ITER Forum website Update 12/16

B.J.Green (13/12/16)

1. Land’s complex role in climate change

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Physics Today
November 2016, page 40
http://scitation.aip.org/content/aip/magazine/physicstoday/article/69/11/10.1063/PT.3.3364?utm_source=Physics%20Today&utm_medium=email&utm_campaign=7688696_November%202016%20Table%20of%20Contents&utm_content=Feat2&dm_i=1Y69,4KSMW,E1OV2B,GZPGO,1

To mitigate climate change at local, regional, and global scales, we must begin to think beyond greenhouse gases.

To date, most reporting on climate has focused on the possibility of catastrophic warming due to carbon dioxide and other greenhouse gases released into the atmosphere. The assessment of climate change risk has essentially been distilled to a single metric: the global average surface temperature. That reality was evident at the 2015 United Nations Climate Change Conference in Paris, where the central negotiating point was whether the global temperature rise should be limited to 1.5 °C or 2 °C. Indeed, a 2016 opinion piece by Simon Lewis (University College London and the University of Leeds, UK) states that, “by endorsing a limit of 1.5 °C, the [Paris] climate negotiations have effectively defined what society considers dangerous.”[1]

But the reality of humans’ impact on climate is exceedingly complex.[2] Even if greenhouse gas emissions could be eliminated completely, other harmful anthropogenic sources of climate change would remain. And even if global average temperatures were contained, human impacts on climate would manifest in other potentially dangerous ways.

One often overlooked human factor is land use. Deforestation, dryland farming, irrigated agriculture, overgrazing, and other alterations to the natural landscape can disrupt Earth’s natural balances and change weather patterns. As with the addition of CO_2 into the atmosphere, the effects can last for decades or longer and affect regions distant from the original offense. Given continued rapid population growth, they threaten to be irreversible.

By focusing only on greenhouse gases and warming, we diminish our ability to respond to the diversity of human influences on climate and to the effects of natural variability and long-term change. In a 2005 article on NASA’s Earth Observatory website, Gordon Bonan of the National Center for Atmospheric Research framed the issue in no uncertain terms: “Nobody experiences the effect of a half a degree increase in global mean temperature…. Land cover change is as big an influence on regional and local climate and weather as doubled atmospheric carbon dioxide—perhaps even bigger.”[3]

In this article we argue that the impacts of modification and management of the land and other human effects on climate merit the same level of research and policy attention given to greenhouse gas effects. The inherent complexity of accounting for all those factors will require redefining the way we think about the risks of climate change.

Not just warming

To fully appreciate the scope and diversity of climate change, one first needs a clear understanding of what is meant by climate. As illustrated in figure 1, the climate system consists of the atmosphere, oceans, land, and the ice- and snow-covered regions known collectively as the cryosphere. Each system component can be characterized by certain state variables— atmospheric temperature, ocean salinity, land moisture, and depth of snow cover, to name a few.

Climate change occurs when a perturbation—a forcing, as it's known in Earth-science parlance—generates a flux that alters the components' natural states. A 2005 US National Research Council report more precisely defines climate change as any multidecadal or longer alteration in one or more physical, chemical, or biological state variables or fluxes within the climate system.[4] The time scale of several decades is typically used to distinguish climate change from short-term variations in weather and other aspects of climate.

Of course, Earth's climate is always changing, so in a sense, the "change" in climate change is redundant. In addition to anthropogenic contributions, climate is subject to both internal forcings—from ocean currents, atmospheric currents, and the like—and external forcings such as solar variability and volcanic activity. The term "change," however, is generally used by policymakers to imply change resulting from human actions.

Global warming, the increase in the average heat content of the climate system, is one type of change. It is best characterized in terms of the spatially integrated temperature of the ocean—where more than 90% of heat change occurs—and is expressed in units of joules. A two-dimensional global average of surface temperature trends is therefore an imperfect metric to diagnose global warming. It's also inadequate to characterize the many facets of climate change.

Arguably, the aspects of climate that most affect us and our environment at local and regional scales are those that influence weather patterns—droughts, floods, tropical cyclones, heat waves, and so forth. (Sea-level rise is one regionally important aspect of climate that is not directly linked with weather.) Weather patterns are influenced primarily by regional atmospheric and ocean circulations such as El Niño, the North Atlantic Oscillation, and the Pacific Decadal Oscillation. Changes in those circulations should be of even greater concern than globally averaged properties. (See the article by Thomas Birner, Sean Davis, and Dian Seidel, *Physics Today*, December 2014, page 38.)

Regional weather patterns are, in part, a function of land cover. Modifications to the biophysical characteristics of the land and to the way we manage it can alter the relative abundances of carbon, nitrogen, and other trace gases and aerosols near Earth's surface and the fluxes of water, heat, light, and momentum between components of the climate system.[5,6] To see how land-cover change can directly impact climate, let's consider an example: irrigation.

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The turf and the tempest

The irrigation of semiarid land can dramatically alter a region's water balance.[7] Due to the combined effects of evaporation and transpiration, collectively termed evapotranspiration, increases in ground moisture tend to raise humidity in the overlying atmosphere. Such increases in humidity can mean the difference between a mild shower and a torrential downpour.

To understand how, consider the concept of moist static energy, S S, which can be expressed as

$$S = C_p T + Lq.$$

The term C_pT
represents sensible heat—the heat derived from an increase in temperature T. The term Lq
represents latent heat, a potential energy that's stored in the vapor phase during the process of evaporation. Here, C_p is the specific heat of water at a constant pressure,
L is water's latent heat of vaporization, and
Q is specific humidity—the mass ratio of water vapor to air.
In essence, S is a measure of the buoyant potential energy. Thunderstorms feed on that energy; the larger it is, the more intense a storm can become. The irrigation of a dry patch of land boosts S by increasing q.

The effect can be dramatic: At atmospheric pressure, a mere 1 °C rise in dew point from 23 °C to 24 °C—equivalent to an increase in q of 1 g/kg—would have the same effect on S as a 2.5 °C rise in temperature. (The same humidity increase would have a smaller effect in a cooler atmosphere and a larger effect in a warmer one.) The increase in moist static energy due to humidity would be partially offset by a reduction in T from the cooling effects of evapotranspiration, and the chances of triggering a thunderstorm by surface heating would also decrease. However, if a thunderstorm were to form, it would likely be more intense and produce more precipitation.

Figure 2 shows an illustrative case study: a weather simulation of 7000 km^2 of farmland, brush, and shortgrass in the Great Plains region of the US.[8] In a simulation using that terrain as it was on 15 May 1991, evapotranspiration generates enough atmospheric moisture and moist static energy to produce heavy rainfall and thunderstorms. But in a scenario in which the terrain is covered by only dry shortgrass—as it was before human influences—no storms form.

Unfamiliar terrain

Examples of large-scale, human-driven landscape transformations are increasingly easy to find. The human footprint on the land is vast and expanding, driven largely by the growth and intensification of agriculture.[9] (See figure 3.) Global cropland cover is estimated to have increased from 300 million hectares to 1530 million hectares between the years 1700 and 2000. Even in some areas where the land cover has not changed, the manner in which the land is used has. Between 1700 and 2000, for example, the global area used for grazing livestock increased 10-fold, from 324 million hectares to 3429 million hectares. By 2000 only a few desert regions, the central Amazon and Congo basins, arid areas of Australia, and the Arctic and Antarctic had not been significantly affected by humans. Roughly half of Earth's land surface is estimated to have suffered intensification in land use.[10] Such shifts in land management can drastically alter carbon, heat, and water fluxes between the surface and the overlying atmosphere. (See the box on page 45.) The growing human footprint on the landscape is disquieting in part because of the sheer magnitude of its effect. In parts of Arizona, urbanization-induced warming—commonly known as the urban heat-island effect—could boost temperatures by up to 7 °C in coming decades, nearly three times the predicted rise in temperature attributable to greenhouse gas emissions.[11] (See figure 4 for a visual illustration of the heat-island effect in London.)

Changes in land cover and management have large impacts at local and regional scales even when their average global effect is small. Unlike added CO_2, which has a globally homogenous effect on radiation, changes in land cover and land management can produce large spatial variations in climate-system fluxes. Those variations are the driving forces disturbing local and regional weather patterns.

The weather effects are all the more concerning because they are often spatially coherent over large scales. The alteration of land at one location may influence weather patterns at distant locales through atmospheric couplings known as teleconnections. The hypothesized mechanism is analogous to that by which El Niño, the periodic warming of the eastern and central Pacific Ocean, affects weather thousands of kilometers away. Although the theory is still being explored, teleconnections are thought to link land use to changes in the polar jet stream, the paths of tropical cyclones, and the frequencies and intensities of droughts, floods, heat waves, and other weather events.

The Land Use Model Intercomparison Project, led by David Lawrence of the National Center for Atmospheric Research and George Hurtt of the University of Maryland, is one of several current efforts to improve our understanding of teleconnections and land's role in the climate system. The researchers are urging modeling groups to examine those and other issues of land-related climate forcings.

A matter of perspective

In 2009, 19 fellows of the American Geophysical Union concluded that

in addition to greenhouse gas emissions, other first-order human climate forcings are important to understanding the future behavior of Earth's climate. These forcings are spatially heterogeneous and include the effect of aerosols on clouds and associated precipitation, the influence of aerosol deposition … and reactive nitrogen, and the role of changes in land use/land cover. Among their effects is their role in altering atmospheric and ocean circulation features away from what they would be in the natural climate system. As with CO_2, the lengths of time that they affect the climate are estimated to be on multidecadal time scales and longer.[12]

A few years later, scientists at the University of New South Wales made the case that the human influence on extreme temperatures cannot be assessed by CO_2 levels alone because at the regional scale, land cover and land management can enhance or mask effects from greenhouse gases.[13] Also, global averaging tends to obscure land-change effects, which can depend on geographical region, latitude, and the previous state of the landscape. Yet anthropogenic greenhouse gas emissions have remained the primary focus of multidecadal climate models such as those that informed the debate that resulted in the 2015 Paris agreement.

However, are CO_2 levels and global averaged surface temperature sufficient to generate accurate and meaningful forecasts? Two leading hypotheses have emerged.

The first argues that the accuracy of climate forecasts emerges only at time periods beyond a decade, when greenhouse gas emissions dominate over other human forcings, natural variability, and influences of initial value conditions. The hypothesis assumes that changes in climate are dominated by atmospheric emissions of greenhouse gases, of which CO_2 is the most important. It represents the current stance of the Intergovernmental Panel on Climate Change and was adopted as the basis of the Paris agreement.

A second hypothesis is that multidecadal forecasts incorporating detailed initial value conditions and regional variation set an upper bound on the accuracy of climate projections based primarily on greenhouse gas emissions. According to that view, successful models must account for all important human forcings—including land surface change and management—and accurately treat natural climate variations on multidecadal time scales. Those requirements significantly complicate the task of prediction.[14]

Testing the hypotheses must be accomplished by using "hindcast" simulations that attempt to reproduce past climate behavior over multidecadal time scales. The simulations should be assessed by their ability to predict not just globally averaged metrics but changes in atmospheric and ocean circulation patterns and other regional phenomena.

