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WIND ENERGY: Constraints and Incentives for Development. Comments on the Final Report of the Wind Energy Technical Panel, and Recommendations for Action by the United Nations.

Prepared by Dr. Jerome Weingart and
Prof. Marshal Merriam

TO: Morris Miller
Deputy Secretary General
United Nations Conference on New and Renewable Sources of Energy

FR: Jerome Weingart
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RE: Comments on the FINAL REPORT OF THE TECHNICAL PANEL ON WIND ENERGY

The following comments are based on a careful review by Prof. Marshal Merriam, University of California at Berkeley. These comments are keyed to an accompanying copy of the FINAL REPORT, in which reference numbers and some comments have been inserted. I.e., 4-2 refers to comment number 2 on page 4 of the FINAL REPORT. I hope these comments, along with Prof. Merriam's discussion of constraints and recommended actions related to wind energy technologies will be of some assistance to you and the Secretariat.

Comments

3-1 This bibliography is both limited and "lopsided" in its coverage. While this may not be of major importance to the Preparatory Committee, researchers should be aware that the bibliography is limited and not meant as a comprehensive listing.

3-2 This sentence should read "The power in the wind is proportional to .."

4-1 This should read

> "The output of the windmill is then used to save fuels. In utility applications some capacity credit may also be achieved."

This is because there are utility applications in which virtually no capacity credit can be taken. An example would be Hawaii, which has some of the best wind sites in the world. Unfortunately, when the trade winds die, they may not reappear for several weeks. Since there is no opportunity in Hawaii for energy storage (eg. pumped hydro) during such an extensive period to cover any substantial amount of wind generation capacity, the actual displacement by wind systems of base load capacity or intermediate generating capacity may be highly limited. There are other examples as well.

4-2 Another advantage is that by interconnecting wind generators in neighboring regions with different wind regimes, improved constancy of output is obtained. This has been demonstrated in a study of wind energy potential in California, where a widely disperssed network of wind generation equipment would be interlinked through the grid. See, for instance:

> E. Kahn (1979), "The Compatibility of Wind and Solar Technology With Conventional Energy Systems", Ann. Rev. Energy 4:313-352

(This report was provided to the Secretariat in January, 1981)

5-1 These wind speeds are for a hieght of 10 meters above the ground.

5-2 This should read:

"Wind systems can be constructed in sizes ranging from a few watts to several megawatts (MW)."

5-3 This should read:

"The lack of thermal conversion losses .."

5-4 This should read:

".. with blades occupying a fraction as little as 3 percent, and often less than half of the "collector" area."

5-5 Add:
"However, more than 99 percent of today's windmills are used either for electricity generation or for direct pumping."

5-6 The last two sentences would be better if they stated:

"...rising cost and economic and environmental penalties associated with fossil fuels, can again lead to the wide scale contribution of energy from the wind. Recent experiments justify the expectation that this can occur."

NOTE FROM J. WEINGART:

Modern industrial societies require primarily high quality liquid and gaseous fuels, and to a lesser extent electricity, to provide their energy needs. Wind generated electricity might displace half of the fuels required for intermediate and peak generation, and little or none of the base load capacity sources. So, while wind may provide a substantial fraction of the intermediate and peak generation needs for utility regions with good wind locations of adequate size, the primary need - production of synthetic fuels from non fossil sources - requires additional technology some decades away from large scale commercial reality. These are the major elements of the "hydrogen" economy, including electrolysis and fuel cells which are economic, of long (10 years or more) lifetime and constructed of materials sufficiently abundant to permit installed capacities approaching a TW or more. This is not to minimize the potential contribution of today's large wind generation systems, which will almost certainly achieve full commercial reality in this decade, but to indicate the much larger possibilities for the long term. This perspective of the long term - the coming half century - ought to be the basis for some of our basic research and development work in the energy field, as indeed it has at places like ISPRA.

6-1 This paragraph would be more accurate if it read:

> "In the later part of the nineteenth century the multi-bladed windmill was developed for pumping water. Some 6 million of these were manufactured in the USA alone between 1850 and 1940. Between 1920 and 1940 hundreds of thousands of small wind driven electric generators were also manufactured and put into service. These windmills were later largely displaced by rural electrification programmes in the United States, and by diesel electric sets in LDC's.

6-2 ..and in the United States as well.

6-3 This should read:

> "..a relatively low efficiency, ranging from about 10 to 25 percent."

6-4 This is peak efficiency, achieved when the wind is blowing at the design speed. Actual average efficiency of the best contemporary wind machines over the year is between 30 and 35 percent.

6-5 This should read:

> "Significant engineering development of these machines ceased in the late 1960's.."

(For instance, this is when the French program for the development of large wind generators ceased.)

7-1 Under these conditions, the pumping which is practical is for livestock and people, not for irrigation.

NOTE BY J. WEINGART: If the usual economic criteria for use of wind energy for irrigation or power generation is used, wind sites which might be unsuitable by these criteria but usable for pumping water for livestock and people might be missed. Since access to clean water is still out of reach (often by just thirty meters) by much of the world's population, suitable wind sites for this very important application should also be identified.

7-2 This should read:

> "..cooling and water desalination has been proposed and is technologically feasible."

NOTE: Since "feasibility" to an engineer often means economic as well as purely technical feasibility, we need to make the distinction between the two when appropriate.

7-3 Note: The only high solidity machines which are commercially proven are the multi-bladed mills.

7-4 This should read:

> "A multi-bladed windmill with direct mechanical drive to a water pump is a well established technology and commercial machines are in extensive use in many parts of the world, including the United States, Canada, Argentina, ..."

NOTE: Hundreds of thousands of such machines are currently in use in the USA.

8-1 It is important to note that these machines are almost never used for irrigation. They simply do not deliver sufficient water for this purpose.

8-2 The machine is not suitable to crop irrigation. only to pastoral agriculture where the people are not nomadic.

8-3 Prof. Merriam does not believe that 30-(c) is true.

8-4 It is more likely that the lack of widespread use of these mills is due to the poor performance and reliability of the machines, which have nowhere achieved commercial status.

8-5 Are all the costs, including distribution and profit, being included here?

8-6 100 watts (average) corresponds to perhaps 500 watts (peak). At present wholesale prices for photovoltaic arrays of about $8000 per peak kilowatt, these means a wholesale cost of about $4000 for the array (the pump being a small additional cost). The prospect for being able to produce such arrays with a wholesale price of $2000 per peak kilowatt is considered quite good, and achieveable in the 1980's. If so, photovoltaics would be an effective competition with wind machines under good wind circumstances, and would in any case have far wider applicability in much of the developing world, where there is more sun than wind. (J. Weingart comment)

9-1 Most crops do not require year-round irrigation. In fact, the irrigation needs are quite cyclic, and may not at all match the wind cycles. Thus this analysis probably underestimates the real costs of such water. (Weingart)

9-2 Experience does not support this claim!

9-3 Also, pastoral subsistence farmers are usually nomadic while wind machines are not.

9-4 This is not true for all LDC's.

9-5 These alternative wind machines are still experimental, not commercially proven. Also, rural extension programs should not promote the use of wind hardware until it is fully proven, as the last sentence says.

10-1 The original diffusion of wind machines did not require such programs.

10-2 While this comment may seem cynical, it appears as if this recommendation is a prescription for building another bureaucracy. Experience indicates that this is not the thing to do.

10-3 It must be pointed out, however, that this has nowhere been done on a commercial basis.

10-4 This is a conclusion based on calculations, not on real experience.

11-1 This should be updated.

NOTE: The fourth of the MOD-0-A machines has been installed in 1980 in Hawaii, on the North Shore of Oahu (at Kahuku) and has been operating with high reliability. In January, it had been operating several months with a capacity factor of about 80 percent! However, the Kahuku sight is one of the best in the world for such machines, and not at all typical, except perhaps of other good wind sites on Pacific Islands in the trade wind belt. (Weingart comment)

12-1 This should read:

"..hydroelectric storage, promise to be an economic alternative .."

12-2 Note: If a wind machine cannot <u>replace</u> a diesel generator (not just some of the fuel which would otherwise be required), it is not literally an alternative. Rather, it is a fuel-saving <u>supplement</u>. The distinction is important.

12-3 At present there are no such energy storage systems on the horizon.

13-1 This should read:

"The plant capacity factor ..."

NOTE: "Load factor" is not the same as "plant capacity factor". The load factor occurs when the generation is load controlled; plant capacity factor occurs when it is source controlled."

NOTE: The term "rated wind speed" is not previously defined in this document.

13-2 So far, these are just studies. Prof. Merriam implies in his review comments that some scepticism is appropriate regarding these results.

14 The U.S. entries in the table are incomplete. They do not include the commercial units produced by WTG (24 meter diameter, 200 kW), Bendix-Schachle (4.0 MW) or Hamilton Standard (4.0 MW). The Alcoa machine rating is 300 kW, not 200 kW as indicated in Table I.

15-1 Economic feasibility is another matter, of course.

17-1 This could read:

> "The issue of capacity credit is controversial, but the value of capacity credit is not decisive to the economics of large scale wind power."

17-2 The major environmental effects are likely to be the secondary impacts, not the direct or primary impacts.

19-1 This statement is too optimistic; it does not really reflect the present situation.

20-1 This is a debateable position. See the comment by Prof. Merriam regarding constraints and incentives for wind energy technology use in LDC's.

20-2 This is not necessarily true. For instance in the United States the investments are, in some cases, being made by private entities, under recent regulations. (See the reference paper in the Teknekron/BNL series of research memoranda prepared in conjunction with the preparations for the UN Conference).

20-3 This cost range is a little high. Also, for a cost of $\$5000/kW(e)_{rated}$ and an annual capacity factor of 0.3, use of a 15 percent fixed charge rate gives a levelized busbar energy cost of

$$(5000)x(0.15)/(8.76 \times 0.3) = \$\ 0.29/kW\text{-}hr$$

21-1 This assertion of economic competitiveness has not been verified. In both cases mentioned the tax credits are very large.

22-1 This is still a highly speculative application of wind energy conversion.

# # #

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CONSTRAINTS AND INCENTIVES FOR THE DEVELOPMENT, INTRODUCTION, AND WIDESPREAD USE OF WIND ENERGY CONVERSION TECHNOLOGIES IN DEVELOPING COUNTRIES

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Prepared for the joint Teknekron/Brookhaven Project on
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PREFACE

The following paper contains comments by Professor Merriam on the "Final Report of the Wind Energy Technical Panel," prepared for the United Nations Conference on New and Renewable Sources of Energy scheduled to convene in Nairobi in August 1981. The comments refer to Parts III and IV of the report, which deal with constraints limiting the development of wind energy and possible measures to overcome these constraints. Professor Merriam, who has had extensive experience related to renewable energy technologies, especially wind energy conversion, both in the industrialized world and parts of the developing world, has provided a set of recommendations that he feels directly address the issues of concern to the Conference. For convenience, Parts III and IV of the UN report are attached to this paper.

This report by Professor Merriam was prepared as part of our efforts to provide USAID and the UN Secretariat with a set of useful and specific recommendations for actions that, if taken, would substantially enhance the rate and scale with which renewable energy technologies could be used in the developing regions of the world. Comments and criticisms are invited.

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Constraint A.1

Wind Resource Estimates May Not Be Reliable

I agree that this is an important constraint, but I don't agree with the measure proposed to overcome it. The proposed measure is "Preliminary evaluation of wind resources can be based on existing meteorological data, the reliability and quality of which should be improved." In my opinion this will be expensive but not very useful. Existing data are usually airport data; in every case I am aware of they have been gathered for some purpose other than wind energy assessment. The sites of existing anemometers are usually low wind locations and the anemometers are not at wind generator heights. Most anemometers are at +10 m above ground. What is needed is new data – not necessarily more accurate than existing data, but taken at potential wind sites. That means the anemometers must be 20, 30, 50 m above ground level. The sites must either be windy areas or areas where the use of wind is currently under evaluation.

Constraint A.2

Lack of an Institutional Framework for Developing Policies, Strategies, and Programmes in Wind Energy

I believe that this could be a constraint, but I do not think it's a very important one. The previous diffusion of water-pumping windmills of the American multivane fan type occurred rapidly and effectively – scores of countries, millions of windmills – without any institutional framework. The profit motive alone sufficed. It is not necessary to create a new bureaucracy for every social need.

In the same vein, the proposed measure "Creation of focal point for wind energy policy and planning units in relevant government department" seems to me to be wrong in most cases, although in a few countries it may be warranted.

Constraint A.3

Past Activities in Wind Energy Have Been Spasmodic and Limited in Scope

In my opinion this was not a constraint. Rather, it was a reflection of past reality, especially of low and declining oil prices. Wind programs in northern Europe in the 1950s and 1960s ended as a response to economic reality, as did the Smith-Putnam program in the U.S. in the 1940s. Wind enthusiasts have historically had a hard time confronting this reality. The proposed measure to cure constraint A.3 is "Specific programmes and goals should be established for wind energy." This is general enough so that I will not argue with it, except to note that the programs and goals should have a solid foundation. In any case, it has little to do with the enumerated constraint.

Constraint A.4

Lack of Rural Infrastructure for Promoting the Development of Wind Pumping and of Autonomous Wind Electric Power

The authors imply that all the elements for rural wind energy systems exist except for the promotion. In my opinion, the hardware is not there, the economics are not there, and the wind is not there. To establish a rural infrastructure, by which I suppose is meant a corps of government agents trying to persuade farmers to invest in wind, seems to me a step backward, except to the extent that present extension agents should be educated in wind and have pamphlets available so that they can give some help in the instances where it makes sense. In my opinion, "Lack of Rural Infrastructure, etc." is not a valid constraint.

Again, the corrective measure recommended, "Establish rural development programmes and include water pumping by wind and autonomous wind electric power where relevant," is hard to dispute because it does not speak directly to the constraint. Rural development programs are found in many, probably most, countries. There is general consensus that they are a good thing, so far as I know. Currently, they have little or nothing to do with wind energy. If the authors are arguing only that wind water pumping and wind electric power should be encouraged by existing rural development programs where relevant, then I agree. The key phrase is "where relevant." That is not everywhere. In my opinion wind energy systems will catch on where they are relevant even without a rural development program. It was not the block development officers who made the green revolution sweep North India in the late 1960s – it was the existence of a newly developed technology that worked and made sense economically.

