The Coming Energy Winter and the Future of Fusion

Brendan McNamara
Leabrook Computing, Bournemouth brendan@leabrook.co.uk

This is a version of a paper given at the 31st. European Physical Society conference on Plasma Physics, Imperial College, London, June, 2004, extended to reflect the consensus views of many participants.

The decline of conventional oil is now imminent and a much more serious crisis than the longer term catastrophes of global warming. Both sets of events are the motivation for rapid development and deployment of non-carbon based energy systems. Fusion is now ready for the final engineering steps for commercial power plants to provide clean energy for tens of thousands of years. It is being funded at a withering rate which will not make it through the energy winter. A global investment of a mere $2Bn per year will secure the Fusion option for mankind in about 20 years.

The Decline of Conventional Oil

The Association for the Study of Peak Oil (ASPO), a 30 strong group of experienced oil geologists and other scientists, has closely examined the history of oil discovery and production, on a country by country basis, using every available public domain source of data. Fig. 1 below shows that production has substantially exceeded discovery for about 20 years, despite a truly global effort to explore all likely rock formations. The global search was quite incomplete in the 1970s so the big finds of the 1980s gave hope that much more remained undiscovered. Of 125 oil producing countries, 95 have passed their peak discovery point and 60 are now in production decline. The data is now almost complete and the general trend is clear. There is now little prospect of finding any new oil fields on the scale of Saudi Arabia, and so the future ASPO projections prudently fade away.

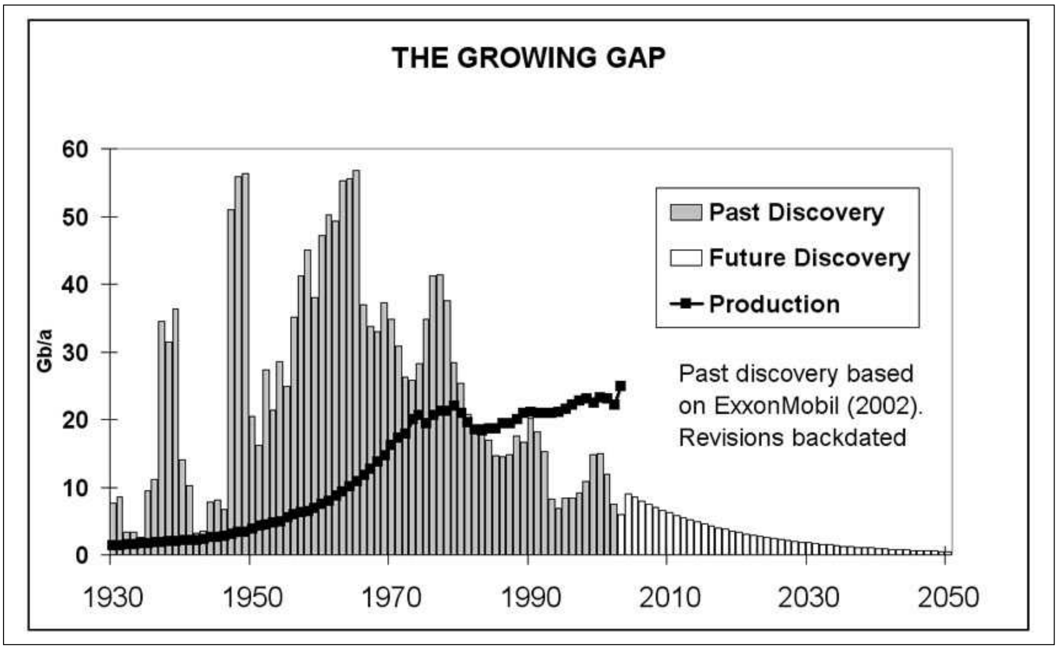

Fig. 1 Production has exceeded discovery for 20 years. (ASPO)

As a consequence, the history and projections of oil production now show a peak in 2008 followed by a 3-5% decline to the end of 'conventional', or cheap easily accessed, oil – Fig. 2 – and a peak in gas supplies only a decade later. With a global economy based on perpetual growth, an exponentiating population, and rising demands and expectations, this can only lead to a coming Energy Winter. It is counter intuitive, at a time when world oil supplies are at their highest and cheapest, that the peak of supplies is the crucial point at which vast economic changes must be made

