

CLIMATE CHANGE

A crack in the natural-gas bridge

Integrated assessment models show that, without new climate policies, abundant supplies of natural gas will have little impact on greenhouse-gas emissions and climate change. [SEE LETTER P.482](#)

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Burning fossil fuels such as coal, gas and oil produces more than 80% of the world's energy and more than 90% of global carbon dioxide emissions. Slowing and ultimately stopping climate change depends on decarbonization — the transformation of the global energy system into one that does not dump CO₂ into the atmosphere. Because gas-fired power plants emit roughly half as much CO₂ per unit of energy produced as coal-fired plants, the greatly expanded gas supplies promised by new hydraulic fracturing (fracking) methods have been celebrated as a means of cutting emissions¹. Progressive substitution of gas for coal and oil can thus decarbonize the energy sector² and serve as a 'bridge' to a more distant future when carbon-free, renewable-energy technologies are more affordable and reliable than they are now³. In this issue, McJeon *et al.*⁴ (page 482) uncover a serious crack in the gas bridge: in the absence of new climate policies, increased supplies of natural gas may have little effect on CO₂ emissions and could actually delay decarbonization of the global energy system.

McJeon and colleagues' findings reveal two effects. First, abundant gas makes energy cheaper, thereby encouraging higher energy consumption and discouraging investment in energy efficiency. Second, natural gas competes for market share not only with coal, but also with very-low-carbon energy sources such as renewables and nuclear.

Previous studies have questioned the climate benefits of natural gas relative to coal owing to the potential for the gas (mostly methane, a greenhouse gas) to leak into the atmosphere during its extraction, processing and transport⁵. More recently, researchers have begun to consider the effects of abundant natural gas on CO₂ emissions in the broader context of the energy marketplace^{6–9}. McJeon and co-workers' paper is the first peer-reviewed study to do so on a global scale. It uses five independent energy-economic models to simulate the effects of gas supplies on the global energy system and on emissions of CO₂, methane, nitrous oxide and aerosols such as sulphur dioxide and black carbon. Their study compares a 'conventional' gas supply with an 'abundant' case in which

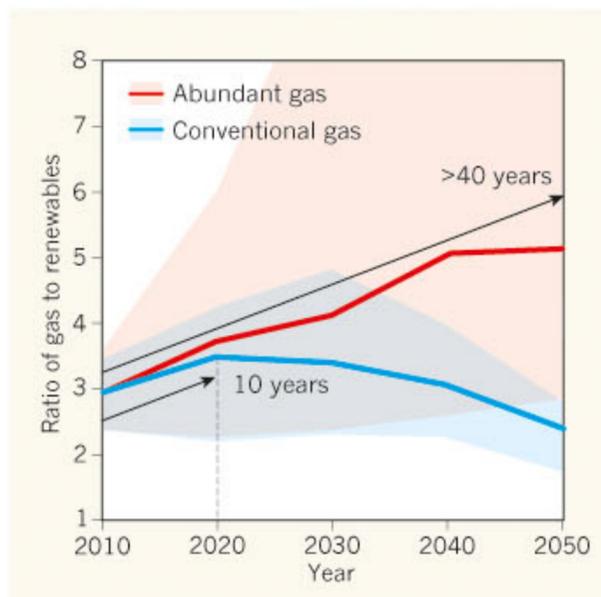


Figure 1 | Relative growth of gas and renewable electricity. The ratio of natural gas to renewables used to generate electricity is sensitive to how much inexpensive gas is available. The red and blue lines show the median of this ratio across five energy-economic models used by McJeon *et al.*⁴ for scenarios of abundant and conventional gas supplies, respectively, whereas the shaded areas show the full range spanned by the individual models. For cases in which less gas is available (that is, in the conventional scenario), renewables as an electricity source begin to grow faster than gas 10 years into the 40-year modelling period. But when gas is abundant, its use grows faster than that of renewables throughout the period modelled and probably beyond it.

natural-gas prices are halved, and evaluates the net influence of emissions on the climate system in the two scenarios.

In all five models used by the authors, CO₂ emissions and their effect on climate (climate forcing) scarcely differed between the conventional and abundant scenarios. At most, abundant gas reduced cumulative CO₂ emissions between 2010 and 2050 by 2%, and reduced climate forcing over the same period by 0.3%. In several of the models, emissions and forcing actually increased under the abundant-gas scenario. But the exact numbers, although revealing, are less important than the overall insight: whether the goal is avoiding CO₂ emissions or hastening the transition to an emissions-free energy system, a global gas boom is not a replacement for energy and climate policies.

