MEGAMMONIA® – the Mega-Ammonia Process for the New Century

Engineers from Lurgi and Ammonia Casale have analysed the conventional ammonia process with a view to doubling the size of ammonia plants on offer. They conclude that conventional technology suffers certain limitations when capacities in the range of 4 000 metric tons/day or larger are contemplated. In this paper a new process is proposed based on the combined experience of both companies which is considered to be both economically attractive and bankable.

Dr William L E Davey CEng, MIChemE, Dr Thomas Wurzel
Lurgi AG, Frankfurt am Main, Germany

Dr Ermanno Filippi
Ammonia Casale SA, Lugano, Switzerland

Introduction

At the beginning of this century, Lurgi and Ammonia Casale decided to co-operate in the development of a new approach to ammonia manufacture on a large scale. It was decided the new approach should be suitable for production rates much larger than was currently available with conventional technology, and for which simply scaling up conventional technology was considered inappropriate.

It is not by chance that Lurgi and Ammonia Casale decided to co-operate on such a task. Lurgi had recently developed the innovative Mega-Methanol® technology, which effectively doubled the size of world scale methanol plants, and Ammonia Casale was well known for its innovative approach to reactor design, and for its focus on obtaining the highest possible productivity from every item of equipment.

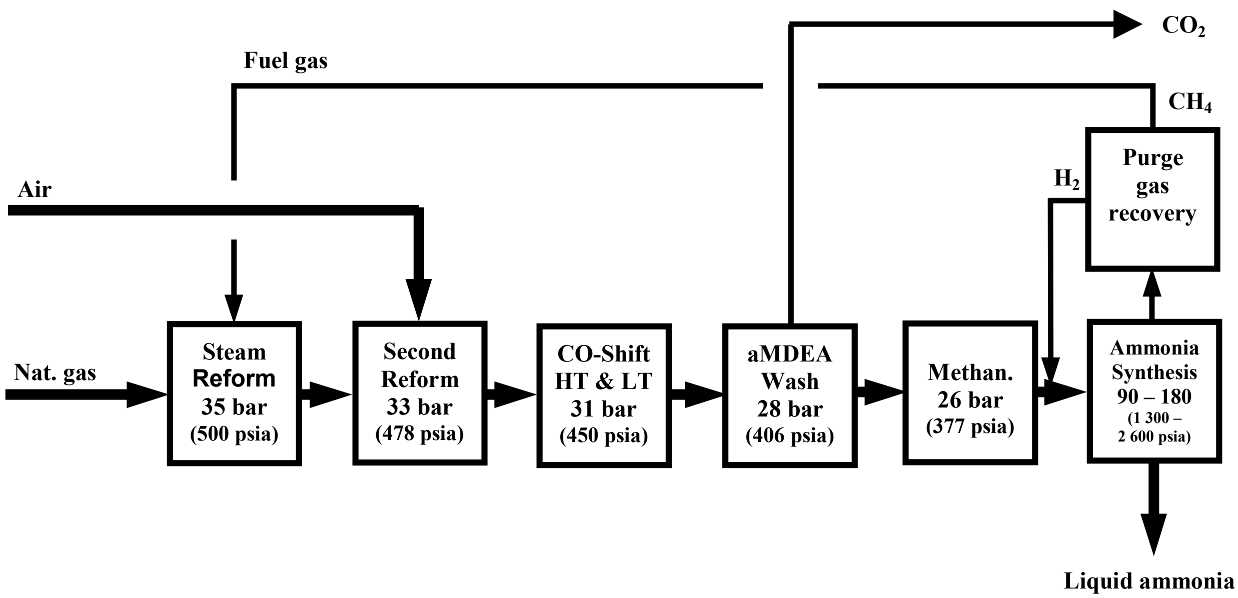
The result of this joint program of study has been the development of the MEGAMMONIA® technology. MEGAMMONIA® is not a spelling mistake. It is the name we have registered for the new ammonia process. The name is intended for a single line ammonia process which is capable of producing 1.4 million metric tons/year of ammonia, or more. In other words, approximately twice the size of the current largest world scale plants.

The conventional ammonia process

In figure 1 a conventional ammonia process is depicted comprising a steam reformer followed, in series, by an air blown secondary reformer, HT and LT-Shift, carbon dioxide removal, methanation, ammonia synthesis, and purge gas recovery units. Nitrogen is added by adjusting the duties between the primary and secondary reformers such that the stoichiometric air required to complete the reforming process in the secondary reformer also brings with it the stoichiometric requirement of nitrogen for the ammonia synthesis.

