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

By

Dr William L E Davey CEng, MIChemE, and Dr Thomas Wurzel
Lurgi Oel.Gas.Chemie, Frankfurt Germany,

Dr Ermanno Filippi,
Ammonia Casale SA, Lugano, Switzerland.

Introduction

With the world-wide trend towards rationalisation and increased focus on core business, competition between the world's major ammonia producers has sharpened significantly. In the absence of any more process improvements, which would significantly reduce their energy consumption, producers have begun focussing their attention on relocating their production capacity out of the major consuming countries to countries having cheap natural gas. This has, in turn, reduced the emphasis on energy efficiency but raised the importance of capital productivity. With a view to economy of scale today's business model contemplates the construction of the largest technically feasible plant as close to the sea shore as possible, then shipping the product to world markets in large ships.

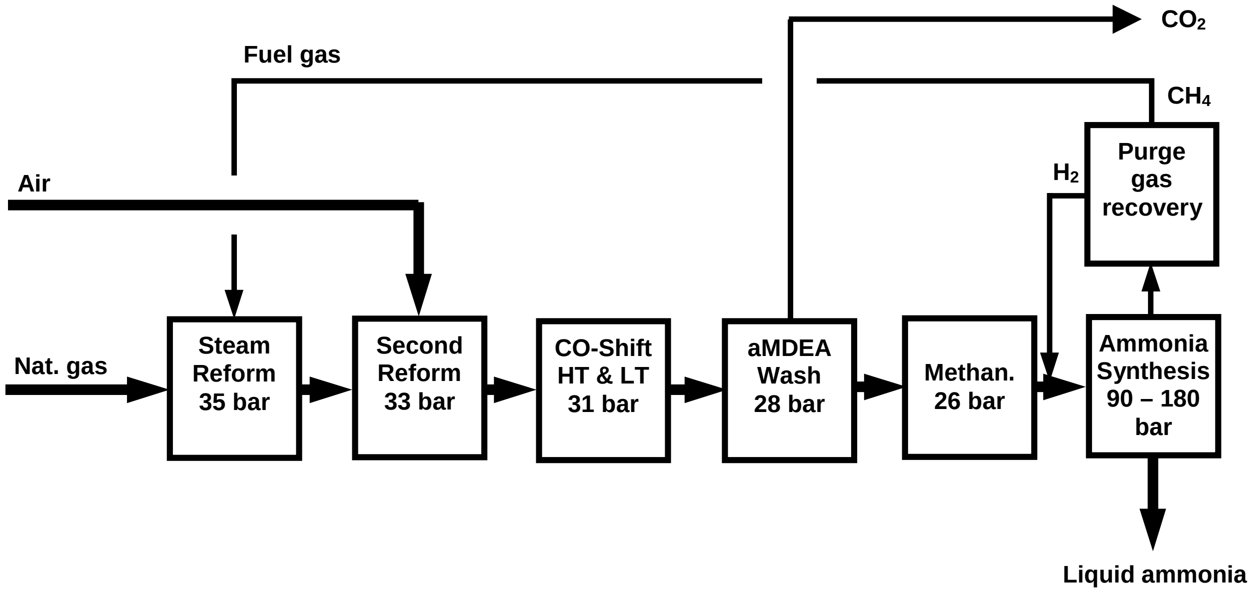
Lurgi had recently developed the innovative Mega-Methanol® technology, which effectively doubled the size of world scale methanol plants, and Ammonia Casale was well known for its focus on obtaining the highest possible productivity from each and every item of equipment. Following from their common perception of the ammonia market trend, Lurgi and Ammonia Casale agreed 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.

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.

Re-entering a market which is today effectively dominated by three experienced suppliers of ammonia plants is not an undertaking to be underestimated. Customers and their bankers demand, and deserve, a significant financial incentive to change from a tried and trusted technology partner. The bankers furthermore require assurances as to the bankability of the new technology. In this paper Lurgi and Ammonia Casale intend to demonstrate that their proposed MEGAMMONIA® technology not only will deliver an attractive economic incentive, but it is also bankable.

The conventional ammonia process

Figure 1: *Block diagram of a conventional ammonia synthesis process*



In figure 1 a conventional ammonia process is depicted comprising the following seven units:

a) Steam Reformer Unit
b) Air blown secondary Reformer Unit
c) CO-Shift Unit
d) aMDEA Unit
e) Methanation Unit
f) Ammonia Synthesis Unit
g) Purge Gas Treatment Unit

In this process nitrogen is added by adjusting the duties between the primary and secondary reformers in such a way 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 tpd, 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 tpd ammonia.

