Accelerated Development of Low Carbon Energy Supply Technologies – and its impact on Energy System Decarbonisation

Dr Mark Winskel, UK Energy Research Centre and University of Edinburgh

Nils Markusson, Brighid Moran and Henry Jeffrey (Edinburgh University); Chiara Candelise, Sophie Jablonski, Christos Kalyvas and Nick Hughes (Imperial College, London); Donna Clarke and Gail Taylor (Southampton University), Hannah Chalmers (Surrey University); Geoff Dutton (Rutherford Appleton Laboratories); Paul Howarth (Manchester University); and David Ward (UKAEA Culham)

Abstract

The UK Energy Research Centre (UKERC) recently undertook a major cross-disciplinary research project, Energy 2050, to examine the means by which the UK can move towards a low-carbon energy system over the next forty years. As part of this, UKERC's Energy Supply Working Group examined the prospects for accelerated technological development of a range of low carbon energy supply technologies, and the potential impact of this on UK energy system decarbonisation pathways. A series of scenarios were developed to represent the prospects for accelerated technological development. Then, using the Markal energy systems model, the impact of this acceleration on the decarbonisation of UK energy system was examined.

The results indicate that there are significant prospects for accelerated development for a range of renewable and other low carbon energy supply technologies, and that this acceleration could make a substantial impact on decarbonisation of the UK energy system from now to 2050. Accelerated technological development offers substantial benefit, in reducing the overall costs of decarbonisation over the longer term. However, because most of this impact is manifested after 2030, rather than over the next decade, the results suggest a disparity between technology performance and cost, and political aspirations for low carbon technology deployment from now to 2020.

1 Introduction: the UKERC Accelerated Technology Development Scenarios

This paper focuses on the prospects for accelerated development of a range of emerging low-carbon energy supply technologies – and the possible impact of this on decarbonising the UK energy system. The technologies analysed here include a number of renewables (wind power, marine energy, solar PV and bioenergy) and other emerging low carbon technologies (advanced designs of nuclear power, carbon capture and storage (CCS) and hydrogen / fuel cells).

The research involved devising accelerated technology development (ATD) scenarios of UK energy system decarbonisation (which assume high levels of technological progress over time), and comparing these with non-accelerated decarbonisation scenarios (see Table 1). Given the large uncertainties involved, the results should be seen as illustrating the possible impact of supply side technology progress, rather than a detailed mapping out of system change over the next decade or beyond.

For each supply technology, the prospects for accelerated development were considered by short statements, or narratives, which highlighted potential trends and breakthroughs in availability, performance and cost from now to 2050. These narratives were developed by technology specialists using research landscape and roadmap reports produced for the

UKERC Research Atlas1 , and also other expert views and reports. For each technology, a corresponding set of data was then devised to enable representation of technology acceleration in the Markal energy system model, in terms, for example, of reduced capital or operating costs, improved efficiency, or earlier availability of advanced designs. (A more detailed account of the ATD scenarios is provided in Winskel et al., 2009).

Table 1: Accelerated Technology Development (ATD) Scenario Set

Non-accelerated Baseline Scenarios (60% and 80% CO_2 reduction by 2050):
- LC Core

Single Technology ATD Scenarios (all 60% CO_2 reduction):

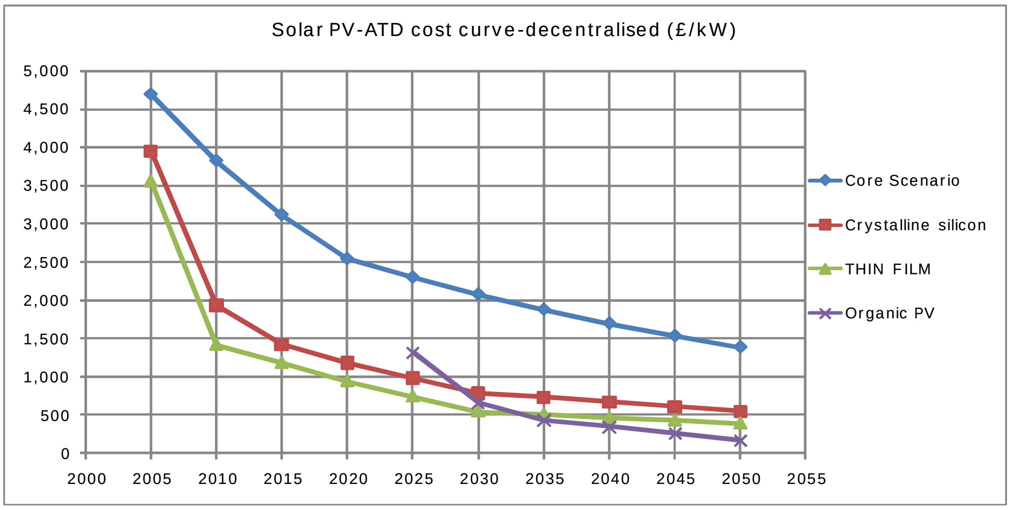
Renewables
- ATD Wind
- ATD Marine
- ATD Solar PV
- ATD Bioenergy

