Executive Summary for:

SCR-Urea Infrastructure Implementation Study
Final Report

Created for:
Engine Manufacturers Association
Chicago, Illinois
July 30, 2003

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Reference: D5197
Overview

- Urea distribution will be focused at the medium- to large-throughput diesel retailers. Together, these public and private retailers provide 97 percent of the on-road diesel consumed by the Class 7 & 8 truck sector.
- The price of urea at the retail outlet depends on the urea throughput at each station.
- The larger stations can obtain urea at lower cost, thus putting a downward pressure on sale price. If smaller stations cannot afford to provide urea at a price that truck operators are willing to pay, then those stations will lose their market share to other stations or be forced to operate at lower margins.
- SCR urea is cost-competitive with alternative technologies under full market penetration scenarios and is cost-competitive with NO\textsubscript{x} adsorbers even if SCR is introduced in MY2010. A more careful life-cycle comparison is needed to determine the viability of SCR in the MY2007+, 50% market penetration scenario.
- For SCR urea to be implemented successfully, all stakeholders must work in a concerted manner.
Several project components were developed in order to determine if a viable business case exists for establishing an on-road SCR-urea infrastructure

• Market Structure
  – Determine the value-chain and market structure in which SCR-urea infrastructure will be implemented

• Urea Cost Model
  – Develop framework of an on-road SCR-urea cost model

• Critical Path Analysis
  – Determine the critical paths within an on-road SCR-urea infrastructure, including any “showstopper” segments

• Potential Business Cases
  – Based upon results from this and previous study components, determine what business cases, if any, are viable
SCR-Urea Implementation Strategies  Executive Summary

Most on-road diesel consumption is consumed by Class 7 & 8 Vehicles

2002 On-Road Diesel Consumption: 35 billion gal

- Light  
  Class 1-2  
  < 10,000 lb

- Medium  
  Class 3-5  
  10,001 - 19,500 lb

- Light-Heavy  
  Class 6  
  19,501 - 26,000 lb

- Heavy  
  Class 7&8  
  > 26,001 lb

85% of all diesel consumption

Profiles of Fueling Stations  
Serving the Class 7 & 8 Market

<table>
<thead>
<tr>
<th>Station Size (Monthly Diesel Consumption)</th>
<th># of Public &amp; Private Stations</th>
<th>Diesel Consumption</th>
</tr>
</thead>
</table>
| Large  
(2,000,000 — 200,000 gal/month)         | 2,200                         | 77%               |
| Medium  
(200,000 – 80,000 gal/month)            | 3,500                         | 20%               |
| Small  
(<80,000 gal/month)                    | >25,000                        | 3%                |
Nationwide annual urea consumption is significantly lower if SCR is adopted starting in 2010 (100% market penetration shown)
Urea Availability and Cost

• Retail urea cost will depend on the urea throughput at each retail station. Urea throughput at a station will be determined primarily by:
  – the SCR technology that drives the urea/diesel consumption ratio,
  – the market penetration and year of introduction of SCR technology

• Under both the full and the 50% engine market penetration scenarios where SCR is introduced in MY2007, urea will cost less than $1.00/gallon to dispense at the largest throughput stations (>1 million gallons diesel/month). Ultimately, the low-cost urea dispensed by these large retail stations will force down prices at stations with a lower throughput.

• The medium to small stations (<200,000 gallons diesel/month) are significant providers of diesel. Yet, if they cannot afford to provide urea at a price truck operators are willing to pay, then the stations will either lose market share to other stations, or be forced to operate at lower margins.

• The stations with the smallest throughput (<80,000 gallons diesel/month) comprise only 3% of the Class 7 & 8 market and will provide urea at very small volumes but at much higher prices
Average cost of retail SCR-urea to truck operators, as a function of retail station throughput, was determined for various urea supply scenarios.

Onsite blending at the retail station is a more expensive option. Purchasing aqueous urea product from a distributor is a more economical option. This is also consistent with views expressed by retailers who, in general, do not want to be involved in the urea processing step.
Example Scenario: Average Expected Price for Urea Melt Transported Directly to and Blended at Retail Site

Example Average Expected Price = (A) + (B) + (C) + (D) = 0.78 to 0.98 $/gal

**Urea supply chain cost segments:**
- Price of imported or manufactured urea
- Transportation to a Central Distribution Facility (CDF)
- Processing at the CDF*
- Transportation to retail station
- Processing and dispensing at the retail station*
- Profit mark-ups

*Includes handling and storage. May also include blending with de-ionized water.

**EXAMPLE SCENARIO NOTES:**
- Product urea refers to 32.2 wt-% aqueous urea solution
- Basis: 20,000 gal/month product urea @ filling station
SCR-Urea Implementation Strategies  Executive Summary

A range of retail SCR-urea prices was determined for several representative implementation scenarios

- Profit mark-ups at the central distribution and retail facilities could add between $0.16 and $0.36 per gallon SCR-urea.

- For each scenario shown, the low price represents the lowest retail cost during the first year of implementation plus $0.16 per gallon SCR-urea of profit mark-ups.

- For each scenario shown, the high price represents the highest retail cost during the first year of implementation plus $0.36 per gallon SCR-urea of profit mark-ups.

SCR-urea Price During First Year of Implementation

NOTE: These prices based on historical average urea cost of $122 per short ton. Given that natural gas prices are expected to remain high for the foreseeable future, urea cost may average $200/ton. This difference in urea cost would increase the price of SCR-urea by 12 cents per gallon. See Appendix for details.
Trade-off with Alternative Emission Controls and Critical Paths

• Economics favor the SCR/urea technology over the alternative emission control technologies for most applications of long-haul and vocational trucks in the long-term (MY2010+).

• Economics also generally favor the SCR/urea technology over the alternative emission control technologies in the near-term (MY2007-09) if early engines have a high fuel penalty (~9%) relative to SCR.

• Truck operators will incur increased operational cost due to urea consumption. In the early years (MY2007-09), this may be partly offset by increased fuel economy as afforded by higher engine out NO\textsubscript{x} levels. In later years, high diesel-to-urea consumption ratios will lower total urea consumption significantly.

• The critical path to implementation of the urea infrastructure requires that decisions to proceed with the SCR/urea technology must be made by the third-quarter of 2003.
The *break-even SCR-urea price* was determined over a representative set of parameters.

### Assumptions:
- $1.55/gal diesel
- 1 million miles over vehicle life
- High EGR used on alternative systems for MY2007-09 and on all vehicles for MY2010+
- Maintenance costs same for all systems.

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<thead>
<tr>
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<tbody>
<tr>
<td>NOx Adsorber Fuel Economy Effect</td>
<td>N/A</td>
<td>-5%</td>
<td>-2%</td>
</tr>
<tr>
<td>High EGR Fuel Economy Effect</td>
<td>-3%</td>
<td>-3%</td>
<td>-3%</td>
</tr>
<tr>
<td>SCR Fuel Economy Effect*</td>
<td>+6%</td>
<td>0%</td>
<td>0%</td>
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<tr>
<td>Installed SCR Cost (relative to alternative emission control system)</td>
<td>$0</td>
<td>-$1,000</td>
<td>-$1,000</td>
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<td>Diesel-to-urea Consumption Ratio</td>
<td>18:1</td>
<td>82:1</td>
<td>131:1</td>
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<tr>
<td>Break-even or allowable price of urea</td>
<td>$2.51/gal</td>
<td>$6.89/gal</td>
<td>$4.91/gal</td>
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*for MY2007-09 engines, it is assumed manufacturers using SCR will not use high EGR, and can thus produce higher fuel economy engines

- The break-even price refers to the highest price at which consuming SCR-urea is more cost-effective on a life-cycle basis than using an alternative emission control technology.
- The break-even price rises with SCR fuel economy effect, diesel price, or diesel-to-urea ratio.
- The break-even price drops as the alternative technology fuel economy effect or installed SCR cost goes up (i.e., becomes less negative).
SCR-Urea Implementation Strategies  Executive Summary

Participants and Milestone Timeline

• Major for-hire truck operators that fuel at both private and public fueling facilities should be involved in early adoption of the technology and the infrastructure

• These truck operators can implement the infrastructure at their private fueling facility and leverage their commercial fueling contractors (truck stops, cardlock stations) to implement the infrastructure

• Strong signals regarding manufacturer intentions to provide SCR-equipped trucks would need to be sent to truck operators and other stakeholders starting 3rd quarter 2003 and no later than mid-2004 in order to meet demand from MY2007 SCR implementation
**Milestones along the path to an on-road SCR-urea infrastructure (MY2007 SCR Implementation)**

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<tbody>
<tr>
<td>(1) Inform truck operators about impending SCR engine delivery</td>
<td></td>
<td></td>
<td></td>
<td>European SCR urea market implemented</td>
<td>Construction begins at retail stations &amp; distribution facilities Phase I</td>
<td>Construction begins at retail stations &amp; distribution facilities Phase II</td>
<td>All retail urea stations online Phase II</td>
</tr>
<tr>
<td>(2) Provide assurances on the availability of SCR urea infrastructure at their existing diesel fueling stations</td>
<td></td>
<td></td>
<td>Final assurances and pre-contracts/relationships with equipment and services vendors begin</td>
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<td>(3) Send strong signals to downstream stakeholders about impending need for SCR urea infrastructure</td>
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</tr>
<tr>
<td>(1) Engine manufacturers decide on: (a) strategy for SCR urea (b) uniform urea specification</td>
<td>(1) Inform truck operators about impending SCR engine delivery</td>
<td>Planning begins by retail vendors, distributors and urea manufacturers</td>
<td>Planning begins by retail vendors, distributors and urea manufacturers</td>
<td>Apply for construction permits</td>
<td>Apply for construction permits</td>
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<tr>
<td>(2) Send preliminary signals to all downstream stakeholders</td>
<td></td>
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<td>Full implementation of SCR urea infrastructure</td>
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Next Steps

• For the successful implementation of the SCR/urea technology, the engine manufacturers should have a concerted strategy. Such an approach has been taken in Europe where SCR/urea technology is being implemented as the sole NO\textsubscript{x} control technology for heavy duty trucks.

