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CARBON SEQUESTRATION AND SUSTAINABILITY

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I. INTRODUCTION

This Essay explores the question of whether the developing technology of geologic carbon capture and sequestration (CCS), which involves capturing CO_2 emissions from industrial sources and power plants and sequestering them underground, is consistent with principles of sustainable development. While there are many definitions of "sustainability," one common definition of the term is to "meet[] the needs of the present without compromising the ability of future generations to meet their own needs."[1] In the context of using natural resources for energy production, many would agree that sustainable development requires "more efficient use of nonrenewable fossil fuel-based energy resources and increased development and use of renewable energy resources."[2] Michael Pollan, author of *The Omnivore's Dilemma* and journalism professor at UC-Berkeley, has noted that while few can define sustainability, lately everybody is for it.[3] With everyone rushing to define their products and technologies as sustainable, some unusual suspects have recently claimed to be part of a more sustainable solution. Perhaps the most unusual among them is CCS, which has the potential to make the use of coal and other carbon emitting technologies more "sustainable" in an era where climate change is one of the world's most pressing environmental challenges. This Essay first discusses the concept of sustainability, then introduces CCS technology along with its benefits and limitations, and proceeds to analyze how CCS might measure up against general sustainability principles. Ultimately, this Essay concludes that while CCS on its own may not be consistent with basic principles of sustainability, it presents a potential opportunity to create sufficiently deep cuts in greenhouse gas (GHG) emissions

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1. World Commn. on Env. & Dev, *Our Common Future* 43 (Oxford U. Press 1990) [hereinafter *Our Common Future*].

2. Lynn Price & Mark D. Levine, *Production and Consumption of Energy*, in *Stumbling Toward Sustainability* 79, 85 (John C. Dernbach ed., Envtl. L. Inst. 2002).

3. Michael Pollan, *Our Decrepit Food Factories*, N.Y. Times Mag. 25 (Dec. 16, 2007) (available at http://www.nytimes.com/2007/12/16/magazine/16wwln-lede-t.html?scp=1&sq=our%20decrepit%20food%20 factories&st=cse) ("The word 'sustainability' has gotten such a workout lately that the whole concept is in danger of floating away on a sea of inoffensiveness.").

to allow the transition to a more sustainable future.

II. WHAT IS SUSTAINABILITY?

It has often been said that "it is . . . easier to identify practices that are *not* sustainable than to define [practices that constitute] sustainable development . . . ."[4] Many cite to the Bruntdland Commission's report *Our Common Future*, which defined "sustainability" as practices that "meet[] the needs of the present without compromising the ability of future generations to meet their own needs."[5] Thus, the idea of sustainable development encompasses economic, environmental, social, and security goals that support each other, along with "effective . . . governance" and legal systems to implement these goals.[6] Simplifying it considerably, current decisions on resource use and development should not adversely impact the ability to "maintain[] or improv[e] future living standards."[7] In the United States, the concept of sustainability is perhaps best codified in the purpose of National Environmental Policy Act, which is to create a government policy to use "all practicable means and measures . . . to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans."[8]

In recent years, the very notion of sustainability has been challenged by climate change. Old metrics come into question as whole ecosystems shift with changing temperature and natural resources, such as water, fail to replenish themselves in certain regions.[9] Unsustainable reliance on fossil-fuel resources by a relatively small portion of the globe's population has adversely impacted our common atmosphere and is likely to bear the worst effects on the world's poor.[10] Reflecting these concerns, increasing attention has been paid to new metrics such as climate or carbon neutrality, carbon footprint, or zero-emissions targets.[11] Indeed, some state public utility commissions have begun including a future price of carbon or carbon liability as part of their assessment of integrated resource plans proposed by electric utilities.[12] For the first time

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4. David R. Hodas, *The Role of Law in Defining Sustainable Development: NEPA Reconsidered*, 3 Widener L. Symp. J. 1, 15 (Fall 1998) (emphasis added).

5. *Our Common Future*, *supra* n. 1, at 43.

6. John C. Dernbach, *Synthesis*, in *Stumbling Toward Sustainability*, *supra* n. 2, at 1.

7. Hodas, *supra* n. 4, at 16 (quoting The World Resources Institute, Robert Repetto, *Overview*, in *The Global Possible: Resources, Development, and the New Century* 1, 10 (Robert Repetto ed., Yale U. Press 1985) ("maintaining or improving living standards in the future")).

8. 42 U.S.C. § 4331(a) (2000).

9. *E.g.* Nicholas Stern, Stern Review: The Economics of Climate Change vi (2006) (available at http://www.hm-treasury.gov.uk/d/Executive_Summary.pdf).

10. *Id.* at vii.

11. *See e.g.* Global Dev. Research Ctr., *Sustainable Development: Concepts*, http://www.gdrc.org/sustdev/concepts.html (accessed Sept. 18, 2008).

12. *See e.g. Order Approving Recommended Decision and Adopting Standardized Carbon Emissions Costs for Integrated Resource Plans*, Case No. 06-00448-UT (N.M. Pub. Reg. Commn. June 19, 2007) (available at http://www.nmprc.state.nm.us/generalcounsel/pdf/06-00448-Utorderapproving.pdf). *See also Energy Info. Administration, Annual Energy Outlook 2009: Early Release Overview*, 3 (available at http://www.eia.doe.gov/oiaf/aeo/pdf/overview.pdf) (including a section on rising concerns over GHG emissions and noting "many State public utility commissions are requiring that the utilities they regulate prepare simulations in their integrated resource plans that include assumed carbon dioxide (CO_2) allowance fees. The utilities often prepare a range of cases, with CO_2 fees ranging widely from $0 to $80 per ton of CO_2

ever, the Energy Information Administration (EIA) is incorporating a percentage point increase, roughly equivalent to $15-per-ton CO_2, when evaluating investments in GHG-intensive capital in its Annual Energy Outlook 2009.[13] Carbon metrics have been a factor in several executive branch and judicial decisions across the country to reject or delay applications to build or expand conventional pulverized coal plants.[14] For instance, in Georgia, where a coal-fired power plant was approved without consideration of the carbon implications, a state judge overturned the decision for failure to evaluate technology that would limit carbon dioxide emissions.[15] In Montana, the Department of Environmental Quality's failure to consider best available control technology for carbon dioxide is now the subject of a lawsuit.[16]

While decisions to build significant new baseload capacity can be delayed temporarily, it is less clear how to create a sustainable or carbon-neutral energy system to meet present and future energy needs. The United States, along with India and China, is heavily invested in coal-fired electricity and has vast recoverable coal resources, leaving many to wonder if coal could still play a role in a carbon-constrained, sustainable energy future. As shown in Part III, CCS (also referred to as carbon capture and storage), could allow continued use of coal and other CO_2-emitting technologies by capturing the would-be emissions and injecting them permanently deep underground.

