Proposed CCS Early Action Initiative for the United States

R.H. Williams
Princeton Environmental Institute
Princeton University
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The Urgent Need for CCS Early Action: In light of the coal-intensity of the US economy, getting broad political consensus on a serious carbon policy is likely to require support from coal industry stakeholder groups. Hence it is urgent[1] to ascertain whether CO_2 capture and storage (CCS) is viable as a major carbon mitigation option—without which there is no future for coal, our most abundant and secure domestic fossil fuel resource, in a carbon-constrained world.

The Context: The international political framework for early CCS action has already been established. At the July 2008 G8 Summit in Japan an agreement was reached that the G8 would sponsor 20 large-scale fully integrated CCS demonstration projects worldwide that would be committed by 2010 with the aim of establishing the basis for broad commercial deployment of CCS technologies after 2020. The US agreed to sponsor at least 10 of these projects. Moreover, there is much early CCS activity underway in other regions (*see Appendix*).

However, the unfolding global financial and more general economic crises have cast doubt on the prospects for major near-term climate-change mitigation actions such as the G8-proposed integrated CCS projects and the US commitment to sponsor ½ of the proposed G8 projects.

The Science: Scientists of the Intergovernmental Panel on Climate Change (IPCC) have reached judgments that: (*i*) CO_2 capture and storage (CCS) is likely to be competitive with other major carbon mitigation technologies;[2] (*ii*) the geological CO_2 storage capacity for CO_2 worldwide is likely to be at least equivalent to about a century of CO_2 emissions from fossil fuel burning[3] and may be much greater, and (*iii*) the share of CCS in the overall carbon mitigation portfolio is likely to increase with the stringency of the greenhouse gas (GHG) mitigation goal.[4] Moreover, IPCC scientists are guardedly

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[1] Al Gore's impatience with the so-far-unfulfilled promise of CCS technologies, as expressed in his 9 November *New York Times* Op Ed ("The Climate for Change"), underscores the urgency of striving to prove to the satisfaction of a wide range of stakeholders the viability of CCS as major carbon mitigation option: "…Some have come up with even dirtier and more expensive new ways to extract the same old fuels, like coal liquids…and "clean coal" technology. But in every case, the resources in question are much too expensive or polluting, or, in the case of "clean coal," too imaginary to make a difference in protecting either our national security or the global climate. Indeed, those who spend hundreds of millions promoting "clean coal" technology consistently omit the fact that there is little investment and not a single large-scale demonstration project in the United States for capturing and safely burying all of this pollution. If the coal industry can make good on this promise, then I'm all for it. But until that day comes, we simply cannot any longer base the strategy for human survival on a cynical and self-interested illusion."

[2] "…Models…indicate that CCS systems will be competitive with other large-scale mitigation options such as nuclear power and renewable energy technologies…" (IPCC, 2005).

[3] "…Available evidence suggests that, worldwide, it is likely that there is a technical potential of at least about 2000 Gt CO_2 of storage capacity in geological formations…" (IPCC, 2005). For perspective, global CO_2 emissions in 2005 from fossil fuel burning were 27 Gt CO_2.

[4] "…Based on the TAR [Third Assessment Report of the IPCC] mitigation scenarios, the average share of CCS in total emissions reduction may range from 15% for scenarios aiming at stabilization of CO_2 concentrations at 750 ppmv to 54% for 450 ppmv scenarios…" (IPCC, 2005).

optimistic about the prospects for the safety[5] and the security[6] of geological CO_2 storage with careful planning and management. These judgments underscore the urgency[7] to demonstrate to the satisfaction of a wide range of stakeholder groups that CCS is a viable major option to be included in the portfolio of carbon mitigation options—an outcome that could lead to a major reduction in the cost of meeting carbon mitigation goals relative to the case where CCS is excluded.[8]

The Technology: The separate elements of capture, transport, and storage of CO_2 have all been demonstrated, but integrated CCS systems have not yet been proven. It is now widely recognized that the most significant obstacle to the routine pursuit of CCS is successful demonstration of CO_2 storage at "megascale"[9] in a variety of geological media—with emphasis on deep saline formations, which account for most of the geological storage opportunity. To be sure, the only CO_2 capture options that are ready to be deployed at commercial scale are pre-combustion capture technologies for gasification energy systems. Post-combustion capture technologies (*proven only at pilot scale*) and oxy-fuel combustion strategies (*not yet demonstrated even at pilot scale*) are also needed.

