The current status of hydropower development and dam construction in Norway

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With a topography characterized by high mountain plateaux, numerous natural lakes, steep valleys and short distances to the sea, Norway is, almost perfectly, made for hydropower. As is the case in many other industrialized countries, Norway had a peak for hydropower development after the second world war up to the early 1980s. Political support for renewable energy, with a view to limiting releases of CO_2, the potential for power exchange with other countries, changing market conditions and the requirement to upgrade old hydropower plants are triggering a new busy period for hydropower development in Norway. Hydro development is still the main reason for dam construction in Norway.

The introduction of the free electricity market in Norway from 1990 followed a decade of extensive work, during which Norwegian hydropower potential was mapped, and a feasibility study was done for all the schemes to document the energy and power potential, as well as economic and environmental impacts. During this period, decisions were taken in the Norwegian Parliament on two conservation plans for watercourses. The activities in the late 1980s resulted in very few applications for hydropower licences. The creation of the Nordic electricity market operated by Nord Pool then turned the hydropower sector upside down. Dedicated development for a specific industry or for specific regions ended, and during the period of the enactment of the Energy law in 1991, some of the largest hydropower schemes in Norway were commissioned. Years with heavy precipitation followed, which allowed for high levels of electricity generation, and this was released into the market. Prices fell to levels far below the cost for new hydropower, and Norway started a support scheme for upgrading of the oldest hydropower plants. From the mid-2000s, energy prices rose as a result of increased oil prices and future expectations for energy prices; the system price is shown in Fig. 1.

Influenced by the global financial crisis, prices dropped again from 2011 because of stabilized electricity consumption and increased electricity generation from other renewable resources.

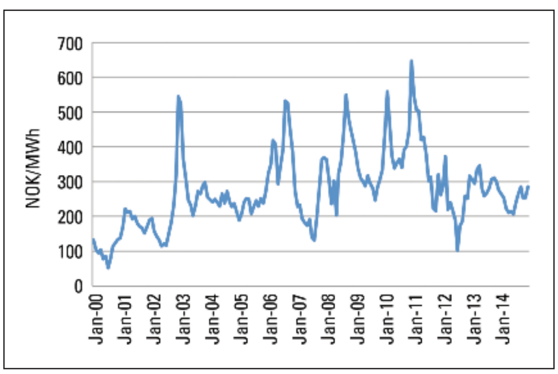


Fig. 1. Electricity prices for the Nordic market in the period 2000 to2014 [Nord Pool Spot, 2014[1]].

Since the beginning of the 21st century, the development of small hydro has been preferred in Norway mostly for political reasons, and because of national screening and studies for small hydro. Studies between 2002 and 2004 by [NVE, 2015[2]] showed that 25 TWh/year could be generated. The trend for 'small is beautiful' provided a lot of incentives for small hydro development, and the significant rise in energy prices shown in Fig. 1 led to a new era for hydropower development. According to Skau [2011[3]] this trend resulted in the construction of 25 new hydropower plants annually from 2005. The implementation of the EU Directive on Electricity Production from Renewable Energy Sources [EU, 2005[4]] in Norway in 2005 triggered more activity to fulfil the commitment of increasing the electricity production from renewable resources to 13.2 TWh/year by 2020, which is equivalent to the Swedish commitment in the same energy market. To achieve that goal, certificates for renewable energy were introduced. The value of the certificates is set in the stock market, this works together with the electricity market. The Renewable Electricity Certificate market is technology neutral, and has boosted activities in the development of all kinds of hydropower.

The increasing average age of large hydro plants and dams in Norway, currently 46 years, is meanwhile triggering upgrade projects throughout the country. Many projects are extended during the upgrade and according to Aas [2014[5]], a potential increased generation of 10 to 60 per cent has been gained by upgrade programmes over the last 15 years. From an environmental point of view, upgrading is considered the most favourable kind of project, as the environmental impact is small. Projects related to the upgrading of dams are now significant in number, and these are stimulating a great deal of activity in the business.