III. COAL AND CLIMATE CHANGE

Part III discusses the existing and future role of coal in meeting worldwide energy needs and its impact on climate change. Despite the increasing media and public awareness of the climate problem[17] and signs that state utility commissions are starting to take the carbon problem more seriously, the overwhelming national and global trend has been to satisfy growing energy demand with coal-based power. Since the time of the Brundtland Commission report in 1987, global energy consumption has grown 50 percent[18] and may increase by another 30 percent or 50 percent again by 2030.[19]

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or more").

13. Energy Info. Administration, *supra* n. 12, at 3.

14. *See e.g.* Mathew L. Wald, *Citing Global Warming, Kansas Denies Plant Permit*, 157 N.Y. Times C4 (Oct. 20, 2007) (available at http://www.nytimes.com/2007/10/20/business/20plant.html); *see also In re Great River Energy's 2005 Integrated Resource Plan*, Dkt No. ET-2/RP05-1100 (Minn. Pub. Util. Commn. Oct. 25, 2007) (available at http://www.puc.state.mn.us/docs/briefing_papers/b07-0174.pdf); Matthew Brown, *Plans for Coal Power Plants Delayed*, Bismarck Trib. B1 (Oct. 19, 2007) ("At least 16 coal-fired power plant proposals nationwide have been scrapped in recent months and more than three dozen have been delayed as utilities face increasing pressure due to concerns over global warming and rising construction costs.").

15. Barney Tumey, *Georgia State Judge Overturns Approval of Coal-Fired Plant, Orders Emissions Limit*, 126 Daily Env. Rpt. A-7 (July 1, 2008).

16. Sherry Jones, *Environmental Advocates File Suit to Push Montana on Regulating Carbon*, Toxics L. Daily (July 16, 2008).

17. *E.g. Special Report on Global Warming: Be Worried. Be Very Worried* 167 Time Cover (Apr. 3, 2006).

18. *See Our Common Future*, *supra* n. 1, at 169 (stating global energy consumption as 10TW in 1980); *see also* Fossil Energy Techline, *DOE Regional Partnerships Find More than 3,500 Billion Tons of Possible CO_2 Storage Capacity* (March 27, 2007) (available at http://www.fossil.energy.gov/news/techlines/ 2007/07016-Carbon_Sequestration_Atlas_Publish.html).

19. Energy Info. Administration, *International Energy Outlook 2008: Highlights*, http://www.eia. doe.gov/oiaf/ieo/highlights.html (accessed Sept. 18, 2008) ("world marketed energy consumption is projected to grow by 50 percent over the 2005 to 2030 period").

Barring significant policy and regulatory changes, CO_2 emissions are expected to mimic this trend by growing slightly more than half again from today's annual emissions by 2030.[20] Even with increasing recognition that concerns over GHG emissions will raise conventional power plant costs, fossil fuels are expected to remain the "mainstay" in energy production for decades to come, thereby steadily increasing atmospheric CO_2.[21] Once emitted, CO_2 persists in the atmosphere for centuries and commits us to the associated warming for a similar period of time, even if dramatic emissions reductions follow.[22]

Meanwhile, eleven of the last twelve years (1995–2006) have stacked up among the twelve warmest on record since 1850,[23] and improvements in modeling and data analysis have caused scientists to assert a "'very high confidence' (at least a 9 out of 10 chance) of being correct in their understanding of how human activities are causing the world to warm."[24] Al Gore, summarizing the irony of the current challenges we face, recently quipped: "[w]e're borrowing money from China to buy oil from the Persian Gulf to burn it in ways that destroy the planet. Every bit of that's got to change."[25]

Of the more than four billion megawatt hours (MWh) of electricity generation produced in this country annually,[26] roughly half comes from coal-fired power.[27] Although the EIA began slowing the modeled increase in coal consumption in its regular Annual Energy Outlook report for 2009 by comparison to earlier reports, coal consumption in the United States is still expected to rise almost 20 percent by 2030.[28] The United States Geological Survey (USGS) is currently updating its national coal assessments,[29] but the EIA estimates coal resources in the United States to be sufficient for over 200 years at current rates of consumption.[30] In fact, the United States is thought

20. *Id.* (stating that growth will be "from 28.1 billion metric tons in 2005 to 34.3 billion metric tons in 2015 and 42.3 billion metric tons in 2030—an increase of 51 percent over the projection period"); Energy Info. Administration, *supra* n. 12, at 11 (noting that even with rising concern over GHG emissions and reduced investment in new coal power plants than expected in previous AEOs, "coal remains the dominant fuel for electricity generation").

21. U.S. EPA. Proposed Rule, Federal Requirements under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells, 73 Fed. Reg. 43492, 43495 (July 25, 2008) [hereinafter "EPA Proposed Rule"].

22. Ga. Inst. Tech., *Global Warming Will Persist at Least a Century Even if Emissions Curbed Now*, ScienceDaily, http://www.sciencedaily.com/releases/2002/02/020218094427.htm (Feb. 18, 2002).

23. Intergovernmental Panel on Climate Change, *Climate Change 2007: Synthesis Report* 2 (Nov. 2007) (available at http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf).

24. Enrique Rene de Vera, Student Author, *The WTO and Biofuels: The Possibility of Unilateral Sustainability Requirements*, 8 Chi. J. Intl. L. 661, 661 (2008) (quoting Press Release, UN Env. Programme, *Evidence of Human-Caused Global Warming "Unequivocal," Says IPCC* ¶ 2 (Feb. 2, 2007) (available at http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=499&ArticleID=5506&l=en)).

