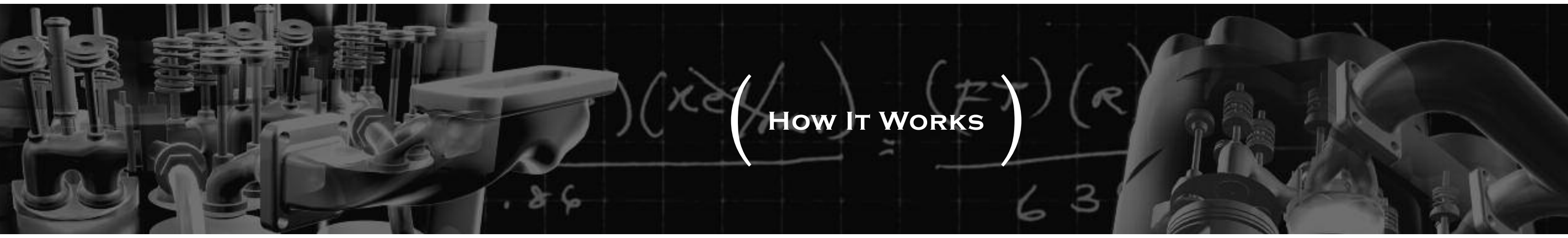
SCUDERI ENGINE

Revolutionary Technology
Evolutionary Design

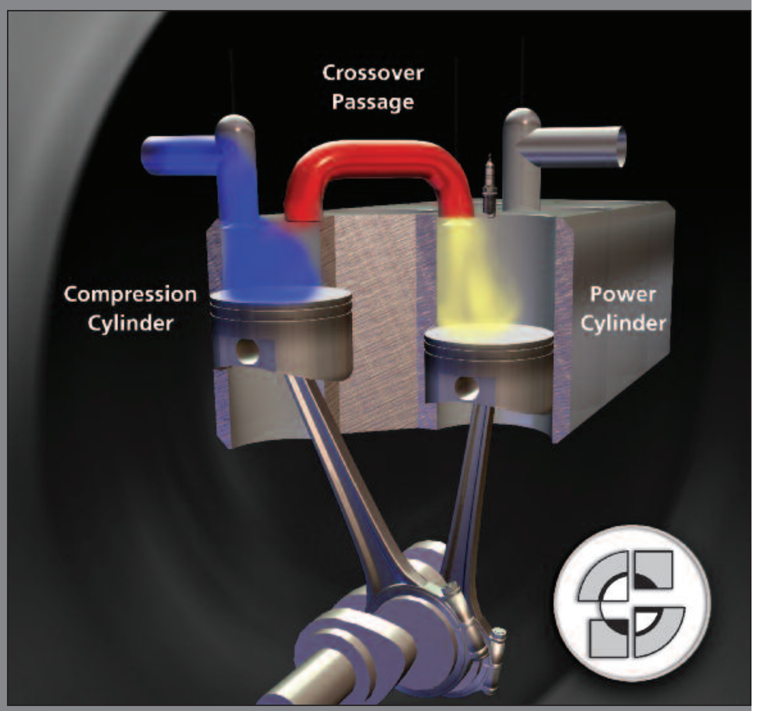


The Internal Combustion Engine's New Era Has Arrived

(Scuderi Powered™)

What's a Split-Cycle Engine?

Split-cycle engines separate the four strokes of intake, compression, power, and exhaust into two separate but paired cylinders. The first cylinder is used for intake and compression. The compressed air is then transferred through a crossover passage from the compression cylinder into the second cylinder, where combustion and exhaust occur. A split-cycle engine is really an air compressor on one side with a combustion chamber on the other.



Previous Split-Cycle Engines

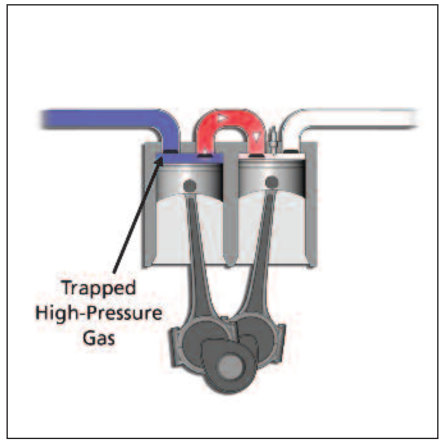
Split-cycle engines appeared as early as 1914. Many different split-cycle configurations have since been developed; however, none has matched the efficiency or performance of conventional engines.