• Once the SCR strategy is determined, truck operators who will become buyers of the urea and the technology must be involved in the infrastructure implementation strategy.

• Key truck operators must be identified to become early adopters of the technology. Characteristics of these operators include major for-hire companies that fuel at their own large central diesel fueling stations as well as public truck stops.

• Also, the size of the urea market must be further refined to accurately convey the demand for SCR-urea to all downstream stakeholders such as the urea manufacturers, distributors, and retailers.
## Agenda

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<td>Task 2 — Urea Cost Model Framework</td>
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<td>4</td>
<td>Task 3 — SCR Urea Cost Model</td>
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<td>Task 4 — Critical Path Analysis</td>
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## SCR-Urea Implementation Strategies

### Agenda

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• Market Structure
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• Urea Cost Model
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• Critical Path Analysis
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• Potential Business Cases
  – Based upon results from this and previous study components, determine what business cases, if any, are viable
The project components for this study were completed as follows:

**Task 1: Market Structure**
- Determine the value-chain and market structure for SCR-urea:
  - ID key stakeholders*
  - Obtain diesel station profiles*
  - Project engine sales and SCR-urea consumption*
  - Obtain urea specification
  - Segment diesel truck population and select 5 cases for modeling

**Task 2 & 3: Urea Cost Model**
- Develop SCR-urea cost model:
  - Define sensitivity parameters
  - Develop functional relationships between urea price and urea consumption and throughput
  - Using Task 1 inputs, determine urea storage and dispensing costs for various stations over time

**Task 4: Critical Path Analysis**
- Perform critical path analysis:
  - Identify critical path items for potential business cases including: product definition, requirements, and constraints for urea TS&D pathways
  - Using Task 1 inputs, determine urea storage and dispensing costs for various stations over time

**Task 5: Potential Business Cases**
- Identify viability for end-users:
  - Identify profitable implementation strategies
  - Determine the economic impact of operating an SCR-equipped vehicle
  - Compare with cost of using NOx adsorber system

**Next Steps**
- Identify steps that need to be taken to establish an SCR-urea infrastructure:
  - Timeline for engine and truck manufacturers
  - Timeline for truck owner/operators
  - Timeline for urea retailers
  - Timeline for other stakeholders

* Completed under the NREL-funded portion of this study
Summary of Results

- It is feasible to provide urea to a large fraction of the heavy-duty on-road SCR-urea consumers (65% to 97% of urea consumption) at prices near the price of diesel. If SCR technology is slow to improve, or doesn’t capture a large enough share of the market, this will make urea more expensive.

- Major for-hire truck operators that fuel at both private and public fueling facilities should be involved in early adoption of the technology and the infrastructure.

- These truck operators can implement the infrastructure at their private fueling facility and leverage their commercial fueling contractors (truck stops, cardlock stations) to implement the infrastructure.

- Strong signals regarding manufacturer intentions to provide SCR-equipped trucks would need to be sent to truck operators and other stakeholders starting 3rd quarter 2003 and no later than mid-2004.
## SCR-Urea Implementation Strategies  
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**SCR-Urea Implementation Strategies**  
**Task 1  Task Details**

### TASK 1  
**Determine the Value-Chain and Market Structure in which the SCR-Urea Infrastructure will be Implemented**

**Identify all key stakeholders/participants within each of the following groups (Source: EMA, ATA, etc.):**
- engine manufacturers
- potential distributors
- potential urea bottlers
- truck stop owners
- truck manufacturers
- urea producers
- central fleet owners
- retail station owners

**Obtain existing diesel fueling stations profiles (Source: NATSO, others for central fleet information, etc.):**
- ownership
- location
- diesel throughput

**Obtain data for projected engine sales for use in SCR-equipped vehicles in 2007-2015 time frame (Source: EMA):**

**Obtain truck fueling habits, including total diesel consumption and the proportion of fueling performed on-road versus at a central (fleet) yard (Source: ATA):**

**Determine projected SCR-urea consumption using engine sales and fuel consumption information**

**Obtain SCR-urea specification to refine previous urea TS&D costs analyses (specification source: EMA)**

### Inputs
- Previous SCR-urea TS&D cost analysis (Source: TIAx Urea Report, 2002)
- Additional inputs (as shown) from stakeholders

### Outputs
- Key Stakeholders, station profiles, truck fueling habits
- Projected annual SCR-urea consumption (gallons)
- Segment SCR diesel truck population by market, general traffic patterns and diesel consumption
- Identify potential segments for developing business cases
- Refined retail urea price ($/gal) for a fully-implemented SCR-urea scenario
**Key Stakeholders and Typical Members**

- **Engine Manufacturers**  
  Caterpillar, Cummins, DDC, Hino, Isuzu, International, Mack/Volvo

- **Truck Manufacturers**  
  International, PeterBilt, Freightliner, Isuzu, Ford, etc.

- **Truck Operators**  
  Private Fleets - UPS, FedEx, Waste Management, etc.  
  For Hire Fleets - Ryder, J.B. Hunt, Schneider, single-owners, etc.

- **SCR Urea Manufacturers**  
  Agrium, Terra Industries, Mississippi Chemicals, etc.

- **Potential SCR Urea Distributors**  
  Existing petroleum distribution chain, agricultural urea distribution chain, and other independent entrants such as FleetGuard

- **Diesel Fuel (and Urea) Retailers**  
  Truck stops, card locks and central fleet fueling facilities.
The 0.9 % gal-urea/gal-diesel/(g/bhp-hr NO\textsubscript{x}) factor was used to obtain urea consumption across all segments of HD trucks, starting with MY2007.

- For 2007 to 2009, we assumed two separate cases of NO\textsubscript{x} reduction:
  - 7.3 to 1.1 g/bhp-hr and 5.5 to 1.1 g/bhp-hr
    - This range bounds the anticipated engine-out exhaust levels seen by the SCR system
    - This assumes that HD vehicles sold in the 2007-2009 time frame will emit 1.1 g NO\textsubscript{x}/bhp-hr, per March 12th Review Meeting input.
- For 2010 onward, the urea consumption was calculated based on SCR efficiencies of 85 to 90%, and an SCR-out NO\textsubscript{x} emission of 0.15 g/bhp-hr

<table>
<thead>
<tr>
<th></th>
<th>Engine Out</th>
<th>SCR Out</th>
<th>Consumption Ratio*</th>
<th>SCR Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g NO\textsubscript{x} / bhp-hr</td>
<td>diesel : urea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007-2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High NO\textsubscript{x} Reduction</td>
<td>7.3</td>
<td>1.1</td>
<td>18:1</td>
<td>85%</td>
</tr>
<tr>
<td>Low NO\textsubscript{x} Reduction</td>
<td>5.5</td>
<td>1.1</td>
<td>25:1</td>
<td>80%</td>
</tr>
<tr>
<td>2010-2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High NO\textsubscript{x} Reduction</td>
<td>1.5</td>
<td>0.15</td>
<td>82:1</td>
<td>90%</td>
</tr>
<tr>
<td>Low NO\textsubscript{x} Reduction</td>
<td>1</td>
<td>0.15</td>
<td>131:1</td>
<td>85%</td>
</tr>
</tbody>
</table>

* Ratio = 1 / (0.9% * (Engine Out - SCR out))
Urea Consumption was calculated using EMA HD diesel data

- Given the consolidated diesel consumption data provided by EMA for HD SCR-equipped trucks, we calculated the urea consumption by MY through the 2007-2015 timeframe

- HD vehicle mileage deterioration factors were obtained from the EPA MOBILE on-road vehicle model. Fuel consumption was assumed to scale directly with mileage over timeframe of interest.

- In order to align MOBILE mileage deterioration factors with EMA data we made the following assumptions about the EMA data:
  - New Class 8 Line-haul trucks were assumed to be Class 8B
  - New Class 8 Mid-range and Vocational trucks were assumed to be Class 8A
  - New Class 6-7 Mid-range trucks were assumed to be Class 7
  - New Class 6-7 Vocational trucks were assumed to be Class 6
Assumptions for Urea Consumption Projections

- Again, annual miles traveled by a given vehicle decreased over time per MOBILE model estimates
- Fuel economy decreased over time due to deterioration and change in application:
  - Primary owner sells truck after 5 years to new owner that operates truck on less efficient duty cycle
  - Secondary owner sells vehicle after 3 years to new owner that operates vehicle on even less efficient duty cycle
- Future on-road SCR-urea consumption bounded by:
  - High NO$_x$ reduction/poorer average fuel economy scenario
  - Low NO$_x$ reduction/higher average fuel economy scenario
- The 50% on-road SCR market penetration case can be represented as achieving only 50% of the projected on-road SCR-urea consumption
- Considered scenarios where SCR first adopted in MY2007 and in MY2010
Total Annual Urea Consumption under 100% and 50% Market Penetration

- 43 billion gallons diesel/year (all on-road vehicles)*
- 57 billion gallons diesel/year (all on-road vehicles)*

High NOx engine out
Low NOx engine out

Urea Consumption (million gallons of urea 32.5%wt solution)

Estimates from previous NREL SCR study

Calendar Year


Urea consumption with 50% market penetration

* Source: ORNL Transportation Energy Book
Nationwide annual urea consumption is significantly lower if SCR is adopted starting in 2010 (100% market penetration shown)
SCR-Urea Implementation Strategies  Task 1  Truck Segmentation

2002 Diesel Trucks; Population: 4,200,000

Light  
Class 1-2  
< 10,000 lb

<table>
<thead>
<tr>
<th>2002 Diesel Trucks; Population: 4,200,000</th>
</tr>
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<tbody>
<tr>
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</tr>
</tbody>
</table>

