Report from the lecture presented by Carlo Rubbia

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Highlights: In view of the current global energy growth (2 %), the increase of the world population (10-12 billion people by 2100) and the end of the fossil era at sight, formidable new research on finding new dominant supplies of energy is urgently needed according to Rubbia. The problem is accentuated by the threats of climate changes caused by the increased use of fossil fuels which may lead to a doubling of the atmospheric CO_2 concentration within 50 – 75 years. Since long lead times are required, technically advanced countries in particular have an obligation to intensify their energy R&D.

New solar as well as new nuclear energy sources are needed to mitigate the situation. The present nuclear reactors make use mainly of the isotope U-235 which represents only 0.7 % of natural uranium. Therefore a fuel shortage will occur on a time scale of about 50 years. For nuclear energy to be sustainable it will become necessary to breed fissile material from U-238 or Th-232. In this way nuclear energy will be truly sustainable at a time scale comparable to that of future DT-fusion based on Li fuel.

Some totally different but adequate nuclear technology must be developed in order to reduce the risks of weapon´s proliferation. Only if the " umbilical chord between energy and weapons production is severed", large-scale nuclear energy usage becomes acceptable. Other factors that must be considered in developing new nuclear energy sources are safety and environmental impact.

To meet these requirements, thorium should be used as a "fuel" and the reactor operated in a sub-critical mode, external neutrons being provided from a high power accelerator. By recovering long-lived actinides and mixing them with the thorium fuel, only fission fragments remain and these convert to stable elements in some hundred years.

The Energy Amplifier invented by Rubbia is a possible candidate to meet these requirements. A high intensity proton beam is injected into the centre of a reactor where a heavy-element target converts the protons to numerous neutrons that enter the reactor core. A suitable target may be a Pb/Bi target of Russian design and an accelerator may be a scaled-up version of the Swiss-Villigen cyclotron. This accelerator now provides 600 MeV protons with a beam power of 1 MW. An increase of beam power by a factor ten would be needed for a sub-critical reactor (k=0.99) with a thermal power of 2.4 GW. The cost per kWh for the energy from an Energy Amplifier is estimated to be comparable to that from a Fossil Power plant.

Concerning solar energy, Rubbia suggests that a very interesting option is to have mirrors concentrating the solar radiation to spots where some liquid can be heated and stored for rather long times. Ongoing activities in this field should be encouraged particularly at sites in the so-called sun-belt. Two cases were presented; hot storage at 550 ºC and cold storage at 290 ºC. In both cases electricity can be obtained by means of a steam generator. The advantage with this direct collection and storage of solar energy compared with today´s wind and photovoltaic is cost and availability; energy is produced only when the sun is available.

Among Rubbia´s concluding bullet points, the following two are particularly noteworthy:
* "The future of mankind is crucially dependent on continued availability of cheap and abundant energy. *Should energy supply breakdown, mankind may collapse*."
* "Although innovative energies may eventually be more essential to developing countries, *only our technically developed society can realistically foster such a change.*"

Discussion:
Astrid Gräslund asked why we do not yet have thorium based nuclear reactors. According to Rubbia the main reason is that the nuclear technology was initially focused on uranium since thorium was of no interest for weapons manufacture.

Ingemar Grenthe pointed out that carbon sequestration may allow using the abundant resources of coal without jeopardizing the climate and wondered why Rubbia had not included

this option. He answered that environmental effects of large-scale storage were not yet sufficiently studied and that there might be unwanted effects on living organisms.

Grenthe also asked if one could really neglect nuclear proliferation in the thorium cycle. Rubbia´s answer was that it is very unlikely that a bomb would ever be constructed based on thorium because of the appearance of gamma emitting nuclides in the decay chain after U-232 (life time 68.9 years) which is produced in addition to U-233. The contact dose rate of 30 kg of U-233 with 2 $x10^{-3}$ of U-232 is practically asymptotic after a few years and it is then about 72 Sv/hour, which corresponds to a 50% lethal dose after 5 minutes exposure to the bare mass. It is evident that contact fabrication of such an engine is impossible and it cannot be transported without very heavy shielding, much too heavy for a weapon to be carried for instance on a rocket.

Bengt Gustafsson asked which one of the two energy alternatives, solar or nuclear Rubbia would favor. The answer was that he thinks both are needed. In the sun-belt, solar may be sufficient but in Hamburg and other Northern locations, nuclear energy will be needed.

Further reading: http://library.cern.ch/archives/isad/isarubbia.html and key word *Energy Amplifier*.