

TENTATIVE LIST SUBMISSION FORMAT

STATE PARTY:**DATE OF SUBMISSION:****Submission prepared by:**

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Name of Property: Rjukan/Notodden and Odda/Tyssedal Industrial Heritage Sites, Hydro Electrical Powered Heavy Industries with associated Urban Settlements (Company Towns) and Transportation System.

**State, Province or Region: Norway, Counties of Telemark and Hordaland
Municipalities of Tinn, Notodden, and Odda**

Latitude and Longitude, or UTM coordinates:

Rjukan/Notodden:

Westernmost point (Vemork): 59° 52' N / 8° 29' E

Northernmost point (Håkanes): 59° 56' N / 8° 50' E

Southernmost point & Easternmost point (Notodden Railway Station): 59° 29' N / 9° 20' E

Tyssedal/Odda: 60° 07' N / 6° 32' E – (Centre point).

DESCRIPTION:

The industrial town (site) of Rjukan and the transport axis of Rjukan–Notodden form together with Tyssedal and Odda an outstanding picture of the early 1900s, when the second industrial phase created the foundations for the growth and prosperity that characterise modern social development in the West. In this perspective these places contain all the facets of this development: technological, economic, social, aesthetic and cultural. Initially, these places – and not least the waterfalls that are found here – were symbols of the wild landscape of Norway and hence were visited in the 1800s by artists and tourists alike.

Due to low prices, vast quantities of power, proximity to international markets, an ice-free coastline etc. Norwegian hydropower resources were highly attractive for the establishment of new ventures at the turn of the 19th Century / early 20th Century, when technological and financial developments had reached a new stage in Europe and North America. At this point in time, the mobility of goods and capital had increased enormously, while electricity was just starting to become a realistic source of power, but not one that could yet be transported over long distances without major losses.

In the European and American race to develop a process for manufacturing artificial fertiliser, the Rjukanfossen waterfall was harnessed in 1911 to provide sufficient power to run Professor Kristian Birkeland's electric arc method for separating nitrogen from air. This method was more effective than any other method tried at that time (Niagara 1903 etc.) and, following test runs at Notodden (1907), the method was seen as promising from an industrial perspective. Together with input from the industrialist Samuel Eyde and with Swedish and French capital an industrial company, Norsk Hydro¹, was formed and an urban community was created in the early 1900s in a poor and remote rural area. This involved a number of elements such as power stations, factories, residential areas, buildings for administrative and social purposes, as well as equipment for exporting calcium nitrate (Norges-salpetre, Norwegian saltpetre), a significant industrial product for agriculture worldwide. In due course, artificial Norwegian saltpetre outperformed Chilean saltpetre, see for example Humberstone & Santa Laura Saltpetre Works in Chile, inscribed on Unesco's World Heritage List in 2005 as representative of the more than 200 saltpetre mines that were once found in Chile.

Tyssedal and Odda also represent the early, hectic phase of heavy processing industry based on hydropower. High waterfalls, good storage facilities and a location on an ice-free fjord in Southern Norway were decisive for the establishment of the power station in Tyssedal and the carbide and cyanamide factories in Odda (1908). The cyanamide factory is one of seven first-phase factories and was the biggest in the world when it started production. Cyanamide was an alternative artificial fertiliser for the world market, but also formed the basis for other products. It was manufactured using the same process throughout the entire production period at the factory (until 2002). Calcium carbide was a contributory factor in the production of cyanamide. The first factories producing cyanamide date from 1905 (Italy and Germany). The three carbide furnaces that are found in the factory today are of the Söderberg anode type, a Norwegian invention that achieved world acclaim. In the late 1920s an engineer at Odda Smelteverk, Erling Johnson, developed an improved method for producing nitrogen fertilizers. The method was patented and named the Odda Process. It was not taken into use there but is spread internationally. In Norway, Yara International ASA (former Norsk Hydro) uses this process in their Herøya plant in Telemark. The power supplies from Tyssedal also formed the basis for smelting plants for aluminium (1916) and zinc (1924).

A typical trait of the new electrochemical industry was the parallel development of power plants and factories. The unity of power plants and factories at Rjukan, in Tyssedal and Odda embody important social and political conditions as well as technical elements. On a grand scale, these apply to a unified plan for the utilisation of major hydropower resources, while on a slightly smaller scale they apply to the technical design of the plant. These places are significant symbols of the growth of Norway as a modern industrial nation in the years following 1900, when foreign capital was combined with the local natural resources, Norwegian entrepreneurship, creativity and manpower. Today these sites form the physical documentation that complements this unity. Norway is today the sixth largest producer of hydropower in the world and the country was a pioneer in the development of power-dependent industries, technical developments and products that quickly acquired global significance.

These places are connected phenomena, but when these former industrial sites were first established, they also provided opportunities for people and for capital investment, for example entrepreneurs, the formation of companies and engineering expertise. The capital operated internationally, but legislation, politicians and to some extent the other players were needed to safeguard national interests. Marginal rural communities, where the monetary economy had barely become established, quickly turned into urban communities on modern lines. These were designed to high aesthetic and social standards. The former was achieved by the use of skilful architects while the latter was achieved through interaction with organised labour movements. This kind of movements began with the industrial phenomena, and is an expression for modernity in the

¹ Norsk Hydro ASA was established in 1905 as Norsk Hydroelektriske Kvælstof Aktiebolag – The Norwegian Hydro-Electrical Nitrogen Company

form of party-organised working conditions. The social divisions could be read in the buildings' design and in the details, and this is still much the case to day.