An important consideration is that systems making synfuels from coal and/or biomass generate, as a natural part of the process of synfuel manufacture, relatively pure streams of CO_2[10] for which the incremental cost of CO_2 capture is very low (NETL, 2009; Kreutz *et al.*, 2008; Williams, 2009)—a fact that can be exploited to facilitate cost-effective early CCS action, as discussed below.

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[5] "…With appropriate site selection informed by available subsurface information, a monitoring program to detect problems, a regulatory system, and the appropriate use of remediation methods to stop or control CO_2 releases if they arise, the local health, safety and environment risks of geological storage would be comparable to risks of current activities such as natural gas storage, enhanced oil recovery, and deep underground disposal of acid gas…" (IPCC, 2005).

[6] " …Based on observations and analysis of current CO_2 storage sites, natural systems, engineering systems, and models, the fraction [*of injected* CO_2] retained in appropriately selected and managed reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1000 years…" (IPCC, 2005).

[7] Al Gore's impatience with the so-far-unfulfilled promise of CCS technologies, as expressed in his 9 November *New York Times* Op Ed ("The Climate for Change"), underscores the urgency of striving to prove to the satisfaction of a wide range of stakeholders the viability of CCS as major carbon mitigation option: "…Some have come up with even dirtier and more expensive new ways to extract the same old fuels, like coal liquids…and "clean coal" technology. But in every case, the resources in question are much too expensive or polluting, or, in the case of "clean coal," too imaginary to make a difference in protecting either our national security or the global climate. Indeed, those who spend hundreds of millions promoting "clean coal" technology consistently omit the fact that there is little investment and not a single large-scale demonstration project in the United States for capturing and safely burying all of this pollution. If the coal industry can make good on this promise, then I'm all for it. But until that day comes, we simply cannot any longer base the strategy for human survival on a cynical and self-interested illusion."

[8] "…The inclusion of CCS in a mitigation portfolio is found to reduce the costs of stabilizing CO_2 concentrations by 30% or more…" (IPCC, 2005).

[9] To characterize needed demonstrations, the term "megascale" is often used—a word that refers to the geological storage of at least a million tonnes of CO_2 per year per project.

[10] To illustrate, a byproduct of the production of about 140,000 barrels per day of synthetic liquids (*3/4 fuels, ¼ chemicals*) from coal by Sasol at its two Secunda plants in South Africa is the production of streams of pure CO_2 that are vented at a rate of 20 million tonnes per year—making this the largest point source of pure CO_2 emissions on the planet.

It is desirable for the Administration to formulate a near-term CCS policy that deals *separately* with the challenges of bringing to commercial readiness selected CO_2 capture technologies[11] and ascertaining (*to the satisfaction not only of the scientific community but also of many stakeholder groups and opinion-shapers*) the gigascale viability of CO_2 storage as a major C-mitigation option (*especially in deep saline formations*). The latter, the more pressing challenge, can be realized via systems with commercial or near-commercial technological components, which is the focus of my Proposed CCS Early Action Initiative for the United States (CEAI).

Proposal: Here an initiative is proposed that would make it feasible for the US to meet its commitment at the July 2008 G8 Summit regarding early CCS projects despite the looming financial crisis. The strategy is based on:

- the likelihood that for early CCS projects government will have to pay for a significant fraction of the incremental CCS cost;
- the premise that federal funds will be scarce for purposes other than for financial crisis resolution;
- the prospect that the cost to government for establishing CCS in the market can be relatively low if co-production systems (*making synthetic fuels + electricity from coal + biomass*) are allowed to compete for the scarce federal funds needed to pay for the incremental CCS cost.

It is proposed that the Departments of Energy and Defense[12] collaborate in carrying out a *CCS Early Action Initiative* (CEAI) to implement the US commitment at the July 2008 G8 Summit to carry out 10 megascale integrated CCS projects based on commercial or near-commercial technologies that would involve CO_2 storage in deep saline formations. Under the CEAI the federal government would provide incentives for 10 megascale integrated CCS projects that:[13]

- Produce at least 300 MW_e of decarbonized power;
- Store at least 1 million tonnes of CO_2 per year in deep saline formations;
- Use domestic coal for at least ¾ of the feedstock;
- Use at least ½ of the coal to make electricity as a product; and
- Come on line by 31 December 2015.