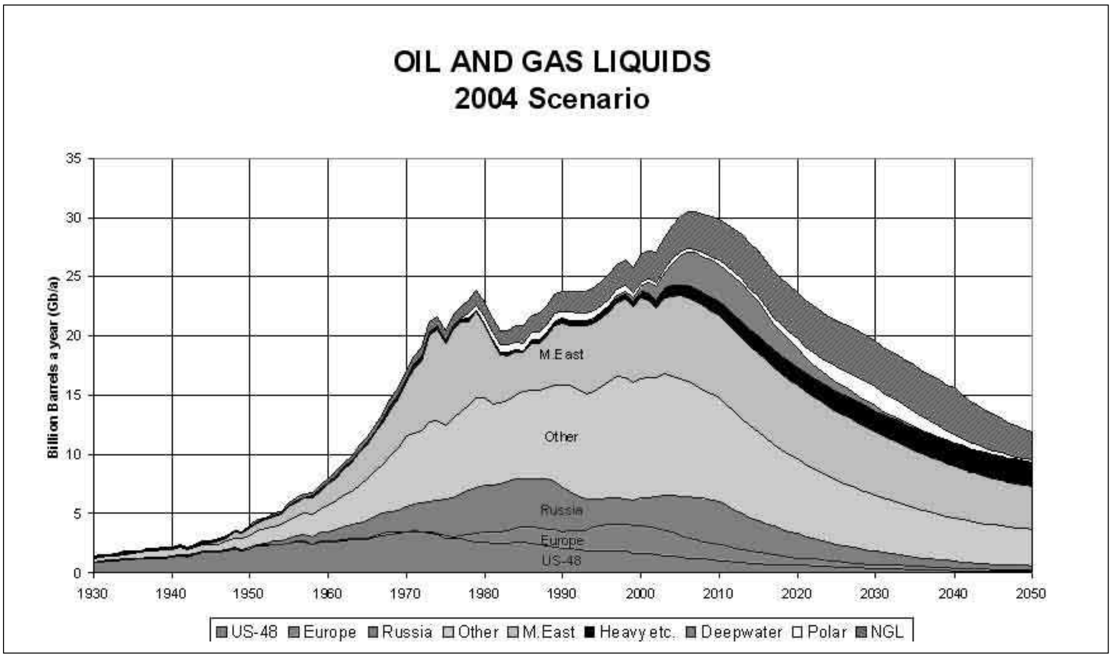

Fig. 2 The peak of conventional oil supply is now predicted to be at 2008. The US, EU, Indonesia, and many others will be almost out of oil by 2020. (ASPO)

The US Geological Survey 2000 report projects continued growth till about 2035 based on the hopes of substantial new discovery and large increases over the average 40% total extraction from oil fields thanks to new technologies. Extraction ranges from 1% to 80%,depending on geological conditions, and sucking the last drops from an oil field is more of a family business than a commercial enterprise. It is common knowledge that the actual results since 2000 have been a remorseless decline in discovery and little final improvement in recovery in the best engineered oil fields in the world, the USA. The oil industry has been highly creative, with horizontal drilling, 3D seismology, and submarine extraction, and more that have achieved the current world recovery rates, but few believe something dramatic may be invented to raise world extraction by another 30%. Such hopes are no substitute for planning.

Recently, the USGS and derivative agencies like the US EIA and the EU IEA, have claimed the huge deposits of tar sands, oil shale, and methyl hydrates as a solution to the oil decline – implicitly agreeing with ASPO on the fate of conventional oil. Tar is oil that has been partially consumed by bacteria and requires expensive processing to manufacture usable crude. Processing tar sands is about the same as digging up highways to make oil, and consumes 1 barrel for every 3 produced – Q=3. Oil shale contains no oil but only the kerogen pre-cursor to oil. Estonia has been processing shale for 50 years, but it is a Q=2 process. No methyl hydrates have yet been recovered successfully in any commercial quantity. Human ingenuity and stunning investment - $ Trillions – could produce the 50 million barrels/day needed by 2035 to fill the gap from these sources, but still too late to avoid the drop into an Energy Winter.

Many analysts, advisors, and planners are confused by the apparent arguments about the imminence of the oil peak and the view that there are immense carbon resources to be found or exploited. The latter views come from a single source, the USGS, and their optimism has been widely adopted without further review. It is now essential the EU, Japan, OPEC and other countries audit the world oil and gas resources independently. Governments, oil companies, and stock markets find bad news very hard to handle, but, as with any potentially terminal illness, it is far better to be open and seek early treatment.