As a result of climate change, Norway now has more rain in its river systems than in the past. This increased precipitation has clearly had consequences for hydropower generation. The precipitation data for recent years has been analysed to calculate new predictions for runoff in rivers, based on the precipitation levels in 2000 and 2010. The latest 30-year hydrology period demonstrated an increase in mean annual generation of 4.7 TWh by 2000, and another 4.3 TWh by 2010. This suggests that the national generation capacity will achieve security of supply. Today, the total hydropower generation capacity based on the averaged runoff of the 1991 to 2010 normal period is approximately 132 TWh/year which is about 95 per cent of total generation. The flexibility of the hydropower generating capacity is guaranteed by a total reservoir storage capacity equivalent to 86 TWh/year. This means that one dry year is not critical: inflow one year of less than 90 TWh/year of production can be compensated by using the reservoirs, and inflow another year equivalent to 155 TWh/year means that water can be stored.

Because of the durability of hydropower and the future trend for renewable energy, foreign investors are now positioned for investments in hydropower. New investors will probably increase the value of the hydropower and new projects may be released despite the strict legal limitations for foreign ownership of hydropower in Norway. Investments in projects < 10 MW will rarely be influenced by such limitations.

Hydro plants currently under contruction in Norway will produce 1.4 TWh/year. Small hydro projects dominate in number, but schemes to upgrade existing plants dominate in terms of capacity. Of the projects with capacities > 10 MW, only about 30 per cent are new schemes.

1. Small hydro

Small hydro in Norway is defined as < 10 MW, and in this article very small projects (< 1 MW) are not covered. As explained above, increasing energy prices and political support boosted development from 2004, when NVE launched the country-wide mapping for potential small hydro sites. Development activity is predicted to increase significantly up to 2020, when the period for electricity certificates expires. According to Skau [2011[3]] and Norwegian Water Resource and Energy Directorate, NVE [2015[2]], 234 new small hydro projects were commissioned between 2001 and 2010. The actual numbers of projects in subsequent years were 34 in 2011, 41 in 2012, 25 in 2013 and 27 in 2014. During the same period, 397 new projects larger than 1 MW were commissioned.

The usual design of small hydro plants, with shallow intakes, penstocks and outdoor powerhouses, is based on well proven technology. Fewer than 5 per cent of the new small hydro projects are licensed for storage and there will consequently be a number of run-of-river projects. Most small hydro projects are designed for high heads, and therefore to be equipped with one Pelton unit or two high-head Francis units. Dams are

(a) Dam and intake structure for the Væla hydro plant.

(b) Typical construction of a penstock for small hydro.

constructed with site-specific features, to reduce environmental impacts, reduce costs, with an intake pond to address ice problems, the withdrawal of air, blocking of trashracks, stability for the turbine governor, and so on. Most dams are constructed as concrete gravity, flat slab dams, or as arch dams because of the required spillway capacity in the case of a narrow dam site. So far no large dams (> 15 m) have been constructed for new small hydro projects in the period 2010 to 2014. Typical construction work for a new intake dam is shown in Photo (a).

Hydropower schemes with intakes in small ponds require a high level of understanding of hydrology, and they involve construction and operation constraints which can be addressed through research. Since 2000, NVE has supported studies on new hydrological models and maps to enhance the planning of unregulated hydropower. New construction technology has been developed, for example, drilling technology to replace surface penstocks. There has also been research into environmental issues, such as fish migration.

An example of recent innovation is the construction of low-cost penstocks based on longitudinal anchoring of divided pipelines. A typical methodology, with buried penstocks, is shown in Photo (b). The longest penstock without any surge chamber was constructed in 2013 at the Usma powerplant, with a length of 5400 m.

To increase the reliability of new small hydro projects, innovative intake concepts are being used, for example, Coanda screen intakes, as well as various new concepts based on backflushing of trashracks [Nøvik, Rettedal, Nielsen and Lia, 2014[6]]. The focus on reliable intakes is currently increasing, because about 400 to 600 new small hydro projects are expected to be constructed over the next five years.

The situation today is slightly different compared with previous years. The electricity certificate market with Sweden started in January 2012 and this adds approximately 0.15 to 0.25 NOK/kWh to the price on the power market. Both markets will fluctuate, and for the time being, they are both low. The consequence of this is that many schemes are licensed, but have not been built so far. This is the case for 406 projects, and 488 projects are still in the pipeline for licensing by NVE.

The commitment to the idea 'small is beautiful' has also had some negative consequences. During the period from 2004 to 2012, many plants were built based on cheap technical designs and technology. The results are now showing, with more operational constraints

(c) A powerhouse for small hydro. Photo: Småkraft.