25. Al Gore, *Renewable Energy* (Constitutional Hall, Washington D.C., July 17, 2008) (copy of transcript available at http://www.npr.org/templates/story/story.php?storyId=92638501).

26. Energy Info. Administration, *State Electricity Profiles: 2006 Edition*, http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html (accessed Sept. 18, 2008).

27. Energy Info. Administration, *State Electricity Profiles 2006* 258 (Nov. 21, 2007) (available at http://www.eia.doe.gov/cneaf/electricity/st_profiles/sep2006.pdf) (ranging from 52.5 percent in 1990 to 49 percent in 2006).

28. Energy Info. Administration, *supra* n. 12, at 7.

29. *See* U.S. Geological Survey, *Coal Resources, Over 100 Years of USGS Research*, http://energy.usgs.gov/coal.html (last modified Mar. 2, 2009).

30. U.S. Geological Survey, *Assessing the Coal Resources of the United States*, http://energy.usgs.gov/factsheets/nca/nca.html (July 1996) (estimating over 250 years of recoverable coal);

to have by far the largest share of economically-recoverable coal in the world with approximately 29 percent of the total proven recoverable reserves (Russia, China, and India follow respectively).[31] Because the current electrical portfolio in the United States is dominated by coal and there do not seem to be any near-term supply limiting factors, coal is expected by many to continue playing a prominent role in the United States electricity system.

Although the United States has been the preeminent developer and user of coal-fired power, rapid growth in developing countries is beginning to exceed the United States. Since 2000, China has doubled its use of coal-fired power and authorities expect its use to represent over 70 percent of the growth in coal-fired power internationally over the next several decades.[32] China became the world's largest CO_2 emitter in July of 2007,[33] surpassing the United States nearly a decade before expected.[34] In late 2004, the *Christian Science Monitor* released an article explaining that by 2012 the increased emissions from China, India, and the United States alone would swamp any CO_2 reductions gained by implementing the Kyoto Protocol.[35] Put another way, China builds the equivalent in coal-fired power plants each year of the entire electric grid in the United Kingdom.[36] Because coal is abundant and remains affordable, many expect this trend to continue into the future.[37] Moreover, each new conventional coal plant has a long average lifespan, locking in the associated carbon liability for future decades.

Meanwhile, affordable alternatives sufficient to meet the climate challenge have eluded energy policy makers for years. In 1998, a study estimated that in order to avoid dangerous changes to our climate and stabilize CO_2 concentrations in the atmosphere, we will need at least as much net new carbon-free energy online by 2050 as the sum of global energy produced currently.[38] Even if there were political, economic, and technical consensus to shift away from coal in the nearer term—retiring old plants and precluding new ones—it is unclear whether alternative sources of energy would prove superior and sufficient to meet the challenge, at least in the near term. Nuclear power currently provides the most carbon-free energy in our system[39] and is becoming more

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accord Cathy Booth Thomas, *Is Coal Golden?* 168 Time A.1 (Oct. 9, 2006) (available at http://www.time.com/time/magazine/article/0,9171,1541270-1,00.html) (estimating over 200 years of economically recoverable coal).

31. *BP Statistical Review of World Energy: June 2008* 32 (June 2008) (available at http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/downloads/pdf/statistical_review_of_world_energy_full_review_2008.pdf) (United States 28.6 percent, Russian Federation 18 percent, China 13.5 percent, India 6.7 percent).

32. Energy Info. Administration, *supra* n. 19.

33. John Vidal & David Adam, *China Overtakes US as World's Biggest CO_2 Emitter*, The Guardian (June 19, 2007) (available at http://www.guardian.co.uk/environment/2007/jun/19/china/usnews).

34. Peter Fairley, *China's Coal Future*, 110 Tech. Rev. 56, 56 (Jan./Feb. 2007).

35. Mark Clayton, *New Coal Plants Bury 'Kyoto'*, Christian Sci. Monitor 1, 1 (Dec. 23, 2004).

36. *The Future of Coal: An Interdisciplinary MIT Study* ix (2007) (available at http://web.mit.edu/coal/The_Future_of_Coal_Summary_Report.pdf) [hereinafter *The Future of Coal*].

37. *Id.*

38. Martin I. Hoffert et al., *Energy Implications of Future Stabilization of Atmospheric CO_2 Content*, 395 Nat. 881, 881 (Oct. 29, 1998) ("A standard baseline scenario that assumes no policy intervention to limit greenhouse-gas emissions has 10 TW (10×10^{12} watts) of carbon-emission-free power being produced by the year 2050, equivalent to the power provided by all today's energy sources combined." (footnotes omitted)).

39. Energy Info. Administration, *supra* n. 27, at 258 (showing nuclear energy as providing just under 20 percent of the nation's total electricity in 2006).

attractive once again as decision-makers struggle to find solutions to the climate problem. Although there have not been any new nuclear power plants built in the United States in decades, at least some estimates assume the 2005 Energy Policy Act production tax credits, among other things, will help foster increased nuclear power generating capacity in the United States in the coming decades.[40] Nuclear power, however, is costly and potentially dangerous, with many still remembering the disasters of Three Mile Island and Chernobyl.[41] More recently, lesser but significant nuclear accidents in France have revived this concern.[42] Even the EIA, while predicting an increase in nuclear power, notes that the future of the industry remains highly uncertain as issues of "plant safety, radioactive waste disposal, and the proliferation of nuclear weapons" continue to raise significant concerns.[43] The recent decision by the Obama administration to keep his campaign pledge and cut funding for the more than two decades old Yucca Mountain project illuminates the current public concern and political controversies over radioactive waste storage.[44]

Estimates also suggest that the role of renewable energy is critical but insufficient on its own to meet climate change goals in the near term. Although large hydroelectric power plants provide roughly seven percent of the nation's total electricity needs, all of the other renewable sources together currently represent less than three percent of the nation's electricity.[45] The EIA estimates that even with rising fossil fuels prices and technology-forcing policies such as renewable energy standards, non-hydropower renewable energy may double[46] or triple[47] by 2030. Of that percentage, wind and biomass make up the majority.[48] Where wind is currently limited by its variable nature, biomass is limited by competing uses for land, namely food production. Despite decades of development, solar energy remains relatively expensive and, as a result, has been and is expected to remain a small fraction of U.S. energy production without significant cost reductions.[49] Thus, the question remains how to create the massive reductions in CO_2 emissions experts say are needed now to limit the effects of global climate change.