Reframing risk

The climate system and our role in it are complex. Not only is climate influenced by human forcings, but those forcings are influenced by a host of societal and environmental factors, including population growth, personal consumption levels, and property-value trends. (See the article by Paul Higgins, *Physics Today*, October 2014, page 32.) How then should we assess vulnerabilities and mitigate risks of future climate change?

In our view, the approach should be a comprehensive one that accounts for the full range of forcings, not just carbon emissions. It should incorporate risks from human modification of the land, including the effect of land use on weather patterns.[14] And it should adopt a resource-based vulnerability framework: Identify climate, environmental, and societal threats to critical water, food, health, energy, and ecosystem resources; then optimize mitigation and adaptation strategies according to the relative risks of the various threats to each resource. (See figure 5.)

In the American Geophysical Union's 2012 monograph on extreme events and natural hazards, several scientists—including one of us (Pielke)—recommended a resource-based framework focused on local and regional scales as a more inclusive approach for policymaking.[15] Compared with conventional approaches, which start from the global-climate-model perspective, resource-based frameworks are better equipped to deal with the diversity and complexity of societal and environmental threats faced at the community level.

A resource-based vulnerability framework would give policymakers a better perspective not only of how human forcings affect climate but of how climate affects risk. For example, restricting development of land in flood plains and in coastal locations affected by hurricane storm surge is an effective adaptation strategy regardless of how climate changes.

At present, land is being considered too narrowly in the development of climate policy. To help reduce unintended impacts of land use on climate, we recommend the following:[16]

► Translating international treaties and protocols into national policies and actions that deliver positive climate outcomes and reduce the spectrum of risks to key societal and environmental resources.
► Updating international protocols to reflect new scientific understanding of the role of land in the climate system.
► Continuing to invest in the measurement, database development, reporting, and verification of land-use and land-management activities while monitoring effects of those activities on the climate system and linking them to emissions-reduction efforts.
► Adding developed countries to the Reducing Emissions from Deforestation and Forest Degradation protocol, which currently covers only developing countries.

Earth's future at the fore

As Earth's population has boomed, human forcings have become an increasingly important driver of climate. Current climate-change mitigation policies do not sufficiently incorporate the effects of changes in land surface and land management on the surface albedo, the fluxes of heat and moisture in the atmosphere, and the distribution of energy within the climate system.[17]
Given the goal of mitigating climate change at local, regional, and global scales, it won't suffice to frame the problem simply in terms of greenhouse-gas-induced warming; one must consider threats posed by the entire climate system—and work toward a fuller understanding of that system.
To be sure, incorporating land-cover change and land management complicates attempts to address climate change through, say, a system of credits and debits such as those being considered for fossil-fuel emissions and carbon sequestration. However, recognition of the complexity of anthropogenic climate change does not absolve us of the responsibilities to understand and minimize our impact on Earth's climate system and to reduce societal and ecological vulnerability to environmental change of all types. The problem is formidable, but so are the tools, technologies, and resources with which we can tackle it.

Box. Deforestation down under

Southwest Australia's landscape has changed drastically over the past several decades, with approximately 13 million hectares of native vegetation cleared for agricultural use. In a series of field campaigns named the Bunny Fence Experiment, Tom Lyons (Murdoch University, Perth, Australia), Udaysankar Nair (University of Alabama in Huntsville), and their coworkers assessed the impact of the terrestrial makeover on the region's climate. The team determined representative midday values of sensible-heat (H), latent-heat (LE) fluxes, net radiation (R_n), solar radiation (Q_s) and ground conduction (G) for the two land surface conditions. The gray arrows indicate reflected solar radiation.
Due to its darker albedo, the vegetated landscapes absorb more—and reflect less—radiation from the overlying atmosphere. As a result, the top of the atmospheric boundary layer (Z), where cumulus clouds typically form, is higher over wooded areas. Woodlands also release more of their energy into the atmosphere in the form of latent heat. Those differences can affect weather and climate phenomena deeper into the atmosphere.
Land-use changes in southwest Australia have altered not only heat and

moisture fluxes but surface temperatures, humidity, and fluxes of trace gases and aerosols. The region is by no means an outlier: Take a flight across virtually any country—for example, from Washington, DC, to Denver, Colorado, in the US—and the human footprint on the landscape is plainly evident in the many cities, towns, and farms that pass below.

ACKNOWLEDGMENTS

We thank Udaysankar Nair of the University of Alabama in Huntsville for providing the box figure and Dallas Staley of the Cooperative Institute for Research in Environmental Sciences in Boulder, Colorado, for her invaluable feedback and edits to the manuscript.

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BIOGRAPHIES

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2. The carbon cycle in a changing climate

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Physics Today
November 2016, page 48
http://scitation.aip.org/content/aip/magazine/physicstoday/article/69/11/10.1063/PT.3.3365?utm_source=Physics%20Today&utm_medium=email&utm_campaign=7688696_November%202016%20Table%20of%20Contents&utm_content=Feat3&dm_i=1Y69,4KSMW,E1OV2B,GZPGO,1

As temperatures rise, precipitation patterns change, and land- and sea-ice extents shrink, scientists are learning how the exchanges of carbon between Earth’s atmosphere, ocean, and land ecosystems respond to and feed back on climate change.

Acknowledgments:
The author acknowledges valuable discussions with Chris Jones and the C4MIP Science Steering Committee and support from the European Commission through a Marie Curie Career Integration Grant.

3. Ocean spray: An outsized influence on weather and climate

David H. Richter and Fabrice Veron

Physics Today
November 2016, page 34

Because the production, behavior, and life span of seawater droplets are complex, measuring and modeling them require a wide range of interdisciplinary techniques.
http://scitation.aip.org/content/aip/magazine/physicstoday/article/69/11/10.1063/PT.3.3363?utm_source=Physics%20Today&utm_medium=email&utm_campaign=7688696_November%202016%20Table%20of%20Contents&utm_content=Feat1&dm_i=1Y69,4KSMW,E1OV2B,GZPGO,1

The oceans cover about two-thirds of Earth's surface. The exchange of heat, moisture, and energy between the air and sea across so large an area exerts a profound influence on the dynamic and thermodynamic state of the atmosphere, including its seasonal fluctuations and longer-term climatic trends. As little as 1–3% of that area is covered at any one time by foamy whitecaps that are created as waves break along the shore or out at sea. Perhaps surprisingly, those small-scale events, accompanied by bubbles, sea spray, and turbulence on both sides of the interface, are essential in driving the air–sea fluxes (see the Quick Study by Grant Deane, Dale Stokes, and Adrian Callaghan in *Physics Today*, October 2016, page 86). Because the production of droplets from breaking waves is inaccessible to even the highest-resolution climate and weather models, however, researchers must use large-scale features, such as water and air temperatures and wind patterns, to quantitatively account for the droplets' effects. Fortunately, the past few decades have seen substantial progress in our understanding of how ocean waves couple the ocean to the atmosphere.[1]

Sea spray, which consists of liquid drops that are ejected from the ocean surface, takes part in a rich variety of physical and chemical processes. Small droplets are often lifted high into the atmosphere and can remain there for several days; their actual time aloft depends on such atmospheric conditions as wind speed, air turbulence, and precipitation. And once airborne, the drops can evaporate entirely to leave behind sea-salt aerosols that may then act as cloud condensation nuclei, scatter or absorb solar radiation, or influence atmospheric chemistry. Current estimates of the global release of salt from the ocean via sea-spray production range between 2 billion and 20 billion metric tons per year.[2] That's enough to cover the city of Houston, Texas, with up to 6 m of salt every year.

The larger droplets that most of us are familiar with by getting wet near the beach on a windy day generally remain in the atmosphere for a far shorter time—from a fraction of a second to perhaps minutes or hours—and do not loft high into the atmosphere. They remain local and usually return to the ocean after having directly exchanged momentum, heat, and moisture with lower atmospheric layers. That means those large drops have the greatest potential to influence local weather by affecting winds, humidity, and air temperature. In fact, in certain circumstances, such as in a hurricane or typhoon, high concentrations of large spray droplets are thought to have a significant influence on the thermodynamic conditions near the air–sea interface.

In this article we focus our discussion on how ocean spray influences the dynamic and thermodynamic interactions between air and sea. The magnitude of the interactions is, at least in principle, easy to estimate. It simply depends on three factors: the rate at which the drops exchange heat, moisture, and momentum with the ambient air; how long they remain in the air; and how many of them are generated at the air–sea interface. Let us start with the last factor.

Classes of drops

Sea spray is mainly generated three ways, all associated with breaking waves.[3] When the wind is strong enough, it literally tears water drops from the ocean surface; in the open ocean, the threshold wind speed is about 7 m/s. The ejection of those spume drops—the largest class of sea-spray drops—is thought to happen at the front of a wave as it starts to break, as shown in figure 1. Moments later, the crashing wave forces air bubbles below the ocean surface. Bubbles entrained in the water rise to the surface, where they are usually visible as whitecaps. When they burst, the bubbles splatter so-called film drops into the air. The cavity left behind then collapses, which produces a liquid jet that shoots upward and pinches off several so-called jet drops.

Together, the three classes make up the whole population of spray drops injected into the atmospheric airflow. Their concentration can be expressed by a size-distribution function, which yields the number of droplets per volume of air at a particular height and within a given size range. But a more convenient quantity, called the sea-spray generation function (SSGF), is the number flux of droplets generated at the surface—that is, the rate at which droplets of a given size range are produced per unit area. Because that flux is generally difficult to measure directly, it is often empirically derived from more readily available data, such as wind speed or whitecap statistics.

For jet and film droplets, one can construct an SSGF based on the physical principles behind their formation because the physics of bubble bursting is well understood. And recent advances in optical and other techniques to directly measure droplet sizes and velocities have helped confirm SSGF estimates and reduce their uncertainties.[4] Details behind the formation of spume droplets, by contrast, are less clear because they are more closely linked to the complex process of wave breaking. The complexity precludes constructing an SSGF from theoretical principles alone. Moreover, because spume droplets are larger and thus tend to stay closer to the ocean surface, measuring their concentration is harder than for the smaller droplets, which reach heights more convenient for measurement purposes.

Adapted from a recent review article,[5] figure 2 plots the production flux, as estimated by several different SSGFs, of the various sizes of spray droplets. Because the fluxes of momentum and heat driven by the spray depend on the total momentum and available energy carried by each drop, the SSGFs have been scaled by the volume of the drops. The scatter among the different estimates of spume-droplet volumes illustrates the need for better, more accurate SSGFs before scientists can effectively parameterize the effects of spume in climate and weather models. What's more, to evaluate the effects of ocean spray on the exchange of energy and moisture between sea and air, one needs to estimate not only the number flux of droplets that are made but also the rate at which they exchange energy and mass with the atmosphere.

