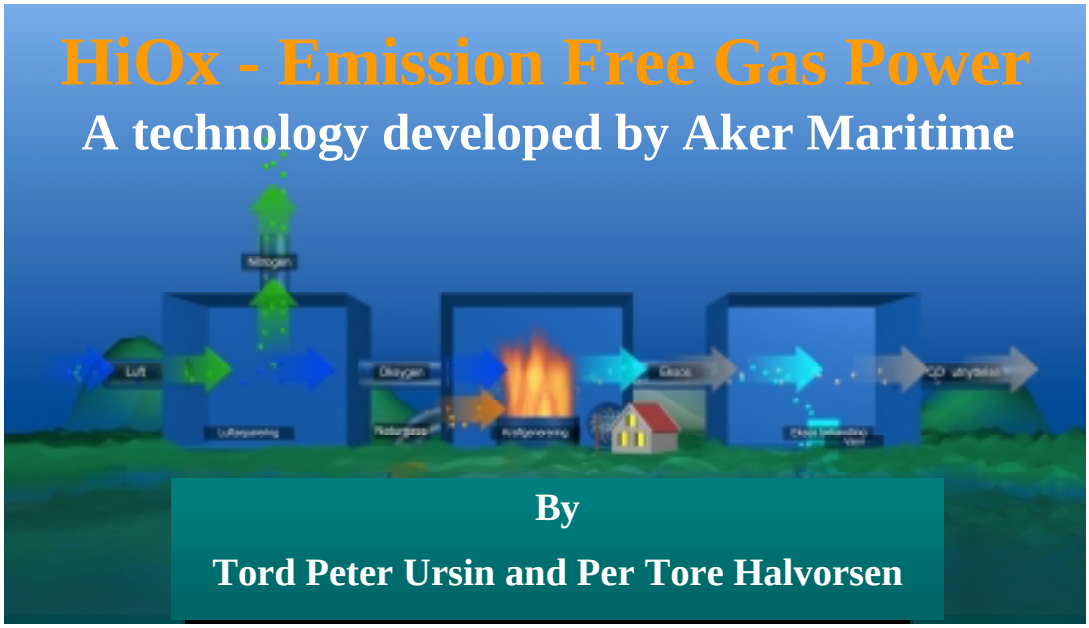


INTRODUCTION

In recent years, the future structure and methods for electric power generation has been a controversial political topic in most European countries. Environmentally friendly and sustainable alternatives are demanded. With increasing availability and reasonable cost, natural gas is a growing energy source for electric power generation. Large-scale, conventional gas power plants emit large amounts of the greenhouse gas CO_2, as well as contributing to regional pollution by NO_x emissions.

Several concepts for gas fired power plants with reduced emissions are known and technically available today. Norway has achieved a strong international position with regard to the development of technologies for CO_2 capture in gas power production and Norwegian authorities are actively promoting the search for new technologies to reduce the emissions of greenhouse gases from gas-fired power plants.

Aker Maritime has been developing an oxyfuel technology, named HiOx, since 1997. The concept is based on combustion of natural gas and oxygen in an atmosphere of combustion products. The technology is generic and can be used in a variety of applications. The process is closed and produces CO_2 suitable for enhanced oil recovery, pressure support in oil fields and below ground sequestration. The HiOx combustion, heat and power generation technology is characterised by zero emission of both CO_2 and NO_x. The technology is accepted as a strong candidate for gas power plants from a technical, economical and political point of view in a future with stronger focus on the environment.

The captured CO_2 must be stored or used and not emitted to the atmosphere. Several alternatives exist:

- Dissolution in seawater at deepwater locations
- Below ground sequestration in aquifers or depleted gas and oil fields.
- Injection into producing condensate or oil fields as part of an Enhanced Oil Recovery (EOR) scheme.

- Injection in coal beds for the purpose of methane production. (This scheme is commonly referred to as Coal Bed Methane)

Both CO_2 and nitrogen have been used for injection into active oil reservoirs and several such fields are in operation. Focus on CO_2 emissions has led oil companies to consider a more extensive use of CO_2 for pressure support and EOR. It is expected that in the near future more oil fields will make use of CO_2 or nitrogen for enhanced oil recovery.