The idea for this process was developed in the 60's when M W Kellogg first announced to the world a design for a single stream natural gas based ammonia process which, at 600 short tons /day, would produce at roughly twice the rate of the then largest ammonia plants. Although over the roughly 45 years since then many improvements and refinements to the process have been made the basic process scheme remains the same. Of course the capacity has grown over time and today's largest plants produce just over 2 000 metric tons /day ammonia.

Figure 1: Block diagram of a conventional ammonia synthesis process



Thus the old business model of building a fertilizer plant in the proximity of one's customers, and large enough to supply only the customers within a given radius of the plant is changing. Today's business model contemplates the construction of the largest plant which the technology of the day will permit, right at the sea shore in a country with low cost gas. Then shipping the product to whichever of the world's markets has the greatest need.

Against this background Lurgi and Ammonia Casale evaluated the conventional technology and found it wanting. If the Ammonia industry is to follow the example set by the Methanol industry, as it probably will, then the conventional technology is no longer suitable for a further doubling in capacity, and a fresh approach is needed.

However with the world-wide trend towards rationalisation and increased focus on core business, competition between the world's major producers has sharpened significantly. In the absence of any more process improvements, which would significantly reduce their energy consumption, producers have started focussing their attention on relocating their production capacity out of the major consuming countries to countries having cheap natural gas. Product is then shipped in very large ships to the major consuming centres.

The conventional technology, in a single stream, suffers from a number of problems when significant capacity increases are considered, and these are, amongst others:

a) For larger capacities a steam reformer begins to present engineering problems that may be difficult to overcome. Also the very nature of a steam reformer limits the pressure, at which syngas can be generated, to a maximum of about 40 bar.

b) Nitrogen is introduced into the process well before it is actually needed thereby contributing to the size of equipment such as the CO-Shift reactors and carbon dioxide absorption column.

c) The vessel sizes of the conventional carbon dioxide removal processes such as aMDEA (activated mono-diethyl amine) and potassium carbonate become so large that they may have to be built as multiple stream processes. In addition the circulation rate required increases beyond the sizes of available pumps.

d) Ammonia syngas is not purified. Catalyst poisons are converted into impurities, which then accumulate in the ammonia synthesis loop increasing the required circulation rate, and the sizes of all the equipment in the loop. To control the accumulation of impurities the loop must be purged, cleaned up, and the associated valuable ammonia syngas returned to the loop.

The MEGAMMONIA® process:

As illustrated in figure 2 the MEGAMMONIA® process comprises five principal units:

a) Air Separation Unit (ASU)
b) Catalytic Partial Oxidation Unit (CPox)
c) CO-Shift Unit
d) Gas Purification Unit
e) Ammonia Synthesis Unit

The separation of air into its components, oxygen and nitrogen, is a well known, and widely practised process. For the MEGAMMONIA® process an ASU produces a gaseous stream of 95% pure oxygen for use in the Autothermal Reformer, and a stream of 99.99% pure nitrogen for use in the Gas Purification Unit.

