Multifaceted

Active and Completed CSLF Recognized Projects

Projects in Australia, Eastern World, Africa

○ active projects
● completed projects



Regional Opportunities for CO2 Capture and Storage in China

CO2 Separation from PressurizedGas Stream

China Coalbed Methane Technology/CO2 Sequestration

Geologic CO2 Storage Assurance at In Salah, Algeria

Gorgon CO2 Injection Project

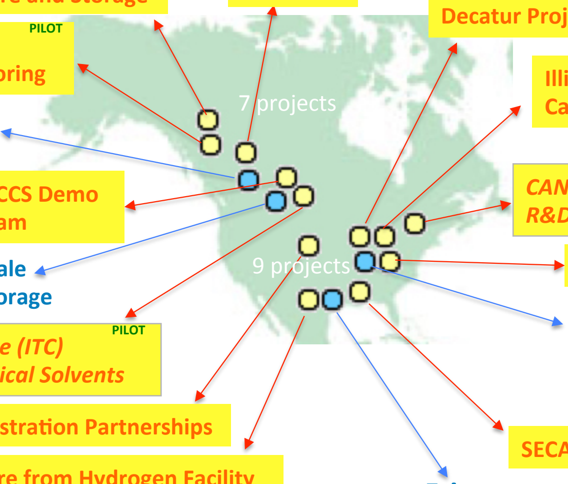
South West Hub Geosequestration

CarbonNet Project R&D Oxyfuel Combustion for CO2 Capture

CO2CRC Otway PILOT

Projects in America

○ active projects
● completed projects



Fort Nelson Carbon Capture and Storage

Quest CCS

Illinois Basin – Decatur Project

Zama Acid Gas EOR, CO2 Sequestration, and Monitoring PILOT

Illinois Industrial Carbon Capture and Storage

Alberta ECBM Recovery

SaskPower Integrated CCS Demo Project at Boundary Dam

PILOT *CANMET Energy Technology Centre (CETC) R&D Oxyfuel Combustion for CO2 Capture*

IEA GHG Weyburn-Midale CO2 Monitoring and Storage

CO2 Capture Project - Phase 3

CO2 Capture Project - Phase 2

International Test Centre (ITC) CO2 Capture with Chemical Solvents PILOT

Regional Carbon Sequestration Partnerships

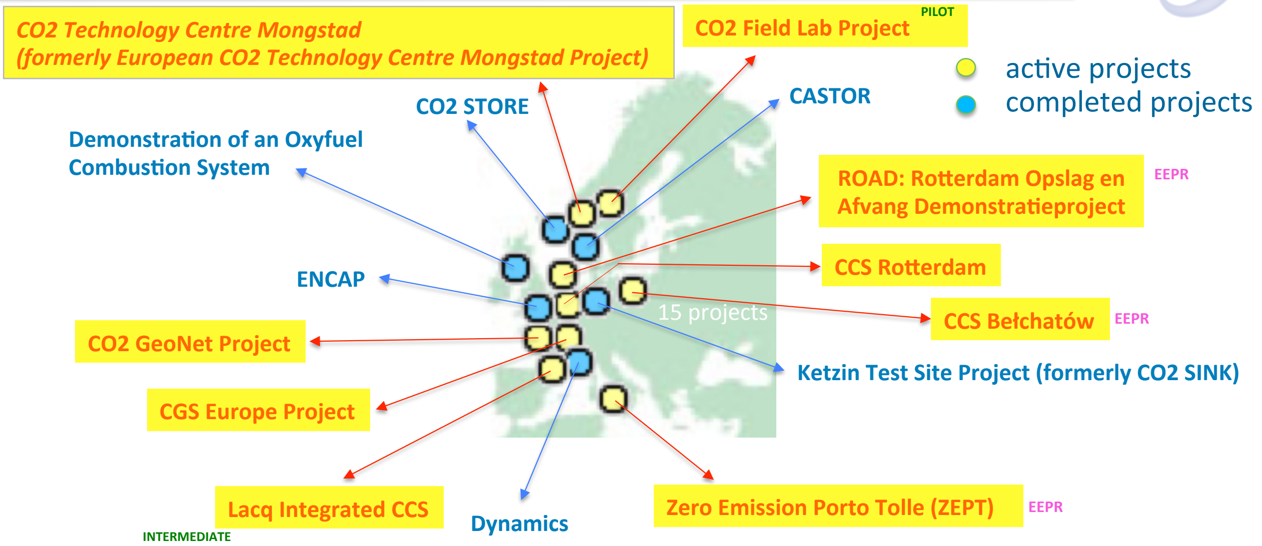
SECARB Early Test at Cranfield

Air Products CO2 Capture from Hydrogen Facility Project R&D Oxyfuel Combustion for CO2 Capture