Getting through the Winter.

The effects of political instability are clearly seen in the historical parts of Fig 2. The energy supply and economic variations in decline will be far more extreme without a huge political effort.

Conservation is the only way to reduce the impact of the decline and extend supplies while new energy systems are put in place. Transport policies must recognise the Energy Winter: Cancel all new roads and airports, stop production of SUVs and their spares, encourage virtual travel by internet wherever possible, electrify all railways, and eliminate non-essential world trade in favour of local independence. Investors should avoid unsustainable enterprises. Natural gas should be reserved by policy and legislation, for transport, not for electricity. Building and zoning regulations must focus on conservation and minimum travel. Manufacturers should be penalized for designing goods to fail quickly. Change is good for business, though not for sustainability. Scrapping SUVs in favour of safer, more efficient vehicles will be good for GM, and what is good for GM ….

Alternative Energies.

Wind and Solar Energy systems will soon be cheaper than oil and gas for electricity generation and will always be cheaper than tar, shale, or hydrate systems. Wind works – it is standard engineering – but windmills must be properly sited to be economic. Investors have to be educated to recognise the longer term prospects of renewable energy. However, renewables will probably never sustain a 10 billion population at a European level. Only nuclear energy, by fission or fusion, can meet our electricity needs.

A simple calculation shows that there is about as much carbon in the known deposits as there is oxygen in the atmosphere – an amusing piece of numerology. Global warming is now accepted as a real threat to the planet and it is clear that coal and the carbon alternatives should not be turned into carbon dioxide. There is no such thing as carbon free coal and the phrase, ‘clean coal’, refers only to other pollutants like sulphur. In the UK, plumbers, electricians, and shop assistants also believe that oil supplies are near their peak, though government departments do not.

Nuclear Fission

Current fission reactor designs are much cleaner, safer, and more efficient than existing nuclear plants and can therefore be deployed rapidly. They are largely more mature versions of existing designs and do not require lengthy research efforts. The operational life of existing reactors should be extended wherever possible to run through the energy winter. All US reactors are now expected to extend their licences for a further 20 years.

Molten Thorium salt reactors offer a safe, fuel breeder option to allow fission an ongoing role throughout the century. Only one was operated in the US (1965-69) and was dropped in favour of the Fast Breeder which essentially failed to meet its performance targets and safety levels. Some development is needed to establish the Thorium breeder as the long term version of nuclear fission power.

While the EU and America are still squeamish about nuclear power, the US is making strong efforts to sell new nuclear stations to China. The French nuclear programme has performed best with no significant ‘accidents’ in 50 years. Each reactor makes about 200 tonnes per annum of nuclear waste – a tiny amount compared with the 3 million tonnes of carbon dioxide produced by an equivalent coal station. The so called accidents at Three Mile Island and Chernobyl are forever fixed in the public mind as a view on fission so the industry has to address these head on. New systems can have safety engineered in and, with modern distributed computer monitoring and control, human errors and follies can be detected promptly. Human engineering of the work force can instil responsibility at every level.

Economics

As conventional oil declines it will become more valuable and expensive. This will enable the oil companies to extract oil from their more difficult oil fields already in reserve, but this does not mean that vast quantities of new oil will be found. The impact of high oil prices on developing countries may be dramatic, though no good studies have been made. They must not ‘dash for gas’ but for wind and solar energy.

Modern economics is based on assumptions of continual growth, no visible limits on resources, and a belief in self correcting market forces to solve all difficulties. The confused Darwinism of this belief ignores the effect of the environment – in this case, legislation – which then selects for men or monsters. Neither the theory nor the modelling is appropriate for large downward economic variations. It is essential that economists now be engaged in plotting the transition to a new energy economy and in reworking all the energy and transport forecasts.

The Future of Fusion

Fusion is the ultimate long term energy source for our civilisation and could have been almost ready to deploy now. It could be ready in 20 years, but not on attenuated funding. It is now urgent to bring Fusion to fruition.