If the Ammonia industry is to follow the example set by the Methanol industry, as it probably will, then the conventional technology is, in our opinion, no longer suitable for a further doubling in capacity, and a fresh approach is needed. We evaluated the conventional technology and concluded that, as a single stream process, it suffers from a number of problems when capacities in excess of 2 000 tpd are contemplated. These are, amongst others:

a) The very nature of a steam reformer limits the pressure, at which syngas can be generated, to a maximum of about 40 bar. For the larger production capacities this results in pipelines and valves very much larger than standard sizes.

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

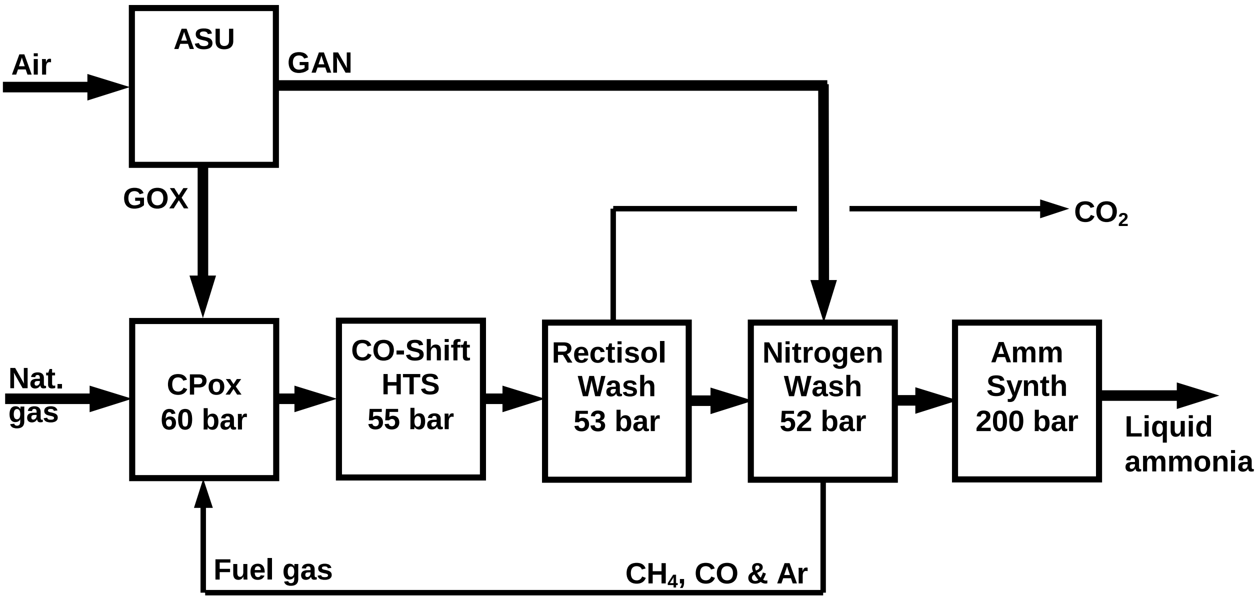
c) The vessel sizes in the conventional carbon dioxide removal processes, such as aMDEA and potassium carbonate, become very large, making fabrication, transport and erection more difficult. In addition the solvent inventory becomes large, and required circulation rates exceed the sizes of readily available pipeline and pump sizes.

d) Ammonia syngas is not purified. Catalyst poisons are converted into impurities, which then accumulate in the ammonia synthesis loop depressing the achievable conversion rates, increasing the required circulation rate, and increasing the sizes of all the equipment and piping in the loop.

e) To control the accumulation of impurities the synthesis loop must be purged, cleaned up, and the associated valuable ammonia syngas returned to the loop.

The MEGAMMONIA® technology

Figure 2: *Block diagram of the MEGAMMONIA® process*



In figure 2 the MEGAMMONIA® process is depicted and comprises six principal units:

h) Air Separation Unit (ASU)
i) Catalytic Partial Oxidation Unit (CPox)
j) CO-Shift Unit

k) Rectisol® Wash Unit
l) Nitrogen Wash Unit
m) 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 CPox reactor, and a stream of 99.99% pure nitrogen for use in the Gas Purification Unit.

In the Catalytic Partial Oxidation Unit (CPox 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 and pre-reformed. Additional steam is added to the pre-reformed gas, to adjust the steam to carbon ratio, and then reformed to CO, H_2 and CO_2 in the CPox reactor by partial oxidation with oxygen. A close approach to equilibrium is ensured by passing the gas over a reforming catalyst located in the CPox reactor. 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 in the CPox Unit to 60 bar.