Other Low Carbon Supply Technologies
- ATD Nuclear Power (Fission and Fusion)
- ATD Carbon Capture and Storage (CCS)
- ATD Hydrogen and Fuel Cells

Aggregated ATD Scenarios (60% and 80% CO_2 reduction):
- LC Renew (all four renewable technologies accelerated)
- LC Acctech (all seven low carbon technologies accelerated)

For each accelerated technology, assumptions were made about how accelerated progress in research and development might result in improved performance, lower costs, or earlier availability of more advanced designs. For example, Figure 1 shows how accelerated technology development was assumed to affect the capital costs for solar photovoltaics.

Figure 1: Revised Capital Cost Curves for ATD-Solar PV Scenario



1 The UKERC Research Atlas is available at http://www.ukerc.ac.uk

2 Impact of Accelerated Development on Supply Technologies

Accelerated development opens up alternative pathways for UK energy system decarbonisation, especially over the longer term. In the short term (to 2020), accelerated development has little impact on the cost and performance of energy supply options in the UK energy mix. Over the medium term, to 2035, more diverse supply portfolios emerge in accelerated scenarios, and in the longer term, to 2050, accelerated technology development makes a very significant impact, with some accelerated technologies playing a much greater role (see Table 2). In attempting to map out desirable decarbonisation pathways for the UK, therefore, it is important that the potential for accelerated technology development be taken into account.

Different technologies contribute at different times in the scenarios presented here. For example, offshore wind and marine renewables are deployed to a much greater extent in accelerated development scenarios, after 2030 (and after 2040 for solar PV). Figure 2 shows the greatly increased deployment of marine energy in the accelerated scenarios. Accelerated hydrogen fuel cells development has a key long term impact on transport sector decarbonisation after 2030. It is important to note that these results reflect, in-part, assumed progress incorporated in the non-accelerated 'core' scenarios. For example, there are relatively aggressive assumptions about the pace of CCS development in the core scenarios. (Additional scenarios have been produced to illustrate decarbonisation pathways in the absence of CCS, or delayed availability of CCS).

Figure 2: Marine Energy Installed Capacity, Single Technology and Aggregated Scenarios

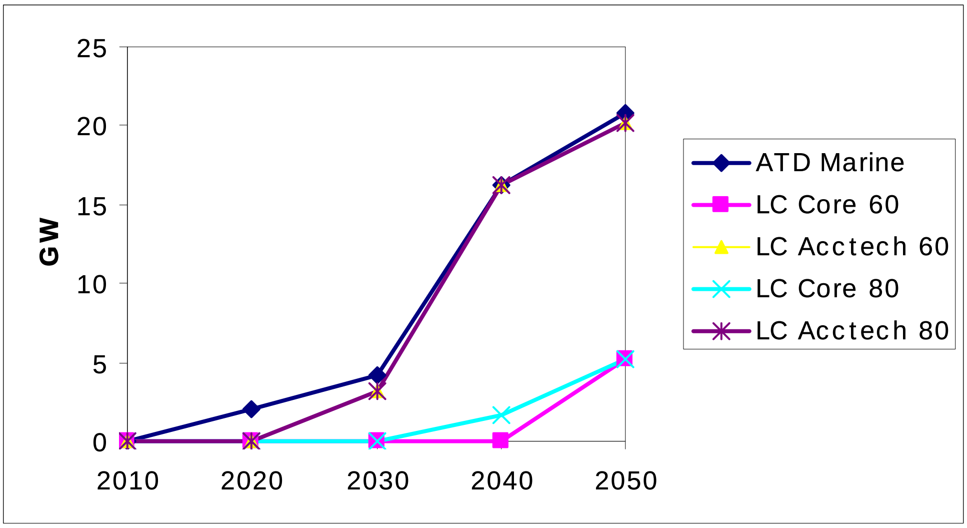


Table 2: Summary of Technology Specific Impacts of Acceleration on UK Energy System Decarbonisation, 2010-2050

