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Hydro-electric Power - potential and limitations.

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Introduction.

This paper focuses on efficiency improvement in electric power production by matching the different characteristics for thermal power and hydropower. The paper introduces **secondary hydropower**, it is: available power stored as hydro-energy in water reservoirs, as a key element to achieve this goal.

With reference to accessible crystal balls no new energy source will be commercially available in the next 25 years. We know what we have and have to act accordingly. Thermal power, including nuclear power is, and will be the main contributor, about 85% of the total power produced. The remaining 15% will be hydropower.

Renewable power's contribution is less then rounding errors in the accounting above.

It is a general understanding that the combustion- and nuclear processes involved with heat production have serious disadvantages due to emissions causing greenhouse effect, radioactivity, etc.

The paper also discusses, in a meditative way, the iron-locked connection between GDP and power consumption. As it also is a general understanding that GDP has to increase to accommodate the worlds growing population the unavoidable conclusion is that we have to produce more power.

> **GDP**
> Gross Domestic Product
>
> Total production of all goods and services by the subjects of a country and foreigners within national borders.
> (WEC)

The ownership of secondary hydropower installations is discussed. Are they a responsibility for power producers, power transmission agencies or are they a part of demand side power management? As long as these questions are unanswered efficiency improvements will suffer.

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Power.

The physical phenomena.

To be able to describe the qualities of the different power-production processes it is necessary to define **Power**. The following definition (see Power-frame) is related to this paper, but is not in contradiction with the accepted definition of electrical energy used by WEC.

In relation to *power production and transmission* power is the final energy. Secondary energy is an intermediate stage in the conversion process.

Final energy in other relations may be heat or low voltage electricity transformed from power. This is depending on the process or the type of energy demanded.

<u>Power must be produced and transferred in the same instant it is used.</u>

Power also have to be defined as a commercial product. This will be dealt with in another section of this paper.

> **Power**
> is high voltage electrical energy produced in power-plants and transferred to the customers through transmission-lines and cables.
>
> Depending on the primary energy-source we have
>
> **Thermal power**
> Coal power
> Gas power
> Nuclear power
> etc.
>
> **Hydropower**
>
> **Renewable power**
> Small hydro < 5 MW
> Wind power
> Wave power
> Solar energy
> etc.

Thermal power.

Thermal power is characterised by a process converting chemical or nuclear energy to heat.

Converting fuel, fossil or nuclear, to heat is not a "clean" process and is considered to be the most critical processes in the world to day due to negative environmental effects.

Heat can be compared to the potential energy in water in a power-plant reservoir, but in contrast to water-energy it is not possible to store significant quantities of high temperature heat for long time without considerable losses.

The "parade" efficiencies for the process of converting heat to power in combined cycle gas turbines are up to 55%. This efficiency is referred to single plants operating under optimum conditions. Mean efficiencies, considering the mix of different thermal power generating systems in operation are much lower; around 35%. Energy used in fuel production is not included.