Under the proposed CEAI qualifying projects would include not only coal electricity projects but also:

- Co-production projects[14] that produce, along with decarbonized electricity, synthetic fuels with GHG emission rates that are not more than for the displaced conventional fossil fuels;[15]

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[11] E.g., post-combustion scrubbing/oxy-combustion are not yet commercially ready but pre-combustion capture systems are.

[12] Both Departments have much to offer to the proposed CEAI. Obviously, a major role for DoE is essential to ensure technical success. The DoD would be a highly motivated partner in light of the Air Force's established goal of meeting ½ of its North American jet fuel demand from secure domestically produced synthetic fuels by 2016—a goal that could plausibly be realized easily under the proposed CEAI. Also the DoD is committed to alternative energy implementation in all sectors and has already established a strong track record

[13] The five criteria that follow were the major criteria specified for qualifying projects under the DoE's Restructured FutureGen competition.

[14] The cost of greenhouse gas emissions avoided is much less for these systems than for stand-alone power systems (Williams, 2009). Thus the cost to government for CEAI incentives would probably be much less if co-production systems were allowed to compete. (*As discussed below, the government would pay for the incremental cost of CCS*.)

- Projects that coprocess modest amounts of biomass[16] that is not grown on good cropland.[17]

The winning CEAI projects would be those that satisfy all the above criteria[18] at the least costs of GHG emissions avoided.[19,20] Of course the cost of GHG emissions avoided cannot be known *a priori* with certainty, but because the CEAI competition is restricted to commercial and near-commercial technologies it should be feasible for the DoE/DoD competition judges to rank the prospective incremental costs for CEAI submissions in a relatively reliable manner.[21]

One component of the incentive provided for winning CEAI projects is that the government would pay over a period of 5 years[22] for the incremental cost of CCS. In addition, winning projects that provide synthetic jet fuel would be offered by the Air Force 20-year procurement contracts[23] at purchase prices consistent with synfuel production costs under competitive market financing conditions.[24] The procurement agreement would be that the government would pay this amount for the procured jet fuel, which implies that the net cost of the procurement program to the government could be positive or negative. At low oil prices the government would pay the synfuel producer the market price for petroleum-derived jet fuel + the difference between the synfuel production cost and this market price. At high oil prices, the government would save the difference between the market price for petroleum-

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[15] Section 526 of the Energy Independence and Security Act of 2007 requires that any synthetic fuels procured by the federal government shall be characterized by a fuel-cycle-wide GHG emission rate for production and consumption that is not greater than the GHG emission rate for the crude oil products displaced.

[16] Coprocessing biomass with coal in co-production systems with CCS makes it feasible over the longer term to realize, at very competitive costs, deep reductions in the GHG emission rates for the synfuels as well as for the electricity produced; for the near term, coprocessing a modest amount of biomass *(< 10% of the total energy input*) makes it feasible to meet the Section 526 requirement for the GHG emission rate for the synthetic fuel at low incremental cost (Williams, 2009).

[17] Concerns about food price impacts (Rosegrant, 2008) and indirect land use impacts (Searchinger *et al.*, 2008) of growing biomass for energy on croplands have led to emphasis on using lignocellulosic biomass supplies such as crop/forest residues and energy crops grown on degraded lands. The biomass required to realize a zero net GHG emission rate via coal/biomass co-production systems with CCS is ~ 2 of that required for cellulosic ethanol (Kreutz *et al*, 2008)—an important consideration if biomass supplies are constrained to non-cropland sources.

[18] Plus additional criteria relating to CO_2 storage that are not explicitly spelled out here.

[19] Measured in $ per tonne of CO_{2eq} emissions avoided.

[20] Even prior to the financial crisis, there was substantial Congressional interest in providing CCS subsidies cost-effectively. For example, the Dingell/Boucher climate change discussion draft introduced on 7 October 2008 as a proposal to amend the Clean Air Act so as to establish an economy-wide Cap and Trade program specified that in allocating federal resources for early CCS action, the government would “give preference to projects that most cost-effectively capture and sequester carbon dioxide, so as to maximize the tonnage of carbon dioxide sequestered per dol1ar of assistance provided.”

[21] Project proposals would be required to present an analytical basis for the expected cost of GHG emissions avoided, using a method of estimation specified in the Request for Proposals issued by the DoE/DoD.