Constraint A.5

Lack of Manufacturing, Distribution and Maintenance Services

The measure proposed to cure the constraint is "Organize manufacturing, distribution and maintenance services." This is best deleted in its entirety. If there is any profit in it, the necessary services will appear. If there is not, the government effort to organize services will soak up resources and accomplish nothing.

Constraint A.6

Concern by Power Authorities over Operational Problems of Integrating Wind Power into Existing Grids

I agree that this is currently a constraint. I believe that it will go away by itself

as experience in handling wind power becomes more general. At present the economic advantage of using wind energy in utility grids is widely perceived as very marginal, and consequently most power authorities are not inclined to make major accommodations for it. As the demonstrated economic advantage improves, power authorities will more seriously try to accommodate it. It is certainly true that system stability and integrity are much more important than marginally lower costs due to wind energy; the burden is on the wind people to show that both can be had together. The measure recommended for this constraint is one with which I find no fault.

Constraint B.1

(Too Long to Quote)

This so-called "constraint" appears to be actually a statement that national wind energy centers should be established to provide services to cure the numerous constraints listed. Actually, the "measure" to cure B.1 is the proposal to establish such centers. This proposal appears to be the work of an experienced empire builder, oriented to building organizations. The words sound fine, but it's very theoretical and not very practical, judging from experience in India and elsewhere. A centralized organization for developing a new industry and bringing its fruits to the people is not appropriate or efficient. One does not bring wind energy into wide use more quickly by hiring a large number of additional government employees and building new centers. Often this has a slowing down effect — it has in the U.S. in some instances. Transfer of technology, when successful, has usually proceeded through the private sector, driven by the profit motive.

In my opinion, Constraint B.1 should be entirely restated. There is some wisdom there, but the way it comes across is as a blatant attempt to build another organization.

Constraint B.2

This is also not really a constraint. The words are perhaps true and the proposed measure to cure the constraint sounds commendable, but there is little content.

Constraint C.1

Lack of Advisory and Consulting Services for Decision Makers

Proposed measure: "International agencies, particularly those of the United Nations system, should provide advisory and consulting services."

I agree completely with both the constraint and the measure.

Constraint C.2

Lack of Rural Extension Workers with Relevant Knowledge and Skills in Wind Pumping

Proposed measure: "National training course in rural uses of wind energy for rural extension workers."

I agree with the constraint and I agree with all of the measures except for the word "national." In many localities or regions an international training course is appropriate (North America, the Caribbean, Central America, some regions of South America, for example) and in some countries a regional training course is needed (India, where there is no common language, for example, or Indonesia,

where there are transport difficulties between regions – also the Philippines). The training course can be operated by whomever has the ability, and need not be associated directly with the national government. In the U.S. an outstanding course of this type is the one operated at New Mexico State University.

Constraint C.3

Lack of Wind Energy Specialists in (a), (b), (c), and (d)
(Text is too abundant to copy)

Measures (a), (b), and (c)

It is true that there is currently a lack of such specialists. However, this is no constraint. If the specialists were available now there would be no jobs for them. When the jobs are created, the specialists will be developed simultaneously and without direct expense. In particular, measures (a) and (b) should be dropped; measure (c) – "fellowships" – may have some application, but does not require a high priority. I have had first-hand experience working with individuals in a less developed country (Chile) who learned wind power easily without any special program. Thus, in my opinion, Constraint C.3 should be deleted from the document.

Constraint C.4

Shortage of Specialists Qualified to Train Others

The specialists in the developed countries learned the subject not primarily from other specialists, but from books and by themselves, for the most part. The individuals I referred to earlier in Chile also seemed to be doing it without much difficulty. "Shortage of specialists qualified to train others" is not a constraint. The proposed curative measure is, again, largely irrelevant. Fellowships, if sufficiently short term, cannot do much harm. Often they are used as a ploy to support people abroad for long periods; then the people never go home.

The emphasis is placed on organizations as the solution for all problems whereas incentives may play a more important role.

Constraint C.5

Absence of Wind Energy Courses in Universities and Technical Schools

The measure proposes support for the development of curricula and books, etc. This may be a minor constraint, but I do not think it's very important. The wind energy courses will appear automatically when the time is ripe. If developed before the time is ripe there will be no employment for the graduates.

Constraint D.1

Insufficiently Detailed Wind Resource Data

I agree that this is indeed an important constraint. It cannot be cured, but it can be alleviated somewhat. The two measures proposed seem quite appropriate.

I do feel, however, that the measure recommended should be more fully described. For example, one could say: "Run-of- wind anemometers should be put in place at exposed sites of high wind potential. These instruments should be at least 30 m above ground and should be read monthly for 36 months. Sites showing mean wind speeds in excess of 7 m/s should be characterized further." Or one could say something such as: "No attempt should be made to map winds below 5 m/s. Efforts should be concentrated on regions of higher wind, with anemometry expenditure scaled according to approximately the cube of wind speed."

Constraint D.2

Absence of Information on Wind Energy

I disagree with the way this constraint is stated. Judging from the discussion

under "Measures," the authors agree with me that it is not a matter of absence of information but of poor availability of information to its potential users.

I generally agree with the measures proposed to alleviate the situation. I do not agree that a wind energy newsletter for developing countries is needed. It would be better to put the funds into better distribution or translation of existing literature. Many of the existing newsletters are not good, being written by nonspecialist journalists. The (a)-(f) enumeration of types of information needed is something I can agree with, in a general way.

Constraint E.1

Lack of Funds for Financing Institutions, Technical Services, and Training in Developing Countries

This is not true in the oil-rich countries. Otherwise it is true but not very new. Lack of funds is commonly a constraint in low-income countries. The proposed measure, "International technical assistance in wind energy," is also hard to dispute. It is not likely to make any big splash.

Constraint E.2

Lack of Funding of Rural Water Pumping and Autonomous Power Where Relevant under Credit Terms Accessible to Subsistence Farmers

In my opinion this sometimes is a constraint, often not. It is established gospel in international development circles that rural credit is very important. The establishment of rural credit to pay for various programs is often a hidden way of subsidizing items that otherwise make no sense. In fact, in the "Measures" part the authors refers to "concessional credit facilities." The authors imply that the more wind machines, especially water pumpers, the better, whether or

not they function. Wind should be exploited where it makes sense and not elsewhere. I think this constraint and the associated measure should be rewritten.

Constraint E.3

Even When Wind Energy Systems Are Expected To Be Cost-Effective . . .

I agree that this can be a constraint on wind development, but I do not think it is generally a very important one. Although wind equipment does have a high initial cost compared with a fossil-fuel system of the same capacity, this is only a problem in small systems. In large systems, such as electric-power-producing plants for utility grids, wind has the great advantage of being modular. The financing source can commit to one or two units and see how they work out before going ahead with the whole project, whereas a fossil-fuel power plant must be built to completion before it is of any use at all. The measure cited to cure the constraint seems to imply that only small systems are being considered. The measure, incidentally, does not specify what is to be done. Only a vague and somewhat threatening statement is made to the effect that government should see to it that local government institutions are sensitive "to the needs of wind energy users." In my experience, financing institutions such as banks care primarily that they will get their money back and that the rate of interest is appropriate. They are not interested in whether the item being financed is cost-effective. Houses, automobiles, and airplane trips are all routinely financed without care for their cost-effectiveness.

Constraint E.4

Lack of Financing of Medium- and Large-Scale Wind Electric Power

I have not observed any viable large-scale or medium-scale project being shelved for lack of financing. To the contrary, it is a good bit easier for wind to get financing than it is for coal or nuclear. In my opinion this constraint lacks reality. Therefore, I urge its deletion, along with the innocuous proposed measure associated with it.

Constraint E.5

It Should Be Recognized That in Many Countries Various Forms of Energy Are Artificially Priced and This Penalizes Wind Energy Even When It Is Cost-Effective

True. Also, it may happen (as it has in the U.S.) that wind energy is artificially priced. In some states a windmill buyer pays only 30 percent of the cost. Almost never does he pay more than 50 percent of the cost in the U.S. today. Unquestionably some wind capacity in the U.S. is installed because of the tax credit and would not be installed without this credit. It is not known how much of the capacity is installed because of the credits. Experience in California has been that the regulations requiring utility companies to accept interconnections have been a bigger stimulus to wind than the large tax credits.

I agree with this constraint, but I do not think it is currently of controlling importance. The proposed measure is satisfactory. Although easy to state, it is not easy to implement.

Comments on Part IV – Recommendations

Recommendation 1

Preliminary Wind Resource Assessment

I agree with this recommendation. I would add to it as follows: ". . . cases, be sought, through UNDP, World Bank, IEA, or other appropriate agency." A good model for a wind resource inventory is the work carried out in the United Kingdom in the 1950s and 1960s and described in Golding's book (ref. 21 of UN wind energy paper). A number of excellent sites were located and established at moderate cost.

Recommendation 2

National Wind Energy Focal Points

The action recommended here is appropriate in some countries and inappropriate in others. I think this recommendation could be safely omitted. The mere designation of a focal point will accomplish little, and if government leaders see the desirability of pursuing wind energy, some person or office will be put in charge of doing it. In fact, the premature designation of a focal point could be disadvantageous. The office designated may be an innocuous one if the designation is made early, when wind is perceived as unimportant. Then later, when it is decided to commit some resources and initiate a program, the originally designated office may not be able to handle it.

Recommendation 3

Wind Pumping for Rural Development

I am in favor of retaining this recommendation, but only in truncated form.

N

There are three sentences in the present recommendation. I would eliminate the first and last. The recommendation would then read, in its entirety, "The panel strongly recommends inclusion of wind powered pumps in rural development programmes wherever local conditions are favorable."

The trouble with the first sentence ("Socio-economic systems studies indicate . . .") is what studies? No references are given. To my knowledge there are no such studies of an objective dispassionate nature. All that exist are promotional pamphlets put out by those who are charged with promoting the rural use of wind (e.g., Small Wind Systems Centre, Rocky Flats, Colorado, in the U.S., and S.K. Tewari's group in Bangalore, India). In fact, the claim that is made in the first sentence of this recommendation is so vague and so broad that it is hard to believe any study came up with it. Credibility of our entire document is impugned by verbiage like this.

The trouble with the last sentence is that it is unnecessary, possibly not true, and is associated with past studies about additional employment generated by wind machines — studies that are best forgotten. I know of one study on additional employment to be expected in rural areas of the western U.S that produced numbers based on pure hot air. That was what the sponsor wanted. Any effect on employment is likely to be small — if it is not, the productivity gain from wind will not be sufficient to pay for the windmills.

Recommendation 4

Wind Energy Centres

I believe this recommendation is undesirable. The dynamic growth of the farm

windmill industry in North America, which spread to the rest of the world in the late 19th and 20th centuries, and the later dynamic expansion of the small wind generator industry both took place without any national or subregional wind energy centers. Today, in the United States, such a center has been established nationally at Rocky Flats, Colorado, and it is still difficult, after five years of operation, to find a consensus that it has substantially and materially assisted in increasing the number of usefully operating wind machines in the U.S. In California, a state the size of many developing countries, there has been a wind office in the state government for several years. Again, there is considerable doubt about its usefulness although the people appointed are capable and the centers appear well managed.

I do not agree with the idea that it is of the highest importance to create national centers for wind energy technology and am opposed to this recommendation. Even without that, however, I believe the recommendation is unnecessary. Countries such as India, where the idea of creating national centers for every interesting and important technology is well established, will do it in any case.

Recommendation 5

Training of Trainers

The title here is a catchword from the old (and discredited) foreign assistance days, and should be changed. I am in favor of education and training of wind energy specialists and I believe this recommendation is sound. A better title would be simply "Education and Training."

Recommendation 6

Wind Energy Information Programmes

I agree that wind energy information programs, especially those sponsored and managed by the national wind energy center at Rocky Flats and by the national Solar Energy Research Institute at Golden, Colorado, have often been inadequate. The people doing the work are "information specialists," and usually do not know a great deal about the subject. Furthermore, a positive statement and attitude have been required, and is always found, even when the facts are otherwise. It is the same kind of situation found in a corporate public relations operation. Even published lists of manufacturers and equipment have contained many wrong entries because they were compiled without checking the information. Another difficulty is that regional or national wind information activities can degenerate into governmental bureaucratic activities, oriented toward serving their parent ministry rather than the public. They can become propaganda mills.

To avoid these problems and still meet the very real need for wind information, I believe this recommendation should be scrapped and replaced with one in the section on New Recommendations.

Recommendation 7

Financing

There are some problems with this recommendation. It comes across as saying "give us more." If something is cost-effective, then it does not need a subsidy. If it is desired to use a subsidy to accelerate what would otherwise be slow and steady growth, then it must be shown that the public benefit is sufficient to justify the subsidy. Moreover, subsidy and financing are not the same.

On a large scale, WECS are not much more capital intensive than hydro or nuclear or roads, all of which have established capitalization avenues. On a small scale for farms, SWECS are not more capital intensive than land itself, the focus of many existing financing arrangements. Perhaps the thrust of the recommendation should be that large and small wind equipment should be included under the financing arrangements now used for large capital projects and for farm enlargement and improvement. Therefore, I would rephrase this recommendation to say:

"Wind energy conversion systems are capital intensive. It is important that the same financing institutions that now provide capital for nuclear and hydro power stations and roads have their charter enlarged to make it possible for them to finance large wind installations, where appropriate, and that the financing institutions now providing capital to farmers for tube wells, tractors, and land acquisition be enabled to finance small wind generators."

Additional Constraints

Constraint M.1

Availability of Proven Equipment

A constraint of wind energy use that was not mentioned in the report of the Wind Energy Technical Panel was the lack of availability of proven equipment having good performance. For example, as yet there is no commercially proven Darrieus rotor available. Some of the units sold have been withdrawn from the market because unforeseen technical problems developed. Similarly, large

HAWTs are still in the experimental stage. To a lesser degree, small wind generators in the 5-100 kW size range are unproven.

I personally expect the equipment to continue to improve, and without doubt there is more available than there was five years ago. However, those who talk as if the technology is as well established as, say, Mercedes trucks, IBM computers, or hydro turbines are living in a dream world. Availability of proven equipment is a major constraint and should be recognized as such.

