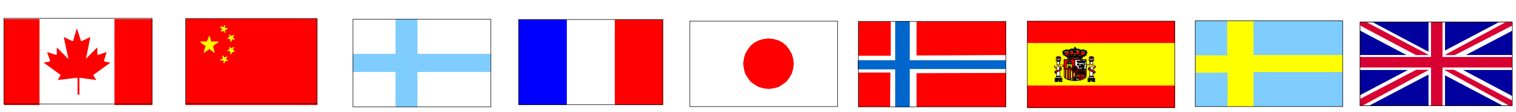
Assessment of Further Opportunities for R&D – Summary Report

IEA Technical Report

IEA Hydropower Agreement



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OVERVIEW OF THE IEA IMPLEMENTING AGREEMENT FOR HYDROPOWER TECHNOLOGIES AND PROGRAMMES

The Hydropower Implementing Agreement is a collaborative programme among nine countries: Canada, China, Finland, France, Japan, Norway, Spain, Sweden and the United Kingdom. These countries are represented by various organizations including electric utilities, government departments and regulatory organizations, electricity research organizations, and universities. The overall objective is to improve both technical and institutional aspects of the existing hydropower industry, and to increase the future deployment of hydropower in an environmentally and socially responsible manner.

HYDROPOWER

Hydropower is the only renewable energy technology which is presently commercially viable on a large scale. It has four major advantages: it is renewable, it produces negligible amounts of greenhouse gases, it is the least costly way of storing large amounts of electricity, and it can easily adjust the amount of electricity produced to the amount demanded by consumers. Hydropower accounts for about 17 % of global generating capacity, and about 20 % of the energy produced each year.

ACTIVITIES

Four tasks are operational, they are: 1. upgrading of hydropower installations, 2. small scale hydropower, 3. environmental and social impacts of hydropower, and 4. training in hydropower. Most tasks have taken about five years to complete, they started in March 1994 and the results will be available in May 2000. To date, the work and publications of the Agreement have been aimed at professionals in the respective fields.

UPGRADING

The upgrading of existing hydropower installations is by far the lowest cost renewable energy available today. It can sometimes provide additional energy at less than one tenth the cost of a new project. One task force of the Agreement is studying certain technical issues related to upgrading projects.

SMALL SCALE HYDROPOWER

Advances in fully automated hydropower installations and reductions in manufacturing costs have made small scale hydropower increasingly attractive. The small-scale hydropower task force will provide supporting information to facilitate the development of new projects.

ENVIRONMENTAL AND SOCIAL ISSUES

For some hydropower projects the environmental and social impacts have been the subject of vigorous debate. There is a need to communicate objective information to the public, so that countries can make good decisions with respect to hydropower projects. The environmental task force will provide such information on possible social and environmental impacts and on mitigation measures.

TRAINING

The availability of well-trained personnel is a key requirement in the hydropower sector. The training task force is concentrating on training in operations and maintenance, and planning of hydro power projects.

THE INTERNATIONAL ENERGY AGENCY – IMPLEMENTING AGREEMENT FOR HYDROPOWER TECHNOLOGIES AND PROGRAMMES

Assessment of Further Opportunities for R&D – Summary Report

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ADEME, France

March 2000

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Other Technical Reports in This Series

Hydro Power Upgrading Task Force (Annex 1)

Guidelines on Methodology for Hydroelectric Turbine Upgrading by Runner Replacement – 1998 (available to non-participants at a cost of US $ 1,000 per copy)

Guidelines on Methodology for the Upgrading of Hydroelectric Generators – to be completed in May 2000.

Guidelines on Methodology for the Upgrading of Hydropower Control Systems – to be completed in 2000.

Small Scale Hydro Power Task Force (Annex 2)

Small Scale Hydro Assessment Methodologies – to be completed in May 2000 (available to non-participants on request)

Research and Development Priorities for Small Scale Hydro Projects – to be completed in May 2000 (available to non-participants on request)

Financing Options for Small Scale Hydro Projects – to be completed in May 2000 (available to non-participants on request)

Global database on small hydro sites available on the Internet at:
www.small-hydro.com

Environment Task Force (Annex 3)

Survey on Positive and Negative Environmental and Social Impacts and the Effects of Mitigation Measures in Hydropower Development – 2000 (available to non-participants on request)

A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies – 2000 (available to non-participants on request)

Legal Frameworks, Licensing Procedures, and Guidelines for Environmental Impact Assessments of Hydropower developments – 2000 (available to non-participants on request)

Hydropower and the Environment: Present Context and Guidelines for Future Action
Volume 1: Summary and Recommendations
Volume 2 : Main Report
Volume 3 : Appendices
– 2000 (available to non-participants on request)

Guidelines for the Impact Management of Hydropower and Water Resources Projects – 2000 (available to non-participants on request)

Education And Training Task Force (Annex 5)

(All of the following reports are available on the Internet at www.annexv.iea.org Some reports may consist of more than one volume.)