[22] Under the Restructured FutureGen program (launched by the US Department of Energy in January 2008 and for which proposals were due 8 October 2008) the government would pay for the incremental cost of CCS for a period of 3-5 years.

[23] As an incentive to help realize the Air Force goal of meeting ½ of its N. American jet fuel demand with synfuels by 2016.

[24] DoE/DoD would specify a competitive market financing algorithm. The competitive financing algorithm implicit in the calculations presented in Tables 1 and 2 is: debt/equity ratio = 55/45; inflation rate = 3%/y; economic plant life = 20 y; nominal annual debt/equity costs = 7.5%/13.5%; 39.2% corporate income tax rate.

derived jet fuel and the synfuel production cost at which it would purchase the synfuel under the procurement agreement.

Implications of a successful CEAI: Although the proposed approach to early CCS action would let the market (*rather than government*) pick the technologies for winning projects, it is worth speculating as to the outcome of a successful competition.

Co-production plants would be very competitive under the CEAI—e.g., the estimated cost of GHG emissions avoided is $25 per tonne of CO_{2eq} for a coal co-production plant with CCS producing 19,300 barrels per day of Fischer-Tropsch liquids (FTL) + 566 MW_e of decarbonized power[25]—much less than for a coal IGCC plant (Williams, 2009). However, this system would not satisfy the CEAI requirement that the FTL GHG emission rate be no more than for the crude oil products displaced when the electricity is assigned a GHG emission rate equal to that for a new coal power plant with 90% capture (Williams, 2009);[26] but a similar CBTL2-OT-CCS plant coprocessing < 10% biomass (*with outputs of 19,300 barrels per day of Fischer-Tropsch liquids (FTL) + 583 MW_e of decarbonized power*) could meet this criterion and would be characterized by essentially the same cost of GHG emissions avoided (Williams, 2009).

Suppose, as a thought experiment, that all 10 winning CEAI projects were such CBTL2-OT-CCS plants. Then:

- *For CCS*:
  - The CEAI would provide in total about 5.8 GW_e of decarbonized power at an ultra-low cost of GHG emissions avoided;
  - These plants would offer a very effective market mechanism for backing out the very carbon-intensive existing coal power plants because they would be highly competitive in economic dispatch competition (Williams, 2009);
  - After 5 years the cumulative CO_2 storage for these 10 projects would be > 250 million tonnes—a large base of experience with CO_2 storage that would go a long way toward ascertaining the viability of CCS as a major carbon mitigation option;
  - This experience would probably lead to significant CCS cost reduction via learning-by-doing, thereby facilitating subsequent widespread CCS deployment.

- *For energy security*, the CEAI would help launch a synfuels industry based on secure domestic energy resources without exacerbating climate change:
  - The Air Force could procure by 2016 ~ 1700 million gallons per year of petroleum-derived diesel-equivalent FTL diesel blendstock—thereby far exceeding its 2016 synthetic jet fuel procurement goal;

[25] The coal-to liquids (CTL) system with once-through (OT) FTL processing and CCS labeled “Small CTL-OT-CCS” in Williams (2009).

[26] For a co-production system the distribution of emissions between the electricity and liquid fuel products is arbitrary. This convention is adopted because of the likelihood that few if any new coal plants will be built in the US without capture and storage of ~ 90% of the coal’s carbon as CO_2.

- The CEAI incentive would help overcome the institutional barriers[27] to co-production, which will often be the least costly approach for providing synthetic fuels.

- *For the quest to evolve low-carbon transport fuels,* the CEAI would:
  - Help establish a biomass supply logistics infrastructure that could lead to deployment of technology offering FTL with extremely low net GHG emission rates for co-production plants that coprocess biomass at higher rates (Williams, 2009); and
  - Provide the basis for evolving to a climate-friendly synfuel production system in which investors would have a high degree of protection against the risk of oil price collapse if a strong climate-change-mitigation policy is in place (Williams, 2009).

The cost to government for the proposed CEAI: The subsidy that the government would have to provide under the CEAI in estimated for two alternative cases. In Case I (*the much more plausible case if the Administration is able to implement a strong carbon-mitigation policy*) it is assumed that a carbon policy is in place characterized by a GHG emissions value that grows exponentially at a rate of 12.7% per year, 2015-2035, from $15/t in 2015, reaching $90/t in 2030.[28] For Case II it is assumed that the GHG emissions value is $0/t CO_{2eq} over the entire period of the subsidies (2016-2035).