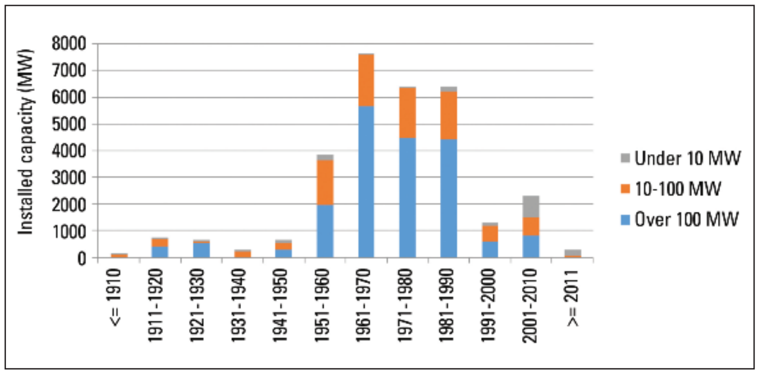


Fig. 2. Installed generation capacity in Norway [NVE, 2015[2]].

than previously anticipated, particularly with intake technology and mechanical and electro-technology in the powerhouses. The trend is that too many schemes (although not the majority) will have shorter technical lifetimes than expected, which will create a problem for insurance companies. The large number of projects with a licence which are not under development can be explained by the difficulties of obtaining loans, for a combination of reasons, including: conditions for granting the licencse; difficulties in getting insurance; and, low prices in both the electricity certificates and the energy market. A typical powerhouse for small hydro is shown in Photo (c).

As a result of the commitment given by the Norwegian Government to introduce 13.2 TWh/year of renewable energy to the European market by 2020, it is likely that developments will go ahead.

2. Upgrading and extension of existing hydro plants

The Norwegian hydropower system has been developed during a period of more than 100 years. The capacity growth in MW per decade is shown in Fig. 2.

As shown in this Figure, considerable capacity was installed between the 1950s and the end of the 1980s. Hence, many powerplants have reached an age when upgrading and extension are becoming relevant. This is, among other factors, because of the state of the existing mechanical and electrical equipment. New market requirements and design philosophies also triggered the uprating of capacity through upgrades and extensions. Power companies are continually considering new opportunities for renewable energy production, and the upgrading of existing plants can make an important contribution to increased production. These projects often have less environmental impact than new powerplants on unexploited watercourses. It is a policy of the Norwegian authorities to promote these opportunities. The economic potential as a result of upgrading and extension is estimated to be approximately 6 TWh/year.

Upgrading is defined as the implementation of measures relating to the mechanical and electrical equipment, to increase efficiency. Other types of upgrade projects involve tunnels, for instance reducing head losses by extending the cross-sectional area, providing a new parallel tunnel or penstocks, or other measures. Extension projects are more wide-ranging, for example including new catchment areas, increasing the size of reservoirs or increasing the overall size of installations.

In many cases it is found to be profitable not only to upgrade, but also to combine the upgrade with extension. The various economic and design criteria are now different from those which prevailed decades ago, and there are often incentives for extending the plants, and then upgrading with the installation of modern equipment or sometimes even by improving the layout.

Some examples of upgrading and extension projects in Norway are given next.

2.1 Hol 1

Mechanical upgrading has taken place at the Hol I hydro plant in Hallingdal, in the southern part of Norway. The plant originally began operation between 1949 and 1956, with four Francis units. The total capacity at that time was 190 MW. As a result of ageing of the plant, and hence wear and tear, the owner decided to implement a comprehensive upgrade of the generating equipment. New turbine runners, (see photos below) have increased both efficiency and the design discharge, and the total capacity is now 34 MW higher than before. Increased production is 20 GWh/year. The unit cost for the additional production (NOK/kWh) is high, but the investment is considered to be favourable for the future because with no upgrade, maintenance and rehabilitation costs would

(d) The old runner being taken out, and the new one on its way in, at Hol 1. Photo: ECO Vannkraft.

(e) The Kongsvinger hydro plant. Photo: Eidsiva Energi.

have increased considerably within several years. This demonstrates the point that it is important to find the appropriate time for upgrading. No new or renewed licence was necessary in this case, which is common practice for such projects in Norway.