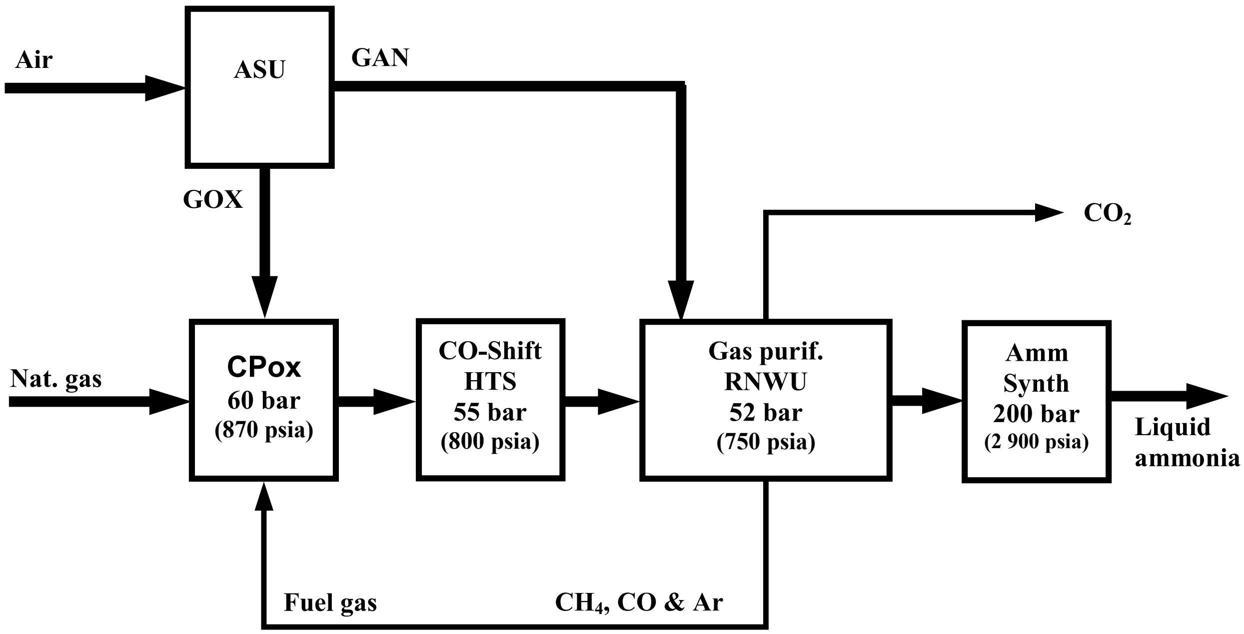
In the Catalytic Partial Oxidation Unit feedstock natural gas is preheated and desulphurized in the conventional manner over a cobalt molybdenum catalyst followed by zinc oxide. The desulphurized gas is then saturated using condensate recycled from the CO-Shift Unit, preheated in a fired heater and pre-reformed over a nickel oxide catalyst so as to convert all higher hydrocarbons to hydrogen and methane. Steam is added to the pre-reformed gas to adjust the steam to carbon ratio, the gas is further preheated in the fired heater, and then reformed to CO, H_2 and CO_2 in the CPox reactor by partial oxidation with oxygen. A nickel oxide catalyst located in the CPox vessel further assists reforming. The resulting hot reformed gas is cooled to a temperature to suit the downstream CO-Shift Unit in a process gas boiler raising high-pressure steam for use in driving the major rotating machines. Catalytic Partial Oxidation with oxygen is a process with which Lurgi has extensive experience and is the basic building block for its Mega-Methanol® process. The absence of a pressure limiting steam reformer makes it feasible to raise the pressure of the CPox Reactor to 60 bar (870 psia).

Within the CO-Shift Unit, the reformed gas is passed over two beds in series of conventional HT catalyst to convert the remaining CO to H_2 and CO_2. As the volume of catalyst required is considerable, each bed is arranged in axial-radial configuration so as to minimise catalyst volume, pressure drop and vessel diameter. Ammonia Casale is well known for its axial-radial reactor designs, has several CO-Shift reactors of this design in operation and a CO shift reactor for a 2 050 metric tons /day plant is currently being implemented. The gas is then cooled to ambient temperature by preheating saturator feed water, boiler feed water and makeup water. The condensate arising is separated from the gas and recycled to the saturator in the CPox Unit.

Figure 2: Block diagram of the MEGAMMONIA® process

ometric proportion, is passed to the Ammonia Synthesis Unit.

The Ammonia Synthesis Unit is of conventional design. The synthesis of ammonia from H_2 and N_2 is carried out over a conventional magnetite catalyst at high pressure provided by a syngas compressor. The ammonia converter is of the most



Gas Purification is accomplished in two wash columns, the first removing CO_2 and the second removing the remaining impurities; namely CO, CH_4 and Ar. CO_2 is removed by absorption in cold methanol - the well known Rectisol® process, proprietary to Lurgi and installed in many plants the world over. CO, CH_4 and Ar are removed by washing the gas with liquid nitrogen, another process frequently used by Lurgi in its gas purification plants. The CO_2 is recovered from the cold methanol by reducing the pressure to near atmospheric, and the recovered gas is sufficiently pure for use in the synthesis of urea. The recovered impurities, CO, CH_4 and Ar are recycled to the CPox Unit for use as fuel in the fired heater. Refrigeration for the Rectisol® process is provided by ammonia supplied from the Ammonia Synthesis Unit. Pure synthesis gas, comprising H_2 and N_2 in the correct stoichi-

advanced axial-radial design by Ammonia Casale. Synthesis is carried out by passing the gas over three inter-cooled adiabatic beds of catalyst in series. The heat of reaction is recovered by a loop boiler, and by a boiler feed water pre-heater. Heat is conserved by heat exchange between feed and effluent streams to and from the converter. Synthesized ammonia is removed from the synthesis loop, in the conventional manner, by condensing the ammonia against low pressure boiling ammonia and by separating the liquid from the unreacted synthesis gas. The pressure of the liquid is reduced in several stages and unreacted gases are recycled to the syngas compressor. The extremely high purity of the ammonia syngas results in higher conversion of gas per pass, lower circulator duty, lower refrigeration duty, and generally in equipment throughout the loop of a size falling within the range of Ammonia Casale's experience.

