AIChE®

2005
National Student Design Competition

If there are any questions about the design problem, student chapter advisors and design course instructors are asked to contact:

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Please read the rules on the following pages carefully before submitting a solution to AIChE.

AIChE

October 2004

Dear Chemical Engineering Department Heads and Student Chapter Advisors,

I am pleased to send you the 2005 AIChE National Student Design Competition booklet. Please forward it to those faculty teaching design courses. Attached is an electronic coy of this year's challenge:

"Extraction of Carbon Dioxide from the Atmosphere."

As always, the names of the sponsoring organization and the authors are being withheld to ensure confidentiality. Both will be announced after the deadline, June 4, 2005.

We welcome participation by individuals and teams of up to three students. Please indicate the names of all team members on each entry form, and be advised that each team member is required to submit a separate entry form.

Because the National Student Design Competition is a benefit of AIChE student membership, entrants must be AIChE national student members. Any non-member submissions will not be considered. To join, students can download a membership application form at http://students.aiche.org/join/.

Please take time to review the rules, found on the first two pages of the problem book. It is important that all solutions strictly adhere to the Final Report Format.

TWO NEW RULES ARE EFFECTIVE THIS YEAR: 1) Only electronic submissions will be accepted and 2) the total report must be no more than 100 pages.

All submissions must be submitted in an electronic format. Submissions must be no more than two documents (totaling 100 or fewer pages) of the following format: PDF, HTM, or MS-Word. The requested format is a single PDF file—the Adobe Acrobat program can be used to combine pages from different sources into one document.

Student Chapter Advisors are asked to select the best solution or solutions, not to exceed two from each category (individual and team). Please email each entry separately to awards@aiche.org. In the event that electronic file is too large to send via email, a link to the solution may be sent to this email address where the link is expected to be active for no more than 2 days and AIChE will contact the advisor as to when the link has been copied by AIChE--the solution should then be removed from the University's system.

Solutions must be emailed/postmarked no later than Wednesday, June 4, 2005. Please maintain a copy for your files. To order additional copies of the Student Design Competition booklet, email awards@aiche.org or call AIChE at 1-800-AIChemE (242-4363).

If I can be of assistance, please contact me at (212) 591-7107 or via email at awards@aiche.org. Questions relating to the substance of the problem should be directed to Professor Richard L. Long, New Mexico State University, at (505) 646-2503 or rilong@nmsu.edu.

Thank you for your support of this important student competition.

Sincerely,

Gordon Ellis
AIChE Volunteer and Membership Activities

AIChE National Student Design Competition 2005

Rules of the Contest

Solutions will be graded on (a) substantial correctness of results and soundness of conclusions, (b) ingenuity and logic employed, (c) accuracy of computations, and (d) form of presentation. Accuracy of computations is intended to mean primarily freedom from mistakes; extreme precision is not necessary.

It is to be assumed that the statement of the problem contains all the pertinent data except for those available in handbooks and literature references. The use of textbooks, handbooks, journal articles, and lecture notes is permitted.

Students may use any available commercial or library computer programs in preparing their solutions. Students are warned, however, that physical property data built into such programs may differ from data given in the problem statement. In such cases, as with data from literature sources, values given in the problem statement are most applicable. Students using commercial or library computer programs or other solution aids should so state in their reports and include proper references and documentation. Judging, however, will be based on the overall suitability of the solutions, not on skills in manipulating computer programs.

The 2005 National Student Design Competition is designed to be solved either by an individual chemical engineering student working entirely alone, or a group of no more than three students working together. Solutions will be judged in two categories: individual and team. There are, however, other academically sound approaches to using the problem, and it is expected that some Advisors will use the problem as classroom material. The following confidentiality rules therefore apply:

1. *For individual students or teams whose solutions may be considered for the contest:* The problem may not be discussed with anyone (students, faculty, or others, in or out of class) before or during the period allowed for solutions. Discussion with faculty and students at that college or university is permitted only after complete final reports have been submitted to the Chapter Advisor.