It is important that events and developments have been documented to a large extent. E.g. Norsk Hydro's historic archive from Rjukan has been safeguarded so that documentation in the form of original drawings and descriptions of all the original buildings at Rjukan has been preserved. A number of the works that were constructed are of considerable size and represent the formal/architectural standards of the early 1900s at their best. As a manifestation of the 1900s industrial entrepreneurship, they are regarded as having universal significance.

Svelgfoss power station at Notodden was the largest in Europe and the second largest in the world when it was built to test-run the Birkeland-Eyde method in 1907. When electricity production began in 1911, *Vemork* power plant was the largest power station in the world (i.e. larger than Ontario Power Co at Niagara). After Vemork (Rjukan I) construction began on *Såheim* power plant with an even larger output. The generators started up in 1915, and powered 40 Birkeland-Eyde furnaces in the same building. The actual buildings of the power stations at Rjukan have been protected (*Såheim* is listed as industrial historic monument) but production continues using new machinery. At Vemork production has been moved to an underground facility in the mountain. A granite *acid tower* has been listed as an industrial historic monument: it is one of a total of 36 towers that were part of the saltpetre factory's tower house in 1911 and were in operation until the 1980s.

At Vemork the *Tungtvannsfabrikken* (Heavy water factory) was erected later. The building was taken down in the 1970s, but the events of the Second World War that culminated in sabotage of the plant (Operation Gunnerside) in 1943 have subsequently meant that the place has acquired global significance.

In Tyssedal the *Tysso I* power station was opened in 1908, and equipped with 15 aggregate turbines in 1918. *Ringedalsdammen* was completed at the same time, then the largest dam in Norway and the first in Northern Europe to have storage facilities and a drop of 400 meters. The dam, the transfer tunnel (3 kilometers long), the pipe trenches and the power station where all the installations are intact, represent pioneering work within engineering. The power station is listed as industrial historic monument. The development in Tyssedal was the decisive factor for the concession legislation in Norway, a political and legal model for controlling industrial development.

The housing stock demonstrates examples of the new, English-inspired planning principles that brought to an end the cramped and dirty living conditions for workers in the 1800s, with developments such as *the garden city* with a garden for every dwelling. *Apartment buildings* in brick were another central element of the housing stock. In 1925, Norsk Hydro spent 22 million kroner on housing and infrastructure at Rjukan, and 1,230 apartments – 80 % of the whole urban community – were under the direct control of the company. The houses have now been sold to the inhabitants. In Tyssedal there is a similar housing stock, on a lesser scale but with a greater degree of originality in the details. In Odda there are examples of housing where not only the social stratigraphy is clear but also the whole of the 1900s is represented chronologically.

While Odda lay in the south end of the Hardanger Fjord, the development of an effective transport system was completely instrumental for the investment at Rjukan. The distance from the factory at *Såheim* in Rjukan to the sea at Skien is about 130 km, and there is about 75 km to Notodden. The Skien waterway was developed as a canal to Notodden (1861), and right from the start the *Rjukanbanen* railway line ended at the quays of Notodden. The line was opened in 1909 and electrified as early as 1911. The line consisted of two railway sections connected by a railway ferry crossing over the lake Tinnsjøen. The first section (Notodden–Tinnoset) is 30 kilometres long. Today it is named Tinnosbanen, and since 1917 it was connected to the national railway net. The upper section, Mæl–Rjukan, is 16 kilometres long. The whole line is still intact and the most important stations have been protected. From Notodden it is regular train service via Hjuksebø (10 kilometers) to Skien.

The Rjukanbanen railway includes a 30-kilometer ferry crossing over *Tinnsjøen* which is unique of its type. Of the two remaining ferries, *SF Ammonia* is the world's only remaining steam-driven railway ferry, launched in 1929. *SF Hydro* lies in deep water in Tinnsjøen, after it was sunk by sabotage with a cargo of heavy water on board in 1944. *MF Storegut* from 1956 continued to serve as a passenger ferry until 1985. Protection status and measures or processes of varying types and degrees exist for the ferries, ferry berths, lighthouses, buildings and elements of the railway.

Justification of Outstanding Universal Value:

(Preliminary identification of the values of the property which merit inscription on the World Heritage List)

Rjukan/Notodden and Odda/Tyssedal together constitutes a unique example of the achievements within scientific, technical, industrial, engineering and social fields that were opened by the use of electricity, when it had become available and practicable in a big scale as energy. The wholeness and complexity of these sites make them a unique document of how combined efforts within a range of fields succeeded to create new synthetic products to human mankind. Complete new communities were built for that sake where the source for hydro-electric power was to be found. The type of industry represented by Rjukan/Notodden and Odda/Tyssedal is a true mark of modernity, representing a distinctive step in the history of developed countries in Europe and North America, and provided a base for further development throughout the 20th Century and around the whole World. Rjukan/Notodden and Odda/Tyssedal is an example of the ingenious and bold solutions that were possible at that stage of a new international industrial breakthrough, and that were necessary to realize in order to fulfil the ambitious and extensive aims.

