ROUSH CLEANTECH

Near Zero Emission Propane Autogas Engines

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Roush at a Glance

Michigan-based

Privately held

Founded in 1976

Over 3,700 employees

Over 2.8 million sq. ft. office/development space

Primary activities:

- Engineering
- Testing
- Prototype Development
- Manufacturing
- Motorsports Management

Enterprise Brand Portfolio

ROUSH Industries
OEM manufacturing, engineering, prototyping and design

Roush Fenway Racing
NASCAR racing team(s)

ROUSH Performance
Industry leading high performance vehicles

ROUSH CleanTech
Propane autogas powered commercial vehicles.

ROUSH CleanTech

- Founded in 2010.
- Dedicated to developing quality alternative fuel solutions.
- Propane autogas focus.
- EPA and CARB certification.
- Platform customization to suit customer needs.
- Reduces operating costs, carbon footprint.
- OEM support through Ford and BPN dealers.
- Creating opportunities for partner companies.
- Using American fuel and American technology.

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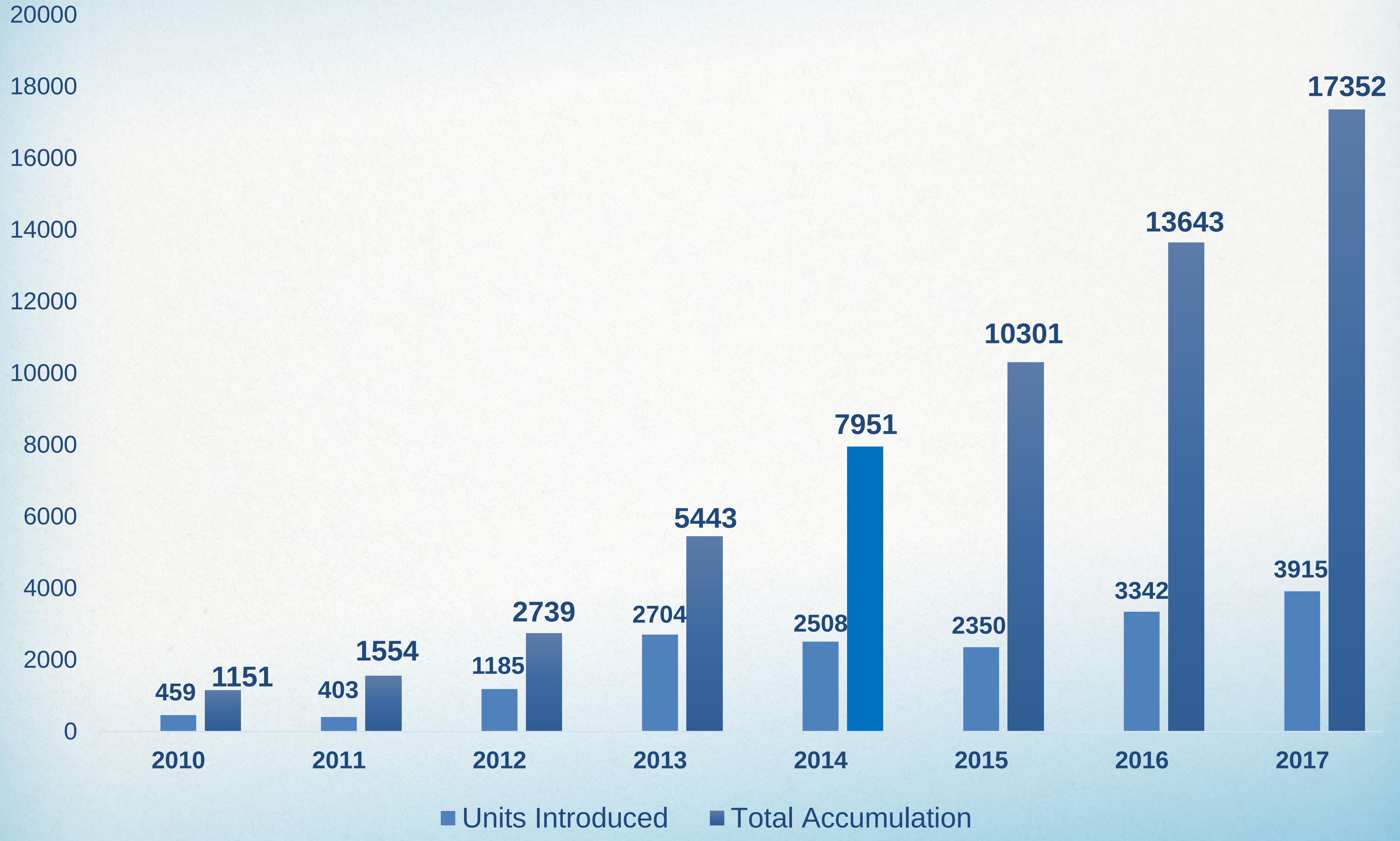
Units in Operation