Problems With Previous Split-Cycle Engines

Previous split-cycle engines have had two major problems — **poor breathing (volumetric efficiency)** and **low thermal efficiency.**

Breathing (Volumetric Efficiency)

The breathing problem was caused by high-pressure gas trapped in the compression cylinder. This trapped high-pressure gas needed to re-expand before another charge of air could be drawn into the compression cylinder, effectively reducing the engine's capacity to pump air and resulting in poor volumetric efficiency.

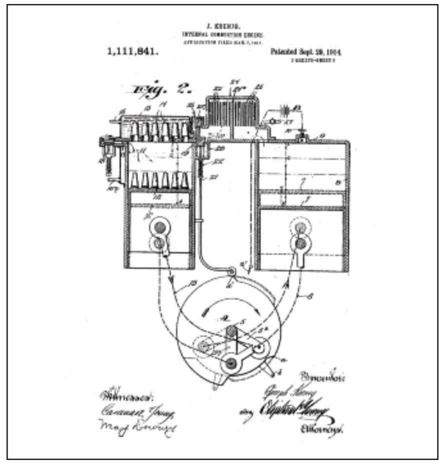


Low Thermal Efficiency

The thermal efficiency of split-cycle engines has always been significantly worse than a conventional Otto cycle engine. The primary reason: They all tried to fire like a conventional engine — before top dead center (BTDC).

In order to fire BTDC in a split-cycle engine, the compressed air, trapped in the crossover passage, is allowed to expand into the power cylinder as the power piston is in its upward stroke. By releasing the pressure of the compressed air, the work done on the air in the compression cylinder is lost. The power piston then recompresses the air in order to fire BTDC.

By allowing the compressed gas in the transfer passage to expand into the power cylinder, the engine needs to perform the work of compression twice. In a conventional engine, the work of compression is done only once; consequently, it achieves much better thermal efficiency.



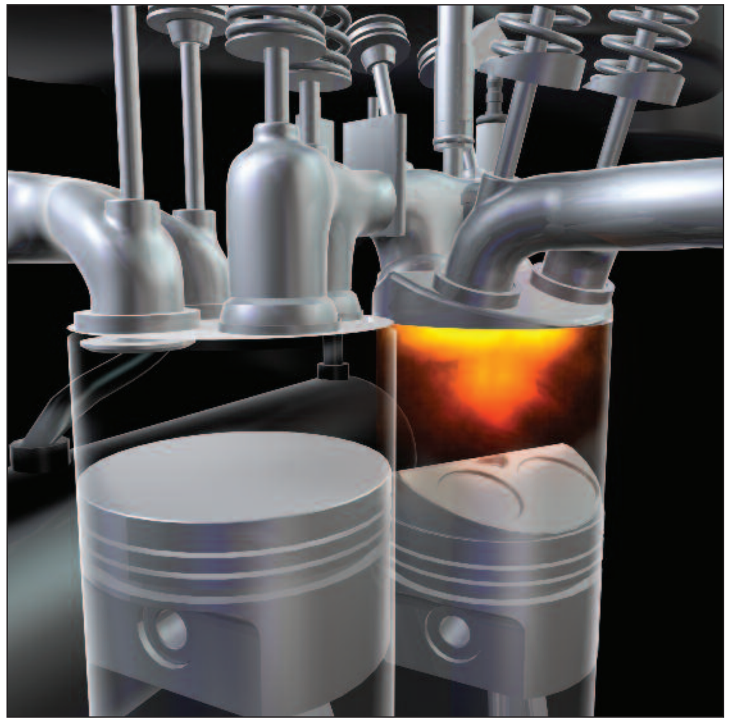
1914 Split-Cycle Patent Drawing

Why is the Scuderi Split-Cycle Engine Better?