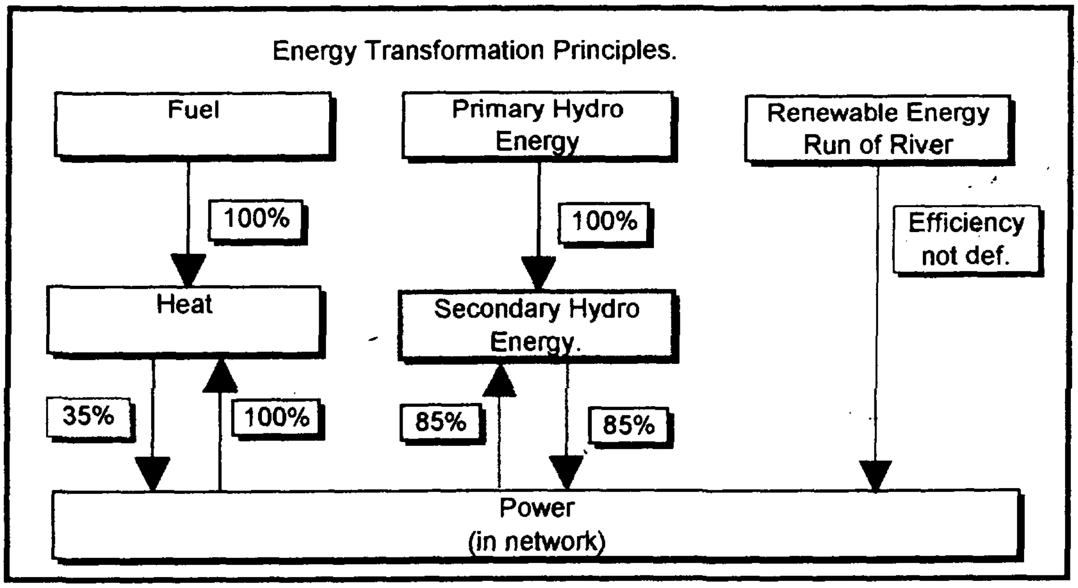
The efficiency of thermal systems is very dependent on the operating temperature. High and constant temperature is necessary to reach acceptable values. Load variation is followed by temperature variations. Because of mechanical and material problems the rate of change of temperature must be kept within certain limits and is therefore restricting the operation severely. In addition complicated exhaust gas cleaning systems and cooling systems tuned to nominal conditions will suffer in off-peak operation.

Efficient operation is consequently connected to nominal load. Load variations should be taken care of by other means. For instance: demand side load control and converting excess power to hydro-energy by pumping. Normal technique used, to be able to respond to fast load increase, is to operate with throttled, but quick opening steam inlet. Throttling spoils efficiency.

Hydropower.
If we consider the processes involved with production of power from natural water the fundamental process is a solar-driven cycle. The man-controlled part of it starts with collecting water from rain and rivers above a reference level and store it in reservoirs for use in hydropower stations. The natural free running water-resources are ***primary hydro energy;*** in contradiction to fossil fuel it is renewable but otherwise comparable to fuel in a thermal process.

The power-plant with dams, reservoirs and power-lines will have both positive and negative effects on the local environment. Development of large dams at rivers with special touristy qualities has attracted very much attention and given rise to a negative opinion to hydropower. Environmental effects from hydropower development is local. People may have to move from dam-sites, flora and fauna will be stirred. On the other side; irrigation, navigation, flood control and increased fish production indicates positive elements related to hydropower development.

The primary hydro energy is converted to ***secondary hydro-energy*** when the water is stored as potential energy in a reservoir connected to a power-plant. Secondary hydro-energy is equivalent to heat in the thermal process. Hydropower plants with insignificant storing capability producing power at a pace set by natural conditions is called ***run of river*** plants.



*The unique qualities of **secondary hydro-energy** are: It is stored energy and the process of converting secondary hydro-energy to power runs equally well in the opposite direction. Both with mean efficiencies around 85 %, all losses included.*
The rate of change of load has very few limitations.