Light  
Class 1-2  
< 10,000 lb

Medium  
Class 3-5  
10,001 - 19,500 lb

Light-Heavy  
Class 6  
19,501 - 26,000 lb

Heavy  
Class 7&8  
> 26,001 lb

L = Local; < 200 miles
MR = Medium Range; 200 - 500 miles
LR = Long Range; > 500 miles
CF = Central company-owned fueling station; Fleet Stations
SC = Single contract fueling facility located off site; Cardlocks
P = Public fueling station; Truck stops and conventional retail stations
O = Other fueling habit

Source: VIUS 97 Database
SCR-Urea Implementation Strategies  Task 1  Truck Segmentation

2002 On-Road Diesel Consumption: 35 billion gal*

<table>
<thead>
<tr>
<th>Light Class 1-2</th>
<th>Medium Class 3-5</th>
<th>Light-Heavy Class 6</th>
<th>Heavy Class 7&amp;8</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10,000 lb</td>
<td>10,001 - 19,500 lb</td>
<td>19,501 - 26,000 lb</td>
<td>&gt; 26,001 lb*</td>
</tr>
<tr>
<td>L 2.9%</td>
<td>L 6.9%</td>
<td>L 3.7%</td>
<td>L 50%</td>
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<tr>
<td>MR</td>
<td>MR</td>
<td>MR</td>
<td>MR</td>
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<td>LR</td>
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</tbody>
</table>

∑ = 23.6%

∑ = 6.9%

∑ = 54.2%

No single leg in the HD fueling segment can be eliminated

*Discussions with truck stop companies indicated that local refueling at public retail stations may be smaller than estimated using VIUS 97, with the balance of refueling taking place at Central Fueling and, to a lesser extent, Single Contract fueling stations.

Source: VIUS 97 Database
SCR-Urea Implementation Strategies  Task 1  Fueling Station Profiles

Heavy Duty, Class 7 & 8, Fueling Station Profiles

Public (P) Truck Stops
- 5,000 truck stops in the U.S.
- Distributed throughout the country. Tracks regional on-road diesel consumption.
- Avg. fuel throughput 200,000 gal/mo
- 78% have below-average throughput
- High: 750,000 to 1,000,000 gal/mo
- Low: 10,000 gal/mo
- 55% of all on-road diesel consumption

Single Contract (SC) Cardlocks
- 2,500 cardlocks serving HD truck diesel
- Distributed throughout the country. Skewed towards urban centers.
- 7% of all on-road diesel consumption
- Average fuel throughput estimated based on the VIUS database (DB) = 80,000 gal/mo

Central Fueling (CF)
- 25,000 central fleet fueling stations for HD trucks
- Assumed distributed throughout the country. Profile under investigation.
- 25% of all on-road diesel consumption
- Average fuel throughput estimated based on the VIUS DB = 25,000 gal/mo

- Truck stops cover a wide range of fueling throughputs and profiles
- Cardlocks and central fueling stations are a subset of the truck stop profiles

Sources: NATSO, EPA, CFN, Waste Management, BP, VIUS
SCR-Urea Implementation Strategies Task 1 Fueling Habits

Truck Activity (1999)

For Hire (53% Revenue Share, R.S.)

Private (47% R.S.)

TL (37% R.S.)

LTL (16% R.S.)

- Avg distance: 375-425 miles
- Gaining market share from private fleets

Fueling Habits - Percent of fuel Consumption
62% Truck Stops
35% Company owned fueling stations
2% Cardlocks
1% Other (Mobile Fueling)

- Avg distance: 50-100 miles
- Market share (revenues) expected to shrink to 42% by 2007
- Most private fleets are used in regional or local hauls

Fueling Habits - Percent of fuel Consumption
23% Truck Stops
66% Company owned fueling stations
6% Cardlocks
5% Other (Mobile Fueling)

Diesel fueling distributed throughout the different categories of fueling stations

Sources: NATSO, OneSource Market Report
SCR-Urea Implementation Strategies  
Task 1  Market Structure

### Urea consumption among diesel fueling stations (100% penetration)

<table>
<thead>
<tr>
<th>Monthly Diesel Fuel Throughput (gallons/station)</th>
<th>Number of Stations</th>
<th>Monthly Urea Throughput (gallons/station)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2007</td>
</tr>
<tr>
<td>High, Low</td>
<td>310</td>
<td>15,143</td>
</tr>
<tr>
<td>2,000,000, 1,300,000</td>
<td>310</td>
<td>11,525</td>
</tr>
<tr>
<td>1,300,000, 1,000,000</td>
<td>1,128</td>
<td>5,155</td>
</tr>
<tr>
<td>1,000,000, 300,000</td>
<td>515</td>
<td>2,334</td>
</tr>
<tr>
<td>300,000, 200,000</td>
<td>262</td>
<td>1,667</td>
</tr>
<tr>
<td>200,000, 140,000</td>
<td>2,436</td>
<td>1,148</td>
</tr>
<tr>
<td>140,000, 80,000</td>
<td>1,115</td>
<td>213</td>
</tr>
<tr>
<td>80,000, 10,000</td>
<td>2,491</td>
<td>8</td>
</tr>
<tr>
<td>10,000, 100</td>
<td>24,251</td>
<td>24,251</td>
</tr>
</tbody>
</table>

*assumes SCR implemented in all heavy-duty engines starting with MY2007

As shown in the table on the left, 77% of the urea will be consumed in the larger diesel fueling stations, 20% in the medium throughput fueling stations (includes truck stops, cardlock, and central fleet stations).
### SCR-Urea Implementation Strategies  
**Task 1  Market Structure**

**Urea consumption distribution in diesel fueling stations: 50% penetration scenario**

<table>
<thead>
<tr>
<th>Monthly Diesel Fuel Throughput (gallons/station)</th>
<th>Monthly Urea Throughput (gallons/station)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Low</td>
<td>Number of Stations</td>
</tr>
<tr>
<td>2,000,000</td>
<td>1,300,000</td>
</tr>
<tr>
<td>1,300,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>1,000,000</td>
<td>300,000</td>
</tr>
<tr>
<td>300,000</td>
<td>200,000</td>
</tr>
<tr>
<td>200,000</td>
<td>140,000</td>
</tr>
<tr>
<td>140,000</td>
<td>80,000</td>
</tr>
<tr>
<td>80,000</td>
<td>10,000</td>
</tr>
<tr>
<td>10,000</td>
<td>100</td>
</tr>
</tbody>
</table>

This distribution represents a scenario where 50% of the new Class 6-8 vehicles will adopt SCR technology starting with MY2007.
Urea consumption distribution in diesel fueling stations (continued)

As shown in the above table, 77% of the urea will be consumed in the larger diesel fueling stations, 20% of the urea will be consumed in the medium throughput stations.
Urea consumption distribution in diesel fueling stations (continued): 50% penetration scenario

<table>
<thead>
<tr>
<th>Station Diesel Throughput Range (gallon/station)</th>
<th># of stations</th>
<th>% of Urea Consumption</th>
<th>Urea Consumption per Station (gallons/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>2,000,000 - 1,000,000</td>
<td>1,438</td>
<td>65%</td>
<td>7,572</td>
</tr>
<tr>
<td>1,000,000 - 200,000</td>
<td>777</td>
<td>12%</td>
<td>2,578</td>
</tr>
<tr>
<td>200,000 - 80,000</td>
<td>3,551</td>
<td>20%</td>
<td>833</td>
</tr>
<tr>
<td>&lt; 80,000</td>
<td>26,742</td>
<td>3%</td>
<td>106</td>
</tr>
</tbody>
</table>

This distribution represents a scenario where 50% of the new Class 6-8 vehicles will adopt SCR technology starting with MY2007.
Distribution of SCR-urea consumption among diesel fueling stations
(full implementation scenario starting in MY2007)

- **65%** of urea throughput will be in stations with diesel throughput between **1,000,000 to 2,000,000 gal/month**
- Number of diesel fueling stations with this range of fuel throughput are estimated to be about **1,400**
- Depending on the whether it is a high or low scenario for urea consumption, the urea throughput in this category will range from **8,000 gal/month to 50,000 gal/month** between 2007 and 2015.

- **12%** of urea throughput will be in stations with diesel throughput between **200,000 to 1,000,000 gal/month**
- Number of diesel fueling stations with this range of fuel throughput are estimated to be about **800**
- Depending on the whether it is a high or low scenario for urea consumption, the urea throughput in this category will range from **1,700 gal/month to 17,000 gal/month** between 2007 and 2015.

- **20%** of urea throughput will be in stations with diesel throughput between **80,000 to 200,000 gal/month**
- Number of diesel fueling stations with this range of fuel throughput are estimated to be about **3,600**
- Depending on the whether it is a high or low scenario for urea consumption, the urea throughput in this category will range from **800 gal/month to 5,500 gal/month** between 2007 and 2015.