The world programmes to develop fusion energy have been stalled for twenty years, running on a third of the peak budgets of 1985. This reflects a failure by the Fusion program to maintain any kind of public understanding of the progress and achievements. The current plans to develop a full scale demonstration reactor are still constrained to run at the half the pace of earlier projects and face financial oblivion in the global readjustment to the decline of conventional oil. The world magnetic fusion project, ITER, to build a final fusion engineering prototype, is not planned with a strong, explicit underpinning of continuing research using the existing global facilities and their upgrades, nor for a large enhancement of computing support. Laser fusion prospects are focussed on a single facility, NIF, at Lawrence Livermore and a 20% larger French facility, LMJ, to be completed a few years later. These giant laser systems will be able to fire 3-10 shots a day, each producing 100MJ of fusion energy - equivalent to that in one gallon of gasoline. No other country has developed lasers on such a scale, though there are many excellent physics support facilities exploring technologies to translate the science into a power system.

The US MFE program was forced to close its principal tokamak, TFTR, in 1998 in favour of small scale, advanced designs with little previous history. The US also withdrew from the ITER project which was then redesigned on a smaller, cheaper basis. The latest US plans from the FESAC committee, in obeisance to long term budget constraints, plan to almost drop out of MFE if the laser fusion option looks really viable by 2020.

To see how far off the pace the present programs are consider the JET project. In 1969 a UK-AEA Culham team verified that the Russian T-3 Tokamak had indeed reached plasma temperatures of 1 kev. This was taken as a complete proof of principle. The machine had a major radius of 1m and a minor radius of 12cm. Bas Pease, Director of Culham, immediately started a push for European collaboration on a large Tokamak. Within 4 years the European lab directors had assigned staff to design JET, a huge leap into fusion engineering and physics, under a team lead by P.H. Rebut. The Fusion Director for the European Commission, D. Palumbo, ran the politics of the project with great skill. The design of a Tokamak with R=3.5m and r=1m took 2 years, 1973-1975. Construction started in 1979 and the first plasma in this huge device was fired in 1983. (A couple of years were lost here in argument about which country should host the facility. This was resolved by the British rescue of all the passengers held hostage by terrorists in a plane at Stuttgart.) Fusion conditions were reached by 1988 but DT experiments were put off till 1997. From conception to meeting the goals was only 20 years, or 10 years from the start of construction. Although JET produced 16MW of fusion power the DT experiments were curtailed by Health & Safety from the licensed level of 10^{24} neutrons to the 10^{20} produced. This reflected the stalled funding but at least leaves JET able to do many more physics experiments.

The project benefited greatly from international cooperation and key results from ASDEX, Alcator, DIII-D, and the many large and small Tokamaks that followed, and from the neutral beam technology created by the US Mirror program. New diagnostics have unravelled a range of Tokamak operating scenarios which can be refined greatly, using the current generation of large Tokamaks, as a portfolio for ITER machines as they are built.

A vital contribution has been made by the US Computational Physics efforts which, in the last 5 years, have produced a tremendous breakthrough of 4 orders of magnitude improvement in the modelling of energy transport in the Tokamak. The calculations required the full power of the largest US supercomputers, but arose from refined experiments which identified the fluctuations driving the energy loss. Computing is set to play a huge role in the plasma physics and nuclear engineering of fusion reactors.

Three British theorists – Taylor, Connor, and Hastie – received a major Swedish award, the Alfven Prize, at the Londen EPS Conference for their work on Tokamak theory. In another masterpiece presentation, Taylor showed their new mathematics which explained this computational breakthrough in detail. This closed the circle of experiment, computation, and theory that has driven the Tokamak program to this point.

Compare this with ITER which is only about double the size of JET: Design and re-design time of 12 years, 5+ years for site selection, 3 years for licences, 10 years for construction (the 42 story London 'gherkin' office tower took 4 years), and 8 years before burning plasmas are generated, a project pace of 35 years. This is far below the capabilities of Japanese, European, or US laboratories. The construction and operation of other key facilities like IFMIF (Fusion Materials Irradiation Facility) and CTX (Large Component Testing) start too late and at an equally leisurely and career eating pace, and all the elements will cost far more because of this. By contrast, the FESAC committee has estimated 6 years for the construction of a Demo Reactor for an independent US program.