A Growing Trend

OVER
9,000
SCHOOL BUSES

FORD QVM QUALIFIED VEHICLE MODIFIER

OVER
650
SCHOOL DISTRICTS

Propane Autogas Product Lineup

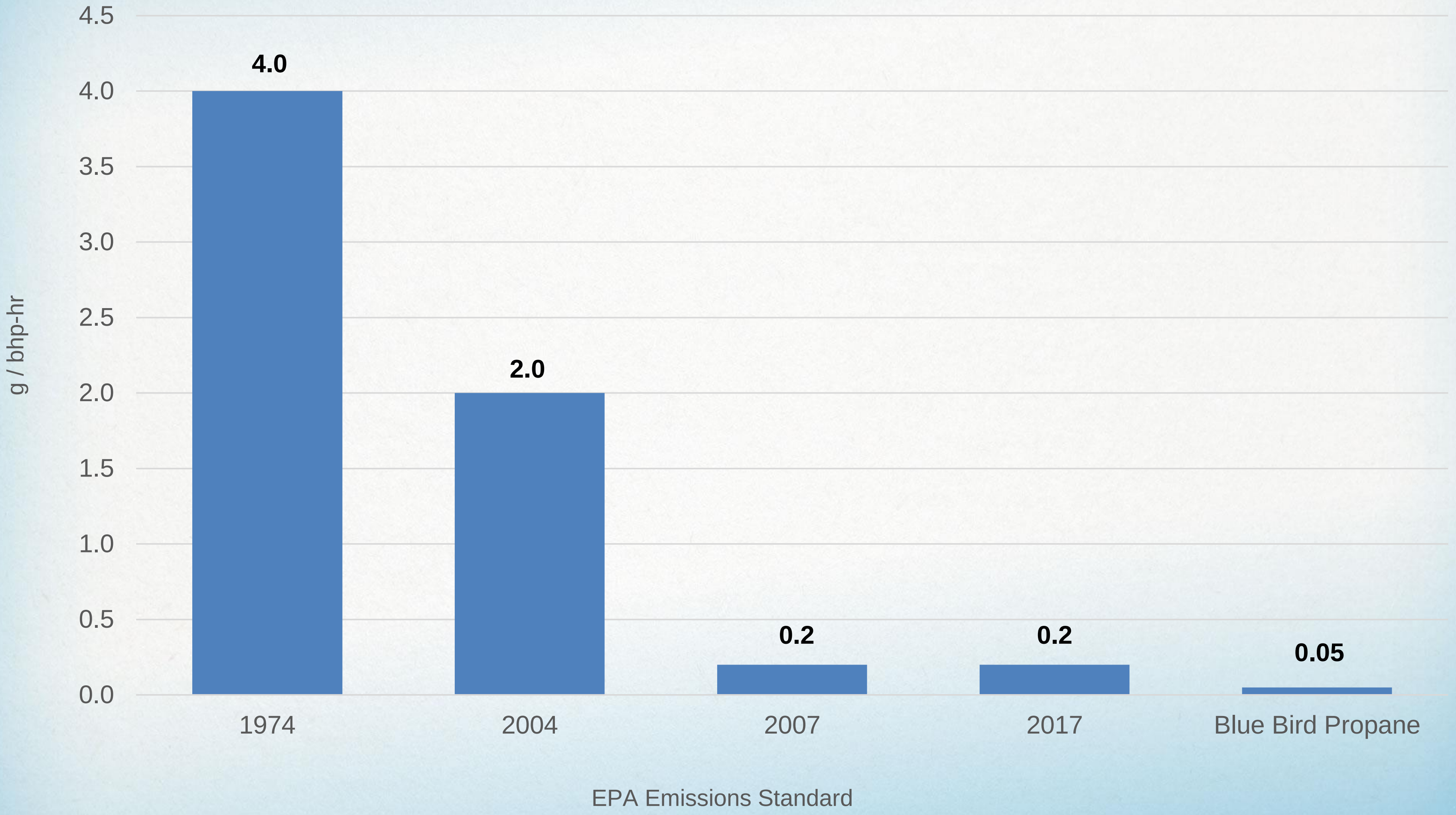
- Medium duty Ford trucks, chassis cabs, cutaways, and stripped chassis; and Blue Bird Type A and C school bus.
- Factory Ford warranty maintained.
- No loss of HP / torque / towing capacity.
- Serviceable with existing diagnostic equipment.
- EPA & CARB Certified.