Frio

Projects in Europe

European Economic
Recovery Plan



CO2 Technology Centre Mongstad
(formerly European CO2 Technology Centre Mongstad Project)

CO2 Field Lab Project PILOT

🟡 active projects
🔵 completed projects

CO2 STORE

CASTOR

Demonstration of an Oxyfuel Combustion System

ROAD: Rotterdam Opslag en Afvang Demonstratieproject EEPR

ENCAP

CCS Rotterdam

15 projects

CCS Bełchatów EEPR

CO2 GeoNet Project

Ketzin Test Site Project (formerly CO2 SINK)

CGS Europe Project

Lacq Integrated CCS
INTERMEDIATE

Dynamics

Zero Emission Porto Tolle (ZEPT) EEPR

1. Gorgon CO2 Injection Project

- LARGE-SCALE PROJECT that will store approximately **120 million tonnes of CO2** in a water-bearing sandstone formation two kilometers below Barrow Island, off the northwest coast of Australia. The project is fully funded

  To demonstrate the safe commercial-scale application of CO2 storage technologies at a scale not previously attempted

  The **CO2 will be extracted from natural gas** produced from the nearby Gorgon Field and injected at approximately **3.5 to 4 million ton CO2 per year**.

  Injection operations are **expected to commence by the end of 2014**.

- *Recognized by the CSLF at its Warsaw meeting, October 2010*
- *Nominators: Australia (lead), Canada, and United States*

2. South West Hub Geosequestration Project

- **LARGE-SCALE PROJECT** that will implement a **large-scale "CO2 Hub" for multi-user capture, transport, utilization, and storage of CO2** in southwestern Australia near the city of Perth.

  Several industrial and utility point sources of CO2 will be connected via a pipeline to a site for safe geologic **storage** deep underground **in the Triassic Lesueur Sandstone Formation**.

  Storage of **2.4 million ton CO2 per year** and has the potential for capturing approximately 6.5 million ton CO2 per year.

  Reservoir characterization and, once storage is underway, MMV (**M**easurement, **M**onitoring and **V**erification) technologies.
- *Recognized by the CSLF at its Perth meeting, October 2012*
- *Nominators: Australia (lead), United States, and Canada*

3. CO2CRC Otway Project

- **PILOT-SCALE PROJECT**, located in southwestern Victoria, Australia; transport and injection of approximately **100,000 tons of CO2 over a two year period** into a depleted natural gas well.

  Operational aspects of processing, transport and injection; new/enhanced measurement, monitoring and verification of storage (MMV) technologies; modeling of post-injection CO2 behavior; and implementation of an outreach program for stakeholders and nearby communities.

  Data from the project will be used in developing a future regulatory regime for CO2 capture and storage (CCS) in Australia.
- *Recognized by the CSLF at its Paris meeting, March 2007*
- *Nominators: Australia (lead) and United States*

4. CarbonNet Project

- LARGE-SCALE PROJECT that will implement a **large-scale multi-user** CO2 capture, transport, and **storage network** in southeastern Australia in the Latrobe Valley. Multiple industrial and utility point sources of CO2 will be connected via a pipeline to a site where the CO2 can be stored in **depleted oil and gas fields in the offshore Gippsland Basin**.

  Storage of approximately **1 to 5 million ton CO2 per year**, with the potential to increase capacity significantly over time.

  The project will also include reservoir characterization and, once storage is underway, measurement, monitoring and verification (MMV) technologies.
- *Recognized by the CSLF at its Perth meeting, October 2012*
- *Nominators: Australia (lead) and United States*

5. China Coalbed Methane Technology CO2 Sequestration

- PILOT-SCALE PROJECT successfully demonstrated that coal seams in the anthracitic coals of Shanxi Province of China are permeable and stable enough to absorb CO2 and enhance methane production, leading to a clean energy source for China.

  The project **evaluated reservoir properties** of selected coal seams of the Qinshui Basin of eastern China and carried out field testing at relatively low CO2 injection rates.

  The project recommendation was to proceed to full scale pilot test at south Qinshui, as the prospect in other coal basins in China is good.
- *Recognized by the CSLF at its Berlin meeting, September 2005*
- *Nominators: Canada (lead), United States, and China*

6. Regional Opportunities for CO2 Capture and Storage in China

- **CHARACTERIZATION OF TECHNICAL AND ECONOMIC POTENTIAL OF CCS IN CHINA**
  - key characteristics of different large anthropogenic CO2 sources
  - candidate geologic storage formations, and to develop estimates of geologic CO2 storage capacities in China.