Microphysics and transport

A droplet sent flying over the ocean surface interacts dynamically and thermodynamically with the turbulent air around it. Dynamically, it feels gravity and hydrodynamic forces, which together determine how much momentum it exchanges with surrounding air via frictional drag. If the droplet is small and light, it quickly adjusts to the local air speed because of its low inertia. Those properties are embodied in a small value of the dimensionless Stokes number $\mathrm{St} = \tau_p/\tau_f$, where τ_p is an acceleration time scale associated with droplet inertia and τ_f is a characteristic time scale associated with the surrounding airflow. In the limit of zero Stokes number, droplets become fluid tracers that instantaneously adjust their speed to that of the local airflow.

Large droplets, on the other hand, have a Stokes number on the order of one or more; they are less likely to travel along with the local air velocity because of their higher mass. And with the greater mismatch in velocity, more momentum is exchanged between droplet and atmosphere. In the limit of a very high Stokes number, the droplets become ballistic particles with little or no influence on their trajectory from surrounding air.

In the simplest models, a droplet, large or small, is assumed to be smaller than the smallest scales of air turbulence and is thus represented as a point particle. The governing equation for the droplet velocity is then a straightforward application of Newton’s second law, with the hydrodynamic force described by the product of a drag coefficient and the difference in velocities of the droplet and the surrounding air.

Just as the local velocity differences drive the exchange of momentum, local differences in temperature and humidity drive the exchange of heat and water vapor. A droplet caught up in the airflow has an initial temperature equal to that of the ocean surface and exchanges sensible heat—the heat associated with a change in temperature but not phase—with the atmosphere during its airborne lifetime. That exchange is generally dominated by convection, and models typically express the heat transfer rate as a product of a (usually empirically derived) convection coefficient and the droplet–air temperature difference.

Likewise, evaporation and condensation of a droplet are also convective processes, in which the total mass-transfer rate of the water depends on the difference between the ambient vapor pressure and that at the droplet’s surface. The latter is usually estimated from the saturation pressure at the droplet temperature, as governed by the Clausius–Clapeyron equation. But the vapor pressure at the droplet’s surface can vary from that estimate, as it is heavily influenced by salinity and surface contamination, which reduce the evaporation rate as the droplet shrinks and salt or contaminant concentrations grow.

If the ambient vapor pressure is less than that at the droplet surface, the droplet evaporates. Because the droplet is the source of latent heat for the phase transformation, evaporation can lower the droplet’s temperature; our skin feels cool on stepping out of a swimming pool for much the same reason. But if the ambient vapor pressure exceeds that of the droplet surface, the converse is true: Water vapor condenses onto the droplet, and the latent heat given to the droplet warms it. A droplet’s temperature therefore depends on its rate of evaporation or condensation and on how much heat it convects. That’s why it’s possible for a droplet to cool below the ambient air temperature during its lifetime. For a more complete treatment of the thermodynamics, see references 4 and 6.

As we’ve seen, droplets smaller than 50 µm or so can remain airborne for days because of their low inertia; large ones remain aloft for mere seconds. The difference matters because the time it takes a droplet to cool is substantially shorter than the time it takes to evaporate, as shown in figure 3. The disparities in droplet lifetimes, temperature evolution, and size evolution produce a complex physical picture. For example, despite not carrying much mass, smaller droplets may possess a greater capacity to transfer latent heat to the atmosphere because of their longer time aloft. Any modeling scheme designed to predict the fate and feedback of spray droplets must therefore account not only for the detailed processes controlling the velocity, size, and temperature of each droplet but also for the meteorological conditions that control its suspension time.

Making models

At low wind speeds, when few waves break and sea spray is minimal, the fluxes of momentum and energy are largely governed by diffusive molecular-transport processes at the air–sea interface. But as the winds pick up speed, more spray is produced, which can, in turn, modify or redistribute the momentum and energy transport throughout a boundary layer filled with suspended droplets. Spray is thought to exert a particularly large effect in tropical cyclones, in which wind speeds can exceed 60 m/s near the ocean surface. Under those extreme conditions, sea spray is pervasive—the normally sharp air–sea interface is replaced by a thick, foamy mixture that gradually approaches pure air on one side and pure water on the other.

A lot of effort has gone into predicting the degree to which the spray can influence the drag felt by the winds over the ocean or enhance the flux of energy from the relatively warm sea to the air. Understanding the impact of strong winds and the resulting spray on the air–sea fluxes is particularly important because the relative balance of energy dissipation through drag (that is, the momentum flux) to energy input through sensible and latent heat heavily affects the development and intensity of large storms.[7] To appreciate how spray may affect air–sea exchange, imagine what happens locally: A droplet goes airborne, partially evaporates, and cools before falling back to the sea. The heat given to the air helps drive the storm.

Three main ingredients are required in a sea-spray model capable of predicting air–sea momentum and energy transfer. The first, outlined earlier, is an understanding of droplet microphysics and thermodynamics, which can be used to calculate the size, velocity, and temperature evolution of a suspended droplet for a given set of ambient conditions. Because those ambient conditions are not usually known, however, the second ingredient is a stochastic model that estimates them based on the suspension lifetimes of droplets of different sizes. The final ingredient is the concentration of suspended spray, given by an SSGF. Uncertainty in the production flux of droplets and their concentrations is one of the key factors that limit current models.

To compute the bulk impact of the spray, it may be tempting to simply take the energy or momentum transfer rate experienced by a single isolated droplet in the atmosphere and multiply it by the total number of suspended droplets. But spray generated at the ocean surface only to return to the ocean forms something of a closed system. For example, a droplet torn from a wave crest and accelerated horizontally extracts momentum from the air and, on impact with the ocean surface, delivers that momentum directly to the sea. From the ocean’s perspective, the total drag would be unchanged; the momentum is merely split between the air and spray. Similarly, a small droplet that evaporates entirely transfers no net heat because during the process the latent heat provided by evaporation is equal to the sensible heat extracted from the air. Only those droplets that partially evaporate can have a net impact on air–sea heat flux.

Moreover, any attempt to model the bulk effects of spray must consider a wide range of feedback effects. Gravity stratifies a suspension of droplets according to its density, with lighter air-spray mixtures sitting atop heavier ones, and some researchers argue that the stable configuration damps turbulence and modifies turbulent fluxes.[8] Others argue that spray could only affect turbulence through more direct interactions and that the momentum carried by the droplets themselves must be taken into account.[9] Droplet evaporation and heat transfer can likewise directly modify air–sea energy transfer, and the additional moisture and heat put into the atmosphere can change near-surface temperature and humidity profiles—and therefore buoyancy. That cascade of effects produces a nonlinear feedback that alters near-surface wind patterns and the spray they create.

Numerical and theoretical models designed to incorporate such feedback effects generally predict that modifications to the overall air–sea momentum flux from sea spray are modest whereas modifications to the overall heat flux can be substantial. In large-scale climate and weather models, those results suggest that spray effects need to be explicitly accounted for in high-wind conditions. Even in conditions where the modifications to the total air–sea momentum flux and energy flux remain small, droplets can still carry a significant fraction of each.

Laboratory and field observations, on the other hand, have yet to quantitatively or conclusively confirm the direct influence of spray predicted by many models. That’s due partially to the difficulty of making measurements in strong winds and partially to the near impossibility of parsing total flux measurements into their interfacial and spray-induced components. Only indirect evidence is currently available,[10] and research is ongoing to provide better validation data for the spray-based models.

Outlook

Estimates of the production flux of droplets at the ocean surface continue to improve as a result of theoretical, laboratory, and observational investigation, and researchers are striving to reduce uncertainties in the concentrations and lifetimes of the spume drops in particular. The stakes are high: The importance of spray in the marine environment goes well beyond its physical effects on air–sea transport. As mentioned earlier, droplets that either are small at inception or become small by evaporating can be carried to altitudes throughout the entire troposphere. They absorb and scatter light, seed clouds, and influence precipitation.

Chemical and biological components of sea spray—the small amounts of oils and other organic debris that mix with water—likewise affect aerosol chemistry in important ways and influence reactions in the marine atmosphere. Ocean spray thus contributes to numerous highly complex and influential processes. It also serves as an example of how a wide range of scientific disciplines and research techniques can be applied to better understand the natural world around us.

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BIOGRAPHIES

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4. Brexit's nuclear fallout: 3,000 cubic metres of Oxfordshire waste

Uncertainty over who will pay an estimated £289m to decommission EU-owned project

https://www.ft.com/content/6ee1ba76-b324-11e6-a37c-f4a01f1b0fa1?accessToken=zwAAAVivYOoQk c9u4bp2syQR5tOjfPSgHxsPoQ.MEYCIQCfOIGEP1fcr69aSN10NyJzLmXCOWz5VMSMHaaAYONDKgIhAM6jgxSODNCybNvmC-ZRrucAuTjXfWCqu2-exqAhnyFM&sharetype=gift

One unusual item affected by the fallout from Britain voting to leave the EU: 3,000 cubic metres of radioactive waste in rural Oxfordshire.

The eventual decommissioning of an EU-owned nuclear tokamak machine, currently the largest nuclear fusion experiment in the world, is a potential flashpoint in Brexit negotiations, with the cost estimated at £289m.

Based at the Culham Centre in south Oxfordshire, the Joint European Torus (JET) project involves some 350 scientists exploring the potential of fusion power, backed by funding from almost 40 countries in the EUROfusion consortium.

The future of the project is in doubt because Britain is potentially ending its membership of Euratom, Europe's treaty framework for the safe civilian use of nuclear energy. Membership is required for participation in EUROfusion.

Established by treaty in 1957, the Euratom community is legally separate from the EU but it is governed by EU institutions such as the European Commission, which oversees the safe operation of civilian nuclear installations.

Britain's plan to trigger the Article 50 exit clause of the EU would, according to EU lawyers, notify intention to exit Euratom as well. "We have no idea what will happen to this British nuclear facility," said one senior Brexit negotiator.

The British government is yet to make clear its nuclear co-operation plans. A spokesperson said: “The government is assessing the legal and policy implications of the public’s vote to leave the EU, including the UK’s membership of Euratom.”

On the day after Britain’s vote to leave the EU, Tony Donné, the programme manager for EUROfusion, said: “Our British member [Culham] is a strong contributor to the European fusion programme. We will be working hard to continue the collaboration after 2018. If and how this is possible is impossible to say today.”

Dr Paul Dorfman, honorary senior researcher at the Energy Institute at University College London, said a departure from Euratom would “necessarily diminish nuclear safety regulation” in the UK.

Britain’s exit from Euratom would send a “confusing” message on the future of nuclear energy, Dr Dorfman added. “The UK government is in favour of nuclear expansion. The last thing they should want to do is leave Euratom.”