The universal values of Rjukan/Notodden and Odda/Tyssedal are linked to elements within four distinctive categories, which are all integrated into and constitute overall functional units.

The four categories are:

- buildings, constructions and installations for the production of hydro-electrical power, situated in dramatic landscapes with mighty waterfalls.
- buildings, constructions and machinery for the production of artificial fertilizers from nitrogen (saltpetre) and/or calcium and carbide.
- urban settlements that were constructed in remote areas for the purpose of providing all the social functions necessary for the industrial developments, including housing and cultural and social institutions.
- a transportation system that linked the industrial site to the rest of the world, to enable industrial products to be traded on the world market. The transport system from Rjukan consisted of two sections of an electrified railway connected by a railway ferry across a lake. Notodden was the original export port, situated on the Telemark canal/waterway.

The universal value lies in the preserved completeness that demonstrates the whole breadth of interrelated functions that were necessary to establish complete urban societies in order to produce artificial fertilizers for the world market.

Criteria considered to be met [see Paragraph 77 of the *Operational Guidelines*]:

(Please tick the box corresponding to the proposed criteria and justify the use of each below)

(i) (ii) (iii) (iv) (v) (vi) (vii) (viii) (ix) (x)

Criterion (ii): (– linked to the exchange of cultural values such as the development of architecture or technology, monumental art, urban planning or landscape design:)

Rjukan/Notodden and Odda/Tyssedal are examples of synergetic international cooperation within technological engineering, enterprise and financial investment that also necessitated achievements within urban planning and architecture. Accumulated knowledge common to these fields formed the basis for this, but the pioneering work at Rjukan/Notodden and Odda/Tyssedal also contributed new knowledge in certain fields.

The dams, power plants, electro-chemical plants, transportation systems and towns are exceptional testimonies *to a vital phase in the development of modern industrial societies and culture*, which is international in its character, but which was transformed and adapted to meet local conditions. Many of the power plants and chemical plants were the biggest in the world at the time they opened, and some of the industrial processes were innovative and at the leading edge in their day. Some of Norway's most renowned architects and engineers were engaged in the planning and design. As a result of technological innovations in the field of electric energy transmission, the establishment of new, integrated industrial towns has disappeared as a solution, and furthermore many heavy electro-chemical industrial complexes have been closed down both in Europe and North America.

Criterion (iv): *(- to be an outstanding example of a type of building, architectural environment or landscape that illustrates significant stages in cultural history:)*

As industrial complexes with associated urban settlements and transportation systems, Rjukan/Notodden and Odda/Tyssedal have outstanding universal qualities, where the exploitation of natural resources forms the basis for the creation of a modern welfare society within the framework set by nature. The «second industrial revolution» constitutes a significant step in cultural history. Through industrial development and the joint actions of a number of factors, the foundations of Norway as a modern Western welfare state were created. The factories and buildings for production, and the associated urban settlements were created from the bottom up. This is particularly evident in Norway, which had just obtained national independence, and was undergoing major political changes in the early 1900s.

Statement of authenticity and/or integrity [see Paragraphs 78-95 of the *Operational Guidelines*]:

Rjukan/Notodden

Integrity: At Rjukan, the upper areas of the town were built during the first three decades of the 20th Century, containing all the necessary buildings organised according to a planned urban layout. The class distinctions are easy to read. This town has been preserved with a high degree of integrity in terms of town planning and the relationship between the distinctive elements of the town, i.e. dwelling houses for the different social classes, a commercial and cultural centre, and the factories. The town is situated in a deep, narrow valley, which has forced further development to take place eastwards along the river valley. All the original plans and drawings for the city have been kept and are safely stored at the Norwegian Industrial Workers Museum in the Vemork Power Plant. Rjukan is still an active industrial town, although the Norsk Hydro Company has closed down most of its heavy industry at the site. However, gas production still takes place in a part of the complex, now under the direction of a new company, Yara International ASA, formerly part of Norsk Hydro. The hydro-electrical power plants are still in production, although the equipment has been modernised. (Together, the power plants in the Rjukan area (municipality of Tinn) produce 4 % of the Norwegian total.)

The railway system has been preserved with the tracks and a large proportion of the rolling stock which was operative until the freight route was closed in 1991. The upper part, Rjukanbanen, was privately owned by Norsk Hydro, while the lower part, Tinnosbanen, was taken over by the Norwegian State Railways (NSB) in two steps (1920 and 1955). The railway line between Tinnoset and Notodden has never been

formally closed down, but has only faced sporadically use in recent years. Between Notodden and Hjuksebø the line is still in use, both by passenger trains and freight trains. The two railway ferries *SF Ammonia* and *MF Storegut* that sailed across Tinnsjøen between Mæl and Tinnoset are preserved, together with the quays, slipways etc. The two ships have recently been protected by law (Cultural Heritage Act). The ferryboat *SF Hydro*, which was sunk during the heavy water sabotage action during World War II, lies at the bottom of the lake at a depth of 440m.

At Notodden there are some remains of the initial stages of this industrial development, where the profitable innovation of extracting nitrogen from the air by means of electric arc furnaces was tested. The Norsk Hydro Company also had administrative and other functions at Notodden, and some of the buildings survive.

