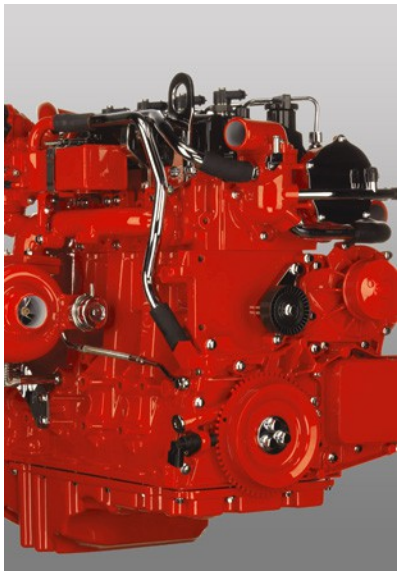
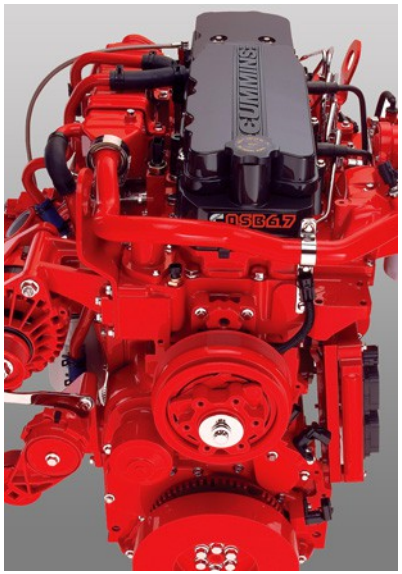
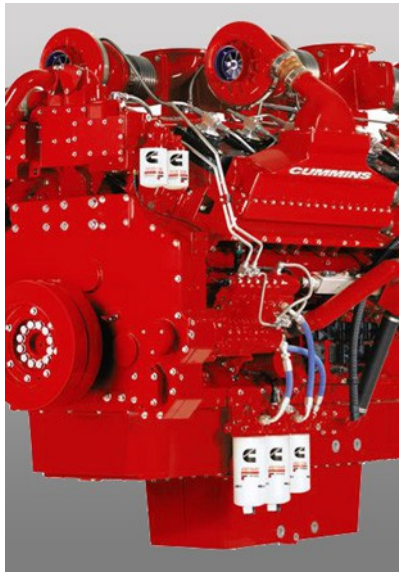
Dual Fuel for Mining:
Same Power, Substantial Savings

Chris Pritchard
Natural Gas Product Manager, Cummins Inc.