Summary of Results of the Survey of Current Education and Training Practices in Operation and Maintenance – 1998 (available to non-participants on request)

Development of Recommendations and Methods for Education and Training in Hydropower Operation and Maintenance - 2000 (available to non-participants on request)

Survey of Current Education and Training Practice in Hydropower Planning – 1998 (available to non-participants on request)

Structuring of Education and Training Programmes in Hydropower Planning, and Recommendations on Teaching Material and Reference Literature - 2000 (available to non-participants on request)

Guidelines for Creation of Digital Lectures – 2000 (available to non-participants on request)

Evaluation of tests – Internet Based Distance Learning – 2000 – (available to non-participants on request)

Brochure

A brochure for the general public is available. It is entitled “Hydropower – a Key to Prosperity in the Growing World”, and can be found on the Internet (www.usbr.gov/power/data/data.htm) or it can be obtained from the Secretary (address on the inside back cover).

Preface

In October 1998 the Small-hydro programme of the IEA Hydropower Technologies and Programmes Implementing Agreement organised a Workshop in Nice, France. The purpose of the Workshop was to assess further opportunities for international small-hydro R&D. What follows is a synthesis of the proceedings of the workshop, a listing of some papers presented at the workshop, as well a summary of recommendations for future R&D is provided.

Over the course of the workshop numerous small-hydro experts discussed various aspects of the industry. The main experts present at the Nice workshop included:

M. Marc Allington - ETSU (United Kingdom)
Prof. Hermod Brekke - NTNU (Norway)
M. Freddy Isambert - ISL (France)
Prof. JL. Kueny - IMG (France)
M. Arun Kumar - Alternate Hydro Energy Centre (India)
M. Henri Pauwels - TREN (European Commission)
Prof. Lambert Pierrat - IMG (France)
M. Celso Penche - (Spain) - ESHA
M. Tony Tung - Canmet (Canada)

1 Introduction

Hydropower has an appreciable contribution in worldwide electricity production. In 1997, global electricity production equalled 13 300 TWh of which 2 600 TWh were supplied by hydropower. Small hydro's annual international production is estimated at 100 TWh.

Hydropower is considered a mature technology, therefore, Research & Development (R&D) is often said not to be necessary in the industry. However, there are two strong reasons why it is important to continue and improve small-hydro R&D:

1) Recent decades have seen a dramatic increase in global energy demands. This increase in demand has helped to compound other issues such as pollution, particularly greenhouse gas emissions. In an attempt to reduce the rise of pollution levels governments around the world are pushing to develop renewable energy sources such as hydropower. Small hydropower is one of the cheapest renewable energy sources available and its impact on the natural environment is minimal if sufficient precautions are taken. Only through further R&D can small hydro remain relevant in this changing atmosphere.

2) A number of aspects of the small-hydro industry are changing quickly. Concern for our local environment is increasing; hydro projects built without regard for natural or human environments discredit the industry. Concern for aquatic ecosystems and the importance of their sustainability is become more relevant and understood. New materials are being identified that can be adapted and used in small hydro development. Computer software applications, telecommunications and remote sensing techniques are becoming more readily available for use in the small-hydro applications.

Further R&D is required to investigate these changes and assess their relevance and importance in the new small-hydro industry in order for it to stay, or become, competitive.