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 reactors for a 2 050 tpd plant are currently being implemented. The gas is then cooled to ambient temperature by exchanging heat with other process and utility streams. The process condensate arising is separated from the gas and recycled to the saturator in the CPox Unit.

CO_2 is removed in the Rectisol® Wash Unit by absorption in cold methanol. The absorbed CO_2 is recovered from the cold methanol by flashing it to near atmospheric pressure. The recovered CO_2 is sufficiently pure for use in the synthesis of urea. Refrigeration for the Rectisol® process is provided by ammonia supplied from the Ammonia Synthesis Unit. The Rectisol® Wash technology is a process proprietary to Lurgi, and has been installed in many plants the world over.

The remaining impurities CO, CH_4 and Ar are removed in the Nitrogen Wash Unit by washing the gas with liquid nitrogen. Simultaneously the stoichiometric requirement of nitrogen is added to the hydrogen. The recovered impurities, CO, CH_4 and Ar are flashed to near atmospheric pressure, thereby providing the required refrigeration for the Nitrogen Wash Unit, and recycled to the CPox Unit for use as fuel in a fired heater. The Nitrogen Wash technology is a process which has frequently been used by Lurgi in conjunction with its Rectisol® Wash process for the production of ammonia syngas from refinery residues. From the Nitrogen Wash Unit pure ammonia synthesis gas, comprising H_2 and N_2 in the correct stoichiometric proportion, is delivered to the Ammonia Synthesis Unit.

The Ammonia Synthesis Unit is of conventional Casale 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 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. Synthesised 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 absorbed 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 second 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® Wash Unit.

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 has been calculated at 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 for the power required for the process and 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.

The economic incentives in favour of the MEGAMMONIA® Process

1 Lower Investment Required

In seeking a sufficiently attractive reduction in the the capital cost of the MEGAMMONIA® technology over conventional ammonia technology Lurgi and Casale have sought to:

- retain the single line character required

- avoid recourse to specialist fabricators and shippers by engineering for vessel sizes of reasonable dimensions i.e. less than 5 m diameter

- Avoid specially fabricated piping and fittings by engineering for sizes within suppliers' standard ranges.

The success of this approach can be judged, in the first instance, by comparing the two technologies. Significantly MEGAMMONIA® has one less process unit than the conventional technology, and two less catalytic reactors.

In the second instance; in table 1 a comparison is recorded between the MEGAMMONIA® technology and scaled up versions of the conventional technology in respect of the sizes of selected vessels, pipes and machines reported in recent literature. The more favourably sized vessels and pipes in the gas generation section of the MEGAMMONIA® technology, and the more favourably sized syngas compressor, is a direct result of the selection of a higher gas generation pressure. The more favourable dimensions of the CO-Shift and Ammonia Synthesis reactors for MEGAMMONIA® is a direct result of incorporating the axial-radial geometry into their design.

Table 1: *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	6,4 m
CO-Shift Reactor ID	3,8 m	7m – 8m
Ammonia Synthesis Reactor(1) ID	3,8 m(1)	3,8 m – 5,5 m
Syngas compressor shaft power	28 MW	20 MW – 43 MW
Refrigeration compressor shaft power	16 MW	20 MW – 40 MW
Maximum syngas pipe DN	800 mm	1 200 mm
Maximum synloop pipe DN	500 mm	750 mm

(1) ammonia concentration at converter outlet > 25 mol%

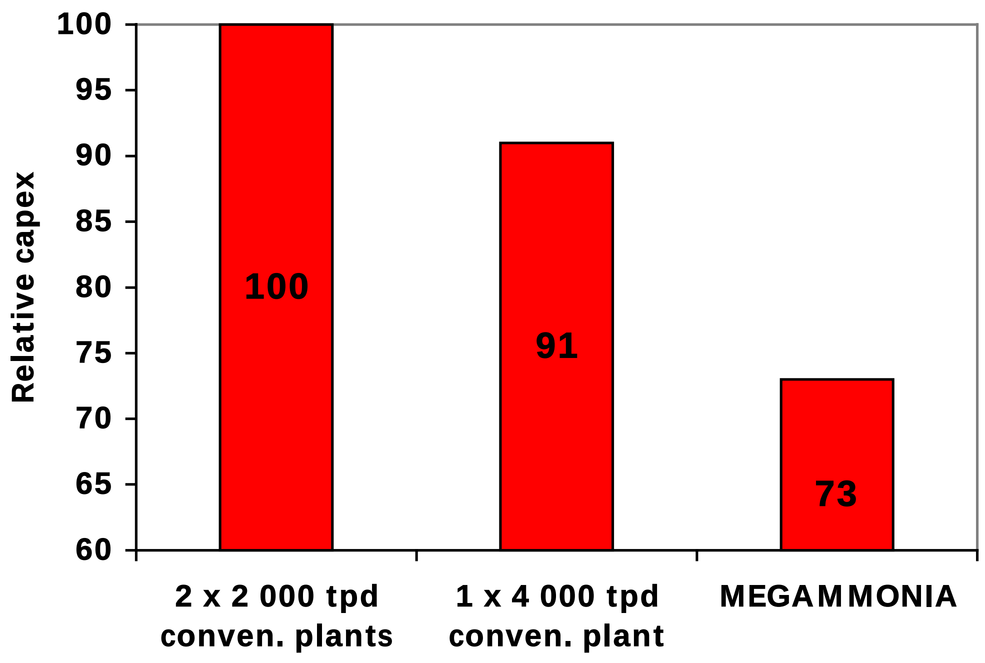
Table 2: *Comparison between the aMDEA process and Rectisol® Wash for the removal of CO_2 from the MEGAMMONIA® process*

