



First application of Uhde's dual pressure ammonia process for revamping of the Duslo ammonia plant

by

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1. Abstract

Duslo operates an Uhde ammonia plant at Šaľa, Slovak Republic. In 2004 Duslo decided to increase the ammonia production capacity and optimise the energy consumption for the total ammonia production at Šaľa.

Uhde provided the basic engineering for the capacity upgrade of the ammonia plant by applying their dual pressure ammonia process.

The front end of the plant will be upgraded by Uhde's latest reformer technology using reformer tubes with increased diameter with state of the art metallurgy and Uhde's latest secondary reformer design.

Process air compressor will be upgraded by a turbine driven parallel machine.

CO₂ removal system capacity will be increased using UOP's Benfield ACT-1 process.

Synthesis gas compression is upgraded for the first 3 stages of the existing compressor by a parallel turbo compressor. Synthesis gas drying will be applied downstream the 3rd stage of the compressor.

The dual pressure ammonia process features Uhde's OT-Synthesis operating at approx. 135 bar and the original Uhde High pressure Synthesis which Duslo operates successfully since 1973. A 2 bed radial ammonia converter will be applied in the OT-Synthesis. Synthesis gas from the OT-Synthesis is fed to the suction of the 4th stage of the existing synthesis gas compressor and subsequently fed to the existing high pressure loop. Thus the changes to existing H. P. equipment are minimised.

The revamp measures for the front end have been started in the annual Shutdown in 2005 and will be continued throughout 2006. Independently from the operation of the existing plant the OT-Synthesis will be installed and commissioning is scheduled for 2007.



2. Introduction

The Ammonia 3 plant at the state-owned production complex previously known as Juraj Dimitrov Bratislava Nitrogen Factory Šaľa in the former Czechoslovak Republic, which was designed and built by Uhde, was brought on stream in 1973. Much has changed since then environmentally, geopolitically and technologically. In 1989, the company Duslo emerged, still as a state-owned entity, but with its headquarters in Šaľa. From 1990 onwards, Duslo was registered to carry out independent foreign trade activities. In 1994, Duslo was transformed into a joint stock company as a result of the Slovakian government's efforts towards privatisation of state-owned properties.

As a result of being transformed into a market-driven company, the operating philosophy of Duslo was also transformed. The focus increasingly began to shift towards cost benefit maximisation. Smaller-scale revamps were carried out in 1988 and 2002, also by Uhde, in efforts to conserve energy and increase financial gains. It was decided in 2003 to cease production at the older, inefficient 300 mtpd ammonia plant. The difference in production was to be made up by revamping the Ammonia 3 plant, increasing its capacity by 30% from 1000 to 1300 mtpd.

Realising that such a major capacity increase of a plant that has already been revamped a number of times would not be easy, Duslo was prepared for major changes in the configuration of the plant. The selection of Uhde for the realisation of such an ambitious revamping project was a natural choice for Duslo to make. Uhde's patented dual pressure process was the logical choice for the realisation of the large capacity increase.



3. Uhde's Four-Phase Revamp Execution Approach

For a successful realisation of the revamp project, a proper plan of execution was essential. Based on Uhde's experience of more than 20 revamps in syngas producing plants, a stepwise, four-phase approach of project implementation is used.

During the first phase, a revamp study is carried out. During this phase, Uhde and Duslo met to discuss the actual status of the plant to localise the real bottlenecks, to discuss possible revamp options and to exchange information vital to the success of the project.

A test-run was also performed to determine the current capacity limits and consumption figures of the ammonia plant. The following data were collected:

- Mass balances, temperatures and pressures representing the base case of the current operating conditions
- Precise pressure drop review
- Catalyst performance data
- Survey of control valve positions for process and machinery
- Maximum load tests of separate parts of the plant

Since a consistent set of data is a prerequisite for a good simulation of the actual status of any plant, the above data were collected while the plant was running as stable as possible at full load.

In addition to the gathering of the above-mentioned data, discussions with the operation staff were carried out to ascertain peculiarities and unmeasurable quantities that are best known by the plant operators.

The current plant conditions were then recalculated in the form of mass and energy balances. Especially for the evaluation of the catalyst performance and its extrapolation to future operating conditions with implemented revamp options, a very close co-operation of Uhde and the catalyst supplier Johnson Matthey Catalysts (JMC) was essential.