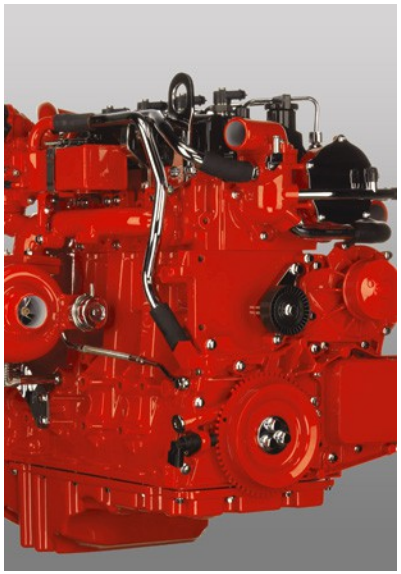



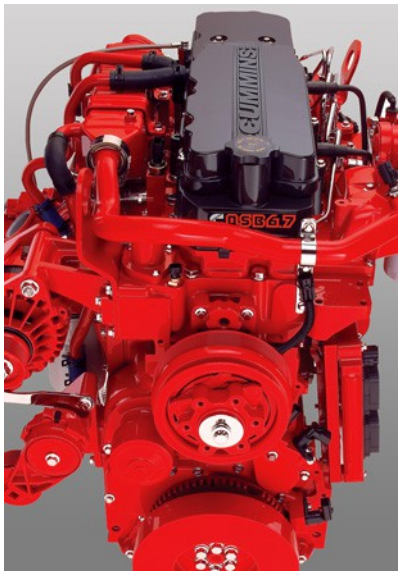


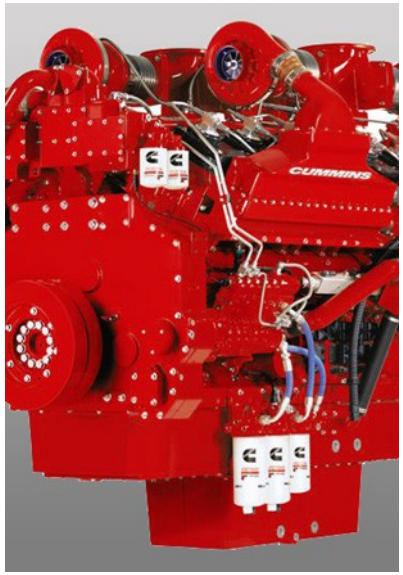
Outline

- What Is Dual Fuel?
  - Why Natural Gas?
  - What Is LNG
  - Alternate LNG Technologies
- How Does Dual Fuel Work?
- Can Dual Fuel Save Money?
- How Do We Prepare For Dual Fuel?

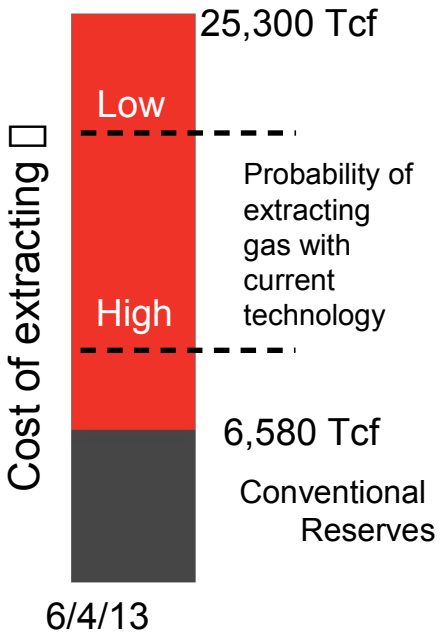
What Is Dual Fuel?

