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ANNEX VIII EXPLORING ENERGY TECHNOLOGY PERSPECTIVES

ETSAP at the International Energy Workshop

ETSAP members joined with the International Energy Workshop and the Stanford Environmental Modeling Forum for an extravaganza of energy systems and modeling. Phillip Tseng, Chairman of ETSAP was one of the speakers at the opening plenary session. GianCaro Tosato, ETSAP Project Head, spoke at the closing plenary session. Several ETSAP members presented papers.

A wide variety of models, analysis, current development of technologies, and programming methods were described. The largest number of papers on a single category was on a hydrogen economy, often coupled with carbon sequestration and fuel cells. We focus first on this issue and then on other papers presented by ETSAP members and friends. Here we have tried to cover the essence of the papers. In most cases, full text is available at http://www.iiasa.ac.at/Research/ECS/IEW2003/papers.htmlsb=5. The final section is "What's going on in ETSAP."

As an introduction to the topic of the hydrogen economy and CO_2 sequestration, we begin with the paper by Phillip Tseng, John Lee, and Paul Friley (USA), "Hydrogen Economy: Opportunities and Challenges." The paper describes the transition from a petroleum-based energy system to a hydrogen economy. A hydrogen economy is the long-term goal of many nations because it provides security, environmental, and economic benefits. The transition involves many uncertainties. They include development of fuel cell technologies, hydrogen production and distribution infrastructure, and the response of petroleum markets. This study used the U.S. MARKAL model to simulate the impacts of hydrogen technologies on the U.S. energy

What's Going On in ETSAP?

- Mr. Phillip Tseng was re-elected as Chairman. Mr. Peter Taylor and Mr. Takashi Yano were elected vice chairs.
- Project (ETP) that makes use of ETSAP tools. The first version of ETP is working. The supply side

In this issue

Visit ETSAP on the www: http://www.etsap.org

Information on ETSAP, its activities and members is also provided on the Internet. The home page contains the latest news, general information on ETSAP, and links to: ETSAP member; ETSAP 'outreach' activities; description of the MARKAL model and its users; archives of new item; selected publications and the ETSAP Newsletter.

Using MARKAL-MACRO to analyze an R&D portfolio - continued -

of the model has been updated. The demand side of the model is undergoing a serious reconstruction. The success of the project is of the highest priority for Annex VIII.

- ETSAP experts are cooperating with the U.S. Department of Energy's Energy Information Administration to develop the System to Analyze Global Energy markets (SAGE). The 2003 issue of the International Energy Outlook is largely based on SAGE analysis and results.

- On behalf to ETSAP, the Project Head participated in the ASEAN-Australia Regional MAKAL Users' Group (AAMRUG) mee-ting, and a workshop for the countries of Central American organized by Brookhaven National Laboratory.

- ETSAP, several of its Contracting parties and

system and identify potential impediments to a successful transition to a hydrogen economy. Insights from the quantitative analysis can provide valuable inputs to decision-makers in planning R&D, and in designing economic incentives.

The authors assumed that, as a result of successful research, development and deployment, hydrogen production system design and fuel cell vehicles would be cost competitive with petroleum-based technologies. They focus on hydrogen production from coal, natural gas, biomass and electrolysis. They do not address the chicken and egg problem in introducing hydrogen technologies into the U.S. Energy system.
The MARKAL model's output includes the equilibrium prices and quantities of energy and environment commodities, level of use of different technologies or cost reductions necessary to make them competitive.

The specific segment of the hydrogen economy modeled consisted of a set of feedstock supply curves of natural gas, coal, and biomass. These feedstocks are sent to three process technologies: gas reforming, coal-, and biomass-gasification. Their output is joined with hydrogen production from electrolysis further downstream. Carbon sequestration is modeled as an option for gas reforming and coal gasification at additional cost. The hydrogen produced is modeled to go through an intermediate delivery infrastructure and storage for meeting the demand of highway vehicles. The economic and technical attributes of the

The transition requires constructing many new hydrogen plants and fueling stations. The new infrastructure must serve the emerging demand for hydrogen, and meanwhile, utilize the existing infrastructure, such as gas pipelines and railroads to minimize the delivered price. In the U.S., hydrogen plants plausibly will be situated close to the load center and to rail or pipeline terminals to minimize the expenses of transportation.