Indeed, by replotting some of McJeon and

colleagues' results, it is possible to observe the extent to which the availability of abundant gas delays the transition to low-carbon, renewable energy sources such as solar and wind. Figure 1 shows the ratio of the amount of gas to renewables used to generate electricity in the authors' models between 2010 and 2050. In the race between fossil fuels and low-carbon energy, the lines in the figure (which reflect the median of all five models) indicate which energy source is gaining ground. In the abundant-gas scenario, the ratio never decreases: gas-fired power pulls further and further ahead of renewable power throughout the 40-year period. But in the conventional-gas scenario, the ratio begins to decrease from 2020: renewables start catching up.

McJeon and co-workers' study assumes that there will be no policies intended to reduce greenhouse-gas emissions or to support low-carbon energy other than those already in place. Future work must carefully assess the effectiveness of various policies in reducing greenhouse-gas emissions and decarbonizing the global energy system. Similarly, the authors' results are probably sensitive to assumptions about the cost of low-carbon energy technologies over time, and systematic analyses of such sensitivity could inform energy funding and policies. Finally, further studies may be needed to evaluate the extent to which natural gas could be used strategically to complement and support variable renewable-energy technologies by providing flexible back-up power that can ramp up quickly¹⁰. Such applications could have very different implications for decarbonization and cumulative CO₂ emissions. Rather than simply building vast fleets of gas-fired power plants that lock in another generation of "committed emissions"¹¹, if we get the technologies and the policies right, natural gas might help us to cut emissions by working with renewable energy sources, rather than against them.

The integrated analysis of McJeon *et al.* makes it clear that emissions per unit of energy is a poor measure of prospective energy sources. Differences in emissions between energy sources, considered in isolation, may be irrelevant given the complex feedbacks of the energy markets. Specifically, the authors' study is the most robust evidence yet that expanding

supplies of natural gas will not help us to avoid climate change and manage the transition to renewable energy sources in the absence of an effective climate policy. ■

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1. www.bbc.com/news/uk-politics-25705550
2. Ausubel, J. H., Grübler, A. & Nakicenovic, N. *Clim. Change* **12**, 245–263 (1988).
3. Podesta, J. D. & Wirth, T. E. *Natural Gas: A Bridge Fuel for the 21st Century* (Center for American Progress, 2009); <http://cdn.americanprogress.org/wp-content/uploads/issues/2009/08/pdf/naturalgasmemo.pdf>
4. McJeon, H. *et al. Nature* **514**, 482–485 (2014).
5. Brandt, A. R. *et al. Science* **343**, 733–735 (2014).
6. Huntington, H. *EMF26: Changing the Game? Emissions and Market Implications of New Natural Gas Supplies* (Energy Modeling Forum, 2013).

7. Newell, R. G. & Raimi, D. *Environ. Sci. Technol.* **48**, 8360–8368 (2014).
8. Shearer, C., Bistline, J., Inman, M. & Davis, S. J. *Environ. Res. Lett.* **9**, 094008 (2014).
9. International Energy Agency. *Golden Rules for a Golden Age of Gas* (IEA, 2012).
10. Channell, J., Lam, T. & Pourreza, S. *Shale & Renewables: A Symbiotic Relationship* (Citi Res., 2012).
11. Davis, S. J. & Socolow, R. H. *Environ. Res. Lett.* **9**, 084018 (2014).

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HIV

A stamp on the envelope

A high-resolution crystal structure of the HIV-1 Env trimer proteins, in their form before they fuse with target cells, will aid the design of vaccines that elicit protective immune responses to this protein complex. SEE ARTICLE P.455

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The surface of the HIV-1 virus is studded with envelope glycoprotein (Env) spikes. The virus uses these trimeric complexes, which each contain three gp120 and three gp41 subunits, to fuse with cells and initiate infection. Sixteen years ago, Kwong and colleagues described the crystal structure of the core of the gp120 subunit¹, but the lability of the complex in its pre-fusion form meant that the trimer structure was not determined until last year, when an engineered, stabilized and soluble version was used to produce highly concordant structures by X-ray crystallography² and cryo-electron

microscopy³. Now, on page 455 of this issue, Kwong and colleagues (Pancera *et al.*)⁴ report a crystal structure of the same Env trimer at higher resolution, providing a better picture, particularly of the gp41 subunits. Together, these structures^{2–4} help us to understand how the Env trimer functions, how antibodies recognize it (or not), and how vaccines exploiting this protein can be better designed.

HIV-1 fusion occurs when the gp120 components of Env trimers interact first with CD4 receptors on a cell's surface and then with a co-receptor (CCR5 or CXCR4). The sequential receptor engagements drive the concerted disentanglement of the intimate, but fragile, embrace between gp120 and gp41. The

ectodomain of each gp41 subunit (the region that extends out from the viral membrane) contains six segments (A–F) that form two heptad-repeat regions (HR1 and HR2). These segments eventually become two long helices in the post-fusion structure, which is known as the six-helical bundle. Pancera and colleagues' pre-fusion structure shows that HR1 and HR2 are each split up into two smaller helices connected by loops; together, the four helices form a ring encircling the amino and carboxy termini of gp120 (Fig. 1). In turn, these gp120 regions act as a 'safety pin' to prevent gp41 from transiting to the energetically more favoured six-helical-bundle form.