Despite the changes that have occurred in process industries (modernisation, ownership etc.) in Norway as well as in the rest of the world, including transport technology, living standards etc., the industrial axis of Rjukan/Notodden has all its original components intact, to varying degrees, but sufficient to offer a high degree of integrity.

The factory for heavy water production, renowned from WW2, was built at Vemork after the pioneering period of the early years of the 20th Century, and the building was demolished in the 1970s. However some equipment from this special production plant is preserved.

Authenticity:

The majority of the industrial buildings that formed the complexes have been preserved with a high degree of authenticity. Some of the original buildings have been demolished. Others have acquired new functions or a new form of industrial activity; but here the exterior has been preserved. Original machinery that has been replaced by more modern equipment has either been preserved through examples – such as one of the Birkeland-Eyde furnaces and one of the acid towers – or is still kept *in situ* deprived of any function other than as museum pieces – such as the turbines in the *Vemork* Power Plant.

The housing stock was owned by the Norsk Hydro Company until the last decades of the 1900s. Under private ownership many houses have been renovated, mostly in the interiors but windows have often been replaced and verandas added etc. Some houses and also some areas are listed and have been given legal protection status.

The railway lines remain with rails, bridges, contact lines, stations, buildings and sheds and a wide range of the rolling stock intact. Because traffic has been non-existent – or very sporadic – for years, they will need to be further restored before any normal use – which may be optional – can be realised. The two ferryboats are preserved: because of their exceptional authenticity, legal protection is now in place and further restoration works are being planned. “*Ammonia*” is steam-powered, while “*Storegut*” is diesel-powered. “*Ammonia*” is the only steam-powered lake railway ferry left in the world.

Odda /Tyssedal

Odda /Tyssedal differs from Rjukan/Notodden in certain aspects, but was established at the same time and to some extent with the same people in important roles, such as Samuel Eyde. As an entrepreneur he was a key person behind the foundation of Norsk Hydro. However, in Odda/Tyssedal the company was not so involved. Odda/Tyssedal is not a strict example of a company town, because the production of electrical power and the smelting works belonged to different companies. The reason for building the hydro-electrical power plant in Tyssedal was the opportunity to sell electricity to the planned smelting works at Odda, 7 kilometers away. When it opened, the smelting works was the biggest manufacturer of carbide in the world, and also of cyanamide, which was produced as artificial fertilizer for the world market – like the nitrogen fertilizers from Rjukan.

Integrity: Odda/Tyssedal broadens and deepens the industrial axis of Rjukan–Notodden. Together they will constitute a serial nomination. In terms of industrial heritage in particular, the Odda Smelting works that was closed down in 2003 represents complementary values to those at Rjukan. In Tyssedal the buildings and constructions for the production of hydroelectric power form a complete entity, with the power plant on the shores of the fjord, the granite dam in Ringedalen, tunnels and penstocks. There is even a mountain railway with cable traction. The height of the waterfall is more than 400 metres, which makes Tyso 1 pioneering in this respect. In Tyssedal there are also living quarters to take into consideration.

Authenticity:

The most essential elements of the production lines at Odda Smelting Works are still preserved, for example some of the huge furnaces are still *in situ*. At present legal protection is being drawn up which is designed to preserve the values of the site through the planned reuse of the complex and area (which may be non-industrial). The hydroelectric power plant Tyso 1 in Tyssedal has been restored with all its original equipment intact, although it is not in use any more. The power plant is listed and protected under the Cultural Heritage Act. Some of the dwelling houses in Tyssedal still have their original architectural details intact.

Comparison with other similar properties:

Entire comparisons have not been undertaken yet.

A comparison in its full scope should take into account industrial sites that make up a whole out of the four components, i.e. hydro-electrical power plant, process industry works, transportation system and urban settlement. In the light of present knowledge, very few other places however exist with an appearance like the serial site of Rjukan/Notodden and Odda/Tyssedal. So the analysis will have to look into the different components separately.

Kinlochleven in the Scottish Highlands may be a parallel and relevant for comparison. A hydroelectric scheme was constructed there in 1907 for the British Aluminium Company. At its early days the Aluminium Reduction Plant employed some 700 people, but its small size in comparison to modern 'smelters' led to its closure in 2000. The loch (Loch Leven) is navigable as far as Kinlochleven, and was used by ships bringing bauxite to the smelter there until its closure. The revamping of the power station saw the transfer of its output to the Lochaber Smelter at Fort William, which was established in 1929 with the Lochaber hydroelectric scheme connected to it. In 1991, the village had just over 1000 inhabitants in some 420 households. The economic revival of the village is based mostly on tourism and other new businesses. Elsewhere in Scotland the Fall of Foyers on the shores of Loch Ness was exploited for an aluminium smelting plant in 1895.

Hydro electrical power plants:

There is at present no hydro-electrical power plants inscribed on the World Heritage List. Included in some of the industrial sites inscribed, will be power supply units of different types, mostly based on coal, which, however, is significantly divergent from the phenomenon that can be represented by Rjukan/Notodden and Odda/Tyssedal.