- **3%** of urea throughput will be in stations with diesel throughput of less than **<80,000 gal/month**
- Number of diesel fueling stations with this range of fuel throughput are estimated to be about **27,000**. These are mostly central fueling stations
- Depending on the whether it is a high or low scenario for urea consumption, the urea throughput in this category will range from **<10 gal/month to 700 gal/month** between 2007 and 2015.
### SCR-Urea Implementation Strategies  
#### Task 1  Market Structure

<table>
<thead>
<tr>
<th>Diesel Throughput, gal/month</th>
<th># of Stations</th>
<th>% Urea Consumption</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,000,000 - 1,000,000</td>
<td>1,438</td>
<td>65%</td>
<td>A</td>
</tr>
<tr>
<td>1,000,000 - 200,000</td>
<td>777</td>
<td>12%</td>
<td>B</td>
</tr>
<tr>
<td>200,000 - 80,000</td>
<td>3,551</td>
<td>20%</td>
<td>C</td>
</tr>
<tr>
<td>&lt; 80,000</td>
<td>26,742</td>
<td>3%</td>
<td>D</td>
</tr>
</tbody>
</table>

#### 100% SCR technology penetration*

<table>
<thead>
<tr>
<th>Urea Throughput gal/month</th>
<th>2007</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>50,000 - 20,000</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>20,000 - 7,500</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>7,500 - 2,500</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>2,500 - 500</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>&lt; 500</td>
<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>

#### 50% SCR technology penetration*

<table>
<thead>
<tr>
<th>Urea Throughput gal/month</th>
<th>2007</th>
<th>2015</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
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<tr>
<td>50,000 - 20,000</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>20,000 - 7,500</td>
<td>A</td>
<td>B</td>
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<tr>
<td>7,500 - 2,500</td>
<td>B</td>
<td>A</td>
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<tr>
<td>2,500 - 500</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>&lt; 500</td>
<td>D</td>
<td>C,D</td>
</tr>
</tbody>
</table>

*Urea throughput at the diesel station is an important parameter that determines the cost and mode of providing retail SCR urea to the truck operator. These charts correspond to a MY2007 SCR implementation.*
SCR-Urea Implementation Strategies

Agenda

1. Project Overview
2. Task 1 — Determine Market Structure
3. Task 2 — Urea Cost Model Framework
4. Task 3 — SCR Urea Cost Model
5. Task 4 — Critical Path Analysis
6. Task 5 — Potential Business Cases
7. Conclusions
8. Next Steps
**SCR-Urea Implementation Strategies**  
**Tasks 2 & 3  Task Details**

**TASK 2 & 3**  
Develop framework for an on-road SCR-Urea cost model and develop cost estimates

---

**Inputs**

- **Input from Task 1:**
  - Line-haul truck fueling habits: % at home base versus on-road
  - Diesel throughput at fueling stations
  - Projected urea consumption by phase-in years 2006–2015

- **Input from TIAX Urea Report, 2002**
  - Full-scale implementation costs
  - Urea TS&D costs for full-scale implementation
  - Cost of urea for full-scale implementation

- **Input from BP, FleetGuard, others:**
  - Cost of bottled SCR-Urea at retail stations
  - Cost of other SCR-Urea dispensing technologies

- **Input from truck mfgs.:**
  Truck payload, diesel fuel tank, and SCR-Urea tank capacities

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**Outputs**

- Cost of large tanks with respect to urea throughput
- Cost of small storage with respect to throughput
- Urea consumption by phase-in year
- Urea cost model

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Develop functional relationships such as:
- cost of transportation, distribution, and storage with respect to throughput
- urea consumption by phase-in year
- urea price (per gallon) based on throughput

Define sensitivity parameters, e.g.:
- price of raw material urea
- variability in costs of dispensing technologies
- Regional variations in above costs
Key pathways for SCR-urea distribution

**Pathway 1** — Solid urea is blended and dispensed at the truck stop. This may be a viable option for truck stops dealing with large urea throughputs.

**Pathway 2** — Aqueous urea blended at a central distribution facility is trucked in tanker-loads to truck stops having large urea storage tank and dispensing facilities. This also represents truck stops with large urea and diesel throughputs.

**Pathway 3** — Aqueous urea blended at a central distribution facility is distributed in small quantities (300 gallons to 55 gallons)

A notable absence is the use of small bottles (1-2 gallons) of urea using the lube-oil market model. Because of the relatively low volume of urea compared to typical mass-market bottled products, specifically in the lube-oil sector, it is assumed that this channel is not economically viable.
**SCR-Urea Implementation Strategies**  Tasks 2 & 3  **Cost Model Assumptions**

## Cost Model Assumptions

### Retail Urea Distribution

#### Potential Pathways

- **Solid Urea or Urea Melt Blending @ Retail Site**
  - **Site with pre-existing DI water facility***
    - Typically large retail stations with diesel throughput in the range 200,000 - 2,000,000 gal/month range. Urea throughput over 10,000 gal/month
    - Assumes existing DI water has capacity to accommodate SCR urea requirements
    - Facility will install a permanent UST or AST with an independent dispensing system that is however integrated with its diesel fueling operations
    - * - Such sites are not common

- **Site without pre-existing DI water facility**
  - Typically large retail stations with diesel throughput in the range 200,000 - 2,000,000 gal/month range. Urea throughput over 10,000 gal/month
  - Requires purchase and installation of a DI water production unit
  - Facility will install a permanent UST or AST with an independent dispensing system that is however integrated with its diesel fueling operations

- **Tanker Loads**
  - Retail stations with urea throughput over 2,500 gal/month
  - Aqueous SCR urea product purchased from a central distribution facility (CDF). CDF may use either solid urea or urea melt to make product urea
  - Facility will install a permanent UST or AST with an independent dispensing system that is however integrated with its diesel fueling operations

- **Small Loads**
  - Retail stations with low urea throughput in two categories (1) 500 - 2,500 gal/month & (2) < 500 gal/month
  - Aqueous SCR urea product purchased from a central distribution facility (CDF). CDF may use either solid urea or urea melt to make product urea
  - Stations with 500 - 2,500 gal/month throughput may still find it viable to install a permanent storage & dispensing infrastructure
  - Stations with < 500 gal/month throughput may operate with totes, 55-gallon drums and an unsophisticated dispensing system
### SCR-Urea Implementation Strategies

**Tasks 2 & 3  Cost Model Assumptions**

- **Central Distribution Facilities (CDFs)** are expected to be existing ag and petroleum terminals, urea plants, or new facilities set up to deal SCR urea specifically by independent entries. About 450 CDFs are expected to be involved by 2015.

- Cost estimates to produce aqueous urea assume capital investment (CI) requirements for storage, material handling, blending, storage in UST/AST, heating requirements, dispensing, systems integration, installation and annual operating cost (AOC).

- The cost of urea presented in $/gal includes AOC and CI amortized using a capital recovery period of 2-3 years and a cost of capital of 12%.

### Retail Site Description

- **Solid urea** historically available between $90 to $200 per ton - depending on the price of natural gas.

- Some fluctuations in price also occur due to supply and demand not matching.

- Assumed an average basket price of urea between 2001-2003 with a normal distribution.

- It is assumed that urea melt will be available at 85% of the price of solid urea in the open market.

### Urea Supply Chain

<table>
<thead>
<tr>
<th>Retail Site Description</th>
<th>Urea Throughput</th>
<th>Urea FOB</th>
<th>Transportation to CDF</th>
<th>Processing @ CDF</th>
<th>Transportation to Retail</th>
<th>Processing @ Retail</th>
<th>Σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-site blending @ large facility with DI water facility</td>
<td>50,000</td>
<td>0.181</td>
<td>0.015</td>
<td>0.050</td>
<td>0.030</td>
<td>0.16</td>
<td>0.441</td>
</tr>
<tr>
<td>On-site blending @ large facility without DI water facility</td>
<td>50,000</td>
<td>0.181</td>
<td>0.015</td>
<td>0.050</td>
<td>0.030</td>
<td>0.20</td>
<td>0.476</td>
</tr>
<tr>
<td>Aqueous urea from blending with solid urea at CDF</td>
<td>50,000</td>
<td>0.154</td>
<td>0.030</td>
<td>0.072</td>
<td>0.040</td>
<td>0.12</td>
<td>0.441</td>
</tr>
<tr>
<td>Aqueous urea from blending with urea melt at CDF</td>
<td>50,000</td>
<td>0.154</td>
<td>0.000</td>
<td>0.000</td>
<td>0.080</td>
<td>0.15</td>
<td>0.385</td>
</tr>
<tr>
<td>Aqueous urea from blending with urea melt at retail site</td>
<td>20,000</td>
<td>0.181</td>
<td>0.015</td>
<td>0.050</td>
<td>0.030</td>
<td>0.37</td>
<td>0.642</td>
</tr>
<tr>
<td>Aqueous urea from blending with solid urea at CDF</td>
<td>20,000</td>
<td>0.181</td>
<td>0.015</td>
<td>0.087</td>
<td>0.040</td>
<td>0.30</td>
<td>0.619</td>
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<tr>
<td>Aqueous urea from blending with urea melt at CDF</td>
<td>20,000</td>
<td>0.154</td>
<td>0.030</td>
<td>0.077</td>
<td>0.040</td>
<td>0.30</td>
<td>0.597</td>
</tr>
<tr>
<td>Aqueous urea from blending with urea melt at retail site</td>
<td>20,000</td>
<td>0.154</td>
<td>0.000</td>
<td>0.000</td>
<td>0.080</td>
<td>0.38</td>
<td>0.612</td>
</tr>
<tr>
<td>On-site blending @ large facility w/ DI water facility</td>
<td>10,000</td>
<td>0.181</td>
<td>0.015</td>
<td>0.050</td>
<td>0.030</td>
<td>0.49</td>
<td>0.767</td>
</tr>
<tr>
<td>On-site blending @ large facility w/o DI water facility</td>
<td>10,000</td>
<td>0.181</td>
<td>0.015</td>
<td>0.050</td>
<td>0.030</td>
<td>0.67</td>
<td>0.942</td>
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<tr>
<td>Aqueous urea from blending with solid urea at CDF</td>
<td>10,000</td>
<td>0.154</td>
<td>0.030</td>
<td>0.072</td>
<td>0.030</td>
<td>0.37</td>
<td>0.696</td>
</tr>
<tr>
<td>Aqueous urea from blending with urea melt at CDF</td>
<td>10,000</td>
<td>0.154</td>
<td>0.000</td>
<td>0.000</td>
<td>0.080</td>
<td>0.37</td>
<td>0.653</td>
</tr>
<tr>
<td>Aqueous urea from blending with solid urea at CDF</td>
<td>10,000</td>
<td>0.154</td>
<td>0.000</td>
<td>0.000</td>
<td>0.080</td>
<td>0.37</td>
<td>0.777</td>
</tr>
<tr>
<td>Aqueous urea from blending with urea melt at retail site</td>
<td>7,500</td>
<td>0.181</td>
<td>0.015</td>
<td>0.093</td>
<td>0.040</td>
<td>0.42</td>
<td>0.747</td>
</tr>
<tr>
<td>Aqueous urea from blending with solid urea at CDF</td>
<td>5,000</td>
<td>0.181</td>
<td>0.015</td>
<td>0.110</td>
<td>0.040</td>
<td>0.53</td>
<td>0.873</td>
</tr>
<tr>
<td>Aqueous urea from blending with urea melt at CDF</td>
<td>5,000</td>
<td>0.181</td>
<td>0.015</td>
<td>0.170</td>
<td>0.040</td>
<td>0.87</td>
<td>1.275</td>
</tr>
<tr>
<td>Aqueous urea from blending with solid urea at CDF</td>
<td>500</td>
<td>0.181</td>
<td>0.015</td>
<td>0.170</td>
<td>0.040</td>
<td>2.03</td>
<td>2.431</td>
</tr>
</tbody>
</table>