The authors use their structure to make inferences about the conformational changes in Env proteins that take place during fusion, adding detail to the existing model of the process (Fig. 1b). When the cellular receptors are engaged, the safety pin is removed in a two-stage process. First, the top of the trimer opens up. The diminished constraints on the N-terminal segments of gp41 and the space vacated at the trimer axis allow segment B to undergo a loop-to-helix transition. The formation of the resulting long helix (HR1), now

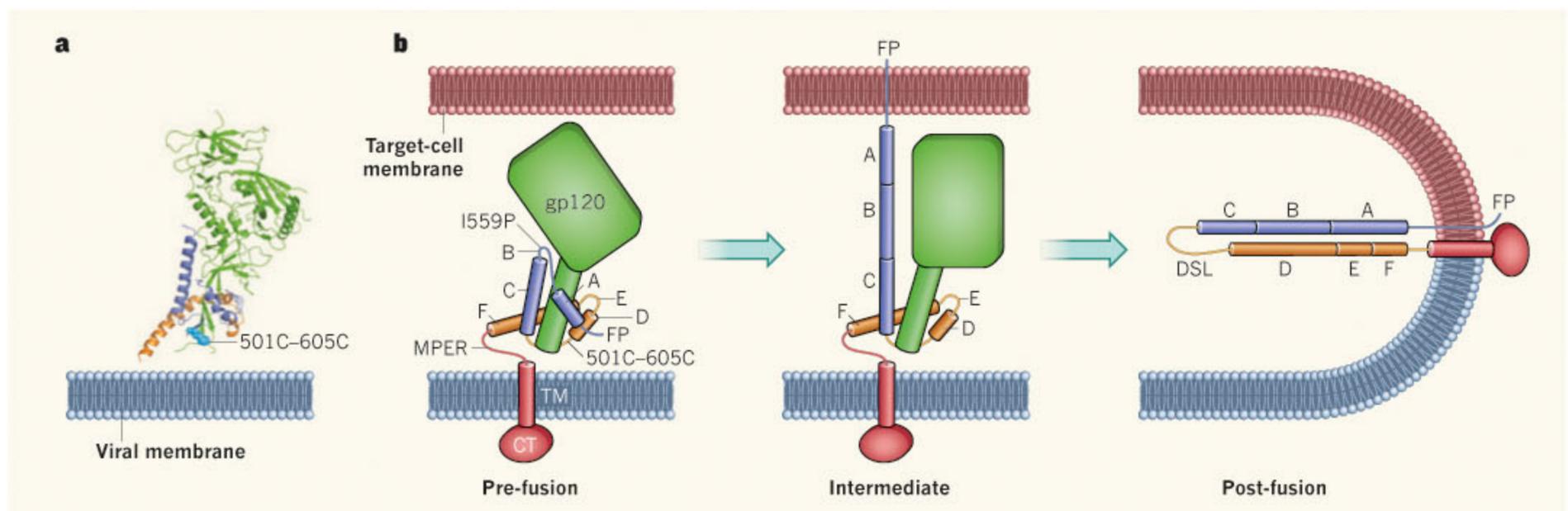


Figure 1 | A model of HIV-1 fusion to target cells. HIV-1 Env proteins are trimers of three identical protomers, each with a gp120 and a gp41 subunit. The gp41 subunit comprises cytoplasmic (CT) and transmembrane (TM) domains, and an ectodomain that has six helix-forming segments (A–F), a fusion peptide (FP), a disulphide loop (DSL) and a membrane proximal external region (MPER). **a**, Pancera and colleagues' trimer structure⁴ (a single gp140 protomer is shown) contains the gp120 subunit (green) and most of the ectodomain of the gp41 subunit (orange and purple), but omits other gp41 domains. The cysteine amino-acid residues (501C–605C) forming the engineered disulphide bond¹² in the trimer are indicated. **b**, The structure, together with previous

data, helps to build a model of viral fusion to target cells. In the pre-fusion protomer, helix segments A and C, and D and F, are interspersed by loop segments B and E, respectively. On binding to cell-surface receptors, a long helix comprising segments A, B and C forms, punching FP into the host-cell membrane. (The approximate location of the I559P amino-acid substitution, which blocks the loop-to-helix transition in segment B of engineered trimers¹¹ and thereby stabilizes the pre-fusion structure, is indicated.) A second long helix of segments D, E and F then forms and aligns with the other helix in a hairpin structure. The formation of the trimer of hairpins (called the six-helical bundle) pulls the viral and target-cell membranes together.