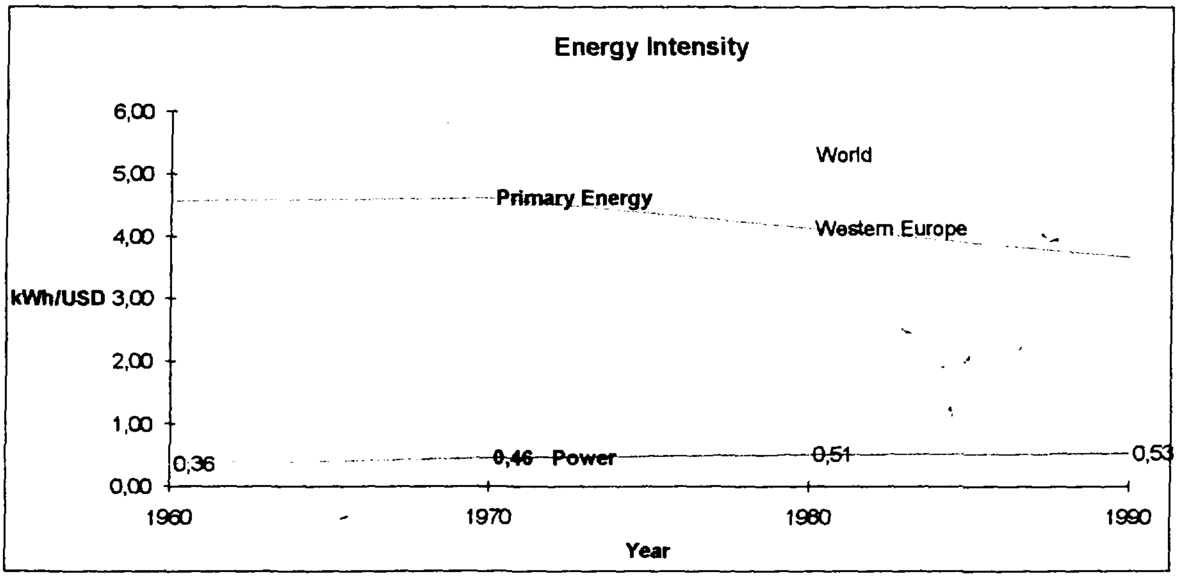
Secondary hydro-energy is a part of a man-controlled cycle.

Renewable power.
Renewable power is mostly non-commercial power due to very small quantities and irregular deliveries. Renewable power can be commercialised if the power is fed into systems with secondary hydropower qualities. Feeding thermal power systems will increase the load variation problems. Due to the small quantities the effect will be negligible.

Power.

- is a refined energy product.
- is easy to transfer and distribute.
- can be converted to heat with high and low temperatures.
- can efficiently be converted to/from mechanical energy.
- can be transformed to low voltage electrical energy
- is input in electrochemical processes.
- can be converted to secondary hydropower.

Power consumption development.
Power is a refined energy product. 38% of the worlds primary energy consumption is used for power production. Statistics show reduced total energy consumption related to GDP, ***but increased power consumption!*** See figure below. Awareness of environmental problems has trigged technology development and increased the general public attention giving that result.



WEC. **Energy Intensity:** The proportion of energy used to Gross Domestic Product at constant prices, changes in which being taken as a measure of energy efficiency shifts.

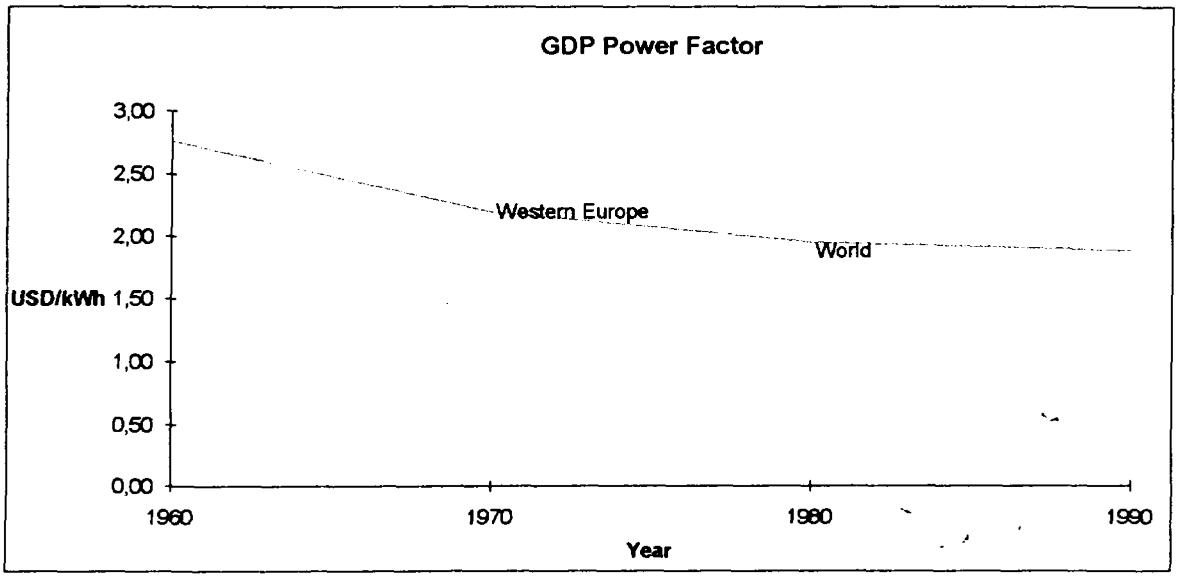
New methods improving efficiency tends to shift energy consumption to power due to much better controllability. Energy systems controlled with fans, pumps and compressors, space heating with heatpumps, etc. use less energy totally, but the electricity share is bigger. Important infrastructure-related activities and processes use electronic and electrical equipment. Examples are communication systems, computers, medical equipment etc.