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40. Energy Info. Administration, *supra* n. 27, at 70.

41. Mark Wilde, *Best Available Techniques (BAT) and Coal-Fired Power Stations: Can the Energy Gap be Plugged without Increasing Emissions?* 20 J. Envtl. L. 87, 88 (2008).

42. *See Concern over French Nuclear Leaks*, http://news.bbc.co.uk/2/hi/europe/7522712.stm (July 24, 2008).

43. Energy Info. Administration, *supra* n. 19.

44. *Our View on Nuclear Power: Responsibility? Yucca Choice Squanders $8B Investment*, USA Today Editorial (March 17, 2009) (available at http://blogs.usatoday.com/oped/2009/03/our-view-on-nuc.html); *see also $13 Billion Later, Nuclear Waste Site at Dead End*, Associated Press (Mar. 9, 2009) (available at http://www.msnbc.msn.com/id/29534497/).

45. Energy Info. Administration, *supra* n. 27, at 258 (2.4 percent in 2006).

46. Energy Info. Administration, *supra* n. 19.

47. Energy Info. Administration, *supra* n. 12, at 8.

48. *Id.*

49. *Id.* at 70 ("Solar technologies in general remain too costly for grid-connected applications, but demonstration programs and State policies support some growth in central-station solar PV, and small-scale customer-sited PV applications grow rapidly"). *But see e.g.* Beth Hart & Keith Hay, *Benefits of Solar Energy Manifold*, Rocky Mt. News 30 (arguing that concentrating solar can operate more like a base load facility by storing power and supplying night-time power and could be more suitable for large-scale application—particularly if public policies support its market entry).

IV. THE POTENTIAL ROLE OF CCS

CCS technology has the potential to significantly reduce emissions from power plants and industrial sources by capturing CO_2 emissions and injecting them into deep geologic formations, sequestering them underground for hundreds to thousands of years. Areas for potential CO_2 sequestration include oil and gas fields, saline aquifers, and, potentially, deep coal seams. Existing "geologic formations containing crude oil, natural gas, brine, and CO_2[] have . . . storage capabilities . . . for millions of years."[50] A DOE report released March 27, 2007 estimates underground CO_2 storage capacity in saline aquifers in Canada and the United States to be from one to over three trillion tons.[51] This means that storage capacity could be plentiful when compared with the 1.5 billion tons of CO_2 emitted from coal-fired power plants annually in the United States.[52] Some electric power industry representatives believe that CCS could reduce power plant emissions by one-quarter in 2030.[53] Federal energy personnel have testified in Congress that at the current rate of energy production and use, the United States and Canada have the capacity to store all of the CO_2 emissions produced over the next 175 to 500 years.[54] CCS technologies would use these storage capacities to drastically reduce CO_2 emissions to the atmosphere.

Worldwide, there are four large-scale CCS projects in existence, each injecting roughly one million tons of CO_2 annually.[55] In addition to the four existing CCS projects, several more are underway or planned in Canada, the United States, and other countries.[56] In the United States, Congress and the DOE have attempted to authorize significant funding for CCS projects across the country. Competing House and Senate bills in 2007 each provided nearly $1.5 billion in funding for research and development of CCS.[57] In October 2007, DOE awarded $1.97 billion to three regional carbon sequestration partnerships in connection with pilot projects to store over one million tons of CO_2 in deep saline reservoirs to test the feasibility of long-term CO_2 sequestration. The money will be spent on these projects over ten years in the Great Plains, the Southeast, and the Southwest.[58] The projects will cost $318 million, with private

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50. Alexandra B. Klass & Elizabeth J. Wilson, *Climate Change and Carbon Sequestration: Assessing a Liability Regime for Long-Term Storage of Carbon Dioxide*, 58 Emory L.J. 103, 107 (2008).

51. U.S. Depart. of Energy, *Carbon Sequestration Atlas of the United States and Canada* 13–15 (Mar. 2007) (available at http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/ATLAS.pdf); Lawrence J. Speer, *DOE Finds Large Capacity for Storing Carbon Dioxide Across U.S., Canada*, Daily Env. Rpt. A-5 (Mar. 29, 2007).

52. Klass & Wilson, *supra* n. 50, at 117. *See also* EPA Proposed Rule, *supra* n. 21, at 43496 (stating that "[w]orldwide, there appears to be significant capacity in subsurface formations both on land and under the seafloor to sequester CO_2 for hundreds, if not thousands of years").

53. Steven D. Cook, *Power Industry Officials Disagree on Future, Feasibility of Carbon Capture, Storage*, 186 Daily Env. Rpt. A-1 (Sept. 26, 2007).

54. *Id.*

55. These projects are Sleipner in the North Sea, run by StatoilHydro; In Salah in Algeria by BP, Sonatrach and StatoilHydro; Weyburn in Canada, operated by EnCana; and Snøhvit in the Barents Sea, operated by StatoilHydro. A comprehensive list of commercial and pilot CCS projects is maintained by the IEA Greenhouse Gas R&D Programme, *CO_2 Capture and Storage: R, D & D Projects Database*, http://co2captureandstorage.info/co2db.php (accessed Mar. 6, 2008).

56. *See id.* (for project summaries, view the linked powerpoint presentation).

57. Dean Scott, *Combined Incentives, Regulation Needed to Spur Carbon Sequestration, Markey Says*, 173 Daily Env. Rpt. A-4 (Sept. 7, 2007).