In developing countries, the growing demand for energy is most often met by thermal power, which has growing consequences for the global environment. In rural areas of these countries energy demand is often limited and the need can often be met appropriately by small or micro hydro schemes. Development of hydropower potential in such countries requires statutory provisions, economic incentives and optimum financing potential. The development of small-hydro power in these areas will also require a systematic solution to reduce equipment costs in order to improve competitiveness and enlarge the economical market. Recent research has made it possible to build suitable, economic plants using local materials and labour. Further research is required to improve these designs, adapt them to local characteristics and make them more economically feasible. In developed countries, the demand for improved development of renewable energy sources is due to the need to reduce pollution and the greenhouse effect. A program of the European Commission aims to increase the role of renewable energy from 6 % of raw energy consumption in the European Union in 1995 to 12 % in 2010. Programs such as this have been developed in many developed nations around the world. In many of these countries increased hydropower production will only be possible through development of small-hydro potential, due to the fact that potential large hydro sites are either currently exploited or located in areas where development is undesirable. Further R&D is required in order to adapt small-hydro technologies and applications to the new demand being placed on the industry.

2 Innovative Projects, The experience of the European Commission

The European Thermie Programme has encouraged activities which are particularly appropriate for successful implementation of the model of sustainable economic development proposed in the European White Paper, in particular as regards investment in cleaner energy technology, advancements in the way industry produces and uses energy, and improved access to new European technologies. A summary of the most interesting projects presented to the Thermie programme was prepared by Henri Pauwels of the European Commission, Freddy Isambert of ISL Consultant and Elisabeth Campion of ADEME. Although the focus of these projects was not necessarily R&D, they do address the need for innovation in the industry. Pauwels et al. present the main focus of these projects presented by the European private sector and lay the basis for new areas of R&D. The following table presents the results of the paper prepared by Pauwels et al.

2.1 Table 1 - Summary of Thermie Proposal (Pauwels et al.)

Component	Number of proposals	% of total proposals	Comments
Civil engineering	12	24%	27% : powerhouse – 23% : dam – 23% : penstock
Control & regulation	20	40%	32% : control-monitoring – 68% : regulation
Electrical equipment	8	16%	75% : variable speed – 12% : off-grid
Environment	22	45%	50% : pollution (of which 64% on lubrication, the main part with water) – 25% : integration in the landscape
Gear box	1	2%	
Overall design	9	18%	45% : submersible plants
Turbines	30	60%	61% : new designs – 14% simplification – 12% improvement of efficiency
Use of water	4	8%	75% : eau potable + energy

2.1.1 Table Definitions

1) **Component –** The component field refers to the focus of the proposal presented to the Thermie program
2) **Number of proposals –** This field highlights the number of presented proposals with similar areas of focus (the same project may refer to several areas).
3) **% of total proposals -** This field highlights the percentage of proposals of a certain focus referred to the total number of proposals presented.
4) **Comments -** The comments field offers more details on the breakdown of proposals

Based on this summary, it is apparent that turbine technology will be the main focus of innovative efforts. Environmental issues are a close second, followed by control and regulation. Each of these topics will be reviewed in more detail later in this report.

3 General topics

3.1 Maps, hydrology and residual flow

Detailed, accurate maps are an important primary tool in the development of a SHP project. However, acquiring such maps is often a difficult task. A vast majority of our planet lacks maps with a sufficient resolution level and many lack reliable maps altogether. The development of digital orthophotography and digital terrain models now offers some solutions. An orthophotograph is an image that has been manipulated to remove the scale inaccuracies from an aerial photograph, resulting in a true-to-scale image that can be exactly geo-referenced.

Accurate hydrological assessment is also essential to a detailed assessment of a project. Several computer software programs have recently been developed to aid in the assessment of sites and the selection of equipment. Remote sensing techniques have also been used to assess isolated sites. For more details on these studies, visit the Tools & Methodologies section of the small-hydro Atlas at www.small-hydro.com. There is also a demand for low-cost flow measurement techniques, especially for developing countries. Setting a correct minimum residual flow and/or appropriate flow regimes is important both for the producer and the public authorities. Different methods have been developed or are in the development phase. A comparative synthesis of these methods would be useful and would help public authorities and producers to optimise flow values.

3.2 Technical know-how

It is important to note that the identification and development of SHP plants is a specialised skill. A common complaint among technical experts is that SHP developers and project managers often lack the knowledge or experience required for the project. According to Prof. Brekke, a systematically optimised design should be possible based on the descriptions of the most important characteristic parameters used for the hydraulic design of small hydro turbines. This is not the case at the present time. Currently, too many manufacturers do not have the necessary technical experience or facilities to design and test turbines. However, optimisation of the design adds to cost. Small-hydro turbines are usually designed without sophisticated techniques, which keeps costs lower.