Ford F-53 / F-59 | Ford E-450 | Ford F-450/550 | Ford F-650/750 | Blue Bird Vision | Micro Bird G5

ULTRA LOW NO_x EMISSIONS

In Heavy-duty Application

Spark Ignition NOx Comparison



Source: https://www.dieselnet.com/standards/us/hd.php#y2004

Drive for Reduced NOx

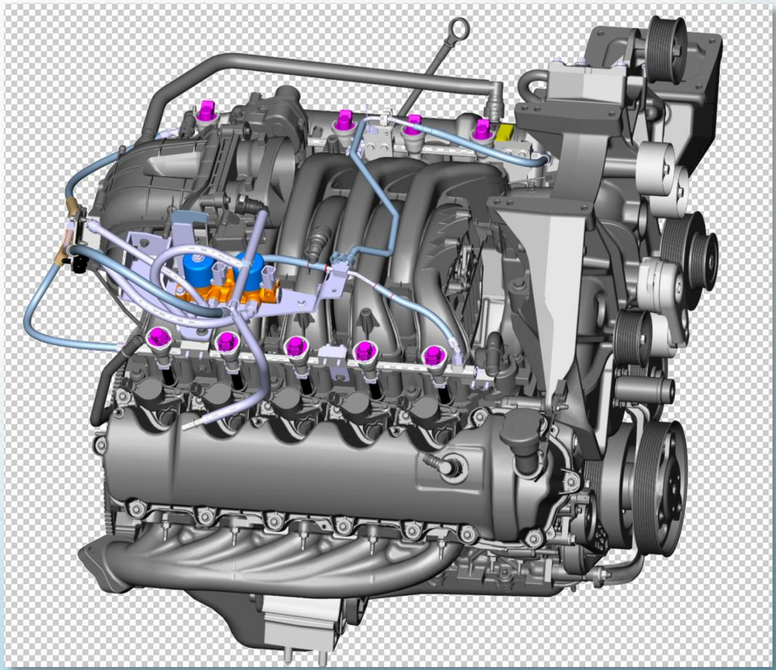
- ARB is encouraging all Manufacturers of Record (MORs) to overachieve on the NOx standard to support smog reduction.
- ARB has issued alternative standards at 0.1, 0.05 and 0.02g/bhp-hr for NOx.
- The recent VW settlement also includes funding that supports NOx reductions across all 50 states that off sets the increase in NOx caused by their diesel emissions.

Production Powertrain

Achievement of Ultra Low NOx starts with a high quality production engine

At ROUSH CleanTech, we start with:

- Ford 6.8L V10 3V Spark Ignition
- Used by Ford in all HD Vehicle applications
- F 450/550 Chassis Cab
- F 650/750 Chassis Cab
- F 53/59 Stripped Chassis
- 320 HP/460 Lbs. Ft
- Close to 2 Million in operation
- Started production in 1997
- For gasoline, meets or exceeds all emissions standards presently through 2017.