Measure to Accompany Constraint M.1

I have no measure to propose to alleviate Constraint M.1. The measures that would work are outside the sphere of action of UN agencies and most national governments. Funded hardware development programs, such as the successful one in the United States, and market guarantees are examples of measures that could be developed to cure this constraint.

Constraint M.2

General Disbelief of Wind Energy Claims

The fact that many reasonable people in policy positions do not believe many of the statements made by wind energy proponents is unquestionably a constraint on wind energy development. Sometimes the lack of belief is justified, often it is not.

Measure to Accompany Constraint M.2

I have no specific measure to propose. Demonstrations and time are the major weapons against this constraint.

Constraint M.3

Confusion of Goals and Purposes

I have encountered wind energy advocates who felt wind electricity was wonderful — unless electric utility companies owned the machines. There are rural development people who feel that wind machines have an important place in farming — as long as they are used by small farmers and not big ones. A single definable goal should be enunciated for all national programs (or at least a list of prioritized goals should be set forth) in order to minimize conflict among those working toward increasing the use of wind. My candidate for the single goal is displacement of the maximum amount of fossil fuel. This goal, put forward here as an example, has the practical effect of favoring large WECS over small water pumpers, among other things.

Measure to Accompany Constraint M.3

National, international, and regional wind programs should be provided with a well-defined goal at the time they are organized and funded. If multiple goals are admitted, they should be prioritized.

Constraint M.4

Lack of Timely and Accurate Information

I can testify personally to the lack of available information in the countries I have visited, with the exception of Denmark. This is certainly constraining the development of wind energy all over the world.

Measure to Accompany Constraint M.4

My new Recommendations M.1, M.2, and M.3 constitute measures to alleviate this constraint.

New Recommendations

These are additional recommendations, to be appended to the eight recommendations made by the Wind Energy Technical Panel of the United Nations Conference on New and Renewable Sources of Energy.

New Recommendation M.1 (replaces old Recommendation 6)

Wind Information

Accurate and timely information is extremely important in facilitating the use of wind energy. It is recommended that authoritative, short (1,000-5,000 words) documents be prepared by, or under the sponsorship of, United Nations agencies, covering the areas of importance. Examples would be "Wind Machine Siting" (WMO); "Interfacing Requirements for Grid-Connected WECS" (IEA); "Wind Water Pumping for Livestock" (FAO); etc. Another class of useful documents would be case studies of successful wind installations. All documents should be reviewed by knowledgeable people on a professional basis, prepared by professional wind experts in the first instance (not by professional writers), and published in the major UN languages. Distribution and further translation could be left to individual countries.

This recommendation casts the UN and its agencies in the role of supporting expert, providing authoritative information, rather than in the role of exhorter, telling member nations to get themselves organized and establish information centers. The UN should be in a position to make sure that the information is accurate and authoritative. (To be equally sure that it's timely will be a challenge.) In most cases the UN/UN agency would contract with experienced

professionals who had the requisite experience to generate the documents rather than trying to accomplish the job in-house. Some organizations that could become involved are EPRI ("Interfacing Requirements for Grid-Connected WECS"); New Mexico State University, West Texas State University, or U.S. Department of Agriculture ("Wind Water Pumping for Livestock"); Battelle Northwest Laboratories ("Wind Machine Siting"); etc.

Some of the member countries may choose to get into the business of exhorting their citizens to invest in wind equipment, but the UN should not be in the position of telling them to do so. It is particularly inappropriate for a technical panel to recommend this, because it's not a technical matter.

New Recommendation M.2.

UN-Sponsored Conference on Wind Applications

It is recommended that the United Nations or one of its member agencies sponsor a conference on wind applications, to take place in 1983 or 1984 and at intervals thereafter if warranted. The purpose of this congress or conference would be the exchange of information and experience. Attendees would represent policy positions and working-level positions, but presentations would be limited to reports of experience. Papers on machine design, on national or regional policy, or for the presentation of wind data or computer methods would be excluded. There has been no such meeting for at least 20 years.

New Recommendation M.3

Wind Energy Fellowships

It is recommended that the United Nations, perhaps through one of its member

agencies, create a fund to support a limited number – say, 20 – of Wind Energy Fellowships. These fellowships would be of limited duration, perhaps six months. The UN funds would provide transportation and living expenses under the proviso that the individual's home government or home institution would continue his salary during his absence. Individuals interested in taking up such a fellowship would have to specify what program they proposed to pursue and where. They would also have to apply through their own governments and report to them upon completion of the fellowship.

New Recommendation M.4

Wind Survey Equipment Loans

Through the appropriate agencies (perhaps WMO, UNDP, and IEA), the United Nations could obtain a stock of standard, simple, run-of-wind anemometers and portable masts for wind survey work. Through a network of existing meteorological or physical laboratories or offices in the various countries, these could be made available on a loan basis for wind survey work. The instrument would be provided together with a siting handbook and a reporting form. The contribution of the national laboratory or coordination office would be to keep track of the instruments and to collect and organize the usable data in order to build up a better knowledge of the wind resource in the country. The contribution of the borrower would be to operate the instrument and collect the data. The contribution of the UN would be to provide the instruments and to maintain a central facility, either in-house or contracted, to check calibration and performance periodically (say, every five years) and to repair instruments when necessary. The recommendation is that discussions to consider this idea be initiated.

Mr Miller

Corrected Text

FINAL REPORT

of the

WIND ENERGY TECHNICAL PANEL

of the

United Nations Conference on

New and Renewable Sources of Energy

Geneva

3 October 1980

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FINAL REPORT OF THE TECHNICAL PANEL ON WIND ENERGY

I. INTRODUCTION

A. Purpose of the Report

1. The basic objective of this report is to review the current status and describe the potential of wind energy and especially its relevance to developing countries. To this end, the Wind Energy Technical Panel of the United Nations Conference on New and Renewable Sources of Energy (UNERG) held two sessions, respectively 12-16 November 1979 in Geneva and 29 September to 3 October 1980, also in Geneva.

2. The Panel was composed of nine members appointed by the Secretary-General of the United Nations from among candidates nominated by governments (see Annex I). Its mandate is defined in Annex II to document A/34/585 and derives from the basic General Assembly Resolution 33/148 of 20 December 1978. The Second Session of the Preparatory Committee for the Conference, 14-25 July 1980 in Geneva, in its Decision 5(II), "Reports of the Technical Panels", and related Resolution 2(II) "ad hoc groups of experts", gave further precision to the form of this report.

3. Documentation on which this report is based, including the Interim Report of the Technical Panel on Wind Energy on its first session, is listed in Annex II.

(1) 4. A bibliography of existing studies on Wind Energy, as requested by Decision 5(II), is listed as Annex III.

5. This report and those of the other seven Technical Panels together with the reports of the consultants on peat and on animal draught power will be used as source material for the six ad hoc expert groups, respectively on financing; information flows; research and development and transfer of technology; education and training; rural energy; and industrial issues. The reports of the Technical Panels and individual consultants will be used in the preparation of the synthesis document requested by Decision 5(II).

B. Basic Characteristics of Wind Energy and the Wind Resource

6. The energy in the wind is derived from the differential heating of the atmosphere by the sun and the irregularities of the surface of the earth. While only a small proportion of the solar energy reaching the earth is converted into the kinetic energy of the winds, the total quantity is extremely large. More importantly, nature concentrates this energy in certain regions, such that the avarage wind energy flux or energy density in many locations can be equal to or greater than the average solar energy flux. For example, a site with 5.5 metre per second (m/s) average wind has an average energy flux of about 200 watts per square metre (w/m^2) which is approximately equal to the average solar flux at a good sunny location.

(2) 7. The ~~power that can be achieved by a wind system~~ is proportional to the cube of the wind speed; doubling the wind speed results in eight times the power. Site average wind speed (in fact, the actual wind distribution characteristic) is therefore an important factor in the economics of wind systems.

3,2

8. The wind energy resource is quite variable in both time and location. The variability with time occurs during intervals of seconds (gusts), minutes (power variations), hours (diurnal cycles) and months (seasonal variations). This variability implies that wind energy is best utilized in three situations:

1 (a) interconnected with other power plants, ranging from a small diesel to a large utility grid. The output of the windmill is then used to save conventional fuels, however in utility applications some capacity credit is also achieved.

(b) utilized in connexion with some form of energy storage such as batteries or pumped hydro-electric systems. In this case, firm power can be supplied, but the additional costs and losses associated with the storage system must be accommodated.

(c) utilized in applications where the energy end use is relatively independent of time, has a time constant which can allow for the fluctuations in the wind, or where an end product can be stored. Examples of these types of applications include some types of irrigation, pumping and desalination of water, and heating, drying and cooling of agricultural products.

9. In addition, there are applications and localities where there is a potentially beneficial correlation or matching, on a statistical basis, of the availability of the wind and the need for the energy. In many localities, the winds tend to blow in the afternoons and evenings, which are also the most usual times of peak energy demands. Winter winds which may correlate with heating needs in cold climates or high spring and fall winds which may match low water reservoir levels are also examples of correlations which can increase the value of the energy from the wind. The ability to know in advance, to forecast, the wind at any moment in time is, however, limited and this uncertainty must be allowed for in calculating economics, reserve margins and storage.

10. Relatively large variations in average wind speed can occur over relatively small geographical distances due to the effects of terrain (mountains, valley funnelling effects, ground contours) and of uneven heating of the earth (coastlines, large lakes and forests). This variation over the terrain proves to be a major advantage, as well as posing a major challenge, for wind energy.

2 11. The advantage is that, by locating areas of good winds, sites with high energy densities can be utilized with a resultant significant increase in the energy captured and hence the economics. Sites with 200-300 w/m^2 square metre at 10m height are not uncommon and sites with 300-400 w/m^2 are not rare. Wind speed generally increases with height and thus hills, as well as towers, are desirable.

12. The challenge is to locate the better wind sites and to determine the practically achievable wind resource of a particular area. Single measurement stations are not adequate and many, if not most, of the existing wind measurement stations were not initially selected with wind power in mind (such as airport installations). Thus wind resource assessment and wind "prospecting" for good locations are necessary.

13. A wind map for the world, developed for this report, is presented in Annex IV. This provides a general idea of the windier regions of the world. Islands, coastlines, hills and areas near lakes represent higher potential winds. Large scale maps cannot truly present, however, the possibilities for wind energy or wind system siting (there can generally be better sites in low wind regions and poor sites in high wind regions). The wind resource assessment must be performed on a geographic scale commensurate with the application and region under consideration, and a number of such assessments have been started in various countries.

14. While the need for a good wind site is important for successful economics, it should not be over emphasized out of context with the particular application and competing alternatives. A high site wind speed (e.g. 5-6 m/s) might be required to compete with electric generation near a large conventional power plant, whereas a low wind speed (e.g. 3 m/s) could be adequate in a very remote area where the costs of transporting oil for a small diesel
1 are high or few alternatives are available.

15. In converting the energy in the wind to energy in a useful form several key characteristics should be stressed.

2 (a) Wind systems can be constructed in sizes ranging from a few watts up to 1 megawatts (MW) or more. For larger amounts of power, additional units can be added whether in "farms" or clusters or spread more randomly based on the terrain.

(b) Practical and effective wind systems can be constructed across a wide spectrum of materials and technological levels ranging from the individual craftsman or community level using local materials through the higher technology high speed systems manufactured in quantity. Across this spectrum however, advances in the understanding of the wind and the design of wind systems
3 have increased their capability and practicality. ~~and~~ the lack of ~~thermodynamic~~ losses means that relatively highly efficient systems, (up to 40 percent) can be obtained. In addition, energy is captured over the rotor swept area (the "collector") with
4 → blades occupying only 10-60 percent of the "collector" area. The materials requirement, compared to e.g. solar collectors where the entire collector area must be filled, is correspondingly less, and the potential cost effectiveness is correspondingly enhanced.

(c) The shaft power from the wind turbine can be utilized for a wide variety of purposes, including electricity (ac and dc generation), direct pumping, direct mechanical work (grinding, sawing, extracting food oils) and direct heating (viscous "churns") although the design of the wind turbine may be different for different
5 applications.

16. Wind energy has been one of the few forms of renewable energy which traditionally has been cost-effective and practical during ~~numerous~~ previous eras. The question is whether the combination of improved knowledge of
6 the wind and wind systems combined with the rising cost and economic penalties associated with fossil fuels, can again lead to the wide scale contribution of energy from the wind. Recent experiments and assessments lead to the probability that this can occur.

'14

C. History of Wind Energy Use

17. The oldest known use of wind energy was to propel sailing ships and dates back to Pharaonic times in Egypt. This form of transport reached its zenith in the nineteenth century and then declined abruptly with the coming of steam engines. The use of windmills dates from at least the sixth century in Persia, and their early use in China is also recorded.

18. By the thirteenth century four-bladed horizontal axis windmills, forerunners of the familiar "Dutch" windmill, were in use in many European countries. They were developed over the succeeding centuries and widely used for grinding grain, pumping water, and operating a variety of machinery. They were also widely used in the Caribbean for crushing sugar-cane. At their peak, in the nineteenth century, it is estimated that in the Netherlands alone there were about 10,000 such windmills, the largest giving power outputs up to about 50 KW. Their use then declined as steam engines became more economic.

1 19. In the later part of the nineteenth century the small multi-bladed windmill was developed for pumping water. Some 6 million of these were manufactured in the USA alone between 1850 and 1940, and between 1920 and 1940 substantial numbers of small wind driven electric generators were also manufactured. These windmills were later largely displaced by rural electrification programmes.

2 20. Today these multi-bladed water pumping windmills are still being manufactured in several countries, including especially Australia, South Africa and Argentina, and about a million are still in use.

21. A particularly inexpensive form of windmill, made from wood and sail-cloth, has been used traditionally around the Mediterranean. On the island of Crete many thousands of these sailmills were used for pumping water for irrigation earlier this century, and many are still in use. A similar sailmill has also been used in Thailand for many years.

3 22. The water pumping windmills described above have a high solidity, i.e. the area of blades or sails is a large fraction of the total swept area. This gives a high starting torque but a relatively low power co-efficient, which is a measure of the efficiency, ranging from about 20 to 30 percent.

23. In the first half of this century low solidity wind turbines were developed, operating at a tip speed ratio of four or more (i.e. with blade tip speeds more than four times the wind speed). Though these require 4 good aerofoil section blades they can achieve efficiencies of 40% or more, and are particularly suitable for low cost electric power generation, where high starting torques are not required. Significant development of 5 these machines ceased in the late 1950s, as their output could not compete with cheap oil. Increased oil prices having now made these machines economically more attrative, as is discussed later.