The Scuderi Split-Cycle Engine solves both the breathing and thermal efficiency problems with **two unique** and **patented concepts:**

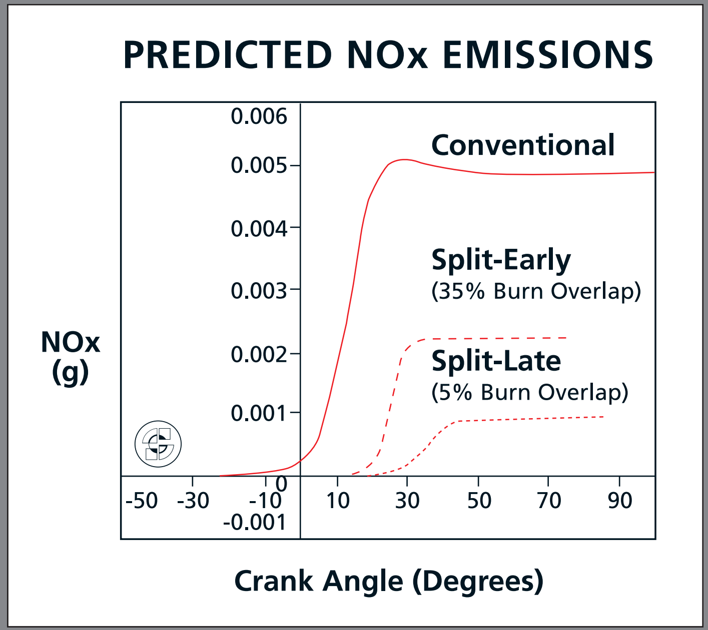
Unique Valve Design

On the compression side of the Scuderi Engine, the breathing problem is solved by reducing the clearance between the piston and the cylinder head to less than 1 mm. This design requires the use of outwardly opening valves that enable the piston to move very close to the cylinder head without the interference of the valves. This effectively pushes almost 100 percent of the compressed air from the compression cylinder into the crossover passage, eliminating the breathing problems associated with previous split-cycle engines.



Solving the Thermal Efficiency Problem — Firing After Top Dead Center (ATDC)

Although considered bad practice in conventional engine design, firing ATDC in a split-cycle arrangement eliminates the losses created by recompressing the gas. The big issue was not how to solve the thermal efficiency problem of the split-cycle engine, but rather how to fire ATDC. In fact, **determining how to fire ATDC is possibly the single most important breakthrough of the Scuderi Engine design.**



High Pressure and Massive Turbulence

In the Scuderi Engine, firing ATDC is accomplished by using a combination of high pressure air in the transfer passage and high turbulence in the power cylinder.

Because the cylinders in a Scuderi Split-Cycle Engine are independent from each other, the compression ratio in the compression cylinder is not limited by the combustion process. A compression ratio in the order of 75:1 is obtained, with pressure in the compression cylinder equal to that of a conventional engine during combustion. The pressure in the compression cylinder and the crossover passage reach more than 50 bar (725 psi) on our naturally aspirated (NA) engine and more than 130 bar (1885 psi) on our turbocharged (TC) engine.

This high-pressure air entering the power cylinder creates massive turbulence. The turbulence is further enhanced by keeping the valves open as long as possible during combustion. The result is very rapid atomization of the air/fuel mixture, creating a fast flame speed or combustion rate faster than any previously obtained. The combination of high starting pressure and fast flame speed enables combustion to start between 11 and 15 degrees ATDC and end 23 degrees after ignition. **The result is a split-cycle engine with better efficiency and greater performance than a conventional engine.**

The Revolution

A Split-Cycle Engine Firing After Top Dead Center (ATDC)

The revolutionary feature of the Scuderi Engine is the combination of a split-cycle design with the combustion process of firing ATDC. This combination is what produces a truly unique thermodynamic process that enables new levels to be reached for both efficiency and power. Its design is elegantly simple, leading to further enhancements that will continue to improve the engine's performance.

The current NA prototype engine demonstrates the viability of the design. It proves that the concept of splitting the cycles and firing ATDC is real, and it is just the start of many design improvements to come.

Developments, Findings and Features of the NA Prototype

Intake and Exhaust Valves Used to Control Engine Load: The intake and exhaust valves are pneumatic valves that are fully variable in both lift and timing. The air needed to operate the valves is provided internally from the compression side of the engine. These valves are used in place of a throttling valve to control the engine during part-load operation.

Crossover Valves: The valves for the inlet and outlet of the crossover passage are cam actuated and are designed to lift outwardly. Air springs are utilized to return the crossover valves with the makeup air for the air springs being supplied internally from the compression side of the engine.

Crossover Passage: The crossover passage is a major control point for the engine. It is utilized for controlling pre-detonation (knock) by providing an additional cooling point after compression has occurred. This is a feature unique to the split-cycle design that is simply not possible in a conventional engine.