A JET paper from 2003 estimates that dismantling the plant would generate approximately 3,000 cubic metres of radioactive waste — enough to easily fill an Olympic swimming pool. The UK Atomic Energy Authority has provisioned for decommissioning costs of up to £289m, although it added there was “significant uncertainty” over the estimate.

It is unclear how any exit from Euratom would affect those calculations or cost-sharing arrangements.

Separately the EU accounts show almost €1.1bn in decommissioning liabilities from other Euratom

installations around Europe, including the 167-hectare Ispra site in Italy. Brussels wants the UK to cover its share of those costs, even after leaving.
Euratom can enter agreements or contracts to co-operate with third countries. Eight such agreements are in place — with the US, Japan, Canada, Australia, Kazakhstan, Ukraine, Uzbekistan and South Africa — but they vary in scope. Any third-party agreement between the UK and Euratom would not be the same as opting-in for membership of the organisation.
For almost half a century, scientists have attempted with limited success to make a commercial success of fusion, harnessing the nuclear reaction that powers the sun and the H-bomb. Since it created its first plasma in 1983, JET has set various milestones in research, including the world record for fusion power in 1997.
Its tokamak is a design precursor and important testing centre for ITER, a project to build a bigger, more powerful experimental fusion reactor in Cadarache in France. Expected delays to that ITER project had raised hopes that research at JET would continue beyond 2018, a decision that will now be part of Brexit talks.
Fuels used in nuclear fusion, which squashes atoms together, are less hazardous than in a fission reactor, which splits them apart.
Nevertheless Culham’s JET experiments have used tritium, a radioactive hydrogen isotope, leaving a legacy of contamination that will take almost a century to clear. The plasma facing walls of Culham’s tokamak are also made of Beryllium, a metal that can be a toxic health hazard.

5. Iter targets first plasma for 2025: Russians offer technical improvement

23 November 2016

http://www.neimagazine.com/news/newsiter-targets-first-plasma-for-2025-russians-offer-technical-improvement-5677360

A new schedule for the International Thermonuclear Experimental Reactor (Iter) fusion project has been approved by the Iter Council, confirming that first plasma is now scheduled for 2025 and the start of nuclear, or deuterium-tritium operation, for 2035. In June 2016 the Iter Organisation, whose work is overseen by the Iter Council, announced an updated schedule which identifies the date of first plasma as December 2025. That schedule has now been rubber-stamped.

First plasma was originally scheduled for 2018 with the start of deuterium-tritium operation set for 2026. However, in July 2010 the Iter Council agreed a new schedule under which first plasma is slated for November 2019, with deuterium-tritium operation starting in March 2027. "The overall project schedule was approved by all Iter members, and the overall project cost was approved ad referendum, meaning that it will now fall to each member to seek approval of project costs through respective governmental budget processes," Iter said in a statement on 20 November.

The statement made no mention of the cost, which Iter previously put it at around €15bn ($16bn). Iter said project construction and manufacturing have sustained "a rapid pace" for the past 18 months, providing "tangible evidence of full adherence to commitments". The successful completion to date of all 19 project milestones for 2016, on time and on budget, is a positive indicator of the collective capacity of the Iter Organisation and the domestic agencies to continue to deliver on the updated schedule, the statement said.

The domestic agencies liaise between the national governments of the seven Iter parties and Iter. The seven Iter parties are the European Union, the USA, China, India, Japan, Russia and South Korea. Iter, under construction at the Cadarache nuclear site in southern France, will be the world's largest experimental fusion facility and is designed to demonstrate the scientific and technological feasibility of fusion as a safe, limitless and environmentally responsible energy source. Thirty-five nations are collaborating to build Iter, a tokamak magnetic fusion device, construction of which began in 2010.

Meanwhile, physicists at Russia's Peter the Great St Petersburg Polytechnic University (SPbPU) have proposed a way to enhance the functioning of the tokamak (Russian acronym for "toroidal chamber with magnetic coils"), the press-service of SPbPU reported. Magnetic coils confine the plasma in which the reaction of controlled thermonuclear synthesis is occurring.

The plasma in the tokamak is confined by a magnetic field instead of by the chamber walls, as modern materials cannot endure the temperature needed for nuclear reactions. However, when the tokamak is operating, the energy released nevertheless ends up on the inner walls of a reactor resulting in its deterioration.

To solve the problem, researchers from SPbPU have suggested a "separation mode" where special admixtures are injected into the reactor via a diverter, a device for online removal of waste material from the reactor. These admixtures control the behaviour of plasma and do not allow energy currents to come in contact with the chamber walls, thereby reducing wear and tear.

"Scientists from SPbPU have demonstrated the method's efficiency and modelled this regime by means of a numerical code known as SOLPS-ITER which has been developed in close collaboration with our European colleagues," said Vladimir Rozhansky, Chairman of the Department of Plasma Physics.

The "sparation mode" will be implemented in modern tokamaks including the ITER tokamak.

6. **Peter Thiel's Other Hobby is Nuclear Fusion**

http://www.bloomberg.com/news/articles/2016-11-22/peter-thiel-s-other-hobby-is-nuclear-fusion

Eric Roston

eroston

November 22, 2016 — 7:00 PM SGT

U.S. President-elect Donald Trump has angered clean-energy proponents by making false statements about climate change and promising to expand fossil-fuel exploration—a policy that could further exacerbate the existential threat he's claimed is a Chinese hoax. Wouldn't it be ironic then if there was someone deep in Trump's confidence who's made a bet on cleaning up energy technology once and for all?

Nuclear fusion, which would harness the power of the

sun without all the nasty byproducts, is a long-shot—politically, financially, and technologically. Despite relative ambivalence toward fusion by the Obama administration, research has continued apace internationally, and in the American public and private sector. At the head of this pack are venture capitalists like Peter Thiel, the Silicon Valley billionaire who spoke at the 2016 Republican National Convention and is said to be working on the Trump transition team. He has funded a fusion start-up called Helion Energy through his Mithril Capital Management to pursue the ultimate dream of environmentalists the world over.
Thiel is on the record as a proponent of the existing form of commercial nuclear energy, fission. He penned an op-ed in the *New York Times* last year lamenting what he described as a functional, safe, and clean energy technology that became “frozen in time,” particularly after the Three-Mile Island nuclear accident of the late 1970s. More than 100 nuclear plants have been canceled over the years. “If we had kept building, our power grid could have been carbon-free years ago,” he wrote.

Fusion, meanwhile, has always drawn energy futurists. It’s the perfect topic for them, since it’s been “30 years away” for at least four decades. While fission produces energy by splitting atoms of uranium or plutonium, fusion would eliminate planet-warming carbon dioxide emissions if scientists could only harness its power in a controlled fashion. Such technology wouldn’t produce long-lasting radioactive waste, and unlike a sun that sets or wind that dies down, fusion wouldn't need battery back-up. It would work all the time.

The world invests almost $2 trillion in energy every year, but just hundreds of millions of dollars on fusion research and development, according to Tom Jarboe, an adjunct physics professor at the University of Washington who studies controlled fusion. He called global investment in the topic "a pittance," singling out President Barack Obama's favoritism of wind and solar over fusion when it comes to clean energy.

But that tantalizing promise of a solution to all our polluting problems has kept investors investing and researchers researching, despite fusion's one debilitating disadvantage: We haven't been able to make it work.

The reason everyone presses on is the enormous upside of limitless, clean, safe energy. Studies over the last generation have found that fusion energy offers a favorable "energy payback ratio," which is a measure of the lifetime output of a theoretical plant, compared with the energy required to build and operate it. A 1998 study by researchers at the University of Wisconsin, Madison, (which has been cited commonly since then) concluded that the energy payback ratio of fusion beats that of fission, coal, and wind power. (A 2006 study found wind to have a higher ratio, and in 2012, the International Energy Agency found hydropower to top the list.)

Nevertheless, the U.S. and its partners have studied nuclear fusion for decades, although without anything approaching commercial success. It's difficult to calculate a cumulative figure for global research-and-development spending on fusion, but an order-of-magnitude guess is solidly in the tens of billions of dollars. A consortium of 35 countries are collaborating on a massive fusion project in southern France, called ITER. The current cost of the initiative is estimated at $20 billion.

Fusion is also increasingly drawing in venture capitalists like Thiel, who think start-ups can achieve better results, faster, than national efforts have yielded. (A spokesman for Thiel declined to comment.)

His Mithril Capital Management and seed funder Y Combinator invested $1.5 million in 2014 in Helion Energy, a start-up in Redmond, Wash., that is trying to commercialize its research. Helion has also drawn almost $4 million from a U.S. Department of Energy's Advanced Research Projects Agency-Energy grant.

Helion hopes to make a fusion generator that's 1,000 times smaller, 500 times cheaper, and 10 times faster than more conventional, massive projects, according to its website. The company is building a "magneto-inertial fusion" generator. It produces power by injecting heated hydrogen and helium at high speed (a million miles an hour) into a "burn chamber," where a strong magnetic field compresses the plasma to a temperature high enough to initiate fusion. Energy from the reaction is used to generate electricity.

It sounds loony to take the most ambitious, expensive, and inconclusive energy experiment in history and shrink it down to a product that can fit on a truck. If so, then loony loves company. Lockheed Martin Corp. in October 2014 announced that its "compact fusion" initiative would need only a decade to deliver a reactor small enough to fit on the back of that proverbial truck. Amazon.com founder Jeff Bezos is included among the backers of General Fusion, a British Columbia company that launched in 2002, and has designed a reactor that compresses hydrogen plasma into fusion reactions with hammer-like jolts. Tri Alpha Energy reported in mid-2015 a breakthrough in the stability of its hydrogen plasma. Its backers have included Microsoft Corp. co-founder Paul Allen.

Jarboe, the University of Washington professor, said he hasn't heard Trump address Energy Department issues yet.

"There are several new ideas out there that are not being tried with the resources we should, if we want to solve the global warming and energy problem," Jarboe said. Others have criticized the fusion start-ups for their reliance on ideas originated decades ago. But ruling out an old idea just because it's never worked commercially is a dangerous game to get into these days. Solar and wind power, long considered "alternative energy," are now competitive with traditional power generation in many parts of the world. The same never-going-to-happen criticism applied to hydraulic fracturing, the technique that made the U.S. a natural gas superpower within the last decade. Patented in 1949, "fracking" never worked—until it did, and changed the world, albeit with environmental headaches and manmade earthquakes. Fusion may have more positive byproducts—if we make it work in time to avoid the climate calamities to come.

7. New schedule agreed for Iter fusion project

21 November 2016

An updated schedule for the Iter fusion project has been approved by the Iter Council, which represents the countries taking part in the project. Under the new schedule, first plasma is now slated for 2025 and the start of deuterium-tritium operation is set for 2035.

http://www.world-nuclear-news.org/NN-New-schedule-agreed-for-Iter-fusion-project-2111164.html

A two-day meeting of the Iter Council at the Iter headquarters at Saint-Paul-lez-Durance in France unanimously approved the project's baseline - its overall schedule and cost. The project is to build the world's biggest tokamak fusion reactor at Cadarache in southern France. It should be large enough and hot enough to reach 'ignition' and maintain a stable heat-generating plasma for minutes.