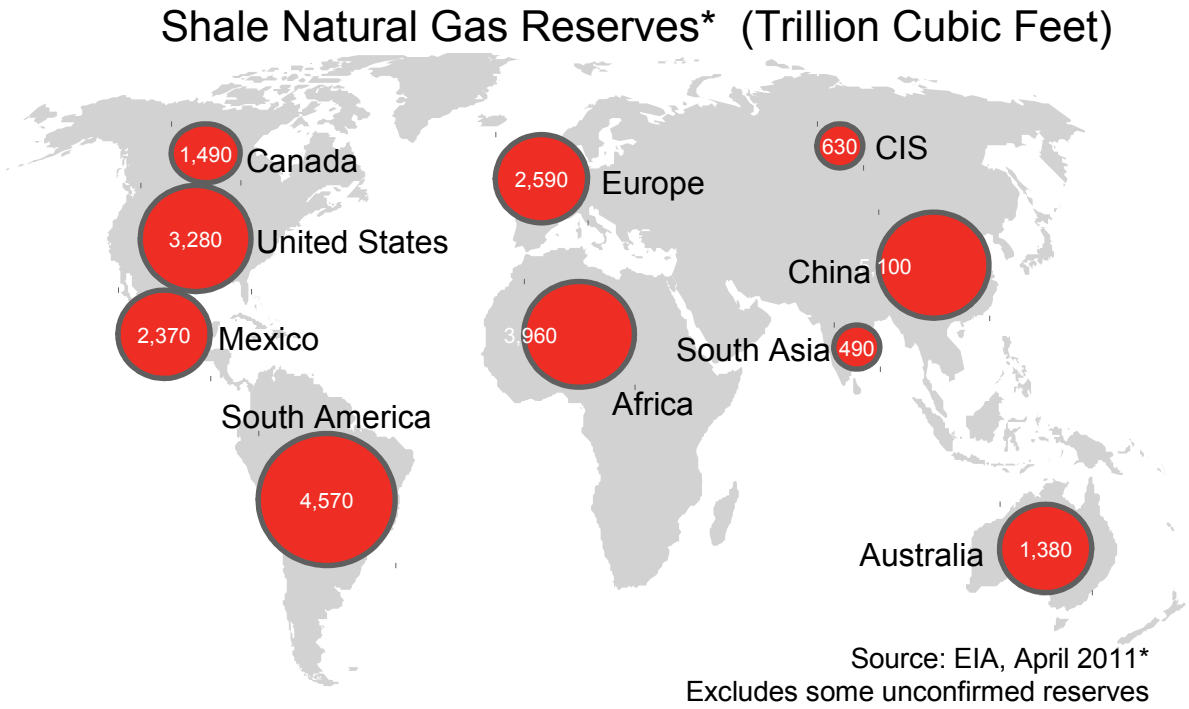






Global Natural Gas Supply



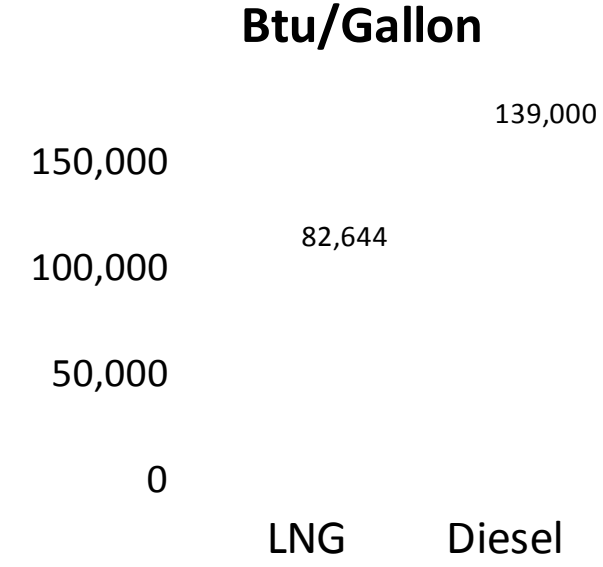


Pressure pumping has dramatically increased global gas reserves and is driving prices down.

LNG supply chains are being developed globally.

What Is LNG: Liquefied Natural Gas

- LNG is composed of mostly methane
  - May have moderate amounts of higher order hydrocarbon
- LNG <u>is not</u> propane
- Lower energy density than diesel
  - About 1/2 including tanks
- Very cold
  - Cryogenic: -260° F



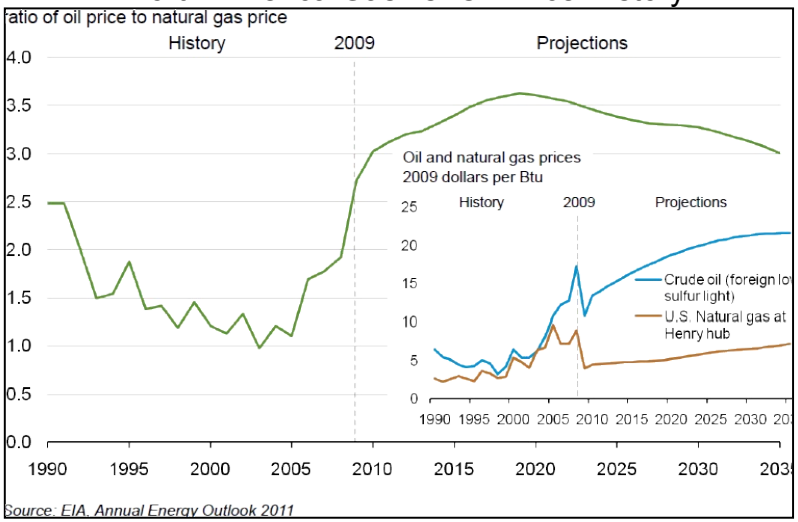
What Is Dual Fuel?

- Allows natural gas to replace diesel fuel during combustion process
  - No loss in performance
  - Matches diesel performance on acceleration, power density
  - Small diesel pilot injection to initiate combustion
- Lower cost of natural gas provides significant cost savings opportunity
  - Magnitude is dependent on gas substitution rate

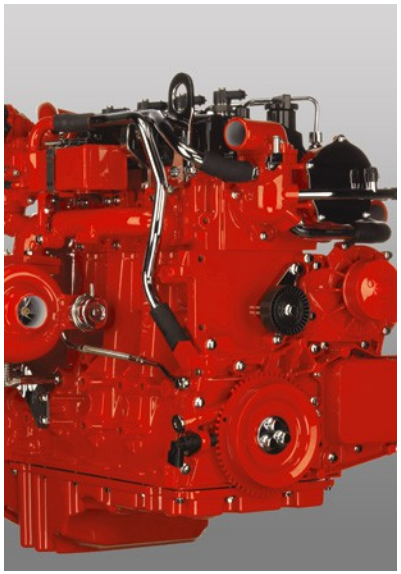
Oil To Natural Gas Price Ratio

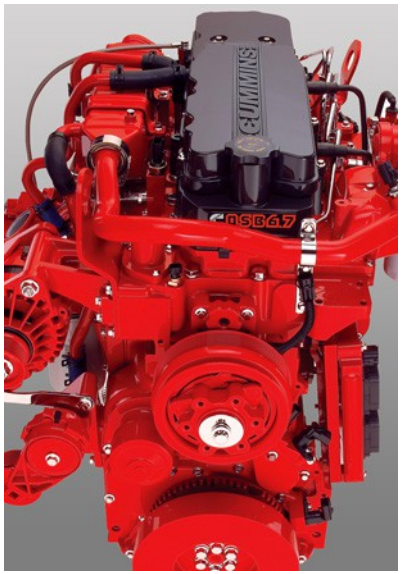
- Diesel to gas price ratio improvements in US will continue, spread globally
- Gas prices will become more standardized globally
  - Increased LNG shipping
  - Spread of oil & gas technology
  - Pressure to move from oil indexed pricing

