Minutes of the 4th Technical Meeting of the International Network on Biofixation of CO_2 and Greenhouse Gas Abatement with Microalgae.

September 29th, Concorde Lafayette Hotel, Paris, France.

INTRODUCTION: The objectives of this meeting was to update the Network Members on R&D projects presently ongoing and planned, to strengthen integration and collaborations between projects and to introduce microalgae technologies and the International Network to new participants and invited observers. The planned agenda included discussions of budgets, ongoing R&D activities and future plans, including proposed LCA (life cycle analysis), TEA (techno-economic analysis) and resource estimates for of microalgae biofixation.

AGENDA

A. 8:00 AM. Assembly, Registration, Coffee.
B. 8:30 - 10:30. Welcome, Introductions.
  a. Paola Pedroni (Chair, EniTecnologie). Welcome – Status, Activities, Objectives.
  b. Angela Manancourt and John Davison (IEA Greenhouse Gas R&D Programme). Budgets, Network Organization.
  c. John Benemann (Network Manager). 3rd Meeting, R&D Activities, Roadmap.
  d. Introductions by Steering Committee Members, Technical Advisers, Observers.
  e. Presentations by observers of current/past/future R&D in microalgae biofixation.

10:30 - 11:00 Break

C. 11:00-12:30. Update on Ongoing and Planned Projects by Network Participants
  Presentations by:
  1. Mario Tredici, Productivities of Different Cultivation Systems.
  2. Paola Pedroni, Comparing Ponds and Photobioreactors.
  3. Vito Maraffa, Growth of Algae on Flue Gases.
  4. Joseph Weissman. Productivity Maximization with Small Antenna mutants.
  5. David Brune. Update of Salton Sea Project for Nutrient Removal/Recycle.
  6. David Barr. Rio Tinto sponsored Research for Rubisco Improvement.
  7. Pradeep Dadhich. Proposed Projects: Wastewater Treatment and Biofertilizers
  8. John Benemann, Photobiological Hydrogen Production.

12:30 - 14:00. Lunch

D. 14:00 - 15:30. General discussions and Q and A sessions related to technical aspects of microalgae biofixation of CO_2. Identification of major R&D issues and needs: productivity, harvesting, genetics, etc. GhG abatement potential, Discussions of ongoing /proposed projects: Biofertilizers, photobiological hydrogen production, wastewater treatment. Coordination and collaborations among projects within / outside the Network.

15:30 - 15:45 Break

E. 15:45 - 17:00 PM. Network Organization. Membership and recruitment. Budget. Objectives for current year. Discussion of a "Systems and Life Cycle Analysis". Information management/web site. Outreach. Schedule for next meeting. Other matters pending or issues raised by participants. Concluding remarks.

F. 19:00 - 21:00 PM DINNER .

PARTICIPANTS

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A. WELCOMES AND INTRODUCTIONS

1. Dr. Paola Pedroni, EniTecnologie, Chair, Welcome to the 4th Technical Meeting.

Dr. Pedroni welcomed the members, technical advisers and observers. She specially welcomed Angela Manancourt the new Contact Person for the Network within the IEA Greenhouse Gas Programme and thanked John Davison for his fundamental contribution for the start of the Network. Dr. Pedroni briefly reviewed the history, organization, status and activities of the Network for the observers and participants attending for the first time and summarized accomplishments for the past year, which saw the start of several R&D projects.

The Network was initially proposed by the U.S. Dept. of Energy and EniTecnologie in the Summer of 2000, following which a Workshop was held in January 2001 in Monterotondo, Italy, at EniTecnologie, where over 30 experts discussed the technology and potential of microalgae in greenhouse gas abatement, and supported the formation of the Network. In January 2002 a pre-organizational meeting was held in Reston Virginia of potential members and the Network was officially started in June of that year, with eight members (Arizona Public Services, ENEL, EPRI, ExxonMobil, GTI, Rio Tinto, in addition to DOE and EniTecnologie). Three technical meetings have been held, in Almeria, Spain (May, 2002), in Kyoto, Japan (October 2002) and Berkeley, California, USA (April, 2003). (Reports are available from the Network Manager).

The Network governance is by the representatives of the member organizations. Six technical advisers (three present at this meeting, Drs. Brune, Tredici and Weissman) assist the Network. (Advisers not present: Dr. Amha Belay, Dr. Bailey Green and Dr. Gerald Cysewski).