D. Present Status of Wind Energy Technologies

24. Since 1973 wind turbines have been the subject of intensive development, and the machines which are now emerging make use of the major technological developments that have taken place in recent years in the fields of structural

design, materials and control, and also take advantage of an improved understanding of wind loadings and rotor aerodynamic performance.

25. Wind energy systems are now seen to have major potential:

(1) (a) For water pumping in rural areas, even with average wind speeds as low as 3 to 3.5 m/s;

(b) To supply electric power to homes and isolated communities, in combination with diesel back-up and/or energy storage systems;

(c) Integrated into large electric power grids, so reducing the consumption of fuel in power stations. Such large-scale applications generally require fairly good average wind speeds, in excess of 6 m/s, to be economic, but wind speeds of this magnitude are found in many countries.

(2) The use of wind machines for other purposes, such as heating, cooling and water desalination is also feasible.

26. There are three principle dimensions to wind energy technology, namely:

- type of machine, e.g. horizontal axis, from sail and multi-bladed to fast running propeller types, and vertical axis from Savonius to fast running Darrieus and variations;

- purpose, e.g. water pumping, water desalination, heating, cooling, autonomous electric power generation, power generation with grid connection;

- size of machine, e.g. small (less than 10 KW), medium (10-100KW), medium-large (100-1000KW), large (more than 1 MW).

(3) 27. Sailmills, multi-bladed mills and Savonius rotors are mostly rated at less than 10KW. They have a high solidity and are not suitable for scaling up to larger sizes. They are mainly used for direct water pumping where there is a premium on considerations such as simple construction and a high starting torque. Low solidity wind turbines, horizontal axis and vertical axis, exist in all sizes and are used primarily for electric power generation.

II. WIND ENERGY TECHNOLOGIES LIKELY TO BE SIGNIFICANT IN THE NEXT 10-20 YEARS

A. Wind Energy for Water Pumping in Rural Areas

28. The Panel foresees the possibility of wind energy playing a significant role in pumping water for household needs, animal husbandry, irrigation and drainage in rural areas, especially in developing countries. Larger irrigation and drainage systems requiring wind electrical conversion will be considered separately.

A.1. High Solidity Water Pumpers

1. Technology of Water Pumping

(4) 29. A small windmill with direct mechanical drive to a water pump is a traditional technology and commercial machines are still in extensive use

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in many parts of the world including Argentina, Australia and South Africa. In most cases, the water is pumped whenever the wind blows and is stored in a tank for use as needed. Careful matching of the windmill to the pump characteristic is important if the wind energy is to be used to maximum efficiency and the windmill, pump and storage must be treated as a system.

30. The conventional multi-bladed windmill is the type that has been widely used for this purpose in the past as it has a good starting torque. It is not, however, widely used in developing countries, probably because:

(a) the conventional multi-bladed design is beyond the scope of local manufacture;

(b) costs are too high for subsistence farmers, and financing has not generally been available;

(c) maintenance and repair is a problem, despite the basic reliability of the machines, when local maintenance services have not been organized.

31. In the past few years some new all-metal multi-bladed windmill designs have been developed by, for example, ITDG in the U.K. and SWD and WOT in the Netherlands. Compared to the traditional multi-bladed windmills, they are considerably lighter in weight, more simple to construct and have a slightly higher overall efficiency. These windmills, after adapting the design to locally available materials, can be manufactured in simply equipped workshops and are cheaper than commercially available mills by a factor of 2 to 4. The resulting savings in foreign currency expenditure are appreciable. A number of these windmills are operating in pilot projects, for example, in Sri Lanka, Pakistan, India, Kenya, Tunisia, and Peru. Experience within these projects is showing that extensive field testing is essential and is resulting in a number of design modifications to ensure the reliability of the machines.

32. Besides the design of all-metal windmills, improved types of sail windmills have been developed in Ethiopia, Colombia, India and the Netherlands, to try to meet the demands of the subsistence farmer. These mills, which can be fabricated in village workshops, are very much cheaper than commercial mills, even allowing for replacement of sails every two years. Such mills have been built in a number of places, but these activities do not seem to have resulted in dissemination of these technologies, possibly because of lack of sufficient promotion and extension services.

2. Economics of Water Pumping

33. Multi-bladed and sail windmills of improved design can be built locally in developing countries for around \$50-\$150/m^2 of swept area (i.e. less than half the cost of traditional imported models). Experience with these windmills indicates, as a conservative estimate, that they deliver an average hydraulic power of $0.1\bar{v}^3$ W/m^2 (where $\bar{v}$ is the average windspeed). This corresponds to about \$20-60 per average watt (pumping power) in a marginal average windspeed of 3 m/s and \$8-24 per average watt for a 4 m/s windspeed. A steady pumping power of 100 W, which is a typical requirement, for example, for irrigating 1 ha from a water table at a depth of 10 m, would correspond to a capital outlay of \$2000-\$6000 for the 3 m/s case and \$800-\$2400 for 4 m/s. By comparison, the corresponding range for a small solar pump in conditions of good solar insolation is \$15000-\$45000.

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34. The value of the pumped water depends on the incremental value of the crops resulting from the incremental water. In many cases this incremental value is around $0.03/m^3. 100W corresponds to 1 litre/s from a depth of 10 m or 30,000m^3/y assuming year-round pumping. If we assume fixed charges, consisting of combined depreciation, interest and maintenance charges, amount to 20 percent of the capital cost annually, the cost of the water in the above example would be $0.013-0.04/m^3 for the 3 m/s regime and $0.005-0.016 per m^3 for 4 m/s. These values correspond to a cost of $0.45-1.35/kWh (hydraulic output) at 3 m/s and $0.17-0.50/kWh at 4 m/s.

35. In practice the cost would depend on the wind regime, pumping depth and seasonal irrigation practices, but irrigation costs by wind pumping appear to be economic even down to marginal wind speeds. Case studies in Indian conditions, taking account of the wind characteristic and seasonal water demands, confirm that even in marginal wind regimes wind pumping is cheaper than the use of diesel or even of bullock power. In most cases it is cheaper than grid-connected electric power if the real cost of rural power distribution is taken into account.

3. Overall Assessment of Water Pumping

36. The use of small direct-drive water pumping windmills has been highly successful in the past in rural areas in many parts of the world. It continues to be so to this day in certain areas where they were never displaced by low-cost rural electrification or diesel pumps. From the large number of such wind pumps still in use (around 1 million) it may be inferred that the potential is very large indeed, perhaps running into many millions of wind pump sets globally.

37. Until recently, conditions have been less favourable in developing countries because:

- subsistence farmers cannot afford the relatively expensive and usually imported multi-bladed windmills;
- there are no rural credit institutions and subsidies to assist farmers in buying windmills, while such facilities have been available for diesel and electric pumps;
- there are no rural extension services to help farmers install and maintain windmills;
- there has been a lack of awareness of the potentialities of wind energy, especially in developing countries.

38. There have now been developed multi-bladed and sailmill pump systems costing much less than conventional ones and capable of fabrication locally. These new designs appear to offer significant benefits for subsistence farmers in many areas of the world with low or moderate wind regimes. Rural extension services should promote programmes to introduce such machines. The feasibility of these programmes in any particular area must first be demonstrated by careful study of local conditions, followed up by demonstrations and extension services, ideally as part of an overall rural development programme, which should include concessionary financing. Traditionally, windmills have been very reliable and new designs of windmills should be introduced only after field testing to ensure that these are equally reliable.

1 39. The further diffusion of these new technologies will require institutional and financial support programmes. This would include services to:

2
- adapt the technologies to local conditions;
- prove their reliability;
- evaluate local wind regimes in relation to wind pump characteristics, water resources and cropping practices;
- demonstrate the equipment;
- train extension workers;
- organize maintenance and repair;
- provide financing on terms accessible to subsistence farmers.

A.2. Low Solidity Wind Electric Water Pumpers

40. For higher wind speed regimes (annual average windspeeds in excess of 4 or 5 m/s) low solidity wind turbines can be used with electric drive. This has a number of potential advantages:

- greater flexibility in siting the wind machine in relation to the well.
- use of high capacity submersible or shaft type turbine pumps instead of piston pumps.
- wind turbines are becoming available for pumping powers up to 100 KW or more and can be used in large irrigation projects.
- 3 → they can be used in conjunction with a rural electricity grid so as to permit continuous pumping, but with reduced electricity consumption.

4 41. Low solidity wind turbine electric pumps are already economically competitive with small diesel driven pumps in many parts of the developing world. Relative costs depend on several factors, including the mean wind speed, the wind turbine's cost and the local price of diesel fuel. Absolute costs, per cubic metre of water pumped, also depend on the water depth and the cost of water storage. However, the comparison which follows does indicate some representative costs for both systems.

42. Small diesel generators cost around $1500/KW ($4500 for a 3 KW engine), and operate at very low overall efficiencies of around 10 percent, leading to specific fuel consumptions of around 1 litre/kwh of hydraulic output. If they operate at full capacity for 8 hours per day (which is exceptional) and if the total annual fixed charge rate (including maintenance) is 30 percent (which is very conservative for small diesel engines) then the fixed cost per kwh of hydraulic output is $0.30. With a fuel price of $0.60 per litre this gives a total cost of $0.90 per kwh hydraulic output.

43. The economics of providing diesel pumping improves rapidly, however, with increasing size, so that in the 25-100 KW range, capital costs fall to around $500/KW, efficiencies increase to as much as 25 percent and maintenance costs are relatively lower. Costs are dominated by fuel costs and the relatively low utilization factors are likely to range from $0.25 - $0.50/kwh, corresponding to fuel costs in the range of $0.40 to $0.80 per litre.

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44. Low solidity wind electric pumps, by contrast, have capital costs of around $4000/KW (electrical) at 3 KW rated sizes reducing to about $1500/KW (electrical) in the 25-100KW range (corresponding to a rated wind speed of 11 m/s). In a moderately good wind regime (5 m/s annual average wind speed) a capacity factor of about 20 to 25 percent can be expected. Given a fixed charge rate of 20 percent, which includes the cost of maintenance, and electrical to hydraulic conversion efficiency of 50 percent, pumping energy costs will range from $0.70/kwh for small units to $0.25/kwh for the larger ones. They therefore offer a comparable or lower pumping cost than diesel pump sets over the whole range of interest, providing the wind regime is favourable. Wind speeds higher than 5 m/s would make the economics of wind electric water pumping even more favourable and it must also be recognized that over the next 10 to 20 years developments in wind turbine technology will lead to further reductions in their cost, whereas the cost of diesel pumping will increase as fuel costs escalate further.

B. Wind Generated Electric Power for Isolated Communities

45. The Panel expects to see wind energy playing a significant role in supplying electric power to isolated communities in good wind regimes, especially on islands and coastal areas and in mountain regions. This application involves meeting power demands of 10-1000 KW from one or a few small to medium sized wind machines with diesel back-up and possibly some form of energy storage (such as pumped hydroelectric), so as to assure supply during periods of little wind. In the longer term advanced energy storage systems may also be economic and eliminate the need for diesel back-up.

1. Technology of Autonomous Power Supply (10-1000 KW)

46. A number of low solidity wind turbines, horizontal axis and vertical axis, are now becoming available in this power range, at the same time as fuel is becoming more costly for the diesel generator sets now commonly used in this application. While the variability of wind, even in relatively favourable locations, requires that the diesel engine be retained as a back-up, wind turbines promise to be economic as fuel savers, and reduce dependence on imported fuel.

(1) 47. In the USA the horizontal axis, 200 KW rated, Mod0A wind turbine has been operating since 1977 in Clayton, New Mexico, supplying power to the local 3 MW capacity diesel engine grid system. Similar machines are now in operation in several other US locations. In Canada an experimental 230 KW Darrieus wind turbine has been operating in conjunction with the Magdalene Island grid system, and in China an experimental horizontal axis, 40 KW, wind turbine is under test in a similar island application. A 550 KW wind turbine system, using two 250 KW machines and five 10 KW machines, is planned for installation in Malta. This last scheme also includes 7 MWh of pumped storage capacity.

2. Economics of Autonomous Wind Power (10-1000 KW)

48. Wind turbines in the range 10-1000 KW are now becoming available commercially at capital costs of around $1000-$2000/KW, corresponding to about $400-$800/m^2 of swept area. These machines are in a size range suitable for supplying power to small islands, isolated communities,

irrigation schemes and so on, without forming part of a large grid.

49. These markets are currently served, most often, by diesel generators. Because of variations in demand (leading to inefficient operation of the diesel), costs of supplying diesel fuel, and maintenance problems, power generated is expensive, ranging in cost from $0.15-$0.50/kwh.

50. Although a wind turbine needs some form of back-up, such as a diesel engine or pumped storage, its energy costs are already competitive in many locations. A mean wind speed of about 6 m/s will give a load factor of 25-30 percent corresponding to the capital costs of $1000-$2000/KW quoted above. With a capital charge rate of 20 percent this gives an energy cost in the range of $0.10-$0.20/kwh. Improvements in wind turbine technology over the next 10-20 years are expected to increase the economic attractions of using wind energy to save expensive fossil fuel, and extend the range of viable applications to locations with lower mean wind speeds.

3. Overall Assessment of Autonomous Wind Power

51. Autonomous wind power systems in the range 10-1000 KW, with diesel back-up and possibly hydroelectric storage, is already an economic alternative to conventional diesel generation for isolated communities in good wind regimes. With existing 1980 technology, the wind turbine cannot replace the diesel but can be used to give significant fuel savings.

52. The development of advanced, low cost, energy storage systems could eliminate the need for a diesel generator, and such developments may be anticipated over the next 20 years.

C. Large Scale Electric Power Generation from the Wind

53. The Panel sees a major potential for large-scale wind generated electric power as part of a grid power supply, with power from conventional thermal power stations to provide the necessary reliability of supply during periods of low wind.

1. Technology of Large-Scale Wind Power

54. Low solidity, high tip speed ratio machines are used in essentially all applications over 10 KW. Currently both horizontal axis and vertical axis turbines are being built or are under consideration in diameters up to about 100 m and with ratings up to about 4 MW (see the attached Table I). It is likely that rather than design much larger machines, requirements for large blocks of power will be met by building arrays of turbines or wind farms. Preliminary studies indicate that in such arrays separation of about 10-rotor diameters is required to avoid excessive aerodynamic interference.