2.2 Kongsvinger

A new parallel project was implemented at the Kongsvinger plant on the River Glomma (Norway's largest river) in southeast Norway, see Photos (e) and (f). The original plant was commissioned in 1975 with one 21 MW bulb generating unit, and a design discharge of 250 m^3/s. This is a run-of-river plant operating with a head of 10 m. The installation was quite small as regards mean inflow, but this was partly for economic reasons and power requirements at the time of the original construction. Following the owner's reassessment of opportunities for additional production a few years ago, the capacity was more than doubled to 43 MW in 2011 with the installation of one new unit (also involving a doubling of the design discharge). This reduces flood losses and provides 70 GWh/year of additional production. The necessary civil construction and assembly works were carried out while the old unit remained in continuous operation, in other words, without any production losses. As environmental impacts were very minor, a new licence was not required.

2.3 Iveland

The Iveland plant in southern Norway was commissioned during the period 1949-1955; it had three Francis units with a total capacity of 45 MW in a surface power station, and is now a similar example of a 'parallel project'. As at Kongsvinger, the design discharge was quite small. However, the capacity and production were sufficient to cover needs at the time of

(f) Draft tube construction at Kongsvinger. Photo: Eidsiva Energi.

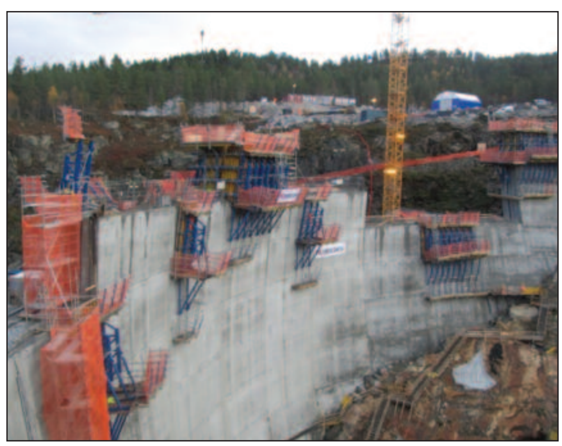
Fig 3, Illustration of the old (left) Iveland powerplant and the new parallel powerplant (right) with the respective tunnels.

commissioning. Fifty years later, the owner decided to consider possibilities to increase production. Two main alternatives were evaluated. The first was upgrading, with the installation of new turbine runners. Increased mean annual production was estimated to be 20 GWh, with a low unit cost. The second option was to double the capacity, with a new headrace tunnel and a new underground power station, in parallel with the existing ones. The original scheme will still be in operation, with upgraded generating equipment. This alternative provides 150 GWh/year of additional production. The cost per kWh is higher than for alternative 1, but the net present value (NPV) is also higher. Alternative 2 is now at the construction stage.

This project demonstrates that extension in combination with an upgrade can be a good solution. Parallel tunnels and powerhouses reduce risks and enable power production to continue during the construction period.

3. New large scale hydro

For political and environmental reasons, new large hydro development on undeveloped rivers is rare. The Norwegian Government is strongly commited to the protection of rivers. This commitment has been revised five times by the Government, which underlines the strength of the desire to protect rivers. But some rivers can still be developed with large-scale hydro. During the past few years, new projects have gone ahead, for example, at Øvre Otta (680



(g) Sarvsfossen dam during construction.

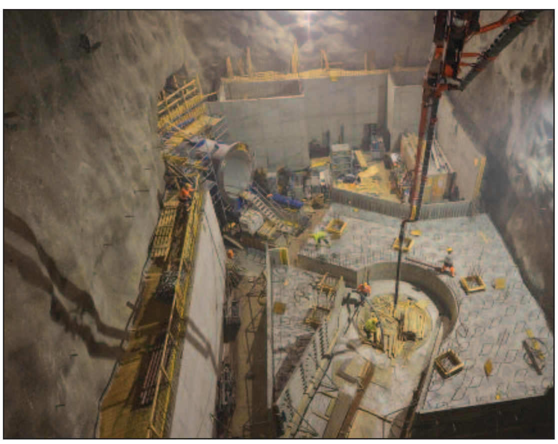
(h) The 7.2 m-diameter tunnel driven by TBM at Røssåga. Photo: Leif Lia.