- Cost estimates to produce aqueous urea assume capital investment (CI) requirements for storage, material handling, storage in UST/AST, heating requirements, dispensing, systems integration, installation and annual operating cost (AOC).
- The cost of urea presented in $/gal includes AOC and CI amortized using a capital recovery period of 2-3 years and a cost of capital of 12%.
- Assumed a uniform distribution in costs based on size of installation and capital recovery factor of 2-3 years.
SCR-Urea Implementation Strategies  Tasks 2 & 3  Cost Model Calculations

Example Scenario:
Determining the price of transporting solid urea to and blending solid urea at CDF, then transporting SCR-urea solution to retail (see notes)

Average Expected Price = (A) + (B) + (C) + (D) + (E) + (F) + (G) = 0.78 to 0.98 $/gal

NOTES
- Product urea refers to 32.2 wt% aqueous urea solution
- Basis: 20,000 gal/month product urea @ filling station
- The cost model does not include mark-ups, mark-ups were added here for demonstration.
SCR-Urea Implementation Strategies  Tasks 2 & 3  Cost Model Calculations

Example Scenario:
Determining the price of transporting urea melt to and blending solid urea at CDF, then transporting SCR-urea solution to retail (see notes)

Processor at CDF to 32 wt% product

Transportation to Central Distribution Facility (CDF)

• Transportation of urea melt to CDF from plant. Assume 450 CDFs nationwide.
• Average price = $.03/gal product urea (B)

Urea Melt FOB

• Urea melt is a precursor of solid urea and is a candidate for direct processing to product urea
• Average price = $.154/gal product urea (A)

Average Expected Price = (A) + (B) + (C) + (D) + (E) + (F) + (G) = 0.76 to 0.96 $/gal

Transportation to retail site

• Transportation of solid urea to CDF from plant. Assume 450 CDFs nationwide with an average of 100-mi radius coverage to retail station.
• Average price = $.04/gal product urea basis (E)

Storage and distribution @ retail filling station

• Storage and dispensing of product urea. Product throughput at retail station 50,000 gal/month.
• Average capital investment = $150 K
• Average annual operating cost = $4K
• Cost of capital = 12%; Capital recovery period = 2 to 3 years
• Average cost = $.30/gal product urea (F)
• Expected retail station profit mark-up = $ 0.07 to $0.12 per gal product urea (G)

NOTES
• Product urea refers to 32.2 wt% aqueous urea solution
• Basis: 20,000 gal/month product urea @ filling station
• The cost model does not include mark-ups; mark-ups were added here for demonstration.
SCR-Urea Implementation Strategies  Tasks 2 & 3  Cost Model Calculations

Example Scenario:
Determining the price of transporting urea melt to and blending urea melt at retail station

Urea Melt FOB

- Urea melt is a precursor of solid urea and is a candidate for direct processing to product urea
- Average price = $.154/gal product urea (A)

Transportation to retail site

- Transportation of urea melt to filling station from plant. Average transportation distance 750 mi
- Average price = $.08/gal product urea (B)

Storage and distribution @ retail filling station

- Storage and dispensing of product urea. Product throughput at retail station 50,000 gal/month. Requires new on-site DI water system.
- Average capital investment = $165 K
- Average annual operating cost = $8K
- Cost of capital = 12%; Capital recovery period = 2 to 3 years
- Average cost = $.38/gal product urea (C)
- Expected retail station profit mark-up = $0.07 to $0.12 per gal product urea (D)

Average Expected Price = (A) + (B) + (C) + (D) = 0.78 to 0.98 $/gal

NOTES
- Product urea refers to 32.2 wt-% aqueous urea solution
- Basis: 20,000 gal/month product urea @ filling station
- The cost model results do not include profit mark-ups at the CDF and the retail facility. Typically these mark-ups can range between 0.09-0.24 $/gal at the CDFs, and 0.07-0.12 $/gal at the retail stations. Profit mark-ups were added here for demonstration purposes.
Average cost of retail SCR-urea to truck operators, as a function of retail station throughput, was determined

- Onsite blending at the retail station is a more expensive option and purchasing aqueous urea product from a distributor is a more economical option.
- This is consistent with views expressed by retailers who, in general, do not want to be involved in urea processing.
- This model was developed using upstream throughput ranges consistent with MY2007 SCR implementation.
- Optimization for MY2010 implementation scenario will require additional analysis.
- NOTE: The cost model results do not include profit mark-ups at the CDF and the retail facility. Typically these mark-ups can range between 0.09-0.24 $/gal at the CDFs, and 0.07-0.12 $/gal at the retail stations.
Average cost of retail SCR-urea as a function of retail facility throughput

<table>
<thead>
<tr>
<th>Urea Throughput (gal/month)</th>
<th>Average Cost ($/gal)</th>
<th>Standard Deviation ($/gal)</th>
<th>Low Cost ($/gal)</th>
<th>High Cost ($/gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50,000</td>
<td>0.45</td>
<td>0.03</td>
<td>0.36</td>
<td>0.54</td>
</tr>
<tr>
<td>20,000</td>
<td>0.61</td>
<td>0.04</td>
<td>0.51</td>
<td>0.74</td>
</tr>
<tr>
<td>10,000</td>
<td>0.72</td>
<td>0.05</td>
<td>0.59</td>
<td>0.86</td>
</tr>
<tr>
<td>7,500</td>
<td>0.78</td>
<td>0.06</td>
<td>0.62</td>
<td>0.93</td>
</tr>
<tr>
<td>2,500</td>
<td>1.28</td>
<td>0.16</td>
<td>0.91</td>
<td>1.64</td>
</tr>
<tr>
<td>500</td>
<td>2.43</td>
<td>0.45</td>
<td>1.55</td>
<td>3.30</td>
</tr>
</tbody>
</table>
The cost model results do not include profit mark-ups at the CDF and the retail facility. Typically these mark-ups can range between 0.09-0.24 $/gal at the CDFs, and 0.07-0.12 $/gal at the retail stations.

Two sets of prices are likely to emerge:
(a) The first will be set by the high urea consumption sector. These prices will be comparable to diesel prices.
(b) The second will be set by the low urea consumption sector that is unavoidable. These prices are likely to be > 2.50 $/gallon. This sector will supply about 3% of on-road urea.
SCR-Urea Implementation Strategies  Tasks 2 & 3  Cost Model

<table>
<thead>
<tr>
<th>Urea Throughput gal/month</th>
<th>2007</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>50,000 - 20,000</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>20,000 - 7,500</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>7,500 - 2,500</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>2,500 - 500</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>&lt; 500</td>
<td>D</td>
<td>C,D</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Urea Throughput gal/month</th>
<th>2007</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>50,000 - 20,000</td>
<td></td>
<td>0.41-0.60</td>
</tr>
<tr>
<td>20,000 - 7,500</td>
<td>0.60-0.74</td>
<td>0.60-0.74</td>
</tr>
<tr>
<td>7,500 - 2,500</td>
<td>0.74-1.28</td>
<td>0.74-1.28</td>
</tr>
<tr>
<td>2,500 - 500</td>
<td>1.28-2.43</td>
<td>1.28-2.43</td>
</tr>
<tr>
<td>&lt; 500</td>
<td>2.43-3.7</td>
<td>2.43-3.7</td>
</tr>
</tbody>
</table>

The cost model results do not include profit mark-ups at the CDF and the retail facility. Typically these mark-ups can range between 0.09-0.24 $/gal at the CDFs, and 0.07-0.12 $/gal at the retail stations.

Two sets of prices are likely to emerge:
(a) The first will be set by the high urea consumption sector. These prices will be comparable to diesel prices.
(b) The second will be set by the low urea consumption sector that is unavoidable. These prices are likely to be > 2.50 $/gallon. This sector will supply about 3% of on-road urea.

Retail cost per gallon of SCR-urea
50% market penetration case, MY2007 implementation
**SCR-Urea Implementation Strategies  Tasks 2 & 3  Cost Modeling Summary**

**Average cost of retail SCR-urea will drop over time as urea consumption increases**

- Under this 100% market penetration case, all heavy-duty engine manufacturers implement SCR systems starting with MY2007.

- Again, profit mark-ups at the CDF and retail facility could add between $0.16 to $0.36 per gallon SCR-urea.

- Higher consumption volumes in outer years bring urea price below price of diesel for the three largest station types.

<table>
<thead>
<tr>
<th>Fraction of Class 7-8 diesel throughput in U.S.</th>
<th>65%</th>
<th>12%</th>
<th>20%</th>
<th>3%</th>
</tr>
</thead>
</table>

- 2007 (100% market penetration)
- 2015 (100% market penetration)

**Current Fleetguard price for 55 gallon drum**

**Current average diesel price in U.S.**

- stations with greater than 1 million gallons of diesel per month
- stations with 200,000 to 1 million gallons of diesel per month
- stations with 80,000 to 200,000 gallons of diesel per month
- stations with less than 80,000 gallons of diesel per month
If only some engine manufacturers adopt SCR, the average cost of retail SCR-urea will be higher due to lower urea throughput at stations.