The relevant sites to consider will be the power plants from the first couple of decades of the 20th Century. The hydro-electrical power plants from the years before will be too small, and made for other purposes, as the providing of electricity for lighting in a modest scale. In the decades that followed technology was invented for the transmission of high voltage electricity over long distances. Because of that, it is a narrow window of time that is subject for this analysis. What is essential is that during that short period of time, the

inventions for the use of high voltage electricity to heat huge furnaces for electro-chemical (and electro-metallurgic) processes were made. The kind of integrated site with a location determined by the source of power, namely the waterfall suitable for exploitation, belongs to this period alone.

The history of the huge hydro-electrical power plants and associated works began at *Niagara Falls*, North America, where numerous electro-chemical plants were built immediately adjacent to the Falls, the first one in 1903. At that time Ontario Power Co in Canada was the largest in the World. Two years later *Svelgfoss I* at Notodden started up, as the World's second largest and the largest in Europe. The power supply from Svelgfoss was intended for testing a new electro-chemical process that would compete with the Niagara works. The next step in Telemark was at Rjukan, where *Vemork* was completed in 1911 as at that time the largest in the World. So, in 1914 *Såheim (Vemork II)* took the podium. Later even more power plants have been constructed in the water system of the valley Vestfjorddalen, and also down the river to Notodden. Svelgfoss and Vemork have been modernised. Most of the original plants still exist, however, and so does the equipment – whether still in use or not. No other places can show off such a succession of remarkable huge hydro-electrical power plants, neither from that specific period of early 20th Century nor regardless of period.

Additionally, in 1908 *Tysso I* power plant in Tyssedal was built. It then was remarkable because of the high drop of water utilised by the generators, 400 meters, which also was the largest of its kind in the World of its time. The *Tysso I* power plant is listed and well preserved.

To day, there are many hydro-electrical power plants in the World that are larger than those of Rjukan and Tyssedal or elsewhere in Norway. Internationally there is of course great power plants which are of immense importance to the communities that are hosting them, and even to whole nations. A few may be mentioned: *Hoover* (or *Boulder*), USA 1936, *Grand Coulee*, USA 1942, *Aswan*, Egypt 1970 (installed capacity 1815 MW), *Three Gorges* (China, under construction, will be World's largest), all situated in main rivers of their continent. The most remarkable with these power plants may however be the adjacent dam, which is a different matter than the case of Rjukan/Notodden and Odda/Tyssedal, though worth to consider on a different basis. The Grand Coulee Dam in Columbia River, for example, is 1586 m long and 168 m high. In Tyssedal, the *Ringedalsdammen* is the most interesting dam belonging to the serial site of Rjukan/Notodden and Odda/Tyssedal. This granite dam was built 1910-18, and measures 521 m (length) by 33 m (height).

More equal to the type of hydro-electrical power plants of Rjukan and Odda, and all over Norway as well, are the plants in small or medium sized river systems of mountainous regions, like i.e. in the Alps. In *Switzerland, Austria, France* and *Italy* there are power plants of great interest from the same period of early 1900s, but with the shorter distance to already existing towns and cities and without the need of raising a complete new associated industrial town.

In *South-Africa* the *Belvedere* power station was built 1910-11. A total of 2.1 megawatt was supplied to various mines and to the town of Pilgrim's Rest. The power line was 30 kilometers long. The Belvedere power station was shut down in 1972.

Technically the power plants utilising medium to high drop of water (i.e. 30-600 m) in modest rivers will have turbines of Francis type, which was invented in 1849. For extreme heights which make high pressure from a small amount of water, the Pelton turbine (1879) will be suitable. Otherwise, huge rivers with a modest fall will have turbines of either Blub or Kaplan type, which however was developed for use as late as in 1922 when the problems connected to the energy loss in long distance power transmissions were solved. That means such a power plant, if situated in a remote area, would not have forced the raising of an industry town in close connection to it.

In Norway, most hydro electrical power plants use Francis or Pelton turbines. Through the 20th Century, turbines have been built in Norway that at their time was largest in the world, for example *Sima* power plant 315 MW (1980) utilising water drop of 885 m. In Switzerland and in Austria hydro-electrical power plants with Pelton turbines utilising extreme heights have been built. Pioneering works in *Austria* are at *Kaprun* and *Reisseck*, the latter consisting of a series of power plants and tube systems with a drop of up to 1,772.5 m. These were constructed between 1950 and 1961. The present highest in the world is at *Bieudron, Switzerland*, housing three Pelton turbines (each turbine rated at 423 MW) and utilising a 1,883 m high drop of water. The production began in 1998.

Heavy processing industry:

There are some industrial sites inscribed on the World Heritage List. The majority of these were established in centuries prior to the 20th Century, and reflects types of industry that was dominant before electric based processes were invented. Many of the industrial sites on the List are connected to mining. Some are inscribed primarily because of their architectural merits more than of industrial importance as such.

Around the beginning of the 20th Century, following the ability to provide huge amounts of stable high voltage electricity, new industrial processes were invented to exploit this energy. The birthplace of the industry was the US. Electric smelters were constructed for the production of carbide and aluminium. The need for fertilizers to better the efficiency of agriculture led to methods for extracting nitrogen using electric furnaces. This analysis will concentrate on the latter type of modern industries, the electro-chemical rather than the electro-metallurgic industry. That is also because the sites of Rjukan/Notodden and Odda/Tyssedal played a role as pioneering sites within this field, during the innovative first decades of the 20th Century.

