5
Integrated Risk Reduction Strategies for Nr

5.1. Importance of Integrated Risk Reduction Strategies

Chapters 3 and 4 of this report presented the environmental impacts and metrics associated with the emission of the various forms of Nr and reviewed ways of organizing these into impact "categories." As noted, Nr has many impacts on the environment, impacts that are interrelated through the nitrogen cascade. As previously stated, the nature of reactive nitrogen demands an integrated approach within EPA and across other relevant federal agencies, as reactive nitrogen cycles through the environment in different forms. A number of risk reduction approaches and the importance of considering Nr control points in the nitrogen cascade are discussed below.

5.2. Control Strategies for Nr

There are several ways in which the release and control of Nr in the environment can be approached. In general these can be classified as follows:

1. Improved practices and conservation – in which the flux of Nr that creates an impact is lowered through better management practices, including those that preserve or enhance Nr controlling ecosystem services (e.g., on-field agricultural practices, controlled combustion conditions, ecosystem function preservation and management)
2. Product substitution – in which a product is developed or promoted which has a lower dependency on or releases less Nr (e.g., N-bearing wastes instead of corn grain as a feedstock for biofuels, development of alternative power sources such as wind and solar)
3. Transformation – in which one form of nitrogen is converted to another form (e.g., nitrification of wastewater, denitrification in engineered or natural systems)
4. Source limitation – in which the amount of Nr introduced into the environment is lowered through preventive measures (e.g., controls on NO_x generation)
5. Removal – in which Nr is sequestered from impacting a particular resource (e.g., ion exchange)
6. Improved use or reuse efficiency – in which the efficiency of production that is dependent on Nr is improved (e.g., increased grain yields for lower Nr applied), or Nr wasted from one source is reused in another (e.g., algal farming)

Effective management of Nr requires combinations of these approaches; none is a perfect alternative for controlling Nr in the environment. Table 14 provides a summary of the pros and cons of each of these approaches.

5.3. Management Strategies for Nr in the Environment

Four types of management strategies for the control of Nr, and other pollutants, in the environment have evolved over the past 40 years:

1. Command-and-control – in which an entity's discharge of pollutants is regulated through a series of permitted limitations on emissions, violations of which may result in penalties being assessed
2. Government-based programs for effecting a policy, such as directed taxes, price supports for a given commodity, subsidies to bring about a particular end, and grants for capital expansion or improvement
3. Market-based instruments for pollution control in which market trading schemes are used to bring about a desired policy end, often at reduced overall cost.
4. Voluntary programs in which desired ends are achieved using private or government-initiated agreements or through outreach and education.

5.3.1. Command-and-control[19]

Policy makers have traditionally used command-and-control strategies requiring individuals and dischargers to meet mandatory guidelines. Such an approach evolved as the country was gearing up to meet the requirements first established nationally through the CWA and CAA enabling legislation in the 1970s. Because U.S. capabilities to monitor contaminant concentrations and predict environmental impacts were, generally, rudimentary, early emphasis was placed on "technology-based" approaches for managing emissions. This resulted in the promulgation of "best practicable technology" controls, and eventually "best available technology" controls, the idea being that mandating some level of control, even with uncertain improvements on impacts, would be better, and less arbitrary, than other approaches of the time.

[19] Based on *Models in Environmental Regulatory Decision-Making,* National Research Council, 2007.

Table 14 : Advantages and limitations of various approaches to Nr control in forestry and agriculture

Control strategy	Advantages	Limitations
Improved practices, conservation	Lessens one or more impacts; utilization of existing ecosystem services	Education cost; availability and cost of preserved lands
Product substitution	Lessens the need for Nr, allows for more targeted uses of Nr	Questions of acceptability, technological issues
Transformation	Reduces one or more impacts to which Nr contributes, for denitrification closes the nitrogen cycle; utilizes natural biogeochemical processes that may be available ecosystem services	May contribute to other impacts; human presence has modified and diminished ecosystem service values
Source limitation	Reduces one or more impacts to which Nr contributes	Decreased crop yields, in some cases few viable alternatives yet developed
Removal	Reduces one or more impacts to which Nr contributes; natural land features/processes and ecosystem services may be used	Residuals containing Nr must still be managed effectively; availability, location and cost of land for natural or enhanced Nr removal
Improved efficiency	Reduces the need for Nr	Research and education costs

Nevertheless, both the CWA and the CAA had more specific goals that were aimed at protecting human health, public welfare, and ecosystem health. For example, the CAA required states to develop implementation plans (SIPs), the approval of which depended on their ability, once implemented, to meet ambient clean air standards. Likewise, the CWA required greater controls to be implemented for certain water bodies for which technology-based limits alone were insufficient to meet standards (this became the TMDL program).

Over time, and as our abilities to monitor, predict, and understand impacts improved, it became possible, or at least plausible, to tailor emission levels on a source-by-source basis, allowing the firm in question to decide its own technological approach. Thus permits, which place strict limits on the amount of pollution a firm is allowed to discharge over a specified period of time, have become the main method for managing the majority of point source contaminants, including the various forms of Nr, in the environment.

While the CWA has had considerable success in controlling point source discharges, it has been largely unsuccessful in limiting nonpoint discharges, and it is these sources that are particularly important for managing nutrient flows into receiving waters. The National Research Council has addressed this deficiency and pointed to the need to fully implement TMDL plans and establish numerical nutrient standards for nutrients (National Research Council, 2008b, 2009).

5.3.2. Government Taxes and Subsidies to Achieve Policy Ends

Government taxes and subsidies have created a variety of results, some in conflict with and some to further the ends of Nr management. Examples include U.S. agricultural and land-use policies, energy and transportation policies, and both point and nonpoint source mandated controls on N-bearing aquatic resources, including domestic and industrial wastewaters and agricultural runoff.

Current and future energy policy with respect to vehicle efficiency and biofuels will help determine the amount of Nr released into the environment from these sources. Some states have chosen to place modest taxes on fertilizer containing Nr, though the demand impact is slight at best. However, revenues may be dedicated to improved Nr utilization efficiency. Crop subsidies and crop insurance may at times expand land use and even encourage increased use of fertilizers, effectively increasing Nr in the environment. There are various agricultural conservation programs in the U.S. administered by the USDA. These include the Conservation Reserve Program and the Wetland Reserve Program (CRP and WRP). The former takes less suitable land out of cultivation and the latter encourages wetland protection and restoration. Both can contribute to better Nr management. The Environmental Quality Incentives Program (EQIP) directly subsidizes nutrient management efforts by crop and livestock producers. Of concern to the Committee is the need for more effective approaches aimed at encouraging farmers and land managers to adopt proven conservation and Nr management practices in fields and feedlots. The extent of proven practices, such as variable rate fertilizer application and installation of stream buffers, fall far below today's technological frontier.