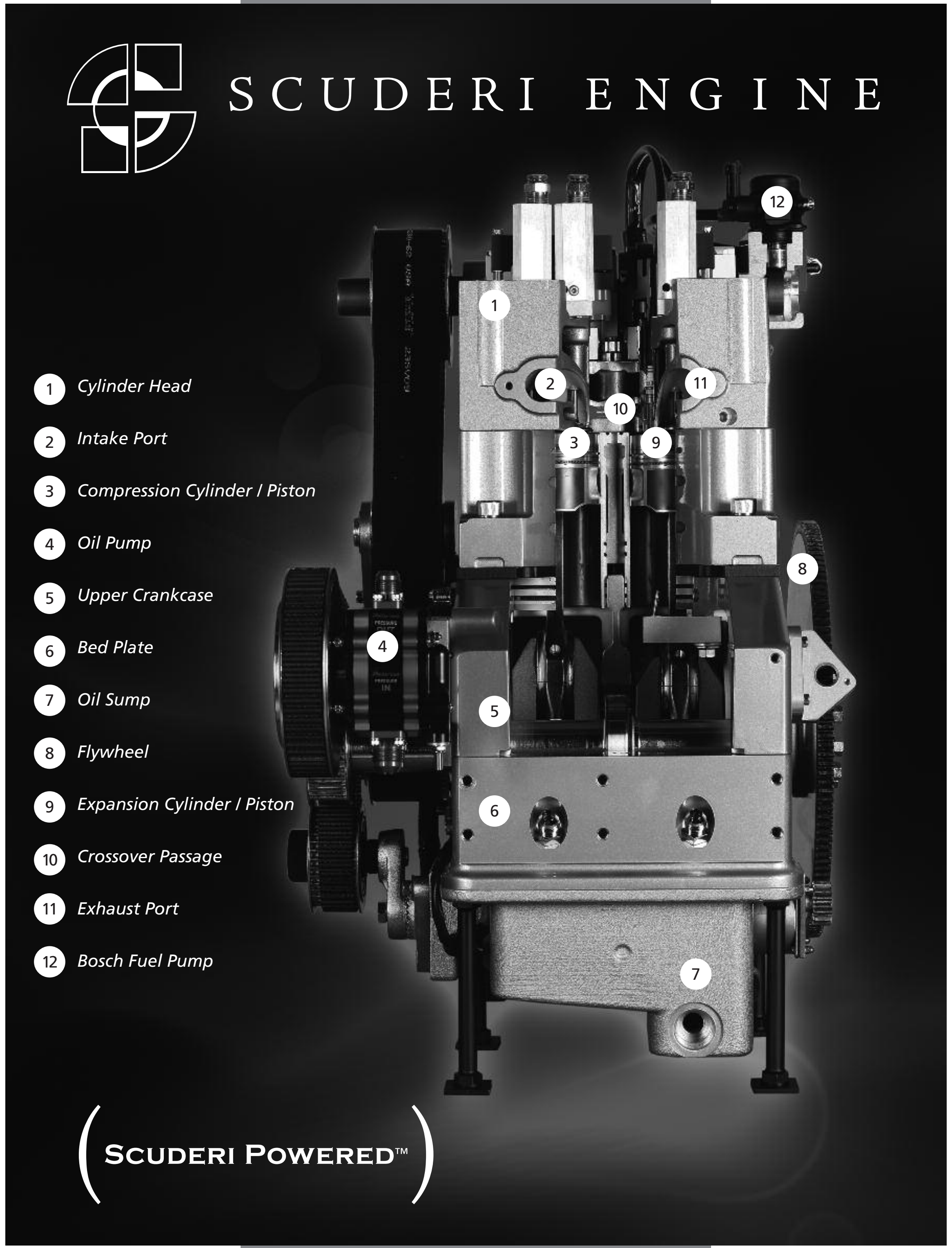
In addition, the configuration of the crossover passage going into the power cylinder has a significant effect on the air/fuel mixing, and the crossover passage design can also play a major role in controlling the engine at part load.

Fuel Delivery System: The Scuderi NA Engine utilizes Bosch injectors configured with a unique spray pattern. These injectors are a high-pressure, direct-injection type operating up to 200 bar. The combination of spray pattern, pressure and injection timing helps to ensure proper air/fuel mixing and prevent fuel from being trapped in the crossover passage.