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 the third instance; Lurgi is owner of the Rectisol® Wash process, but is also a licensee of the aMDEA process, the standard process for the conventional technology. Recorded in table 2 is a comparison of duties, vessel and pipe sizes between the two technologies for the given CO_2 removal duty. Selection of the Rectisol® Wash process for MEGAMMONIA® has resulted, again, in a favourable reduction in duties and equipment sizes.

The ultimate test of whether the foregoing strategy had delivered a sufficiently attractive reduction in capital cost was determined, as part of a recent feasibility study, by comparing the capital required for MEGAMMONIA® with information reported in the literature, scaled appropriately for size. The basis for this comparison was an ammonia facility complete with cooling tower, boiler feed water treatment, and an ammonia storage tank of 40 000 tons. The result of this comparison, recorded in figure 3, shows that, at a plant size of 4 000 tpd, the MEGAMMONIA® technology offers a reduction in specific investment cost of between 15% and 20% over a scaled up version of conventional technology.

Figure 3: *Comparison of MEGAMMONIA® Investment with conventional technology. Scope is an ammonia facility complete with all utilities and ammonia storage. The cost of 2 x 2 000 tpd conventional plants is taken as 100%. The range of uncertainty is also shown.*



2 Air Separation Unit permits off balance-sheet financing

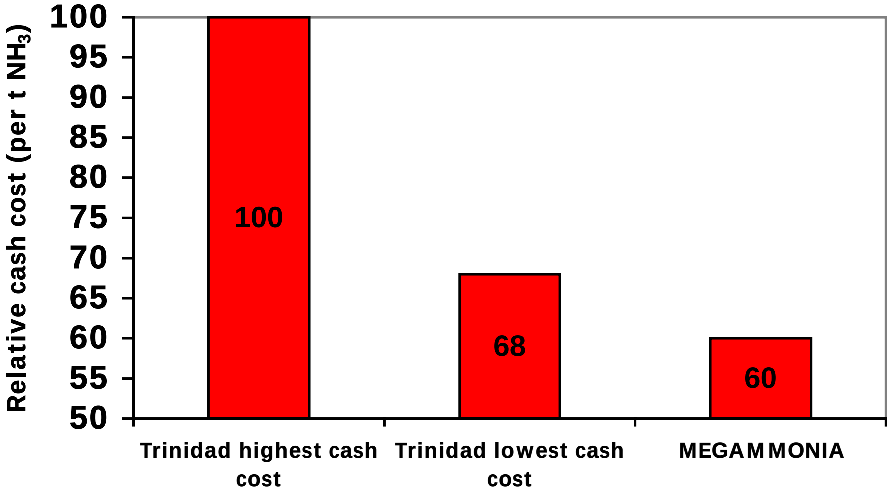
In these times where capital productivity has become so much more important, having an Air Separation Unit as part of the plant presents a unique opportunity for “off balance-sheet financing”. In table 3 the breakdown of the Investment cost of a MEGAMMONIA® plant is given, and shows that the Air Separation 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 then the MEGAMMONIA® technology affords an ammonia plant owner the opportunity to reduce his capital investment by a further 17% by entering into a supply agreement with an Industrial Gas Company. For the ammonia plant owner this portion of the capital required can then be converted into an operating cost without degrading the economic attractiveness of a given project.