5.3.3. Market-Based Instruments for Pollution Control[20]

A fundamental shift in environmental management philosophy was initiated with the 1990 Clean Air Act Amendments, which combined regulatory requirements with market flexibility allowing lower compliance costs through tradable credits. Most market-based policy instruments operate on the principle that if the regulatory framework or some other factor sufficiently alters the relative value of available decision choices for an individual or firm, subsequent decisions they make will be in alignment with the policy makers' objective.

As an example, if a government wants to limit pollution in a river where a number of polluters discharge, it need not adopt a uniform command and control limit on each discharger. Instead, a regulatory cap on the total pollutant loadings can be established and individual permit limits can be issued to all dischargers, with provisions that allow the dischargers to trade between their individual limits as long as the overall cap is not exceeded. Those dischargers having low pollution control costs will have incentive to control more pollution than their permit limit and thus generate water quality credits that can be sold to dischargers with high costs of pollution control. Because the overall cap on the pollutant is fixed, the regulatory goal is achieved. Water quality trading thus brings about the desired reduction in pollution level at lower cost than if all dischargers were required to use traditional onsite treatment technology. Water quality trading also encourages cost-effective pollution control investment by giving each firm a clear economic signal to invest in new technology to reduce pollution at a level that corresponds to the market value of the permit.

As with control strategies for Nr, there is no one universal market-based strategy that is applicable to every policy maker's objective. For example, the nature of incentives available to and effective with producers involved in over-fishing is different from landowners providing environmental amenities. In the former case, the objective is to restrict the intensity of fishing. In the latter case the objective is to encourage private landowners to provide environmental goods and services at the lowest cost possible.

Evolution of new market-based strategies is a continuous process. Most strategies have been customized over time to meet local needs. One can group such market based approaches under the following conceptual headings:

1. Water Quality Tradable Credits – Every polluting entity is allowed to discharge pollutants up to a certain pre-determined limit, defined in concordance with the terms of the CWA. The entities discharging less than their allocated limit generate credits. Under this strategy, credits can be traded with other polluting entities that have exceeded their allocated limit provided that water quality standards are not exceeded.
2. Auction-Based Contracting – Environmental or conservation contracts are auctioned, where individual landowners place their bids to provide such goods or services from their land. Two factors jointly determine the selection of the bids: the amount of the bid and the expected value of the environmental or conservation benefit resulting from accepting the bid.
3. Individual Transferable Quotas – An individual transferable quota (ITQ) is an allocation privilege to extract a specified quantity of a resource among a selected number of quota holders. The distinctive feature of the ITQ is that the privilege is transferable or leasable. An ITQ may be a right to produce under favorable circumstances, such as a tobacco quota when tobacco production would normally be limited.
4. Risk Indemnification for Specified Behavior – An example of this is crop insurance designed to protect farmers from uncertainty in the adoption of best management practices that provide a public good but are inherently riskier.
5. Easements – Conservation easements or conservation servitudes refer to the case in which a landowner enters into a legally binding agreement to surrender certain property rights for a specified period of time, either voluntarily or for compensation. Such arrangements usually provide public goods relative to the environment or conservation.

Policy maker objective, local conditions, and several other factors determine the suitability of a particular market based strategy. For example, water quality trading is well suited where there are a variety of dischargers at different levels of contribution and with varying control costs. A policy framework that facilitates the emergence of multiple options for dischargers to meet their permit limits, such as buying from more efficient controllers of discharge or investing in new equipment to achieve further reductions, is likely to accomplish the desired level of water quality at the least possible cost to the economy. Table 15 illustrates the potential effective application of a number of market-based approaches in specific situations. Accompanying this chapter are two examples of the application of

[20] Based on Canchi, D., P. Bala and O. Doering, *Market Based Policy Instruments in Natural Resource Conservation,* Report for the Resource Economics and Social Sciences Division, NRCS, USDA, Washington D.C., March 3, 2006, pp. 4-9.

market-based approaches for the design of water quality trading schemes for Nr in watersheds (Box 4: Water Quality Trading to Meet the Long Island Sound Wasteload Allocation in Connecticut, and Appendix C: Water Quality Trading in the Illinois River Basin).

Table 15 shows pair-wise comparison between different market-based strategies. The objective and the incentive structure of the participants determine the suitability of one market based strategy over another. Each pair of cells briefly lists the most relevant set of conditions for which the respective strategy may be optimal (left cell points to strategy at the top of the column and right cell points to the strategy at the end of the row). Consider the two strategies (illustrated below): Auction-Based Contracting and Tradable Credit. If the participation of every private entity is essential, then Auction-Based Contracting works best. For example, if the objective is to preserve a large tract of privately owned contiguous land, Auction-Based Contracting is the appropriate strategy. This requires the participation of every private land owner to set aside a portion of their land. An auction designed to reveal the individual's land owner's reserve price for participation leads to the most efficient solution. A classic example of this is the Australian Government of Victoria's auction based Bush Tender program. Here it was essential to enlist blocks of land with particular hydrological and other characteristics to maximize the reduction in salinity and provide other environmental benefits. (Department of Sustainability and Environment, 2008). The goal was to bring about the reintroduction of native vegetation, its protection, and management where it would slow the development of salinity in soils. Offsets would not accomplish this, and as one looks at Table 15's characteristics of alternative approaches, neither would quotas, or insurance for BMPs. Easements might be used, but auctions were much more cost effective and more suited to the long term management commitment needed, as indicated in the second row of Table 15 under "Easements." Compared to this, if the objective is an overall reduction of a pollutant regardless of the individual private entity's contribution to the abatement, the Tradable Credit strategy with a cap is more appropriate. As another example, if aggregate depletion is of concern (as with fisheries) then individual transferable quotas are appropriate. However, auction-based contracting is preferable to individual quotas when no offsets exist.

Although there are significant differences between water and air quality trading, there are also several potential barriers to effective trading systems for both media. These are related to: accountability and monitoring; establishing standards and management goals; complexities of cross media and multiple source trading, including parity of sources; insurance that outcomes would reduce risk (environmental benefit); economics and marketability of traded credits; and transparency of the program, including public outreach and stakeholder involvement.

5.3.4. Biophysical and Technical Controls (control points) on Transfer and Transformations of Nr in and between Environmental Systems

Within the nitrogen cascade there are a number of places where the flow of Nr is constrained or regulated, either by nature or by human intervention, or a combination of the two. This report refers to these places in the cascade as "control" points. The control points may restrict the flow of Nr species within environmental systems (atmospheric, terrestrial, aquatic) or between them. The control points vary from primary controls where Nr is minimized through conservation measures or through after-the-fact measures that attempt to convert Nr that is emitted or not fully used to nonpolluting products (such as conversion to N_2 by denitrification or through long-term storage). The discussion of control points in this section is primarily focused on biophysical controls in terrestrial and aquatic environmental systems. However, the section concludes with a discussion of possibilities for decreasing NO_x emissions from combustion.