- At this time, some heavy-duty engine manufacturers have indicated they will not use SCR to meet emission standards through MY2009.

- Low-cost urea dispensed by the largest retail stations will place a downward pressure on prices at stations with a lower throughput.

<table>
<thead>
<tr>
<th>Fraction of Class 7-8 diesel throughput in U.S.:</th>
<th>65%</th>
<th>12%</th>
<th>20%</th>
<th>3%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Fleetguard urea price, 55 gallon drum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current average diesel price</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea Cost ($/gallon)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007 (50% market penetration)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015 (50% market penetration)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If engine manufacturers adopt SCR starting with MY2010, the average cost of retail SCR-urea will be higher due to lower vehicle urea consumption.

- If on-road SCR systems are not implemented until MY2010, retail urea will cost more.

- Starting with MY2010, SCR-equipped vehicles will consume much less urea per mile, thus keeping national urea consumption lower.

- Lower urea consumption enjoyed by MY2010+ vehicles will help offset higher urea cost.

- Further investigation is needed into the trade off between implementing SCR with MY2007, thus lowering urea cost, and delaying SCR implementation.

MY2010 implementation scenario involves smaller volumes that could be replaced at engine service intervals. This scenario may involve urea distribution to maintenance yards and less to retail stations. Further investigation needed to determine the cost impact of following such a pathway.
Cost Model Summary

- The cost of retail on-road SCR-urea was estimated for two main pathways:
  - Solid urea or urea melt blended at the retail site
  - Retail site involved with only aqueous urea

- A retail site dealing with only aqueous urea is the more attractive option, both economically and operationally

- The cost of retail SCR-urea to the truck operator is a function of the urea throughput at the retail facility. For facilities with a urea throughput greater than 7,500 gallons/month, the cost to retail is less than $1.00/gallon.

- The cost for facilities with a urea throughput around 2,500 gallons/month is about $1.28/gallon. This is comparable to the average price of diesel. This urea throughput segment is also the low-end of the type A and B urea stations.
Cost Model Summary

• The cost of retail urea for stations with a urea throughput less than 500 gallons/month ranges from 2.4 to 3.7 $/gallon. This cost range is based on the current FleetGuard cost schedule for obtaining urea in such volumes.

• The majority of private fueling stations (>25,000) fall into this low-throughput segment. Under the MY2007 implementation scenarios, some commercial retailers may fall into this category and also carry urea at the high cost (such as remote locations, etc.).

• Under the MY2010 penetration scenarios, low throughput volumes may place medium-throughput stations in this price range during the first few years of implementation. For the 50% market penetration with MY2010 SCR introduction, only the largest stations (>1 million gallons diesel/month) dispense more than 500 urea gallons/month in the first year.

• The price of urea in this segment (less than 500 gallons urea/month) will be set independently of the large throughput retailers.
SCR-Urea Implementation Strategies

Agenda

1. Project Overview
2. Task 1 — Determine Market Structure
3. Task 2 — Urea Cost Model Framework
4. Task 3 — SCR Urea Cost Model
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6. Task 5 — Potential Business Cases
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8. Next Steps
Critical Path Analysis Approach (for MY2007 implementation)

- Identify key requirements of implementing a urea infrastructure by 2007
- Identify availability of key requirements by 2007
- Identify key stakeholder issues with respect to requirements and availability
- Identify key milestones between now and 2007
- Identify critical path items
On-road SCR-urea production status, requirements, and availability

- Significant domestic and international urea production capacity exists.
- Currently, world urea production capacity is under-utilized.
- The expected on-road SCR-urea demand, between 0.5 and 1.7 MM tons per year under the full market MY2007 implementation scenario, can easily be met and most likely will be available through the existing commodity markets for urea.
- It appears, based on limited European and U.S. experience, that commonly existing urea specifications can cover on-road SCR-urea specification requirements.
- However, a common on-road SCR-urea standard specification must be communicated to urea-manufacturers immediately.
On-road SCR-urea distribution status, requirements, and availability

- Currently, the main commercial distribution network for urea is in the agricultural sector, with over 1,200 petroleum and agricultural distribution terminals.

- Some urea is currently distributed in the U.S. for stationary SCR/SNCR applications; however, these volumes are low.

- Urea CDFs will be operated by some of the existing players, including urea manufacturers, petroleum companies, and jobbers.

- Some new entrants with stakes in the value chain, such as FleetGuard, will also appear.
On-road SCR-urea distribution status, requirements, and availability

- Between 250-500 CDFs are expected to develop for on-road SCR-urea *
  - Distribution centers will range in function from plants that operate as CDFs to brokering facilities that are just resellers
  - Infrastructure requirements will depend on the function of the facility
  - The more complex facilities will have solids handling and liquid blending operations
  - All CDFs will require storage and dispensing facilities
- Depending on the urea specification, a few hundred dedicated SCR-urea tanker-trucks will be required
  - Some of these tankers will need heaters
  - Our discussions with agricultural urea distributors did not reveal this to be a big hurdle

* Under the MY2010 implementation scenarios, lower volumes projected may lead to fewer CDFs
Tanks and auxiliary equipment status, requirements, and availability

• Under the MY2007 implementation scenario, over 5,000 tanks and auxiliary equipment to handle 1,000 and 20,000 gallons of storage capacity will be required

• There are well over 100 tank manufacturers that could meet this demand in aggregate

• Due to the recent history of diesel/gasoline UST replacement (during the 1990’s), there is significant experience in installations at diesel fueling stations
  – However, the tank and auxiliary manufacturing equipment industry will require strong advance signals to tool-up to meet the demand
  – 1 to 1.5 years of advanced notice is desirable

• The < 500 gallon/month vendors are likely to operate through 200-gallon totes and 55-gallon drums
Dispensing equipment and systems status, requirements, and availability

- Under the MY2007 implementation scenario, 5,000 + systems required
- Many key players (e.g., Veder-Root, ABB, GE, Marathon, Mitsubishi, etc.)
- Niche players, like Identic (Sweden), are involved with developing systems for the European market – the European market is expected to be fully active in early 2005
- At least a 1.5 to 2 year lead-time will be required from planning to initial production
SCR-Urea Implementation Strategies  Task 4  Critical Path Analysis: Key Infrastructure Issues

Financing requirements

• Much of the capital investment for this infrastructure will have to be undertaken by the final retailers of on-road SCR-urea: the public and private fueling stations

• The average capital expenditure will range from $25,000 to $200,000 per station depending on the designed throughput for the dispensing facility
Summary of key issues for the major downstream stakeholders

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Urea Manufacturers</strong></td>
<td>–No special issues</td>
<td>No special issues</td>
<td>None</td>
<td>–Will require strong signals from distributor and retail level stakeholders</td>
</tr>
<tr>
<td></td>
<td>–Urea Specification required for planning</td>
<td></td>
<td></td>
<td>–Timeline: minimum 1 year from planning to production</td>
</tr>
<tr>
<td><strong>Urea Distributors</strong></td>
<td>No special issues</td>
<td>–UST/AST installation</td>
<td>Operating &amp; construction permits 0.25 years</td>
<td>–Strong signals from truck operators and upwards such as engine manufacturers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>–0.25 years</td>
<td></td>
<td>–Timeline: 1-1.5 years from planning to installation</td>
</tr>
<tr>
<td><strong>Equipment &amp; Systems Manufacturers</strong></td>
<td>Storage equipment no special issues. Dispensing systems will have to be developed but European experience will be available</td>
<td>–Manufacturing</td>
<td>None</td>
<td>–Strong signals from engine manufacturers, truck manufacturers, distributors, and retailers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>–1.5 – 2 years lead time</td>
<td></td>
<td>–Development in the U.S. can be accelerated due to European experience</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>–Timeline: 1.5 – 2 years from planning through production</td>
</tr>
</tbody>
</table>
### Summary of key issues for the major downstream stakeholders

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea Retailers (Truck Stops, etc)</td>
<td>Expect turnkey dispensing systems/services.</td>
<td>–UST/AST installation 0.25 years</td>
<td>Operating and construction permits 0.25 years</td>
<td>–Strong signals required from truck operators and upstream stakeholders such as engine and truck manufacturers. –Timeline: at least 1 – 1.5 years planning horizon.</td>
</tr>
<tr>
<td>Truck Operators</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–Strong signal indicating impending sales of SCR-equipped engines/trucks. –Assurances from engine and truck manufacturers regarding the availability of SCR-urea and an easy-access refueling infrastructure. –Truck operators will be key to catalyzing a urea distribution network by demanding urea from existing diesel refuelers</td>
</tr>
</tbody>
</table>
The SCR-urea infrastructure should be implemented in two phases

- As the first phase, test SCR-equipped trucks should be introduced in MY2006 (or earlier) and a seed infrastructure should be developed consisting of a few major refuelers and distributors.

- Following Phase 1, the second phase (full implementation of SCR-urea infrastructure) needs to occur.

- The following issues must be addressed immediately for these two phases to be implemented according to the milestone presented on the next slide.