During this initial period, three different methods were in use for production of artificial nitrogen fertilizers, namely the Cyanamid process (Frank-Caro, Germany), the electric arc process (Birkeland-Eyde) and the Haber-Bosch process (Germany). These processes were a supplement to Chilean saltpetre until WW1, and later replaced the fixed saltpetre, causing the closing down of Chilean saltpetre works (WH Sites of *Humberstone* and *Santa Laura*). The Cyanamid process was dominating until after WW1, measured in the number of factories. The following table shows the tendencies from 1913 till 1928:

	1913	1918	1928
Arc process	7	12	5
Cyanamide	15	35	28
Haber-Bosch	1	3	51

The Cyanamid process was the one first invented (Adolph Frank and Nikodem Caro, in the 1890s). Calcium cyanamide is manufactured through a reaction between calcium carbide and nitrogen. Calcium carbide is produced with burnt lime and coal/coke at very high temperatures. It is an important product in itself, used for example in the production of acetylene. The main use of cyanamide, however, was as fertilizer and weed killer in farming, and as a raw material in the chemical industry. Cyanamide treated with steam under pressure becomes ammonia. Ammonia can be used to make ammonium sulphate and ammonium nitrate. Ammonium nitrate was also used in the production of explosives. Among the phase 1 (1905-09) cyanamide factories in the world, Odda was by far the largest:

Cyanamide factories built or under construction in 1909 with estimated production capacity, in tons

Built 1909	Production capacity	Operating
Odda (N)	12 000	1908 - 2003
Notre Dame de Briancon (F)	3 750	
Martigny (CH)	3 750	
Piano d'Orta, (I)	5 000	1905 - ?

Bromberg (PL)	2 500	1913 - 15
Westeregeln (D)	5 000	1905 - 09
Knapsack (D)	5 000	

Cyanamid factories of phase 2 (1909–13)

Works	Production (1912)	Operating	What is left
Notre Dame de Briancon, France	7 500		
Martigny, Switzerland	8 000		
Trostberg, Germany	15 000	1908 - 1911	Kilns demolished 2006
Knapsack, Germany	15 000	1906 -1920	
Kayna, Germany		1913 – 1916	No remains
Odda, Norway	24 000	1908 - 2003	
Alby, Sweden	15 000	1912 - 1945	
Terni, Italy	24 000	1907 - 1973	
St. Marcel, Italy	3 500		
Sebenice, Dalmatia	5 000	1912 - ?	
Niagara Falls, Canada	24 000	1903 - 1992	Demolished 1995
Osaka, Japan	12 000	1909 - ?	

From these production facilities, Odda is the best preserved today. Odda Smelteverk (smelting works) was closed down in 2003 after 95 years of production. Its main products were calcium carbide, calcium cyanamide, and later also dicyandiamide. During the years of operation the kilns were modernised and the plant extended, but the process remained mainly the same. The factories were physically on the original site. Still buildings, Frank-Caro-kilns and part of the Linde plant are to be found on the site. To a large extent buildings and industrial equipment are intact, as for example the vital and huge Kiln 3, a kiln of Söderberg-type, which was invented in Norway and is spread around the world. Many of the other works mentioned above are demolished, some without any remains to be discovered, as for example is the case at Niagara. Additionally, it is known that the Union Carbide Co in Sault Sainte Marie, USA, did remove their machinery from the upper level of the Michigan Lake Superior Power Co powerhouse after they ceased operating in the 1960s.

The breakthrough of the fixation of nitrogen from the air shortly after 1900 by the electric arc process and the Cyanamid process made production of inorganic fertilizer and raw material for explosives, and later the plastic industry, possible. Explosives were in addition to be used by the weapon industry used for road works, land clearing and mining. In the form of ammonia, nitrogen was also later used by the refrigeration industry, for the manufacture of artificial ice and in the operation of cold-storage plants.

Notodden and Rjukan are closely connected to the innovation of the Birkeland-Eyde process. The Norsk Hydro Company was founded by these men, and the power plants, the industrial works, the transportation system and the complete new town were all raised according to their plans. Prior to that, in the US, The Atmospheric Products Company was established in 1902. This company took over the process and equipments from two Americans, C.S. Bradley and R. Lovejoy, and set up large works at Niagara Falls, New York State. The method of fixation was known as the arc process. It was not an economic success, and therefore closed down already in 1904. At the same time a furnace was developed in Norway by Kristian Birkeland and Samuel Eyde. Their electric arc process for fixation of atmospheric nitrogen was tested and put to commercial use in 1905 at Notodden by Norsk Hydro. The brand name of the nitrate fertilizer was *Norges-salpeter* (Norway saltpetre). The production of *Norges-salpeter* increased dramatically from barely 1 200 tonnes in 1906, 15 000 tonnes in 1911 to 71 000 tonnes in 1912. Behind this increase was the use of hydro power from the harnessed waterfall Rjukanfossen, with the construction of Vemork power plant in the period 1907-11. In 1916 the company produced 80 000 tonnes of ammonium nitrate and 11 000 tonnes of *Norges-salpeter*, mainly from the full scale works at Rjukan, where a new

town was raised and connected to Notodden with a railway line that included a ferry section across lake Tinnsjøen.

