**Historical perspective:**

Direct-injection spark-ignited four-stroke engines have been and are of interest because:

1. They have the potential for very lean operation.

2. They might operate unthrottled (or less throttled) at part load.

3. They would not be, or would be less, knock limited.

4. They should have higher volumetric efficiency since charge heating can be minimized, and charge cooling through fuel vaporization is feasible.

5. They should have better start-up and dynamic response characteristics.

6. Some concepts might use a less refined petroleum-based fuel.
Emissions from GDI Spark-Ignition Engines

1. In homogeneous mode (early injection), emissions mechanisms and rates similar to standard engine.

2. In lean stratified mode:
   (a) HC are higher due to lean flame quenching
   (b) NO is high due to close-to-stoichiometric flame propagation: needs EGR.
   (c) CO low, but higher than when premixed at same \( \lambda \).
   (d) Particulate emissions higher.

3. Catalyst requirements:
   (a) Homogeneous (stoichiometric) uses TWC.
   (b) Stratified lean operation needs a lean NO\(_x\) trap which is regenerated by periodic rich engine operation. Very low S fuel.
TOTAL ENGINE PLUS CATALYST SYSTEM

Baseline: Standard port injected 4-stroke cycle spark-ignition engine operating stoichiometric with some EGR, close coupled oxidation catalyst and spark retard for warm-up, and three-way catalyst. Good potential for low NO$_x$ and HC emissions.

DI options:

1. Homogeneous early injection, stoichiometric, EGR, TW catalyst: increased power density (and hence some improvement in part load efficiency), better start-up and transient performance, low emissions, but higher injection system cost.

2. Lean,stratified late injection at part load; early injection homogeneous at high load as in (1) above. Plus: much better part-load fuel economy. Minus: significantly higher NO$_x$ and HC emissions, fueling control complexity, additional high cost components.
NO\textsubscript{x} CONTROL

1. Part load, lean stratified: high levels of EGR (much of which is “air”) for control of engine-out NO\textsubscript{x}.

Catalyst:

1. NO\textsubscript{x} storage-reduction system. Store NO\textsubscript{x} (as nitrate) when lean; then operate stoichiometric/slightly rich for short period to reduce NO\textsubscript{2} to N\textsubscript{2}. Higher load; stoichiometric three-way catalyst operating mode (Toyota).

2. Lean, selective reduction, catalyst: NO\textsubscript{x} reduced by reaction with hydrocarbons. Claimed less subject to sulfur poisoning (Mitsubishi).

3. Low energy, low temperature, surface plasma system (Ford, AEA UK). Power requirements seem reasonable.