She summarized the activities expected for the present FY 2003 – 2004, which are, in brief, to:

assist participating organization in developing and advancing R&D projects that meet their strategic goals and are pertinent to the common vision of the Roadmap.

promote cooperation and collaborations among projects

asses the potential of microalgae technologies in global greenhouse gas abatement (e.g. a systems/life cycle analysis of greenhouse gas abatement by microalgae).

recruit new member and publicize the Network.

2. Dr. John Davison. GHG R&D Programme, Budget and Organizational Matters

The budget for 2002-2003, $72,000 (eight members, @$9,000/each) was essentially completely spent, without significant carry over. He gave a forecast for the 2003-2004 budget. The budget was spent mainly on the first three meetings (Almeria, Kyoto and Berkeley) as well as support of the Network Manger ($24,000, for half the year). Based on 7 members this year, ExxonMobil had dropped out of the Network, a total of $63,000 would be available and a forecast of expenses would be as follows: $40,000 would be planned for the Network Manager, $5,000 for the IEA Greenhouse Gas R&D Programme and $18,000 for two meetings, this one in Paris and the one planned for the U.S. in the Spring. If additional members joined this budget could be revised.

Dr. Davison reported that India was officially joining the IEA GHG Programme and TERI would be joining the Network. He also introduced Angela Manancourt, who is going to provide contact with and support for the Network, including through the IEA GHG Programme web site.

3. Dr. John R. Benemann, Review of Network Organization, Activities and Status.

Dr. Benemann presented some viewgraphs on the Network organization and activities. The goals of the Network are to demonstrate technologies for GHG mitigation within five years and achieve practical applications in ten years. Network members participate through both internal and/or extramural R&D projects carried out individually or in collaborations

Functions, Goals and Structure of the Network.

- Information sharing and coordination of R&D projects
- Development of bi- or/or multi-lateral R&D projects
- Technical assistance in evaluation of processes and R&D projects
- Techno-economic analyses and resource assessments.
- Organization of technical meetings and technical resources.
- Development and updating of the "Technology Roadmap" for practical R&D projects.

The Technology Roadmap concluded that stand-alone systems for algal production of fuels (e.g. "energy farming") is not plausible within the five to ten year R&D horizon for the Network and thus nearer-term goals and opportunities need to be developed. The focus of the Roadmap is on processes that utilize power plant CO2 resources. These include:

- Municipal wastewater treatment with CO_2 utilization to produce biofuels, conserve energy.
- Agricultural/aquacultural/industrial wastewater treatment, as above and co-products (feeds),
- Fertilizer production, in combination with the above and/or nitrogen fixation microalgae.
- Co-production of biofuels with large volume/higher value by-products (biopolymers, etc.).

These processes are similar in that they all:

1. Use flue-gas CO_2 sources and produce renewable fuels to mitigate GHG emissions
2. Aim to achieve very high productivities (> 100 metric tons biomass /hectare /year)
3. Depend on cultivating selected algal species, genetically improved.
4. Employ the standard raceway, paddle wheel, unlined open pond culture system
5. Require low cost harvesting systems, either settling or screening (filamentous algae).
6. Have secondary greenhouse gas abatement benefits in addition to biofuels produced.
7. Accrue economic benefits from by-products and co-services, greater than from the biofuels.
8. Can be economical at a reasonably modest scale (e.g. 100 hectares).
9. Can plausibly be developed within the time horizon of the Network.
10. Can have in aggregate significant potential for global greenhouse gas abatement.

The last point is a critical uncertainty at present. There are also questions about the overall greenhouse gas abatement of technologies such as wastewater treatment, when considered on a comparative basis to other technologies. This was discussed later in the meeting.

4. Introductions by Participants .

David Barr, Rio Tinto, Member, Australia
Rio Tinto is a large international mining company with significant coal mining interests, in particular in the USA. The company is interested in CO_2 reduction in defense of the coal industry. It is supporting research related to microalgae CO_2 fixation (see below).

Daniel Ballerini, IFP (Institut Francais du Petrol), Observer, France,
IFP was the initial company that developed the Spirulina production technology in the 1960's. The company has experience and interest in biofuels from biomass, biotechnology, conversion of lignocellulosics to ethanol and acetone-butanol fermentations. Capture and sequestration of CO_2 is also of interest.