The "Hydrogen Economy" scena-rio was based on achieving a production cost of $0.50 to $1.00 per gallon of gasoline equivalent at gate (GGE). At $0.75 per GGE the respective feedstock costs for natural gas, coal and biomass are $3.5, $2.0 and $1.0. per GJ. For transporting via pipeline and storing hydrogen (in gas form), approximately $0.65 to $0.85 per GGE based on an average delivery distance of 50 to 100 miles between production facilities and demand centers. In the next five years the US government will provide R&D funding of about $1.7 billion for hydrogen and fuel cell technology.

The transition from a petroleum-based energy system to a hydrogen economy will reduce demand for petroleum, lower oil prices, and reduce crude oil throughputs into petroleum refineries. Energy security will improve as sources become more diverse.

On the demand side, the model's results show that hydrogen fuel cell vehicles compete well against conventional and hybrid vehicles.

Given the assumptions on hydrogen conversion technologies and resource costs, coal appears to be the most competitive way to produce hydrogen without considerations about carbon emissions. Recent studies showed that capturing CO_2 adds about 25 to 30% to the cost of producing hydrogen. Hydrogen technologies can reduce carbon emissions if hydrogen is produced from renewable technologies or nuclear energy.

There are several challenges. These include lowering hydrogen price at the pump to $1.60 to $2.00/GGE. This will require improvements throughout the entire hydrogen economy. Improvements in fuel cells requires revolutionary breakthroughs. An economic incentive is needed to encourage the building of hydrogen infrastructures. Determining the best method of transport of hydrogen is a challenge.

Miller and Duffey of Atomic Energy of Canada Ltd. Focus on generating hydrogen through electrolysis driven by nuclear reactors. They estimated that some 600,000 vehicles could be fuelled by the hydrogen from one medium-sized (700 MW) reactor. The energy requirement for electrolysis production of hydrogen is ~56 kWh per kg H_2.

The authors argue that distributed hydrogen production is likely to launch hydrogen fueling for the road-transport, but fueling stations must be widely available. Electrolytic hydrogen solves this distribution task - especially if electrolysis occurs only with off-peak power. The energy content of hydrogen is rather more than three times greater than gasoline on a weight basis. A typical fill-up for a gasoline-fuelled care 30 Kg will become 3 kg of hydrogen – stored as a gas on-board in 700-atmosphere aluminum, carbon-fire reinforced cylinders (which are all ready available). The volume of the compressed gas is about 80 L. Storage cost is significant. This cost is difficult to estimate since this is a new type of activity and is likely to get

Using MARKAL-MACRO to analyze an R&D portfolio - continued

associated institutes are cooperating with other organizations to propose the New Energy Externalities Development for Sustainability Project (NEEDS) to the 6th Framework Research Program launched by the European Commission for the years 2003-6. The ultimate objective is to evaluate the full costs and benefits (direct and external) of energy policies of future energy systems. ETSAP experts will contribute to the development of a consistent and robust analytical platform allowing to integrate the full range of information and data on Life Cycle Assessment and external costs (with ExterE methodology) into a Pan-European modeling framework based on ETSAP tools.

hedged around with regulation.

Evangelos Tzimas* and Stathis D. Peteves of the European Commission, DG-Joint Research Centre, Institute for Energy presented a paper on "The impact of carbon sequestration on the cost of electricity and hydrogen in Europe in the medium term."

These authors state that "Even when hydrogen is considered as the universal energy carrier of the future, … at the outset, hydrogen will be produced by fossil fuels via processes that also emit CO_2. One of the options considered to control CO_2 emissions … is carbon sequestration. … a major factor that may dictate whether or not carbon sequestration will be deployed in Europe is the associated economics. … Chemical absorption is considered as the state-of-the-art for the separation of CO_2 when present at low partial pressures, having demonstrated at least 90% removal efficiency, hence making this process ideal for removing CO_2 from the flue gases of gas turbine combined cycle (GTCC) plants and supercritical pulverized coal (SC) plants. Physical absorption combined with pressure swing adsorption is suitable for removing CO_2 from integrated gasification combined cycle (IGCC) and hydrogen production plants."