Power has no substitute and is a critical factor in relation to GDP. GDP is a measure for activity. No activity without energy. We have no substitute for power, but on the other hand power can be converted to almost any other type of energy with efficiencies close to 100%, as heat, mechanical energy or secondary hydro-energy. Conversion of power to heat cannot be considered to be a rational process as long as the opposite process is the most critical process in the World to day because of emissions from combustion- and nuclear processes.

Consequently it is not possible to reduce or restrict power consumption without accepting a reduction in GDP.

If we consider Norway in relation to that we find that much hydropower is converted to heat and that energy conservation programs are pushed very hard from all political parties. Reduced hydro to heat conversion and increased efficiency on production and demand side releases power and boosts new activities. It is consequently reasons to believe that the Norwegian ENØK-programs (or any other similar program) will stimulate growth in GDP counteracting the intended reduction in power consumption.

kWh, the basic currency?



GDP is measured with an inflation-adjusted currency as USD, NOK, ECU etc.

If we measure a distance, an area or a volume the size of the measured object is of course not dependent of the measuring unit applied, as meter or inch. The measured objects normally also has other qualities then size. E.g. shape or colour. If we define the qualities of our object it can be fully described by one characteristic dimension. A 6" polished stainless steel cube indicates a cube with 6" sides made of stainless steel and polished. In an environment where this type of cubes are dominating they will be named as "6-inch" or "5-inch".

If we return to GDP and the diagram above the "Power-factor" showing USD output per kWh power input is such a characteristic dimension in relation to GDP because the diagram indicates that the factor is stabilizing around 2.0 USD/kWh.

GDP is therefore tending to be proportional to power input.

With proportionality between input and output, **1 kWh** could also be considered as a unit for measuring GDP, a global currency. (1 kWh = 1 ECU = Electric Current Unit !?)

Even if these meditations could be considered as not quite serious they indicates qualities connected to GDP that has to be taken into consideration when discussing GDP and Power. For instance: power price only indirectly influences GDP.

The practical version of these statements is that GDP should be expressed in terms of power, and not in USD or another national currency, because power represents the most critical element in an activity-factor like GDP.

A GDP like that will reduce the incompatibility between wishes and actions and force discussions in the directions of realistic and acceptable standards for life or living.

Hydropower Potential.
Primary hydro-energy.
Norway.
The Gross Theoretical Potential is 560 TWh; calculated by considering, area, levels and precipitation in a reference year. The exploitable potential is restricted to technically, economically and politically feasible sources. Today it is around 150 TWh. Most probably this potential will be affected by changed operational strategies due to the commercial situation in the Norwegian power market created by the Energy-act of 1991.

Total output can be increased by better coordinated production without changing the primary energy-base. Due to different location production and demand characteristics will vary. If each power-plant defines its own characteristics it is possible to match them into an optimal group. To utilize this extra potential power transmission capacity must be increased and installed capacity in the power-stations will also have to be adjusted.

