Thus the authors note that the improvements in the performance of engine hydrocarbon light-off, observed for palladium-only catalysts when used in conjunction with a secondary air-pump, are due to the present generation of gasoline engines emitting a higher proportion of olefinic hydrocarbons from utilising the currently available fuel specifications.

The performance of three metal autocatalyst systems was also considered in this paper. The authors noted that to combine platinum, palladium and rhodium into one catalyst would involve complex impregnation techniques. Therefore for this study combinations of different metal catalysts within the vehicle exhaust system were evaluated. Results indicate that the best conversion performance for carbon monoxide and hydrocarbons is achieved with those systems that place a palladium catalyst first, but the best compromise for simultaneous conversion of carbon monoxide, hydrocarbons and oxides of nitrogen is achieved by using a platinum-rhodium catalyst followed by a palladium-only catalyst. Within the context of European legislative requirements it was demonstrated that a platinum-rhodium catalyst followed by a palladium-rhodium catalyst gave the best results. However, in the context of United States legislative requirements it is noted that a single catalyst combining all three noble metals gives the best vehicle test results.

The Congress held this year has shown the determination and capability of the automobile manufacturers to meet the forthcoming stringent emission standards. It has also demonstrated that the use of platinum group metals can meet this challenge for application in vehicle exhaust systems. C.J.

Encapsulation of Palladium Crystallites in Carbon

The growth in carbon nanotechnology has produced carbon in the form of giant clusters, large nested fullerenes, bamboo-like structures and nanotubes. Metals and metal carbides have been successfully included into these structures, and carbon clusters in tubular form encapsulating a metal are expected to result in new technology. However, encapsulating a metal has generally been selective with respect to the metal.

Palladium is an important catalyst and is used in many chemical reactions, often supported on carbon. Now a researcher at the DuPont Company in Delaware, has succeeded in encapsulating cubic palladium crystals inside giant carbon clusters and produced worm-like carbon nanotubes ("nanoworms") (Y. Wang, "Encapsulation of Palladium Crystallites in Carbon and the Formation of Wormlike Nanostructures", *J. Am. Chem. Soc.*, 1994, **116**, (1), 397–398).

The carbon-encapsulated palladium was found in the cathode deposit produced from arcing between a hollow carbon anode filled with palladium oxide/graphite cement paste and a carbon cathode within a chamber filled with flowing helium at 500 Torr. The ratio of the palladium oxide:carbon, in weight per cent, was from 0.05 to 1.0. The worm-like structures were mainly observed in the core of the cathode deposit and rarely found in the shell.

Deposits formed at the tip of the cathode were analysed by transmission electron microscopy. The head region of the "worm" was examined by energy dispersive X-ray analysis and was found to consist of palladium encapsulated in carbon clusters; electron diffraction of the body of the "worm" showed that it consisted of many sections of carbon tubes 20–50 nm in diameter and several hundred nanometres long. The tubes had mostly cone-shaped internal voids, with the tip of each void always pointing to the back of the worm.

Palladium appears to act as the seed for the growth of the "nanoworm"; the cone-shaped internal void being the result of tube closure caused by pentagonal ring formation due to the presence of palladium. Each closure is followed by new growth from the outer layer which forms the next section. This periodic tube closure and regrowth eventually produces the worm-like structure. Some worm-like bodies were without palladium in the head, but the internal cone-shaped voids indicated that palladium had once been present.

As it is already known that chemical methods and electron beam radiation can open the ends of nanotubes and nanowires it is suggested that such carbon-encapsulated palladium could become very useful. The carbon protects the palladium in a pristine form and only needs to be able to release it periodically under controllable conditions. This would allow the palladium to be introduced into a chemical reaction with regulated and timed release.