THE HiOx DEVELOPMENT

HiOx History

Aker Maritime has been developing the HiOx concept since 1997. The first evaluations were done during the project: "Oxygen based combustion of natural gas for production of energy without emissions", which was supported by the Norwegian Research Council via the KLIMATEK Program. Several cycles were examined and rigorous combustion simulations were performed.

Technical work and cost calculations have been carried out for a variety of differently sized plants both onshore and offshore. In addition to the development program presented below, recent work includes a conceptual study for Elf at the Frigg field and a feasibility study for an onshore plant as part of the licence application for block 35/3 on the Norwegian Continental Shelf.

Development program

In autumn 2000 Aker Maritime launched a long-term development program for HiOx with the aim of building a demonstration plant for development, verification and demonstration of the technology. This program is split into phases as follows:

- definition phase
- design phase
- fabrication phase
- operation phase

The definition phase of this program commenced in October 2000 and was completed first half of 2001. The main target for this phase has been to carry out a conceptual screening and to establish the basis for the design phase of the HiOx development. BP, RWE-DEA and FORTUM participated as technical partners and financial sponsors of the definition phase. Additional funding was received from the Norwegian Research Council via the Klimatek program. SINTEF and ALSTOM Power have contributed to the technical evaluations.

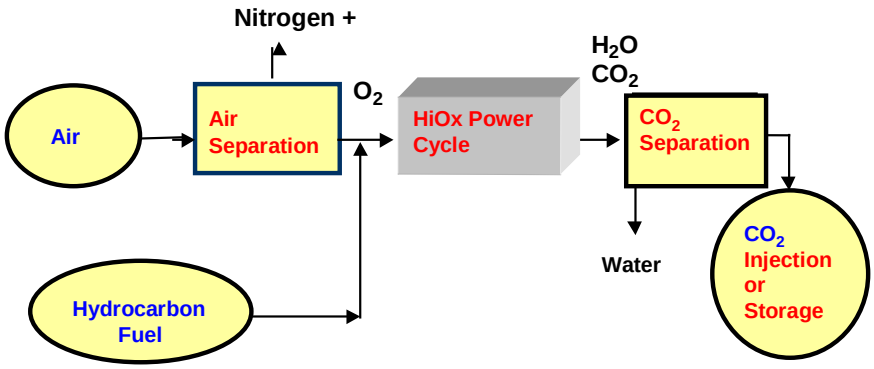
In the 2-year design phase, a technical basis, plan and cost estimate for a HiOx demonstration plant in Norway shall be developed. The target is that this documentation shall be sufficient background for a decision to build the HiOx demonstration plant. In the same period, the market opportunities for environmentally friendly electricity production are expected to become clearer, providing additional backing for a decision. Aker Maritime has presented the plans for the design phase for the Klimatek program and received their consent to partly finance the development.

A demonstration plant of a considerable size (20 – 50 MWel) is an important step towards gaining operational experience and market acceptance for the technology. In addition, experience gained through the demonstration plant will reduce the time required, and the technological and economical risks, for further development into large-scale, emission free gas power plants.