  The project found **2,300 gigatons of potential CO2 storage capacity in onshore Chinese basins**, significantly more than previous estimates. The heavily developed coastal areas of the East and South Central regions appear to have less access to large quantities of onshore storage capacity than many of the inland regions.

  Therefore, China's economic growth with coal can continue.
- *Recognized by the CSLF at its Berlin meeting, September 2005*
- *Nominators: United States (lead) and China*

7. CO2 Separation from Pressurized Gas Stream

- **SMALL-SCALE PROJECT** will evaluate processes and economics for **CO2 separation from pressurized gas streams**.

  To test new gas separation membranes, initially at atmospheric pressure.

  To improve the performance of the membranes for CO2 removal from the fuel gas product of coal gasification and other gas streams under high pressure.
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: Japan (lead) and United States*

8. Geologic CO2 Storage Assurance at In Salah, Algeria

- **MULTIFACETED PROJECT** To develop technologies, techniques and management systems required to cost-effectively demonstrate, safe, secure, and verifiable **CO2 storage in conjunction with commercial natural gas production**.

  To develop a detailed dataset on the **performance** of CO2 storage; provide a field-scale example on the verification and regulation of geologic storage systems; test technology options for the early detection of low-level seepage of CO2 out of primary containment; evaluate **monitoring** options and develop guidelines for an appropriate and cost-effective, long-term monitoring methodology; and quantify the **interaction of CO2 re-injection and hydrocarbon production for long-term storage in oil and gas fields**.
- *Recognized by the CSLF at its Berlin meeting, September 2005*
- *Nominators: United Kingdom (lead) and Norway*

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9. Quest CCS Project

- **LARGE-SCALE, FULLY INTEGRATED PROJECT**, located at Fort Saskatchewan, Alberta, Canada, with **integrated capture, transportation, storage, and monitoring**, which will capture and store up to **1.2 million ton CO2 per year** from an oil sands upgrading unit. The CO2 will be transported via pipeline and stored in a deep saline aquifer in the Western Sedimentary Basin in Alberta, Canada.

  Large-scale deployment of CCS technologies and methodologies, including a comprehensive measurement, monitoring and verification (MMV) program.
- *Recognized by the CSLF at its Warsaw meeting, October 2010*
- *Nominators: Canada (lead), United Kingdom, and United States*

10. Fort Nelson Carbon Capture and Storage Project

- **LARGE-SCALE PROJECT** in northeastern British Columbia, Canada

  2 million tonnes per year CO2 emissions from a large natural gas-processing plant will be stored into deep saline formations of the Western Canadian Sedimentary Basin (WCSB).

  Technical and economic feasibility of using brine-saturated carbonate formations for large-scale CO2 injection

  demonstrate that robust monitoring, verification, and accounting (MVA) of a brine-saturated CO2 sequestration project can be conducted cost-effectively.

  regulations and MVA technologies for future large-scale CO2 injection.
- *Recognized by the CSLF at its London meeting, October 2009*
- *Nominators: Canada (lead) and United States*

11. Zama Acid Gas EOR,
CO2 Sequestration, and Monitoring

- **PILOT-SCALE PROJECT** Utilization of acid gas (70% CO2 and 30% hydrogen sulfide) derived from natural gas extraction for enhanced oil recovery.

  Acid gas injection was initiated in December 2006 and will result in sequestration of about **25,000 ton CO2 per year**

  - To predict, monitor, and evaluate the fate of the injected acid gas;

  - to determine the effect of hydrogen sulfide on CO2 sequestration;

  - to develop a “best practices manual” for measurement, monitoring, and verification (MMV) of acid gas storage.
- *Recognized by the CSLF at its Paris meeting, March 2007*
- *Nominators: Canada (lead) and United States*

12. Alberta Enhanced Coal-Bed Methane Recovery

- **PILOT-SCALE PROJECT**, located in Alberta, Canada, aimed at demonstrating, from both economic and environmental criteria, the overall feasibility of **CBM** and simultaneous **CO2 storage in deep unmineable coal seams**.

  To determine baseline production of CBM from coals; determine the effect of CO2 injection and storage on CBM production; assess economics; and monitor and trace the path of CO2 movement by geochemical and geophysical methods.

  All testing undertaken was successful.
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: Canada (lead), United States, and United Kingdom*

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13. SaskPower Integrated CCS Demonstration Project at Boundary Dam Unit 3

- **LARGE-SCALE PROJECT** , located in the southeastern corner of Saskatchewan Province in Canada, which will be the first application of **full stream CO2 recovery from flue gas of a 139 megawatt coal-fueled power plant**. Post-combustion CO2 capture retrofit on a commercial power plant. Capture of approximately **1million tonn CO2 per year**, which will be sold to oil producers for enhanced oil recovery (EOR) and injected into a deep saline aquifer

  Commissioning of the reconfigured power plant unit is expected by early 2014.