"The overall project schedule was approved by all Iter members, and the overall project cost was approved ad referendum, meaning that it will now fall to each member to seek approval of project costs through respective governmental budget processes," the Iter Organization said in a statement yesterday.

The Council concluded that project construction and manufacturing have sustained a rapid pace for the past 18 months, "providing tangible evidence of full adherence to commitments". The successful completion of all 19 project milestones for 2016, on time and on budget, is "a positive indicator of the collective capacity of the Iter Organization and the Domestic Agencies to continue to deliver on the updated schedule", it said.

The Iter Council added, "The staged approach as selected in the updated schedule after first plasma increases confidence and minimizes risk by focusing on completing Iter in stages and carrying out fusion power experiments in between each stage. This approach is the best way forward in alignment with the priorities and constraints of all Iter members."

The Iter Council is responsible, in accordance with the Iter Agreement, for the promotion and overall direction of the Iter Organization. The two regular meetings every year - in June and November - can be supplemented by an extraordinary meeting for the examination of specific issues.

Thirty-five nations are collaborating to build Iter. The magnetic fusion device is designed to prove the feasibility of the fusion of hydrogen nuclei as a large-scale and carbon-free source of energy. The EU is funding half of the cost while the remainder comes in equal parts from six other partners: China, Japan, India, Russia, South Korea and the USA. Construction began in 2010.

First plasma was originally scheduled for 2018 with the start of deuterium-tritium operation set for 2026. However, in July 2010 the Iter Council agreed a new schedule under which first plasma is slated for November 2019, with deuterium-tritium operation starting in March 2027.

Researched and written
by World Nuclear News

8. Swiss reject rapid nuclear phase out

27 November 2016

UPDATED -This article was updated on 28 November to indicate the final result of the referendum and to include comments from the Swiss Nuclear Forum and the World Nuclear Association.

http://www.world-nuclear-news.org/NP-Swiss-reject-rapid-nuclear-phase-out-2711161.html

The proposal to force older nuclear power plants to close in Switzerland has been rejected in a referendum. The five reactors that provide over one-third of electricity can continue to operate according to their economic lives.

Nuclear power is Switzerland's second largest source of electricity, providing about 35% of electricity in 2015 and complementing 52% hydro to give the country one of the cleanest and most secure electricity systems in the world.

In 2010 there were active plans to replace the five current reactors based on a supportive referendum and confirmation by regulators that the sites were suitable. This program was scrapped by a National Council vote in June 2011, just four months after the accident at Fukushima Daiichi, and Switzerland was put on a path to lose nuclear power when existing reactors retired in the 2030s and 2040s.

Today Switzerland went to the polls on a further proposal that would have accelerated the retirements by forcing reactors to close at the age of 45. Because they are already over this age, Beznau 1 and 2 as well as Muehleberg would have closed in 2017. Gösgen would have followed in 2024, and Leibstadt in 2029.

A majority - 54.2% - of people voted 'No' to the rapid phase out, recording a clear victory by winning both the popular vote and by taking majorities in the most cantons. The participation rate in the referendum was some 45% of voters.

The Swiss Nuclear Forum said, "Swiss voters have expressed their confidence in the nuclear power plant operators and in the safety authorities by a clear majority. The clear rejection of the nuclear phase-out initiative shows that the Swiss attach great importance to a reliable and environmentally friendly power supply with domestic plants."

Daniel Aegerter, co-founder of pro-nuclear NGO Energy for

Humanity (EfH) said: "Swiss voters have sent a strong message to the world by rejecting the Greens' disorderly nuclear exit initiative. Our efforts now must be on expanding clean electricity generation, not shutting it down."
Now Swiss nuclear plants can operate according to their owners' commercial plans, subject to approval from safety regulators. They are now likely to continue until the age of 60, closing in the 2030s-2040s. They are expected to generate some 320 TWh of electricity in the longer operating period, which would avoid "at least 50 million tons of CO2" compared to a typical replacement mix of natural gas and imports from France and Germany, said EfH.
Wolfgang Denk, European director of EfH said: "Germany has been trying for years to succeed with their energy transition and they are facing huge difficulties. By keeping their existing plants online, Switzerland will be in a much better position to face the upcoming challenges in climate change and the energy sector in general."
World Nuclear Association director general Agneta Rising said, "The Swiss people have chosen to use their existing nuclear energy assets more wisely and to preserve their wonderful clean energy system. Relying on a balanced mix of hydro power and nuclear, their energy mix is one of the cleanest in the world and it provides a successful model for other countries that are seeking to decarbonise."
Researched and written
by World Nuclear News

9. Have carbon emissions peaked?

Global output of carbon dioxide has flattened. But the atmospheric concentration of the greenhouse gas has grown at record levels.
David Kramer

30 November 2016
http://scitation.aip.org/content/aip/magazine/physicstoday/news/10.1063/PT.5.1101?utm_source=Physics%20Today&utm_medium=email&utm_campaign=7804167_The%20week%20in%20Physics%2028%20November–2%20December&dm_i=1Y69,4N9QF,E1OV2B,HBGT3,1
Global anthropogenic carbon emissions grew only slightly in 2014 and 2015, and only a small increase is expected for 2016, according to an analysis released 14 November during the United Nations Framework Convention on Climate Change in Marrakech, Morocco. The total rise of less than 1% for those three years contrasts with a 2.3% average annual increase in emissions seen between 2003 and 2013. And the slowdown happened despite a global economic growth rate of around 3% a year.
“This third year of almost no growth in emissions is unprecedented at a time of strong economic growth,” said analysis lead author Corinne Le Quéré (University of East Anglia, UK) in a statement. “This is a great help for tackling climate change, but it is not enough. Global emissions now need to decrease rapidly, not just stop growing.”

Whether emissions growth will recur in the next few years depends on whether energy and climate policies from Marrakech take hold, added report coauthor Glen Peters from the Center for International Climate and Environmental Research–Oslo in Norway.

Despite the progress in curbing emissions, humans still emitted a record 36.3 gigatons of carbon dioxide in 2015, a 60% increase from 1990. And the concentration of CO_2 in the atmosphere continues to rise at record or near-record levels. The unrelenting increase is due to the recent strong El Niño event, which led to high temperatures and dry conditions that diminished the amount of CO_2 absorbed by trees, Le Quéré said. The recent onset of La Niña should slow the rate of CO_2 buildup.

The report says that 2016 will be the first full year in which global CO_2 concentration will be measured at or above 400 ppm. The preindustrial concentration was 277 ppm.

China is by far the world's largest carbon emitter, accounting for 29% of the world's annual output. But the surge in Chinese emissions that began around 2000 topped off in 2013, and output has since declined slightly as coal use decreased, the report shows. The US, which produces 15% of global emissions, saw a 2.6% falloff in 2015, and a further 1.7% decline is expected this year. That decrease is also due to less coal combustion, the report says.

The European Union's carbon emissions, which make up 10% of the global total, increased 1.4% last year to end a decline that began in the mid 2000s. And India's emissions, 6% of the total, jumped 5% in 2015.

On a per capita basis, the US remained by far the biggest emitter in 2015, at 16.8 metric tons of CO_2 per person per year. China is second at 7.5 tons per person annually, followed by the EU at 7 tons and India at 1.7 tons.

10. Special Report: Advancing fusion research in Finland

http://horizon2020projects.com/special-reports/advancing-fusion-research-finland/

Fusion energy is a CO2-free nuclear energy source with low environmental impact using ubiquitous fuels. Fusion electricity, together with other energy sources, could meet predicted energy supply shortages. On the basis of current research, fusion electricity using magnetically confined plasmas could be available in the second half of the century. ITER is the key facility in this strategy, and the DEMO design and R&D will benefit largely from the experience gained with ITER construction and operation.

Finland in European fusion research The EUROfusion Consortium is an organisation implementing the Euratom fusion research programme in parallel with ITER construction. It provides a distinctive culture of international collaboration within and outside the European Union. The multidisciplinary skills available in the European fusion laboratories and the intellectual diversity of staff and collaborators facilitate research advances in all topics related to the realisation of fusion electricity.

Finland joined the Euratom fusion programme in 1995 after acceding to the EU. As a small country Finland concentrated its efforts on a small number of focus areas – plasma physics, materials science, novel steel structures and remote handling. Through participation in the European fusion programme, the national objective was to develop critical competences networks to major European organisations involved in developing fusion energy. In 2004 Finland was chosen to host a remote handling laboratory, ITER Divertor Test Platform 2 (DTP2), in the city of Tampere.

During the EU's Horizon 2020 framework programme, and in order to govern the fusion research activities in Finland, the FinnFusion Consortium was established in 2014 to replace Association Euratom-Tekes, which ran fusion research in a similar role. VTT Technical Research Centre of Finland Ltd is a co-ordinator in the FinnFusion Consortium, whilst science/technology universities and private companies are members. The FinnFusion Consortium is linked to the EUROfusion Consortium via VTT. The roles of funding organisations and other key stakeholders are described in the FinnFusion organigram (Fig. 1).

Upon the construction of ITER and the design of DEMO, fusion is becoming an increasingly industrial field of research. With this position Finland remains strong in European fusion research and will take advantage of the synergy between fusion and fission expertise and their presently quite separate networks.

Objectives The main objectives of the FinnFusion Consortium can be shortly condensed as below:

- Designate R&D resources to the two centres of excellences: 1) fusion power plant analysis and materials, and 2) remote handling. Transfer skills to industry;
- Upgrade the competences required for demanding international deliveries, such as networking, management,

quality and methods, and successful tendering in the ITER project; and

Link the industry strongly to the existing co-ordinated R&D research programme in the universities and research units.

The main goals of the power plant analyses and materials and remote handling R&D centres of excellence within FinnFusion are:

Foster the growth of expertise in fusion plant operation, knowledge and skills transfer to Finnish decision makers, industry involving SMEs, research units, universities and the public;

Lead experiments in present fusion research facilities at ITER, JET (UK), ASDEX-U and W7-X (Germany), DIII-D (General Atomics, US), C-Mod (MIT, US);

Exploit the synergy between fusion and fission R&D, such as requirements and specifications for the ITER fusion plant simulator, radiation and reactor safety, and the design phase of the so-called 'Early Neutron Source' (for the neutron-resistant material project);

Develop new technologies (e.g. surface processing techniques) and advanced materials (including steels) for fusion power plants; and

Develop systems engineering and remote handling skills. Systems engineering is a key method for upgrading all kinds of industrial activity.