58. *DOE Funds Three Large-Scale Projects to Test Feasibility of Carbon Dioxide Storage*, 196 Daily Env.

partners providing the balance of the funds. In January 2008, DOE funded a fourth project in the Midwest to inject one million tons of CO_2 one mile below the earth's surface within the Illinois basin.[59] Even more recently, President Obama included $3.4 billion for CCS demonstration projects as part of the American Recovery and Reinvestment Act, an increase in federal support for this technology in the United States by 70 percent to over $8 billion.[60]

There are risks, of course, associated with CCS. In order for CCS to have a real impact on climate change, projects must sequester millions of tons of CO_2 per year at each individual storage site, with injected CO_2 potentially spreading over tens of square miles for a single project and with subsurface pressure effects being felt over even greater distances.[61] Moreover, the injected CO_2 should remain in the subsurface for hundreds to thousands of years for significant climate benefit,[62] thus using the subsurface property in perpetuity. Injected CO_2 will be more buoyant than the formation waters into which it is injected, creating upward pressure and the possibility of leakage to the surface or near surface. Although large surface releases of CO_2 are unlikely, such releases at high concentrations could cause immediate human death from asphyxiation[63] or non-fatal but still severe adverse health effects at lower but prolonged exposures.[64] Slow CO_2 seepage into the near subsurface could also disrupt local ecology or agriculture.[65] Even if injected CO_2 remains underground, its presence in such large quantities could displace saline groundwater into potable aquifers, contaminate hydrocarbon resources, or trigger seismic events.[66]

Thus, there are risks associated with CCS but also the potential to make significant cuts in GHG emissions. A few years ago, a group of professors at Princeton University began illustrating how a combination of technologies could help meet this ambitious goal. In their study they projected an upward trend in CO_2 emissions over 50 years under the "business as usual" model and contrasted it with a horizontal line extending out from the level of emissions in 2004 and staying constant through 2054. The triangle created by the two scenarios represented the seven gigatons of expected new CO_2

Rpt. A-7 (Oct. 11, 2007).

59. Michael Bologna, *Energy Department, Midwest Partners Launch Carbon Sequestration Project in Illinois Basin*, 3 Daily Env. Rpt. A-1 (Jan. 7, 2008).

60. *Flurry of U.S. State, Federal Policies Advance CCS*, Carbon Capture J. (Feb. 20, 2009) (available at http://www.carboncapturejournal.com/displaynews.php?NewsID=344&PHPSESSID=10343389bcbaec9b35c5 10344a0524b43&PHPSESSID=1043389bcbaec9b35c510344a0524b43).

61. Karsten Preuss et al., *Numerical Modeling of Aquifer Disposal of CO_2*, 8 SPE 49, 52–53 (2003).

62. *E.g.* Minh Ha-Duong & David W. Keith, *Carbon Storage: The Economic Efficiency of Storing CO_2 in Leaky Reservoirs*, 5 Clean Techs. & Envtl. Policy 181, 182 (2003) (discussing benefits of sequestration of shorter timeframes).

63. Sally M. Benson et al., *Lessons Learned from Natural and Industrial Analogues for Storage of Carbon Dioxide in Deep Geological Formations*, Lawrence Berkeley Natl. Laboratory Paper LBNL-51170 app. 11, A25 (2002) (available at http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1710&context=lbnl).

64. *Id.* at 1–2; Kay Damen, André Faaij & Wim Turkenburg, *Health, Safety and Environmental Risks of Underground CO_2 Storage—Overview of Mechanisms and Current Knowledge*, 74 Climatic Change 289, 297 (2006).

65. *See* K.P. Saripalli, N.M. Mahasenan & E.M. Cook, *Risk and Hazard Assessment for Projects Involving the Geological Sequestration of CO_2*, in *Greenhouse Gas Control Technologies: Proceedings of the 6th International Conference on Greenhouse Gas Control Technologies* vol. 1, 511 (J. Gale & Y. Kaya eds., Pergamon 2003).

66. *See* Benson et al., *supra* n. 63; Damen, Faaij & Turkenburg, *supra* n. 64, at 293–96.

emissions the globe needs to avoid in order to escape fully doubling pre-industrial levels of CO_2 and the dangerous climate change that would result. The professors then divided the triangle into single gigaton "wedges" and discussed what technologies were available today to form a future wedge. One wedge represented anything from increasing global wind power 50-fold or solar photovoltaic energy 700-fold to applying conservation tillage to all of the world's cropland. In addition, several wedges included increasing coal-plant efficiency. Notably, the study concluded that implementing CCS at 800 gigawatts (GW) of baseload coal plants worldwide would create a wedge.[67] Likewise, a recent study by the Massachusetts Institute of Technology (MIT) concluded that CCS was the critical enabling technology that would allow us to meet our growing energy needs while reducing CO_2 emissions significantly.[68] Others put it more forcefully, arguing there is no chance of meeting the necessary global carbon targets without CCS.[69]

The DOE anticipates that commercial use of CCS in connection with clean coal operations could be operational by 2015.[70] The question remains, however, whether CCS is consistent with a path toward achieving a sustainable future or whether it is simply a diversion of attention and resources from other more sustainable energy sources. Part V explores this issue.

V. IS CCS SUSTAINABLE?

The current use of fossil fuels is widely thought to be unsustainable. That is, our society is using the resource much faster than it can be replenished.[71] In addition, "[u]pstream impacts from coal combustion include the adverse environmental effects of mountain-top removal, acid mine drainage, and land subsidence."[72] Yet some have suggested CCS can and should play a role in making our continued use of coal more sustainable by avoiding downstream pollution, associated adverse health impacts, and, perhaps most importantly, the worst consequences of climate change. Overall, CCS has been hailed by many as the best solution to address climate change in the near term, decried by others as a crutch that will continue our dependence on fossil fuel, and cautiously supported by yet others who see it as the best option among many bad options. Certainly, the United States government and industry are investing huge sums of money in the technology, in the hopes that we can continue as a nation and as a world to rely on plentiful coal resources while at the same time significantly reducing CO_2 emissions.

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67. *See* S. Pacala & R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, 305 Sci. 968, 969 (Aug. 13, 2004).

68. *The Future of Coal*, *supra* n. 36, at x.

69. Armond Cohen, Founder & Dir. Clean Air Task Force, Presentation (Milwaukee, Wis., Nov. 2007) (available at http://www.midwesterngovernors.org/MGA%20Energy%20Initative/2007%20Summit/Thursday%20Cohen%20Session%202.pdf).