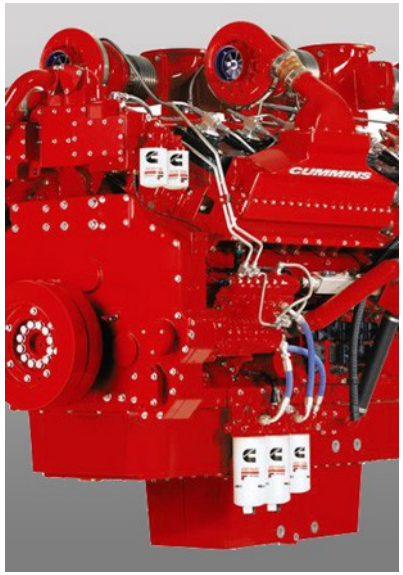
North America Gas vs. Oil Price History



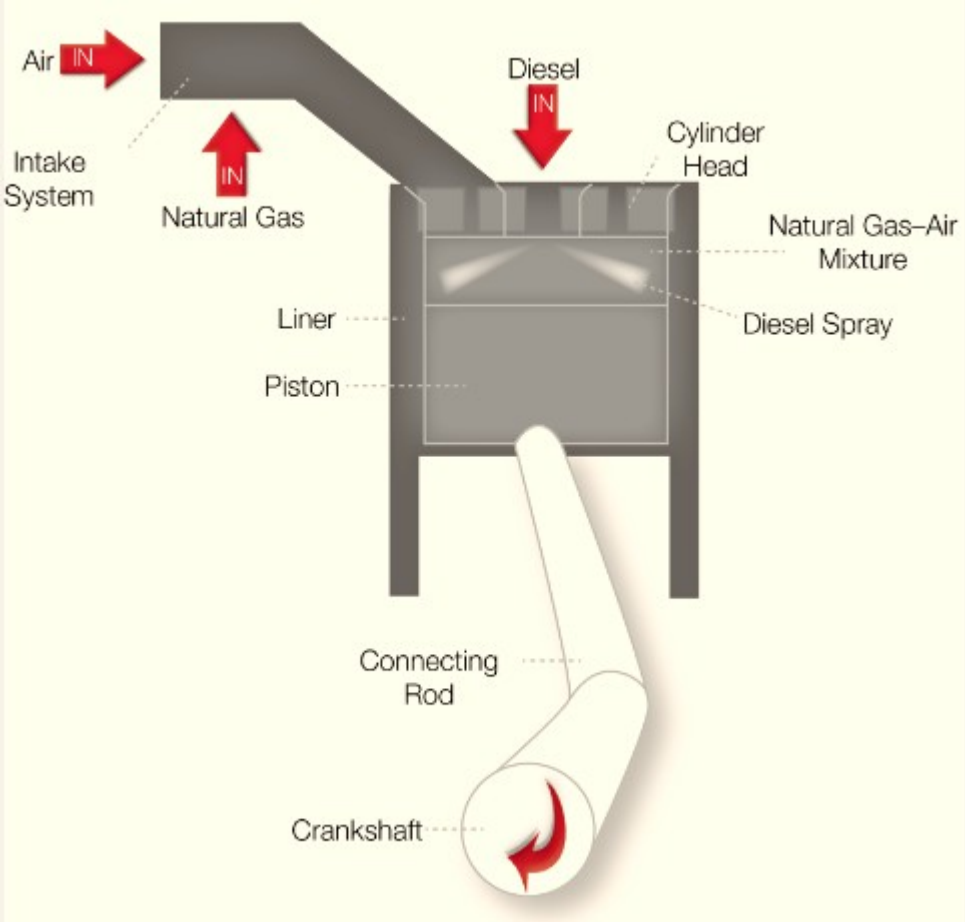
How Does Dual Fuel Work?