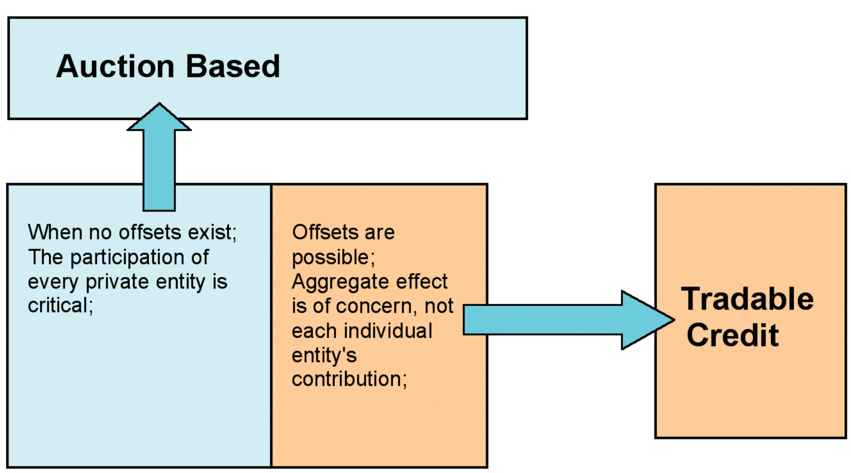

Table 15: Summary of market-based instruments for pollution control with conceptual examples

Auction Based Contracting		Individual Transferable Quotas		Insurance for the Adoption of BMPs		Easements		
When there exist no offsets; The participation of every private entity is critical;	Offsets are possible; Aggregate effect is of concern, not each individual entity's contribution;	When the depletion is of concern;	When the discharge is of concern;	Homogenous polluters; Offsets not feasible; Excessive pollution is primarily to mitigate uncertain profits; Modest short-term objective;	Not homogenous polluters; Offsets are possible; Pollution is an absolute consequence of the production process;	Unidirectional; When offsets are not possible; One entity retiring more property rights cannot trade with the other retiring less property rights.	Bidirectional; Offsets are possible; Requires specific action on the part of the participant to accomplish the objective;	**Tradable Credit**
		Aggregate depletion is of concern;	When there exist no offsets; The participation of every private entity is critical;	Tied to a production process; When risk averseness of the entity can be used to motivate participation;	Not tied to any production process; Suited for motivating participants to engage in secondary activities;	Auction based contracting can be seen as a refined and improved cost-efficient alternative to easements;	Designing of auction based contracting requires considerable professional expertise;	**Auction Based Contracting**
				Discharge of effluents is of concern;	Depletion of a resource is of concern;	Retirement of rights is of concern;	Acquisition of rights is of concern;	**Individual Transferable Quotas**
						No uncertainty; No action required on the part of the participant;	Tied to a production process:	**Insurance for the Adoption of BMPs**

Each pair of cells briefly lists the most relevant set of conditions for which the respective strategy may be optimal (left cell points to strategy at the top of the column and right cell points to the strategy at the end of the row).

Box 4: Water Quality Trading to Meet the Long Island Sound Wasteload Allocation in Connecticut

Pollutant trading is increasingly being promoted as a cost-effective means for attaining water quality standards. Connecticut and New York have been working with the EPA Long Island Sound Study (LISS) for more than 20 years to address low oxygen conditions (hypoxia) in Long Island Sound that have been linked to excessive loadings of nitrogen. A Total Maximum Daily Load (TMDL) for nitrogen, drafted by the two states and approved by the EPA in 2001, set a 58.5% nitrogen reduction target in 2014 from point and nonpoint source/stormwater sources. Connecticut has initiated a point source trading program for 79 municipal sewage treatment plants (STPs) to facilitate implementation of the TMDL wasteload allocation (WLA) and is investigating the potential for incorporating nonpoint source/stormwater into the existing Nitrogen Credit Exchange (NCE).

Several prerequisite conditions essential to the success of the current point source trading program have been met. Briefly, (1) all the STPs contribute to the same water quality problem; (2) the technology to remove N and meet the targets exists; (3) there are compelling member benefits to participate, especially cost savings; (4) sources can easily be monitored and tracked by end-of-pipe monitoring; (5) credit cost calculations are based on established and agreed upon protocols founded in state legislation; (6) sources of N are diverse and create viable supply and demand conditions while reducing overall cost, with close control by a Nitrogen Credit Advisory Board (NCAB); and (7) transaction costs are low relative to credit prices. In operation since 2002, the NCE has proven to be a viable and effective mechanism for meeting the nitrogen WLA.

The economic record of the NCE demonstrates the vigor of trading over the first five years of completed trades from 2002 to 2006 (Table 16). In sum, more than 10 million credits have been traded on the NCE, representing more than $22 million in economic activity.

The use of geographically-based trading ratios is instrumental to the relative cost of meeting N reduction limits at the 79 treatment plants, which are scattered throughout the state (Figure 21). Because N is reactive as it travels down rivers into the Sound, and the Sound's currents further affect relative impacts as they transport N and the resulting algal blooms to the hypoxic areas at varying efficiencies, location of each treatment plant makes a difference in relative impact on dissolved oxygen per pound of N discharged at end of pipe. Generally, the closer a POTW is to the edge of the Sound, and the closer to the hypoxic zone, the higher the trading ratio (Figure 22). For plants with high trading ratios, economics often favor treatment, while those with lower ratios may find the purchase of credits economically advantageous over treatment.

Table 16: Performance of the Nitrogen Credit Exchange

Trading Year	Credit Price (Dollars)	Purchased (Dollars)	Sold (Dollars)	Purchased (1000 Credits)	Sold (1000 Credits)
2002	$1.65	$1,317,223	$2,357,323	798	1,429
2003	$2.14	$2,116,875	$2,428,636	989	1,135
2004	$1.90	$1,786,736	$2,659,804	940	1,400
2005	$2.11	$2,467,757	$1,315,392	1,170	623
2006	$3.40	$3,828,114	$2,394,956	1,126	704
Total		$11,516,705	$11,156,111	5,023	5,291

Source: Connecticut Department of Environmental Protection, 2007

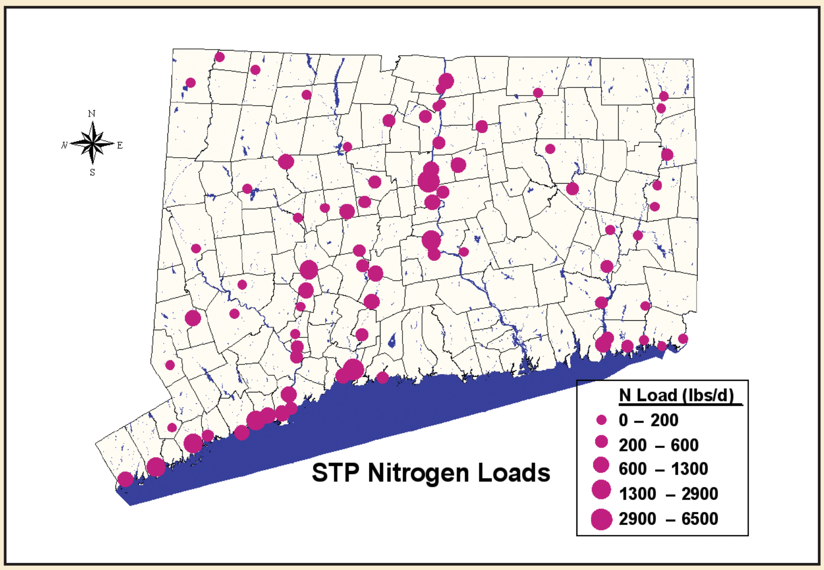

Figure 21: Relative nitrogen discharge (lbs/day) from 79 POTWs.