John Benemann, Network Manager, USA
One topic of increasing interest in connection to the Network is using microalgae for hydrogen fuel production (see below).

David Brune, Clemson University, Adviser, USA,
Clemson University is working on integrated algal production –aquaculture systems for wastewater treatment and fish production. These systems have applications in algal biomass production and greenhouse gas abatement (see below).

Pradeep Dadhich, TERI, Member, India
India joined the IEA Greenhouse Gas R&D Programme, with TERI representing India on the ExCom board. TERI itself is joining the Network due to its interest in developing technologies using microalgae I waste treatment and biofertilizers for greenhouse gas abatement (see below).

John Davison, IEA GHG R&D Programme, UK
The IEA Greenhouse Gas R&D Program has over the past decade carried out engineering and economic studies of greenhouse gas abatement technologies. It has over a score of member countries and participating energy companies, and now includes several research "networks".

Jose Maria Fernadez, University Almeria, Observer, Spain
The University of Almeria has a long-standing R&D effort in microalgae culture for high value products and photobioreactor development. The specific interest at present is through the potential support by Endesa, the major Spanish electric utility of microalgae related R&D. (Endesa participated in the first meeting of the Network in Almeria, Spain in May 2002).

Peter Heifetz, Diversa Corp., Observer, USA
Diversa Corp. is a relatively new, but fairly large biotechnology company that has developed advanced techniques for "bioprospecting" for novel genes, directed evolution and related techniques. The company has a general interest in the potential of microalgae biotechnology.

Phlippe Lutz, EDF (Electricite de France), Observer, France
EDF is a major electric utility and is devoting considerable resources to addressing the issues of greenhouse gas abatement and development of new technologies in this area.

Angela Manancourt, IEA GHG R&D Programme, UK
As the new contact person for the Network, Ms. Manancourt will support its administrative, organizational, and information management needs (see www.ieagreen.org.uk).

Vito Maraffa, ENEL Produzione Ricerca, Member, Italy
ENEL, the major Italian electricity company, is producing almost 100 TWhr per year and generating on average 550 g CO_2/kWhr. The company is carrying out two projects related to CO_2 abatement, one dealing with CO_2 absorption by serpentine rocks and a microalgae R&D project using actual power plant flue gases and photobioreactors as cultivation systems (see below).

Patrick McMullan. ESAA, Observer, Australia
CSRIO in Australia has a general interest in this area, and specifically as it may relate to biohydrogen

Arnaud Muller, IFREMER, Observer, France
IFREMER carries out marine-related research, including aquaculture.   Specific interest is in the use of microalgae for aquaculture feeds and higher value products. The application of such systems to greenhouse gas abatement would be of interest.

Paola Pedroni, EniTecnologie, Member (Chair), Italy
EniTecnologie, the R&D arm of the major Italian oil company Eni, is engaged in wide variety of R&D efforts related to greenhouse gas abatement, including a project on microalgae biofixation (see below).

Richard Rhudy, EPRI, Member, USA
EPRI has been involved in a wide variety of R&D activities as they relate to the electric power industry for over thirty years, including, in the past, some microalgae projects related to biofuels production and greenhouse gas abatement.

Blair Seckington, Ontario Power, Observer, Canada
Ontario Power has been active in a number of areas related to greenhouse gas abatement R&D.

Mario Tredici, University Florence, Adviser, Italy
The University of Florence has been a center of microalgae R&D for over thirty years, with several research groups currently active in this field. (See below).

Joseph Weissman, SeaAg, Inc., Adviser, USA
Current research at SeaAg, Inc. emphasizes the development of high productivity strains of algae (see below).

6. Presentations of Ongoing Research Projects.

1. Mario Tredici, University of Florence, Italy. Productivities of Different Cultivation Systems.

The main recent research of interest to the Network has been a study comparing open vs. closed photobioreactors as mass cultivation systems growing *Tetraselmis suecica* in vertical photobioreactors panels and annual columns compared to open ponds. (This project is supporting also that of EniTecnologie, see below). Prof. Tredici discussed that to compare the ponds to photobioreactors one needs to overall areal productivity, not area of light capture by the photobioreactor.