The third method for the fixation of nitrogen was the Haber-Bosch process, which was invented in *Germany* and internationally had its breakthrough in the 1920s. One obvious reason for this shift is the lack of correlation between the consumption of power and the amount of nitrogen produced by the initial methods. The fact that Norway had abundant amounts of hydro power, which could be easily bought for cheap until state regulations (concession) was in place from 1910, explains why the arc process was operated with economic success in Norway. Soon international capital was attracted to the Norsk Hydro Company's giant investments in Telemark, Norway.

Together with the production of calcium cyanamide, Norway held one of the world's leading positions in the fixation of atmospheric nitrogen before World War I. Estimates indicate that Norway produced about 20 per cent of the industrial nitrogen. Other electric arc process furnaces were developed and put into operation in countries like *France, Italy, and Austria*. The installations were relatively small compared to those at Notodden and Rjukan, and combined they represented about 33 per cent of the total installed capacity of nitrogen per year.

Norsk Hydro shifted to the Haber-Bosch process in their works at Rjukan, starting in 1928 and ending 1940. Although this comparative analysis is limited to production sites from the period ca. 1900 till the 1920s, the secondary production of heavy water at Vemork is another feature related to the history of Rjukan which underlines the uniqueness of this site. The heavy water story is closely connected to WW2, as a never ending source to speculations about its potential importance for world history at a critical point in time.

Transportation systems:

Odda/Tyssedal is situated by the Hardanger Fjord and is easily accessible by boat all year round. In Telemark, Rjukan/Notodden is situated in the inland. Since the opening in 1861 of the first part of the Telemark canal system Notodden was accessible by boat. Between Rjukan and Notodden, however, it was necessary to establish a railway system, Rjukanbanen, which included a ferry section. In 1991, the Rjukanbanen railway system was closed down for transportation use by the Norsk Hydro Company.

On the World Heritage List some few railways are inscribed, all still in use:

- Semmering Railway, Austria (1998)
- Mountain Railways of India (1999, extended 2005, 2008)
- Rhaetian Railway in the Albula / Bernina landscapes, Italy and Switzerland (2008).

The *Semmering Railway* is inscribed to commemorate the skillfull and solid engineering works from the pioneering phase of railway building. The high standard of the works has ensured the continuous use of the line up to present day, now as an electrified main line. The line also opened up a mountain landscape for leisure activities.

The *Mountain Railways of India* first was only the *Darjeeling Himalayan Railway*, a narrow gauge line opened in 1881. Together with the later added railway lines, the *Nilgiri Mountain Railway* and the *Kalka Shimla Railway*, they represent the most outstanding example of hill passenger railways. Bold and ingenious engineering solutions, representing the latest technology of their time, was applied to the solutions of establishing effective rail links elevating up to 2000 m across mountainous terrains.

The *Rhaetian Railway* in the Albula / Bernina landscapes is inscribed because it constitutes an outstanding technical, architectural and environmental ensemble of structures, like viaducts, bridges, covered galleries

and tunnels, in harmony with a mountainous landscape. Opened in 1904, the railway was used to overcome the isolation of the settlements in the Central Alps.

As railways all these lines differs a lot from Rjukanbanen. Their technology belongs to 19th Century, prior to electricity, and as primarily passenger lines they served a quite different purpose. In common with Rjukanbanen they all exemplify how important railways have been to modern community. The historic importance of railways might be said is not yet reflected in the World Heritage List to its full scope.

Technically, in many aspects these lines do better represent the magnificence of railway engineering than Rjukanbanen. There are two exceptions, however, to this statement. First, Rjukanbanen was planned and built for electric traction on standard gauge line from the beginning. Second, but of greater interest, the ferry element is unique. Rjukanbanen with its two ferries is among the very few preserved railway system which includes a lake crossing in the world, still in operative shape. Not only is the electrified railway intact with all its equipment, a lot of buildings and rolling stock. One of the ferry boats, *SF Ammonia*, is the only steam powered ferry of its kind in the world. Furthermore, the ferry *SF Hydro* is localised on the bottom of lake Tinnsjøen at a depth of 440 m. The wreck has still the cargo of heavy water barrels on board, the reason why it was targeted in a sabotage action during WW2.

Throughout the world, only a few railway ferries do exist on lakes. In *Turkey*, the railway connecting Turkey and Iran built in the 1970s uses a train ferry across *Lake Van*. The ferry eliminates the need for rails along the rugged shores of this large saline lake in eastern Turkey. Talks have been started between Iran and Turkey to upgrade the ferry to a double track electrified railway. Between *Bolivia* and *Peru*, the *Lake Titicaca* is crossed by a ferry with dual gauge. On *Lake Victoria* a railway ferry connects the railways of *Tanzania* and *Uganda*. Formerly, there has been railway ferries crossing many lakes, as *the Great Lakes* between *USA* and *Canada*, the *Lake Baikal* in *Russia* – filling a gap in the Transsiberian Railway, the *Bodensee* in *Germany* (until 1976). Also train ferries has been used for river crossings on all continents of the World. Sometimes they connected different countries, like *Paraguay* and *Argentina*. Most often these train ferries are now replaced by bridges.