2. *For students whose solutions are not intended for the contest:* Discussion with faculty and with other students at that college or university who are not participating in the contest is permitted.

3. *For all students:* The problem may not be discussed with students or faculty from other colleges and universities, or with individuals in the same institution who are still working on the problem for the contest, until after June 4, 2005. This is particularly important in cases where neighboring institutions may be using different schedules.

Submission of a solution for the competition implies strict adherence to the following conditions:

(Failure to comply will result in solutions being returned to the appropriate Faculty Advisor for revision. Revised submissions must meet the original deadline.)

ELIGIBILITY

- ONLY AIChE NATIONAL STUDENT MEMBERS MAY SUBMIT A SOLUTION. Non-member entries will not be considered. If you would like to become a National Student member, we must receive your membership application prior to submitting your solution. Application forms are found at **http://students.aiche.org/join/**.
- Entries must be submitted either by individuals or by teams of no more than three students. Each team member must meet all eligibility requirements.
- Each Faculty Advisor should select the best solution or solutions, not to exceed two from each category (individual and team), from his or her chapter and submit them per the instructions below.

TIMELINE FOR COMPLETING THE SOLUTION

- A period of no more than thirty (30) days is allowed for completion of the solution. This period may be selected at the discretion of the individual advisor, but in order to be eligible for an award, a solution must be emailed/postmarked no later than midnight June 4, 2005.
- The finished report should be submitted to the faculty advisor within the 30-day period.

REPORT FORMAT

- The body of the report must be suitable for reproduction, that is, typewritten or computer-generated. Tables, supporting calculations and other appendix material may be handwritten.
- The solution itself must bear no reference to the students' names and institution by which it might be identified. Please expunge all such references to the degree possible.
- *Final submission of solutions to AIChE must be in electronic format (pdf, HTM, or MS-Word) and must be 100 pages or less. The final submission to AIChE must consist of 1 or 2 electronic files totaling 100 or fewer pages.*

SENDING THE SOLUTION TO AIChE

- There should not be any variation in form or content between the solution submitted to the Faculty Advisor and that sent to AIChE National. The Student Chapter Advisor, or Faculty Advisor, sponsoring the student(s), is asked to maintain the original manuscript(s).
- Email an electronic file of the solution accompanied by its corresponding entry form to **awards@aiche.org**.
- **DEADLINE: Entries must be emailed no later than midnight June 4, 2005**.

Extraction of Carbon Dioxide from the Atmosphere

1.0 Introduction and Scope

Over the last 60 years, Tthe atmospheric carbon dioxide (CO_2) concentration has increased the amount of anthropogenic carbon dioxide (CO_2) emitted to the atmosphere has risen from pre-industrial levels ofapproximately 280 ppm to 380 ppm since 1850, the beginning of the industrial revolution and atmospheric CO_2 concentration is "now increasing at the unprecedented rate of 0.4 percent a year" (Smithsonian, August 2004, p. 49). –There is growing concern about the long term effects of rising level of CO_2, which causes global warming. Some of these concerns are mentioned in recent publications: A Smithsonian magazine article ("Will Tuvalu Disappear Beneath the Sea", August 2004) speculates about the fate of the islands of Tuvalu as sea levels rise and storms intensify. A Business Week ("Special Report: Global Warming", August 16, 2004, p. 60) article says, "Consensus is growing among scientists, governments, and business that they must act fast to combat climate change. This has already sparked efforts to limit CO_2 emissions. Many companies are now preparing for a carbon-constrained world." National Geographic (September 2004), in a series of 4 articles, reports and speculates about the effects of global warming: "What do you get when you compare hundreds of thousands of years of climate data from glaciers, caves, and coral reefs with climate projections modeled by the world's most powerful supercomputers? Factor in a heavy dose of greenhouse gases, and you get a harrowing forecast. Plants flower sooner, habitats change, diseases spread, coral reefs bleach, snow-packs decline, exotic species invade, calciferous organisms become severely stressed, coastline erode, cloud forests dry, temperatures spike at higher latitudes. Glaciers are retreating, ice shelves are fracturing, sea level is rising, permafrost is melting. What role do humans play?"