  Fnancial support from the Government of Canada and the Saskatchewan Provincial Government.
- *Recognized by the CSLF at its Beijing meeting, September 2011*
- *Nominators: Canada (lead) and the United States*

14. IEA GHG Weyburn-Midale CO2 Monitoring and Storage

- **LARGE-SCALE PROJECT** CO2 for EOR at a Canadian oil field.

  To determine the performance and undertake a thorough risk assessment of CO2 storage in conjunction with its use in enhanced oil recovery.

  The work program will encompass four major technical themes of the project: geological integrity; wellbore injection and integrity; storage monitoring methods; and risk assessment and storage mechanisms. Results from these technical themes will result in a Best Practices Manual for future CO2 Enhanced Oil Recovery projects.
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: Canada and United States (leads) and Japan*

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15. International test centre ITC CO2 Capture with Chemical Solvents Project

- **PILOT-SCALE PROJECT** to **demonstrate CO2 capture using chemical solvents** and **develop improved cost-effective technologies** for separation and capture of CO2 from flue gas.

  Supporting activities include bench and lab-scale units that will be used to optimize the entire process using improved solvents and contactors, develop fundamental knowledge of solvent stability, and minimize energy usage requirements..
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: Canada (lead) and United States*

16. Regional Carbon Sequestration Partnerships

- **MULTIFACETED PROJECT** will identify and test the most promising opportunities to **implement sequestration technologies in the United States and Canada**
  - conduct field validation tests of specific sequestration technologies and infrastructure concepts;
  - measurement, monitoring and verification (MMV) protocols;
  - characterize the regions to determine the technical and economic storage capacities;
  - regulatory requirements for each type of sequestration technology;
  - identify commercially available technologies for large scale deployment.
- *Recognized by the CSLF at its Berlin meeting, September 2005*
- *Nominators: United States (lead) and Canada*

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17. Air Products CO2 Capture from Hydrogen Facility

- **LARGE-SCALE COMMERCIAL PROJECT**, located in eastern Texas in the United States, will demonstrate a state-of-the-art system to concentrate CO2 from two steam methane reformer (SMR) hydrogen production plants, and purify the CO2 to make it suitable for sequestration by injection into an oil reservoir as part of an ongoing EOR project.

  To recover and purify approximately **1 million ton CO2 per year** for pipeline transport to Texas oilfields for use in EOR. To capture at least 75% of the CO2 from a treated industrial gas stream that would otherwise be emitted to the atmosphere.
- *Recognized by the CSLF at its Perth meeting, October 2012*
- *Nominators: United States (lead), Netherlands, and United Kingdom*

18. Frio Project

- **PILOT-SCALE PROJECT** demonstrated the process of CO2 sequestration in an **on-shore underground saline formation** in Eastern Texas, USA. This location was ideal, as very large scale sequestration may be needed in the area to significantly offset anthropogenic CO2 releases.

  Injection of relatively small quantities of CO2 into the formation and monitoring of its movement for several years thereafter.

  To verify conceptual models of CO2 sequestration; demonstrate that no adverse health, safety or environmental effects will occur; demonstrate field-test monitoring methods; develop experience for larger scale CO2 injection.
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: United States (lead) and Australia*

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19. SECARB Early Test at Cranfield Project

- **LARGE-SCALE PROJECT**, located near Natchez, Mississippi, USA, involves transport, injection, and monitoring of approximately **1 million ton CO2 per year** into a deep saline reservoir associated with a commercial enhanced oil recovery operation, but the focus of this project will be on the CO2 storage and monitoring aspects.

  This “early” test will set the stage for a subsequent large-scale integrated project that will involve post-combustion CO2 capture, transportation via pipeline, and injection into a deep saline formation.
- *Recognized by the CSLF at its Warsaw meeting, October 2010*
- *Nominators: United States (lead) and Canada*

20. CO2 Capture Project – Phase 2

- **PILOT-SCALE PROJECT** continued the development of new technologies **to reduce the cost of CO2 separation, capture, and geologic storage** from combustion sources such as turbines, heaters and boilers.

  These technologies will be applicable to a large fraction of CO2 sources around the world, including power plants and other industrial processes.