A refrigeration compressor in the Ammonia Synthesis Unit raises the pressure of gaseous ammonia to a level at which it can be liquefied against cooling water, thereby providing a means of refrigerating the synthesis loop and the Rectisol® process.

Owing to the absence of impurities from the ammonia syngas, the synthesis loop needs no purge, nor purge gas treatment system. Pure ammonia is stored as a liquid in atmospheric pressure storage tanks.

Energy consumption for this process is estimated to be 27 - 29 MMBtu/ metric ton ammonia, based on the Lower Heating Value of a representative natural gas. The range given covers the supply of warm ammonia to a downstream urea plant, or the storage of cold ammonia in an atmospheric pressure tank. This energy consumption includes the power required for the process, the ASU, and all its utilities, inclusive of natural gas compressor, sweet water and sea water cooling systems, and a water treatment plant. The import of electricity is not required other than to start the plant.

Advantages of the MEGAMMONIA® Process

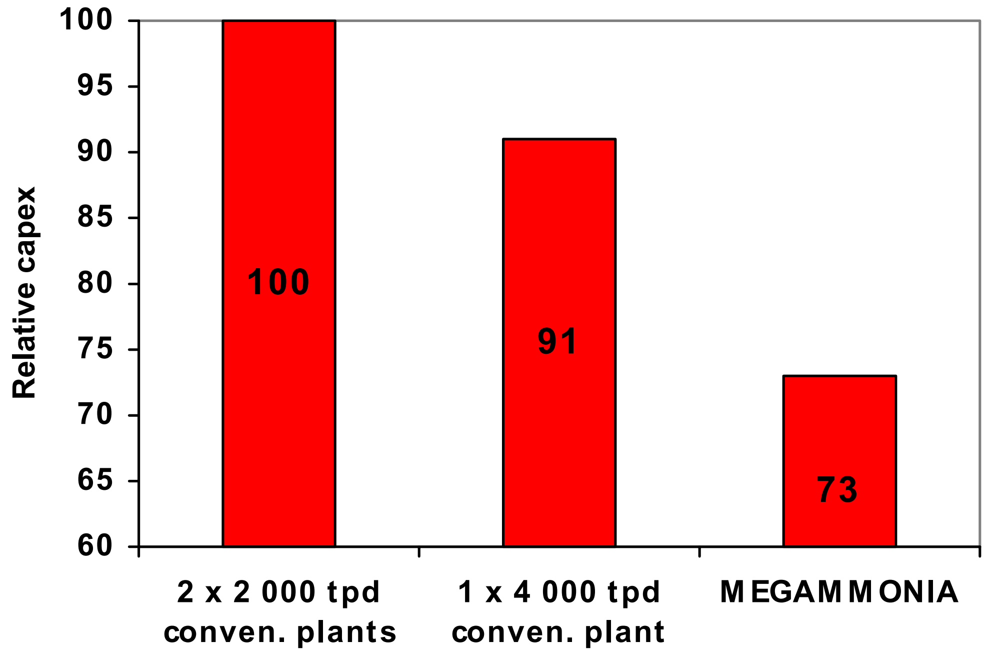
Compared with the conventional steam reformer process the MEGAMMONIA® process provides several significant benefits for potential owners:

1 Lower Investment Required

Comparing investment cost is always difficult in view of the large number of factors which can influence a price estimate. Nevertheless an investment comparison is vital to an appreciation of the new technology. On the basis of a recent feasibility study, information in the public domain, and on the basis of an independent assessment of the technology, we are able to report that the MEGAMMONIA® technology offers the potential for a reduction in investment cost of 18% to 20% over a scaled up version of conventional technology, at a size of 4 000 metric tons/day. In making such a comparison the scope of the projects is very important. Our comparison was made on the basis of an ammonia facility complete with cooling tower, boiler feed water treatment, and an ammonia storage tank of 40 000 metric tons.