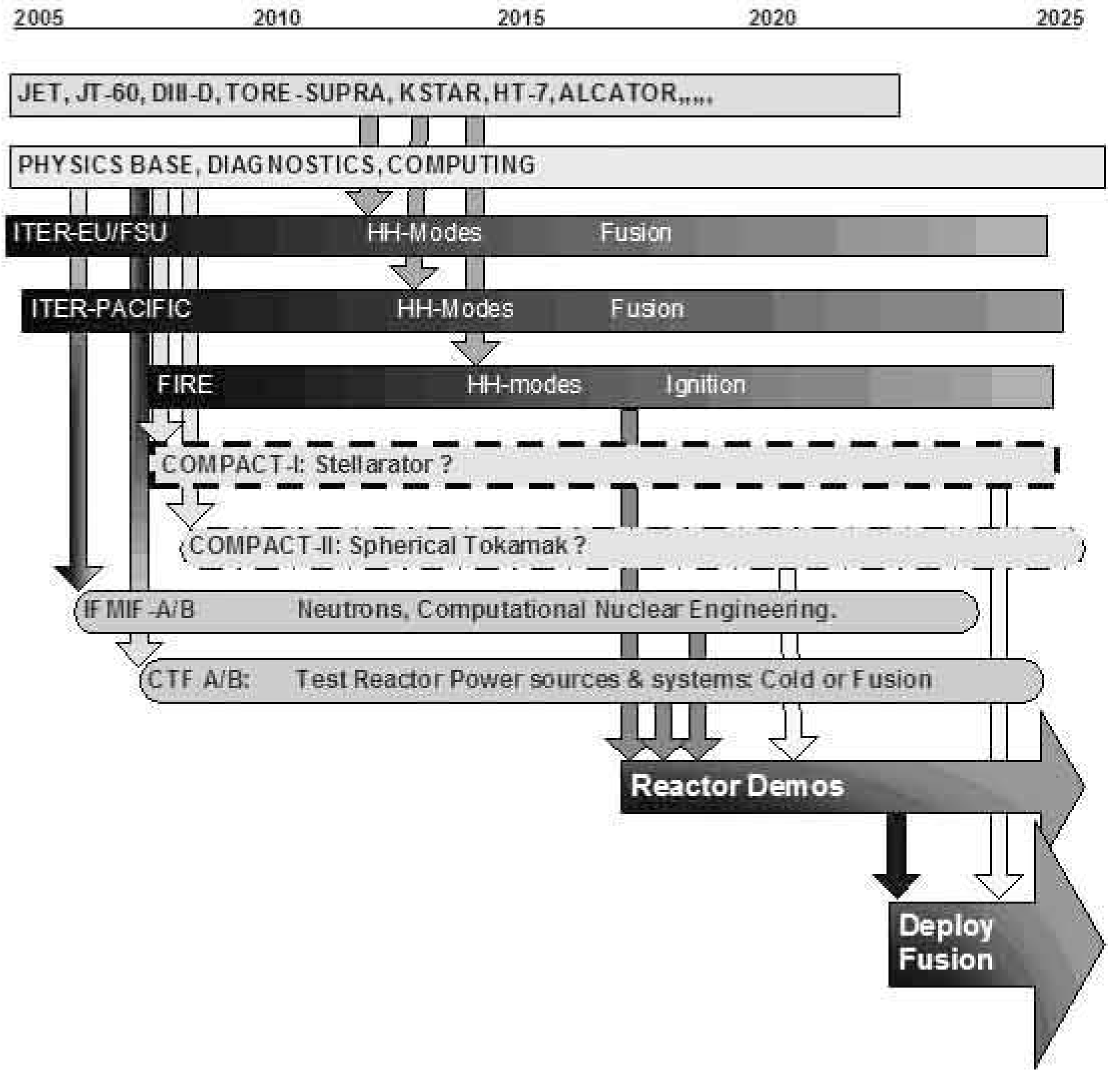

Fig. 3 Fast Fusion: Ongoing support, Multiple paths, Compact upgrades, early nuclear engineering, and multiple reactor demo designs done in a 20 year period.

The schedule above shows what the Fusion community is really capable of. It is important that more than one ITER class device be built with separate managements, overlapping goals, shared components, shared data, and competitive science. It is well understood that this approach is much the most cost effective at producing desired results in a short time span. There are alternatives to the existing IFMIF accelerator system and to the Component Test Facility – a Gas Dynamic Trap, for example -, so options are indicated as A/B. Some cold testing of robotics, blankets, and other components can be undertaken early at modest expense.