70. Press Release, *DOE Takes Next Steps with Restructured FutureGen Approach* (May 7, 2008) (available at http://www.netl.doe.gov/publications/press/2008/PrinterFriendlyHTML_1_119460_119460.html) (releasing draft Funding Opportunity Announcement for multiple clean coal power plants utilizing CCS technology, anticipating $290 million in funding available through fiscal year 2009 and an additional $1.01 billion in subsequent years, and projecting the commission of plants by December 31, 2015).

71. Pollan, *supra* n. 3, at 25 ("What [sustainability] means is that the practice or process can't go on indefinitely because it is destroying the very conditions on which it depends.").

72. Klass & Wilson, *supra* n. 50, at 112.

CCS is divisive in the environmental nonprofit community, which, as shown by the United States' experience with nuclear power, is likely to be influential in shaping government and public perceptions of CCS as a potential solution to climate change. Greenpeace released a report in May 2008 entitled "False Hope," in which it contends that CCS wastes energy, creates unacceptable risks of leakage, is too expensive, undermines funding for sustainable solutions, carries significant liability risks, and cannot be implemented in time to avoid dangerous climate change.[73] Greenpeace argues instead for investing in renewable energy technologies and increased energy efficiency that can begin to reverse climate change today. Other environmental nonprofit groups, however, such as Environmental Defense, Natural Resources Defense Council, World Resources Institute, and the Nature Conservancy, favor CCS as a promising mitigation solution to climate change because CCS is designed to deal with the "coal issue" in a way that renewable energy and energy efficiency initiatives are not.[74] As one environmental nonprofit representative has stated, CCS "'is a terrible idea that we desperately need.'"[75]

Building on this diversity of opinion within the environmental nonprofit community with regard to CCS and its role in a sustainable future, this Part explores how CCS may be viewed using traditional ideas of sustainable development. This yields three primary lines of questioning. First, is the practice of CCS itself capable of being sustained? Second, to what extent does its implementation promote or detract from broadly sustainable solutions? Third, how will CCS technology impact future generations? While exploration of these questions does not provide complete answers to the question of the extent to which CCS is sustainable, it suggests that CCS technology could be used as a component of an energy policy that helps us begin a path toward a sustainable energy future.

A. *Sustainability Question 1: Is CCS Itself Capable of Being Sustained?*

The United States is home to more than five hundred 500 megawatt (MW) coal-fired power plants[76] and coal-fired electricity production is responsible for approximately one-third of total U.S. CO_2 emissions.[77] According to the DOE and the International Energy Agency, there is theoretically enough storage potential in the United States to sequester three teratons of CO_2 or roughly the equivalent of one thousand years of emissions from one thousand coal-fired power plants.[78] In other words, there may be plenty of storage capacity in geologic formations to fully remove carbon emissions from the power sector and beyond, thereby buying time to transition

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73. Emily Rochon et al., *False Hope: Why Carbon Capture and Storage Won't Save the Climate*, Greenpeace Intl. Rpt. 16–33 (May 5, 2008) (available at http://www.greenpeace.org/raw/content/international/press/reports/false-hope.pdf).

74. Gabrielle Wong-Parodi, Isha Ray & Alexander E. Farrell, *Environmental Non-Government Organizations' Perceptions of Geologic Sequestration*, 3 Envtl. Research Ltrs. 1, 7 (June 6, 2008).

75. *Id.* at 3.

76. *The Future of Coal*, *supra* n. 36, at ix.

77. U.S. Environmental Protection Agency, *Human-Related Sources and Sinks of Carbon Dioxide* (citing 2006 data) (available at http://www.epa.gov/climatechange/emissions/co2_human.html).

78. EPA Proposed Rule, *supra* n. 21, at 43496 (arguing that CCS could represent a "significant percentage of the cumulative effort for reducing CO_2 emissions" nationally and worldwide).

carefully into a much more sustainable energy system as additional technologies become available.

Beyond storage capacity, however, a basic question is whether CCS can actually accomplish the significant reduction in CO_2 its proponents are promising. The case for CCS hinges on the ability to trap and keep the CO_2 emissions deep underground and prevent them from entering the atmosphere. Although there is much discussion over whether there should be an acceptable rate of leakage allowed at such plants,[79] physical trapping of CO_2 has been demonstrated in natural analogs for millions of years.[80] Geologic formations containing crude oil, natural gas, brine, and CO_2 have the proven ability to store gases and liquids underground for millions of years. CCS technologies would attempt to take advantage of these natural storage capacities to reduce CO_2 emissions.[81]

There is also substantial industry experience injecting and managing gases in underground formations, including CO_2. For decades, oil producers have injected CO_2 into oil formations to increase production from depleted fields, often called enhanced oil recovery or EOR.[82] In West Texas, 30 million tons of CO_2 are injected into the ground annually in connection with EOR.[83] While supporters of CCS hold up the success and safety of CO_2 injection for EOR purposes, it is clear that CO_2 storage for purposes of controlling GHG levels in the atmosphere will be several orders of magnitude larger. The MIT "Future of Coal" study states, "[i]f 60% of the CO_2 produced from U.S. coal-based power generation were to be captured and compressed to a liquid for geologic sequestration, its volume would about equal the total U.S. oil consumption of 20 million barrels per day."[84] This number highlights the massive volumes of CO_2 involved in a large-scale carbon capture program. Thus, while existing practices and data support the idea that there is sufficient storage capacity and technical ability to store very large amounts of CO_2, questions remain surrounding the application of current technology to the scale necessary to meet climate change goals.

B. *Sustainability Question 2: Will the Practice of CCS Have Adverse Impacts on Other Resources?*

Although it appears likely that CCS alone may be capable of being sustained, a sustainability analysis should also explore what effects the practice will have on other resources over time. Indeed, a common theme in any sustainability analysis is a concern

79. Klass & Wilson, *supra* n. 50, at 117–118.

80. EPA Proposed Rule, *supra* n. 21, at 43495 (noting that "CO_2 has been trapped for more than 65 million years under the Pisgah Anticline, northeast of the Jackson Dome in Mississippi and Louisiana, with no evidence of leakage from the confining formation" (citation omitted)).