"It has been reported that in coal plants, about half of the increase in capital costs is due to the cost of CO_2 capture and half is a result of reductions in the power output. Furthermore, the higher increase in capital costs in GTCC compared with coal plants is due to the lower concentration of CO_2 in the flue gas of GTCC plants, that makes CO_2 capture more demanding in terms of equipment and energy consumption. About a third of the efficiency penalty for CO_2 capture in a coal plant is due to auxiliary power consumption, such as the flue gas fan and the CO_2 compressor, while the rest is due to steam consumed for the regeneration of the amine. In contrast to the relatively high availability of information on capital costs, operating and maintenance costs are not typically reported. … The cost of CO_2 transport is significantly lower than that of capture, being about €1.1 per tonne CO_2 when the throughput is 5 million tones annually and the pipeline is 100 km. the cost increases to €4.4/ tonne CO_2 for a pipeline of 400 km. The costs of storage are … roughly within the range of €1-3/ tonne CO_2 stored."

The analysis included three types of plant, SC, GTCC, and IGCC. "The results show that the deployment of carbon sequestration technologies will increase the cost of electricity by 35-57% depending on the power plant technology. GTCC technology will continue to be the most economic pathway to produce electricity, even with the deployment of carbon sequestration technologies. IGCC technology cannot be completive with other electricity generation technologies when carbon sequestration is not considered. However, the deployment of carbon sequestration makes IGCC an attractive pathway, bringing the technology at the same level of competitiveness with supercritical pulverized coal plants. The cost of CO_2 transport and storage is unlikely to have a significant contribution to the total cost of electricity. The main component in the cost of electricity in SC and IGCC plants is the capital cost, and in GTCC plants the cost of fuel. As such, technological developments that can reduce capital costs offer a higher potential to lower the COE in coal plants than in natural gas–fueled plants. The last conclusion highlights the strong dependence of electricity costs on natural gas price."

Timothy Johnson and David Keith of Carnegie Mellon University (USA) presented a model and results that show the extent to which carbon capture and sequestration (CCS) might lower the cost of CO_2 control. The fundamental advantage of CCS is its compatibility with today's infrastructure. The analysis assumes a classical utility planning perspective. Individual operators in a real electric market will seek to maximize profit, and the resulting investment pattern may not minimize costs. This framework, they assert, is suitable for estimating the social costs of CO_2 Controls.

Model parameters were based on the Mid Atlantic Area Council (AMAAC) Region of the North American Electric Reliability Council, the largest integrated power pool in North America. Cost and performance specifications used are based on both academic and industry assessments and reflect the authors' judgment about what might be expected around 2105 for a cumulative CCS installation of 5 GW in the MAAC region. Retrofits of existing coal plants are parameterized by four generic variables: a step increase in marginal O&M of 0.5 cents per kWh, a capital cost of 250$/kW (thermal), an energy penalty of 15%, and a CO_2 capture efficiency of 90%. The baseline model assumes an additional cost of 30$/tC (8.2$/tCO_2) for CO2 transport and sequestration. Actual cost would be site specific. New coal units with carbon capture become competitive near 75$/tC.

The findings highlighted three key factors that control the role of CCS in a carbon-constrained electricity market: natural gas prices, the initial distributing of generating capacity, and the cost of carbon sequestration.

Socrates Kypreos of the Paul Scherrer Institute (Switzerland) reported selected results of the MERGE-ETL model with endogenous technological learning (ETL). MERGE divides the world into nine geopolitical regions: Canada, Australia and New Zealand, China, Eastern Europe, OECD Europe and the former Soviet Union, India, Japan, Mexico and OPEC; USA and the rest of the world. Special emphasis was given to CO_2 sequestration systems. He defines three reference technologies: an IGCC plant, a pulverized coal plant, and a combined gas and steam turbine power generation system without sequestration options. Then, a parallel set of the same technologies, with the exception that these include sequestration of CO_2. In the baseline cases, technological learning favors new, advanced systems such as integrated coal gasification with combined cycle, gas combined cycle, wind turbine and new nuclear plants, as well as non-electric back-stop systems. Apart from this, the model formulation does not significantly change the conclusions of the original MERGE model for the first half century. The results differ significantly for the second half of the century, however. Without learning, use of synthetic fuels dominates, while in the case with endogenous learning, the market penetration of carbon-free technologies reduces emissions to 16.3 Gt of carbon per annum. In the 550-ppmv stabilization cases, a significant development and market penetration of low-carbon generation options is required to fulfill the imposed CO_2 reduction targets. Technology learning in this case favors new advanced systems, in particular GCC, NNU, WND and mainly IGCC systems with carbon sequestration together with non-electric renewables. The application showed the importance of technological progress for carbon control, since this brings in low-cost reduction options and hence reduces GDP losses and the marginal cost of carbon control.