The estimated government subsidy required to pay for the incremental CCS cost for 10 co-production systems coprocessing < 10% biomass is ~ $0.4 billion for Case I and $4.8 billion for Case II (Table 1). The estimated cost to government of the 20-year jet fuel procurement program depends sensitively on the oil price levelized over the period 2016-2035 and is calculated for four oil prices in the range $35 to $65 a barrel in Table I. Notably, the net cost to government for the two subsidies would be negligible or negative for levelized oil prices > $50 a barrel in Case I—which is a plausible outcome.

An alternative approach to early CCS action was put forth recently in the Dingell/Boucher climate change discussion draft released on 7 October 2008. It would offer subsidies of $90/t, $70/t, and $50/t for CO_2 emissions avoided over a period of 10 years for the 1st, 2nd, and 3rd tranches of 3 GW_e per tranche of decarbonized coal power plants deployed in the US. Under Dingell/Boucher the required subsidy would be ~ $16 billion with the Case I GHG emissions price trajectory or ~ $25 billion if it is assumed that the GHG emissions price is constant at $0/t CO_{2eq}. The Dingell/Boucher approach would be far more costly than the proposed CEAI under all plausible conditions (Table 1).[29]

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[27] Despite the economic attractions of the co-production approach to making synfuels (Williams, 2009), there is no rush to embrace this technology in the market. This is probably due in large part to the complications of managing and marketing simultaneously such disparate commodity energy products as electricity and liquid fuels.

[28] A GHG emissions price of $90/t in 2030 is what the IEA has estimated to be consistent for OECD+ countries with an ultimate stabilized atmospheric GHG content of 550 ppmv (IEA, 2008). At the hypotheticized growth rate for the GHG emissions price, the levelized price, 2016-2035, is $51/t.

[29] It is assumed for the Dingell/Boucher approach that a new coal IGCC plant with 90% CO_2 capture for storage replaces a pulverized coal plant that vents CO_2; for this shift the cost of GHG emissions avoided is $48/t CO_{2eq}, about twice the cost of GHG emissions avoided for a shift from a CTL-OT-V co-production plant to a CBTL2-OT-CCS co-production plant.

Table 1: Cost to Government (present worth[a]) for:					
Proposed CEAI if all 10 winning projects were CBTL2-OT-CCS units (co-production cost valuation from"fuels perspective"[b])					**Dingell-Boucher Proposal**
Levelized crude oil price, 2016-2035 ($/barrel)	35	45	55	65	
Case I: If GHG emissions price grows 12.7%/year, 2015-2035, from \$15/t CO_{2eq} in 2005					
PW of subsidy for incremental CCS cost[c] ($\$10^9$)	0.39				-
PW of synthetic jet fuel procurement[d] ($\$10^9$)	6.46	2.60	- 1.27	- 5.13	
PW (present worth) of total obligation ($\$10^9$)	***6.84***	***2.98***	***- 0.88***	***- 4.74***	***15.75***
Case II: If GHG emissions price = \$0/t of CO_{2eq}					
PW of subsidy for incremental CCS cost[c] ($\$10^9$)	4.84				-
PW of synthetic jet fuel procurement[d] ($\$10^9$)	12.24	8.86	5.47	2.08	
PW (present worth) of total obligation ($\$10^9$)	***17.08***	***13.70***	***10.31***	***6.92***	***24.51***

[a] Costs are the present worth on 1 January 2016 (in $2007) of obligations over the period 2016-2035 assuming a 7% real discount rate.
[b] For a discussion of the economics of co-production from both a fuels perspective and an electricity perspective see Williams (2009a).
[c] See note a, Table 2.
[d] See note b, Table 2.