Source: Connecticut Department of Environmental Protection, 2007

The point source NCE does not reflect a free market approach to trading. Demand is set by the annual general permit limit and supply of credits is constrained by the availability of Clean Water Fund dollars and the timing and location of N removal projects. Credits are bought and sold from the state, thus the number of credits purchased does not need to match the number of credits sold (as would typically be true in a tradable permit system). Nevertheless, there is a tendency towards implementing cost effective projects as sewage treatment plant authorities decide whether it is less expensive to treat or buy credits, and try to predict when that break-even point might occur that would warrant application for project funding.

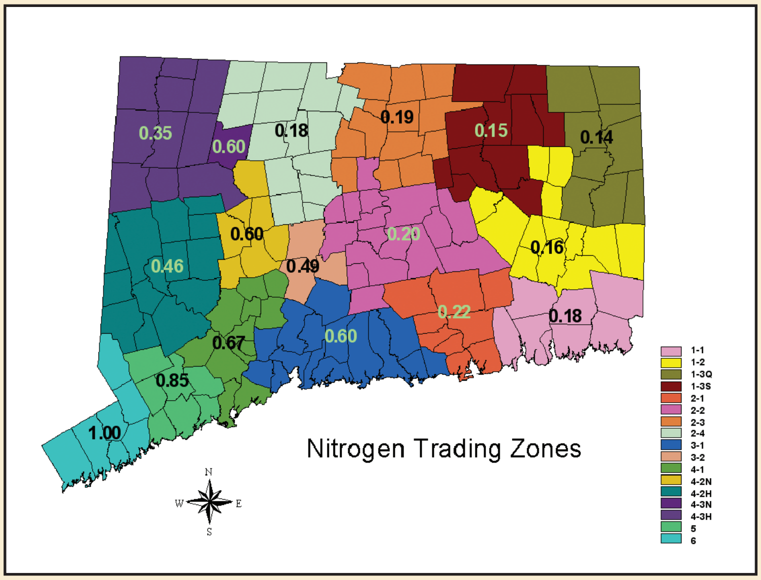

Figure 22: Trading ratios for municipalities in Connecticut.

Source: Connecticut Department of Environmental Protection, 2007

Incorporating a nonpoint source/stormwater (NPS/SW) component into the existing point source trading program presents some difficult challenges. Among the seven prerequisite conditions listed above that are well met by the current point source program, NPS/SW trading does not provide compelling economic benefits for members; NPS/SW N is difficult to quantify and track; credit cost estimation does not have a strong foundation in any existing programs; NPS/SW credit costs, though geographically diverse, may not result in significant implementation savings; and transaction costs (or time spent negotiating the ground rules for NPS/SW trading) may be considerably higher than for point source credits. Many of these obstacles can be overcome by deferring to models and textbook costs and efficiencies for NPS/SW BMPs. Tracking will still be a challenge because of the sheer number and distribution of BMPs that can be applied throughout the state.

Basic economic principles suggest that a free-market arrangement will not produce many NPS/SW credits for market. Costs are much higher than for point source credits and a regulatory approach must therefore be instituted to formalize the load allocation for nitrogen and to structure participation by municipalities.

If a NPS/SW trading component were to be added in the future, it would most likely also be an incentive-based program rather than a free-market approach. Nitrogen is difficult and costly to control in Connecticut's urban/suburban setting, and reductions are unlikely to be cost- competitive with POTW credits in a free market system. However, because municipalities are required to implement the Phase II stormwater permit, and various federal, state, and local programs require or emphasize NPS/SW management, there may be benefits for an incentive-based approach to offset some of those costs. For example, payment for NPS/SW reductions at the same credit prices paid to POTWs under the NCE would help defray costs and encourage additional nitrogen reductions from stormwater/NPS sources. Connecticut and the NCAB will continue to evaluate and explore the viability of these options.

Market approaches and trading can lower costs and increase economic efficiency of Nr control. The approaches may well have to be situation specific and depend on a structured regulatory framework to create the market or trading opportunity. As with the 1990 Amendments to the Clean Air Act, the design of market based instruments is a product of technical capability, regulatory design, and public preference. Implementation can be tedious but the benefits in efficiency substantial, even after being balanced against equity concerns. However, there can be something of a geographical and supply/demand mismatch between nonpoint sources and point sources that might be trading partners. Ribaudo and Nickerson identify only 142 of 710 eight-digit Hydrologic Watershed Units containing waters impaired by nitrogen where trading would be most likely (Ribaudo and Nickerson, 2009).

Further, the cost for management will be enormous. EPA's Clean Water Needs Survey (EPA, 2008b) has identified more than $200 billion in wastewater management infrastructure needs, and those needs do not fully address nutrient control from both traditional point and nonpoint/stormwater sources or consider alternative technologies.

Biophysical controls in terrestrial environmental systems

As indicated in Figure 2, approximately 36 Tg of new Nr is introduced into the U.S. each year. This new Nr is derived from sources that include consumption of ~11 Tg of synthetic N fertilizer, ~8 Tg of N that is fixed biologically by crops, and ~ 5 Tg that is emitted from fossil fuel combustion annually. This N is used to produce food and fiber (~15 Tg) or is formed during electrical generation, industrial production, or transportation. Efforts to decrease the creation of new Nr should first look to conservation.

Reduction in use of fossil fuel and/or decreased Nr emission can come through a variety of mechanisms such as more energy-efficient industrial processes, homes, and vehicles. Further gains are possible through conservation practices and alternatives to wasteful approaches, such as improving public transportation to minimize use of personal automobiles, and use of local products that do not require long-distance shipping.

Improvements in food and fiber production and changes in diet can also play an important role in limiting Nr. Because agriculture is the largest consumer and producer of Nr, consumption of fertilizer N could be decreased by changes in diet and increasing fertilizer N use efficiency in crop and fiber production systems. The control points discussed in this section include: protein consumption in the human diet; removing croplands that are highly susceptible to Nr loss from crop production; decreasing fertilizer N demand by increasing fertilizer use efficiency in crop and fiber production, as well as on residential and recreational turf grass; and better management of Nr in manure from livestock production in CAFOS.