THE HiOx TECHNOLOGY

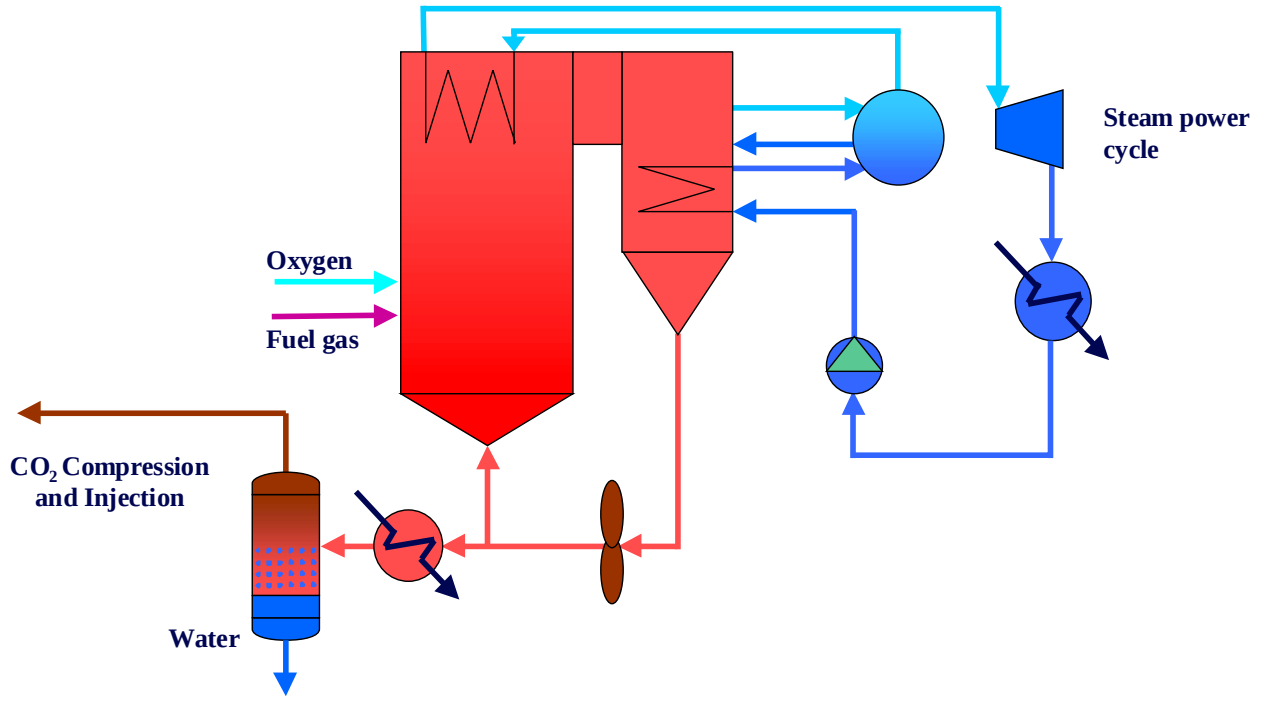
The HiOx Principle

A general flow diagram, illustrating the HiOx principle, is given in the figure below:



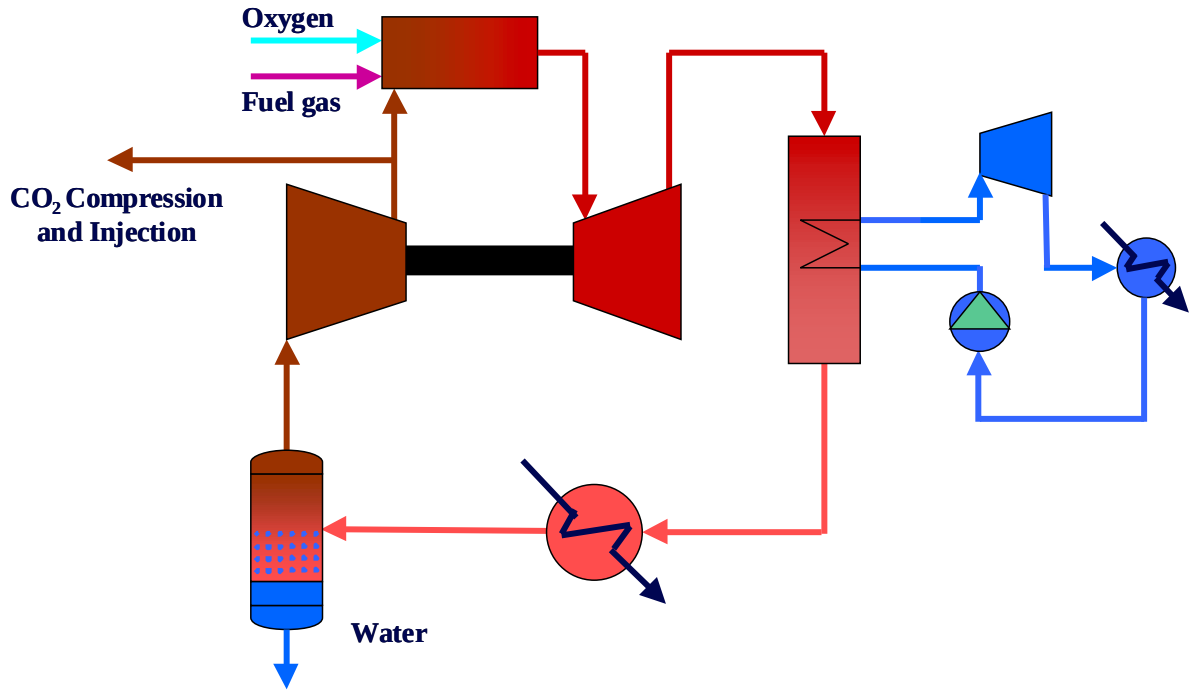
HiOx operating principle

The heart of the HiOx technology is the combustion of natural gas in a nearly nitrogen free atmosphere. Nearly pure oxygen is separated from air and used in the combustion. The energy from combustion is used to generate electricity and heat. The flue gas comprises mainly water vapour and CO_2. Part of the flue gas is cooled and circulated back to the combustion zone in order to control the temperature at an acceptable level. The water is separated from the flue gas by cooling and the CO_2 is injected. Nitrogen from the cryogenic air separation unit (ASU) is normally vented back to the air. The primary feature of this combustion system is that it is “closed” and has no emissions to air.



HiOx steam cycle

Two alternative power generation solutions are presented on the figures in this section. In the first, steam is produced in a conventional steam boiler and is used to drive a standard steam turbine. A net electrical efficiency of 8-9 percentage points lower than new, conventional steam power plants is expected for this solution. This efficiency loss includes the power consumption of a cryogenic ASU and a CO_2 compression train. The second solution is dependent on a custom gas turbine, which is driven by flue gases from the HiOx process. For this solution the efficiency is expected to be 10 percentage points lower than a conventional gas turbine combined cycle plant, including the same losses as above.



HiOx Gas turbine cycle

Significant scale effects exist for both solutions, both with respect to specific costs and efficiency. Going from 40 to 400 MW sized plants, an efficiency gain of 7-10 percentage points is expected. The capital cost for the cryogenic ASU and CO_2 pipeline have particularly large scale effects contributing to an even greater change in the cost of electricity.

Technological challenges

The technical challenges for the HiOx process are the combustion and power generation sections. All other elements in the process are industrially proven. For the combustion, the challenge is primarily to achieve a stable and sufficiently complete combustion with minimal excess oxygen.

The working medium of the HiOx cycles primarily consists of H_2O and CO_2. This is fundamentally different from conventional cycles where N_2 is dominant. Especially the changes in aerodynamics and heat transport will have large impact on the gas turbine design, even if the cycle fluid's operating pressure and temperature are not increased.

Based on the investigations so far, there is little doubt that turbo machinery for HiOx plants can be realised.

Advantages of the HiOx technology
HiOx is fundamentally different from the other concepts in that it is a "no exhaust gas stack"-concept, i.e. there is no discharge to atmosphere. After condensation of water, the combustion product will be CO_2 ready for compression and transport / injection. Thus, any NO_x formed during combustion will, by nature, not be discharged to the atmosphere.

The HiOx concept does not include any chemicals with corresponding waste products handling or loss to the environment.

In addition to electricity, the HiOx power plant produces CO_2, argon and nitrogen as bi-products. All of these gases are commercially traded industry gases representing a value. The size of this market though, is not sufficient to absorb the quantities from full scale gas power plants. However, both nitrogen and CO_2 are currently injected into oil fields for enhanced oil recovery and pressure support. Hence, these gases represent a definite value provided an infrastructure is established.