***Table 3**: 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 %**

3 Reduced Operating Cost

***Figure 4:** Comparison of relative cash costs between MEGAMMONIA® and a representative range of Trinidad producers. The highest reported cash cost cash cost in Trinidad is taken as 100%.*



MEGAMMONIA® has fewer unit operations and fewer catalytic steps than the conventional ammonia process, it is self-sufficient in electricity, more ammonia is produced by a given staff complement, and the maintenance cost (related to the capital cost) is lower. It goes without saying, therefore, that the cost of producing ammonia should be lower than for the conventional process. We have estimated the operating cost for MEGAMMONIA® and compare this, in figure 4, with a representative range of producers located in Trinidad. On the basis of this comparison MEGAMMONIA® offers the potential for a reduction in cash cost of some 10% - 15% below the most advanced conventional ammonia technology in operation today.

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 will report to the Rectisol®

Wash Unit than is the case in a conventional ammonia process. Provided there is a use for the CO_2 recovered from the Rectisol® Wash Unit 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 Nox emissions will be lower, as steam reformer burners have a higher Nox emission than conventional fired heater burners. The absence of a steam reformer also means that low frequency burner noise will be reduced.

Overall 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 tpd urea from 4 000 tpd ammonia, it is feasible to speak of the energy efficiency of making urea, rather than ammonia. By our calculation the energy efficiency of making urea will be about 21 MMBtu/t urea, some 15% - 20% less than equivalent published data for the conventional ammonia technology.

Bankability

New projects are today financed, in large measure, by means of bank loans and, as a consequence, "bankability" has become a feature of the utmost importance. Bankability is a rather general term meant to describe the confidence level a bank may be expected to develop in the prospect of recovering their investment in a given project, timeously. There are no hard and fast rules for the measurement of bankability, but experience with large Methanol projects has taught us that, amongst other factors, the extent to which a proposed technology can be said to be "proven", and the extent to which a proven technology is being scaled up, are important criteria which will be carefully scrutinised.

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.

Table 4: *List of technologies incorporated in the MEGAMMONIA® process and the degree to which each can be said to be proven.*

Technology	**State of provenness**
Partial Oxidation (Pox)	41 plants built, 74 x 10^6 m^3n syngas/day installed capacity
Catalytic Partial Oxidation (CPox)	Over 20 plants built, 107 x 10^6 m^3n syngas/day installed capacity
CO-Shift Units	133 plants built
Axial-Radial CO-Shift Reactors	10 reactors installed
Rectisol® Wash	Over 40 plants built, 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 tpd
Ammonia reactors	130 reactors installed
Ammonia Synthesis Loops	23 units built or under construction

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.

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

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 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 make 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.

References

1) H Goehna; “Concepts for Modern Methanol Plants”. Proceedings of the World Methanol Conference, Tampa, USA (December, 1997)

2) Max Appl; “Ammonia”. Ullmann’s Encyclopedia of Industrial Chemistry, 6th Edn, Electronic Release (1998)

3) Max Appl; “Ammonia, Methanol, Hydrogen, Carbon Monoxide, Modern Production Technologies”. Published by British Sulphur Publishing (1997)

4) Max Appl; “Ammonia, Principles and Industrial Practice”. Published by WILEY-VCH (1999)

5) Heinz Hiller et al; “Gas Production”. Ullmann’s Encyclopedia of Industrial Chemistry, 5th Edn, Vol A 12 (1989)

6) J Larsen, D Lippmann and C W Hooper; “A new process for large-capacity ammonia plants”. Nitrogen and Methanol no. 253 (September/October, 2001)

7) J S Larsen and D Lippmann; ”The Uhde Dual Pressure Process – Reliability Issues and Scale Up Considerations”. Proceedings of the 47th Annual Safety in Ammonia Plants Symposium, San Diego, USA (September, 2002)

8) S E Nielsen; “Ammonia Plant Capacity Considerations”. Proceedings of the 46th Annual Safety in Ammonia Plants Symposium, Montreal, Canada (January, 2002)

9) J Abughazaleh, J Gosnell and R B Strait; “Single Train 4 000 – 5 000 MTPD KBR Ammonia Plant”. Proceedings of the 47th Annual Safety in Ammonia Plants Symposium, San Diego, USA (September, 2002)

10) J T Sommerfeld; “Petrochemical plant costs for the new millennium”. Hydrocarbon Processing, pg 103 – 108 (June, 2001)

11) “Investment and re-investment in ammonia and nitrogen fertilizer production: The changing structure of industry costs and competitiveness, 2000 – 2015”. A multi-client report by British Sulphur Consultants (December, 2001)

12) “An independent economic evaluation of the MEGAMMONIA® process”. A single-client report by British Sulphur Consultants (September, 2001)