365ppm; and, the level of CO_2 in the atmosphere is currently increasing at the rate of 0.4%/year................ Predictions of future global energy use in the next century suggest a continued increase in carbon emissions, rising CO_2 concentrations in the atmosphere, and increased CO_2 uptake by the oceans lowering the pH of the highly productive ocean surface waters. This will continue unless major changes are made in the way energy is produced and, in particular, the manner in which carbon emissions are managed. There are at least three ways through which increased atmospheric CO_2 accumulated could be abated. First, energy could be used more efficiently. Second, the use of low-carbon and carbon-free fuels and technologies (e.g., nuclear power and renewable energy sources) could be increased. Third, the amount of CO_2 in the atmosphere could be managed through capture and sequestration.One way to manage carbon is to use energy more efficiently in order to reduce the need for a major energy and carbon source. Another way is to increase the use of low-carbon and carbon-free fuels and technologies (nuclear power and renewable energy sources). The third way is to manage the amount of carbon in the atmosphere by carbon sequestration.

Carbon sequestration refers to the provision of long-term storage of carbon in the biosphere, underground, or in the oceans in order to reduce so that the buildup of atmospheric CO_2 (the principal greenhouse gas) concentration in the atmosphere will

~~reduce or slow~~. This can be accomplished by maintaining or enhancing natural processes or developing novel techniques to dispose of carbon.

The U.S. Department of Energy (DOE) has a great interest ~~been interested~~ in carbon sequestration alternatives. In accord with that interest, DOE has shown a keen interest in five concept papers that~~, which~~ evaluate various alternatives for permanent CO_2 sequestration ~~of CO_2~~. ~~it let five contracts to develop~~ These papers proposed and evaluated -five concepts for collecting and sequestering CO_2. Because the goal of the concept development studies ~~contracts~~ was to propose new and innovative methods for removing carbon dioxide from the atmosphere and then ~~to store~~storing it in a "permanent" and environmentally acceptable manner, the ~~RFP~~ request for proposals through which these five papers were generated did not require ~~the concept papers to apply~~ a uniform design basis for the concepts developed nor did the development project require~~d~~ technical documentation.............. You have been assigned the task of doing the detailed engineering of the DACE (Direct Atmospheric Carbon Extraction) process. Your work may become the basis of future international treaty commitments, so careful attention to details is important.

2.0 Point Source versus Environmental Capture

CO_2 c~~C~~apture ~~of CO_2~~ can occur from the atmosphere or from point sources. The five ~~concepts~~alternatives offered in the concept papers employ a variety of capture methods. You should keep in mind that the government interest is to manage the overall level of greenhouse gas (CO_2) in the atmosphere in a cost effective way (preferably less than $10 per metric ton of sequestered carbon dioxide [i.e., $36.60 per metric ton of C sequestered]). We however note that the carbon tax in Norway exceeds $200 per metric ton of carbon for gasoline and natural gas fuels making CO_2 removal and sequestration profitable for the Sleipner project, which is able to separate and dispose of CO_2 from a CO_2 contaminated natural gas field at under $50/metric ton of CO_2. At the present the ultimate cost for separation and disposal is unknown although the Sleipner project sets an upper limit. Cost will clearly be a major driving factor in deciding which solutions are adopted.