The comparison for different plant sizes is illustrated in figure 3. Owing to differences in the scalability of air separation units versus steam reformers, the advantage of MEGAMMONIA® over conventional technology diminishes as the plant size decreases, and vanishes at a plant size of around 1 500 metric tons/day. It is for this reason that MEGAMMONIA® technology is best suited to the larger production volumes.

Figure 3: Comparison of MEGAMMONIA® Investment with conventional technology. Scope is an ammonia facility complete with all utilities and ammonia storage



great value. In table 1 the breakdown of the Investment cost of a MEGAMMONIA® plant is given, and shows that the Air Separation Unit accounts for about 17% of the total investment. Today's industrial gas companies make a business of erecting and operating air separation plants with the objective of selling the products "across the fence". In effect, the MEGAMMONIA® technology affords an owner a unique opportunity to reduce his capital investment by a further 17%. By entering into a supply agreement with an industrial gas company this portion of the capital required can be converted into an operating cost without degrading the economic attractiveness of a given project.

2 Air Separation Unit permits off balance-sheet financing

Table 1: Breakdown of MEGAMMONIA® Investment Cost

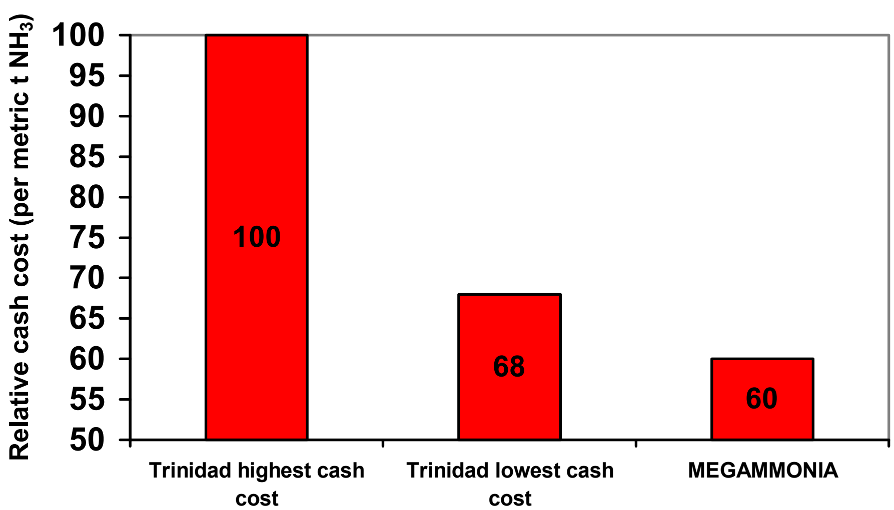
Process Plant	61 %
Utilities (including cooling tower)	15 %
Tank farm (40 000 t NH_3)	7 %
Air Separation Unit	17 %
TOTAL	**100 %**

It is often argued that ammonia producers know nothing about air separation and would rather have nothing to do with this technology. However, in these times where capital is difficult to come by, having an Air Separation Unit as part of the plant could present a business opportunity of great value.

3 Reduced Operating Cost

MEGAMMONIA® has fewer unit operations and fewer catalytic steps than the conventional ammonia process. It goes without saying therefore that the cost of producing ammonia will be lower than for the conventional process. We have estimated the operating cost for MEGAMMONIA® and present this in figure 4 as a comparison with a representative range of producers located in Trinidad. On the basis of this comparison we are able to report that MEGAMMONIA® offers the potential for a reduction in operating cost of some 12% - 15% below the most advanced conventional ammonia technology in operation today.

Figure 4: Comparison of Operating Cost between MEGAMMONIA® and a representative range of Trinidad producers



4 Lower environmental emissions

In the absence of a steam reformer the heat required for the reforming of natural gas, in the MEGAMMONIA® process, is supplied by chemical reaction within the CPox Reactor. It follows, therefore, that more of the carbon dioxide by-product is available to the CO_2 Removal Unit than is the case in a conventional ammonia process. Under these circumstances we estimate that the emission of unrecoverable CO_2 to the atmosphere from the MEGAMMONIA® process will be 30% less than from a conventional process.

In the absence of a steam reformer we expect that NO_x emissions will be considerably lower, as steam reformer burners have a higher NO_x emission than conventional fired heater burners. The absence of a steam reformer also means that low frequency burner noise will be reduced.