GWh/year) and Kjøsnesfjorden (250 GWh/year). The most recent project is Skarg (70 GWh/year) which involved the construction of the 50 m-high double curved arch dam in Sarvsfossen (see also p44), 11 km of new tunnels and six secondary intakes. The project was completed in 2014. The dam during construction is shown in Photo (g).

An example of a large ongoing project on an untouched river section is the Rosten scheme (190 GWh/year) in the upper reach of the river Glomma. This project has a typical Norwegian design, with a long headrace tunnel, an underground powerhouse.

The most common large hydro projects, however, are on rivers which have already been utilized for hydropower. Current new hydro schemes on rivers already developed include Lysebotn, (370 MW, 1500 GWh/year) close to Stavanger, which has a completely new powerplant and tunnels; and, Røssåga (300 MW, 2150 GWh/year) in northern Norway, which involves a 7.2 m-diameter tunnel bored by a TBM, see Photo (h), and an additional powerhouse, see Photo (i). The third largest scheme at present is Matre, (180 MW, 610 GWh/year) close to Bergen, on the west coast. Those projects can be classified as upgrades, because they involve replacing existing generating units.

New large projects in the pipeline to be constructed in the future are Smibelg and Storåvatn in northern Norway (> 200 GWh/year), Nedre Otta (350 GWh/year, not yet licensed), Blåfalli Fjellhaugen (325



(i) The new 225 MW powerhouse at Røssåga.

(j) Møsvatnet dam before demolition of the existing concrete dam. Photo: Øst-Telemarkens Brukseierforening.

(k) Simulated image of new dams at Skjerkevatnet. Image: Sweco Norway.

GWh/year, not yet licensed) as well as several others.

The replacement of existing dams is becoming more and more common, examples being the 23 m-high and 800 m-long Stolsvatnet rockfill dam (2009) and the Møsvatnet dam (2006), a 28 m-high and 260 m-long rockfill structure. The latter is shown in Photo (j). These two dams represent a modern way of upgrading dams, involving the construction of a new dam and spillway downstream of the older one. This procedure allows for continuing power production during the construction period and reduces the risk of failure during construction.

There are some current projects involving the construction of new dams, for example the Skjerkevatnet dam project. This includes two large rockfill dams with asphaltic cores: the 50 m-high and 450 m-long Skjerkevatnet dam, and the 30 m-high and 590 m-long Heddersvika dam. The new dams form one large reservoir, by increasing the water level in the downstream reservoir. The dams are replacing one former arch dam, two multiple arch dams, and two flat slab dams in the reservoir area. The project, currently under construction, is shown in Photo (k). The 25 m-high and 330 m-long Namsvatnet rockfill dam is a similar project, also under construction.

Another growing realization is that many small plants with little or no reservoir capacity at all probably have higher environmental impacts per GWh than large hydro. Many small schemes with high heads, exploiting rivers from mountain plateaux, must compete with alternative solutions, for example diverting part of the river flow to existing hydro plants with reservoirs, thus increasing the storage capacity. The generation from these large plants has much higher value for society than generation which depends on the availability of adequate river flow at any particular time.

(l) The Venemo dam during upgrading. Photo: Statkraft.

(n) The Votna arch dam. Photo: Hydro Energi.

4. Upgrading of existing dams

There are 345 large dams (higher than 15 m) in Norway, the oldest dating back to 1890. Many of these are rockfill dams built between 1950 and 1990, as this was the most intense period for hydropower development in Norway. There are few new large dams, but many of the old ones have been upgraded because of a combination of ageing and the development of a stricter legal framework for dam safety. The majority of large dams were built before the first national dam safety regulations were issued in 1981, and new methods and improved data have caused changes in theoretical loads, such as the design flood.

Compulsory regular dam safety reassessments were introduced in 1995. Since then, 59 per cent of the large dams have been reassessed, and 26 per cent have been rehabilitated or upgraded. No dam failures have occurred, but some of the upgrading projects have been extensive, as the dams were built long before the introduction of modern safety analyses and requirements. Climate change is already taken into account, to some extent, in the current flood calculations, but the regulations have not yet included requirements with respect to predicted future increases in the design flood. However, dam owners are advised by the regulatory authorities to account for any predicted increase, if a dam needs to be upgraded for other reasons. Three examples of upgrading are presented below.