One of the key issue in the productivity of the cultures is the hydraulic dilution rate, with about 50% dilution rate per day being generally optimal in summer. A productivity (organic ash-free) of about 36.3 g/m^2/day was achieved with a vertical annular column photobioreactor, corresponding to about 150 t/ha/y or land area. This compares to only a little over half as much, 19.5 g/m^2/d, for ponds. However, ponds are much cheaper, 25 Euro/m^2, vs. 300 Euro /m^2 for annular photobioreactors. Panel-type photobioreactors are estimated at 50 Euro/m^2. Clearly, costs vs. productivity is a major issue.

2. Paola Pedroni, EniTecnologie, Monterotondo, Italy. Comparing Ponds and Photobioreactors.

The objective of the EniTecnologie Project in "direct biofixation" is to produce biofuels to replace fossil fuel methane. The target is to determine achievable algal biomass productivity under operating conditions outdoors using a simulated flue gas (simulating a NGCC power plant, with relatively low concentrations of CO2). The specific objective of the initial phase of the project is to optimize the productivity of the microalgae cultures using such flue gas. One key issue, as suggested from the prior discussion, is the productivity of open ponds vs. closed photobioreactors. This was tested this year experimentally at the Monterotondo R&D facility.

As an initial goal this project was to demonstrate if there are, indeed, significant differences in productivities between these different culture devices. For this purpose two ponds, of about 2.5 m^2 each and two tubular photobioreactors, of about 1 m^2 each, were designed and constructed by Prof. Tredici and his team. The ponds were operated from April to October of 2003. Cell density, cell numbers, and a number of other parameters were measured. An initial conclusion of this work is that there are no major differences between the two types of cultivation systems in terms of productivities based on intercepted sunlight. Thus open ponds are a suitable for algal mass cultures. Dr. Pedroni showed a short film clip of the operating ponds and photobioreactors.

3. Vito Marraffa ENEL Produzione Recherche, Brindisi, Italy. Growth of Algae on Flue Gases.

The objective of this project is to combine greenhouse gas mitigation with production of high value co-products. The experimental approach is to compare productivity of various algal strains under well controlled laboratory conditions (12hr light, 12 hour dark cycles, relatively low light) in closed photobioreactors using flue gas composition, with 4 -15% CO2, 50-200 ppm NOx and 100 to 400 ppm SOx. No effects of inhibition by the gases were noted. Several algal strains were tested: *Botryoccocus, Chlorella, Akistrodesmus, Dunaliella, Phaoedactylum and Amphora.* The first two did not do well, not surprising for *Botryoccoccus* but not expected for *Chlorella*, although this could be a strain effect. The results obtained so far suggest that the next stage would be to take these experiments outdoors with actual sunlight, possibly in open ponds.

4. Joe Weissman, SeaAg, Inc., Vero Beach, Florida. Maximizing Productivity in Mass Cultures.

This project is being supported through a "Phase II" U.S. Dept. of Energy "Small Innovative Business Research" grant to SeaAg, Inc. and Brooklyn College (Prof. Juergen Polle). The objective is to increase the productivity of algal mass cultures through development of so-called "small antenna" strains of algae. At present the peak average monthly productivity is about 30 - 35 g/m^2/day, corresponding to a 4-5% photosynthetic efficiency (of PAR, photosynthetically available radiation) and the annual average is about half this. It is estimated that a doubling of productivity could result from the reduction of pigment content, that is reducing the antenna size of the light-harvesting pigments. Mutant strains that have such reduced pigment contents are being developed and will be tested in the outdoor ponds. This project is just beginning, and thus results are not available as yet.

The Phase I effort was reported in some detail in the prior meeting in Berkeley and is not repeated here. Suffice it to state that the experimental results from open pond cultures suggested that both light saturation and photoinhibition significantly reduce algal productivity in mass culture ponds. These can be reduced by using vertical photobioreactors, but these suffer from many limitations, in particular the very high costs of such systems. Both light saturation and photoinhibition are expected to be minimized by using algal strains that are selected to have reduced harvesting pigment content. The near-term goal is to demonstrate that such strains could overcome current limitation and exhibit productivities exceeding 100 metric tons dry organic biomass per hectare per year, a key goal of this Network.