The government may wish to make treaty commitments in the future dealing with atmospheric carbon emissions. In considering the DACE alternative, you should carefully evaluate any limitations of the proposed solution and note that it is likely best suited for dealing with the transportation sector or addressing incomplete scrubbing from large point sources. The capture method ~~considered is:~~consists of- absorption from the atmosphere by a chemical absorbent followed by absorbent~~and~~ regeneration. One approach might be using a solar tower to move air while providing power for sorbent regeneration through use of the solar chimney. Another approach would be to use "conventional" electric power and coal produced thermal energy (both with integral CO_2 capture and sequestration) to move the air and provide the energy required for absorbent regeneration. Variants or mixtures of these approaches should clearly also be considered.

3.0 Sequestration Technology

Once the carbon is captured it must be sequestered. Several sequestration technologies have been considered in the five alternatives. The choices considered in the DACE alternative are: (1) storage in depleted oil and gas reservoirs and~~,~~ (2) storage in saline aquifers. To avoid introduction of additional uncertainty into the process, the contestants will be required to only include the costs for pressurizing the collected gas to a pressure of 2500 psi, which should be suitable for injection purposes rather than also making assumptions about the sequestration costs for the captured CO_2. For any supplemental power requirements such as heat for absorbent regeneration or energy to move the air, the cost for separation and sequestration of the CO_2 associated with that power generation will be assumed to be $10/metric ton of CO_2.

4.0 Global Implications

The government might make international treaty commitments based on your recommendations, and the government may decide to supply capital or tax incentives based on your recommendations. Thus, geographic constraints may need to be a considered in your evaluation of the alternative.

5.0 Alternative to Be Considered

The DACE case is based on an absorbent based design. The contestants should provide a rational for their choice of their collection and regeneration approach, be it solar, or a far more conventional method. A recent estimate for the cost of a solar chimney is $700 million, not including the carbon capture process for a unit that produces power at a yearly average rate of 200 MW and sequesters ~~O~~0.8 x 10^6 metric tons/year of CO_2. This system could be located in the American southwest. The Kyoto accords would require the U.S. to reduce CO_2 by 4.1 x metric ~~1x~~10^8 tons/year. This solar unit would meet 1/500 of the U.S. carbon reduction required and could be a good test case for additional units. A small scale test unit has been built in Spain, but this solar chimney will be the first operational unit. It is critical to get the process engineering right to ensure that this approach is the best, which it may very well not be.

6.0 Technical Requirements of the Study

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~~All technical~~The technical work must be done thoroughly ~~and~~ on a sound technical basis~~.~~ ~~And,~~ and
~~All technical work~~ must be documented within the report. You will note that the concept report includes minimal documentation; however, your report will include detailed documentation; especially for the following work:

1. The system size needed to collect 0.8 x 10^6 metric tons of CO_2 per year,
2. The system can use ambient (prevailing wind) air flow, solar tower driven airflow, or externally powered air flow. The choice should be justified,

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3. The system can use internally generated or externally produced energy to move the air and to generate the needed energy to recycle the sorbent,
4. The system is designed to be a DACE system, not a wind farm. As such, although the system could be designed to internally generate its required energy needs, it is not allowed to sell any more electricity than would be required to meet its internal power consumption needs including absorbent regeneration,
~~2.~~5. See section 9 for the costs of external energy and selling price for internally generated energy,
~~3.~~6. Caustic soda will be used as the CO_2 absorbent.
~~4.~~7. Droplets, films or some other approach can be considered to provide the contact between the sorbent and the air stream.
8. The water required to deal with evaporation losses from the caustic solution used as a CO_2 sorbent.
9. The contact area required to remove the specified mass of CO_2 and the size of the solar collection area to produce the internally consumed energy if the solar route is chosen,
10. The required sorbent flow rate, associated pumping costs, and energy expenditures,
11. The possibility of entrainment of caustic solution in the exhaust air stream,
12. The effect of the caustic solution entrainment on downwind air quality and on the downwind flora and fauna fallout if the entrainment occurs.
13. The pressurization of the captured CO_2 stream to pressures of 2500 psi for transport and/or injection.
~~5.~~14. A cost of CO_2 separation and sequestration of $10/metric ton for any CO_2 produced from internal energy needs,
~~6.~~15. A 40% electric generation efficiency for externally produced electric power
16. A 90% thermal efficiency for externally generated thermal energy required for absorbent recycling (if any). (If internal produced absorbent recycling energy is used (e.g. from a solar tower), 100 % conversion efficiency from electric to thermal energy should be assumed).
17. A detailed mass and heat balance for the caustic recovery process,
~~7.~~18. A capital and operating cost estimate for the caustic recovery process.
19. Separated energy requirements and costs for the air flow, absorbent recycling, and other system requirements