The Venemo dam is a 64 m-high rockfill dam with an upstream asphalt concrete facing, built in 1964. A reassessment in 1998 resulted in the conclusion that the dam did not meet current safety requirements with respect to crown width, freeboard and downstream drainage capacity. New riprap cover was placed on the downstream slope, as shown in Photo (l), and a downstream drainage toe was constructed during the summers of 2005 and 2006. The upstream asphaltic facing was heightened, and all the monitoring instrumentation was upgraded.

(m) The Svartevatn dam during upgrading. Photo: Sira-Kvina.

Svartevatn dam is a 129 m-high rockfill structure with a sloping moraine (till) core, built in 1976. The downstream slope as constructed was 1.0:1.35.

During a reassessment of the dam in 1999, deviations from the current dam safety regulations were found:

- the crest width and the freeboard above the highest regulated water level were too small; and,
- the dam had undergone larger deformations than expected during design, affecting both the slender moraine core and the downstream slope.

Upgrading work was carried out, which involved flattening the downstream slope to an inclination of 1.0:1.5, and the dam toe was moved 20 m downstream. Furthermore, the core was raised to the level of an extreme flood situation. Transport of the construction material during upgrading of the dam is shown in Photo (m). The transport road had a gradient of up to 1:3, which is very steep, but this proved to be satisfactory, as briefly described by Hiller *et al*. [2014[7]]. The upgrading will be completed this year.

The Votna dam is a composite 55 m-high arch dam with a buttress (flat slab) section and a gravity section in the right abutment, built in 1960, see Photo (n). Alkali-silica reaction (ASR) was observed on the dam from 1987, but with alarming consequences from 2003. In the buttress sections, the concrete slabs had been displaced, reducing the contact between the slab and the pillars/buttresses. The ASR had affected the arch section by reducing the resisting capacity of the thrust blocks and increasing stresses to the thrust blocks as a result of expansions in the arch sections.

In the buttress dam section, the existing vertical joints in the concrete slab have been widened to provide room for further expansion of the concrete as a result of the ASR. To increase the shear capacity, new reinforced concrete slabs have been constructed onto the old concrete slab. The thrust block has also been strengthened. Furthermore, future load scenarios from the arch sections up to the years 2025 and 2045 have been taken in to account in redesigning the thrust block, as ASR can be a continuous process.

5. Current situation

Over the past five years there has been experience of unregulated rivers flooding, causing damage to houses and other properties. This could lead to decisions to collect excess flow in the rivers (over the natural mean flow) and diverting the flood waters to existing hydropower reservoirs, or in a few cases building new reservoirs with hydropower plants which can then partly finance the flood protection element of the schemes. Climate change therefore represents a new driver for hydropower development. Climate change will also have an influence on general energy consumption, but not necessarily on electricity consumption.

With more than 200 power companies and well distributed hydropower resources, there is currently hydro development activity in most regions of Norway. Several engineering companies are working closely with developers, and the business has attracted large numbers of new engineers over the last few years. The number of Norwegian suppliers of electro-mechanical equipment is quite modest, but several manufacturers of small hydro turbines, together with Rainpower Ltd, are playing a major role in the business.

Construction work is mostly carried out by national construction companies, but because of the current high level of activity, other European companies are also sometimes awarded contracts on the large projects. Research and education often run in parallel with construction activities. Launching the Norwegian Hydropower Centre (NVKS) at the Norwegian University of Science and Technology (NTNU) will improve hydro education and increase the number of Master's Degree and PhD candidates graduating in the field of hydropower. NTNU is also providing education on hydropower as part of various international programmes.

Recognition of the value of renewable electricity and the importance of exploiting untapped Norwegian hydro resources (both new and upgrading projects) has been enhanced by the two markets for electricity: the Electricity Market and the Renewable Electricity Certificate Market. Both these markets work together in Norway and Sweden. Many of the hydro plants are publicly owned (Municipality, County and the State) and as with privately owned schemes they like to take out the economic benefit from generation.

The next five years, up to 2020, are expected to be the busiest period for hydropower since the 1980s. Then, after 2020, the upgrading and redesigning of hydro plants will maintain a high level of activity in the profession. ◊

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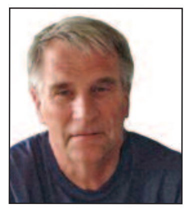

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