A programme focusing on education and training of manufacturers and customers interested in purchasing small-hydro machinery would help to improve the design and efficiency of turbines. The aim of such a programme, in order of priority, should be:

- Assist customers choose the most economical equipment that will meet the needs of their plant. This could involve on-site testing for specification and performance guarantees.
- Improved education on turbine design.
- Development of simplified testing procedures for on-site acceptance tests of installed turbines.
- Improve simplified theories for control systems presented in educational materials.

3.3 Reduction of costs

The most common economic handicap that most SHP plans face is size effect, an inverse relationship between size and cost (ex. as the rated power of a piece of equipment, such as a turbine, decreases, its specific cost increases). Solutions have to be developed to overcome these issues. R&D support for low cost, low head equipment is required to solve these problems.

3.4 Multipurpose projects

In many areas dams are built in rivers for the purpose of flood control, water regulation for navigation, irrigation, or drinking water supply. Potential exists to adapt these sites to multipurpose projects, for example installing a power plant to generate hydropower in conjunction with other purposes as outlined above. The additional costs of civil engineering for the power plant are often minimal and can expand the economic potential of the site. Given the obstacles many developers have met in developed countries in their attempt to obtain a license to develop new sites, the use of supply and irrigation water for power is of interest for future developments.

Examples from the Thermie program demonstrate that efforts have been made to improve the condition and R&D focusing on improving standards and techniques for multipurpose projects, however, more commitment is required.

4 Overall design

Technical advances over the last two decades have made small hydro an economically viable supplier of electricity. This progress is due in large part to the standardization of equipment and use of adapted materials that have helped to reduce the cost of building and maintaining a SHP project. Studies continue to look at these issues in attempts to further reduce costs and improve the economic viability of the project.

In developed countries, small hydro is often connected to large grids. Using small hydro during periods of peak demand can be quite profitable due to the reduced costs in generation and supply. However, in some circumstances the quality of small-hydro supply is very important and is now an important subject of research.

4.1 "Environmentally friendly" small hydro

Many sites have the potential for hydropower production; however, development of many of these sites could lead to significant ecological issues. Past hydropower projects have disrupted fish runs, flooded large areas, and converted rapids into placid lakes. Today, it appears that with some forethought and precautions, small-hydro power can be adapted to local environmental concerns and made to fit with new environmental policies.

R&D has identified various techniques that can help minimise ecological impacts, including fish ladders, operation of reservoirs, discrete powerhouse integration into the landscape, and noise reduction. In some instances small hydro plants can actually help to improve water quality, help regulate the river, enrich the water's oxygen levels, and eliminate floating debris or waste. The Thermie project has received proposals covering each of these techniques.

4.2 Global integrated design

Prof. K.L. Kueny, is his paper *Objectives for Small-hydro Technology*, discusses the importance of global integrated design in the development of SHP projects. Advances in turbine efficiency have limited the opportunities for energy savings through turbine design improvements. Today, a more global model that optimises all elements of the plant is required to reduce operation and maintenance costs. Using this model, machinery characteristics should be adapted to plant characteristics. Prof. Kueny concludes that if a good hydrologic database is available with a corresponding power load schedule of the plant, "a global model based on simulation of all possible components can be constructed."

If this design model is to be successful, close cooperation of all designers (mechanical, electrical, and civil) is required to ensure optimal results and cost reductions.

5 Turbines

In terms of development and operating costs the turbine accounts for 15-30% of the total cost of the SHP plant. Developers are continually searching for ways to reduce the actual cost of the turbine. For small-hydro plants the cost corresponding to efficiency improvement must be accounted for in the overall financial balance and the least-cost solution must be researched.

However, turbine technology is now mature in small hydro. Small hydro now has its own techniques and methodology for turbine design. In recent years the focus of research has shifted towards the reduction of design costs, manufacture, control, and maintenance of the turbine. According to European studies, the main innovative topics in turbine technology are the use of new materials, standardization, and pre-assembling. New turbine designs are still being presented and work is being done on adapting large turbines for very specific small-hydro projects, however, these activities do not receive the focus they once did.

5.1 Standardization

In the past years, many manufacturers have developed standard turbine designs, as is done in pump design, however it has proved to be a difficult task. Given the diversity of small-hydro site characteristics and total operational ranges of small hydro, manufacturers would have to design a large number of turbines, many of which that would become obsolete before they were put into use and paid for. Standard design is often only applicable to small-hydro projects where cost is the most important and efficiency is not. In most cases, the end-user gains no advantages from standardization. Standard design does not often fit well into the diverse small-hydro market and the consequence can be important energy losses. Rather than standardization, the key lies in rationalization, where the design procedures, the general arrangement, and most of the elements can be standardized, but the global size and primary elements (runner, high pressure part), have to be individually calculated and manufactured.