MERGE-ETL views the development of clearer and innovation energy technologies as a long-term strategy to mitigate global climate change. Kypreos points out, however, that such a penetration of new technologies is not necessarily going to happen in the real world relying on market forces. These new technologies are still expensive and not competitive against fossil fuels or other barriers. The new systems identified as promising require initial support for their development, otherwise they may be locked out of energy markets.

most 7% to 8% between 2020 to 2035 while with CO_2 removal 38% reduction can be achieved.

Papers (condensed) presented by ETSAP members

Heesung Shin, Jongchul Hong, and Younggu Park (Korea) presented a paper of carbon emissions reductions and carbon capture and sequestration in the iron and steel industry of Korea. Korea's iron and steel industry was ranked 6th in the world on the basis of production of crude steel. Production in 2000 was 43 million tons. The main facilities of the iron and steel industry are the iron production facilities that have a total of 11 blast furnaces with capacity of 26,010 thousands tons/year. The steel-making facilities are 12 basic oxygen furnaces with capacity of 26,180 thousand tons/year, and electric arc furnaces with capacity of 23,475 thousand tons/year. The energy consumption of iron and steel in 2000 was about 696.3 PJ. The CO_2 emission from iron and coal works was estimated to be 14.3 million tons carbon, about 12% of the national total.

This study used the MARKAL-MATTER model, with special regard to the characteristics of the iron and steel industry that is able to do the Material Flow Analysis. MARKAL-MATTER is able to evaluate various technologies including the flows of products and materials through their life cycles. One hundred technologies were evaluated. The data are mostly from other countries owing to the shortage of statistical data in Korea. The study period was 1995 to 2035. Five cases were analyzed: a base case, a technology case (all technologies are applied), and three carbon tax cases 30USD/ton CO_2, 60USD/ ton CO_2, and 90USD/ton CO_2. Consumption (PJ/y) goes from 682 in 2000 to 718 in 2035 in base case. In the tech case emissions go to 684 PJ/y in 2035. The 30USD/ton was identical to tech case. The 60USD/ton CO_2 and the 90USD/ton was 655 and 656 PJ/y. The main reason of the high reduction potential in the 60USD/ ton CO_2 tax and 90USD/ton CO_2 tax case is due to the selection of CO_2 removal technology. The reduction potential without CO_2 reduction technologies will be at most 7% to 8% between 2020 to 2035 while with CO_2 removal 38% reduction can be achieved.

Denise Van Regemorter (Belgium) and GianCarlo Tosato (Italy) explored a new methodology, where Life Cycle Assessment and externalities are linked to a linear programming framework, combining the strengths of each tool. ExternE evaluates external costs of energy supply options (i.e., power plants) and energy use (e.g., transport) assuming a specific location but taking into account the transboundary aspects of pollution. The Process Life Cycle Inventories (P-LCI) are specific to a set of well defined processes/ commodities, also basically linked to a specific location. At the boundary of the detailed process/ commodities model, the system effects are accounted for usually using country averages. The Integrated MARKAL-EFOM system (TIMES) generates technology rich partial equilibrium solutions for the long term development of energy-environment systems. Essential to the methodology is the sum over the lifetime of each process of emissions, impacts, and valuation. The models built with MARKAL-TIMES may be local, national, regional or global, according to the policies of interest. They provide long term equilibrium prices as well as quantities. the tools mostly represent at least national systems, where price related policy indications are interesting. The three methodologies take different approaches to the economics. LCA and ExternE follow more of a simulation/ accounting approach, concentrating on specific energy supply/use options. The MARKAL-TIMES on the other hand follows an optimization approach and computes a full system equilibrium. With the new methodology energy system analysts add to the long-term economic equilibrium quantities and prices represented explicitly, the quantities of energy, material and emissions used indirectly and their external costs. Life cycle impact analysts add to the static and locally based details made available by standard LCA the dynamic development of energy production mix at the national levels. The best example is PV: if the silicon wafers are produced with coal based electricity, the LCA looks bad, if produced with carbon free electricity, the LCA is much better than other options.