Overall then MEGAMMONIA® has the potential for greater environmental friendliness than the conventional ammonia process.

5 Increased Urea Production

The reduction in CO_2 emission to atmosphere has already been discussed under the heading of environmental benefits. From a different perspective the recoverable CO_2 from MEGAMMONIA® will be sufficient to convert all of the ammonia produced to urea, whereas the conventional ammonia process, which uses a steam reformer, is always about 10% short of CO_2. Whilst this shortfall can be made up by adjusting the process, the cost is a reduction in energy efficiency, and an increase in CO_2 emissions.

Assuming all the ammonia from a MEGAMMONIA® plant is converted to urea, in other words 7 000 metric tons/day urea from 4 000 metric tons/day ammonia, it is feasible to speak of the energy efficiency of making urea, rather than ammonia. By our estimates the energy efficiency of making urea should be about 19 MMBtu (LHV)/metric t urea, some 15% - 20% less than equivalent published data for conventional ammonia technology.

The choice between aMDEA and Rectisol® Wash

To imply that the aMDEA process can simply be scaled up from 2 000 t/day to 4 000 t/day is in our view an oversimplification. Lurgi is a Licensee for the aMDEA process and is also the owner of the Rectisol® Wash process. Early on in the development of the MEGAMMONIA® technology we recognised that CO_2 removal might prove to be a bottleneck, and so it has turned out to be. Both processes were carefully studied and compared before making a final choice in favour of the Rectisol® process. So as to remove any bias against aMDEA, our calculation was also submitted to the licensor for checking and was confirmed. The result of the comparison is shown in table 2.

Table 2: Comparison between the aMDEA process and Rectisol® Wash for the removal of CO_2 from the MEGAMMONIA® process

Comparison item	aMDEA	Rectisol® Wash
Circulation shaft power	20 MW_e	4.0 MW_e
Refrigeration shaft power	-	2.0 MW_e
Steam for regeneration	33 MW_{th}	6.0 MW_{th}
Cooling water	25 MW_{th}	6.7 MW_{th}
Absorption column ID	8.5 m	4.1 m
Flash column ID	10.5 m	4.0 m
Regenerator column ID	3.7 m	3.2 m
Loaded solution pipeline DN	1 500 mm	500 mm

In presenting this comparison we do not wish to imply that in general the Rectisol® Wash process is a better choice than aMDEA. Rather we wish to make the point that the choice of CO_2 removal process is a function of the process conditions, and for the conditions prevailing in the MEGAMMONIA® technology the Rectisol® Wash process represents the preferred choice.

In essence, the aMDEA process is a chemical wash which means the circulation rate is almost directly proportional to the amount of CO_2 to be removed. In contrast the Rectisol® Wash process is a physical wash and the solvent loading increases in proportion to the partial pressure of CO_2. MEGAMMONIA® is characterised by large amounts of CO_2 to be removed at a partial pressure which is favourable to the Rectisol® Wash process.

Reduced Equipment and Pipe Sizes

A very important aspect to consider when scaling up processes to much larger sizes is the likely effect on equipment and pipe sizes. When pipe diameters outside the range of nominal sizes are required, the pipes and their fittings become special orders, and the price escalates accordingly. Similarly when vessel sizes become large the number of fabricators able to make such vessels decreases, the number of shippers able to carry such vessels decreases, and again the price escalates. In the extreme, as Lurgi has experienced, shipment from fabricator to site may cost as much, or more, than fabrication itself.

Table 3: Sizes of items of equipment and piping selected from the MEGAMMONIA® technology compared with figures reported in the literature for the equivalent sized conventional ammonia technology.

Comparison item	MEGAMMONIA®	Literature report
CPox Reactor ID	4.1 m (161”)	6.4 m (252”)
CO-Shift Reactor ID	3.8 m (150”)	7m – 8m (276”-315)
Ammonia Synthesis Reactor ID	3.8 m (150”)	3.8 m – 5.5 m (150”-217”)
Syngas compressor shaft power	31 MW	20 MW – 43 MW
Refrigeration compressor shaft power	16 MW	20 MW – 40 MW
Maximum syngas pipe DN	800 mm (32”)	1 200 mm (48”)
Maximum synloop pipe DN	500 mm (20”)	750 mm (30”)

The sizes of vessels and piping in the CO_2 Removal Unit have already been dealt with in the previous section. In table 3 we present the sizes of selected pieces of equipment expected in the MEGAMMONIA® technology. For comparison we show typical sizes of equipment reported for scaled up versions of the conventional technology reported to date in the literature.