5.2 Design tools

Large hydro constructors have developed tools to assist in turbine design. These tools integrate statistical data to calculate the main parameters of the turbine and propose geometry for all the parts of the machine. The development of these tools on the PC makes it now possible to develop such tools for small-hydro projects, and not only for turbines, but also for supply canals, inlet gates and grids, draft tubes, etc.

The same kind of tools can be proposed for rehabilitation projects via reverse engineering techniques.

5.3 New materials

Research into the use of newly adapted low-cost materials in small hydro is required. Some possibilities include rapid machining steels with good characteristics for cavitation and/or sand erosion, materials such as ceramics to protect sensitive areas against erosion, low-cost machine components made out of plastic, glass-fibre, etc. The use of plastics in some part of the hydro machinery has already been studied with a limited success.

6 Electrical engineering

6.1 Generators

As stated earlier small-hydro projects suffer numerous handicaps related to the size effect, primarily, when rated power decreases, the power-to-volume ratio increase and the losses-to-power ratio increases.

Using higher performance materials (for example, high performance magnets for synchronous machines) may improve the efficiency, but would also increase costs. Increasing the constraints on materials (ex. using a more efficient cooling and/or a higher operating temperature) may also reduce costs, but the efficiency would decrease.

Two main types of generators are used in the small-hydro industry:

Asynchronous generators: very similar to the ones currently used in industry, these are the most robust and the least expensive. Their main disadvantage is that they require reactive power to magnetize the machine. This power has to be supplied by the grid or by static capacitors.

Synchronous generators: these have a better efficiency than the asynchronous generator, but their cost is higher. Also, the control of their rotor excitation implies the use of more complex and more expansive regulating device.

These two types of generators are very well known throughout the industry and have already received improvements to better adapt them to the demands of the industry. Appreciable cost reductions from more R&D are uncertain, the benefits of developing suitable, cheap to manufacture, multi-poles generators to eliminate gear-boxes in low head applications need to be better understood.

6.2 Variable speed

The adjustment of turbine speed allows for maintenance of maximum turbine efficiency regardless of operating conditions (flow, head). However, as electrical power has to be supplied at constant voltage and frequency, an electronic frequency converter must be used, which implies an additional investment as well as a certain loss of revenue. The economic balance of such a solution has to be carefully studied in terms of both the turbine characteristics and plant hydraulic variability.

It should be pointed out that in such projects the standard voltage-frequency regulation is modified. This can result in certain advantages, for example creating a better stability of the process.

Variable speed equipment would allow for the efficient use of fixed blade propeller turbines at variable head and speed. The application range and the resultant benefits need to be better understood through demonstration. This could involve transfer of technology from wind energy applications to small-hydro applications.

The European programme confirms the effort made to present projects with variable speed and frequency converters.

6.3 Control and monitoring

In recent years, most small-hydro projects have employed personal computers for system control and monitoring. Specific software can be used for data collection and remote control of the plant. The application of intelligent electronic devices (IED) for operation, closed loop control, protection and monitoring offers cost-effective solutions. The use of a wired or unwired telecommunication link to a regional control center for remote control and monitoring also encourages cost-effective maintenance strategies.

Some innovative projects able to operate both in connection to the grid and as isolated sites have been presented to Thermie.

6.4 Strategic orientation proposals

In his paper, *Technical Discussion: Electrical, Control, Monitoring, and Governing (1998), Prof. L. Pierrat*, proposes to focus for small-hydro R&D:

- Reduction of project diversity by selecting a power domain and small-hydro plant type that has similar characteristics and a sufficient energy potential.

- Implementation of all accessible technical and technological hydro-electric conversion innovations
- Integration of all functions into one set with good energy production characteristics, large performance flexibility, high operating reliability and minimal impact on the environment.

This concept of integration and modularity constitutes an innovative response to the technical standardisation needs.

7 Civil engineering

The cost of civil engineering represents a major portion of the total cost of a small hydro power plant, often more than 50% (including the penstock in the case of high heads). Nevertheless, in the European study, few innovations were proposed in this area. Only the use of inflatable weirs appeared in the contracts as a more or less innovative solution. However, a case study prepared by ADEME has demonstrated that in the studied cases, the use of inflatable weirs instead of standard weirs did not improve the economic balance of the project.