Decreasing the amount of fertilizer N needed through changes in human diet

Along with increasing fertilizer N use, continued high intake of protein in developed countries and changes in the diet of people in developing countries will likely lead to greater N losses from global food production in the future. The first aspect of changes in food production concerns the increasing protein consumption that is occurring as global population increases and gets wealthier. This is likely to require increased N input into food production (Naylor et al., 2005; Galloway et al., 2007).

The average protein supply per person in developed countries is presently ~100 g per day, while in the developing countries it is only ~65 g per day (Food and Agricultural Organization Statistical Database (FAO FAOSTAT, 2010a). There is a direct proportionality between protein and nitrogen composition of food (ca 0.16 g N per 1 g protein). On average in 1995, developed countries consumed ~55% of total protein from animal sources while developing countries derived ~25% of total protein from animals. Protein consumption was highest in the U.S. and Western Europe, ~70 and ~60 g animal protein per person per day, respectively. In 2003, total protein consumption in the U.S. was 115 g per person per day (74 derived from animals and 41 from vegetable) (FAO FAOSTAT, 2010a). In developing countries, the greatest change in animal protein consumption has occurred in China where the consumption of meat products has increased 3.2 fold (from ~10 to ~32 g per person per day) since 1980. In Sub-Saharan Africa there has been no increase in either total (~50 g per person per day) or animal protein (~10 g per person per day) consumption during the past 30+ years (Mosier et al., 2002).

The reason for focusing on the consumption of animal protein is that more N is needed to produce a unit of animal protein than an equal amount of grain protein. Bleken et al. (2005) note that the N cost of animal production in Norway and the Netherlands was approximately five units of N in feeds for each unit of N produced. Approximately 2.5 units of N are required to produce a unit of wheat protein-N. Bequette et al. (2003) report that dairy cattle consume four units of N in feeds (including forage and grains) for every unit of N that appears in milk. Using a range of efficiencies for animal production practices, Kohn et al. (1997) estimated that 4 to 11 units of fertilizer N would be used in a whole farm system to produce a unit of milk protein. This ratio would be lower when using legume N to feed cattle, as is commonly done. Based upon the extra N required to produce animal protein compared to grains, continued high protein consumption in developed countries and changes to higher protein diets in developing countries will likely increase N input and losses in food production.

Moderating this increase by decreasing the average amount of total protein consumed in developed countries is one mechanism of limiting part of the expected increased N requirement in food production. One example of a country with a healthy diet and moderate consumption of animal protein is Italy in 1963. At that time, food supply was adequate to ensure sufficient nutrition to all groups of society (Bleken, 1997). Total protein consumption was 85 g per person per day, and consumption of animal protein was 32 g, roughly half of the current U.S. diet, and yet much higher than the average of developing countries. Another example is Japan, where animal protein consumption has traditionally been low, although it has increased from 25 g in 1963 to 54 g animal protein per person per day in 1995. In the same period the total protein consumption has increased from 73 g to 96 per person per day.

Bleken (1997) analyzed the relation between human diet and global N need for food production. Her analysis indicates that the total N needed for diets with high animal protein intake (comparable to many industrialized countries today) is almost twice as high as the N needed for the average diet in Italy 1963, or for Turkey in 1993. Based on her analysis, the Committee assumes that in the high-N input regions, per capita N need for food production may be reduced by 45%, which would reduce present-day N inputs by 15% worldwide.

Switching to a lower protein diet may not, however, reduce N losses if the new diet includes increased quantities of fruits, vegetables, and nuts, in addition to staple grains, beans and pulses. Vegetables, fruit, and nuts are high value crops that typically require large inputs of fertilizers and pesticides when produced at a large, commercial scale, and N fertilizer losses can be considerably larger than for grain crops. Having a very diverse diet that includes a wide range of high-value fruits and vegetables available year round (whether they are in-season locally or not) also has consequences for N inputs/outputs from agriculture – both within the U.S. and globally. EPA and USDA are encouraged to develop programs that stress how both human health and environmental health will improve with a greater focus on the human diet. It has been estimated that 30% – 40% of the food prepared for consumption in the U.S. is wasted (Kantor et al., 1997; Hall et al., 2009). Thus, additional Nr may be conserved by decreasing the amount of food that is wasted.

Removing croplands that are susceptible to Nr loss from crop production

An analysis of NO_3^- loading in the Mississippi River Basin (Booth and Campbell, 2007) provides estimates of N input from agricultural lands. Similar estimates were provided by Del Grosso et al. (2006). Recommendations in this analysis are essentially the same as those arrived at in the original national hypoxia assessment, which suggested that the most leaky lands be taken out of production (Doering et al. 1999). Booth and Campbell state:

> *Nitrogen derived from fertilizer runoff in the Mississippi River Basin (MRB) is acknowledged as a primary cause of hypoxia in the Gulf of Mexico. To identify the location and magnitude of nitrate runoff hotspots, and thus determine where increased conservation efforts may best improve water quality, we modeled the relationship between nitrogen inputs and spring nitrate loading in watersheds of the MRB. Fertilizer runoff was found to account for 59% of loading, atmospheric nitrate deposition for 17%, animal waste for 13%, and municipal waste for 11%. A nonlinear relationship between nitrate flux and fertilizer N inputs leads the model to identify a small but intensively cropped portion of the MRB as responsible for most agricultural nitrate runoff. Watersheds of the MRB with the highest rates of fertilizer runoff had the lowest amount of land enrolled in federal conservation programs. Our analysis suggests that scaling conservation effort in proportion to fertilizer use intensity could reduce agricultural nitrogen inputs to the Gulf of Mexico, and that the cost of doing so would be well within historic levels of federal funding for agriculture. Under this simple scenario, land enrolled in conservation programs would be increased by about 2.71 million hectares, a 29% increase over 2003 enrollments, while land taken out of traditional fertilized agriculture and enrolled in conservation programs would constitute about 3% of 2003 fertilized hectares.*

The Booth and Campbell approach places the leakiest intensively cropped lands into government programs like the Conservation Reserve Program – where they would be put into grass or cover crops. Doering et al. (1999) had a somewhat different approach. Under their analysis, nitrogen use or nitrogen loss reductions were imposed on agriculture, and the U.S. Agricultural Sector Mathematical Programming (USMP) model adjusted crop rotations, tillage practices and fertilizer inputs within the Mississippi Basin – meeting the given Nr constraint while maximizing producer and consumer welfare. The model favored those crops and cropping systems at different points in the landscape having low nitrogen leakage. Where the model could not find a crop production system having positive returns while meeting the Nr restrictions, the land was retired from production. This analysis suggests opportunities for maintaining land in agricultural production while still reducing Nr losses through better matching of land characteristics with crops and cropping systems.

