Introduction
Linear Alpha Olefins (LAO) represent a group of chemical intermediates with a wide range of applications in the Chemical and Petrochemical Industry and will gain increasing importance in the future. With their bonding propensity they can be reacted with a variety of other chemical species from a multitude of chemicals.

Linde as one of the leading contractors for plants for the production of petrochemical base products – such as ethylene and propylene and the respective polymers – has been working intensively on the development of an α-Olefin-Technology based on ethylene oligomerisation for more than a decade (Fig. 2), starting with laboratory tests and feasibility studies in 1993. In 1997 we concluded a cooperation agreement with Sabic that, after a period of joint R & D work, resulted in the installation of a pilot plant at Riad and the successful demonstration of the α-SABLIN-Technology in 2001. The technology trade mark α-SABLIN originates simply in combining the first three letters of both companies' names – SABIC and LINDE.

Structure and properties of LAO
LAO are characterized by a terminal double bond and a straight chain as in 1-Butene, 1-Hexene, 1-Octene etc. In this regard they differ from Internal Olefins and the vinylidene Olefins (Fig. 3). Except for 1-Butene, which is gaseous, LAO from C6 to C16 are clear, colourless liquids with a characteristic smell. C18+ LAO are waxy solids (Fig. 4).

Application of LAO (Fig. 5)
The main areas of application for LAO are:
• Polymers (comonomers for Polyethylene)
• Plasticizers (oxo alcohols)
• Synthetic lubricants (poly-alpha-olefins)
• Detergents (oxo alcohols, linear-alkyl-benzenes).

The most important application (Fig. 6) is that as comonomers for the polyethylene production which consumes some 50 % of the LAO. The implementation of LAO molecules in a polyethylene chain influences the physical properties of the polymer significantly offering a wide range of products with tailored physical properties. Modern polymerisation processes utilize up to 10 % α-Olefins, either 1-Butane, 1-Hexene or 1-Octene.

The second largest consumption of LAO is for detergents production with an approximate 25 % share.

Consequently the main driving force for the emerging LAO market is the application of C4 - C8 LAO as comonomers for high performance polyethylene (Fig. 7) such as the so called PE 100 or PE 150 grades, which are used to produce pipes for a nominal pressure of 10 and 15 bars. These pipes are used for natural gas supply systems. The expected annual growth rate for LAO is in the range of 5 - 10 % representing one of the fast growing chemical intermediates.
Basic Chemistry of the α-SABLIN-Technology
The α-SABLIN-technology utilises a 2 component catalyst system for homogenous, liquid phase oligomerisation of ethylene into LAO (Fig. 8). The catalyst consists of a proprietary Zirconium compound and an aluminium alkyl co catalyst and can be activated at site or supplied in an activated form by qualified catalyst manufacturer.

This catalytic cycle consists of chain growth by ethylene insertion reaction at the co-ordination site and the displacement of the co-ordinated hydrocarbon from the organometallic complex. The molecular ratio of Al/Zr determines the extent between chain growth and displacement reaction. With a high Al/Zr ratio it is possible to shift the product spectrum to about 80 % C4 - C8 comonomer range LAO. With a lower Al/Zr ratio the spectrum can be adjusted to produce more towards the medium or heavy end LAO (Fig. 9).

α-SABLIN-Reactor
The oligomerisation of ethylene to LAO is carried out in a bubble column reactor with the solvent and catalyst fed to the liquid phase (Fig. 10). Ethylene is introduced via a gas distribution system at the bottom of the reactor. In this arrangement ethylene has 3 functions. Besides feedstock ethylene is used as coolant and to mix the reactants. Liquid LAO product together with the solvent and catalyst is leaving the reactor and send to the recovery section. Ethylene, light LAO and solvent which leave the reactor according to the vapour / liquid equilibrium are condensed in a reflux condenser and sent back to the reactor.

The function of ethylene as a coolant in the LAO reactor is a unique feature of the α-SABLIN technology. As the reaction is a highly exothermic reaction, heat has to be removed from the reactor. All heat of reaction is removed by the sensitive heat of ethylene, boiling in the reactor inventory and the reactor reflux. No indirect heat exchange is used in the liquid phase, as this could be an area of fouling or deposits of products on cold surfaces. The ability to avoid plugging or to handle it represent one of the key success factors of the technology.

Reaction mixing is another important role of ethylene since it is important to provide and sustain a homogenous, uniform reactor inventory in order to avoid hotspots and product degradation.

Fig. 11 shows the start-up of the process by injection of catalyst to the reaction system. The system changes from isothermal conditions without reaction into a steady state with lower ethylene temperature at the reactor inlet and a higher temperature of the reaction zone. This temperature spread is required to operate the reactor at constant conditions.

The α-SABLIN process is characterised by moderate reaction conditions (Fig. 12). LAO are produced in a liquid phase reaction at temperatures of 60 – 100 °C at 20 – 30 bar pressure, which is significantly milder than competitive processes.

All of the results have been verified in a pilot plant that was operated for more than 2 years (Fig. 13). The LAO produced in the pilot plant were tested and positively qualified for LAO applications.
In a future industrial scale plant the reactor section is integrated into the ethylene cycle as shown in the simplified process flow diagram of Fig. 14. Ethylene is routed via the cycle compressor and the heater/coolor to the reactor and recycled via a two stage condenser system. The light and the heavy LAO streams are combined after the catalyst removal and routed to the alpha-olefin separation. The dissolved catalyst is extracted from the reactor effluent in a simple removal system and Zr and Al are recovered separately as the corresponding metal oxides.

The separation train applies standard distillation technology (Fig. 15). Due to the high selectivity of the catalyst there is no need to install sophisticated superfractionation steps for removal of impurities. Typically the separated products are Butene-1, Hexene-1, Octene-1, Decene-1 and a C12+ fraction.

The highly selective LAO reactor system produces high purity LAO which are suitable for superior quality LAO's applications meeting the whole range of different consumer specifications. Typical purities are 99 % for C4, 97 % for C6, 95 % for C8 and 94,5 % for C10 LAO content in the product (Fig. 16). The content of branched and internal olefins is low, due to the selectivity of the catalyst system. Going to higher product fraction, the content of branched and internal olefins is increasing somewhat (Fig. 17).

**Status and Summary (Fig. 18)**
LINDE and SABIC have jointly developed a new competitive technology for the production of LAO. The highlight of the α-SABLIN technology is the catalyst system. The highly active catalyst produces LAO at moderate reaction conditions with high yield and purity meeting the whole range of consumer specifications. The technology is flexible to satisfy virtually any current and future marked demands. The process perfectly fits into Linde's technology portfolio as a link between our ethylene technology and downstream polymer and other plants consuming LAO. Linde has already performed a FEED package for a worldscale LAO plant and created the basis for the future licensing of the technology.

From an economical point of view the last two years have been difficult for producers as the sector struggled with excess capacity due to rapid expansion. Moreover, demand growth was virtually not existent in 2002 and 2003, which mainly reflects the turndown of the global economy.

The long term outlook, however, is still positive and the average growth of at least 6 %/year will resume once the global economy recovers and the demand into PE increases, both in Europe but particularly in the larger North American market.

There are plans at Sabic and Jubail United Petrochemical Company respectively to build a first commercial α-SABLIN based plant for the production of 150.000 t/y LAO. Fig. 19 shows a 3D plot about how the plant would look like. A final decision will be most likely made in May 2004.

Hopefully we can add another milestone to the list of technology experience, namely that of the award of the 1st large scale commercial unit (Fig. 20).