M. Celso Penche, in his paper *Status of R&D programmes in Civil Engineering and Environment,* proposes that civil engineering in small-hydro is too conservative and expects that few advances can be expected. However he does outline that advances have occurred in the use of *geotextiles*. Particularly applications such as weir construction, daily storage lagoons, and drainage under the power canals to prevent landslides can benefit from the proper use of those materials.

Penche proposes several topics where more research could be completed, including:
- Problems of *sediments sluicing*, especially in high head sites, where silt can destroy turbines runners very quickly;
- Appropriate screening systems for downstream migrating fish and in particular for eels. Studies into these areas have been undertaken in Canada, the USA (DOE Idaho studies), the UK, France (CEMAGREF, M. Larinier).

Of the total cost of civil engineering, the cost of penstock development can account for almost 50%. Research into reducing the cost of this element of the plant would directly result in increasing the cost-effectiveness of the plant. For example, different penstock materials have been studied and it appears that the use of fiberglass can be cost-effective up to 2 MW power. Powerhouses also have to be studied to ensure that they are integrated into the local environment and soundproofed at a moderate cost.

8 Conclusion

Based on the proceedings of the Nice Workshop assessing further small-hydro R&D opportunities it is clear that small hydro is not as mature a technology as it is sometimes argued. Though quite advanced, small-hydro research and development are still necessary to improve the industry and let it benefit from new technologies. The following section summarises the main topics proposed for further small-hydro R&D.

9 Summary of recommendations

9.1 General Topics

- Improve the development and availability of digital orthophotography, accurate hydrological data, remote sensing techniques, low-cost flow measurements, and residual flow/appropriate flow regimes.
- Develop education and training programmes aimed at small-hydro manufacturers and customers to improve turbine design, on-site testing procedures, and control system theories.
- R&D support of low-cost, low-head, equipment to overcome economic handicaps often experienced in small-hydro.
- Improve technologies for use in water supply and irrigation systems for small-hydro production.

9.2 Overall design

- Improve R&D efforts that are aimed at minimizing ecological impacts (ex. fish passages, reservoir operation, power-house, landscape integration, etc.)
- Advancement of the ‘global model’ for small hydro that optimizes all parts of the plant in an effort to reduce operation and maintenance costs.

9.3 Turbines

- Improve standardization of design procedures, general arrangement and other elements of the turbine to reduce costs.
- Further development/refinement of software to be used for calculation, manufacture and turbine design.
- Further research into the use of newly adapted low cost materials used in turbine construction.

9.4 Electrical

- Further R&D with the aim of reducing development costs of multi-pole generators.
- Improve the use of variable-speed equipment in small-hydro projects to offer a better understanding of the application range and resulting benefits.
- Further the application of computer based control and monitoring of the small-hydro system.

9.5 Civil engineering

- Further research into desilting methods and development of desilter technology.
- Further development of appropriate screening systems for migrating fish and eels.
- Improved research aimed at reducing penstock costs.

10 Available Papers from IEA Nice Workshop, October, 1998

The following papers are available from the *Small-scale Hydro Energy International Locator Atlas* website at www.small-hydro.com. All of these papers were presented at the *IEA Workshop – Assessment of Further R&D Opportunities* in Nice France in October of 1998.

Author	Topic
ALLINGTON, Mark	Small-hydro research and development in Europe
BREKKE, Hermond	Mechanics for small hydro
ISAMBERT, Freddy	Dépouillement des dossier Thermie
JIAN DONG, Tong	Chinese government continuously gives energetic support to medium and small hydropower in rural areas
KUENY, J.L.	Hydraulic engineering : objectives for small hydro technology
KUMAR, Arun	Assessment of further opportunities for development and application small hydro technologies
PAUWELS, Henri	Orientations générales des programmes de technologie énergétique de la Commission Européenne dans le domaine de la petite hydraulique
PENCHE, Celso	Status of R & D. programmes in civil engineering and environment
PIERRAT, Lambert	Technical discussion : Electrical, control, monitoring and governing
TIAGO, Geraldo	Politics of development of small hydropower plant in South America
TUNG, Tony	Canadian small hydro technology development programme and international development and collaboration opportunities

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