Achievements The main achievements of the Finnish Fusion Programme (presently FinnFusion) in 1995–2016 can be summarised as follows:

Starting from scratch in 1995, the R&D programme has developed to the level of about 50 professional person years with around 150 internationally well-networked fusion experts involved in more than 30 companies and six research organisations. This has enabled Finland to win ITER procurements, to learn and upgrade its competences, and to create networks within both industry and research organisations;

After long-term investment in relevant R&D by various FinnFusion activities, Finnish companies and research organisations have gained access to several large international consortia responsible for ITER procurements;

Finland is considered a well-respected partner in the European fusion programme and therefore has committee members and leaders in many of the key positions; and

Excellence in research and development is exemplified in 835 refereed journal publications with over 9,200 citations to them, 1,235 conference papers, 46 doctoral theses and 77 master's theses.

Key features As is clear from the various lists above, the peculiar and quite unique feature in FinnFusion, among the other European fusion research units, is the strong involvement of technology and industry in all fusion energy-related activities. The Divertor Test Platform 2 laboratory hosted by VTT, together with the Remote Operation and Virtual Reality (ROViR) centre, is exploited by both fusion research and Finnish industry. In fact, there is knowledge and expertise on fusion technology in around 30 Finnish companies, and FinnFusion is focusing more than half of the fusion research effort on fusion technology and engineering-related topics. In recent years, the fusion and fission research and existing industry around the fission infrastructure have been brought closer to each other, resulting in the establishment of fruitful connections and synergy effects.

The other special feature in FinnFusion is the close collaboration of all participating members, including the research laboratories, funding agencies, authorities and private companies. Therefore, as all bodies involved have a common goal, as represented in Fig. 1, the FinnFusion Consortium is an organisation functioning in an efficient way.

The annual FinnFusion seminar gathers all the participants and, as an example, the main theme in the FinnFusion annual seminar in 2015 was 'Industry Involvement in ITER and Fusion Research: Finnish Success Stories'. Industry was very well presented in the seminar, which was hosted by VTT in Tampere.

Challenges and opportunities ITER is a unique and challenging scientific and technological project, and FinnFusion's participation in such a very large international programme has major scientific, technological and economic benefits. For

Finnish industry and the research units ITER is an effective platform for developing expertise, networking and prestige. The level of new skills, technologies, expertise and networks is immeasurably high, and FinnFusion must be proactive in exploiting all the benefits from the project to achieve all these clear focus areas in research; each having a critical mass and producing significant results is, after all, mandatory. FinnFusion, however, is well suited to the ongoing change in the international trend from academic to project-oriented work. Strong connection to nuclear technology in line with the industrialisation of fusion is being established right now.
The future challenge is to further exploit these international networks and this expertise for national benefit and, in particular, to find national funding to complement the EU-funded projects. FinnFusion is now at an all-time high of its lifecycle in terms of the number of research activities, number of organisations involved, and the magnitude of EU-level funding – the future is in the hands of the national funding bodies and authorities upon which FinnFusion can harvest the fruits of its labour.

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11. **After 60 years, is nuclear fusion poised to deliver?**
It's been a long time coming, but the world's top powers are now betting billions on the ITER collaboration to de3liver clean, sfe, limitless energy for the modern world.
https://www.theguardian.com/environment/2016/dec/02/after-60-years-is-nuclear-fusion-finally-poised-to-deliver

"We are standing on the ground that could change the future of energy," says engineer Laurent Pattison, deep in the reactor pit of the world's biggest nuclear fusion project. Around him is a vast construction site, all aimed at creating temperatures of 150mC on this spot and finally bringing the power of the sun down to Earth. The €18bn (£14.3bn) Iter project, now rising fast from the ground under the bright blue skies of Provence, France, is the first capable of achieving a critical breakthrough: getting more energy out of the intense fusion reactions than is put in.

"It is a bet that is very important for humanity," says Johannes Schwemmer, the director of Fusion for Energy, the EU partner in the international Iter collaboration. "We need to get this energy once and for all."

The long allure of nuclear fusion is simple: clean, safe, limitless energy for a world that will soon house 10bn energy-hungry citizens. But despite 60 years of research and billions of dollars, the results to date are also simple: it has not delivered.

Fusion is in danger of following its atomic cousin, conventional fission nuclear power, in over-promising – "electricity too cheap to meter" – and under-delivering. The Iter project itself, which stems from a cold war Reagan-Gorbachev summit in 1985, has seen years of turmoil. The US pulled out entirely between 1998-2003 and in 2008, Iter had to treble its budget and shift its deadline back a decade. But leaders representing half the world's population – through the Iter partners, the EU, China, Russia, US, India, Japan and South Korea – are now making the €18bn wager that fusion can deliver and have radically overhauled Iter's management to fix the mistakes of the past.

The goal is to trap a plasma in a huge magnetic ring and force heavy hydrogen isotopes to fuse together to release prodigious amounts of energy – four times more than the splitting of uranium atoms produces in conventional fission reactors.

"We are convinced we can deliver hundreds of megawatts through Iter," up to 10 times more energy than is put in, says David Campbell, the director of science and operations at Iter (which means "the way" in Latin).

To achieve that breakthrough, Iter will use a donut-shaped magnetic cage called a tokamak to trap the plasma. More

than 200 smaller tokamaks have been built around the world and Campbell says the decades of physics and engineering that Iter is building on is a strong guarantee of success.
But nothing has ever been attempted on the scale of Iter. The world record for fusion power – 16MW - was set in 1997 at the JET reactor in the UK. The longest fusion run – six minutes and 30 seconds – was achieved at France's Tore Supra in 2003. Iter is aiming for 500MW and 50-minute runs.
The site is a cathedral to the fusion dream: it spans the equivalent of 60 football fields and the reactor building will weigh 320,000 tonnes, all resting on rubber bearings in case of an unlikely, but not impossible, earthquake. The reactor itself will weigh 23,000 tonnes, three times more than the Eiffel Tower. It is the most complex engineering project in history.
More than 2,800 tonnes of superconducting magnets, some heavier than a jumbo jet, will be connected by 200km of superconducting cables, all kept at -269C by the world's largest cryogenic plant, which will pump 12,000 litres per hour of liquid helium.
Millions of precision components will be shipped in from the seven partners to be assembled by thousands of workers.
This is all aimed at keeping just two grammes of plasma hot enough and stable enough in the 30m-diameter tokamak for fusion to take place.
Iter's schedule is to create the first plasma in 2025, then start firing tiny 5mm frozen pellets of heavy hydrogen – deuterium and tritium – into the plasma and generating energy. Deuterium is easily refined from seawater and fuses with tritium, which is harvested from fission reactors but could be self-generated in Iter in future. The aim is to reach its maximum power output by 2035 and, if so, Iter will be the foundation of the first fusion power plants.
Bernard Bigot, the director general of Iter, is certain it will produce plentiful power, "but what is not granted so far is

that this technology will be simple and efficient enough that it could be industrialised," he says.
The point of Iter is finding out, says Bigot: "The world needs to know if this technology is available or not. Fusion could help deliver the energy supplies of the world for a very long time, maybe forever."
Even if things go well, getting real fusion power plants online before 2050 would be a triumph, raising an awkward question: what if fusion comes too late? Climate change is driving an accelerating transformation to low-carbon energy and drastic cuts in emissions are needed by 2050. If these are achieved, will there be a need for fusion power, which will be expensive at the start?
"It is certainly not going to be too cheap to meter," says Campbell. But it's a question of timescale, he says: "In the long term there are very few available options: renewables, fission and fusion."
For Schwemmer, there is only one long-term option. "You would have to cover whole continents with wind turbines to produce the energy needed for 10 billion people," he says. "And if our children's children are not to sit on piles of [fission] nuclear waste, we have to make fusion work. Even if it takes till 2100, we should still do it." Nuclear fission is also limited by uranium supplies, perhaps to a few decades if it were to play a large role.
Bigot said: "People have to realise, if we want a breakthrough [that could provide energy] for millions of years, 10 or 20 years is nothing." He thinks fusion may still come in time to meet the need to move the world to zero emissions in the second half of the century to defeat global warming.
As a nuclear technology, some will remain implacably opposed to fusion. While fusion reactions produce only harmless helium, the high-energy neutrons also ejected irradiate the walls of the reactor, leading to radioactive waste.
gain, the key is timescale, says Campbell. Waste from fission

can remain radioactive for 250,000 years, making plans to store dangerous waste for many times longer than the whole of human civilisation speculative. In contrast, fusion waste will decay on the scale of decades. “Looking after the waste for 100 years is credible,” he says.

Fusion is also intrinsically safe, with the large meltdowns seen in fission accidents such as Fukushima and Chernobyl physically impossible. Part of the reason is the tiny amount of fuel in a fusion reactor at any one time and part is the temperamental nature of plasma, a boiling gas of ions and electrons. “If you lose control of the plasma, it doesn’t just sit there, it disappears like that,” says Campbell, clicking his fingers.

“After Fukushima, we thought we would be flushed down the toilet like all nuclear,” says Sabina Griffith, a communications manager at Iter. “But the opposite happened – governments thought if not fission, then what?”

There are other fusion reactor designs that might be better and, in particular, smaller. A €1bn reactor opened in Germany by chancellor Angela Merkel earlier in 2016 uses a stellarator, in which the plasma ring is shaped like a Mobius strip. This makes it potentially more stable and, crucially, able to operate continuously, rather than in pulses like a tokamak.

There are also numerous private companies, staffed by serious fusion researchers, promising much smaller reactors, including the UK’s Tokamak Energy and Tri Alpha Energy and General Fusion in Canada.

“There are technology routes that might let you build something smaller – in principle,” says Campbell. But he says they either rely on unproven “exotic” ideas or underestimate the heavy engineering needed to contain burning plasmas. “Iter is the size our present technology allows us to build,” he says.

Politics remains a challenge to delivering Iter and uncertainty has been ramped up by the election of Donald Trump as president of the US, where some powerful voices

want to leave the project for good. Britain's vote to leave the EU has also added to the uncertainty.
But Bigot believes the need to know if full fusion power is feasible will keep the partners in. "To be frank, the US is only 9% of the project, if they were to leave alone, I believe we could go on," he said. "But it would be the wrong signal [showing] the most powerful country in the world is not preparing for its future." On Brexit he says: "It would damage Iter a little, but it would damage the UK a lot," given its long and continuing research in fusion.
The political problems usually boil down to costs and the governments of Iter partners wanting to reduce the taxpayers' money spent on the project. "Iter looks very expensive to the ordinary person in the street," says Campbell. "But the cost is spread across half the world's population. Seen in that context I don't think it is such a big investment to make." The world spent $325bn on fossil fuel subsidies in 2015 alone, according to the IEA, and $150bn on renewable energy support.
Fusion supporters such as Campbell also suggest fusion has geopolitical benefits because its key fuel – heavy hydrogen – is accessible to all. "No one has a monopoly on the fuel so no one is going to fight each other over it."
The 1985 Reagan-Gorbachev summit that kickstarted the Iter project called for "the widest practicable development of international collaboration" in nuclear fusion to obtain "energy which is essentially inexhaustible, for the benefit of all mankind".
So how far is the world from achieving that, 30 years and numerous stumbles on? Many still point to the answer given by Lev Artsimovich, the father of the tokamak and head of the Soviet fusion power programme for more than two decades until his death in 1973. Fusion power, he said, will arrive "when mankind needs it – maybe a short time before that".
• This article was amended on 2 December 2016 to correct General Fusion's location.