Many options resulting from the discussions and ideas of the revamp study were worked out by Uhde with Duslo. The feasibility of these options were evaluated, along with CAPEX/OPEX optimisations, then it was decided which options were to be evaluated further.

The basis for the development of the revamp concept was the computer simulation of the process under its actual operating conditions. This simulation is based on physical and chemical properties of reactants and products and on various unit operations, fitted to the data that was gathered in the plant. In the simulation the catalyst activity was based on the actual age of the catalyst. The same applies for heat exchangers where the heat transfer coefficients were calculated based on actual measurements rather than taking the original coefficients from the design phase.



The feasibility of the options was then evaluated, and a cost estimate was prepared with an accuracy of 15%. The conclusions of the study were presented in a final report which was comprised of:

- description of the revamp concept
- process flow diagrams for the revamp case
- steam balance for the revamp case
- production and consumption figures
- cost estimates for implementing the modifications suggested in the BEP

The result of this phase was the decision by Duslo as to whether the revamp was attractive or not, and whether the project should continue. Since it was decided by Duslo to pursue the revamp further, phase 2, the basic engineering phase, was begun, based on the results of the study. During basic engineering, the following documentation was prepared as part of the basic engineering package (BEP):

- The Final process flow diagrams including steam and cooling water system
- Specifications for new and modified equipment
- Preparation of detailed time schedule
- Update of plot plan
- Confirmation of consumption figure and cost estimate

After the completion of basic engineering, phase 3 commences, which is detail engineering. As of this writing, phase 3 is in the process of being carried out. Uhde participates in the execution of this phase by providing engineering for various topics of the revamp, and delivers proprietary equipment to Duslo.

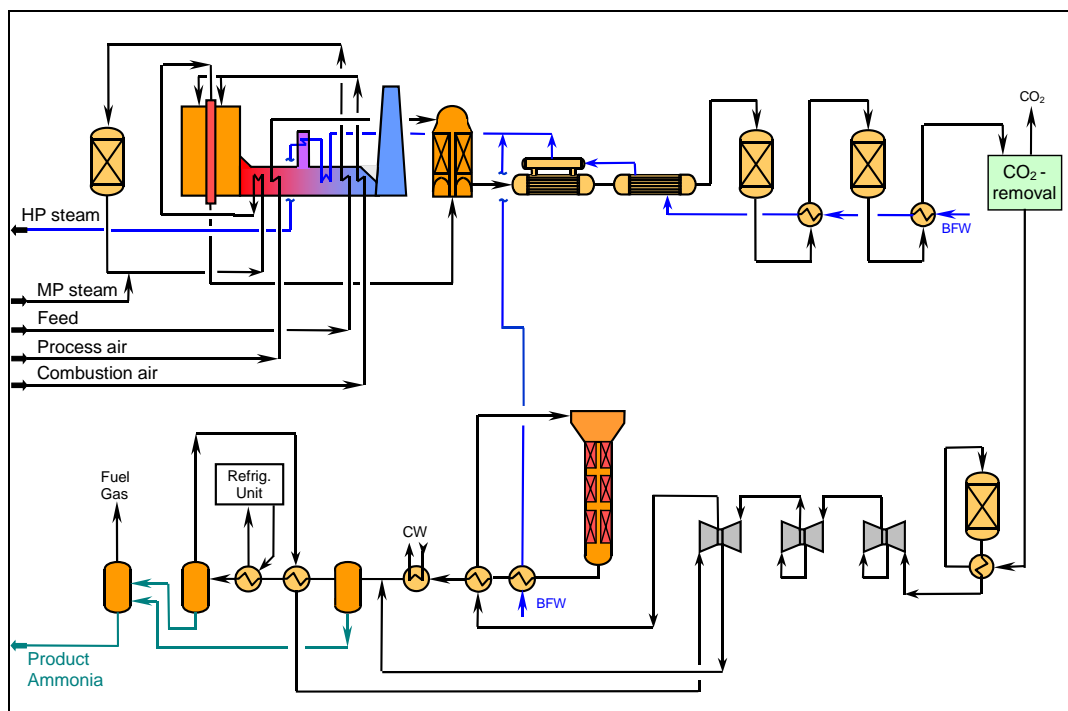
Phase 4 is the erection and commissioning phase, which normally overlaps somewhat with phase 3. The planned modifications in the case of Duslo are to be implemented during planned annual shut-downs. The first of the modifications have already taken place during the summer of 2005. Other tie-in work will continue during the shut-down in the summer of 2006, and the commissioning will take place during the summer of 2007.