Fumigation Dual Fuel Technology

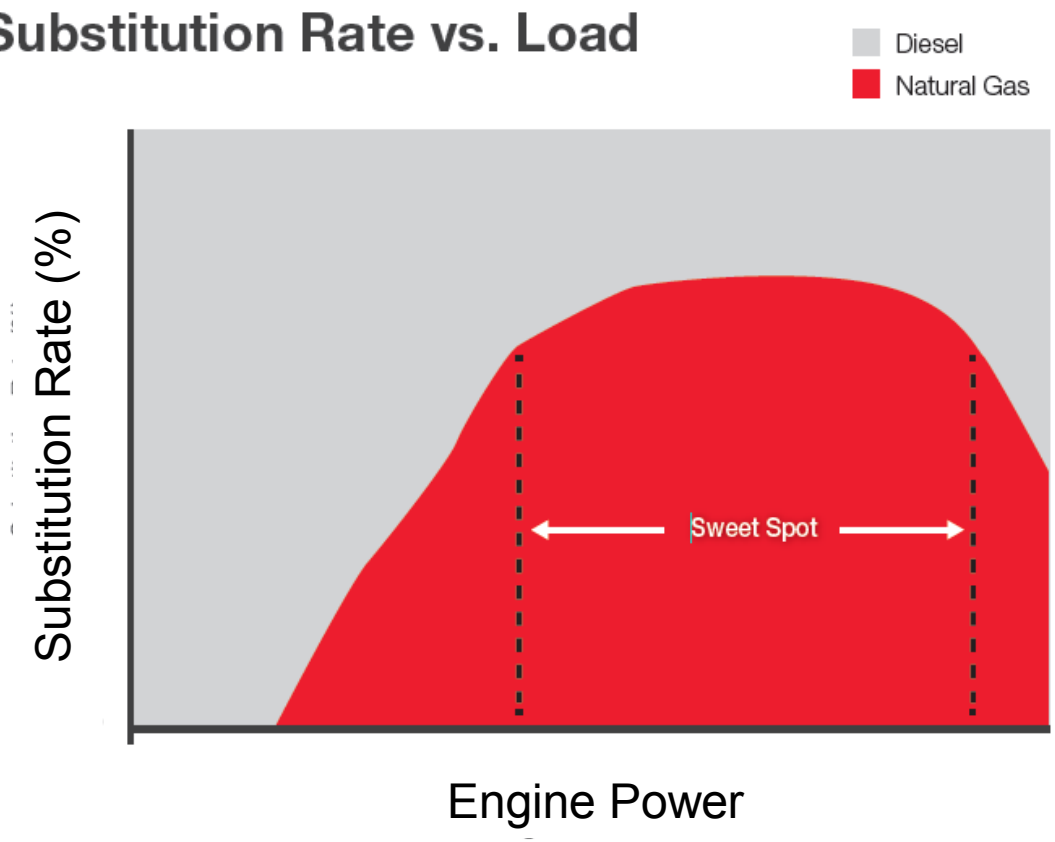


Operation

- Mixes low pressure natural gas with intake air
- Diesel provides ignition source
- Full power on 100% diesel or a mix of gas and diesel
- Matches diesel for power density and transient performance

Substitution Rate

- Varies with load, application and fuel quality
- Fuel cost saving based on average substitution, not peak
- Fuel cost savings vary with substitution rate, diesel price and LNG price