Overall Role in Accelerated Technology Development (ATD) Scenarios	Specific Technologies Involved
Wind power acceleration has major long term impact (and moderate medium term impact) in single technology and Acctech scenarios.	Offshore wind has a significant medium and major long term role in ATD scenarios. Shorter term deployment is relatively modest.
Marine energy (wave and tidal flow) acceleration has major long term impact (and moderate medium term impact) in single technology and Acctech scenarios.	First deployments of both tidal flow and wave energy appear much earlier than in non-accelerated scenarios. Longer term deployment of both wave and tidal flow is constrained by resource assumptions.
Solar PV acceleration has major long term impact in single technology scenario; moderate impact in aggregated scenarios.	Third generation organic solar cells have a significant long term role. Earlier deployments of first and second generation solar cells are not represented in the ATD scenarios, but may be anticipated in practice.
Nuclear power acceleration has moderate medium and long term impact in single technology scenarios; ATD assumptions are relatively modest, and long term deployment reduces in aggregated accelerated scenarios compared to non-accelerated equivalent scenarios; much greater medium term role if is CCS excluded.	Generation III Fission reactors have significant medium and long term role. Later generations of fission reactors (III+ and IV) not represented in ATD scenarios, but their deployment may be anticipated over the longer term. Fusion ATD assumptions are relatively modest; projected fusion deployment is post-2050.
Carbon Capture and Storage (CCS) has a major medium and long term role. Core scenario assumptions are relatively aggressive for CCS, and were left essentially unchanged for ATD scenario.	Long term impact is sensitive to assumed capture rate. The ATD modelling assumptions do not explicitly distinguish between different forms of CCS technology.
Fuel cells acceleration has a major long term impact on transport sector decarbonisation. Fuel cell power generation has minor role.	The ATD modelling input assumptions do not explicitly distinguish between different types of HFCs for transport.
Bioenergy acceleration has major medium and long term impacts. Biomass resources are limited, and their preferred uses are sensitive to overall decarbonisation ambition, and the changing availability of other low carbon supply technologies. For example, preferred use of bioenergy resources in 2050 depend on assumptions regarding the accelerated development of fuel cells	Significant medium and long term impact, arising from bioengineering improvements to energy crops and improved gasification technology; second generation ligno-cellulosic ethanol technology also deploys

3 Accelerated Development and UK Energy System Decarbonisation

The overall impacts of accelerated technology development on UK energy system decarbonisation are complex, changing over time as different low carbon supply options are made available, and as overall decarbonisation ambitions increase. For example, accelerated fuel cells development changes the relative attractiveness of decarbonising different energy services, and the supply technologies involved. The most attractive supply technologies – and the research priorities associated with their commercialisation – are also sensitive to the overall level of decarbonisation ambition. Raising the decarbonisation ambition from 60% to 80% does not simply mean doing 'more of the same' – it introduces new technology preferences and research priorities. For example, the preferred use of bioenergy resources switches between electricity, heating and transport, according to the overall level of decarbonisation ambition and the availability of alternative ways of decarbonising particular energy services.

In terms of decarbonisation by sector, the electricity supply sector decarbonises first and most deeply, and is substantially decarbonised by 2030 in all 80% scenarios, with or without accelerated technology development. Other carbon intensive energy services (especially transport, but also residential demand) decarbonise in the medium and longer terms. Accelerated development makes some difference to this broad pattern. For example, the introduction of fuel cells acceleration is associated with greater decarbonisation of transport (and reduced decarbonisation of the residential sector) over the longer term.