55. The large modern turbines listed in the table achieve efficiencies for extracting power from the wind of up to about 40 percent. As there is a theoretical limit of 59 percent (the Betz limit) for such conversion (at least for conventional horizontal axis and vertical axis wind turbines) there is only limited scope for further improvements in conversion efficiency. For this reason most current effort is devoted to improving the overall cost effectiveness. (see paragraph 62).

56. The load factor is the ratio of the average power generated over the year to the rated power. It can be shown that the optimum rated wind speed should be in the range from about 1.5 to 2 times the average annual wind speed at the site, and in these cases the load factor is in the range from 40 to 30 percent respectively.

57. Preliminary analyses by utilities in the USA, Britain and Denmark indicate that existing large-scale grid systems could accpet 10 to 30 percent of their energy from wind systems, though the value of the fuel saved diminishes as the penetration increases.

58. The combination of wind power and hydroelectric systems is considered of particularly high potential. In many locations the hydroelectric system is limited by the amount of rainfall and water. The combination allows the windpower to save water, which is then utilized during low wind periods. In some cases additional generating capacity, usually relatively inexpensive, must be added to the hydro-electric system. Studies in Denmark and the USA have shown that this technique can provide both base and peaking power. Studies in the Netherlands are under way to investigate a combination of enclosed artificial lakes (polders) and wind power in a similar manner. The Bonneville Power Administration of the US Department of Energy will commence testing three 2.5 MW, Mod-2 wind turbines interconnected with their hydroelectric system in 1981. A similar test project is being undertaken by the US Department of the Interior which will commence testing one, and possibly two, 2-MW wind turbines in the Upper Missouri Valley hydroelectric system in early 1982.

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Table I. MEDIUM-LARGE AND LARGE WIND TURBINES

Turbine	Location	Diameter	Rated Power	Rated Wind Speed (m/s)	Status/Remarks[c] (as of October 1980)
Mod 0	Ohio, U.S.	38m	100kW	6.5[b]	Research Tests
Mod OA-1	New Mexico, U.S.	38m	200kW	7.7[b]	Utility Test- 8000 hrs
-2	Puerto Rico, U.S.	38m	200kW	7.7[b]	Utility Test
-3	Rhode Island, U.S.	38m	200kW	7.7[b]	Utility Test
-4	Hawaii, U.S.	38m	200kW	7.7[b]	Utility Test - 1500 hrs.
Mod 1	North Carolina, U.S.	61m	2.0MW	11.5[b]	Utility Test
Mod 2	Washington, U.S.	91.5m	2.5MW	8.9[b]	Tests start 11/80 2 additional units 6/81
Mod 5-A/B	-	~100m	~4MW	~10[b]	Starting design 2 types
Mod 6-H/V	-	~40-60m	~0.4-0.8MW	~10[b]	Starting design 2 types[d]
Alcoa	Penn., U.S.	38m	300kW	-	On test - Vertical Axis
NRC/Hydro-Quebec	Magdalene Is., Canada	36m	230kW	13.5[a]	Utility Test - Vertical Axis
Nibe A	Nibe, Denmark	40m	630kW	13[a]	In Operation
Nibe B	Nibe, Denmark	40m	630kW	13[a]	On Test
Tvind	Tvind, Danmark	54m	2MW	~12[a]	In Operation
KMW	Goteland, Sweden	75m	2.5MW	13[a]	In Fabrication
Karlskronavarvet	Maglarp, Sweden	78m	3MW	13[a]	In Fabrication
McAlpine/Musgrove	- U.K.	25m	130kW	11[a]	In Design - Vertical Axis
Taylor-Woodrow	- U.K.	60m	3.7MW	22[a]	Design Completed
Growian I	Kaiser Wilhelm kog, FRG	100m	3.0MW	11.8[a]	In Fabrication
Growian II	- FRG	145m	5.0MW	11.3[a]	In Study
Voith	- FRG	52m	265kW	8.7[b]	In Fabrication
Growian II preprototype	- FRG	48m	~265kW	-	In Fabrication
25m HAT	Petten, Netherlands	25m	300kW	13[a]	Tests starting 1/81

a denotes at hub height, b denotes at 10 m, c horizontal axis unless otherwise stated, d one vertical axis.

59. Offshore winds are usually stronger than winds on land, and acceptable onshore sites are limited in many otherwise suitable regions. A number of countries have therefore undertaken studies on the technical and economic feasibility of siting large arrays of wind turbines on offshore platforms. The technology would in many ways parallel that of offshore oil and gas drilling platforms and, at least for shallow water, serious technical difficulties are not anticipated.

2. Economics of Large-scale Wind Power

60. Estimates of all inclusive electric power costs from the few existing prototype large wind turbines vary widely in the range $0.15 to $0.50/kWh (based on a fixed charge rate of 18%). However, the cost of electricity from second generation machines such as the US Mod-2, which was completed in late 1980 and has a diameter of 91m and a rated output of 2.5 MW, is significantly lower, as indicated in the table below. (For purposes of comparison the table also indicates costs for smaller machines).

61. Table II. Wind Energy Cost Estimates and Goals

	Replicate Present Prototypes	Present Types if Mass Produced	Advance Designs if Mass Produced
Large Systems	$0.08 - 0.10/kWh	$0.05 - 0.06/kWh	$0.035 - 0.045/kWh
Medium Large	$0.10 - 0.25/kWh	$0.08 - 0.20/kWh	$0.05 -- 0.10/kWh
Medium and Small	$0.15 - 0.50/kWh	$0.10 - 0.20/kWh	$0.05 - 0.10/kWh

Assumptions: Site mean wind speed 6.3 m/s; 18% fixed charge rate; 20 year amortisation period. Quoted costs do not include the reduction possible with tax credits. Mass production implies the manufacture of 100 machines or more. Costs quoted are in 1980 dollars.

62. For all the use of wind power in past eras, the technology of wind systems, especially large systems, has been changing rapidly in the last few years, and is expected to continue so for the next few years. This is primarily due to the major advances over the last 30 years in materials, controls and electronics, helicopters and aviation, and computers and analytical tools, which have not before been applied to the field of wind energy. Specific areas of present and expected advances include:

- understanding of wind loading and blade stresses
- blade materials such as fiberglass and wood epoxy techniques
- microprocessor controls for operational optimization
- capability for vibration/fatigue analysis with the resulting "soft" (low stiffness) systems and significant reductions in machine weight and cost
- advanced rotor configurations such as the teetered hub, delta-3 hinge, tip control and free yaw concepts
- simpler and less costly electrical power and interface equipment
- advanced system configurations such as the Darrieus, variable geometry and variable pitch vertical axis systems.
- development of speed, frequency and voltage regulation systems for small machines.

Many of these advances also apply to small and medium systems. Advances in the understanding of aerodynamic loads, vibration and aerodynamic performance can also assist the design and performance of small systems intended for local or community fabrication. Research is underway in a number of countries on highly innovative concepts such as "tip vanes", vortex generators and diffusors. Conceivable radical advances or "breakthroughs" from such concepts, being unpredictable, have not been incorporated in the estimates presented above.

63. It may be noted from Table 2 that the cost of present large machines, when in quantity production, should be competitive in many locations. By comparison, the fuel cost alone, for electricity from large oil-fired power stations, is about $0.06/kWh with oil at $35/barrel.

64. Since large wind turbines will be installed as part of a grid they will not only act as fuel savers but will also reduce the requirement for installed capacity in the system, i.e. they will have some capacity credit. One recent Canadian study for Prince Edward Island showed that it would be cost effective to add some 10 MW of wind power to the existing 100 MW system and that some capacity credit was justified, in this case about 25% of the 10 MW wind power rating. U.S., British and

studies confirm this order of capacity credit, at least for low wind penetrations. However, the value of this capacity credit is not decisive to the economics of large scale wind power.

65. Studies of offshore wind power generation have been undertaken in the Netherlands, U.K., Sweden, the U.S.A. and by Eurocean. The U.S. study considered floating platforms 200 km offshore in 150 m of water, whereas the other studies assumed shallow water (10-30 m depth) fixed platforms typically only 20 km offshore.

66. The study done for the Central Electricity Generating Board of the U.K. is especially encouraging. Including costing of construction shipyards for the platforms and regular maintenance, including scheduled blade replacement every ~~five~~ ten years, this study foresees costs of $0.08/kWh for electricity delivered to the shore from arrays of 100 m wind turbines. Offshore wind energy systems are seen as an attractive longer term (1990-2000) option for harnessing wind energy, that may be of particular interest in regions of high population density and limited land availability.

3. Environmental Aspects of Large Scale Wind Power

67. Wind energy systems generally appear to be environmentally benign. However, as in any large scale power system, all possible effects must be considered. The primary potential effects and their anticipated magnitudes are as follows:

(a) Weather or microclimate effects: The slowing down of the wind by the wind turbine has been estimated as having about the same effect on the local climate as a group of trees and only minutely small changes are expected.

(b) Effect on wildlife: Bird strikes have been considered possible. However both analyses and the experience of several machine-years of operation have shown the extremely low likelihood of such impacts. The low solidity (2-3 slender blades) and their visibly "slow" rotation alert birds to the turbine's presence, and wind turbines represent a much smaller hazard than TV or radio towers. Cattle and deer routinely graze and several water birds nest adjacent to existing machines.

(c) Noise: Aerodynamically well-designed machines produce little noise and are generally inaudible over background levels beyond 100-200 metres from the machine. Any particular design, large or small, can, however, produce significant noise if aero-accoustic problems arise. One widely reported case was the US 2 MW Mod-1 which encountered a very low frequency blade-tower wake inter-action which, combined with the focussing effect of the mountainous terrain, led to unacceptable noise levels in a dozen homes in certain valley "pockets". Changes in rpm (tip speed), tower details and blade design appear capable of ameliorating the problem on this machine; it also appears to be unlikely in upwind designs (the Mod-1 has the rotor behind the tower, as do the four relatively silent Mod-OAs.)

(d) Radio and TV interference: The blades of a wind turbine can reflect electromagnetic waves, the effect being proportional to blade area and other parameters. Interference with radio and navigational signals is unlikely except within metres of the machine. The video (picture) portion of television can be affected by the larger machines at distances out to a few hundred metres or, in the worst cases, to a kilometre or two. This principally occurs when the wind turbine is at a high elevation and the TV receivers are normally receiving weak signals due to distance or to terrain shielding from the TV station. The relative positions of the station, receiver and wind turbine also have an effect. Low solidity (slender) blades, fiberglass or wood (instead of metal) blades, good receiving antennas and care in siting all reduce the potential for interference.

(e) Energy Use: One of the advantageous aspects of wind turbines is that the energy equivalent of that required for producing the materials and constructing the wind turbine can be returned (i.e. produced) by the wind turbine in only 6 to 9 months' operation, This short energy "payback" time is an important point in a time of energy shortage and demand growth.

(f) Safety: As in any large, rotating structure, safety must be a major consideration. Tower-overturning in a major storm is not considered a serious or particularly dangerous problem. Throwing a blade, or fragment, is a potentially hazardous occurence. The high solidity, multibladed water pumpers present few problems since their slow tip speeds and external bracing preclude a major blade throw. The low solidity, high rpm and high tip speed (up to 100 M/S) modern electric generation wind turbine can present a potential blade hazard which must be allowed for in both the design and siting of these machines. Careful load assessment, stress analysis and quality control during the design phase, combined with vibration and crack detection and automatic shutdown sensors during operation are believed to be capable of reducing the probability of an actual blade throw in a production wind turbine to an extremely low level. However, additional care and inspections are required in the first experiments. Regardless, it is generally considered wise to place a safety or restricted zone around the wind turbine of 200 metres. While not yet accurately known (nor are there yet international or national standards) a distance of 200 metres or perhaps slightly more appears to be the farthest range that a blade, fragment or accumulated ice is likely to be thrown. The probabilities are considered sufficiently low that this area could be used for agricultural, grazing, roads and equivalent purposes, but until more experience is built up, caution dictates that residences or dense population activities should not be within such a range. It should be noted that the possible range of a thrown blade is, to a first order, independent of the size of the wind turbine.

(g) Land use: The actual land used by a large MW scale wind turbine is relatively small, about 2000 m^2, not including transmission lines or rights-of-way. About 12 hectares would be utilized by a safety zone, but this would not remove that land from agricultural use. For groups of machines, aerodynamic losses dictate a separation of about 7-10 diameters; i.e. a kilometer apart for 100 meter machines. The land in between would remain essentially unaffected except for any necessary access roads and transmission lines.

(h) Aesthetics and Public Acceptance: The reaction of the general public to the visual aspects and mere presence of wind turbines is a highly unknown and probably highly variable situation. Research has been done in both Europe and the USA, but with inconclusive results. Reaction to the first experimental machines, has been highly positive. Townspeople feel that they are pioneering or contributing to helping resolve their dependence on imported energy. This initial situation,while favourable, cannot be extrapolated to the future or to the large numbers of machines necessary for supplying large blocks of power. However, it should be noted that, because of the spacing requirements, only a few machines would normally be obtrusive from any given point. Nevertheless, the nature of the terrain, the attitudes of the local people and the manner in which they are involved in the decision process, as well as the cost and environmental consequences of other energy sources, will all affect public reaction. All that can be stated at this time is that in rural and agricultural areas, given reasonable care in the siting process, there is probably not a serious problem. However, in highly scenic or historic areas or in semi-urban/urban areas, one can anticipate possible problems and limitations on the use or number of wind turbines. In general, this will be a locally specific issue, quite variable in extent from country to country and locale to locale.

4. Overall Assessment of Large Scale Wind Power

68. Major progress in the wind power programmes of a number of developed countries now seems to assure the economic viability of large-scale wind power projects over the next few years. Wind power should be capable of making a significant contribution to the electric supply grids of a number of countries before the end of the century.

69. Developing countries with favourable wind regimes stand to benefit from this development. Island countries and countries with coastal population centres should in many cases be able to make significant wind power contributions to their electric power grids by the end of the century.

70. Much of the technology of fabrication of large wind systems should be within the capabilities of the more industrialized developing countries themselves, given appropriate assistance in establishing the industry and acquiring the necessary know-how.