4. Technical Options

In order to achieve the desired 30% production capacity increase to 1300 mtpd, virtually every process unit in the plant was modified to some degree. The key modifications undertaken for the revamp are illustrated in the following paragraphs. Although there are also numerous minor alterations of the plant, they are excluded from the scope of this paper.

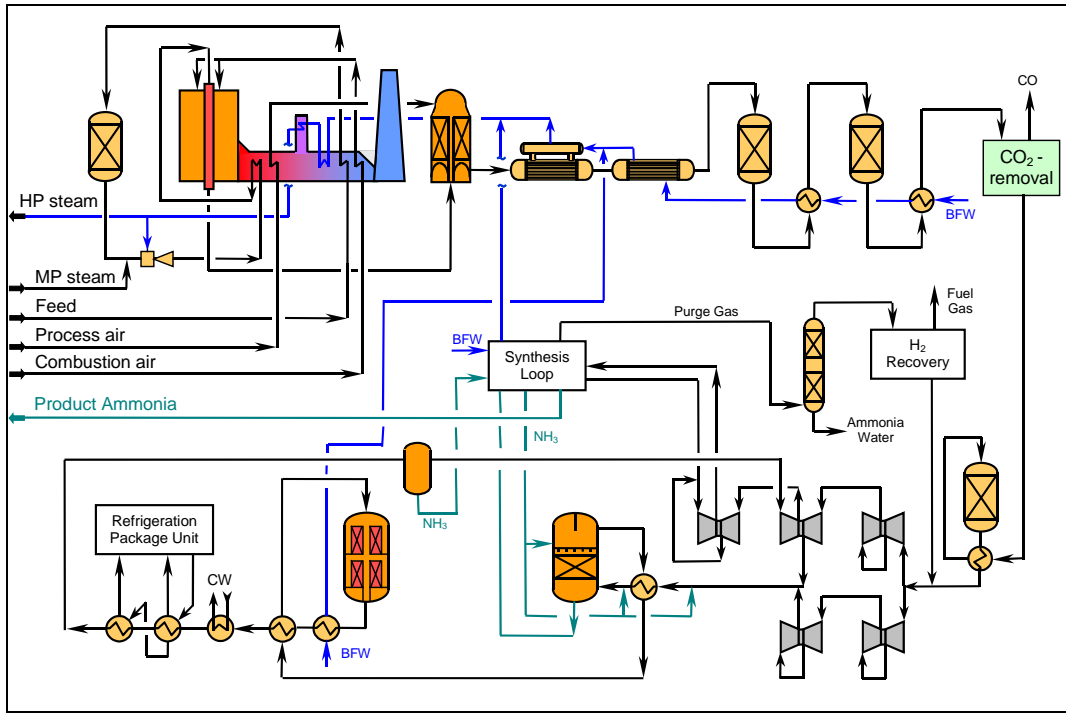
Figure 1: Existing Ammonia 3 Plant at Duslo in Šal'a



4.1 Pressure Drop Issues

One of the key issues of the revamp, and of any higher-capacity revamp for that matter, was to find solutions to overcome the increased pressure drop arising from the higher gas throughput of the existing plant. For the Duslo revamp, this applies essentially only to the front end of the plant, since the original synthesis loop will have a circulation rate that is effectively unchanged with respect to the pre-revamp conditions. This is a direct consequence of Uhde's once-through synthesis concept, in view of the fact that the extra ammonia production capacity takes place in the new once-through synthesis, which is situated upstream of the existing synthesis loop.

Figure 2: Revamped Ammonia 3 Plant at Duslo in Šaľa



As far as the front end is concerned, the increased pressure drop was compensated for in such a way so as to ensure that the suction pressure of the existing synthesis gas compressor would remain unchanged. A number of measures were taken to ensure that this condition would be met.

One important option to minimise pressure losses was to use improved catalyst with a new shape, developed by JMC, in the primary reformer tubes, leading to significant pressure drop reduction. The catalyst, together with larger diameter reformer tubes, as discussed below, significantly helps keep pressure losses to a minimum.

Another key issue in reducing the pressure drop within the front end was the reduction of the steam-to-carbon-ratio. The plant is normally operated with a steam-to-carbon ratio of 3.8. The revamped plant is intended to be operated with a S/C ratio of 3.4, which enters the realm of most modern plants that are taken online today.