Diesel / LNG Fuel Flexibility

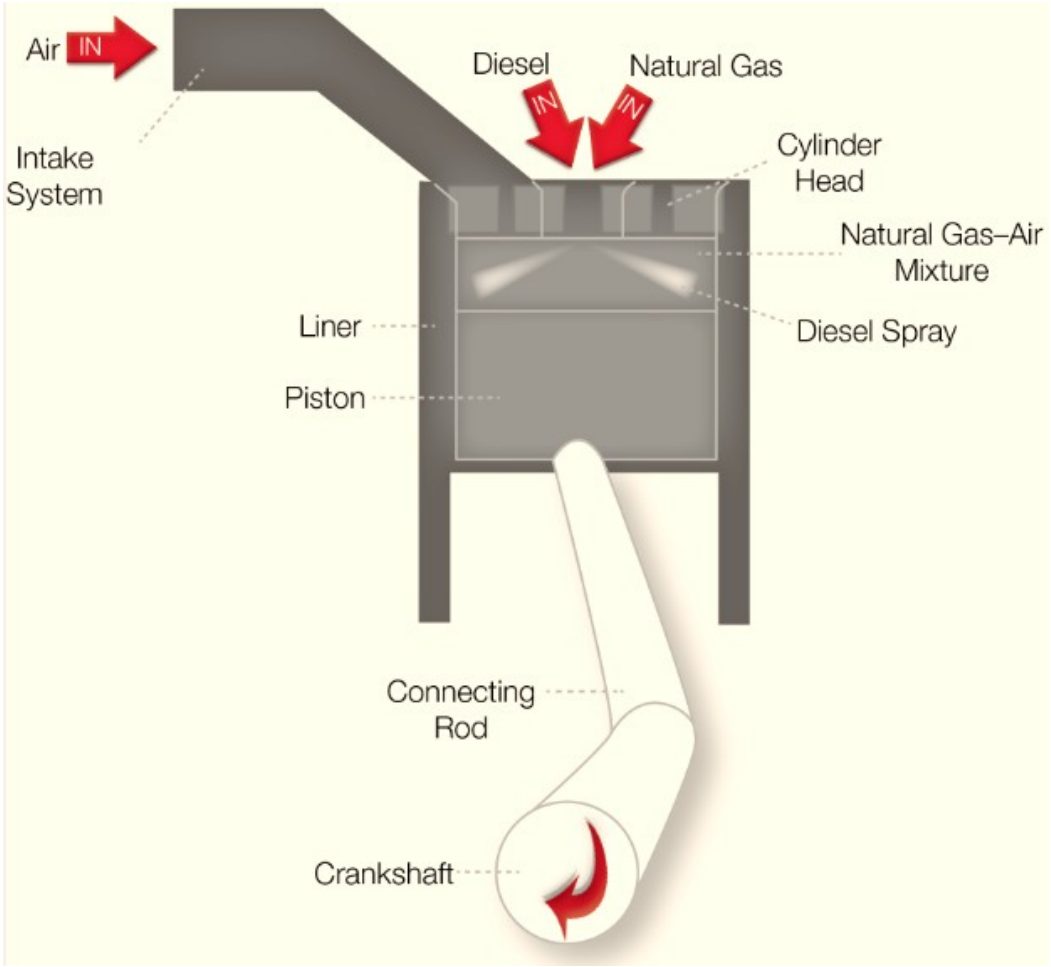
- Fumigation dual fuel engines can run on 100% diesel or a mix of natural gas and diesel
- Allows operators to run in dual fuel mode when gas is available but always have the option to run on 100% diesel when it's not
  - Important in markets where LNG delivery may not be reliable

Constraints to Gas Substitution Rates

- Knock
  - Knock is uncontrolled combustion that can damage an engine in very little time
- Over Temperature
  - Excessive fuel energy from mix of gas and diesel can push engine over desired temperatures and cause failures

Control system must manage balance of diesel and natural gas flow with operating conditions to maximize gas substitution and protect the engine.

High Pressure Gas Injection Technology



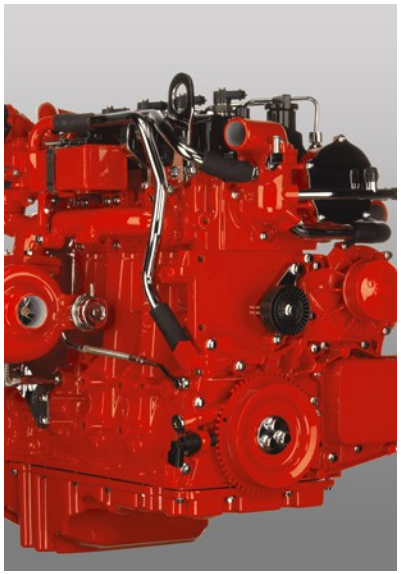
Operation

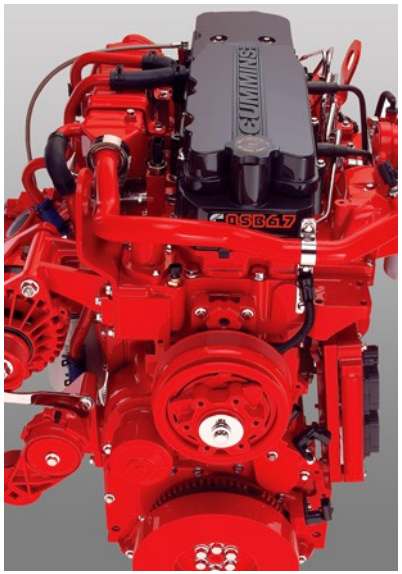
- Natural gas injected directly into cylinder at high pressure
- Pilot diesel injection provides ignition source
- Some systems provide limited power on 100% diesel