<table>
<thead>
<tr>
<th>Critical Path Items for Immediate Action (2003 II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Issue on-road SCR-urea specification and/or standard</td>
</tr>
<tr>
<td>- Issue a combined strong signal by all key engine and truck manufacturers on the impending sale of SCR-equipped engines</td>
</tr>
<tr>
<td>- Issue signals by to all downstream stakeholders of impending need for an on-road SCR-urea infrastructure</td>
</tr>
</tbody>
</table>
Milestones along the path to an on-road SCR-urea infrastructure (MY2007 SCR Implementation)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Inform truck operators about impending SCR engine delivery</td>
<td>(2) Provide assurances on the availability of SCR urea infrastructure at their existing diesel fueling stations</td>
<td>(3) Send strong signals to downstream stakeholders about impending need for SCR urea infrastructure</td>
<td>European SCR urea market implemented</td>
<td>Final assurances and pre-contracts/relationships with equipment and services vendors begin</td>
<td>Construction begins @ retail stations &amp; distribution facilities Phase I</td>
<td>Construction begins @ retail stations &amp; distribution facilities Phase II</td>
<td>All retail urea stations online Phase II</td>
</tr>
<tr>
<td>(1) Engine manufacturers decide on: (a) strategy for SCR urea (b) uniform urea specification</td>
<td>(2) Send preliminary signals to all downstream stakeholders</td>
<td>Planning begins by retail vendors, distributors and urea manufacturers</td>
<td>Apply for construction permits</td>
<td>(1) Partial implementation of SCR urea infrastructure Phase I</td>
<td>(2) Apply for construction permits</td>
<td>Full implementation of SCR urea infrastructure</td>
<td></td>
</tr>
</tbody>
</table>
SCR-Urea Implementation Strategies

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Two key implementation strategies have been identified

Strategy 1:

- SCR urea infrastructure should be initially concentrated on the large diesel fueling stations (with diesel throughputs between 200,000 - 2,000,000 gallons/month).

- As shown in the table below, fueling station types A & B comprise this segment, supporting 77% of the total on-road SCR-urea market.

<table>
<thead>
<tr>
<th>Diesel Throughput, gal/month</th>
<th># of Stations</th>
<th>% Urea Consumption</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,000,000 - 1,000,000</td>
<td>1,438</td>
<td>65%</td>
<td>A</td>
</tr>
<tr>
<td>1,000,000 - 200,000</td>
<td>777</td>
<td>12%</td>
<td>B</td>
</tr>
<tr>
<td>200,000 - 80,000</td>
<td>3,551</td>
<td>20%</td>
<td>C</td>
</tr>
<tr>
<td>&lt; 80,000</td>
<td>26,742</td>
<td>3%</td>
<td>D</td>
</tr>
</tbody>
</table>
Two key implementation strategies have been identified

Strategy 2:

- For early adoption of the technology and the infrastructure, major for-hire truck operators that fuel at both private and public fueling facilities should be involved.

- These truck operators can implement the infrastructure at their private fueling facility and can leverage their commercial fueling contractors (truck stops, cardlocks) to implement the infrastructure.

Fueling habits of the for-hire sector
62% Truck Stops
35% Company owned fueling stations
2% Cardlocks
1% Other (Mobile Fueling)
### Economic Impact on Truck Operations

Example: a line-haul truck with a lifetime mileage of 1,000,000 miles

<table>
<thead>
<tr>
<th>Lifetime Mileage</th>
<th>1,000,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Economy, miles per gallon</td>
<td>6</td>
</tr>
<tr>
<td>Lifetime diesel consumption, gal</td>
<td>166,667</td>
</tr>
<tr>
<td>Lifetime fuel expense (@ and average diesel price of 1.50 $/gal )</td>
<td>$ 250,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lifetime Urea Consumption, gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (1:20)</td>
</tr>
<tr>
<td>Low (1:130)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lifetime Urea Expense</th>
<th>High (1:20)</th>
<th>Low (1:130)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea price basis:</td>
<td>$ 1.5 /gallon</td>
<td>$ 12,500</td>
</tr>
<tr>
<td>Average operating cost of urea, $/mile</td>
<td>0.013</td>
<td>0.002</td>
</tr>
</tbody>
</table>

The worst-case cost of operating (early years) an SCR system for the truck operator is 0.013 $/mile.

The best-case cost of operating an SCR system for the truck operator is 0.002 $/mile.

Typical profit margin for long-haul operators is 0.01 - 0.02 $/mile.

NOTE: an average fuel economy of 6 mpg was assumed here. This does not account for the potential for improved fuel economy in the early years due to higher engine-out NO\textsubscript{x} operation. Such an improvement in fuel economy would lower the fuel cost for the operator and help offset the cost of urea use.
We compared the incremental lifetime cost of competing technology use with the lifetime cost of SCR use

- The incremental lifetime cost of competing technology use depends upon several parameters. These parameters and their assumed ranges are:
  - Lifetime mileage: 750,000 to 1,000,000 miles
  - Fuel economy: 4 mpg (vocational) to 8 mpg (line-haul and mid-range)
  - Diesel price per gallon: $1.45 to $2.00
  - Fuel penalty relative to SCR: 5% (later years) to 9% (early years)
  - Incremental initial competing technology cost: from $2,000 less than to $2,000 more than the initial SCR cost

- The incremental lifetime cost of using the competing technology was then compared with the incremental lifetime cost of using SCR for various urea to diesel consumption ratios

- A *break-even price* was determined for on-road SCR-urea. The *break-even price* is the maximum SCR-urea price for which the incremental lifetime cost of using SCR is less than that of using another technology.
The break-even SCR-urea price was determined over a representative set of parameters.

Assumptions:
- $1.55/gal diesel
- 1 million miles over vehicle life
- High EGR used on alternative systems for MY2007-09 and on all vehicles for MY2010+
- Maintenance costs same for all systems.

<table>
<thead>
<tr>
<th>Assumptions:</th>
<th>Cost Comparison Parameters for Line-haul Application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MY2007</td>
</tr>
<tr>
<td>NOx Adsorber Fuel Economy Effect</td>
<td>N/A</td>
</tr>
<tr>
<td>High EGR Fuel Economy Effect</td>
<td>-3%</td>
</tr>
<tr>
<td>SCR Fuel Economy Effect*</td>
<td>+6%</td>
</tr>
<tr>
<td>Installed SCR Cost (relative to alternative emission control system)</td>
<td>$0</td>
</tr>
<tr>
<td>Diesel-to-urea Consumption Ratio</td>
<td>18:1</td>
</tr>
<tr>
<td>Break-even or allowable price of urea</td>
<td>$2.51/gal</td>
</tr>
</tbody>
</table>

*LH baseline: 6.5 mpg. For MY2007-09 engines, it is assumed manufacturers using SCR will not use high EGR, and can thus produce higher fuel economy engines.

• The break-even price refers to the highest price at which consuming SCR urea is more cost-effective on a life-cycle basis than using an alternative emission control technology.
• The break-even price rises with SCR fuel economy effect, diesel price, or diesel-to-urea ratio.
• The break-even price drops as the alternative technology fuel economy effect or installed SCR cost goes up (i.e., becomes less negative).
Break-even point rises with competing technology capital cost and diesel price

For this set of assumptions, the break-even price is equal to diesel price when competing technology incremental capital cost is zero.

As shown, assumes a Near-term LH/MH scenario:
1 million miles,
6.5 mpg,
5% competing technology fuel penalty,
20:1 urea to diesel ratio

<table>
<thead>
<tr>
<th>Incremental Competing Technology Cost ($)</th>
<th>Diesel Price ($/gallon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,000</td>
<td>$2.00 - $2.25</td>
</tr>
<tr>
<td>1,200</td>
<td>$1.75 - $2.00</td>
</tr>
<tr>
<td>400</td>
<td>$1.50 - $1.75</td>
</tr>
<tr>
<td>1,200</td>
<td>$1.25 - $1.50</td>
</tr>
</tbody>
</table>

Urea price ranges
- $2.00 - $2.25
- $1.75 - $2.00
- $1.50 - $1.75
- $1.25 - $1.50
Break-even urea price is much higher in later years, when diesel to urea ratio is much higher.

Assumes:
1 million miles, 8mpg, $1.55/gal diesel, $1,000 more for competing technology.

Urea Price Ranges
- $3.50 - $4.00
- $3.00 - $3.50
- $2.50 - $3.00
- $2.00 - $2.50
- $1.50 - $2.00
- $1.00 - $1.50
- $0.50 - $1.00
- $0.00 - $0.50

Urea Ratio (diesel gallons/urea gallons)
In the near-term, the break-even point will depend more on the competing technology fuel penalty and the price of fuel.

Break-even price equal to diesel price at about 3.5% fuel penalty.

- If the competing technology were $1,000 less than SCR, the break-even price would be at 4.5%
- If the urea-to-diesel ratio were 18:1, the break-even price would be at 5.0%

As shown, assumes a Near-term MR/LH scenario:
- 1 million miles,
- 8 mpg,
- 25:1 urea-to-diesel ratio
- $1,000 more for competing technology

<table>
<thead>
<tr>
<th>Diesel Price ($/gallon)</th>
<th>Urea Price Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.45</td>
<td>$0.50 - $1.00</td>
</tr>
<tr>
<td>$1.60</td>
<td>$1.00 - $1.50</td>
</tr>
<tr>
<td>$1.75</td>
<td>$1.50 - $2.00</td>
</tr>
<tr>
<td>$1.90</td>
<td>$2.00 - $2.50</td>
</tr>
</tbody>
</table>
Conclusions

• It is feasible to provide urea to a large fraction of the truck SCR-urea consumers (65% to 97% urea consumption) at prices that are cost-competitive with competing emission control technologies.

• The cost of retailing urea will depend on the urea throughput at each station.

• Urea throughput at a station will be determined primarily by two factors:
  – the SCR technology that drives the urea/diesel consumption ratio
  – the market penetration of SCR technology

• Larger stations can obtain urea at lower cost, thus putting a downward pressure on sale price.

• If smaller stations cannot afford to provide urea at a price that truck operators are willing to pay, then those stations will either lose their market share to other stations, or be forced to operate at lower margins.
Conclusions

- On-road SCR-urea infrastructure should be initially concentrated on the larger diesel fueling stations (with diesel throughput between 200,000 and 2,000,000 gallons/month. These mid- and high-volume stations comprise 65% - 77% of the projected on-road SCR-urea consumption market.

- Major for-hire truck operators that fuel at both private and public fueling facilities should be involved in early adoption of the technology and the infrastructure

- These truck operators can implement the infrastructure at their private fueling facility and leverage their commercial fueling contractors (truck stops, cardlock stations) to implement the infrastructure

- Strong signals regarding manufacturer intentions to provide SCR-equipped trucks would need to be sent to truck operators and other stakeholders starting 3rd quarter 2003 and no later than mid-2004
Conclusions

- Economics favor the SCR/urea technology over the alternative emission control technology for most applications of long-haul and vocational trucks in the long-term (MY2010+).