81. Klass & Wilson, *supra* n. 50, at 107.

82. Richard C. Maxwell, Patrick H. Martin & Bruce M. Kramer, *The Law of Oil and Gas* 13–14 (8th ed., Found. Press 2007).

83. Steven D. Cook, *Researchers Optimistic on Prospects for Successful Carbon Capture, Storage*, 94 Daily Envtl. Rpt. A-1 (May 16, 2007). In addition, Dakota Gasification, a subsidiary of Basin Electric Power Cooperative, has been capturing a significant portion of the CO_2 emissions at its 1970s era coal gasification plant in Beulah, North Dakota and piping the CO_2 to Saskatchewan for tertiary oil recovery and permanent storage. Tony Spilde, *A Look at the Basics of Carbon Sequestration*, Bismarck Trib. 8A (Jan. 20, 2008).

84. *The Future of Coal*, *supra* n. 36, at ix.

that when one part of a system is altered, it may cause adverse effects elsewhere in the system. The formation pore spaces that injected CO_2 would fill are rarely, if ever, empty. The spaces contain other gases and liquids, primarily brines, which will either be elevated in pressure or displaced by the CO_2 injection. These effects must be carefully monitored to avoid unintended consequences.

Among the least likely but most dramatic concern over CCS is that a substantial CO_2 leak could cause widespread but localized asphyxiation of people, plants, and animals. In 1986, Lake Nyos in Cameroon suddenly shifted and emitted a large plume of carbon dioxide, killing approximately 1,700 people and 3,500 livestock in nearby villages.[85] Critics of CCS have raised this and other catastrophic events involving CO_2 releases as a caution in proceeding CCS.[86]

The remote but severe possibility that a substantial leak could asphyxiate local residents and animals must be taken seriously. There appear to be significant differences, however, between what happed in Cameroon and the process of CCS. First, the Lake Nyos incident took place because slow and continuous accumulation of CO_2 over time near the lake's surface exceeded the lake's holding capacity.[87] With CCS projects, CO_2 will be injected many times deeper into the subsurface and in formations with solid trapping layers above, reducing the ability of the CO_2 to escape in large volumes to the surface.[88] Second, unlike the Lake Nyos incident, CO_2 stored in a geologic formation would tend to diffuse rather than concentrate.[89] Third, CCS projects will be highly monitored, making it unlikely a leak would go undetected as it did in Cameroon. Such monitoring will be important not only in avoiding significant releases of CO_2 but also in avoiding less grave but potentially harmful effects of slow leaks to the surface.

Another critical concern over CCS is that it be implemented and closely monitored to avoid any adverse affects on underground drinking water. The Environmental Protection Agency (EPA) is authorized under the Safe Drinking Water Act (SDWA) to regulate and protect the nation's drinking water sources. The Underground Injection Control (UIC) program of the EPA helps to regulate underground storage to protect potential sources of drinking water and is likely to regulate future CCS permits.[90] There are three primary risks to underground safe drinking water from CCS. The first is that the pressure front created by the CO_2 plume could push native brines upward through geologic formations into Underground Sources of Drinking Water (USDW). The second is that when CO_2 is brought in contact with water it forms acids and could acidify water systems or lower the overall pH. This acidification could in turn create a third problem:

85. *See* EPA Proposed Rule, *supra* n. 21, at 43498 (discussing Lake Nyos incident and another similar incident in the 1980s at Lake Monoun in Cameroon); Mark Anthony de Figueiredo, *The Liability of Carbon Dioxide Storage* 185–191 (Ph.D. dissertation, M.I.T., Feb. 2007) (copy on file with M.I.T. Librs. & available at http://esd.mit.edu/people/dissertations/ defigueiredo_mark.pdf).

86. Rochon et al., *supra* n. 73, at 30.

87. de Figueiredo, *supra* n. 85, at 186.

88. EPA Proposed Rule, *supra* n. 21, at 43498 (stating that "[w]hile lake turnover can bring CO_2 stored in the deepest layers of lake water to the surface almost instantaneously, geologic confining systems do not experience this type of rapid and complete turnover").

89. de Figueiredo, *supra* n. 85, at 186.

90. EPA Proposed Rule, *supra* n. 21, at 43495.

the leaching of undesirable minerals found naturally in the rock formation or compounds into the ground water supplies. This third problem could also be made worse by the presence of undesirable compounds in an impure CO_2 stream. While the second and third concerns will be monitored and regulated under the SDWA, it is less certain that the cumulative pressure effects from multiple projects in a single CO_2 sequestering basin will be as closely regulated. The recent EPA proposed rules for CCS, however, suggest that the agency is taking a very precautionary approach even toward the pressure impacts of CCS on safe water.[91]

Although the formations suitable for CCS are estimated to be vast in the United States, some are already being used for different storage purposes and could be used in the future for additional, potentially more sustainable, storage purposes. In Illinois for example, the Mount Simon formation is currently used for natural gas storage, oil field brine disposal, and hazardous waste disposal. Underground compressed air storage is being tested in Iowa with wind power that could potentially be another competing use for underground formations.[92] Given the vast storage capacity in the United States, it is less likely that this will mean making frequent decisions between competing uses of storage space, but does suggest that management of CCS will need to coordinate with management of other underground storage operators and other CCS projects.

The next question is whether investment in CCS will continue our dependence on coal and delay the transition to more sustainable energy sources.[93] One can argue that CCS alone does not necessarily drive technology choices on the energy production side but simply is a way of preventing CO_2 from being emitted into the atmosphere from any given source. It could be applied to any centralized facility from a biomass to natural gas to coal power plant, as well as other industrial facilities. Put most simply, it is a downstream climate pollution control device most effective for large-scale point source emissions where the biggest carbon benefit can be obtained. As such, large-scale centralized coal-fired power plants are ideal candidates. How CCS eventually gets deployed may have significant impacts on the role of coal in our future energy system, possibly enabling deep cuts in emissions or widening the role of fossil fuels in our energy system at a time when economics and a reduced supply of oil would otherwise drive alternative research and development of more sustainable technologies.