  The ultimate goal of the entire project is **to reduce the cost of CO2 capture from large fixed combustion sources by 20-30%**, while also addressing critical issues such as storage site/project certification, well integrity and monitoring.
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: United Kingdom (lead), Italy, Norway, and United States*

21. CO2 Capture Project – Phase 3

- **COLLABORATIVE VENTURE** of 7companies (international oil and gas producers) plus the Electric Power Research Institute. Duration: 2009 to 2013; funded by member partners

  To increase technical and cost **knowledge**, to **reduce CO2 capture costs by 20-30%**, to quantify remaining assurance issues surrounding geological storage of CO2, and to validate cost-effectiveness of monitoring technologies. 4 areas: CO2 Capture; Storage Monitoring & Verification; Policy & Incentives; and Communications; a fifth activity is Economic Modeling.

  At **least two field demonstrations of CO2 capture technologies** and a series of **monitoring field trials** CO2 monitoring in the subsurface.
- *Recognized by the CSLF at its Beijing meeting, September 2011*
- *Nominators: United Kingdom (lead) and United States*

22. CANMET Energy Technology Centre (CETC) R&D Oxyfuel Combustion for CO2 Capture

- **PILOT-SCALE PROJECT**, located in Ontario, Canada, that will demonstrate **oxy-fuel combustion technology** with CO2 capture.

  To develop energy- efficient integrated multi-pollutant control, waste management and CO2 capture technologies for combustion-based applications and to provide information for the scale- up, design and operation of large-scale industrial and utility plants based on the oxy-fuel concept.
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: Canada (lead) and United States*

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23. Illinois Industrial Carbon Capture and Storage

- **LARGE-SCALE COMMERCIAL PROJECT** CO2 captured from the fermentation process used to produce ethanol at an industrial corn processing complex in Decatur, Illinois. **3,000 ton CO2 per day, for deep geologic storage**

  To design, construct, and operate a new CO2 collection, compression, and dehydration facility capable of delivering up to 2,000 ton CO2/day, integrated with an existing 1,000 ton CO2/day compression and dehydration facility (total injection capacity of 3,000 ton/day (1million ton/y).

  To implement deep subsurface and near-surface MVA of the stored CO2.

  To conduct community outreach, training, and education initiative.
- *Recognized by the CSLF at its Perth meeting, October 2012*
- *Nominators: United States (lead) and France*

24. Illinois Basin – Decatur

- **LARGE-SCALE RESEARCH PROJECT** CO2 is captured from the fermentation process used to produce ethanol at an industrial corn processing complex in Decatur, Illinois. Geologically storage of up to **1 million ton CO2 over 3 years**.

  After three years, the injection well will be sealed and the reservoir monitored using geophysical techniques that will.

  Monitoring, verification, and accounting (MVA) efforts include tracking the CO2 in the subsurface, monitoring the performance of the reservoir seal, and continuous checking of soil, air, and groundwater during and after injection.
- *Recognized by the CSLF at its Perth meeting, October 2012*
- *Nominators: United States (lead) and United Kingdom*

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25. CASTOR

- **MULTIFACETED PROJECT** that had **activities at various sites in Europe**, in three main areas: strategy for CO2 reduction, post-combustion capture, and CO2 storage performance and risk assessment studies.

  To reduce the cost of post-combustion CO2 capture and to develop and validate, in both public and private partnerships, all the innovative technologies needed to capture and store CO2 in a reliable and safe way.

  The tests showed the reliability and efficiency of the post-combustion capture process.
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: European Commission (lead), France, and Norway*

26. CO2 Field Lab Project

- **PILOT-SCALE PROJECT**, located at Svelvik, Norway, which **will investigate CO2 leakage characteristics** in a well-controlled and well-characterized permeable geological formation. Relatively small amounts of CO2 will be injected to obtain underground distribution data that resemble leakage at different depths. An extensive set of monitoring methods deployed by the project partners will be used.

  To assure and increase CO2 storage safety by obtaining valuable knowledge about monitoring CO2 migration and leakage.
- *Recognized by the CSLF at its Warsaw meeting, October 2010*
- *Nominators: Norway (lead), France, and United Kingdom*

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27. CO2 Technology Centre Mongstad (formerly European CO2 Technology Centre Mongstad)

- **LARGE-SCALE PROJECT** (100,000 ton CO2 per year capacity) facility for parallel testing of **amine-based** and **chilled ammonia** CO2 capture technologies from two flue gas sources with different CO2 contents.

  To reduce cost and technical, environmental, and financial risks, while allowing evaluation of equipment, materials, process configurations, different capture solvents, and different operating conditions.