Table 2: Specific Subsidy for CEAI Elements ($ per gallon of diesel equivalent)				
Subsidy for incremental CCS cost[a]				
Case I: : If GHG emissions price grows 12.7%/year, 2015-2035, from \$15/t CO_{2eq} in 2015				
2016 (P_{GHGE} = \$17/t CO_{2eq})	10.4			
2017 (P_{GHGE} = \$19/t CO_{2eq})	5.8			
2018 (P_{GHGE} = \$22/t CO_{2eq})	0.59			
2019+	0			
Case II: If GHG emissions price = \$0/t of CO_{2eq}				
All years	41.0			
Subsidy for synthetic jet fuel procurement[b]				
Levelized crude oil price, 2016-2035 ($/barrel)	35	45	55	65
Case I: Under assumed GHG emissions price trajectory				
2016 (P_{GHGE} = \$17/t CO_{2eq})	62.1	41.2	20.3	- 0.61
2020 (P_{GHGE} = \$27/t CO_{2eq})	53.8	32.9	12.0	- 8.9
2025 (P_{GHGE} = \$50/t CO_{2eq})	36.1	15.2	- 5.7	- 26.6
2030 (P_{GHGE} = \$90/t CO_{2eq})	3.88	- 17.0	- 37.9	- 58.8
2035 (P_{GHGE} = \$164/t CO_{2eq})	- 54.6	- 75.5	- 96.4	- 117.3
Case II: If GHG emissions price = \$0/t of CO_{2eq}				
All years	75.5	54.6	33.7	12.8

[a] Incremental CCS cost per gallon of diesel equivalent = (FTL cost via CBTL2-OT-CCS) – (FTL cost via CTL-OT-V). See Williams (2009a) for details.
[b] Diesel procurement subsidy per gallon of diesel equivalent = [market value of FTL diesel (value of crude-oil-derived diesel displaced)] – (production cost of FTL via CBTL2-OT-CCS, assuming competitive market financing conditions for the synfuels plant) .

Appendix A: Some Early CCS Action Initiatives Launched Recently Around the World

The EU Flagship Programme: In March 2007 the EU Spring Council called for 10-12 full scale CCS demonstration projects being operational in the EU by 2015 to ensure that CCS is commercially viable for all new fossil fuel power plants by 2020. In October 2007 the EU General Assembly proposed the Flagship Programme as the instrument to develop and have operational Europe-wide by 2015 10-12 full-scale, integrated CCS demonstration projects covering a wide variety of CCS technologies. In January 2008 the European Commission proposed a Directive to enable environmentally safe capture and geological storage of carbon dioxide (CO_2) in the EU as part of a major legislative package. On 18 December 2008 the European Parliament voted overwhelmingly[30] to approve a comprehensive climate and energy package that includes a directive on CCS to provide the legal framework needed to further develop the technology as well as a provision that 300 million allowances[31] from the EU ETS will be used to fund 12 commercial-scale CCS projects.

Alberta, Canada**:** In July 2008 the provincial government of Alberta, Canada, announced, as a major element of its Climate Change Strategy, creation of a $2 billion fund aimed at advancing CCS as a major carbon mitigation option. This fund will be used to encourage construction of Alberta's first large-scale CCS projects and to attract substantial investments in CCS by both the Canadian government and Alberta industries. The province has issued a request for expressions of interest to begin identifying those CCS proposals both with the greatest potential of being built quickly and which provide the best opportunities to significantly reduce greenhouse gas emissions: 54 companies applied, and 20 of these were invited submit full proposals: 3 utilities, 3 pipeline companies, 10 or so major oil sands producers (Shell, Total, Statoil Hydro, Petro-Canada, ConocoPhillips, Suncor, Syncrude, etc.), and a few others. Proposals are due in March 2009 and "winners" will be announced in late 2009.

Australia**:** On 19 September 2008 the Australian Prime Minister Kevin Rudd announced the creation by Australia of a $100 million Global Carbon Capture and Storage Institute (GCCSI) to be launched in January 2009 as a key part of a Global CCS Initiative to accelerate the global adoption of commercially and environmentally sustainable CCS technologies. The Institute would foster international action to partner, financially support, build capacity and share information to facilitate realization of the G8 goal of committing to 20 integrated industrial-scale CCS projects worldwide by 2010. Intended GCCCSI activities would be to define and commit to a shared target portfolio of industrial-scale projects and track global progress toward the target before 2020.

[30] The vote was 610 votes for, 60 against, with 29 abstentions

[31] At the 18 December 2008 exchange rate of $1.43 US dollars per Euro, these allowances would be worth $6.7 billion at the 18 December ETS trading price of 15.7 Euros per tonne of CO_2 and $16.7 billion at the projected 2020 reference scenario price of 39 Euros per tonne (Commission Staff, 2008).

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