The same broad pattern of declining overall energy demand, as the energy system decarbonises, is followed with or without accelerated technology development. Gas and coal remain important primary fuels in 2050, although gas has much reduced demand, and oil is almost absent from the energy mix by 2050. The introduction of accelerated fuels cells development means that hydrogen has become the dominant transport fuel in the accelerated scenario by 2050.In terms of final energy demand by sector, however, accelerated technology development makes a significant difference over the long term. In the non-accelerated scenario, residential energy demand almost halves between 2035 and 2050 – a key contributor to long term system decarbonisation. In Acctech, however, residential energy demand declines much less steeply – only by around 20% between 2035 and 2050.

4 Costs and Benefits of Acceleration

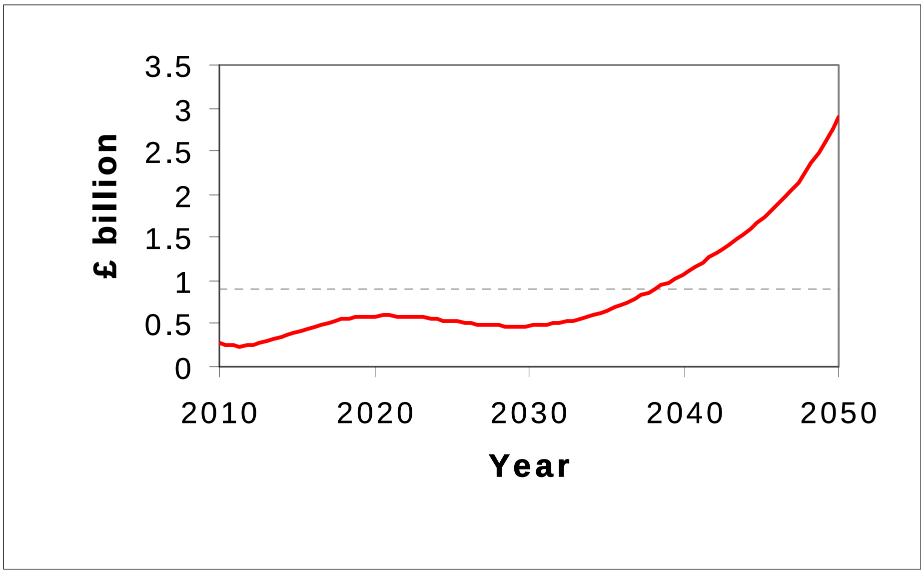
The modelling results offer some indication of the overall advantages of supply side technology acceleration on energy system decarbonisation. These advantages accrue mostly in the long term, as accelerated development provides more affordable ways to achieve deeper decarbonisation. Two Markal modelling parameters – the marginal cost of CO2 abatement, and the overall 'welfare cost' of decarbonisation – provide some quantification of this benefit. Given the high levels of uncertainty embedded in the scenarios, especially over the longer term, these figures only offer an illustration of the possible benefits of accelerated development, under assumptions of high levels of progress.

The marginal cost of carbon abatement increases over the longer term as progressively more expensive carbon abatement options are deployed. In the accelerated development scenarios, however, this increase is considerably less than in non-accelerated equivalent scenarios – by 2050, the marginal cost of CO2 abatement is around £130/tonne in the Acctech accelerated development scenarios, compared to £170/tonne in the equivalent non-accelerated scenario.

The modelling results suggest that technology acceleration may also substantially reduce the overall societal cost of decarbonisation, especially for 80% scenarios (see Figure 3). Over the forty years 2010-2050, accelerated development is associated with a total saving in the 'welfare costs' of achieving 80% decarbonisation of £36bn; most of this benefit accrues in the longer term, after 2030. This 'saving' should be benchmarked against the added investment costs of accelerated development, in terms of additional spend on RD&D to realise accelerated performance improvements and cost reductions.

In practice, making this comparison is not straightforward, given that the investments associated with technology acceleration will be made internationally. However, evidence from the International Energy Agency (IEA, 2008) suggests that the overall benefits to the UK of accelerated development considerably outweigh the investment costs. From a purely UK perspective, the suggested savings associated with low-carbon technology acceleration could be translated into an annual budget for additional UK RD&D investment in low-carbon technology development of just under £1bn per annum – although much of this investment would need to be committed well before significant 'returns' start appearing after 2030.