This 1999 analysis of the Mississippi Basin was carried out in the context of cost effective approaches – starting with the most cost-effective (in terms of producer and consumer welfare) and moving to less cost-effective approaches as more and more nutrients were controlled. This included both restriction of fertilizer inputs, buffers, and wetland remediation as well as the land use changes and crop rotations referred to above. The suggestions presented by the Committee for Nr reductions that could be achieved from agriculture with existing technology are consistent with the cost effective approaches in the 1999 Hypoxia Assessment's economic analysis. Cost effectiveness and alternative cropping systems were considered in the SAB report, *Hypoxia in the Northern Gulf of Mexico: An Update by the EPA Science Advisory Board* (U.S. EPA SAB, 2007) but unfortunately as pieces from individual study examples rather than as an integrated approach like the 1999 Hypoxia Assessment (Doering et al., 1999).

Decreasing fertilizer N demand by increasing fertilizer use efficiency in crop and fiber production

The largest input of Nr in North America is N fertilizer used for crop production. The mean annual N fertilizer input to North America between 1999 and 2003 was 12.5 Tg. Of this fertilizer N, 66% was used to fertilize cereal crops, mainly corn and wheat (Dobermann and Cassman, 2005).

As previously discussed, corn yield in the U.S. has increased (from an average of 100 bushels per acre in 1985 to 136 bushels per acre in 2005) as a result of improved nutrient and pest management, expansion of irrigated area, conservation tillage, soil testing, and improved crop genetics (yield and pest resistance) (Council for Agricultural Science and Technology [CAST], 2006). From 1980 to 2000, N-fertilizer use efficiency (NFUE, kg grain produced per kg applied N, or kg grain / kg N) increased from 42 to 57 kg grain / kg N, a 35% efficiency gain during a period when average U.S. corn yields increased by 40% (Fixen and West, 2002). Despite this steady increase in NFUE, the average N fertilizer uptake efficiency for corn in the north-central U.S. was 37% of applied N in 2000 based on direct field measurements (Cassman et al. 2002). These results indicate that greater than 50% of applied N fertilizer is vulnerable to loss pathways such as volatilization, denitrification, runoff, and leaching. The results also suggest there is substantial room for improvement in N efficiency currently achieved by farmers. Although progress has been made to increase both cereal yield and NFUE, a concerted effort to further increase NFUE remains a logical control point to reduce production costs, because N fertilizer represents a significant input cost, and to limit Nr leakage (e.g., NH_3, NO_x, N_2O, NO_3^-) from agroecosystems.

The goal of reducing Nr while sustaining adequate rates of gain in cereal production to meet expected food demand will require increases in NFUE, which in turn will require innovative crop and soil management practices. This need is exacerbated by the recent increase in demand for corn to produce ethanol biofuel. The concept of improved N synchrony (practices that better match the amount, timing, and geospatial location of applied N to crop-N demand and the N supply from indigenous soil resources) is generally viewed as the most appropriate approach for improving NFUE (e.g., Appel, 1994; Cassman et al., 2002). The challenge is to attain greater synchrony between crop N demand and the N supply from *all sources* (e.g., soil, fertilizer, organic inputs such as manure, compost, or green manures) throughout the growing season. Losses from all N-loss mechanisms increase in proportion to the amount of available N present in the soil profile at any given time.

Several promising technologies and combinations of technologies have emerged in recent years. Significant increases in NFUE are often achieved through reducing N fertilizer use by 10 to 30%, while still maintaining or even slightly increasing yields (Giller et al. 2004). Figure 23 indicates where the greatest gains in NFUE are expected to be realized from investments in different technology options. Improvements in crop and soil management practices will contribute to higher NFUE by achieving greater congruence in timing of the supply of applied N with crop-N demand and the N supply from

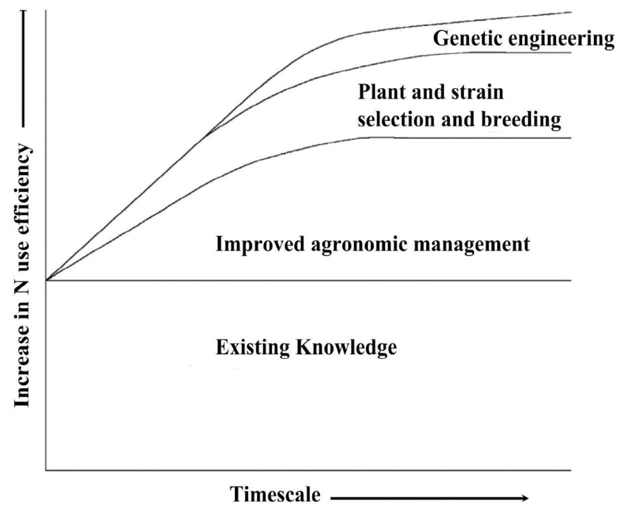

Figure 23: The likely impact of research investment in increasing N fertilizer use efficiency

Source: Giller et al., 2004 (Figure 3.2, p. 48). Reprinted with permission from Island Press; copyright 2004, SCOPE.

indigenous soil resources. While there is relatively small scope for specific biotechnology traits to improve NFUE, overall improvement in crop genetics from commercial breeding efforts that focus on increasing yield and yield stability will continue to play a significant role in improving overall NFUE. However, large investments in research, extension education, and technology transfer will be required, and significant incentives must be implemented, to achieve the degree of improved synchrony needed to make substantial improvements in NFUE. The need to accelerate the rate of gain in crop yields to meet increasing demand for human food, livestock feed, and biofuels represents an additional new challenge. Crop prices are expected to rise as they more closely track the price of petroleum (Council for Agricultural Science and Technology, 2006). Higher crop prices will motivate farmers to achieve higher yields, and higher crop yields require a greater amount of N uptake to support increased biomass production (Greenwood et al., 1990). Therefore, an explicit emphasis on developing technologies that contribute to both increasing yields and NFUE will be needed to ensure that the goals of food security, biofuel production, and protection of environmental quality are met.

Alternatives to current urban landscaping practices

Section 2.2.4 discussed the use of turf grasses as a prominent feature in U.S. urban landscapes with over 1 TgN used to fertilize lawns each year (Table 9). New developments are most amenable to landscaping practices that may minimize the need to use supplemental fertilizer. These practices include preservation of the natural soil profile, use of turf types that require little or no fertilizer, minimizing turf areas, using organic maintenance techniques, and choosing alternatives to lawns and exotic plant species such as naturalistic landscaping. Many of these practices are part of a low impact development philosophy, which can also combine other best management practices to mitigate the effects of impervious cover and landscape changes. Existing development is also amenable to many of these practices, especially conversion of typical residential and commercial lawns to natural landscapes and retrofitting other BMPs that promote infiltration, such as rain gardens.

