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Why did experts in nitrogen science, environmental assessments, and environmental policy convene in Paris earlier this year to chart the initial phases of a multiyear, global nitrogen assessment (GNA)? The explanation requires understanding the impact of a vital technology that accounts for billions of human lives, yet remains inexplicably absent from most lists of the important discoveries of the 20th century.

Near the dawn of the last century, German chemist Fritz Haber figured out how to turn a vast but unusable resource—dinitrogen gas in the atmosphere—into one critical for feeding an expanding population: reactive nitrogen in the form of ammonia. Before Haber's discovery, nitrogen for fertilizer or industry depended on earthbound reserves, such as animal manures, guano, and nitrogen-fixing legumes, that would soon prove insufficient to meet the demands of a growing world population. Initially, much of the interest in Haber's discovery had roots in darker goals: the use of reactive nitrogen in explosives. But by the mid-20th century, widespread application of Haber's discovery to produce synthetic fertilizers was a pillar of the Green Revolution, becoming one the most significant boons to human well-being in history (Erisman et al. 2008).

Yet the transformation of the global nitrogen cycle has come at a price, one that is growing daily. Today, humans are creating reactive nitrogen at a record pace, and moving it around the world as never before (Vitousek et al. 1997, Galloway et al. 2008). Of course, much of it still helps grow food, but far too much of the reactive nitrogen that is produced for fertilizer and as a by-product of industrial activities does not end up on the dinner table. Instead, it cascades through major parts of our environment, including terrestrial ecosystems, air, freshwater, and even remote portions of the open ocean. Once in the environment, that nitrogen can cause a suite of environmental and health problems such as air pollution, climate change, coastal dead zones, and losses of biodiversity (Vitousek et al. 1997).

Those problems present an increasingly difficult and pressing set of tradeoffs. We are awash in reactive nitrogen as never before. To be sure, some of it—for example, nitrogen created during fossil fuel combustion—is an unwanted waste product, and could, in theory, be eliminated. But the majority is an input required for modern agriculture, and a transition to food-production systems that do not require human-created nitrogen is neither practical nor desirable. The challenge, then, becomes one of maintaining the benefits of nitrogen to society while minimizing the collateral damage.

Of late, nitrogen-related trade-offs are also emerging in the energy sector as a result of the rapid expansion of the biofuel industry. Proponents of biofuels often argue that they are a path toward energy independence and sustainability, as well as a way to reduce the contribution of energy-generation to climate change. As it does with food crops, the use of synthetic fertilizers can increase biofuel production per square kilometer—including production of the now widespread corn-based ethanol (in 2007, one-quarter of the US corn crop was used for ethanol). But corn, be it for food or fuel, is a nitrogen-intensive and nitrogen-leaky crop, and the fertilizers put on fields contribute not only to air and water pollution but also to climate change through emissions of nitrous oxide (N_2O) to the atmosphere. What is more, fertilizer production requires energy and thus adds to the atmospheric carbon-dioxide burden. Recent studies suggest that increased N_2O emissions from ethanol production—a consequence of high-nitrogen fertilizer use—may make the global warming potential of a gallon of corn-based ethanol worse than that of gasoline (Howarth et al. 2009).

Regrettably, the consequences of biofuel production for the nitrogen cycle are not restricted to the corn-based ethanol sector. Although ethanol from sugarcane and biodiesel from rapeseed typically do not have the high fertilizer demands that corn does (though inputs of phosphorus fertilizer can be significant and problematic), here too increased N_2O emissions appear to diminish any climate benefits that these crops might provide. Moreover, the concerns can extend beyond fertilizer: Brazilian ecologist Luiz Martinelli has shown that the common practice of burning sugarcane at harvest causes substantial air pollution, much of it consisting of nitrogen oxides produced during combustion of the sugarcane residues.

Because of such environmental and public health threats, society must do a better job of managing the global nitrogen cycle.

Fortunately, if many of the most pressing issues are addressed correctly and soon, there is marked room for improvement. In part, the challenge is about optimizing the distribution and use of a resource all people need. Today, some countries are nitrogen gluttons, using far more than enough to feed their citizens (with consequent public health problems from overconsumption). Others, such as those in sub-Saharan Africa, battle malnutrition that more fertilizer use could ameliorate (Sanchez 2002).