The focus of your study is the capture of CO_2 from the atmosphere and not the permanent sequestering post capture.

7.0 ~~o~~ Environmental/Health/Safety

You must comply with U.S. law. A well engineered process will protect the health and safety of the public and the plant personnel and meet environmental law requirements.

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8~~7~~.0 Economic Criteria

~~–~~The concept papers do not all use the same design basis to make their respective evaluations. The system design is your choice. Total costs (capital and operating) will be an important evaluation parameter. It is up to you to justify the best process choice. The process should be technologically feasible as well as economically feasible. Thus detailed CO_2 process removal engineering design is required. Do a complete process flow diagram (PFD), including a complete stream attributes table, for the entire process for capturing ~~the~~ atmospheric CO_2 ~~from the atmosphere~~. Use costs for external energy requirements for separation and ~~-~~sequestration as given in section 9. Sequestration costs for the CO_2 captured by the DACE system are not considered as part of the overall system cost estimate as this is uncertain and will be the same for all approaches considered.

9~~8~~.0 Design Keys

The design keys are:

1) The Kyoto accords requirement is that the U.S. reduce CO_2 emissions by 4.1x 10^8 metric tons/year. The DACE plant will be design to remove 0.8 x 10^6 metric tons of CO_2 per year or approximately 1/500 of U.S. carbon reduction requirement from Kyoto accords,~~.~~
2) Assume unit operates forever,
3) Determine the capital cost,
~~3)~~4) Determine the ~~Find~~ yearly operating cost,
5) Assume that the cost to the US taxpayers for the capital required is 5%/year to float Treasury Bonds, in perpetuity,
6) Determine the total (yearly capital cost component, plus net operating cost component) yearly operating cost and then determine the \$/year/metric ton CO_2,~~.~~

~~(1)Identify how much of the cost should be provided by the U.S. taxpayers.~~

~~(6)~~7) Revenue from any excess electricity sales would be 6¢/~~-~~kWh. (Note that we limit the energy sold to be not more than required to recycle the absorbent used per year.),
~~6)~~8) Cost for external electric energy used by the system will be 3¢/~~-~~kWh plus the costs of separating and sequestering the CO_2 associated with its production which will be assumed to have a 40% efficiency.
~~7)~~9) The efficiency for the production of thermal energy required absorbent recycling will be assumed to be 90%,
~~8)~~10) The separation and sequestration costs for CO_2 associated with externally supplied energy will be \$10/ metric ton of CO_2.
~~(7)~~11) CO_2 is to be sequestered in underground reservoirs requiring injection pressures of 2500 psi,
12) ~~(7)~~ Air contacting methods, diffusion, and air flow velocities will be key parameters in the design,
13) ~~(8)~~ Cooling and water loss associated with evaporation will also impact the design,~~.~~

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~~10)~~14) ~~(10)~~ Determine the desirability (if any) of internal power generation by placing power generating wind turbines within the system,

15) If internal power generation is desirable, determine whether it is best to use the electric energy internally or to sell it to an external market. ~~can possibly be placed at the top if the tower is to generate electricity.~~

10~~9~~.0 Cost Data

Cost data for the process engineering part of the project can be found in Peters and Timmerhaus, 5th edition, McGraw-Hill, 2003.