The development of hydropower sources in Norway started around the turn of the century. Developers attacked at that time an estimated potential of 40 TWh. Power transmission technique was among other factors limiting the potential. As time has passed the potential has gradually increased and is now estimated to 150 TWh. Environmental concerns have become the major limiting factor.

Studies indicate that a future acceptable combined potential related to optimisation of existing production systems and developing new sites might exceed 200 TWh.

World.
The world-wide exploitable potential for hydropower exceeds 14 000 TWh. It is accidentally the same as the World's total power consumption today. Around 18%, or 2500 TWh of this potential is utilized. The Gross Theoretical Capability is estimated to around 36 000 TWh.

The limelight on hydropower development has been reflected from power-plants with controversial large dams. If we turn the light to the huge number of uncontroversial sites and sites with marginal environmental problems and adopt technique, tools and experience developed in Norway during the last 100 years hydropower could cover a fair share of the future increase in power demand. Norway has specific experience related to sites with very high heads. Unlined pressure tunnels, tunnel blasting and drilling, air cushion chambers for dynamic control of long tunnels, super high head Francis turbines are among the specialities worth mentioning. High head power plants with outputs around 100 MW will represent less financing problems because investments will not be dominating in aid-budgets or in the local economy in the region where the construction take place.

Entrapped hydropower.
Many hydropower sites are geographically located in an area with no reasonable access to a power transmission network. The power transmission technique still has limitations. In such cases it has to be considered if energy-intensive industry could be relocated to the power source. This will in case be a continuation of what happened during the start of the hydropower era when industrial activities grew up in close connection to a hydropower plant.

If we consider Norway's energy profile in relation to the rest of Europe's and suppose that satisfactory interconnections are in operation, it is obvious that making energy intensive products in Norway based on clean hydropower will "force" the rest of Europe to increase production of thermal power, resulting in emissions transported back to Norway by the wind and a reduced GDP in Europe including Norway. This is in accordance with the conclusions drawn above where GDP should increase if power is shifted to more critical activities.

Secondary hydropower.
Secondary hydro-energy technique is the only technique available for improving interconnected power-generating systems efficiency. By implementing this technique the increased thermal power output due to higher efficiency, increased output from run of river power- plants or other power-producing units relying on natural cycles can be considered as a secondary hydropower potential. European thermal power output is around 2100 TWh and the difference between maximum attainable efficiency and mean efficiency is about 20%, representing 420 TWh. Optimizing the operation dynamically and stationary by using the secondary hydro power resources could increase the output by 5-10% with the same primary energy input.

The primary hydropower production in the European area is also around 420 TWh. A reasonable part of the yearly rate of growth in power demand can be realised through secondary hydropower development.

Power.
The commercial product.
It is a general agreement that splitting power production and power transmission systems into separate economical units with access for any party to the transmission system will stimulate competition and knock out inefficient activities.

To understand more of the underlying problems and advice solutions to improve efficiencies it is necessary to discuss the difference between power treated as a commercial product and power or electricity used as an energy source always available at your personal plug-connection.

Trading of power is characterised by contracts defining volume and delivery time in addition to financial and economical details. But it is not granted that the sum of all contracts will satisfy the actual demand in the market at a specific moment. The Norwegian Power Bourse fastest market element has a response-time down to 15 minutes, but power production systems have to respond within fractions of seconds to satisfy the physical conditions at your plug-connection. If not, the distribution network will collapse. This is due to the fact that power has to be produced and transferred in the same instant it is used.

The conclusion is that the power market system must rely extensively on technical installations in power stations as well as on perfect power transmission networks and interconnections. The responsibility for the dynamic qualities necessary for a power network system to function is placed in the lap of the power producer. But the capability to support a network dynamically is not considered as a power product and therefore not given an adequate price!

Power transmission systems and services have been defined as a natural monopoly. If we consider a transmission system to be limited to a nation this will work. Investments and operational cost is consequently covered more or less automatically. Power production units operating in a competitive market do not have the same possibility. Dynamic response and power-storing capabilities is not defined as a product and no incentives for investments exists. At the same time most of the potential for improving system efficiency is in connection to the difference in dynamic and energy-storing capabilities for thermal power and hydropower.