  The project will result in validation of process and engineering design and will provide insight into other aspects such as thermodynamics, kinetics, engineering, materials, and health / safety / environmental (HSE).
- *Recognized by the CSLF at its London meeting, October 2009*
- *Nominators: Norway (lead) and Netherlands*

28. CO2 STORE

- **A FOLLOW-ON TO THE SLEIPNER PROJECT monitoring of CO2 migration** (involving a seismic survey) **in a saline formation** beneath the North Sea and additional studies on geochemistry and dissolution processes. There were also several preliminary **feasibility studies for additional geologic settings of future candidate project sites** in Denmark, Germany, Norway, and the UK.

  The project was successful in developing sound scientific methodologies for the assessment, planning, and long-term monitoring of underground CO2 storage, both onshore and offshore.
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: Norway (lead) and European Commission*

29. Demonstration of an Oxyfuel Combustion System

- **PILOT LARGE SCALE PROJECT**, located at Renfrew, Scotland, UK, demonstrated oxyfuel technology on a **full-scale 40-megawatt burner**. The goal of the project was to gather sufficient data to establish the operational envelope of a full-scale oxyfuel burner and to determine the performance characteristics of the oxyfuel combustion process at such a scale and across a range of operating conditions.

  Data from the project is being used to develop advanced computer models of the oxyfuel combustion process, which will be utilized in the design of large oxyfuel boilers.
- *Recognized by the CSLF at its London meeting, October 2009*
- *Nominators: United Kingdom (lead) and France*

30. ENCAP

- **MULTIFACETED RESEARCH PROJECT** consists of **six sub-projects**: Process and Power Systems, Pre-Combustion Decarbonization Technologies, O2/ CO2 Combustion (Oxy- fuel) Boiler Technologies, Chemical Looping Combustion (CLC), High-Temperature Oxygen Generation for Power Cycles, and Novel Pre-Combustion Capture Concepts.

  To develop promising pre-combustion CO2 capture technologies (including O2/ CO2 combustion technologies) and propose the most competitive demonstration power plant technology, design, process scheme, and component choices. All sub-projects were successfully completed by March 2009.
- *Recognized by the CSLF at its Berlin meeting, September 2005*
- *Nominators: European Commission (lead), France, and Germany*

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31. CO2 GeoNet

- **MULTIFACETED PROJECT** is focused on **geologic storage options for CO2**, and on **assembling an authoritative body for Europe** on geologic sequestration.

  Major objectives include formation of a partnership consisting, at first, of 13 key European research centers and other expert collaborators in the area of geological storage of CO2, identification of knowledge gaps in the long-term geologic storage of CO2, and formulation of new research projects and tools to eliminate these gaps.

  This project will result in re-alignment of European national research programs and prevention of site selection, injection operations, monitoring, verification, safety, environmental protection, and training standards.
- *Recognized by the CSLF at its Berlin meeting, September 2005*
- *Nominators: European Commission (lead) and United Kingdom*

32. CGS Europe Project

- **COLLABORATIVE VENTURE, INVOLVING 35 PARTNERS** from participant countries in Europe, with extensive structured networking, knowledge transfer, and information exchange. 3 year FP7 project, starting in November 2011

  To create a durable network of experts in CO2 geological storage and a centralized knowledge base which will provide an independent source of information for European and international stakeholders.

  The CGS Europe Project is intended to provide an information pathway toward large-scale implementation of CO2 geological storage throughout Europe.
- *Recognized by the CSLF at its Beijing meeting, September 2011*
- *Nominators: Netherlands (lead) and Germany*

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33. Lacq Integrated CCS Project

- **INTERMEDIATE-SCALE PROJECT** demonstrate an entire integrated CCS process, from emissions source to underground storage in a depleted gas field.

  Capture and store **60,000 ton CO2 per year** for two years from an oxyfuel industrial boiler in the Lacq industrial complex in southwestern France.

  To demonstrate the technical feasibility and reliability of the integrated process before proceeding to a large-scale demonstration.

  The project will also include geological storage qualification methodologies, as well as monitoring and verification techniques.
- *Recognized by the CSLF at its London meeting, October 2009*
- *Nominators: France (lead) and Canada*

34. Dynamis

- This was the first phase of the **MULTIFACETED EUROPEAN HYPOGEN** program, which will result in the construction and operation of an advanced commercial-scale power plant with H2 production and CO2 management.

  The overall aim is for operation and validation of the power plant during the 2012-2015 timeframe.

  Assessment of the various options for large-scale hydrogen production while focusing on the technological, economic, and societal issues.
- *Recognized by the CSLF at its Cape Town meeting, April 2008*
- *Nominators: European Commission (lead), and Norway*

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35. Zero Emission Porto Tolle Project (ZEPT)

- **LARGE-SCALE PROJECT**, located in northeastern Italy; **post- combustion CCS on 40% of the flue gas from one of the three 660 megawatt units** of the existing Porto Tolle Power Plant (which is being converted from heavy oil fuel to coal).