Unique Power Piston Head Design: This engine utilizes a kidney-shaped depression in the piston head to enhance the air/fuel mixing. This unique design is part of the Company's patent portfolio.

Valve and Ignition Timing: One of the major factors required to obtain a good combustion process is combining valve performance with ignition timing. The Scuderi Engine utilizes a patented valve actuation mechanism that ensures high-velocity airflow into the power cylinder. Our combustion process of firing ATDC is then optimized by controlling the ignition timing of the engine.

Valve Lash Control: The combination of outwardly opening valves with low lift and rapid timing profiles requires a unique lash control device. Our team has developed a patented lash control mechanism specifically designed to accommodate the various operating conditions that the crossover valves will be under.



The Evolution

If the revolution is the Scuderi Split-Cycle Engine firing ATDC, then the evolution is the designs that flow from this unique engine concept.

Turbocharged Split-Cycle Engine

(High Torque, High Speed, Enormous Power, Smaller Engines):

The next step in the development of the Scuderi Split-Cycle Engine is the turbocharged version. Because the crossover passage provides an opportunity to cool the intake air after it is compressed, the Scuderi Split-Cycle Engine has a very high resistance to pre-detonation (knock). This high resistance to knock potentially enables the Scuderi Split-Cycle Engine to boost or turbocharge to more than 2.5 bar absolute pressure. A conventional gasoline engine typically can boost to only 1.5 bar absolute before pre-detonation occurs.

The result is a significantly higher brake mean effective pressure (BMEP) and torque level. In fact, the torque level of the Scuderi Split-Cycle Engine matches or exceeds most turbocharged diesel engines. However, a Scuderi Split-Cycle Engine can potentially obtain rated speeds of up to 6000 rpm. The combination of diesel like torque levels matched with gasoline like speed levels would result in a power density higher than any conventional engine available today. **The Scuderi Split-Cycle Turbocharged Engine has a potential power rating at 6000 rpm of up to 135 hp per liter.**

The Scuderi Engine enables the industry to drastically downsize its engines **(reducing fuel consumption and CO2 emissions)** without compromising performance.

Scuderi Split-Cycle Diesel Engine

(Reduced Emissions)

One of the biggest benefits of the Scuderi Split-Cycle Engine for diesel applications is the reduction in emissions. The tougher emission standards that will begin in 2010 are causing the cost of diesel engines to dramatically increase while performance is being compromised.

The Scuderi Engine's combustion process of firing ATDC has an unusual effect of reducing both soot and NOx. This results from the combustion cylinder in the Scuderi Engine having a higher average temperature but at the same time a lower peak temperature than a conventional engine. The high average temperature, along with the high turbulence in the combustion process, is expected to reduce soot. However, lower peak temperatures resulting from combustion gases rapidly expanding when firing ATDC occurs, reduces NOx emissions by as much as 80 percent.

The Scuderi Split-Cycle Engine offers a unique opportunity to reduce emissions to the new levels without the need for costly after treatment systems.

Promise of the Scuderi Split-Cycle Engine

With the revolution of the Scuderi Split-Cycle Engine firing ATDC and its evolution into the various configurations of naturally aspirated, turbocharged, air-hybrid and diesel designs, the Scuderi Split-Cycle Engine Technology provides a simple but elegant solution to meet today's — and tomorrow's — engine demands for increased efficiency, improved power, downsizing and lower emissions.

Air-Hybrid Design

Because the Scuderi Engine is really a dedicated compressor on one side and an engine on the other, it simply requires the addition of an air storage tank and some controls to convert it into a hybrid system that can capture and store energy lost during the normal operation of the engine.

Since the turbocharged version of the Scuderi Engine operates at 130 bar, it will be able to store a significant amount of energy in its air tank. There are various engine control strategies that can be employed to improve the overall reduction in fuel consumption. This includes engine shutoff at idle, air-only driving, off-loading of the compression cylinder and regenerative braking.

The Scuderi Air-Hybrid provides a cost-effective hybrid solution that does not compromise performance.

P-V Curves

How does storing energy in the form of compressed air increase the efficiency of the system?