Structural and non-structural Best Management Practices (BMP) to treat runoff

There are probably hundreds, if not thousands, of BMPs that have been designed and manufactured to treat runoff from both urban and agricultural lands. Whether applied to new development or existing agricultural or urban land use, most follow basic principles that simulate natural land features and processes that remove pollutants from runoff. They promote infiltration to take advantage of the cleansing value of passage through soils and to reduce runoff volumes, and provide for biological or chemical conditions that help remove pollutants (NRC, 2008b, 2009).

The most notable of the processes for managing Nr is providing conditions that are adequate to denitrify Nr in the waste-stream in a process called biological nitrogen removal (BNR). BNR simply creates conditions that convert initial forms of nitrogen to nitrate via oxidation, and convert nitrate to dinitrogen gas by providing conditions (especially high carbon and low oxygen) where the denitrification process can occur. These simulate natural conditions such as nitrification that occurs in oxic soils as water-borne nitrogen infiltrates into the soils and groundwater, and denitrification that occurs in highly-organic, saturated soils such as in wetlands where oxygen is low.

Most BMPs are considered structural, and may be highly engineered "package" plants that can treat sewage or runoff, depending on scale and structure, or simple detention basins that allow sediments and adhered pollutants to settle out. "Artificial" wetlands are a good example of a more sophisticated BMP that takes advantage of natural processes, and may be created at the end of the stormwater pipe, or at edge of field. Structural BMPs are an important part of any strategy to limit reactive nitrogen loss to the environment. For example, The State of Iowa contains some of the most productive agricultural land in the world. Of the 36 million acres of land, 23 million acres are planted in corn or soybeans. Approximately 39 percent of the corn/soybean acres are drained with an estimated 800,000 miles of tile (Cutler, 2000). Each year, thousands of miles of new or replacement tile are installed. This drainage network is responsible for the conveyance of 90 percent (Crampton et al., 2006) of the nitrate that appears in Iowa's surface waters. Control of nitrogen discharge from drainage tile will be needed to limit reactive nitrogen loss to the environment from agriculture.

Various approaches have been proposed with varying degrees of success. Constructed wetland, bio-reactors, and drainage tile encapsulated with biomass have proven to reduce 90 percent of the reactive nitrogen loss to the environment (Blowes et al., 1994). It would seem reasonable to require any new or replacement drainage tile to implement a control strategy at the time of construction and a retrofit program for the remaining drainage systems. With an average of two years to pay back the cost of drainage systems due to increased crop yield, the added cost for nitrogen control does not seem to be unreasonable.

Non-structural BMPs are often preservation actions, as discussed earlier, or activities that prevent pollutants from entering the waste stream such as street sweeping or fertilizer limitation.

Engineered and restored wetlands to decrease NO_3^- loading of aquatic systems

The construction and/or restoration of wetlands have received considerable attention in the past two decades as a conservation method. Such an approach has several positive attributes including promoting denitrification in watersheds containing or receiving Nr, flood protection, habitat preservation, and recreational potential (Hey and Philippi, 1995). In the upper Mississippi basin optimum siting of wetlands could result in as much as 0.4Tg of NO_3^- converted to N_2 (Mitsch et al., 1999, 2001; Hey, 2002).

Much of the nitrate leached from agricultural fields could be removed from drainage water in natural, created, or restored wetlands. Nitrate removal from the water column in wetlands is performed by plant uptake, sequestration in the soils, and microbial transformation that includes immobilization and denitrification. Plant uptake and microbiological immobilization result in temporary storages in the system since most nitrogen will eventually return to the wetland via plant death and decomposition. In contrast, denitrification can constitute a real nitrogen sink because NO_3^- is converted mainly to N_2 that is emitted to the atmosphere (Clement et al., 2002). As discussed in Section 4.7, the potential for the formation of N_2O is of concern if such systems are not operated properly.

In addition to preserving existing wetlands, there are two other basic approaches that utilize wetlands to reduce the Nr and other nutrients reaching rivers, streams, and vulnerable downstream coastal systems. These approaches are: 1) creation and restoration of ecosystems, principally wetlands and riparian forests, between farms and adjacent ditches, streams and rivers; and 2) diversion of rivers into adjacent constructed and restored wetlands all along the river courses (Mitsch and Jorgensen, 2004; Mitsch and Gosselink, 2007).

The Committee notes that if wetlands can be economically and effectively restored where croplands now exist on hydric soils within the 100-year floodplain, this may be an important NO_3^- control mechanism. Cropland on hydric soil in the floodplain occupy about 6.9 million acres (2.8 million hectares). If this area and its wetlands were given back to the Mississippi River, over a million tons of NO_3^- -N would be annually removed or prevented from reaching the Gulf of Mexico (Mitsch et al., 1999; Hey, 2002; Hey et al., 2004). To give scale to the solution needed, restoration of over 4.9 million acres (2 million hectares) of wetlands is needed in the Mississippi-Ohio-Missouri (MOM) river basin to reduce the nitrogen load to the Gulf of Mexico sufficiently to ensure a reduction in the size of the hypoxic zone in the Gulf of Mexico (Mitsch et al., 2001).

At a series of workshops on restoration of the MOM river basin in 2003-2004 (Day et al., 2005; Mitsch and Day, 2006), scientists and managers were asked to focus on needed research and chokepoint opportunities for managing N in that basin. They concluded that a major, interdisciplinary research program (as a lead-in to the actual restoration of wetlands and rivers) was needed, with sufficient funding, study sites, and time to reduce remaining uncertainties about the efficacy of wetlands to solve pollution problems related to N. It was recommended that, to implement this program, 20 to 30 full-scale, existing and new agricultural/wetland demonstration projects should be located throughout the country and instrumented to study agricultural runoff into wetlands in a variety of soil conditions. Pilot and full-scale studies of diversions into riparian systems along river channels were recommended in order to determine the effectiveness of these systems for nutrient removal. The Committee notes that these research and demonstration projects have not been undertaken, and that there is a continuing need for this work.

Further illustration of the use of wetlands as a tool for Nr management tool is presented in Appendix C, Water Quality Trading in the Illinois River Basin (D. Hey, personal communication).

Technical controls (control points) on transfer and transformation of atmospheric emissions of Nr in and between environmental systems: NH_3

Newly fixed Nr is produced biologically or added as fertilizer to meet the demand for food and fiber production. Much of the N is used in cereal crop production and cereal crops are then used to feed livestock. The new Nr is then recycled through the livestock production system where it becomes again susceptible to losses to the atmosphere as ammonia and NO_x, and is available for additional N_2O production and movement into aquatic systems as NH_4^+ and NO_3^-.