71. Research and development is currently taking place primarily in a few developed

countries. Developing countries should endeavour to enter this field gradually through the establishment of demonstration and training centres. These could develop basic skills and then, as the technology begins to be applied, they could progressively formulate suitable research programmes geared to their domestic needs.

72. To participate in these developments (the remarks of this paragraph apply to both small and large wind machines) countries will need to augment their capabilities in the following areas:

- awareness on the part of energy planners and policymakers;
- assessment of wind resources and of favourable regions for wind power;
- wind data collection and interpretation and site prospecting;
- wind power system analysis and design;
- wind power system economics;
- wind power system management;
- wind power system operation and maintenance;

73. Since financing would normally be made through electricity supply authorities, early projects are likely to suffer from the conservative approach of such authorities to new technologies, especially so since most of the lifetime system cost must be expended at the outset. International lending agencies should therefore be urged to support financially early demonstration projects.

D. Small Wind Power Systems (below 10 kW)

74. Wind turbines driving brushless DC generators for charging batteries have been used since the beginning of the century for supplying electric power to isolated farms, weather stations, navigation aids and similar applications in remote areas. The cost of battery storage restricts the use of such machines to rated power outputs up to about 3 kW. This corresponds to the power range within which simple and efficient permanent magnet generators can be used, which offers the prospect of substantial future cost reductions. However, at present a 2 kW horizontal axis wind turbine would cost in the range of $10,000 to $20,000, tower and battery storage for four days included. Future applications which can be expected are for homes and clinics in rural areas. The cost of power from such systems ranges from about $0.5 to $1.0/kWh.

75. Somewhat larger autonomous systems can be provided by using a wind generator with a small diesel engine for back-up, and some battery storage (which not only provides some storage for surplus wind energy, but also ensures that the diesel engine never operates inefficiently at low part-loadings). A recent U.K. study for such systems arrived at the conclusion that, with diesel fuel at $0.6/litre and with battery storage amounting to 10 hours of mean load, power costs would be around $0.30/kWh. This is

about the same as the cost of conventional small-scale diesel generation, but with reduced diesel fuel consumption. Subsequent studies have shown that power costs can be further reduced, but they emphasise the need for careful system optimisation.

76. Electricity generation by wind turbines at the 10 kW rating is already being effected by private owners, especially in Denmark and the U.S.A. The wind generator, equipped with an inexpensive asynchronous alternator is connected to the utility grid, which is then used as frequency control, storage and back-up. These systems have already been shown to be cost-effective, depending somewhat on the difference between the utility's "buy" and "sell" rates for electricity. Typical prices range from $400 to $1000 per m^2 swept area of the wind rotor (e.g. $30,000 for a 10-m diameter machine with 10 kW rating). It is expected that this application will expand considerably as technical improvements and increased production rates lead to substantial cost reductions.

77. There is a need to supplement existing diesel power supplies, with ratings up to about 50 kW, using wind turbines with individual ratings up to about 10 kW. Experience with such systems is not yet available and the development of hardware for control for these applications should be promoted.

78. Wind electric turbines in the range up to 10 kW are also used for water pumping (see paragraph 44) desalination (paragraph 80) and heating and cooling (paragraph 79).

E. Wind Energy for Heating and Cooling

79. Where heat is required it is possible to convert wind energy with high efficiency to thermal energy through the wind turbine by means of a mechanical, hydraulic or electrical converter. There is scope to make the wind turbine simpler and less costly by direct mechanical coupling. Principal applications are in rural residential heating, hot water production, and in heating or drying agricultural products. In colder climates the potential correlation between wind availability and heating needs leads to the possibility of good economics in this application. Wind systems can also be used for cooling, either through the intermediary of electricity, or by direct coupling to a heat pump or compressor. Applications include preservation of medicines and foodstuffs in remote areas, as well as fish drying.

F. Desalination of Brackish and Sea Water

80. A study in Indian conditions (coastal areas of Gujurat State) indicated that brackish water can be desalinated by reverse osmosis, using wind power for the high pressure pumps. Calculations using a 5 m/s average wind speed and presuming an annual 20 percent fixed charge rate show the water costs to be about $2/$m^3$. These costs are about half those for solar distillation in the same arid area. Desalination of brackish water by electrodialysis, using wind-generated energy, is presently being done

in the USSR. Since most coastlines tend to have a high wind potential, there is also a potential use for windpower for desalination of sea water, either through reverse osmosis or electro-dialysis.

G. Wind Energy for Sea Transport

81. There is now considerable interest in reviving the use of wind energy in sea transport making use of modern materials and automated technology. The wind energy would be used in a fuel saver mode in conjunction with more conventional propulsion machinery. A particularly important application in developing countries is the renewed interest in sail for coastal fishing boats. In Japan a sail assisted tanker, Shinaitoku Maru, is about to enter experimental service. It is a 1600 deadweight ton ship of 66m length, equipped with two rectangular sails of steel frame and polyester canvas, each 12m high and 8m wide, mounted on the centre line and forward of the bridge. The sails are each made in three vertical sections and can be unfurled, given optimum orientation to the wind, and furled automatically under computer control. There has been a recent UK study for a packet boat powered by vertical axis wind turbines (with auxiliary diesel) for supplying remote islands. All of these developments deserve serious attention for the future.

III. CONSTRAINTS LIMITING THE DEVELOPMENT AND UTILIZATION OF WIND ENERGY AND POSSIBLE MEASURES TO OVERCOME THEM.

Constraints	Measures
A. Infrastructure and Institutional	
82. 1. Wind resource estimates may not be reliable.	Preliminary evaluation of wind resources can be based on existing meteorological data, the reliability and quality of which should be improved.
2. Lack of an institutional framework for developing policies, strategies and programmes in wind energy.	Creation of focal point for wind energy policy and planning units in relevant government department.
3. Past activities in wind energy have been spasmodic and limited in scope.	Specific programmes and goals should be established for wind energy.
4. Lack of rural infrastructure for promoting the development of wind pumping, and of autonomous wind electric power.	Establish rural development programmes and include water pumping by wind and autonomous wind electric power where relevant.
5. Lack of manufacturing, distribution and maintenance services.	Organize manufacturing, distribution and maintenance services.
6. Concern by power authorities over operational problems of integrating wind power into existing grids.	Preliminary operational experience in several developed countries suggests there are no serious operational problems. However this must be demonstrated to the power authorities in many more instances, due the diversity of situations in different countries.
B. Research and Development and Transfer of Technology	
83. 1. Even after a decision has been made to proceed with a wind energy programme in a country, the successful transfer of technology into the country and its subsequent diffusion is dependent on a number of factors which will be similar for small-scale rural technologies and larger-scale power technologies, although each may require a different institutional setting. These factors include: (a) Access to technical information concerning technologies available on the market; (b) Access to equipment designs and manufacturing know-how; (c) Access to experienced technical advice during the initial stages of the programme; (d) Research and development facilities to adapt foreign equipment to local conditions and to local manufacturing	(a) Most of these constraints may be overcome by the creation of an appropriate wind energy centre in the country with services corresponding to the relevant items (a) to (i). Such centres might cover both rural wind pumping and wind electrical power, although in many cases there may be good institutional reasons for separating these functions. (b) In certain instances there may be a case for an internationally-supported centre organized on a sub-regional basis.

Constraints	Measures
(e) Test facilities to test imported and local equipment under realistic conditions; (f) Performance standards for wind equipment and corresponding engineering services to assist local manufacturers in meeting these standards; (g) Demonstration facilities to demonstrate suitable imported or domestic equipment; (h) Consultant and advisory services to carry out wind surveys and to evaluate wind energy prospects, e.g. in relation to local water resources and cropping practices for rural wind pumping, or to carry out system design and feasibility studies for wind electric power; (i) Training services for local wind energy specialists.	
2. In many instances, university research may lack direction and priority, small industry may lack technological capability, and both may lack sufficient understanding of local practical problems of the user.	As wind energy programmes or centres are developed, they should be implemented in a manner to cause close ties and communications between these three groups.

C. Education and Training

34. 1. Lack of advisory and consulting services for decision-makers.	International agencies, particularly those of the United Nations system, should provide advisory and consulting services.
2. Lack of rural extension workers with relevant knowledge and skills in wind pumping.	National training course in rural uses of wind energy for rural extension workers.
3. Lack of wind energy specialists in: (a) Data collection and interpretation and site prospecting; (b) Systems design, engineering and management; (c) Systems analysis and economic feasibility; (d) Systems operations and maintenance.	(a) Establish national or regional training centres. (b) Introduce these subjects into universities and technical training schools. (c) Provide practical training through fellowships.
4. Shortage of specialists qualified to train others.	Fellowships should be provided to, and training courses should be developed in, suitable advanced centres of wind energy technology, in order to train the trainers.
5. Absence of wind energy courses in universities and technical schools.	To develop curricula and supporting text books and lecture notes for universities and technical schools.

Constraints	Measures
D. Information Flows	
5. 1. Insufficient detailed wind resource data.	(a) Meteorological services should be encouraged to augment their wind measurement activities and to take account of the special needs of wind energy. (b) Carry out wind resource surveys, prepare wind energy maps, and prospect for suitable sites.
2. Absence of information on wind energy.	There is a proliferation of information services in the world, but access of users, especially users in developing countries, to these services is not always adequate. Actions to strengthen user access to the existing services, e.g. by the compilation and updating of directories and through the production of a wind energy newsletter for developing countries are required. In particular, information should be made available on: a) Availability and capability of analytic tools, handbooks and computer software b) Catalogues and equipment information; c) Equipment performance standards, test methods and testing services. d) Consulting and design services e) Training services f) Manufacturing processes including blueprints, licenses, patents and know-how.
E. Financial	
86. Lack of funds for financing institutions, technical services, and training in developing countries.	International technical assistance in wind energy.
2. Lack of funding of rural wind pumping and autonomous power where relevant under credit terms accessible to subsistence farmers.	National and international funding of rural development programmes to include concessional credit facilities for wind energy for subsistence farmers and isolated communities.
3. Even when wind energy systems are expected to be cost-effective, they may have difficulty in attracting financing due to high initial costs (compared to fossil fuel systems) and to lack of familiarity on the part of financing institutions.	Government measures to assure sensitivity of local financing institutions to the needs of wind energy users.
4. Lack of financing of medium and large scale wind electric power.	International lending institutions to be urged to include financing of medium and large-scale wind power projects on their merits when financing electric power projects.
5. It should be recognized that in many countries various forms of energy are artificially priced and this penalizes wind energy even when it is cost-effective.	Governments should ensure that wind energy projects and equipment receive equitable treatment, in terms of subsidies, with other forms of energy.

IV RECOMMENDATIONS

1. Preliminary Wind Resource Assessment

87. A preliminary wind resource inventory should be undertaken as soon as possible in all countries having some wind energy prospects. This could normally be based on meteorological data which should be improved as necessary and could be carried out by national staff assisted by the wind energy technical note now under preparation by WMO. If necessary further international assistance could, in specific cases, be sought.

2. National Wind Energy Focal Points

88. Countries having some prospects for wind energy should designate a national focal point for wind energy policy making, planning and implementation, within an appropriate department of government (planning, finance, energy or rural development), or an agency nominated by the government.

3. Wind Pumping for Rural Development

89. Socio-economic systems studies indicate that small wind powered water pumping systems are quite appropriate to irrigation in small farms, even in comparison with other renewable energy sources. The panel strongly recommends inclusion of wind powered pumps in rural development programmes wherever local conditions are favourable. An important positive aspect of small windmills is the likelihoof of creation of additional employment in rural areas.

4. Wind Energy Centres

90. Because of the importance of creating national (and in certain cases sub-regional) centres for wind energy technology, it is strongly recommended that international assistance, through the United Nations system and other agencies active in the field, be given to countries wishing to establish such centres. They should be tailored to suit the needs of the individual countries taking account of those areas discussed in detail in para.83 (Constraints in Research and Development and Technology Transfer).

5. Training of Trainers

91. Because of the shortage of wind energy specialists all over the world, it is recommended that training courses be established on a permanent basis at one or more suitable advanced wind energy centres or other appropriate institutions.

6. Wind Energy Information Programmes

92. In view of the present initial use of wind power and the anticipated potential for rapidly expanded use, national focal points, wind energy centres and appropriate international organizations should develop active information programmes to provide prompt, accurate and useful information and related materials on developments, techniques and experiences to potential users, decision-makers and other interested parties.

55

7. Financing

93. The panel noted that wind energy conversion systems are capital intensive (compared to conventional ones) even though they are cost-effective over a period of time. It is essential to devise suitable financial packages including low interest loans and subsidies to accelerate the pace of utilization of this energy resource.

8. Time Scales

94. The panel takes note of the feasibility of using small windmills in large numbers in the rural areas of many developing countries and recommends that it is now time to make definite commitments backed up by adequate infrastructural facilities and financial support. Small and medium-size wind powered electriegeneration systems are expected to be economically viable on a significant scale within the next five years. In fact, many isolated communities can take advantage of this technology in the immediate future. The Panel also believes that supplying electric power from land-based wind turbines into power networks could become commercially viable in 5-10 years' time and from offshore systems by the turn of the century.

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UNITED NATIONS CONFERENCE ON NEW AND RENEWABLE SOURCES OF ENERGY

ANNEX I

Technical Panel on Wind Energy
Second Session
29 September - 3 October 1980,
Geneva

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ANNEX II

LIST OF DOCUMENTATION

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   General Assembly Resolution on United Nations Conference on New and Renewable Sources of Energy.

2. A/34/585 29 October 1979

   United Nations Conference on New and Renewable Sources of Energy. Report of the Secretary-General.

3. A/CONF.100/PC/12 9 May 1980

   Interim Reports of the Technical Panels. Report of the Technical Panel on Wind Energy on its First Session.

4. A/35/43 (Part II) 10 September 1980

   Report of the Preparatory Committee for the United Nations Conference on New and Renewable Sources of Energy. Second Session.

5. Issue Paper on Wind Energy (UNERG/WP/1/2)

   Prepared by Bent Sorensen

6. Report for the Technical Panel on Wind Energy (UNERG/WP/1/Z/Inf.1 and Corrigenda)

   Prepared by Ulrich Hütter.