12. Post-Brexit business as usual at JET

30 November 2016

"Nothing has changed" regarding the future for the UK's Culham Centre for Fusion Energy (CCFE) and the Joint European Torus (JET), centre head Ian Chapman said today.

http://www.world-nuclear-news.org/NN-Post-Brexit-business-as-usual-at-JET-3011168.html

The CCFE is the UK's national laboratory for fusion research based at Culham Science Centre in Oxfordshire, where it hosts JET on behalf of its European partners. JET is the largest tokamak in the world and the only operational fusion experiment currently capable of producing fusion energy. The JET facilities are operated by the CCFE under a contract between the European Commission and the United Kingdom Atomic Energy Authority (UKAEA), and collectively used by all European fusion laboratories under the EUROfusion consortium.

Chapman, who is also CEO of the UKAEA, was responding to reports published earlier this week by the *Financial Times* and the *BBC*, questioning the future of the CCFE and the JET project following the UK's anticipated withdrawal from the European Union - popularly known as Brexit. The *Financial Times* report described the eventual decommissioning of the JET tokamak - along with associated radioactive waste - as a "potential flashpoint" in Brexit negotiations. The *BBC* said many of the centre's staff had become "extremely nervous" amid uncertainty about future financing and freedom of movement, since many of them are from outside the UK.

"In light of recent media reports (notably on the *BBC* and *Financial Times*) on the impact of Brexit for the future of JET, I would like to be clear nothing has changed regarding the future for CCFE and JET," Chapman said. "Discussions are continuing with UK Government; they remain very positive about the fusion program and options for continued JET operation are actively being discussed. Although no firm decisions or commitments have been made, I know that the Government values the international collaboration in fusion and I remain confident for our long-term prospects.

"It is also worth noting that these discussions are helped enormously by excellent recent results on JET. Routine high heating powers and excellent machine reliability have led to plasmas with very high confinement and stored energy - by far the best results with the new Iter-like wall. This augurs very well for key experiments planned for 2019/20 using the fusion fuels deuterium and tritium, and is invaluable for the early operation of Iter."

The Iter fusion reactor, currently under construction in France, will be JET's successor on the route to developing commercial fusion power. Since producing its first plasma in 1983, achieving the world's first release of deuterium-tritium fusion power in 1991, and setting the world record for fusion power - 16 megawatts - in 1997, JET has carried out much important work to assist the design and construction of Iter and remains closely involved in testing plasma physics, systems and materials for the project.

JET's 2015-2016 experimental campaign, which ended on 15 November, included: the rehearsal of procedures for future tritium-tritium and deuterium-tritium experiments; a hydrogen campaign during which physicists learned about the dependence of plasma parameters on the mass of the hydrogen fuel used; and a high-power deuterium campaign. Upcoming campaigns will include tritium-tritium and deuterium-tritium experiments that will be crucial foundations for the operation of Iter.

Iter is currently scheduled to produce its first plasma in 2025 and start deuterium-tritium operations in 2035. Like JET, Iter will not demonstrate the use of nuclear fusion to produce electricity. That will be the objective of Iter's successor, the Demonstration Fusion Power Reactor, or DEMO, which will aim to demonstrate the continuous output of energy, supplying electricity to the grid. According to EUROfusion, DEMO is expected to follow Iter by 2050.

European nuclear fusion research comes under the auspices of the European Atomic Energy Community (Euratom) which pre-dates the EU.

Researched and written
by World Nuclear News

13. Fusion energy: A time of transition and potential

November 30, 2016 2.04pm AEDT

http://theconversation.com/fusion-energy-a-time-of-transition-and-potential-64728

For centuries, humans have dreamed of harnessing the power of the sun to energize our lives here on Earth. But we want to go beyond collecting solar energy, and one day generate our own from a mini-sun. If we're able to solve an extremely complex set of scientific and engineering problems, fusion energy promises a green, safe, unlimited source of energy. From just one kilogram of deuterium extracted from water per day could come enough electricity to power hundreds of thousands of homes.

Since the 1950s, scientific and engineering research has generated enormous progress toward forcing hydrogen atoms to fuse together in a self-sustaining reaction – as well as a small but demonstrable amount of fusion energy.

Skeptics and proponents alike note the two most important remaining challenges: maintaining the reactions over long periods of time and devising a material structure to harness the fusion power for electricity.

As fusion researchers at the Princeton Plasma Physics Lab, we know that realistically, the first commercial fusion power plant is still at least 25 years away. But the potential for its outsize benefits to arrive in the second half of this century means we must keep working. Major demonstrations of fusion's feasibility can be accomplished earlier – and must, so that fusion power can be incorporated into planning for our energy future.

Unlike other forms of electrical generation, such as solar, natural gas and nuclear fission, fusion cannot be developed in miniature and then be simply scaled up. The experimental steps are large and take time to build. But the problem of abundant, clean energy will be a major calling for humankind for the next century and beyond. It would be foolhardy not to exploit fully this most promising of energy sources.

Why fusion power?

In fusion, two nuclei of the hydrogen atom (deuterium and tritium isotopes) fuse together. This is relatively difficult to do: Both nuclei are positively charged, and therefore repel each other. Only if they are moving extremely fast when they collide will they smash together, fuse and thereby release the energy we're after.

This happens naturally in the sun. Here on Earth, we use powerful magnets to contain an extremely hot gas of electrically charged deuterium and tritium nuclei and

electrons. This hot, charged gas is called a plasma.
The plasma is so hot – more than 100 million degrees Celsius – that the positively charged nuclei move fast enough to overcome their electrical repulsion and fuse. When the nuclei fuse, they form two energetic particles – an alpha particle (the nucleus of the helium atom) and a neutron.
Heating the plasma to such a high temperature takes a large amount of energy – which must be put into the reactor before fusion can begin. But once it gets going, fusion has the potential to generate enough energy to maintain its own heat, allowing us to draw off excess heat to turn into usable electricity.
Fuel for fusion power is abundant in nature. Deuterium is plentiful in water, and the reactor itself can make tritium from lithium. And it is available to all nations, mostly independent of local natural resources.
Fusion power is clean. It emits no greenhouse gases, and produces only helium and a neutron.
It is safe. There is no possibility for a runaway reaction, like a nuclear-fission “meltdown.” Rather, if there is any malfunction, the plasma cools, and the fusion reactions cease.
All these attributes have motivated research for decades, and have become even more attractive over time. But the positives are matched by the significant scientific challenge of fusion.

Progress to date

The progress in fusion can be measured in two ways. The first is the tremendous advance in basic understanding of high-temperature plasmas. Scientists had to develop a new field of physics – plasma physics – to conceive of methods to confine the plasma in strong magnetic fields, and then evolve the abilities to heat, stabilize, control turbulence in and measure the properties of the superhot plasma.
Related technology has also progressed enormously. We have pushed the frontiers in magnets, and electromagnetic

wave sources and particle beams to contain and heat the plasma. We have also developed techniques so that materials can withstand the intense heat of the plasma in current experiments.

It is easy to convey the practical metrics that track fusion's march to commercialization. Chief among them is the fusion power that has been generated in the laboratory: Fusion power generation escalated from milliwatts for microseconds in the 1970s to 10 megawatts of fusion power (at the Princeton Plasma Physics Laboratory) and 16 megawatts for one second (at the Joint European Torus in England) in the 1990s.

A new chapter in research

Now the international scientific community is working in unity to construct a massive fusion research facility in France. Called ITER (Latin for "the way"), this plant will generate about 500 megawatts of thermal fusion power for about eight minutes at a time. If this power were converted to electricity, it could power about 150,000 homes. As an experiment, it will allow us to test key science and engineering issues in preparation for fusion power plants that will function continuously.

ITER employs the design known as the "tokamak," originally a Russian acronym. It involves a doughnut-shaped plasma, confined in a very strong magnetic field, which is partly created by electrical current that flows in the plasma itself. Though it is designed as a research project, and not intended to be a net producer of electric energy, ITER will produce 10 times more fusion energy than the 50 megawatts needed to heat the plasma. This is a huge scientific step, creating the first "burning plasma," in which most of the energy used to heat the plasma comes from the fusion reaction itself.

ITER is supported by governments representing half the world's population: China, the European Union, India, Japan, Russia, South Korea and the U.S. It is a strong international statement about the need for, and promise of, fusion energy.

The road forward

From here, the remaining path toward fusion power has two components. First, we must continue research on the tokamak. This means advancing physics and engineering so that we can sustain the plasma in a steady state for months at a time. We will need to develop materials that can withstand an amount of heat equal to one-fifth the heat flux on the surface of the sun for long periods. And we must develop materials that will blanket the reactor core to absorb the neutrons and breed tritium.

The second component on the path to fusion is to develop ideas that enhance fusion's attractiveness. Four such ideas are:

1) Using computers, optimize fusion reactor designs within the constraints of physics and engineering. Beyond what humans can calculate, these optimized designs produce twisted doughnut shapes that are highly stable and can operate automatically for months on end. They are called "stellarators" in the fusion business.

2) Developing new high-temperature superconducting magnets that can be stronger and smaller than today's best. That will allow us to build smaller, and likely cheaper, fusion reactors.

3) Using liquid metal, rather than a solid, as the material surrounding the plasma. Liquid metals do not break, offering a possible solution to the immense challenge how a surrounding material might behave when it contacts the plasma.

4) Building systems that contain doughnut-shaped plasmas with no hole in the center, forming a plasma shaped almost like a sphere. Some of these approaches could also function with a weaker magnetic field. These "compact tori" and "low-field" approaches also offer the possibility of reduced size and cost.

Government-sponsored research programs around the world are at work on the elements of both components –

and will result in findings that benefit all approaches to fusion energy (as well as our understanding of plasmas in the cosmos and industry). In the past 10 to 15 years, privately funded companies have also joined the effort, particularly in search of compact tori and low-field breakthroughs. Progress is coming and it will bring abundant, clean, safe energy with it.

14. Fusion reactor that employs liquid metal shower

November 28, 2016

http://phys.org/news/2016-11-fusion-reactor-liquid-metal-shower.html

In a magnetic field confinement fusion reactor, we maintain the high-temperature plasma through the magnetic field lines by floating the plasma apart from a vessel. However, there forms inevitably a location where the plasma hits. In such a place, in order to receive the heat from the plasma a heat absorption device called the divertor is mounted. In current plasma experimental devices, including the Large Helical Device (LHD) at the National Institute for Fusion Science (NIFS), a solid divertor is typically used, where the plasma is guided to a plate or block composed of carbon or tungsten and those plates or blocks are cooled by water. In the International Thermonuclear Experimental Reactor (ITER), too, a solid divertor composed of tungsten blocks that will be cooled by water is being adopted.