11~~10~~.0 Websites of Interest

(1) http://www.wbgu.de
(2) http://www.globalwarmingsolutions.co.uk/the_solar_chimney.htm
(3) www.abc.net.au/m/science/earth/stories/s381152.htm
(4) www.sbp.de/en/fla/projects/solar/aufwind/pages_auf/techno.htm

12~~11~~.0 Reporting Requirements

The documentation you are preparing is called a “Preliminary Project Definition Report”.

NOTE: FOR CONSISTENCY, CLARITY, AND UNDERSTANDABILITY, ALL OF THE REPORT MUST BE DONE IN SI UNITS!!!

The report format must adhere to the following outline.

1. Title page.
2. Table of Contents.
3. Executive Summary – Two (2) page (maximum) condensation of the report.
4. Introduction – Orient the client to the assigned task.
5. Summary – Summarize the results of the study, emphasizing the costs (operating, capital, and NPW) and summarize the conclusions and recommendations. Briefly tell what was designed and when it will startup and shutdown.
6. Conclusions – Interpret your results. List your conclusions in decreasing order of significance.
7. Recommendations – Emphasize technical and operational feasibility and optimum economics.
8. Project Premises – Itemize all pertinent process and economic premises, including: (1) the overall project schedule, battery limits, etc., (2) feed and product specs, (3) costs of raw materials, utilities, etc., (4) selling prices of all products, (5) economics, including depreciation schedule, taxes, project life, etc., (6) environmental requirements, (7) processing limitations, (8) extraordinary costs, (9) labor costs, (10) product quality considerations.

9. Process Flow Diagram (PFD) – Include all items of process equipment, include and number all process streams, indicate all utilities needed per individual process equipment item, and include all process control loops required to fully automate the process (e.g., there are a minimum of 5 contral loops needed for a distillation column).
10. Stream Attributes – For each and every stream on the PFD include on the PFD or on a separate page a Tabulation of Stream Attributes (SA's), including Stream Number, Mass Flow of Rach Component, Total Mass Flow, Temperature, Pressure and Volumetric Flow Rate. Proper SA's from a process simulator will suffice.
11. Process Description – Include process conditions, equipment type and size and how the process equipment is integrated to achieve process objectives. Explain the purpose of each process equipment item.
12. Safety and Environment – Conduct and document a safety review that includes: (a) major safety and environmental concerns (b) design features that were added to improve the safety of the system, and (c) inherent safety concepts that were considered and adopted in this design solution.
13. Utility Summary – Itemize each utility by user (i.e., by process equipment item). Include in the tabulation the unit cost of each utility and the yearly cost of each utility for each user.
14. Operating Cost Summary – Itemize using the categories given in Peters, Timmerhaus, and West, 5th edition, Tables 6-17 and 6-18, pages 273 and 274.
15. Equipment Information Summary – Itemize operating conditions, sizes, materials of construction for all process equipment.
16. Capital Estimate – Itemize process equipment costs and itemize the overall estimate per Method C (or equivalent), page 250, Peters, Timmerhaus and West, 5th edition.
17. Economic Analysis –Include a discussion of the economic methods and analysis. Include appropriate cash flow analysis tables. Include any graphical representations, such as NPW.
18. Innovation and Optimization – Explain and document what was done to economically optimize the project.
19. Engineering Calculations – Include all (not just samples and examples) pertinent hand calculations.
20. Computer programs **–** Include input and output files, and an explanation of the model(s) used and nomenclature.
21. Computer Process Simulation – Include input and output files and a simulator flow chart for one set (the set of optimum conditions is preferred) of documented process conditions for any process simulation using standard process simulator programs.

NOTE: THERE MUST BE A ONE-TO-ONE CORRESPONDENCE BETWEEN STREAM NUMBERS IN THE PROCESS SIMULATION AND STREAM NUMBERS ON THE PROCESS FLOW DIAGRAM.

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CHEMICAL ENGINEERS

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