  10 years operation: to demonstrate the technology, clarify the real costs of CCS, and prove the retrofit option for high-efficiency coal fired units

  1 million ton CO2 per year captured and stored in a deep saline aquifer beneath the seabed of the Adriatic Sea, 100 kilometers from the project site.
- *Recognized by the CSLF at its Beijing meeting, September 2011*
- *Nominators: Italy (lead) and European Commission*

36. Ketzin Test Site Project (formerly CO2 SINK)

- **Pilot-scale project** that tested and evaluated CO2 capture and **storage** at an **existing natural gas storage facility** and in a **deeper land-based saline formation**.

  A key part of the project was **monitoring the migration characteristics of the stored CO2**. The project was successful in advancing the understanding of the science and practical processes involved in underground storage of CO2 and provided real case experience for use in development of future regulatory frameworks for geological storage of CO2.
- *Recognized by the CSLF at its Melbourne meeting, September 2004*
- *Nominators: European Commission (lead) and Germany*

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37. CCS Belchatów Project

- **LARGE-SCALE PROJECT**, located in central Poland, which will demonstrate commercial-scale CO2 capture, transport and storage at a **new lignite-fired power plant unit**. Geological **storage of up to 1.8 million ton CO2 per year**

  Identification of potential issues related to intellectual property, storage site selection, permitting, facilities and pipeline construction, and public engagement activities.
- *Recognized by the CSLF at its Warsaw meeting, October 2010*
- *Nominators: Poland (lead), European Commission, and United States*

38. CCS Rotterdam Project

- **LARGE-SCALE "CO2 HUB"** for capture, transport, utilization, and storage of CO2 in the Rotterdam metropolitan area.

  The project is **part of the Rotterdam Climate Initiative** (RCI), aimed at reducing Rotterdam's CO2 emissions by 50% by 2025 (as compared to 1990).

  A "**CO2 cluster approach**" will be utilized, with **various point sources of CO2** connected via a hub / manifold arrangement to multiple storage sites such as **depleted gas fields** under the North Sea.
- *Recognized by the CSLF at its London meeting, October 2009*
- *Nominators: Netherlands (lead) and Germany*

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39. Rotterdam Opslag en Afvang Demonstratieproject (ROAD)

- **LARGE-SCALE INTEGRATED PROJECT**, located near the city of Rotterdam: **CO2 capture from a coal-fired power plant**, pipeline transportation of the CO2, and **offshore storage of the CO2 in a depleted natural gas reservoir** beneath the seabed of the North Sea (20 kilometers from the power plant).

  1.1 million ton CO2 annually over a five year span starting in 2015

  Focus on technical, legal, economic, organizational, and societal aspects

  Fnancial support from the European Energy Programme for Recovery (EEPR), the Dutch Government, and the Global CCS Institute, and is a component of the Rotterdam Climate Initiative CO2 Transportation Network.
- *Recognized by the CSLF at its Beijing meeting, September 2011*
- *Nominators: Netherlands (lead) and the European Commission*

CSLF Task Forces

Operating Task Forces:

- CSLF Projects Interaction and Review Team (PIRT)
- Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2
- CO_2 Utilization Options
- Technical Challenges for Conversion of CO_2 EOR to CCS
- Technology Opportunities and Gaps

PIRT: Projects Interaction and Review Team

- A proposal for project recognition can be submitted by any CSLF delegate to the Technical Group.
- The representatives of the project sponsors and the delegates of Members nominating a project sign the Submission Form.
- The CSLF Technical Group evaluates all projects proposed for recognition. Projects that meet all evaluation criteria are then recommended to the Policy Group.
- Final step: approval by the Policy Group

Task Force Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2

Launched at the CSLF Ministerial Meeting in Beijing, China, in September 2011. Norway volunteered to chair the Task Force

TF mandate

- The Task Force shall perform initial identification and review of standards for storage and monitoring of injected CO_2
- The application of such standards should inform CO_2 crediting mechanisms
- Economic and policy issues are outside the scope of the TF, as these are policy matters and belong to the Policy Group

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Best Practices Task Force Work Plan

- Identify and review existing standards for geological CO_2 storage and monitoring on an annual basis;
- Identify shortcomings and/or weaknesses in standards/ guidelines;
- Communicate with the ISO CCS working group (Technical Committee 265) that has been established;
- Produce annual summaries of new as well as updated standards, guidelines and best practice documents regarding geological storage of CO_2 and monitoring of CO_2 sites;
- Follow the work of other task forces related to CO_2 storage