Perhaps the most promising early path nationally and worldwide is to deploy CCS with new plant development. Applying CCS to new power plants, while requiring more energy, could reduce the overall CO_2 emissions from a coal-fired power plant 80–90 percent.[94] This could help meet immediate, increasing energy demands without committing to decades of new CO_2 emissions. Even more dramatic and important reductions could be realized by using CCS either in combination with modified, older combustion units or replaced units to displace existing CO_2-emitting power production.

To the extent that any of the coal used in these power plants is ultimately replaced with biomass, the net avoided emissions becomes even greater. The most optimistic of

91. *Id.* at 43499.

92. *See Trapped Wind*, 384 Economist 82 (July 28, 2007).

93. Rochon et al., *supra* n. 73, at 7.

94. Intergovernmental Panel on Climate Change, *Carbon Dioxide Capture and Storage* 4 (Burt Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos & Leo Meyer eds., Cambridge U. Press 2005).

this research suggests that replacing a small amount of coal used in such a system with biomass from good carbon-sequestering plants like native prairie grasses could yield a completely carbon neutral system and may be cost competitive with the old fully depreciated coal plants under relatively modest carbon prices.[95] This is because plants intake carbon dioxide in their growth cycle through photosynthesis, something that would no longer be re-released when combusted in a plant employing CCS. It is conceivable that a gasification unit running on biomass without coal could also be a candidate for CCS, effectively pulling carbon out of the atmosphere over its life cycle. Because CO_2 lasts for hundreds of years in the atmosphere and emissions are continuing to rise, a system that would pull CO_2 from the atmosphere is highly attractive. Power companies in Europe are already combining large amounts of biomass wastes with coal in units that will eventually capture and store the CO_2 emissions and thereby present a much improved carbon profile.[96]

Conversely, however, one could imagine a scenario where CCS breathes new life into fossil fuels and permits their long-term use even in a carbon-constrained world. When the lifecycle of the system is considered, coal mining must also be brought into question. The idea that certain mining practices could fall under a sustainability rubric (e.g. mountaintop removal) is contrary to logic and good sense for many. Such practices also constitute a dangerous enterprise that continues to take human lives and cause ongoing health problems.

There is also the possibility that CCS will permit coal-based fuels to enter the transportation sector either through the electrification of vehicles or through coal-based liquid or gaseous fuels to power new vehicles. To the extent CCS helps improve the overall emissions profile of the electric grid, pulling from the grid to also power electric vehicles might be among the most emissions-efficient ways of reducing the use of expensive oil in the transportation sector. Gasification of coal can also lead to other potential transportation fuels including diesels and hydrogen. Although it is unlikely that coal-to-liquids (CTL) will be adopted widely without CCS (because it would double the CO_2 emissions for each mile driven assuming no changes in vehicle efficiency), it may well be adopted with CCS.

In fact, most of the proposed coal gasification plants with CCS are poly-generation units that would produce power, fuels, and, potentially, other chemicals. The main concern is that the fuels from these plants could reintroduce a fossil resource that, even with full CCS, would be no better in terms of CO_2 emissions than today's refined petroleum products. This, of course, would impact the transportation sector at a time when hundreds of millions of consumers from rapidly developing countries like India, China, and Brazil begin new consumption patterns, including personal travel, potentially greatly increasing pressure on the energy sector at a time when a reduced supply of

95. Robert Williams, *Toward Polygeneration of Fluid Fuels and Electricity Via Gasification of Coal and Biomass, NCEP* 5-10 (Nov. 2004) (available at http://www.bipartisanpolicy.org /files/news/finalReport/ IV.4.a%20-%20Toward%20Polygeneration.pdf); *See also* Robert Williams, *Fischer-Tropsch Fuels from Coal and Biomass* (Pittsburg Coal Conference, Pittsburgh, PA Oct. 1, 2008) (available at http://www.princeton.edu/pei/energy/presentations/Williams-PCC=talk-Handout-October-2008.pdf).

96. For information about Nuon's Willem-Alexander Plant at Buggenum, Holland and plans for the company's Magnum plant, see generally http://www.nuon.com/company/core-business/energy-generation/power-stations/buggenum.jsp; http://www.nuon.com/company/Innovative-projects/magnum.jsp.

petroleum would otherwise encourage a movement away from fossil-based transportation. Nevertheless, there are good arguments that CCS may be among the most important chances to displace significant carbon emissions from the current generation profile while more sustainable alternatives are developed.

C. Sustainability Question 3: How Will CCS Impact Future Generations?

CCS could play a major role in mitigating the rapid rise in CO_2 emissions, making it perhaps a critical component in solving one of the biggest environmental challenges of our time. As mentioned at the beginning of this Essay, however, one of the age-old questions asked in sustainability circles is how will such a decision impact future generations? To the extent CCS helps avoid the worst effects of climate change and thereby leaves future generations at less climate risk, it would be seen in a positive light. Unfortunately, it also leaves a sizeable management responsibility for many generations to come, which is a problem less associated with climate change solutions that focus on increased energy efficiency and use of more renewable resources.

Even so, nearly all energy sources have adverse consequences of their use. Using large amounts of biomass in energy production may remove arable land from food production over time and leave depleted top soils and chemical-induced problems like the dead zone in the Gulf of Mexico to future generations. The use of hydropower in the United States and across the globe has resulted in siltation, species loss, and flooding problems for future generations. Certainly, nuclear power leaves the longest management legacy to future generations with still no good resolution to the tens of thousands of years needed for nuclear waste storage. Energy efficiency is arguably among the very few truly benign options in reducing our global CO_2 emissions but does not have as significant a potential in the short term to bring about the necessary reduction in CO_2 emissions without a drastic change in government policy and lifestyle choices. Although wind has been criticized for bird and bat deaths, it does not have the intergenerational management problem that exists with CCS. Thus, the critical question is whether the potential contribution of CCS in avoiding the worst effects of climate change outweighs the risks and responsibilities it imposes on future generations. When viewed in this light, CCS, if implemented soon enough and safely, may provide the drastic CO_2 reductions necessary to give future generations a chance at creating a more sustainable solution to the climate change problem.