5. David Barr, Rio Tinto, Melbourne, Australia. Improving the CO_2 Fixation Enzyme.

Rio Tinto is funding ongoing projects on improving the process for biological CO_2 fixation both in Australia and through the genetic modification of the enzyme *RuBisCo* from a cyanobacterium by Codexis Co. a biotechnology company in California. Their gene shuffling and directed evolution techniques have been applied to developing an enzyme that is catalytically much more active than the original "wild type" enzyme. Rio Tinto is now looking at the potential application of this development, which will be published in the open literature soon as a peer reviewed publication. Rio Tinto would like to find projects and processes where this technology could be used and scaled up. This will require addressing issues of GMOs, conversion and products.

6. Prof. David Brune, Clemson University, Clemson, South Carolina, USA. The CEP Process.

Clemson University has been working with Kent SeaTech, Inc., on the development of a process for removing nutrients (P and N) from the agricultural drainage waters flowing into the Salton Sea, in Southern California. Assuming that algal strains can be developed that exhibit high productivities (e.g. small antenna size strains), about 1,000 hectares of algal ponds, producing 100,000 tons of biomass, will be required to reduce nutrients flowing into the Sea to acceptable levels. At present the "Controlled Eutrophication Process" (CEP) being developed at the Kent SeaTech, Inc., facility by the Salton Sea is being demonstrated with two 0.3 hectare ponds. (Background to this project is provided in prior meeting reports and recent publications). The primary development since the Berkeley meetings has been the demonstration of the harvesting method for the algae, which involves a fish-mediated flocculation settling process, with the settled algal biomass recovered by a moving belt. The digestion of the algal biomass to produce methane gas was also discussed, in particular the greatly increased methane yield from adding a cellulosic biomass (actually waste paper).

7. Pradeep Dadhich, TERI, New Delhi, India. Wastewater Treatment and Biofertilizer Projects

TERI is joining the Network with the immediate objective in obtaining technical assistance in the development of two research projects: the use of microalgae for wastewater treatment and the production of bio-fertilizers with nitrogen-fixing cyanobacteria. Both projects would involve small-scale test experiment using outdoor ponds followed by larger demonstration projects. TERI is interested in exploring the concepts of wastewater treatment as developed by Prof. Oswald and Dr. Bailey Green at Berkeley, with the objective of also reducing significantly greenhouse gas emissions. India has already carried out extensive R&D on the development of nitrogen-fixing cyanobacterial cultures that are produced as inoculum for rice paddies, with some practical applications reported. However, there are still many uncertainties, including the actual growth and survival of such inocula. TERI is planning to study some new approaches.

8. John Benemann, Network Manager, Walnut Creek, California. Photobiological H_2 Production.

Photobiological hydrogen production is becoming an ever more popular research topic, mainly due to the perception that the production of H_2 from water and sunlight with microalgae acting as catalysts would allow, somehow, very high photosynthetic efficiencies. Much of this perception is based on the so-called direct biophotolysis process, in which water is split into H_2 and O_2 by action of the photosynthetic apparatus in algae with simultaneous release of these gases without any intermediate CO_2 fixation being required. CO_2 fixation is seen by some as being wasteful and inefficient (one reason for the interest in improving the CO_2 fixation enzymes, see above). However, such analyses do not consider the likely insurmountable problem of O_2 inhibition of H_2 production, the impractical cost of the photobioreactors and the hazards of working with O_2-H_2 mixtures. An alternative approach is proposed, in which algal ponds produce a biomass high in carbohydrates (starches in green algae or glycogen in cyanobacteria) which is then converted to H2 in a high yield dark fermentation (recovering 10 H_2/glucose). Such a process requires no expensive closed photobioreactors and should have overall efficiencies that are 75 to 80% of the theoretical direct biophotolysis reactions (theoretical as direct biophotolysis has not been demonstrated under actual operating conditions). In brief, the proposed process would fit in well with other approaches being investigated by the Network, such as algal-methane processes.

7. General Discussions.

A number of issues were discussed during the concluding hour of the meeting.

1. Information Management / Web Site. Angela Manancourt (IEA GHG R&D Programme) discussed information management for the Network on the web site of the IEA GhR R&D Programme. She asked for inputs on how this should be structured. It was decided that the Roadmap should be included in an open section (available to the public) along with publications related to the Network, but that the minutes of the meetings and budgets should be available only to members. She will bring the Network information into the IEA Greenhouse Gas R&D Program web site before the next meeting.