The favourable sizes of both the CO-Shift and Ammonia Synthesis Reactors in the MEGAMMONIA® technology is made possible by the use of the axial-radial geometry for which Ammonia Casale is well known. Clearly as the scale of the plant increases the benefits of this geometry become increasingly attractive.

The more favourable size of the Syngas Compressor for MEGAMMONIA® is made possible by the use of a substantially higher pressure in the reforming section of the process.

Bankable Technology

“Bankability” has become a feature of the utmost importance in circumstances where most large projects are today financed in large measure by means of bank loans. A measure of bankability is the extent to which a proposed technology can be said to be “proven”. In table 4 we list the technologies which have been used in developing the MEGAMMONIA® process and against each item we list information with regard to the frequency with which it has been built. The numbers quoted represent the pooled resources of the Alliance partners Lurgi and Ammonia Casale. As can be seen there is an adequate installed base of plants to support the claim that all components of the MEGAMMONIA® technology are well proven. Further the specific combination of technologies, now named MEGAMMONIA®, has been the basis of most of the ammonia plants listed, however the feedstock was either coal or refinery residue, and not natural gas.

In addition the ability of the Lurgi-Casale Alliance to build new ammonia plants is supported by the fact that Ammonia Casale has recently supplied the complete basic design package, plus proprietary equipment, for a new, grass roots, 2 050 metric ton/day ammonia plant being built in Iran, based on the conventional steam reforming flow sheet.

Table 4: List of technologies incorporated in the MEGAMMONIA® process and the degree to which each has been proven

Technologies	State of provenness
Partial Oxidation (Pox)	41 plants, 74 x 10^6 m^3n syngas/day installed capacity
Catalytic Partial Oxidation (CPox)	Over 20 plants, 107 x 10^6 m^3n syngas/day installed capacity
CO-Shift Units	133 plants built
Axial-Radial CO-Shift Reactors	3 reactors installed
Rectisol® Wash	Over 40 plants, 229 x 10^6 m^3n syngas/day installed capacity
Nitrogen Wash Units	Over 30 units built
Gas generation for ammonia plants	32 plants built or under construction largest plant – over 2 000 mtpd
Ammonia reactors	140 reactors installed
Ammonia Synthesis Loops	14 units built or under construction
Complete ammonia plants, steam reforming technology	1 new 2 050 mtpd plant under construction 1 x 1 500 mtpd plant in operation

In table 5 we list the extent to which proven technologies will need to be scaled up from previous plants to meet the requirements of MEGAMMONIA®. There is, in fact, no single technology within the MEGAMMONIA® process which requires a scale-up by more than the guideline limit of 1.5 applied by the lending institutions.

Conclusion

Lurgi and Ammonia Casale have pooled their experience and technologies to come up with a technology developed specifically for large scale ammonia production. The new technology has been named the MEGAMMONIA® technology and is intended for production capacities in the order of 1.4 million metric tons ammonia /year. The new technology has been shown:

- To offer a reduction in capital cost sufficiently large to offset the perceived risk of investing in a new technology.
- To offer a unique opportunity for off balance-sheet financing not available with conventional technology.
- To offer an attractive reduction in operating cost over the most advanced of the conventional technologies available.

- To be bankable in that the process is well proven for feedstocks other than natural gas, and the required scaleups are all less than 50%.

Furthermore MEGAMMONIA® is a technology which is not restricted to coastal locations, the favourably sized equipment makes it also suitable for an inland location.

Lurgi and Ammonia Casale believe their MEGAMMONIA® technology is therefore ready for commercial use and are willing to offer it on a fully guaranteed basis.

Table 5: List of technologies incorporated in the MEGAMMONIA® process, and the degree to which each has been scaled up.

Technology	Degree of scale-up	Basis
Air Separation Unit	0.7 x largest unit	O_2 production
Catalytic Partial Oxidation (CPox)	0.9 x largest unit	CO + H_2 produced
CO-Shift Unit	0.7 x largest unit	CO converted
Rectisol® Wash	0.6 x largest unit	CO_2 removed
Nitrogen Wash	1.2 x largest unit	CO removed
Syngas compressor	1.1 x largest unit	Shaft power
Ammonia synthesis loop	1.4 x largest unit	Gas recirculation rate

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