The bulk of the N fed to livestock ends up in manure, and where this manure (approximately one-half in urine and one-half in feces) is produced, there is often a much greater supply than can be efficiently or economically used as fertilizer on crops. For large concentrated animal feeding operations there is considerable expense associated with disposal of the manure. Various storage systems have been developed to deal with this excess manure, the most interesting of which, from the standpoint of integrated policy on N, convert the urea to N_2. The fraction of manure N that can be and is converted to N_2 remains a major unanswered scientific or technical question.

The NRC (2003) noted the paucity of credible data on the effects of mitigation technology on rates and fates of air emissions from CAFOs. The report did, however, call for the immediate implementation of existing atmospheric emission technology. The NRC (2003) also called for a mass balance approach in which the losses of N species such as NH_3, NO, N_2, and N_2O are expressed as a fraction of the total N loss. Quoting from the NRC report:

> *Storage covers for slurry storage tanks, anaerobic lagoons, and earthen slurry pits are being studied as a method to decrease emissions from those containments. Both permeable and impermeable covers are being studied. Tested covers range from inexpensive material such as chopped straw (on slurry containments only) to more expensive materials such as high density polyethylene. Covers can decrease emissions from storage but their net effect on emissions from the system is conditional on how the effluent is used on the farm.*
>
> *Anaerobic digestion in closed containment has been studied for many types of applications. Anaerobic digestion is the process that occurs in an anaerobic lagoon. When conducted in closed vessels, gaseous emissions including methane, carbon dioxide and small amounts of other gasses (possibly ammonia, hydrogen sulfide, and VOCs) are captured and can be burned for electricity generation, water heating, or simply flared. The in-ground digester being tested on a swine farm in North Carolina is an example of the ambient temperature version of this technology (there are also mesophilic and thermophilic designs). The concentration of ammonia remaining in effluent from that digester is higher than the concentration in lagoon effluent and can be volatilized once exposed to air.*

Recent research (e.g., Bicudo et al., 2004; Funk et al., 2004a,b; Shores et al., 2005) demonstrates reduction in NH_3 emissions after a permeable cover was installed. Miner et al. (2003) reported that a polyethylene cover can reduce NH_3 emissions by ~80%, but it is not clear what fraction of that N was converted to N_2. Harper et al. (2000) reported that in a well-managed swine lagoon denitrification N_2 losses can be equivalent to N lost as NH_3, in other words about 50% efficiency. Kermarrec et al. (1998) reported that sawdust litter helped reduce NH_3 emissions from pig manure with 44-74% of manure

N converted to N_2, but greater than 10% of the manure N was released as N_2O. Sommer (1997) found that NH_3 was emitted from cattle and pig slurry tanks at the rate of 3.3 kg N $m^2 yr^{-1}$ until covered with straw. After straw application NH_3 emissions were below detection limit. Mahimairaja et al. (1994) reported that NH_3 volatilization was reduced by 90-95% under anaerobic conditions. Section 2.2.4 contains a discussion of best management practices to minimize NH_3 emissions from livestock waste, and presents finding and recommendation 6 on the need for a framework for manure management.

Technical controls (control points) on transfer and transformations of atmospheric emissions of Nr in and between environmental systems: NO_x

As previously discussed, a major contributor to Nr in the atmosphere is fossil fuel combustion. During the combustion process NO_x ($NO_x = NO + NO_2$) are released to the atmosphere. Globally the production of NO_x has accelerated in the last few decades, primarily through the increase in fossil fuel combustion (Galloway et al., 1995; 2008). With this increase in emissions from ~5 Tg N in 1940 to ~ 25 Tg N in 2005, combustion of fossil fuels accounted for about 50% of the total global NO_x emissions for 1990. Of the anthropogenic sources, fossil fuel, aircraft, biomass burning, and part of the soil emission are most important (Holland et al., 1997). Although global NO_x emissions continue to increase, these emissions are declining in the U.S. (see Section 2.2.1).

Nitrogen oxide is formed during combustion by three mechanisms:

- Thermal NO_x where N_2 and O_2 combine at high temperatures (thermal pathway dominates at temperatures greater than approximately 1500 C) to form NO through the Zeldovich mechanism
- Fuel NO_x where nitrogen from a fuel (e.g., coal and biofuels) is released as some intermediate and then combines with O_2 to form NO
- Prompt NO_x where N_2 reacts with hydrocarbon radicals in flames, forming various compounds including hydrogen cyanide and other cyano radicals. These in turn form NO_x. Contributions of prompt NO_x are usually low as compared to fuel NO_x.

There are several ways to control emissions of NO_x. The most common controls are on coal-fired electric utility generators and those are discussed below. Following the discussion of electric utility generator controls, or external combustion systems, there is a discussion on internal combustion controls.

Reduction of the temperature limits the kinetics of the N/O_2 reaction. Temperature can be controlled by using a fuel-rich mixture versus fuel lean. In this case the reactions take place at lower temperatures. Fuel-rich mixtures also reduce the amount of O_2 available for reaction and there are changes in the chemical mechanisms which limit the oxidation of N_2. If fuel-lean mixtures are used for temperature control, while the temperature is lower there is a significant amount of O_2 present. Typically, in external combustion systems controls are implemented by using less excess air and using staged combustion. In addition, flue-gas recirculation (FGR) is used to lower the temperature. Low-NO_x burners operate under the principle of internally staging the combustion. To reduce fuel NO_x, air and fuel staging are used to reduce the peak temperature where air and fuel are admitted in separate locations.

Chemical reduction of NO_x is also possible. These methods include: selective non-catalytic reduction (SNCR), selective catalytic reduction (SCR), and fuel reburning. SNCR is an add-on technology where urea or NH_3 is injected in a controlled temperature zone to allow the reduction of NO_x. SCR is also an add-on technology where the flue gas must pass through a catalyst bed to allow reaction between ammonia and NO_x. Care must be taken with both technologies to avoid NH_3 slip. Fuel reburning requires the injection of a fuel to create a zone where NO_x is reduced to N_2. Low NO_x burners may also use an internal fuel reburning to reduce the NO_x.

For internal combustion engines, the same mechanisms discussed above are used in a variety of different ways, since these systems are using high pressure and predominately have thermal NO_x versus fuel NO_x formation. Most technologies involve the need to reduce the peak temperature and duration of high temperatures of the combustion zone. For example, gas turbines utilize low NO_x burners, while spark ignition engines utilize a three-way catalyst which requires less than 0.5% O_2. In this case, additional NO_x is reduced by utilizing unburned fuel as a reagent over the catalyst for chemical reduction of NO_x. It should be noted, however, that a side reaction for the three-way catalyst system produces ammonia. NO_x emissions can be reduced in diesel engines by delaying the injection of the fuel, and by retarding the timing in spark-ignited engines. Engines also use exhaust gas recirculation (EGR) to reduce the peak temperatures. Recent road side studies have indicated high efficiency (~90%) for NO_x removal from the American light-duty fleet (Bishop and Stedman, 2008).