ANNEX III

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WINDMILLS AND SOLAR WATER HEATERS FOR EASTER ISLAND

January 1981

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SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Windgenerators to supply electric power to the grid and save fuel appear to be practical on Easter Island. A program of additional wind measurements and procurement of wind generation equipment is recommended.

Measures to reduce electrical system losses are also recommended, independently of the windgenerator recommendation.

Solar water heaters are certainly practical on Easter Island.

Windmills for pumping water should be considered as one of a number of possible ways to provide greater security of water supply.

BACKGROUND

History of the Project. This project originated with community leaders on Easter Island who brought their concerns about energy cost and security to the central government in Santiago. In 1980 the Comision Nacional de Energia together with Professor Pedro Roth of the University of Santa Maria, Valpariso, began a program to study the situation. The planned program involved measuring the wind and possibly installing wind generators on the island. There was also interest in solar water heaters, though, to my knowledge, not much had actually been done in connection with solar water heaters. When I met with Bruno Philippi and Patricio Solminihac of the Comision Nacional de Energia in early December 1980 in Santiago, concerning other matters, Bruno Philippi stated that the Comision had an interest in wind energy for Easter Island. He proposed that I extend my stay in Chile and visit Easter Island to observe the situation there. I agreed, and visited Easter Island on 23-25 December with Patricio Solminihac and Pedro Roth. This report contains my observations and analysis of the situation.

Electric Power on Easter Island. Electric power is presently supplied 24 hours/day, every day of the year. Unscheduled service interruptions are not common; the service is very reliable. We were told that 24 hour electric service is found nowhere else in the South Pacific east of Fiji, excepting the city of Papaeete.

The electric power system is in the hands of CORFO (Corporacion de Fomento de la Produccion, Chile) whose local director, Gerardo Valasco, was extremely cooperative and helpful in sharing information with us. The power system has 11 full time employees, 6 in the power station and 5 on the lines. One of the 5 is the line chief and one of the 6 is a meter reader. Mr. Velasco and his office staff share their time between the power system and other CORFO activities.

Generation plant presently in use consists of four diesel electric units inherited from the U.S. Air Force (which had a base on the island in the 1960's). Each of the four units is rated 415 KVA at 400 volts,

50 hertz (note: to convert KVA to KW, multiply by 0.8 -- thus 415 KVA becomes 332 KW). Before modification for compatibility with Chilean practice the units were rated 625 KVA, 480 volts, 60 hertz. The modification consisted only of reducing rpm to 600 from 720. All four of the units are operational, though no more than two are ever needed at any one time, and often one is sufficient to carry the island load. There are three other diesel electric generators which predate the U.S. Air Force. These are rated at 250 KVA each and are presently not working. However, it is expected that they soon will be working and connected into the system. The power station operator will then have more flexibility in matching generation to load than presently.

Transmission voltage is 6600 volts, distribution is at 400 volts. There are approximately 22 km of 6600 volt lines and 30 km of 400 volt lines. Peak load is about 450 KW and minimum load is about 195 KW. There are 525 customers. Every house on the island is electrified. In 1979 the number of KWH produced was 2,157,000, in 1980 it was about the same. About 690,000 liters of fuel oil are required each year to make this electricity. Analysis of a twenty month record of fuel oil purchases and KWH production at the generating station resulted in a figure of 0.318 liters of fuel oil consumed per KWH produced. This number is reasonable when compared with experience elsewhere. It appears that production of electricity is accomplished with good efficiency.

Two aspects of the electric power situation are of concern to Easter Island residents. One is vulnerability to interruption of oil supply. The other is cost of electric power.

Considering first the question of vulnerability of supply, the concern of the residents is completely understandable. There is no hydro or other non-diesel source of power to feed the central power system if oil supply is interrupted. (Some of the power system's customers have small emergency generators, but these also burn diesel oil or gasoline.) Oil supply interruption has never occurred, but it certainly could. A shipping strike, an accident destroying the supply ship or the oil stores on shore, or even a war with hostile submarines

in the thousands of kilometers of ocean between Easter Island and Valpariso are all credible possibilities. If they are credible possibilities, some people argue, they will sooner or later happen. Interruption of electric supply would result in immediate interruption of water supply also, since the water is pumped from wells and there is no reservoir storage. Of the possible non-diesel sources of electricity wind is the only realistic possibility for the near term.

The other aspect of concern is the very high and rapidly increasing cost of electric power to Easter Island consumers. The residential tariff in effect for September-October 1980 was as follows:

KWH Used Per Month	Pesos Per KWH	U.S. ¢* Per KWH
0 - 100	16.00	41.0
101 - 200	23.00	59.0
201 -	29.00	74.4

*Based on 39 peso = 100 U.S. ¢.

Thus a consumption of 200 KWH/month, which costs about U.S. $10 in San Francisco and about twice that in Santiago costs 3900 pesos or U.S. $100 on Easter Island. (Average electric power consumption per household in the United States is considerably more than 200 KWH/month. In Hawaii, where climate is similar to Easter Island, it is 1000 KWH/month for the average single family home customer.)

Easter Island residential electric rates are the highest I have ever seen anywhere. The cause of these high rates is not known to me in full detail, but three important contributing factors are clear.

One is the cost of oil. In July-September 1980 CORFO paid 23.50 peso/liter for diesel fuel. This is 3731 peso/bbl or U.S. $96/bbl, a very high price. The international price of diesel fuel in large port cities is less than half the Easter Island price. Easter Island is remote, and a very small market, and there is only one supplier.

Another reason for the high electric rates is the need to cover 11 salaries, plus construction and maintenance materials, from sales of a

rather small number of kilowatt hours. This problem is found in all small systems.

The third readily identifiable reason for the high rates is that only a fraction of the electricity produced is sold. Specifically, less than half of it is sold. Some electricity is delivered without charge for important public services (pumping community water and lighting street lamps). Some electricity cannot be accounted for, and is lumped under the general heading of 'losses'. Some of the 'losses' may be theft. The numbers for several months in 1980 are:

1980	KWH Produced	KWH Sold	KWH for Public Purposes: Water Pump*	KWH for Public Purposes: Street Lamp*	KWH Losses**
June	180,800	72,258	32,000	15,000	61,540
July	180,000	83,395	32,000	15,000	49,610
August	192,800	81,789	32,000	15,000	64,010

*Estimated, not metered.
**Obtained by difference.

I will make two comments. One is that the buyers of electricity are paying for more than the electricity they buy. They are paying part of the costs of water supply and city street lights as well. This is not necessarily bad. If these items were metered and billed separately the same population of consumers would have to pay in the end (though perhaps not in exactly the same proportion as they do now). Nevertheless, not billing the water pumping and street light consumption does inflate the electric rates. For the three months shown, KWH sold would increase 60% if these two items were billed and paid for. An increase of 60% in sales with no change in production means electric rates could be cut to about 60% of present values.

The second comment is that losses seem very high. (Mr. Velasco has also noted this, but does not understand it.) Typical loss levels in a

large power system are 5-10%, mostly ohmic loss in transmission and distribution. It is possible that losses could be reduced substantially by technical means -- for example, by changing wire gauge or voltage levels, or by replacing defective meters, or in some other way. An expert in electric power system operation (which I am not) would have to examine the situation. Perhaps an engineer from Chilectro or Entesa could be provided to CORFO/Easter Island for a week to examine the system in detail.

Aside from technical problems leading to real losses, it is possible that an important part of the apparent losses could be due to theft. Physical theft should be detectable by direct inspection in such a small system. Intermediate metering, between power station and customer, could be helpful in localizing the problems.

If losses were reduced to 10% of production, which seems not unreasonable, the effect on rates would be noticeable immediately. With 40,000 KWH/month saved the cost of sending one or two experts from the mainland would be recovered quickly. Discovering the causes of the excessive losses and taking the appropriate actions to eliminate them will not be easy. If it were easy it would have already been done. However, it is certainly possible. No other action will give such a large immediate return.

Controlling the losses will have little impact on the security of the supply problem. To impact this problem windgenerators will be need even if losses are drastically reduced. Depending on how the windgenerators are financed they could even increase the near term cost of electricity over what it would be without them. The diesel-electric generation plant now in use is completely amortized; adding wind capacity means that the new equipment will have to be paid for somehow.

WINDGENERATORS FOR ELECTRIC POWER

General Situation. The mechanical power in the wind is given by

$$P_{wind} = \frac{1}{2} \rho v^3$$

where v = speed of the wind, in m/s

ρ = density of the air, in kg/m^3 (typical value 1.2 kg/m^3)

P_{wind} = power in the moving air in watts/m^2. It is necessary to consider a planar area of one square meter perpendicular to the wind; P_{wind} is the power crossing this area.

Not all the power in the wind can be extracted by a wind machine. It is customary to define a performance coefficient, C_p.

$$C_p = \frac{\text{mechanical power from machine}}{\text{power in the wind}} .$$

Clearly, C_p cannot exceed 1. In fact, it cannot be as high as 1; there is a theoretical upper bound of 0.59 (for horizontal axis machines). Typical values of C_p are 0.3--0.5, though lower values are often found in poorly designed machines. The value of C_p for any particular machine depends on rpm and windspeed and on aerodynamic design.

Not all the mechanical power produced by the machine shaft can be delivered as electricity. The electrical generator has an efficiency η_{gen} and (except in the very smallest machines) there must be a speed increasing gearbox, which also has an efficiency, η_{gear}. Typical values for each of these is 0.9, or 0.8 for the product (η_{gen} η_{gear}). Slightly higher values, to 0.85 or 0.9 for the product, are possible under the best conditions.

Considering then a machine which intercepts an area A of wind, the electrical power output is given by

$$P_{elec} = \frac{1}{2} \rho A C_p (\rho_{gen} \rho_{gear}) v^3 .$$

where P_{elec} is in watts and A is in square meters.

If now the machine is supposed to be a 2-blade or a 3-blade propeller driving a horizontal shaft (so-called 'horizontal axis' machine), and the diameter of the circle swept by this propeller is D, then $A = \frac{\pi D^2}{4}$. Using typical values of 0.4 for C_p and 0.8 for the product of gearbox and generator efficiencies, and 1.2 kg/m^3 for air density, we can use the equations above to construct the table below, which gives an idea of the physical size of machine to deliver a certain kilowatt output in various winds. The output is more dependent on windspeed than on machine design or anything else.

Horizontal Axis Windgenerator Rotor Diameters

Electrical Output (KW)	Windspeed (miles/hr)	Windspeed (km/hr)	Windspeed (m/s)	Diameter (meters)
10	22.37	36.00	10	8.14
	26.84	43.20	12	6.19
	31.32	50.40	14	4.92
20			10	11.52
			12	8.76
			14	6.95
50			10	18.21
			12	13.85
			14	10.99
100			10	25.75
			12	19.59
			14	15.55
200			10	36.42
			12	27.70
			14	21.99

Notice that the physical size of windgenerators is quite large, even for moderate electrical ratings.

Windgenerators are customarily described by a rated windspeed and a rated output. Thus, a machine might, for example, be rated 10 KW at 12 m/s or more. At less than 12 m/s less than 10 KW will be obtained. It is not possible to obtain more than the rated output, except for short periods, because of overheating and damaging the generator. Thus the

rated windspeed is usually chosen high enough so that most of the time it is not exceeded, since when it is exceeded some of the potentially extractable power in the wind is not being extracted. Therefore, most of the time the windgenerator is delivering less than rated output. A 10 KW windgenerator, as an example, is not equivalent to a 10 KW gasoline generator from the point of view of generation capacity, since the windgenerator gives the rated output only some of the time, and the gasoline generator gives the rated output whenever the load requires it.

A parameter of interest is the expected annual energy production, in KWH/yr. There are 8,766 hours in a year. A properly sized windgenerator would normally have a plant capacity factor of 0.25--0.35, where plant capacity factor is defined by

$$\text{PCF} = \frac{\text{KWH produced per year}}{(\text{KW rating of machine})(8{,}766)} .$$

Thus, with a PCF of 0.30, a 10 KW windgenerator could be expected to deliver 26,300 KWH/yr. If the site is a very good one with frequent high winds the PCF might be as high as 0.5--0.6. If this were the case it would normally mean that a larger generator, driven by the same rotor, with a higher rated windpeed, would have been a better design choice. The object is to maximize the number of KWH/yr. delivered by dollar invested.

Wind Resource on Easter Island. The wind resource was surveyed briefly and incompletely by Pedro Roth, Patricio Solminihac, and myself. Measurements of average windspeed over a 30 minute interval at two meters height were made at half a dozen or so exposed locations, mostly tops of rounded hills. Measurement with strip chart recording of windspeed and direction at 4 meters height over a 36 hour period was accomplished at one exposed site. Professor Roth has the detailed records. The following appear to be true:

1. At the tops of the exposed hills, which look out to the sea without obstruction and stand several hundred meters above the sea the southeast tradewinds prevail. The wind blows constantly from the southeast and windspeed appears to be sufficient to operate windgenerators.

The highest value of windspeed measured (30 minute average) was obtained at the top of the highest hill, 536 m above sea level. The value was 12 m/s. Values of 8, 9, or 10 m/s were obtained at other places.

2. The wind in the valleys, at the airport, on the edges of the island, near the sea, appears to be insufficient for the operation of windgenerators.

3. Some of the hilltop sites which have good wind are close enough to existing roads and transmission lines to make their use practical as windgenerator sites.

Although the wind resource appears to be somewhere between adequate and excellent, long term anemometry is essential to establish this fact. At present we have only an indication; the presence of the resource is not established.

Available Equipment. Considering the load and the capacity of existing equipment, and also the presently available wind equipment, the size range of interest for windgeneration equipment to be owned and operated by the utility company (CORFO) is 10 KW to 200 KW. Selection of wind equipment to supplement the existing diesel equipment, should the resource prove out as expected, must be based on a number of considerations. These include:

1. Funds available. Perhaps only a small machine can be purchased.

2. Importance attached to having a high fraction of electricity supplied by wind. A high wind fraction means increased fuel savings but more investment will be needed.

3. Degree of confidence in moving quickly into this unfamiliar generation technology. A cautious approach would be to install one machine, try it for a time, then add another, etc.

4. Commercial reliability and cost of equipment available for purchase. Cost can be obtained on a firm basis, but reliability can only be judged subjectively.