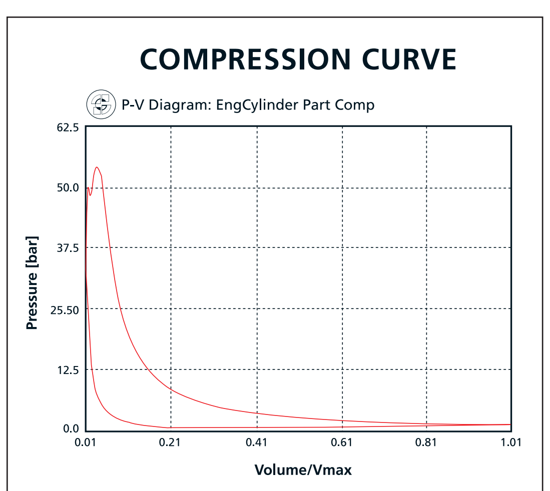
The answer is in the thermodynamics of the pressure and volume changes that are used by an engine to produce mechanical work.

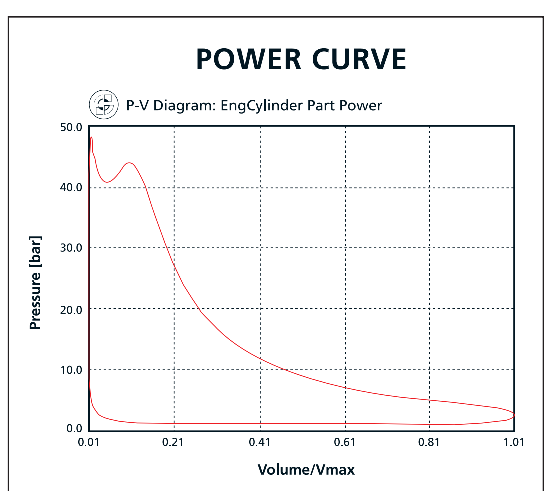
In an internal combustion engine, the two high-pressure strokes of compression and power consume and produce energy. The compression stroke is negative work, or energy that the engine expends to do work on the gas. The power stroke is positive work, or energy that the expanding gases of combustion perform on the engine to create mechanical work.

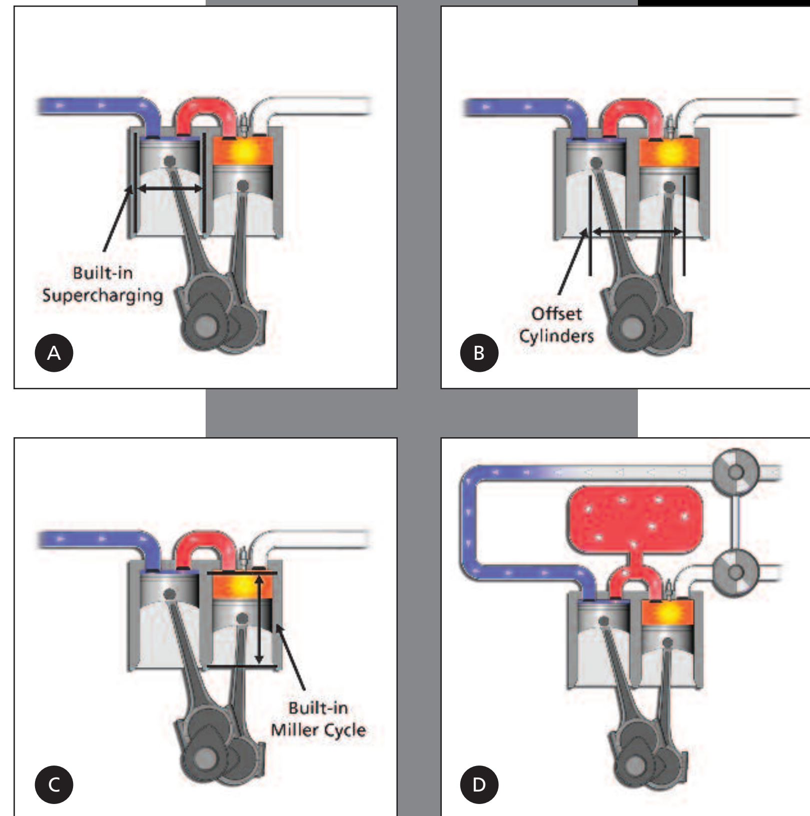
The net energy produced by the engine (its efficiency) is the energy generated during the power stroke less the amount of energy consumed by the compression stroke. The areas inside the curves reflect the amount of energy used or generated during each cycle.