Industrial railways have often been built to be used during the construction works on hydro-electrical power plants. In Scotland, the *Lochaber Narrow Gauge Railway* was a relatively long line, built for the construction and subsequent maintenance of a 24 km long tunnel excavated to carry water for the Lochaber hydro-electric power scheme to a factory near Fort William. In 1971 part of the Upper Works Railway was washed away. It was then decided that access roads should be built in the area. The railway finally closed in 1977. Following closure, most of the track was lifted, but the steel bridges were mostly left in place. Some odd lengths of track remain in place. There has been talk of reopening part of the Upper Works Railway as a tourist attraction.

At Rjukan, a standard gauge railway was constructed in 1909 for the building of Vemork power plant. This industrial line, *Vemorkbanen*, with a length of 4.66 kilometers, had a gradient of 55.6 ‰. The track was removed in 1991. The track from this line passes along a mountain hillside where there is danger of avalanches of rock and snow. At Tyssedal, there is a cable traction line, *Mågelibanen*, built for the freight of equipment to the Hardangervidda plateau. The line is 985 m long, the top station is 400 above the bottom in Skjeggedal. Since the 1950s the line has been opened for passenger traffic, and it is popular among hikers for providing easy access to Hardangervidda.

Urban settlement:

Among the industrial sites inscribed on the World Heritage List, an associated residential area is part of the site in some cases. Typically, however, these sites were established as industrial complexes before electricity was available for industrial purposes. The settlements tend to be both small or medium scale and result of random planning, or planned as an ideal city. The latter is exemplified at the *Saltworks in Salins-*

les-Bains and Arc-et-Senans (France, 1982, 2009), where the progress of the Enlightenment was reflected in industrial architecture in the 18th Century, forming a semicircular complex designed to permit a rational and hierarchical organization of work. *New Lanark* (United Kingdom, 2001) is an example of a 19th Century philanthropic model industrial community, built around a cotton mill. *Saltair* (United Kingdom, 2001) is also an example of an industrial village of second half of the 19th Century, where textile mills, public buildings and workers' housing are built in harmonious style according to an urban plan that reflects Victorian philanthropic paternalism. Examples of the former will be found at *the Derwent Valley Mills* (United Kingdom, 2001), and also at the *Verla groundwood and board mill* (Finland, 1996). When located near large cities, like New Lanark, these company towns will tend to have undergone major changes.

Crespi d'Adda (Italy, 1995) is in fact inscribed as an example of the 19th- and early 20th-Century company towns built in Europe and North America by enlightened industrialists to meet the workers' needs. The site, however, is connected to industries of different character compared to Rjukan/Notodden and Odda/Tyssedal, as powered by coal and manufacturing cotton textiles. A hydroelectric power station was built there, to supply the workers with free electricity, public lavatories and other common services. To day however, the site is only partially devoted to industrial activities.

Worldwide the phenomenon of company town is well renowned. Such towns have been raised in connection with a wide range of industries, typically built by a company running a business in an area that was non-developed prior to its investment which often was allocated due to prospects for rapid profit. However, quality housing also was a mean to attract workers to settle in a remote area. Many company towns, and especially those connected to mining activities, will retard to ghost towns after the closing down of the initial industrial activity.

In Canada, for example, *Shalalth* was erected as a "model village" in the mid-1920s when the Bridge River was developed for hydro-electric production. The town also was a communication hub in a gold-mining area, and was situated at Pacific Great Eastern Railway. There was no electro-chemical or other heavy industries at the site, which has become sleepy after its booming periods. The hydro power project was completed in 1962.

In the US, a city named *Boulder City* was built in 1932 for housing the workers who were building Hoover Dam. The hydro-electric power plant at the Grand Coulee Dam, was built in the 1940s to provide energy for the Alcoa Aluminium Works in *Bellingham*, which is some 270 km away. The company town of *Alcoa* in Tennessee is more relevant to compare with Rjukan and Odda. The Aluminium Company of America, Alcoa, started planning and the purchase of land in 1910, and had their smelting plant ready during the WW1. Massive amounts of electricity were provided from the Little Tennessee River. The company maintained a paternalistic relationship with the city, making Alcoa a classic company town.

There is more to Rjukan than an ordinary company town, in the respect of being closely related not only to the raise of a company – Norsk Hydro, but also to the raise of a new nation. This aspect was evident in the quality of the planning and design of the town, which was intended to last for long. Both the innovative new industry, the impressive power plants and the town itself was reviewed as a national pride, icons for the making of Norway as a modern community. The influence from international economical fluctuations and macro-political events has of course left their marks in Rjukan, but never put the shared responsibility for the living of the town in question. Though Norsk Hydro to a great extent has fulfilled the withdrawal of its electro-chemical industry from Rjukan, the town still is hosting heavy industries, among them Yara International ASA which is a gas producer and a derivate of Norsk Hydro. The company started selling out the housing stock to the residents during the 1970s. However, local authorities, the Norsk Hydro Company and the citizens to day do take joint care of the municipality.

In Norway some other industrial sites were established during the early 1900s with close similarities to Rjukan/Notodden and Odda/Tyssedal. To be mentioned is *Høyanger*, *Sauda* and *Glomfjord* which all holds notable values of the kind in question. The completeness and significance of Rjukan/Notodden and Odda/Tyssedal is however not surpassed by any of these sites.