In this section I provide information bearing on the fourth point. A large number, more than 25, wind machines are advertised for commercial sale in the United States in sizes between 10 and 200 KW. A few more are made in Europe and advertised for sale there. None of these machines can be said to be commercially proven in the sense of a Caterpillar diesel generator, or a Mercedes bus. In every case the number of machines of a particular size and manufacturer which have been sold is fewer than 1000; in most cases it is fewer than 100. The machines offered for commercial sale are not prototypes, but neither are they completely free of mechanical and electrical problems. There simply has not been sufficient time to work out all the many problems which arise during field operation. (One partial exception to this statement is the Jacobs (see below), which is claimed to be an improved version of a machine sold in large numbers about 40-50 years ago. About 50,000 of the original Jacobs machines were sold between 1925 and 1955. They established a reputation for reliability and performance and many are still in use.)

With the above cautions I provide data on a few machines of which I have knowledge. Manufacturers literature is being obtained and sent to Professor Roth. The discerning reader will note a certain lack of correlation between rated output, rated windspeed, and rotor diameter in the wind machines listed in the table.

Rated Output (KW)	Rated Windspeed (m/s)	Rotor Diameter (m)	Manufacturer	Approximate Price 1/81
10	11.2	7.41	Millville	10,500
10		7.01	Jacobs	15,700
10	10.0	10.06	Windworker (Energy Unlimited)	30,000
25	11.2	9.76	Jay Carter	25,000
40	13.4	12.20	Mehrkam	26,300
200	12.5	24.39	WTG	230,000

Notes on the above table:

1) Prices are approximate. Prices include tower, except for Millville. For Millville, 60 ft (18.3 m) tower is $3,000. Prices do not include freight or installation, except that Jay Carter includes one technician to supervise installation.

2) All units are for direct utility interfacing. Only WTG is intended to operate alone, the others depend on other generators in the system to maintain frequency. Jacobs and Windworker use synchronous inverter, which should maintain system stability even when wind is the dominant source.

3) Jacobs does not choose to state rated windspeed.

4) All are horizontal axis machines with three blade rotors except Mehrkam, which has 4 blades. All are upwind rotors except Jay Carter and Windworker.

5) None of these firms are large. All have 10-25 employees and have been in business 3-6 years. (Jacobs was previously in the wind-generator business, but activities ended in 1955.)

6) Windworker is the name of a machine manufactured by Energy Unlimited Inc.

7) The only large firms in the windgenerator business producing machines in the size range of interest in recent years have been Grumman and Alcoa. Both are temporarily out of the market, because of technical difficulties with their product. Alcoa's product is a Darrieus rotor.

Addresses: Millville Windmills Inc.
10335 Old 44 Drive
Millville, CA 96062 916/547-4302

Jacobs Wind Electric Company
2180 W. 1st Street, Suite 410
Fort Myers, Florida 33901 813/334-0339

Addresses (Cont.):

Energy Unlimited Inc. 2 Aldwyn Center Villanova, Pennsylvania 19085	215/525-5215
Jay Carter Enterprises P.O. Box 684 Burkburnett, Texas 76354	817/569-2238
Mehrkam Energy Development Co. RD 2, Box 179E Hamburg, Pennsylvania 19526	215/562-8856
WTG Energy Systems 251 Elm Street Buffalo, N.Y. 14203	716/856-1620
Grumman Energy Systems 4175 Veterand Memorial Hwy Ronkonkoma, N.Y. 11779	516/737-3714
Windgenerator Group Alcoa Technical Center Alcoa Center, Pennsylvania 15069	412/339-6651

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Recommendations and Alternatives. I recommend the following sequence of actions:

1. Selection of two or three hilltops which are acceptable from the point of view of land ownership, non-interference with aviation, reasonable access to existing power lines, and accessibility to construction equipment. This selection should be made from a group of ten or twelve which may be expected to have adequate wind.

2. Instrumentation of the two or three candidate sites with anemometers at a realistic height of at least 20 meters (25 meters is preferable). If installation of a machine of 100 KW or more is being considered the anemometer height should be at

least 30 meters. If the anemometer mast is not at the very top of an exposed hill the height should be taken as the distance above the top of the nearest obstacle within 150 m. The windspeed must be measured; wind direction should be recorded if instrumentation permits. (Wind direction is relevant for determining machine spacing.) The minimum usable data is monthly mean windspeed. Daily or hourly mean windspeeds, durations of wind below a certain minimum (e.g., 4 m/s), and maximum windspeeds during storm gusts are also of interest, but may be dispensed with if the measurement is too difficult.

3. If all the measured monthly mean windspeeds are 8 m/s or more after six months of measurement the site may be declared acceptable. If all the measured monthly mean windspeeds are 5 m/s or below after six months of measurement the site may be declared unacceptable. Otherwise, continue measurements for an additional six months. If then all the twelve monthly mean windspeeds are 7 m/s or more or if the mean windspeed for the 12 month period is 7.5 m/s or more the site may be declared acceptable. If the mean windspeed for the 12 month period is 5 m/s or less the site may be declared unacceptable. Otherwise the situation should be considered carefully.

4. In parallel with step 3 the wind machine or machines should be selected. This involves questions of strategy (how many machines, how much risk at the outset, how much capacity is needed to be meaningful), of financing (who is paying for the machines in the long term, how are they to be financed in the short term), of logistics and management (order dates, delivery dates, installation plan), of utility system interfacing (safety devices, synchronization) and of equipment selection. If it is judged necessary or desirable procurement may be initiated before a site is selected.

5. One or more sites is selected, one or more machines is ordered, delivered, and installed. Installation should include enough

instrumentation so that performance can later be evaluated.

I will now make a few recommendations on equipment selection. All the machines listed in the table, as well as some which are not listed, have their advocates. My judgement is based on conversations with installers and manufacturers and on knowledge of the situation on Easter Island. No certainty is possible.

I recommend that two of the 10 KW machines be purchased at the outset, or at least closely considered for purchase. These are the Millville and the Jacobs. If it is decided that only one machine be purchased at the outset then I recommend the Jacobs. In the second phase of the project I recommend that the Jay Carter, Mehrkam, Grumman, Alcoa and WTG machines be considered. The WTG machine has the advantage that it has been specifically designed for isolated island environments and in fact has operated on an island similar in size (electrically) to Easter Island for several years. It is large enough to contribute a noticeable fraction of Easter Island electricity supply with just one machine. The Alcoa machine, being a vertical axis Darrious rotor of simple design, is likely to be less expensive per KW of capacity than the others.

WINDMILLS FOR PUMPING WATER

General Situation. Water for human and animal use on Easter Island comes from below ground, except for a small amount of surface runoff in one locality. The water is pumped with electricity or with diesel operated pumps.. Citizens are very aware that if the ship bringing diesel fuel fails to arrive and replenish supplies their electricity would stop and water could not be pumped. This has never happened, but it could happen. Water is vital, and the citizens would like to have a greater degree of control over the situation than presently. (The methods used in ancient times were cisterns, rainwater catchment. These are not believed to be practical for today's population, so far as I could tell. There was no enthusiasm for cisterns at all.)

The proposition naturally arises: Why not use windmills for pumping water?

Several abandoned windmills of the waterpumping type were seen on the island. We were told that formerly it had been practical to use these machines to pump water but that now it was not. The reason given was that the fresh water is found at a level which is more or less the same distance above sea level in all parts of the island. Only near the coast is the level close (5-10 m) to the ground surface. Near the coast the waterpumping windmills have been used successfully, but further inland the depth to water is greater (30-80 m) and the windmill pumps cannot deliver water at an acceptable rate, even with good wind. Since the creation of the National Park on the island the government has had a policy of moving people away from a 500 m coastal strip and resettling them inland.

While the correctness of this account is not doubted, it is probably also true that the advent of CORFO and electric pumps made the water production of the windmill pumps look very small by comparison. Windmill pumps rarely survive when electric or fuel driven pumps are practical.

Type of Equipment Available. The type of windmill widely used for water pumping in many parts of the world is the American multivane fan, sometimes called the American farm windmill. Today this type of windmill is produced in the United States, Australia, Argentina, South Africa and the USSR. The American brand names are: Aermotor, Dempster, Heller-Aller. The maximum depth from which water can be pumped exceeds 100 m. Though old, the design is not obsolete. The machines are rugged, reliable, require minimal maintenance, and pump some water even in low winds.

Policy Alternatives. The policy objective is to provide increased assurance that there will be at least partial water supply for human consumption and essential needs even if the fuel supply is interrupted. There are a number of possible alternative routes to this objective.

1. Increased oil storage can be provided. This can be expensive, because of the interest charges on the value of the additional oil stored, as well as the cost of the tankage. Oil storage to pump water for six months at the present rate would be about

60,000 liters. The security gained by storage is limited, and the oil in storage could be accidentally or intentionally destroyed.

2. A large water storage tank or reservoir could be constructed and kept full.

3. Wind electric capacity can be provided so that some electricity will be available for essential needs, of which water pumping is one.

4. A modern rainfall catchment-cistern system could be constructed. As already mentioned, this did not seem to be very popular with the few people I talked to. It is, however, done in other places (e.g., Gibralter).

5. Solar desalination can supply emergency drinking water. A system large enough to supply water for use at the normal rates would probably be too expensive. Historical experience with solar distillation has not been very encouraging. Costs are high and maintenance requirements are substantial.

6. A few waterpumping windmills could be installed in or near the town, or elsewhere, and kept in good order, as visible evidence that at least some water will always be available. The wind at the possible sites should be verified before any equipment is purchased.

Recommendation. My recommendation is that the matter should be studied further, with all the above alternatives being considered. If wind electricity goes ahead as now proposed the urgency of considering the water problem separately is diminished.

SOLAR WATER HEATERS

General Situation. Conditions for solar water heating, both the physical conditions and the economic conditions, are extremely favorable on Easter Island. Certainly they are more favorable than anywhere in the United States. Low latitude and clear skies mean good insolation.

(There are instruments on Easter Island to measure insolation, but I have not seen any data or summary reports. I would expect insolation to be similar to Hawaii, which is excellent.) Average ambient temperatures are high, so collector heat loss is low, even with inexpensive collectors. A major plus is the fact that there is no freezing. Solar water heaters without freeze protection are cheaper and more reliable than those required in freezing climates. On the economic side, domestic hot water is presently heated with electricity and the electricity is very high cost. Some may be heated with LPG (propane-butane) but this is also high cost.

The fraction of Easter Island electricity used to heat water is not known. Probably it is not very high. Many people do without hot water, or use very little of it, because of the expense. The reduction of electric power system load if solar water heaters came into wide use is difficult to predict. In Hawaii, with a much larger population and higher income levels the average single family home uses 12,000 KWH/yr. About 5000 of this is for water heating.

Solar water heaters not requiring freeze protection are simple and reasonably foolproof devices. Several million are in use worldwide. The highest per capita use in any country is in Israel where 20-30% of the people get their hot water from solar water heaters.

At the electric rates prevailing on Easter Island there is no question that solar water heaters are cost effective on a life cycle cost basis, under practically any set of assumptions.

Types of Solar Water Heaters. There are three basic types of solar water heaters: pumped circulation, thermosiphon, and the 'breadbox', or 'passive' type.

The pumped circulation type has a collector, tank, pump, and controller. The controller turns the pump on if the temperature of the water in the tank can be increased by circulating it through the collector. Advantages of pumped circulation systems are: easier to protect from freezing than the other types, and tank can be lower than collector--i.e., on the ground when the collector is on the roof.

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Disadvantages are greater complexity and cost and the fact that electricity is required for operation.

The thermosiphon type of solar water heater has a collector and tank, but no pump or controller. An important physical constraint is that the tank must be higher than the collector. A common rule of thumb is that the distance between the top of the collector and the bottom of the tank should be at least two feet (0.6 m), but as little as half this may be adequate. There is no upper limit on the separation distance. The practical problem resulting from the constraint is that a tank of water weighing hundreds of kilograms must be supported safely above the collector. If the collector is on the roof, which it often must be to minimize shading, the weight of the tank must be borne by the roof. In Hawaii it was found that few roofs were strong enough to carry the load safely. Consequently most systems installed in Hawaii are pumped circulation, even though the cost is higher. Thermosiphon systems are used almost exclusively in Israel. The advantages of thermosiphon systems are simplicity and cost, as compared to the pumped circulation type, while having comparable effectiveness and the ability to operate without electricity. The major disadvantages are the problem of supporting the tank and difficulties in freeze protection.

The 'breadbox' or 'passive' type of solar water heater (this device needs a better name) consists only of a tank. There is no collector, pump, or controller. The tank is painted black, and is not insulated. It is installed in an insulated box with a glass window facing the sun. It is more effective if movable insulation is used over the window to reduce nocturnal heat loss. The tank is the absorber, as well as the storage. Advantages are low cost and great simplicity, and no need for electricity. Disadvantages are the need to support a heavy tank, and somewhat lower performance than the other types.

With any of the three types an electric or gas-fired booster heater may be used, so that hot water can be obtained even on cloudy days. In the United States very few solar water heaters are installed without boosters. In Israel, on the other hand, very few are installed with

boosters. The booster can be an expensive extra, both in first cost and in energy use. One compromise, sometimes seen in the U.S., is to disconnect the booster in summer.

Aspects of Design and Installation. This is not the place for an extended discussion of the many important details which must be taken into account if a solar water heater is to work properly. It is perfectly possible to spend a lot of money and install a solar water heating system which will never work properly. An experienced installer, or an extremely detailed set of instructions, are the only alternatives to a long process of trail and error. Even if all the parts of the system are imported (and it is recommended that at least collectors, controllers, and pumps be imported) there are still pitfalls. Large multifamily systems, for hotels, hospitals, apartment houses, etc. are especially tricky. The physics is simple but the plumbing and structural details are not.

Recommendations and Alternatives. It is difficult for me to make recommendations because I am not familiar with Chilean government policy. It seems to me that wind electricity is a higher priority project if resources are limited. However, it might be that wind electricity and solar water heating could go forward in parallel. In that event, demonstration solar water heaters on some single family homes or government offices, or on large public buildings such as the hospital could be considered. Alternatively the government could offer to cost share a solar water heating system for the hotel, which uses a lot of electricity to heat water now. For planning purposes, a system large enough for a single family home, replacing a 300 liter tank with electric heating elements, would cost about U.S. $1500-2500 in the United States, without installation.

Specific equipment recommendations can be made when the application is defined.