2. Business Case. Paola Pedroni and others discussed the need for developing a "Business Case", essentially a document that would help prospective new/existing members to promote the joining/continuing participation in the Network internally. This Business Case would be structured to provide a clear statement of the subject, applications, future benefits, and arguments of why a specific organization would join/continue with the Network activity. It was decided that Dr. Benemann would prepare such a Business Case prior to the next meeting for discussion, review and adoption during the next meeting, for addition to the Network website.

3. Membership. The loss of ExxonMobil, due to the company placing all its R&D efforts in greenhouse gas abatement into the "GCEP" program at Stanford University, will likely be made up by PNNL (Pacific Northwest National Laboratory, in Washington State) later in the year. Additional recruitment of members is a priority. Dr. Benemann will be working on this aspect.

4. Future Meetings. The next meeting will be held in the Washington D.C. area, in conjunction with the 3rd Annual DOE-NETL Carbon Sequestration Conference, May 2-6, 2004, Alexandria, Virginia, (http://www.carbonsq.com). The specific date will be announced later. The following meeting will be in conjunction with GHGT-7, 5-9 September 2004 in Vancouver, Canada (see www.ieagreen.org.uk).

5. Project Coordination and Development. Several projects are being closely coordinated with each other through the exchange of algal strains and coordination in experiments. As the Network develops, these collaborations will be expanded. Specifically the Network Manager will assist the members in developing their own projects, in particular TERI. A report on such activities will be presented to the members at the next meeting.

6. Techno-Economic Analysis (TEA), Life Cycle Assessment (LCA), and Potential Abatement Projection (PAP). These issues were discussed at some length. One of the problems with microalgae technologies as outlined in the Technology Roadmap is the lack, or at least perceived lack, of rigorous analysis of the overall processes, either in terms of economics, benefits (net greenhouse gas abatement for individual processes) and potential resource (abatement) for countries and globally. Prior estimates for stand-alone biomass fuels production systems are not applicable to multi-purpose, multi-product processes, generally of smaller scale. The large variation in systems is another problem. John Benemann stated that such studies would be carried out at last on a preliminary basis during he coming year.

He pointed out that some misconceptions hamper such analyses. For example only, water use efficiency, a major issue in land-based biomass production systems, can be very low for algae production if water is recycled (e.g. 200 tons water used/ton biomass, assuming 100 t/ha/y), compared to higher plants (typically 2000 tons water/ton biomass), which is counterintuitive. Another one is that high mixing is required for high productivity, which leads to very high power in puts.

John Benemann presented an overview of his approaches and methodologies to carrying out the TEA and LCA:

A. Methodology for Carrying Out the Techno-economic Assessment:
- Mass (CO2, water, nutrient) and energy balances for algae cultivation
- Land requirements, solar energy conversion efficiency
- Harvesting, processing (fuels, etc.), nutrient recycling, waste disposal
- Integration with wastewater treatment, water and nutrient recycling
- Economics: capital and operating costs.
- Greenhouse Gas Abatement Costs (CO2 equivalent)
- Research goals: near- and long-term. Impacts on TEA.
  Are research goals technically and economically feasible?
  Which areas of research should be the focus to reduce costs?
  What are research plan and how plausible is the plan?

B. Methodology to Life Cycle Assessment (LCA)
- Inventory of air, water, and solid waste emissions
- Non-renewable resources consumed (energy, water, nutrients, etc.)
- Water and land utilization and impacts
- Non GhG environmental effects – positive/negative
- What are other environmental impacts – Positive and Negative?
- What environmental impacts can R&D reduce/improve?
- How do microalgae process compare to others/status quo?

Some participants thought that such analysis, to be carried out with any rigor, would be well beyond the current state of the technology and the time available. Dr. Benemann suggested that he would report back at the next meeting to allow assessment of progress.

The final issue was the impacts on GHG emissions, both regionally and globally of these microalgae technologies. It was no clear how to assess these in light of the large uncertainties. The only plausible approach is to carry out estimates for specific systems, such as municipal wastewater treatment, animal and agricultural effluent treatment, and biofertilizers and assign some, relatively modest, default value in terms of market penetration, for climatically favored regions. For example a 10% market penetration for municipal wastewater treatment systems would likely be reduced to 2% in the U.S., where perhaps only 20% of the population lives in climatically favorable areas. Similar projections could be made for other technologies. Even if at present uncertain, some estimate and projection of future greenhouse gas abatement potential is essential for the development of the Network, and this was highlighted as a high priority.