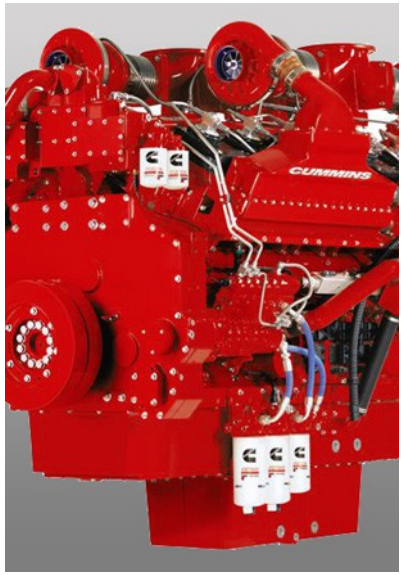
Technology Comparison

	Diesel	Fumigation Dual Fuel	Direct Injection DF
Fuel Cost			
Power Density			
Acceleration			
Complexity			
Cost			
Diesel / LNG Flexibility			
Emissions Performance			

Can Dual Fuel Save Money?



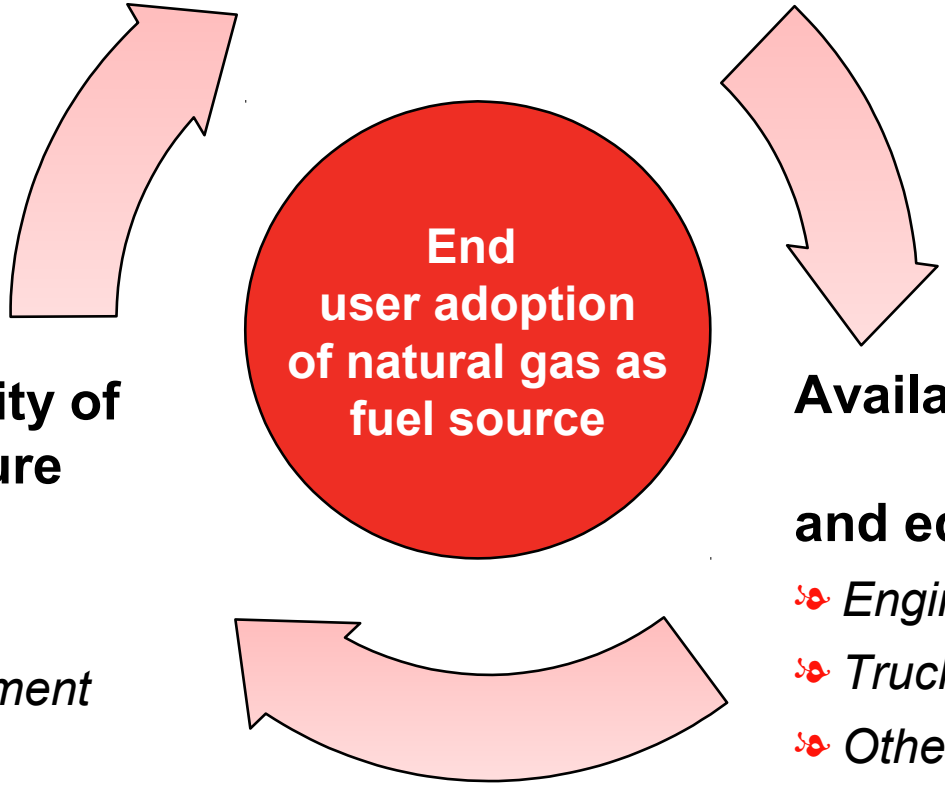




Key Factors For Adoption Of Natural Gas

Favorable Natural Gas price Delta / Economic benefits

- *Diesel price vs. gas price & infrastructure cost*



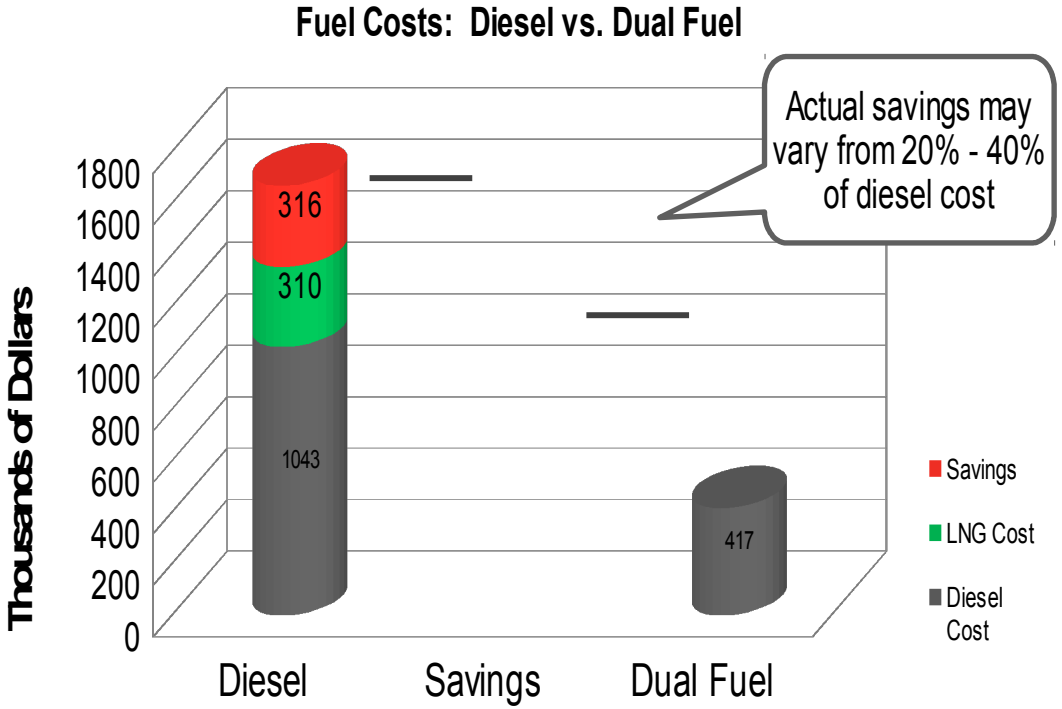