Figure 3: Welfare cost savings associated with Decarbonisation

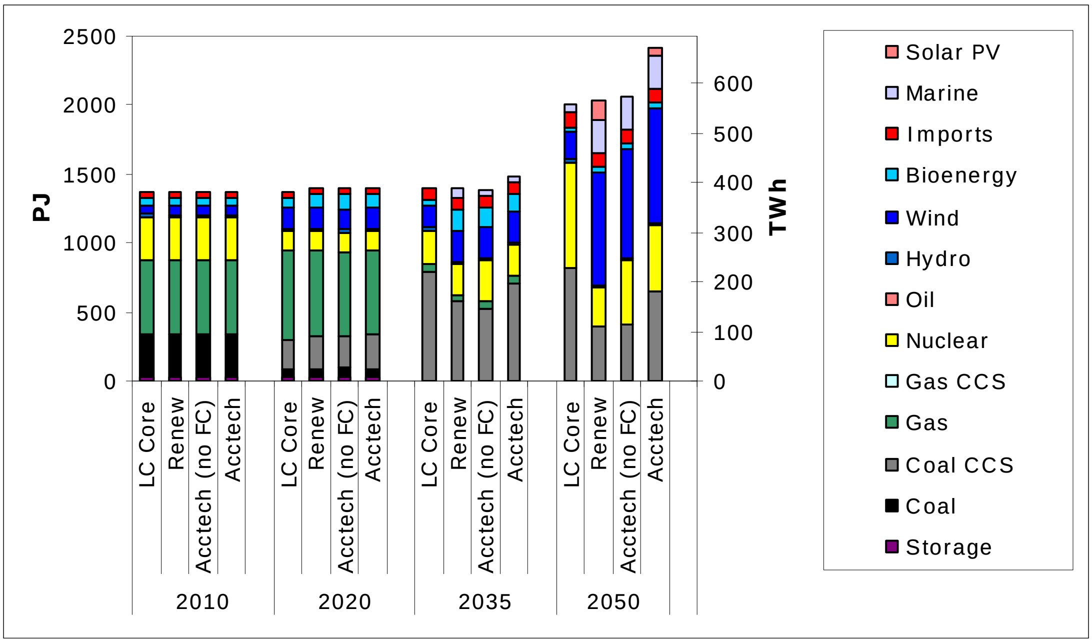


5 Electricity Supply Sector

For all 80% scenarios, the electricity supply sector undergoes near complete decarbonisation over the period 2010-2030. After 2030, low carbon electricity is used to enable decarbonisation of transport and residential sectors. Accelerated technology development introduces alternative pathways for decarbonising the UK power system in the longer term, and is associated with significantly increased contributions from renewable technologies such as marine, solar PV and especially offshore wind power (Figure 4).

The results also suggest that achieving 80% decarbonisation ambition may involve the development a much larger UK power supply industry over the long term. While some expansion is seen with or without accelerated development, it is much more pronounced in accelerated development scenarios, with installed capacity doubling in the long term between 2030 and 2050. This growth is associated with the much greater deployment of renewables (especially offshore wind power) and hydrogen / fuel cells technologies under accelerated development assumptions.

Figure 4: UK Power Sector Supply Technology Portfolios, Aggregated Scenarios, 80% Decarbonisation to 2050