Task Force CO_2 Utilization Options

- ❑ Identification of the most economically attractive CO_2 options - CO_2 utilization technology or application – the use of which:
  - ❖ has a reasonable potential for an economically viable venture, or
  - ❖ has a reasonable potential to partially offset the cost of anthropogenic CO_2 capture
- ❑ Focus on utilization option that have the potential to yield a significant, net reduction of CO_2 emissions

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Task Force CO_2 Utilization Options

Hydrocarbon Recovery

- ~~CO_2-EOR~~
- CO_2-EGR
- CO_2-ECBM
- CO_2-EGHR
- Oil shale recovery
- CO_2-fracturing

Non-consumptive

- Fuels & chemicals
- Desalination
- Slurry transport
- Beneficiation
- Working/HT fluid
- Extractant
- Inerting Agent
- Fire Suppression
- Food/Products
- Refrigerant

Consumptive

- Soil amendment/fertilizer
- Synthetic cementitious materials, building materials
- Chemicals
- Polycarbonates / polymers

- summary of existing information

- state of each relevant technology and application

- preliminary assessment of the relative value of the utilization option to make a meaningful impact on CO_2 emission reduction

- economic viability of the technology.

Technical Group Meeting

Rome, 16 – 19 April, 2013

Tuesday **16 April** **Hotel Ambasciatori Palace**	**Wednesday** **17 April** **Hotel Palatino**	**Thursday** **18 April** **Hotel Ambasciatori Palace**	**Friday** **19 April** **Latera Caldera**
CSLF Projects Interaction and Review Team (PIRT) *Sala Stucchi* *10:00-12:00*	Meeting Registration *08:00-09:00* *Sala Cesarini Foyer* CSLF Technical Group *Sala Cesarini* *09:00-12:30*	CO_2 MONITORING WORKSHOP Plenary Session *Sala Ambasciatori* *09:00-09:15* Session 1: Monitoring CO_2 Storage in Deep Saline Aquifers and Oil Reservoirs *Sala Ambasciatori* *09:15-12:35*	Site visit to Latera Caldera *Bus departs TBA*
Lunch *12:00-14:00*	Lunch *12:30-13:30*	Lunch *12:30-14:00*	Lunch
Technical Challenges for Conversion of CO_2 EOR to CCS Task Force *Sala Stucchi* *14:00-15:00* Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2 Task Force *Sala Stucchi* *15:00-16:00* CO_2 Utilization Options Task Force *Sala Stucchi* *16:00-17:00* Technology Opportunities and Gaps Task Force *Sala Stucchi* *17:00-18:00*	CSLF Technical Group *Sala Cesarini* *13:30-16:30*	CO_2 MONITORING WORKSHOP Session 2: Monitoring CO_2 at Controlled Release Projects in Shallow Subsurface *Sala Ambasciatori* *14:00-16:30*	Site visit to Latera Caldera and visit to historical site *Bus returns 20:00* *(Earlier bus returns to airport after lunch)*
	Dinner Event *19:00-22:30*		

Thank you
for your attention

and

see you in Rome

Giuseppe Girardi, CSLF – ENEA
giuseppe.girardi@enea.it

How to propose a Project

- A proposal for project recognition can be submitted by any CSLF delegate to the Technical Group.
- The representatives of the project sponsors and the delegates of Members nominating a project sign the Submission Form.
- The CSLF Technical Group evaluates all projects proposed for recognition. Projects that meet all evaluation criteria are then recommended to the Policy Group.
- Final step: approval by the Policy Group

39 projects recognized: 27 active, 12 already completed

Best Practices Task Force Deliverables

- An annual interim report by the end of 2012;
- A report with recommendation on continuation or termination of the task force to the CSLF Ministerial Meeting, November 2013.
- Further deliverables to be decided after the decision gate in November 2013.
- Possibly annual reports that coincide with CSLF Annual Meetings in 2014 and 2015 and final report in 2016

Best Practices Task Force Membership

- Rob Arts, Netherlands
- Andre Bocin-Dumitriu, EC
- Grant Bromhal, USA
- Andy Chadwick, UK
- Niels Peter Christensen, Norway
- Tim Dixon, UK/IEAGHG
- Bin Gong, China
- Qi Li, China
- Xiaochun Li, China
- Jacques Monne, France
- Niels Poulsen, Denmark
- Jeroen Schuppers, EC
- Martin Streibel, germany
- Evangelos Tzimas, EC
- Trygve Riis, Norway
- Lars Ingolf Eide, Norway

Best Practices Task Force: Next step

- ❑ Continue assessment of standards/guidelines;
- ❑ Establish communication with the ISO CCS working group Technical Committee (TC) 265