Achieve Ultra Low NOx Standards

- Given a solid base of a high quality production powertrain Roush CleanTech then certified the same engine utilizing propane autogas.
  - The ROUSH CleanTech designed fuel control system starts with the PCM as provided by Ford
    - RCT then adds the complete fuel system including the injectors and an add on control module (SRM)
    - Creates a new calibration but maintains normal drivability
  - Initially certified the 6.8L for the 2013MY
  - Meets and exceeds all applicable emissions standards

	CO	CO2	NOx	NMHC
Full Useful Life STD	14.4	627	0.2	0.140

  - Need to significantly over achieve NOx to statistically achieve the standard.

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RCT Status of Low NOx

June 7th 2017 ROUSH CleanTech announces achievement of very low NOx with the 6.8L V10 Engine.

- For the 2017 MY RCT LPG Blue Bird Buses and applicable Ford Truck upfits are now certified to **0.05 g/bhp-hr NOx**.
- This is achieved with **no extra hardware or increased variable cost.**

	CO	CO2	NOx	NMHC
Full Useful Life STD	14.4	627	0.05	0.140
Actual Cert Level	2.7	614	0.03	0.04

- The low NOx levels were achieved through careful, significant calibration changes and a CSSR (cold start spark retard) approach.

Near Zero NOx

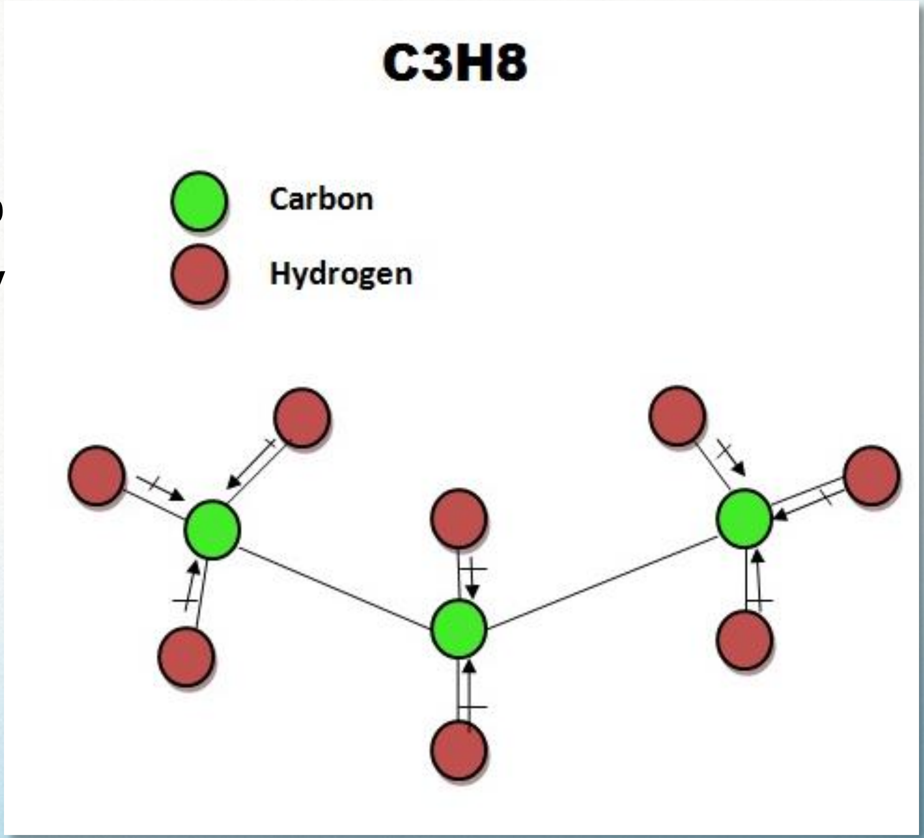
How to achieve Near Zero NOx - the level reported to equal the complete energy balance of a Battery Electric Vehicle

- One engine has thus far achieved 0.02 NOx. The Cummins ISLG NZ running on Natural Gas was the first engine to achieve this level.
- There is a reportedly significant increased cost level associated with the Low NOx versions. Both the L9N and ISX12N utilize increased after treatment and significant EGR to achieve the Near Zero level.
- The RCT 6.8L V10 3V, presently at 0.05 is being studied for the next step to 0.02 utilizing Propane Autogas.