Many Norwegian power-plant owners have invested in expensive air cushion chambers and surgeshafts to improve dynamic characteristics. A wrong investment or foresightedness? The answer is not as obvious as could be expected.

Visions and hindrances.

The obstacles to increased power production efficiency is political and strategical restrictions on power trade and interconnections and inadequate cost estimation of primary energy. Also due to local political strategies.

Interconnections between national systems crossing other nations area, can be used as a mean to apply political pressure on the parties involved just by opening and closing switches. To secure positions restrictive conditions are laid down on crossings. It is simply not politically acceptable to be dependent on power-supplies through interconnections.

No technical obstacles exists.

> **Interconnection.**
> The connection, by one or more lines, between two or more networks or parts of networks, and the equipment for such connection.
> (WEC)

To release the secondary hydro potential it is necessary to connect systems with different production- and demand characteristics with really high capacity power-transmission lines or cables. Within this integrated system it will be possible to balance production with demand better than today resulting in increased efficiency and better economy.

This has at least been apparent since 1915 when a submarine cable came into operation between Sweden and Denmark. Interconnections between Norway and Germany and a European integrated network was proposed in 1930. About 8 years before that submarine DC-cables from Norway to Denmark had been proposed.

Hydropower "alternatives"

The NORDEL area.

The European Power Bank.

Up to now Denmark, Finland, Iceland, Norway and Sweden have co-operated in power-management with a mutual benefit. Iceland has participated as an observer. Norway, Sweden and Finland with a spread population and a high share of hydropower rely today very much on energy distributed as power. These systems dominated by hydropower could be developed to a capacity able to match the European systems (including Denmark) with gas and power interconnections and play an active role in power trade in Europe. Norway's reservoirs totalling around 80 TWh would be a vital part of this system, a power bank. Capacity for secondary hydropower will have to be increased in the region, it is anticipated that Norwegian topography offers the best possibilities. It is not unrealistic to believe that the next ten years will show interconnections terminating in Norway increasing to a total capacity of ± 15 GW. (1 GW = 1000 MW).

> **Load factor**
> The ratio of consumption within a specified period (year, month, day, etc.) to consumption that result from continuous use reflecting maximum or other specified demand occurring within the same period.
> (WEC)

Todays generating capacity in Norway is close to 27 GW matching the primary hydro energy developed with load factor 0.5. To meet the requirements for flexible capacity backing the interconnections it will be necessary to reinforce the installations in many Norwegian hydropower-stations. Preferably with pumpturbines. In addition a system for central continuous valuation and setting of governor parameters will be necessary.

Dynamic network support.

As the NORDEL area's capability to respond to power and frequency variations is mandatory in this concept, all interconnections between the local transmission systems in the area and to the thermal system should take place via frequency independent links, AC-AC or AC-DC links. These links will guarantee support during power failure by accepting asynchronous operation. Frequency and load control will be improved considerably and also allow thermal power plants to reduce throttling losses.

Down-town "Power-batteries."

A region with thermal power production capacity and normal demand variations can benefit from hydropower technique by constructing completely underground secondary hydropower stations located in the gravity-point for consumption. These high head, high capacity power-stations with both upper and lower reservoir underground can take over fast frequency-related load control. The operation periods would be very short, we are talking about minutes, until other generating units with longer reaction time can take over. Power is accumulated in the "batteries" by pumping. Peltonturbines running idle, connected to the network is able to pick up *unexpected* load increase in fractions of seconds and stabilizing the network until other units can take over.

By increasing the artificial reservoirs secondary hydropower-stations like that could take part in the load control connected to the daily demand-cycle as well. This is principally a similar problem, but the expected load variations have low frequency and could therefore be compensated by the commercial power-exchange systems. Special dedicated dynamic network-supporting units of the type as mentioned above could be installed in the underground power-station utilizing the same reservoirs.