Compact versions of the Tokamak will soon have sufficient input power and diagnostic capability to show a scalable match to JET and ITER confinement and stability conditions and a corresponding energy performance parameter, $n\tau_E T_i$. This a much higher level 'proof of principle' than T-3 had to meet, but would justify a much larger device within the global program. Advanced computing, with the excellent understanding of the physics, can allow a compact Tokamak to be built on a JET scale or even as a CTF, with confidence. The initial round of commercial reactors deployed could then be a Mark II version rather than Mark I.

It is now clear that Japan has earned its place in fusion science and technology and can lead the Pacific Rim countries – China, Korea, India, and the USA – in an independent development of an ITER class machine or better. The EU and the FSU is able to build ITER alone if the world consortium stalls further. The USA has plans for a separate program based on FIRE and NIF and also the development of other compact alternatives. The best situation would be for all three groups to proceed and collaborate in the development, with total timescales under 20 years. This would also prime industrial partners in the engineering needed for deployment. The EU and Japan have fallen significantly behind the US in the application of computing to Fusion and this should be remedied with dedicated supercomputers and significantly larger teams. Japan makes many of the world's best supercomputers, but the EU makes none.

The strongest fusion research groups should be reassembled from the diaspora of physicists and engineers scattered by the Reagan/Bush funding crash of the 80s. A useful number of bright and brilliant people are still joining the diminished program and will have to lead it into the future. Many fine scientists could be available from other fields like astrophysics and accelerators. The large Tokamak sites should establish international training efforts to consolidate the skills needed for the proposed 20 year program.

A critical task for Fusion is to raise its public image and engage political support wherever it can be found. No business can survive without appropriate marketing – even Fusion websites are poorly layered to respond to people, politicians, and professionals. The views expressed here are widely held within the fusion community – see the GA website - who must make it clear that the current plans are not optimal and not what they want. It is also important to regain trust in scientists by distancing ourselves from fantasy science like cold fusion and Star Wars. The inability of other scientific groups to protect sea life, save rain forests, stop tobacco deaths, or get strong action on global warming shows that moving politicians and public opinion is not easy.

Exxon and others have estimated that $500Bn needs to be spent on oil, gas, and renewable energy systems by 2020 to keep pace with global energy demand. A more realistic estimate to scramble renewables, expensive hydrocarbons, and advanced fission plants into place would be $5Tn. The cost of an accelerated global Fusion program is minute on these scales at around $2Bn a year, with a tremendous prize in 20 years. These beginnings of global readjustment will, if handled well, actually be a huge stimulus to the global economy rather than a debilitating cost to society.

This 20 year plan, or something close to it, is what is really required to bring fusion on line in the needed timescales. It is unfair to our politicians to agree on the attenuated ITER funding and give the impression that this will still guarantee success. Instead, they should be aware of what has been dropped from a full program and the attendant risks.

It is too late for Fusion to help with the Coming Energy Winter but, in the midst of the large efforts required to deploy wind, solar, and stop-gap nuclear power , Fusion can be brought up for the high summer of our energy future.

This short paper on such broad topics may seem to be just a series of assertions. A full account with in depth original sources on all the key issues is available on request by e-mail to brendan@leabrook.co.uk You are recommended to browse the ASPO website, www.peakoil.net which concentrates on the oil issues without analysis of energy alternatives. Their newsletters give current country and regional data. A review of the Thorium breeder reactor is available as a Livermore reprint by Moir and Teller, UCRL-JRNL-155591.

Postscript: The possibility of Cold Fusion is excluded by quantum mechanics, the properties of nuclei, and the carefully measured behaviour of the interaction of hydrogen isotopes. At room temperatures the electric repulsion between nuclei keeps them apart by interatomic distances, which are thousands of times larger than the range of nuclear forces. Paul Rebut was the first senior fusion figure to denounce the work of Pons and Fleischman. Cold Fusion survives as cult science, along with flying saucers, creationism, and astrology.

Acknowledgements

This paper is based on extensive recent discussions with Roger Bentley, Secretary of ASPO, and with many people at Lawrence Livermore, JET, Culham, R.A.L., and F.O.M. laboratories.

Author

Brendan McNamara worked on Fusion Theory and Computations with AEA Technology, Culham (1961-71) and at the Lawrence Livermore National Labs in California (1971-85). He also ran a series of Plasma Colleges at ICTP, Trieste, 1974-84. He was V.P. of a Supercomputer Center in Princeton (1985-88) and now operates Leabrook Computing as a Consultancy.