Propane Autogas, does it help?

Advantages of Propane:

- Simple chain of Hydrogen and Carbon
- Relatively easy to break apart
- High Octane fuel
- Recent adds of ethane to about 4%
- Fairly consistent across the country and getting better.
- Widely available



Getting to 0.02 g/bhp-hr

- High NOx levels are generated at a number of points during the cycle.
  - Cold starts – cold CATs
  - Hot Starts
  - Mid cycle breakthroughs during high combustion pressures
  - If the compression ratio of the engine takes advantage of the higher octane levels of Propane, then cylinder pressures are increased, increasing the production of NOx.

- Actions that can reduce NOx
  - Added EGR to reduce mid cycle combustion pressures and reduce pumping loses
  - Faster CAT light off – trade off is FUL
  - Air/Fuel control for tip in tip out excursions.
  - Bias for CO vs NOx
  - CAT functionality through chemical / precious metal variations.

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Cold Starts

- Cold Spark Start Retard (CSSR) – helps heat up the engine and cat quicker to clean up NOx with hotter cat temps. This hurts CO_2 slightly but can be limited to around 1%.

- Spark retard also helps with the feedgas temps. Spark retard will lower peak combustion pressures which will reduce NOx formation.
  - Lower compression engines also with lower peak combustion pressures will help reduce the formation of NOx.
  - Increases in exhaust temps and CO_2 levels are minimal <1%

- Fuel enrichment during cold cat conditions also helps during warm up and is used only on a limited scale.

Hot starts/Hi Combustion Pres.

- During hot start, added some enrichment only for the first 2-3 minutes. Cat is already warm so its impact is limited in time.
  - NOx are usually very low at the Hot start cycle anyway.
  - Using closed loop fuel control to be slightly greater then Stoich.

- More than half of total cycle NOx was being emitted during the high load periods of the cycle
  - Rich excursions on tip out require a lean bias. But if there is a load increase at that time it can result in NOx spike.
  - Also on tip in there is a lean excursion which can cause a spike
  - Closed loop controls and enrichment strategies are required to control these spikes during the power cycles.

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CAT Modifications

- The last step is to improve the catalyst function.

- CATS are cost sensitive to the precious metals used.
  - Platinum
  - Palladium
  - Rhodium
  - Wash Coats
  - Brick size, shape, cone pattern impacting the front of the brick

- Increased in Precious Metals and Washcoats
  - Very effective in improving NOx levels and overall emissions
  - Optimizing the precious metal content can force significant dyno testing, and revised calibrations to take advantage of the metals.
  - New DF and FUL required with the new CAT. But usually the greater wash cost will extend the life

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Beyond 0.02 - Renewable Propane

- Renewable Propane was first formulated in 2014 at the Manchester Institute of Biotechnology.
- The chemical composition of what has been produced so far is the same as propane that was derived from Natural Gas or petroleum.
- HD-5, must be 90% Propane, the formulation is not different than normal.
- Neste MY (Rotterdam) is one of the leading producers of renewable propane in Europe. They have a contract to supply 160,000 tones over the next 4 years.
- Untested, but if the formulation and attributes are the same, the ability to certify to the low NOx standards with Renewable Propane should be the same as conventional propane.

THANK YOU

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Background

- Emission control catalysts are typically manufactured by applying washcoat onto catalyst supports. The washcoat, which serves as the carrier for a precious metal catalyst, is a porous refractory oxide layer which is applied to the substrates from an acidified aqueous slurry, dried and calcined. Aluminum oxide is the most common washcoat material. Other materials, used either as catalyst carriers or as promoters and stabilizers, include silicon oxide, cerium dioxide, titanium dioxide, zirconium oxide, and zeolites.

background

- Precious metal catalyst(s) may be either present in the washcoat slurry, or else are applied in a second step called *impregnation*. During the impregnation, the washcoated monolith is exposed to a water-based solution containing catalytic precursors. The supported catalyst is then dried and calcined to its final form. During the calcination, the catalyst precursors decompose to form the final catalyst, usually a metal or a metal oxide. The most common catalysts are platinum group metals (PGM) such as platinum itself (Pt), palladium (Pd) and rhodium (Rh).