The solid divertor, because it suffers wear from being struck by high temperature plasmas, requires frequent maintenance. At NIFS, the helical-type fusion reactor, for which design research is being advanced, has the special characteristic of good prospects for steady operation. Conversely, because the structure is three-dimensional and complicated, how divertor maintenance will be undertaken is becoming a difficult technological issue.

In the future fusion reactor, the quantity of heat that the divertor will receive will grow larger, and there is concern that the heat flux will surpass the ITER design value substantially, which is approximately 20 megawatts per one square meter. As a divertor that will bear this extremely high heat flux, methods using liquid metal have been proposed and considered for more than 40 years.

The idea has been to receive the high heat flux with the flow of melted lithium, tin, and other liquid metals. If the flow velocity can exceed several meters per second, then the divertor can withstand the fusion plasma's high heat flux. On the other hand, because particles that have been converted into neutral gas from a plasma stop on the divertor, the role of exhausting those gases to the outside is thus demanded. In particular, regarding the helical-type fusion reactor with its complicated structure, there had been no suggestion of the idea of a liquid metal divertor where high heat resistance and evacuation performance are compatible.

The research group of Professor Junichi Miyazawa, Professor Akio Sagara, and others, all of the National Institute for Fusion Science, constructed a new type of liquid metal shower divertor system that evacuates plasma as neutral gases before arriving at the vessel. They aimed a fine jet stream of liquid metal lined up in a shower condition at peripheral areas of the high-temperature plasma. They utilized tin, which is excellent for low vapor pressure and for being inexpensive, and also for safety.

In this new method, they placed the apparatus at intervals in just ten places inside the toroidal confinement device (see Figure 1). In this way, maintenance becomes much easier to perform. Conversely, the area which the plasma may contact decreases, and then the heat load is greatly increased. If we utilize high-speed liquid metal flow, then this will become a countermeasure.

Because high-temperature plasma moves along the magnetic field lines, in placing the liquid metal at a slant, a strong wall is formed through which the plasma cannot pass. (See Figure 2 to the left.) The plasma neutralized on the surface of the liquid metal shower passes through the interstices of the shower toward the rear face, and thus effective evacuation is possible. (See Figure 2 to the right.)

The liquid metal shower can bear an extremely large heat load that exceeds by approximately ten times the value tolerated by the recent ITER divertor. Even with such a high heat load, we have learned that if we use a liquid metal flow of 4 meters per second then the high heat load can be easily blocked. As shown in Figure 3, because there is the important characteristic in which when plasma touches the shower one time, it does not strike the vessel.

In the liquid metal shower divertor, a stable flow over a length of a few meters is necessary. The flow is accelerated by gravity, and when the diameter becomes thin the surface simultaneously becomes unstable, drips fall, and spray is generated. As a device that receives heat, this is not desirable. In order to suppress the

speed by the gravity, we inserted an object that would become resistance against the flow inside the liquid. In the internal resistance, we use wire and tape, or a chain. Which is best will vary depending upon the variety of the fluid and the desired flow speed. When there is internal resistance, because the high temperature area and the low temperature area will easily become agitated, we also anticipate the effect which lowers the highest temperature and suppresses the evaporation of the liquid metal.
In this new procedure, compared to procedures utilized to date which used carbon and other solids, together with heat-resistant performance growing by more than 10 times, it may be anticipated that high evacuation performance will also be achieved. Further, there are no restrictions against device longevity from wear caused by plasma, and device maintenance becomes easy. Because the helical fusion reactor has a complicated three-dimensional structure, it is believed that using liquid metal in the heat-receiving device will be problematic. But according to this research, it has been indicated that this will be possible.
These research results were presented at the 26th International Atomic Energy Agency conference held October 17-22 in Kyoto, Japan.
Regarding the divertor that is expected to bear the extreme high heat load in the fusion reactor, there had not yet been an answer. This research will provide a breakthrough regarding this difficult problem, and will be an important step toward achieving the future fusion reactor.
Regarding this research, we have developed a technology for stabilizing a flow that exceeds several meters. (The patent application is currently under review.) The liquid flow, such as drinking water that flows from taps and fire truck water, is a conventional phenomenon. But in the ways of using liquid flow many possibilities are hidden. In particular, in a stable and long flow of liquid, from the fields of agriculture and chemistry to the fields based on our lives such as the humidifier and interior decorations, there are a wide variety of applications. Even as a topic of academic research, water is captivating. If attention is drawn to the utility of liquid flow by this research, we may anticipate further activities in related research fields.

15. Japanese reactor resumes operation after periodic inspection

09 December 2016

Kyushu Electric Power Company yesterday began the process of restarting the reactor of unit 1 at its Sendai nuclear power plant in Japan's Kagoshima prefecture following a periodic inspection. The prefectural governor had opposed the restart of the unit, which resumed operation in August 2015 following a shutdown of the country's nuclear fleet.

http://www.world-nuclear-news.org/C-Japanese-reactor-resumes-operation-after-periodic-inspection-0912164.html

Sendai 1 was the first of Japan's idled reactors to be restarted after confirmation that it meets new safety standards introduced in mid-2013 following the March 2011 accident at the Fukushima Daiichi plant. Unit 1 was restarted August 2015, followed by Sendai 2 last October. Sendai 1 was taken offline on 6 October for a routine outage.

Kyushu began the operation to extract the control rods from the reactor's core at 9.30pm yesterday, allowing the fission process to begin, the Japan Atomic Industrial Forum (JAIF) reported today.

The utility said in a 7 December statement it expected Sendai 1 to achieve criticality - a controlled self-sustaining nuclear fission chain reaction - today and that power generation would resume on 11 December. Kyushu will then gradually increase output from the unit, with normal operation scheduled to be resumed in early January.

It is the first unit to undergo a periodic inspection following its restart after meeting new regulatory standards, JAIF noted.

Satoshi Mitazono, the recently-elected governor of Kagoshima prefecture, made a request on 26 August that the operation of the two Sendai units be suspended immediately for safety checks. However, Kyushu rejected this request in early September, saying it would carry out additional safety checks during planned routine outages. The governor repeated his request, but Kyushu again rejected it. Mitazono conceded in October he does not actually have the authority to tell Kyushu to keep Sendai 1 offline.

Sendai 2 is scheduled to be taken offline for a periodic inspection, together with additional safety checks, on 16 December.

To date, five Japanese reactors have been given final approval to restart, although two of these - units 3 and 4 of Kansai Electric Power Company's Takahama plant - have remained offline due to a legal challenge. Another 20 reactors are moving through the restart process, which has been prioritised to bring on the most-needed reactors first, in the localities and prefectures more supportive of restart.

Researched and written
by World Nuclear News

16. Small reactors for heat and power

in Russia

12 December 2016

Four Russian cities have expressed an interest in using small reactors to supply heat and power, according to Yuriy Kuznetsov of NA Dollezhal Research and Development Institute of Power Engineering (NIKIET). A Rosatom feasibility study has concluded that up to 38 cogeneration reactors could potentially be deployed at 14 sites for this purpose.

http://www.world-nuclear-news.org/NN-Small-reactors-for-heat-and-power-in-Russia-1212161.html

In many Russian cities district heating is a common feature that sees a local power plant supply up to around 250 MWe to the grid, as well as process heat to a communal system to warm homes, schools, factories and offices. These systems have traditionally relied on fossil fuels but will need to change in line with incoming goals to gain in efficiency and to decarbonise, as set out by a Presidium of the State Council which specifically mentioned nuclear as a potential technology.

In response, NIKIET has completed the detailed design of the VK-300 reactor. The organisation's chief researcher, Yuriy Kuznetsov, spoke to Rosatom's *11th International Public Forum Dialogue* in Moscow on 29 December.

VK-300 is a boiling water model with 750 MW thermal capacity and 150-250 MW electric depending on the required mix of heat and power. It uses proven components, including similar fuel elements to the large established VVER pressurized water design. Kuznetsov said VK-300 features fully passive cooling and safety features and has no need for operator action in an emergency or for offsite electricity or water supply. VK-300 has two containments and the consequences of any accident should not extend beyond the site boundary, he said.

The design was originally developed with a view to deployment at the Siberian Chemical Combine, but the new directive to modernise district heating across the country has prompted a 'comprehensive feasibility study' on VK-300 deployment in 2020-2030, said Kuznetsov. The study was based on potential deployment at Arkhangelsk, although there is not a firm proposal to do so. Nevertheless, the study also found public support in Arkhangelsk to be over 50%. VK-300 systems were considered to have a rate of return 1.6 times higher than fossil systems when financed at a 5% discount rate.

NIKIET counted 14 towns it considered suitable for two, three or four VK-300 units adding up to 38 units in total: Arkhangelsk, Ishevsk, Ivanovo, Kazan, Khabarovsk, Komsomolsk-on-Amur, Kurgan, Murmansk, Perm, Tver, Ufa, Ulyanovsk, Vyatka and Yaroslavl. Furthermore, NIKIET was approached by

Arkhangelsk, Perm, Tver and Ulyanovsk, whose officials expressed an interest in using nuclear energy for their heat and power needs. The next step, said Kuznetsov, would be to set up a program to implement a pilot plant.

Researched and written
by World Nuclear News

17. Pakistan's Chashma 3 completes acceptance test

09 December 2016

Pakistan's fourth reactor - unit 3 of the Chashma nuclear power plant in Punjab province - has passed a preliminary acceptance test, supplier China National Nuclear Corporation (CNNC) has announced.

http://www.world-nuclear-news.org/NN-Pakistans-Chashma-3-completes-acceptance-test-0912165.html

Construction began on the Chinese-designed CNP-300 pressurised water reactor in March 2011. The unit achieved first criticality on 3 October and was connected to the grid on 15 October. The unit's output has since been gradually increased to 100%.

In a 7 December statement, CNNC said Chashma 3 completed a "100-hour reliability demonstration test" at 3.30am on 6 December, marking the end of acceptance tests for the unit. The reactor is expected to enter commercial operation before the end of this year.

Chashma 3 is one of two CNP-300 units being built at the site. Unit 4, which began construction nine months after unit 3, is currently undergoing commissioning and is expected to be connected to the grid during the first half of 2017.

The Chashma site - also referred to as Chasnupp - is already home to two Chinese-supplied 300 MWe PWRs: unit 1, in commercial operation since 2000, and unit 2, in commercial operation since 2011. Pakistan also has a 125 MWe Canadian-supplied pressurized heavy water reactor, Karachi unit 1, which has been in commercial operation since 1972.

Two 1161 MWe Chinese-supplied Hualong One plants are also planned at the Karachi site. A ground-breaking ceremony for Karachi 2 was held in August 2015, and the units are scheduled to enter service in 2021 and 2022.

Researched and written
by World Nuclear News