Despite measures to reduce the pressure drop in the front end, a larger pressure drop is an inevitable result of a higher gas throughput, resulting from the increased capacity of the revamped plant. In order to compensate for the resulting pressure losses, a high-pressure steam ejector was added to the feed/steam mixing station just upstream of the feed/steam superheater. The pressure at the outlet of the ejector is controlled via addition of HP steam (108 bar abs), whereas the S/C ratio is controlled as before via addition of MP steam (41 bar abs) from the existing line. The pressure increase across the ejector is approximately 2.4 bar.



4.2 Reforming Section

As the life of the existing reformer tubes was coming to an end, it was chosen to upgrade to larger-diameter tubes. As a result of exchanging the existing 4" tubes for 5" tubes, a new pre-reformer was compared with larger tubes but had been withdrawn from the revamp due to pressure drop considerations. Due to certain heat transfer and mechanical design boundaries, this 5" tube diameter is generally deemed to be the maximum allowable. As described above, the larger tubes are also advantageous with respect to pressure drop considerations.

Adjusting the steam-to-carbon ratio from 3.8 to 3.4 as discussed above is not only advantageous with respect to pressure drop, but is also beneficial with regards to the load of the primary reformer, since it reduces the amount of gas to be reformed. This reduction in the reformed gas throughput therefore reduces the heat absorption of the process gas, allowing modifications of the reforming section to be comparably small.

In order to complete the gas reforming, an upgrade was also needed to the secondary reformer. It was decided to completely replace the existing secondary reformer, which was troubled by insulation deficiencies, in favour of the state-of-the-art Uhde secondary reformer. The process gas is fed from the primary reformer to the bottom of the secondary reformer, and with an internal, axially-arranged tube, is directed to the vortex-flow combustion chamber situated in the upper section, where it is mixed with process air, combusted, and sent through the catalyst bed for final reforming. Upon leaving the catalyst bed at the bottom, the gas passes through a ring-shaped arch, which has the dual function of effectively leading the gas out of the reformer, and supporting the catalyst in a highly stable manner.

A modification of the existing process gas cooler was also deemed necessary in order to prevent excessive heat fluxes that would have caused damage to the cooler after the revamp was carried out. The first chamber of the process gas cooler was enlarged, although the second chamber was left unchanged.



4.3 Process Air Compression

In order to deliver the required amount of process air to the secondary reformer as a result of the capacity increase of the plant, a 5-stage, turbine driven parallel compressor is included in the revamp. The turbine-driven, bull-gear type compressor will fit within the existing compressor house. The process air from the existing compressor and new parallel compressor is joined together and sent to the secondary reformer for combustion after passing through the convection bank for preheating.

As it is possible for one process air compressor to be in operation while the other is idle, special considerations were undertaken to ensure that the two compressors can be completely isolated from each other. This insures maximum protection of equipment and personnel.

4.4 CO₂ removal

The CO₂ removal unit was rather extensively revamped in the late 1980s. The basic configuration of the CO₂ removal unit therefore was left unchanged as a result of the current revamp. The main changes to the unit consist of new packings in the Absorber and Desorber, and a upgrade from the classic Benfield activator DEA to the more modern activator Act-1. The new packings selected for the revamp are Raschig super rings, which replace the old packings, some of which were the original ceramic packings installed for the initial start-up in 1973.

The changeover to Act-1 will be accomplished slowly over an extended period of time leading up to the commissioning of the revamped plant. This will be achieved by using the activator Act-1 as makeup for lost DEA. This will allow the existing solution to be used, which will prevent substantial costs that are normally involved for the disposal of spent solution.

As a result of installing new high-performance packings, the distributors and redistributors in the Absorber and Desorber were deemed insufficient for the future demands that were required of them. Therefore, these items were also selected for replacement.

4.5 Synthesis Gas Compression

It was agreed upon at the outset of the project that modifications of the existing synthesis gas compressor would be avoided if possible. The compressor, which is a triple-casing, turbine-driven turbo compressor with five stages plus recycle, has had vibration problems since the very start of operation in the early 1970s. For this reason, the compressor has been operating at a somewhat lower rotation speed (10700 rpm) than was originally intended (11346 rpm), in order to keep vibrations at an acceptable level.

With this in mind, a new synthesis gas compressor is installed parallel to the first three stages of the existing synthesis gas compressor. Directly downstream of the Methanation unit, the process gas stream is split into two parts. The larger part of the split gas stream, containing an equivalent of almost 1000 mtpd ammonia production is sent to the original synthesis gas compressor, where it is compressed in the first three stages to 135 bar



absolute. After this third stage, the gas is extracted from the compressor and is diverted via the modified outlet piping to be joined with the gas from the new parallel compressor.