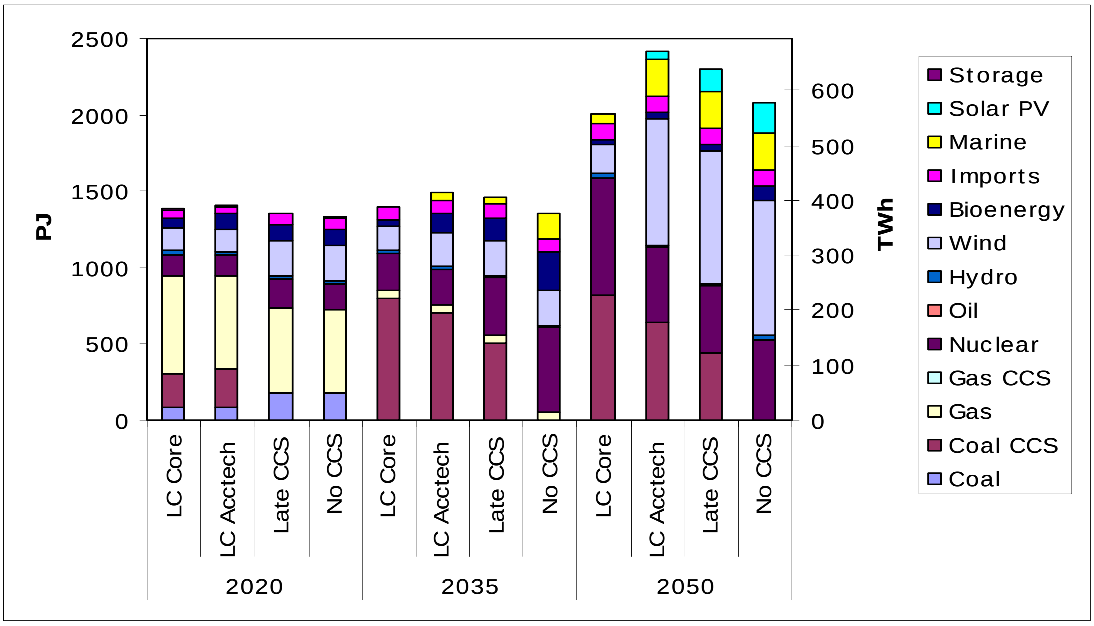


For each accelerated technology, assumptions were made about how accelerated progress in research and development might result in improved performance, lower costs, or earlier availability of more advanced designs. For example, Figure 1 shows how accelerated technology development was assumed to affect the capital costs for solar photovoltaics.

Carbon Capture and Storage (CCS) is a particularly important potential source of low-carbon power, and the overall pattern of energy system decarbonisation is significantly altered if CCS is assumed to be unavailable. Decarbonisation scenarios without CCS feature less overall demand for electricity, reduced take-up of hydrogen fuel cells, and a switching of bioenergy resources from residential heating to transport. The power sector technology mix also changes significantly in the absence of CCS, with nuclear power and renewables having significantly expanded roles in power system decarbonisation (Figure 5).

Assuming delayed commercialisation of CCS (to after 2030) reduces its long term market share, as residual emissions from CCS become significant, and as other low carbon supply technologies mature, such as solar PV.

Figure 5: Electricity Generation in LC Core 80, LC Acctech 80 and LC Acctech 80 (no CCS and delayed CCS)



6 Summary and Conclusions

The UKERC Energy 2050 accelerated technology development scenarios allow a structured analysis and illustration of the potential of emerging supply technologies to contribute to UK energy system decarbonisation. The results suggest that emerging technologies could contribute significantly to energy system decarbonisation, especially over the longer term. Therefore, in attempting to map out desirable decarbonisation pathways for the UK, it is important to take into account the potential for more affordable decarbonisation by deploying more advanced but currently less well-developed technologies.

Although it carries shorter-term implications for system planning and innovation support, supply side technology acceleration only changes deployment patterns over the longer term. The results suggest that system decarbonisation and low-carbon technology deployment, over the shorter term (i.e. over the next decade), require responses from other areas, such as demand reduction, improved energy efficiency and making best use of more mature supply technologies.

The scenarios suggest some disparity between the availability, performance and cost of low-carbon power supply technologies, and policy targets for renewables deployment, especially in the short term to 2020. Realising very high levels of renewables deployment by 2020 will require policy support measures and market interventions that go well beyond those embedded in the scenarios presented here. At the same time, the 'learning potential' of emerging technologies over longer timescales imply that short-term targets for technology deployment may be inconsistent with the most economically desirable long-term decarbonisation pathways, but may direct the energy system into less attractive pathways, seen from a longer-term perspective. In the accelerated development scenarios, sustained RD&D investment makes a substantial difference to the cost and performance of renewables and other low-carbon supply options, so that their longer-term deployment becomes much less dependent on market subsidies.

Accelerating the development of emerging low carbon energy supply technologies may offer significant long-term benefit, in enabling alternative and more affordable decarbonisation. It may well also offer wider benefits in terms of system diversity and security. Realising this potential will require the UK to participate fully in global efforts at low-carbon technology innovation. A step-change increase in RD&D investment is economically justified, and promises significant reward in the longer term.

There are many uncertainties involved here, and no simple messages in terms of 'picking winners' – many of the technologies analysed here, and many others not included – have a significant potential role in UK energy system decarbonisation. Rather than a premature selection of 'silver bullets', the need is for sustained international support of a broad range of emerging low-carbon technologies, with the UK playing a committed role as a developer and deployer in the wider international context.

7 References

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