The challenge is also about efficiency: By targeting key points in the creation, transport, and use of reactive nitrogen, its benefits can be enhanced while the problems it gives rise to can be reduced. Opportunities for targeted management abound—for example, reactive nitrogen from waste gases produced during fossil-fuel combustion and from sewage can be removed. This is possible using current technologies. The opportunities also include improved efficiency of nutrient use in agriculture, which could be a win-win scenario: Multiple studies have now shown that this approach can be beneficial to both the environment and the financial bottom line (e.g., Matson et al. 1998).

And in part, the challenge is about redrawing boundary lines. Artificial accounting boundaries that do not capture the full effects of reactive nitrogen mask its true costs, and therefore prevent accurate assessments of the net benefits of a given use. When nitrogen, whether for agriculture or for industry, inevitably spills into nontarget arenas, those costs should be assessed and counted. Only then can scenarios for the most sustainable course of action be properly developed and implemented.

This is not to imply that a switch to more sustainable nitrogen use will come easily. There is no silver bullet. But many of the tools, ranging from technological solutions to policy instruments, already exist. In many cases, making those solutions a reality is hindered not by the lack of an option but by a lack of political will and an understanding of the magnitude of the problems.

It is both the urgency of those problems and the potential for their solution that motivated the formation of the International Nitrogen Initiative (INI; *http://initrogen.org*). The INI, sponsored by the Scientific Council on Problems in the Environment and the International Geosphere-Biosphere Program, comprises networks of scientists around the globe who are committed to furthering our understanding of a changing nitrogen cycle and communicating its importance to the world, as well as to helping solve the problems it is causing. Much like the case with climate change, achieving those goals requires a broadly interdisciplinary community of experts, ranging from research scientists, to land managers, to policymakers, to members of the private sector.

The INI is forging such collaborations in several ways—for example, through its new efforts to launch a GNA. Though a successful GNA will be a substantial undertaking (and is additionally challenged by the need to consider the changing cycles of nitrogen and phosphorus jointly [Vitousek et al. 2009]), modern society faces increasingly pressing questions about managing reactive nitrogen. Making wise decisions requires information on the nature, extent, and pace of change in the nitrogen cycle; the threats such change may bring; and the options for mitigating them. A GNA makes that information more readily available to decisionmakers worldwide. Similarly, the INI is stressing the important but complicated role of reactive nitrogen in climate change. We are therefore forging new partnerships with the Intergovernmental Panel on Climate Change (*www.ipcc.ch*), which is now working on its fifth assessment report. Our aim is to better quantify the ways in which a changing nitrogen cycle affects our climate. As members of the current INI Steering Committee, we invite anyone interested to join in our efforts.

No single group will solve the problems of nitrogen or capitalize on all its opportunities. But whether through the INI or other channels, more attention must be paid to an ever-accelerating nitrogen cycle and its burdens. The scale and pace of change are startling and worrisome: In only two generations, humans have become the dominant influence on global nitrogen cycling, and no slowdown is in sight. New approaches are urgently needed—indeed, they are fundamental to society's struggle to achieve environmental sustainability.

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References cited

Erisman JW, Sutton MA, Galloway J, Klimont Z, Winiwarter W. 2008. How a century of ammonia synthesis changed the world. Nature Geoscience 1: 636–639.

Galloway JN, Townsend AR, Erisman JW, Bekunda M, Cai ZC, Freney JR, Martinelli LA, Seitzinger SP, Sutton MA. 2008. Transformation of the nitrogen cycle: Recent trends, questions, and potential solutions. Science 320: 889–892.

Howarth RW, Bringezu S, Bekunda M, de Fraiture C, Maene L, Martinelli L, Sala O. 2009. Rapid assessment on biofuels and the environment: Overview and key findings. In Howarth RW, Bringezu S, eds. Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment; 22–25 September 2008, Gummersbach, Germany.

Matson PA, Parton WJ, Power AG, Swift MJ. 1998. Agricultural intensification and ecosystem properties. Science 277: 504–509.

Sanchez P. 2002. Soil fertility and hunger in Africa. Science 295: 2019–2020.

Vitousek PM, Aber JD, Howarth RW, Likens GE, Matson PA, Schindler DW, Schlesinger WH, Tilman GD. 1997. Human alteration of the global nitrogen cycle: Sources and consequences. Ecological Applications 7: 737–750.

Vitousek PM, et al. 2009. Nutrient imbalances along trajectories of agricultural development. Science 324: 1519–1520.

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