The new compressor, which is a motor-driven, four-stage machine, is responsible for the compression of the equivalent of a slightly more than 300 mtpd ammonia, to an end pressure of 135 bar abs. The two compressed gas streams are then reunited and introduced to the drying unit.

As with the process air compressors, special considerations are also taken with respect to the synthesis gas compressors to ensure that they are able to be fully isolated.

4.6 Synthesis Gas Drying Unit

In order to prolong the life of the catalyst in the once-through reactor, it is vital to remove traces of water, since the water can lead to loss of activity on the catalyst surface. For this reason, a drying unit was devised that will remove water to a level of approximately 3 PPM.

After the compressed synthesis gas streams are joined together as described above, they enter the drying section. The drying is accomplished by cooling the synthesis gas with product ammonia to such an extent that the water condenses and leaves the system with liquid ammonia.

Upon entering the drying unit, the synthesis gas stream is injected with a small amount of ammonia extracted from the ammonia separator in the synthesis loop. This first ammonia injection serves the purpose of depressing the freezing point of the water in the syngas stream, ensuring that freezing does not occur within the downstream equipment. The syngas stream then enters a gas-gas heat exchanger, where is cooled to -20°C by gas leaving the drying unit. Immediately after this, the gas stream is injected with a larger amount of ammonia via an ammonia injector, saturating the synthesis gas stream with ammonia, and is then introduced to the drying column.

Within the drying column, the synthesis gas stream enters through a gas distributor and is subsequently washed counter-currently with liquid ammonia within a fixed bed of structured packing. The liquid ammonia is recovered within the sump and is sent to the existing ammonia flash drum in the synthesis loop. The gas leaving the top of the drying column is sent once again through the gas-gas exchanger as mentioned above, thereby being warmed to about 29°C .

After the water is removed from the synthesis gas, it may then enter the once-through synthesis.



4.7 Once-Through Ammonia Synthesis

The centrepiece of the revamp is Uhde's so-called once-through ammonia synthesis. The once-through synthesis, together with the traditional synthesis loop, is the central feature that defines Uhde's patented dual pressure process. The once-through synthesis allows for the reduction of conversion duty in the synthesis loop by first employing a low-pressure ammonia synthesis conversion. This new distribution of ammonia conversion made possible the momentous capacity jump for the 3300 mtpd Safco IV plant, which is scheduled to go on-stream in 2006. The new configuration also has a profound impact on older plants that are to be revamped, such as the one Duslo operates, since large capacity increases are possible while leaving most of the existing equipment unchanged. Most of the tie-in work can be completed during scheduled shut-down times, allowing construction work to be completed with minimal disturbances to the original plant. The final integration can be accomplished whenever the original plant is in full operation. Operation of the original plant will also be possible by simply bypassing the once-through synthesis section, allowing a scaled-back production of the original 1000 mtpd ammonia.

The use of this new technology for the upgrading of the Duslo plant is the ideal solution for achieving the desired capacity increase to 1300 mtpd. While there is very limited free space within the existing plant, a large adjacent plot of land is used for most of the new equipment, most of which does not necessarily need to be spatially integrated. In fact, most of the new equipment is situated at a considerable distance from the existing plant, with the existing compressor house being an additional barrier between the new and old equipment. The equipment designated to occupy this new space includes the entire once-through synthesis, the ammonia and Hydrogen recovery units, the drying unit, and a small new compressor house for the parallel synthesis gas compressor and refrigeration package unit.

Once the process gas has left the drying unit, it is led to the new once-through synthesis, where it first passes through the gas/gas heat exchanger to be heated against reacted gas from the ammonia converter. Once heated and introduced to the two-bed, radial-flow, intercooled converter, the process gas reacts to produce about 300 mtpd of ammonia. The pressure at the inlet of the converter is 132.5 bar abs.

Conversion of synthesis gas to ammonia at low pressure requires a special high activity catalyst. Johnson Matthey's 74-1 catalyst has been in commercial operation since the mid 1980s and has proven to be extremely reliable and trouble-free. With the basic material being magnetite, a continuous future of competitive pricing compared to some novel precious metal catalysts is insured.