Shifting investments from peak thermal power or transmission lines to local secondary hydropower will increase thermal power generating efficiency and reduce transmission losses. The cost of underground secondary hydropower units located close to consumption centres must be compared with cost for natural sites including additional transmission capacity. Politically this should be acceptable because regional self-supporting is obtainable.

Kværner is considering developing secondary hydropower at different places in USA and has been granted FERC licences for two projects. Both projects is in connection with abandoned very deep mines, but with upper reservoir on the surface. To increase the head to an optimum for one of the projects a new lower reservoir will be excavated on a deeper level than the original mines. The installed capacity is planned to be ±2500MW and ±3000MW, ± because of both generating and pumping.
But completion of the projects moves slowly because of problems related to the definition and acceptance of the power products offered.

Combined Heat and Power.
Combined production of Heat and Power (CHP) is considered as a possibility to increase energy output in thermal power systems. Heat is distributed in District Heating (DH) systems as hot water or steam which limits the selection of power station site to densely populated areas. This potential is only available if heat and power is requested at the same time. The relation between the volume of heat energy offered and the power produced is connected to the efficiency of the specific thermal process. Efficiency is normally defined as power output related to heat input, but if low temperature heat is considered as output the total "efficiency" will be better. A CHP potential is also found in many industrial processes where heat is a necessary part of the process. Power is produced in addition to heat increasing the useful energy output.

In relation to CHP, size, type and location of generating units, as well as distribution and heat storing systems are areas for both political consideration and technical R&D.

Without considering volumes or economy in relation to CHP it can be stated that the fundamental problem is balancing heat and power output maintaining a high efficiency. The problem can be solved by energy storing and export/import to the district in question. Transmission and storing of access power is an available alternative, but storing of heat do not have the same flexibility. During temporary mismatch between heat and power demand an optimal solution may call for converting imported power to heat, preferably supported by heat-pumps utilizing local low-temperature heat-sources. Exchange of energy between districts is only possible as power.

Again secondary hydropower has the possibility to absorb access power or deliver extra power in case of unbalance.

More thermal power?

Even if the CHP potential is utilized 100% the need for power will not be satisfied. In other words; it will always be an over-production of heat. Special high efficiency baseload power generating units has still to be built. Type and location criteria will be related to access to *primary energy, power transmission, power storage and power transmission network security.*

Technology development.

Hydropower technology is a mature technology, but promising improvements can still be made, particularly in the field defined as **secondary hydropower** in this paper, with profound effect on power supply in the network.
For the time being, market incentives on R&D work in this interesting field is lacking, and the efforts on R & D work is modest and occasional . This is the case in spite of the fact that the key properties of **secondary hydropower**, the dynamic and storing capabilities, are properties on which the operation of a power network is fully dependent.
The cause for these conditions might be found in the commercial agreements between power suppliers, network operators and power consumers, where these properties are not specified and, consequently, not given a price. In reality the properties are "offered" as a "free service" from the power suppliers.

As long as such services do not represent a business potential, most probably there will be no *incentives on R&D work in the field* .

Who will solve the problem ?

To provide a power network with these important properties, the dynamic and storing capabilities, losses are unavoidable, both on the production side and on the consumption side. **Secondary hydropower** represents the most efficient, loss-saving and practical tool to increase significantly the power output in the network without feeding into it new, primary energy. The more this tool is implemented, the more thermal power systems can operate constantly at peak efficiency and even the run of river and renewable energy systems can funnel all their available primary energy into the network without disturbing side effects.
It is not, however, easy to see which one of the involved parties: the power producer, the network operator or the power consumer, is the closest to make this tool a commercial asset. It looks like secondary hydropower is a part of the power transmission systems, and consequently a part of the same natural monopoly as power transmission. Secondary hydropower will also give the transmission-system operator a practical tool to secure the quality of power.

The *problem has commercial as well as practical and political implications.*