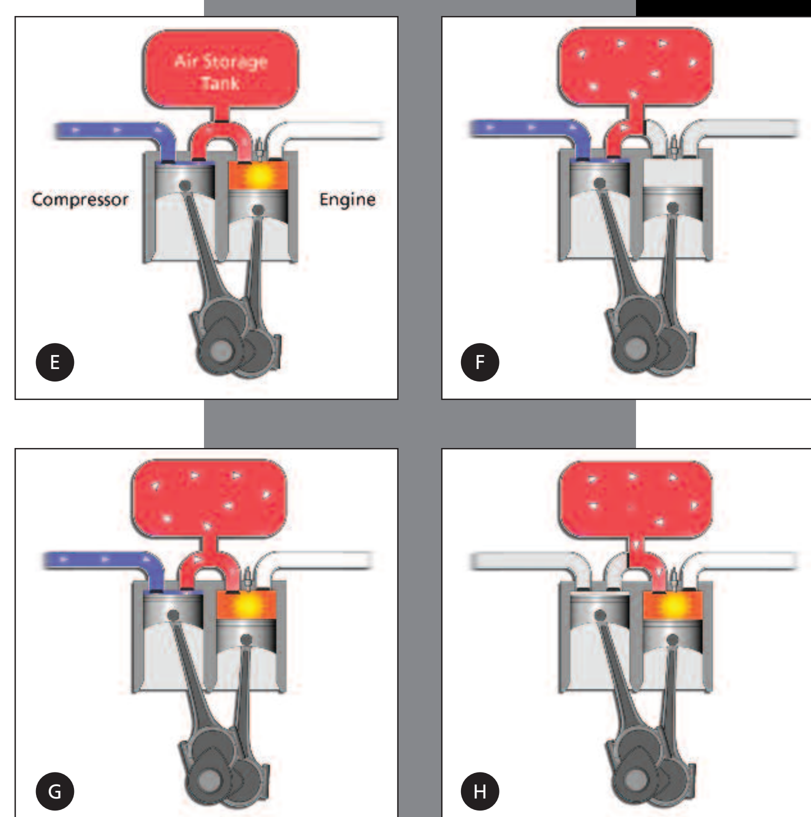
The net energy produced by the Scuderi Split-Cycle Engine is the difference between the two pressure-volume curves.

Whenever the engine is operating on compressed air stored in its air storage tank, the losses due to compression are reduced to nearly zero. The resulting efficiency of the engine under this mode of operation is essentially the total area of the power curve.









Advantages of the Scuderi Split-Cycle Design

A One of the biggest advantages of the Scuderi Split-Cycle Technology is design flexibility. Many features that require additional equipment or are just too difficult to implement in a conventional engine design are easily accomplished with a Scuderi Split-Cycle configuration. For example, supercharging can be added simply by increasing the diameter of the compression cylinder.

B Piston friction can be reduced by offsetting the compression and power cylinders.

C A Miller cycle can be achieved simply by increasing the length of the power cylinder.

D In the Scuderi Split-Cycle Engine, a turbocharger can be used to recover energy from the exhaust of the engine. Pressurized air from the turbocharger is fed into the compression cylinder, reducing the amount of energy needed for compression. The net energy gain provided by the turbocharged operating mode is unique to the Scuderi Split-Cycle Engine and cannot be achieved when using conventional engine technology.

Scuderi Air-Hybrid Engine — The First Hybrid System that Makes Sense

E **Normal Operating Mode:** Because the Scuderi Split-Cycle Engine is a dedicated compressor on one side and an engine on the other, it only requires the addition of an air storage tank and related controls to convert it into a hybrid system that has the ability to capture and store the energy that is normally lost during operation of the engine.

F **Regenerative Braking Mode:** By turning off the power cylinder while the vehicle is still engaged with the engine, and diverting the flow of compressed air to the air storage tank, the momentum of the vehicle continues turning the engine, thereby compressing air and storing it in the storage tank for later use.

G **High-Efficiency Mode:** By turning off the compression cylinder and utilizing high-pressure air from the storage tank to supply the power cylinder, losses due to compression are reduced to nearly zero when operating in the high-efficiency mode.

H **Cruising Mode:** High-efficiency cruising mode is achieved by sending only a portion of the compression cylinder's charge to the power cylinder. The remainder of the charge is sent to the air storage tank for later use. Whenever the air storage tank is full, the compression cylinder shuts off, and the vehicle operates in high-efficiency mode.

SCUDERI GROUP

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