After the partial reaction in the ammonia converter, the gas is subsequently cooled and chilled to a temperature of -16°C . Chilling of the gas is carried out with a new dedicated refrigeration unit. The liquid ammonia is sent to the existing flash drum as product, and the remaining gas is sent back to the fourth stage of the existing synthesis gas compressor with a temperature of -16°C , where it is further compressed by the final two stages to a pressure of 238 bar abs. The subsequent compressor inlet thus operates at a much lower temperature than the normal temperature of 40°C . The benefit of the chilling is that each impeller in the fourth stage of the compressor produces more head than is typical for an inter-cooled synthesis gas compressor. That offsets most of the pressure drop throughout the once-through converter.



After leaving the compressor again, the gas is sent to the original synthesis loop, which for the most part was left unaltered during the revamp. The only changes to the synthesis loop are the tie-in points for new ammonia product, and the feed location of makeup gas, which was moved from the cooling train to the suction side of the recycle stage due to pressure drop reasons.

4.8 Ammonia Recovery Unit

In order to achieve the maximum performance of the revamped plant, new units were also added. One such new unit is the ammonia recovery unit. This unit uses chilled boiler feed water within an absorber containing structured packings to remove ammonia from the gas purged from the synthesis loop. The amount of stripping water was chosen so that the concentration of ammonia in the resulting exit stream is 25 wt%. This ammonia water is sent to the battery limit where it is collected and sold.

Since a large portion of the purge gas was ultimately used as fuel in the primary reformer, the addition of the ammonia recovery unit was deemed a necessary addition to the Duslo plant. The unit allows the recovery of the maximum amount of produced ammonia, and also reduces the amount of NO_x introduced to the atmosphere as a result of less ammonia being sent to the reformer as fuel.

4.9 Hydrogen Recovery Unit

A further optimisation of the plant is carried out in the form of the Hydrogen recovery unit. The gas leaving the absorber in the ammonia recovery unit contains over 58 mol% Hydrogen that was originally produced in the front end. This gas, including the valuable Hydrogen, was formerly used as fuel in the primary reformer. By separating the Hydrogen out of the rest of the gas stream using Prism membrane technology from Air Products, the load of the front end can be reduced by some 4%, since less Hydrogen has to be produced and directed through the front end equipment. By means of a CAPEX/OPEX optimisation, it was seen that the investment costs for the Hydrogen recovery unit are amortised within a period of two years.

The Hydrogen that is recovered is introduced to the main synthesis gas stream at the suction side of the synthesis gas compressors, where it is compressed and sent to the downstream ammonia synthesis units as described above.



5. Revamp Results

Once the revamped plant goes on stream in 2007, not only will the production capacity of the Ammonia 3 plant at Duslo be increased from 1000 to 1300 mtpd, but the specific energy consumption is also expected to decrease.

The decrease in the consumption figure is a result of several factors, including larger reformer tubes, a new state-of-the-art secondary reformer, more efficient compressors running in parallel to the originals, improvements in the CO₂-removal unit, new improved catalysts, new ammonia and hydrogen recovery units, and, of course, the once-through synthesis operating at low pressure, saving compression costs.

The operational flexibility of the plant is also increased. Bypassing the drying unit and once-through synthesis allows the plant to be operated in the usual pre-revamp fashion, which is advantageous for maintenance. Shifting of ammonia production duty between the high- and low-pressure synthesis trains is also possible to a certain extent, allowing fine tuning of the plant to achieve more production or cost-savings.



6. Conclusion

Uhde's dual-pressure ammonia process with JMC catalysts represents a low-risk and fast-track path to large-capacity ammonia plants, as well as a method of significantly increasing the capacity of existing plants, as in the case of Duslo in the Slovak Republic. Although the plant was subject to numerous smaller-scale revamps already in the past, it was still possible to achieve a major capacity increase, while simultaneously reducing the specific consumption figure.

The capacity expansion of 30% was brought about mainly through the introduction of the once-through ammonia synthesis, as well as improvements in the front end, such as larger reformer tubes, a new secondary reformer, and an HP steam injector that allowed the resulting higher pressure drop to be effectively dealt with. All new equipment is to be installed with minimal disturbance to the existing plant, and tie-in work to be completed during normally scheduled shutdowns.

The reduced specific consumption figure was also realised as a result of the new once-through synthesis, as well as the introduction of the ammonia and hydrogen recovery units.

The first plant to receive a revamp of this kind, Duslo is sure to serve as a model for other plants that are in need of significant capacity increases with reduced specific energy consumption.