Alfred Voß and Ulrich Fahl (Germany) presented a philosophical and practical approach to sustainable development, coining the term "creative capacity." They observe that in the Brundtland Commission and the Rio Declaration, the concept of "sustainable development" embraces two intuitively contradictory demands. Namely the sparing use of natural resources and further development. The Brundtland Commission defined sustainable development as a "development that meets the needs of the present generation without compromising the ability of future generations to meet their needs."

In a broad sense, sustainable development incorporates equity within and across countries and integrates economic development, the conservation of the environment and the natural foundation of life as well as social welfare. A key challenge is to address those three dimensions in a balanced way. Energy has links to all. Thermodynamically, life necessarily produces entropy by degrading workable energy and available material. But energy and material constitute a necessary but not sufficient condition for life supporting states of order. Knowledge and information, although always limited, is never consumed and can be increased. This "creative capacity" is of significance to sustainability because it allows for a more efficient use of natural resources and an expanding of the available resource base for future generations.

Is the use of finite energy resources compatible with the concept of "sustainable development?" If not, then only "renewable resources" are compatible with sustainable development. This is not sound for two reasons. Use of renewable resources, e.g., solar energy, always goes hand and hand with a claim on non-renewable resources. For example, he cites wind power, which requires 3.7 – 24 kg/GWh$_e$ of iron, 47 – 140 kg/GWh$_e$ copper, and 32-95 kg/GWh$_e$ bauxite. In the absurd, non-renewable resources could not be used at all, not even for future generations.

The energy and raw material base available is fundamentally determined by technology. Deposits of energy and materials that exist in the earth but cannot be found or extracted today cannot make a contribution to securing the quality of life. It is therefore the state of technology that turns valueless resources into available resources.

As far as the environmental dimension of sustainability is concerned, one has to recognize, that is not the use of the working potential of energy that pollutes the environment, but the release of substances connected with the energy system. The efficient use of all resources being a key element of sustainability suggests, that total social cost (including the external cost) of the various energy and electricity supply options are a suitable yardstick for measuring their relative sustainability.

M.I. Howells, T. Alfstad, D.G. Victor, G. Goldstein and U. Remme presented a description, an analysis and projections of a South African village. Based on a survey, it was determined that the majority of respondents used wood in an imbaula (an informal wood stove, often constructed from a 25l metal paint can) as fuel. Most respondents used the fuel because it was easily available or they were familiar with it. There was also an absence of alternatives other than high cost kerosene. Of the people who used wood, many preferred kerosene as a secondary fuel, the least expensive fuel after wood. Paraffin was used in rain when it was difficult to gather wood. Many households reported coughing, smoke and smelliness as problems with wood. In some households, different appliances were used for water heating and cooking. Typically one would find that space heating and cooking are carried out in an imbaula, while water heating is done with Paraffin. Lighting was by candles or kerosene wick-devices. Most households owned a radio and about one-third had a TV; one-fifth reported having a cell phone.

Several future scenarios were run. In the base case, wood dominated. Open fires contribute roughly 75% to final energy demand. LPG and paraffin serve as backup fuels. Water heating and cooking are similar. Over the modeling period total final energy consumption for lighting drops significant due to a technology transition from kerosene wicks to more efficient paraffin pressure lantern. By the end of the period (2017) pressurized paraffin lanterns provide half of the useful energy, but consume less than 25% of the fuel that is burned for lighting.

In the "Stand Alone" scenario, the most significant change from the Base Case was that the model selects diesel generator, but only with the capacity for lighting, where they replace paraffin and for radio and TV.

In the "Grid Electrification" Scenario the model calculates that supplying these low volumes of electricity from a new grid connection would be less costly than purchasing or charging of batteries. This strategy with only low volume consumption has been followed in other countries. While this is an economic option, it does not promote a more complete move to electricity.

Operating Agent

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