- Economics also generally favor the SCR/urea technology over the alternative emission control technology in the near-term (MY2007-09) if early engines have a high fuel penalty (~9%) relative to SCR.

- Truck operators will incur increased operational cost due to urea consumption. In the early years (MY2007-09), this may be partly offset by increased fuel economy as afforded by higher engine out NO\textsubscript{x} levels. In later years, high diesel-to-urea consumption ratios will lower total urea consumption significantly.

- The critical path to implementation of the urea infrastructure requires that decisions to proceed with the SCR/urea technology must be made by the third-quarter of 2003.
SCR-Urea Implementation Strategies

Agenda

1. Project Overview
2. Task 1 — Determine Market Structure
3. Task 2 — Urea Cost Model Framework
4. Task 3 — SCR Urea Cost Model
5. Task 4 — Critical Path Analysis
6. Task 5 — Potential Business Cases
7. Conclusions
8. Next Steps
Next Steps

- For the successful implementation of the SCR/urea technology, the engine manufacturers should have a concerted strategy. Such an approach has been taken in Europe where SCR/urea technology is being implemented as the sole NO\textsubscript{x} control technology for heavy duty trucks.

- Once the SCR strategy is determined, truck operators who will become buyers of the urea and the technology must be involved in the infrastructure implementation strategy.

- Key truck operators must be identified to become early adopters of the technology. Characteristics of these operators will include that they are major for-hire companies with large central diesel fueling stations as well as have contracts with truck stops.
Next Steps

• The SCR implementation strategy (i.e., MY2007 vs. MY2010) needs to be determined. For example:
  – If only 50% of the market implements SCR in MY2010, low urea consumption rate may allow operators to refill at service intervals rather than fueling intervals. Under this scenario, the SCR-urea infrastructure could resemble the lube oil distribution infrastructure, supplying urea to maintenance yards where urea tanks are refilled at the appropriate service intervals.
  – If 50% of the market implements SCR in MY2007, the higher throughput levels would support the establishment of retail station urea infrastructure.

• Thus, the size of the urea market must be further refined to accurately convey the demand for SCR-urea to all downstream stakeholders such as the urea manufacturers, distributors, and retailers.
The following contacts were initiated and are ongoing to obtain input and data for Tasks 1-3 and the overall project

- EMA SCR-urea committee members
- Mr. Bill Gouse, ATA
- Ms. Tracy Embree, FleetGuard
- Ms. Sharon Corigliano, NATSO Foundation
- Dr. Adam Schubert, BP
- Mr. Jeff Herzog, US EPA
- Mr. Fred Kirchner, PetroNJ

- Mr. George Strickland, Director of Engineering/Construction for TravelCenters of America
- Mr. Anders Hedgren, IDENTIC (Sweden)
- Gilbarco, Marketing Division
- Mr. David McClure, Petro Stopping Centers
- Mr. Jerry Kroon, Agrium
A bimodal distribution as shown here, was developed to profile the truck stops. \(0.78F_1 + 0.22F_2 = 290,000 \text{ gal/month}\), where \(F_1\) and \(F_2\) are average throughputs for each segment.

The use of an average throughput of 290,000 gal/month leads to an average annual consumption of 22 billion gallons of diesel. An estimate of the same using the VIUS 97 database indicates that the annual diesel consumption in this segment (HD, truck stops) is around 19 billion gallons.

This distribution was applied to all refueling stations: truck stops, cardlocks, and private central fueling stations. The total diesel fuel consumption for all of these stations for 2002 adds up to 31.8 billion gallons. The VIUS database estimates 31 billion gallons for these stations in 2002.

Sources: EPA, NATSO, ATA, VIUS97

---

### Monthly Diesel Fuel Throughput (gallons/station)

<table>
<thead>
<tr>
<th>Fuel Throughput Range</th>
<th>Number of Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>2,000,000</td>
<td>1,300,000</td>
</tr>
<tr>
<td>1,300,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>1,000,000</td>
<td>300,000</td>
</tr>
<tr>
<td>300,000</td>
<td>200,000</td>
</tr>
<tr>
<td>200,000</td>
<td>140,000</td>
</tr>
<tr>
<td>140,000</td>
<td>80,000</td>
</tr>
<tr>
<td>80,000</td>
<td>10,000</td>
</tr>
<tr>
<td>10,000</td>
<td>100</td>
</tr>
</tbody>
</table>

**Total Number of Stations**: 32,509

**Total Diesel**

- **gallons/month**: 2.6
- **gallons/year**: 31.8
Given the distribution of throughput at fueling stations, the anticipated urea consumption per station was calculated for each throughput range.

The proportion of the total fuel throughput for each range was applied to the total urea demand for the years indicated.

<table>
<thead>
<tr>
<th>Monthly Diesel Fuel Throughput (gallons/station)</th>
<th>Number of Stations</th>
<th>Monthly Urea Throughput (gallons/station)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Low</td>
<td></td>
<td>2007 2015</td>
</tr>
<tr>
<td>2,000,000 1,300,000</td>
<td>310</td>
<td>15,143 10,747 50,411 28,944</td>
</tr>
<tr>
<td>1,300,000 1,000,000</td>
<td>1,128</td>
<td>11,525 8,179 38,365 22,028</td>
</tr>
<tr>
<td>1,000,000 300,000</td>
<td>515</td>
<td>5,155 3,658 17,161 9,853</td>
</tr>
<tr>
<td>300,000 200,000</td>
<td>262</td>
<td>2,334 1,657 7,771 4,462</td>
</tr>
<tr>
<td>200,000 140,000</td>
<td>2,436</td>
<td>1,667 1,183 5,548 3,185</td>
</tr>
<tr>
<td>140,000 80,000</td>
<td>1,115</td>
<td>1,148 815 3,823 2,195</td>
</tr>
<tr>
<td>80,000 10,000</td>
<td>2,491</td>
<td>213 151 709 407</td>
</tr>
<tr>
<td>10,000 100</td>
<td>24,251</td>
<td>8 6 27 16</td>
</tr>
</tbody>
</table>
SCR-Urea Implementation Strategies  Tasks 2 & 3  Assumptions & Steps to Urea Cost Model

Summary of assumptions and steps leading to the urea cost model development

- Based on the EMA data, diesel consumption for new SCR trucks and the potential urea consumption over the years 2007-2015 was estimated.

- Truck stops, cardlocks, and central fueling station populations and diesel throughput profiles were developed. We assumed that the cardlocks and central fueling stations are a subset of the truck stop profiles - i.e., cardlocks with an average diesel fuel throughput of 80,000 gal/month and central fleet stations with an average diesel fuel throughput of 25,000 gal/month fall into the first mode of the truck stop distribution profile.

- Urea consumption was estimated based on the assumptions stated earlier and the new SCR truck data for 2007-2015 provided by EMA.

- We assumed that the urea throughput at a fueling facility will scale directly with the diesel throughput. The fraction is the same as the overall fraction of SCR to non-SCR trucks’ diesel consumption ratio. The overall HD truck diesel consumption for each year is estimated using the VIUS database as the reference point. SCR HD truck diesel consumption is estimated using the EMA data.
Higher urea cost would increase the projected SCR-urea prices

- Initial cost analysis assumed urea cost $122 per short ton, the historical average price for urea.
- Natural gas prices are expected to remain high, leading to an average urea price of $200/ton in the timeframe considered here.
- A urea price increase from $122 to $200/ton increases the on-road SCR-urea retail price by $0.12 per gallon.
- Based on discussions with urea manufacturers, 70% urea melt and granular urea prices will not differ. Although their prices were originally assumed different, this correction would not affect the range of prices shown.

SCR-urea Price During First Year of Implementation*

* Shaded box represents range of SCR-urea prices if urea costs $122/ton urea. The dashed lines represent the expansion to that price range if urea costs increase to $200/ton.
SCR-Urea Implementation Strategies  Task 5  Urea Consumption Assumptions

The *break-even SCR-urea price* was determined over a representative set of parameters.

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>2007</th>
<th>2010</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>overall</td>
<td>$1.18</td>
<td>$2.39</td>
<td>$3.17</td>
</tr>
<tr>
<td>Class 8B, LH</td>
<td>$1.25</td>
<td>$2.29</td>
<td>$3.48</td>
</tr>
<tr>
<td>Class 8A, MR</td>
<td>$1.22</td>
<td>$2.33</td>
<td>$3.36</td>
</tr>
<tr>
<td>Class 8A, V</td>
<td>$1.28</td>
<td>$2.24</td>
<td>$3.61</td>
</tr>
<tr>
<td>Class 7, MR</td>
<td>$1.18</td>
<td>$2.39</td>
<td>$3.17</td>
</tr>
<tr>
<td>Class 6, V</td>
<td>$1.25</td>
<td>$2.28</td>
<td>$3.50</td>
</tr>
</tbody>
</table>

**Assumptions**

- NOx adsorber fuel penalty
  - 5%  5%  3%  3%  2%  2%
- Price of diesel per gallon
  - $1.50 $1.70 $1.60 $1.80 $1.80 $2.00
- Incremental cost of NOx adsorber unit (wrt SCR unit)
  - -$1,000 $1,000 -$1,000 $1,000 -$1,000 $1,000
- Gallons diesel/gallon urea
  - 18  25  82  131  82  131
- Vocational LH & MR
  - Lifetime (million miles)
    - 0.75  1.00  0.75  1.00
  - Average mpg
    - 4.0  8.0  4.0  8.0

- No fuel penalty was included for SCR systems
- Maintenance costs for NO\textsubscript{x} adsorbers and SCR-urea systems are the same
- Note: large volume stations will be able to provide SCR-urea at a cost less than the price of diesel fuel