Local Availability of NG infrastructure

- *Fuel supply*
- *Fuel storage*
- *Refilling equipment*

Availability of engines and equipment

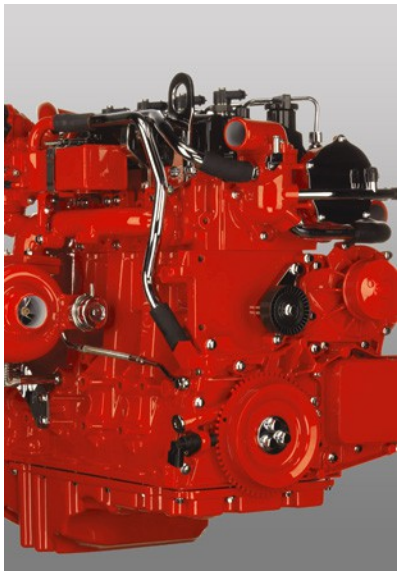
- *Engines*
- *Trucks*
- *Other equipment*

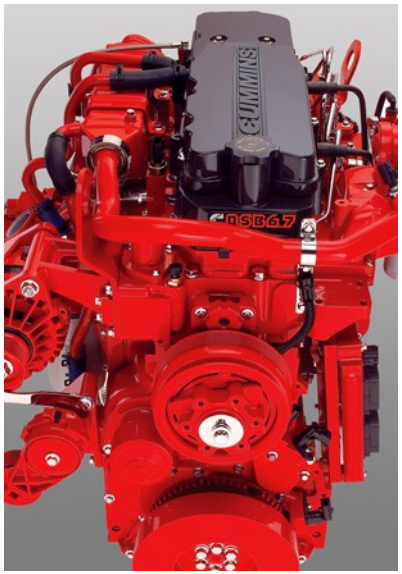
Fuel Savings

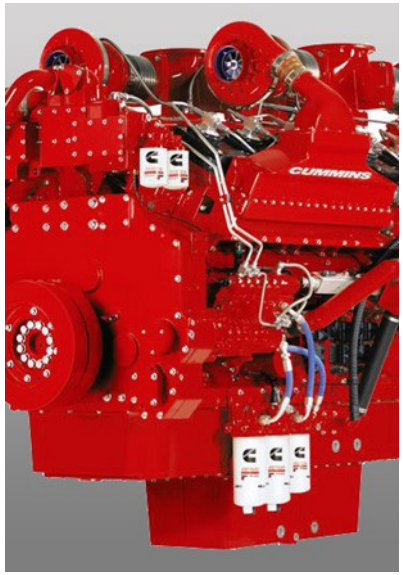


- By running a major portion of operation in dual fuel mode:
  - Significant diesel fuel savings by offsetting with less costly natural gas
  - Natural gas may cost as little as a quarter the cost of diesel

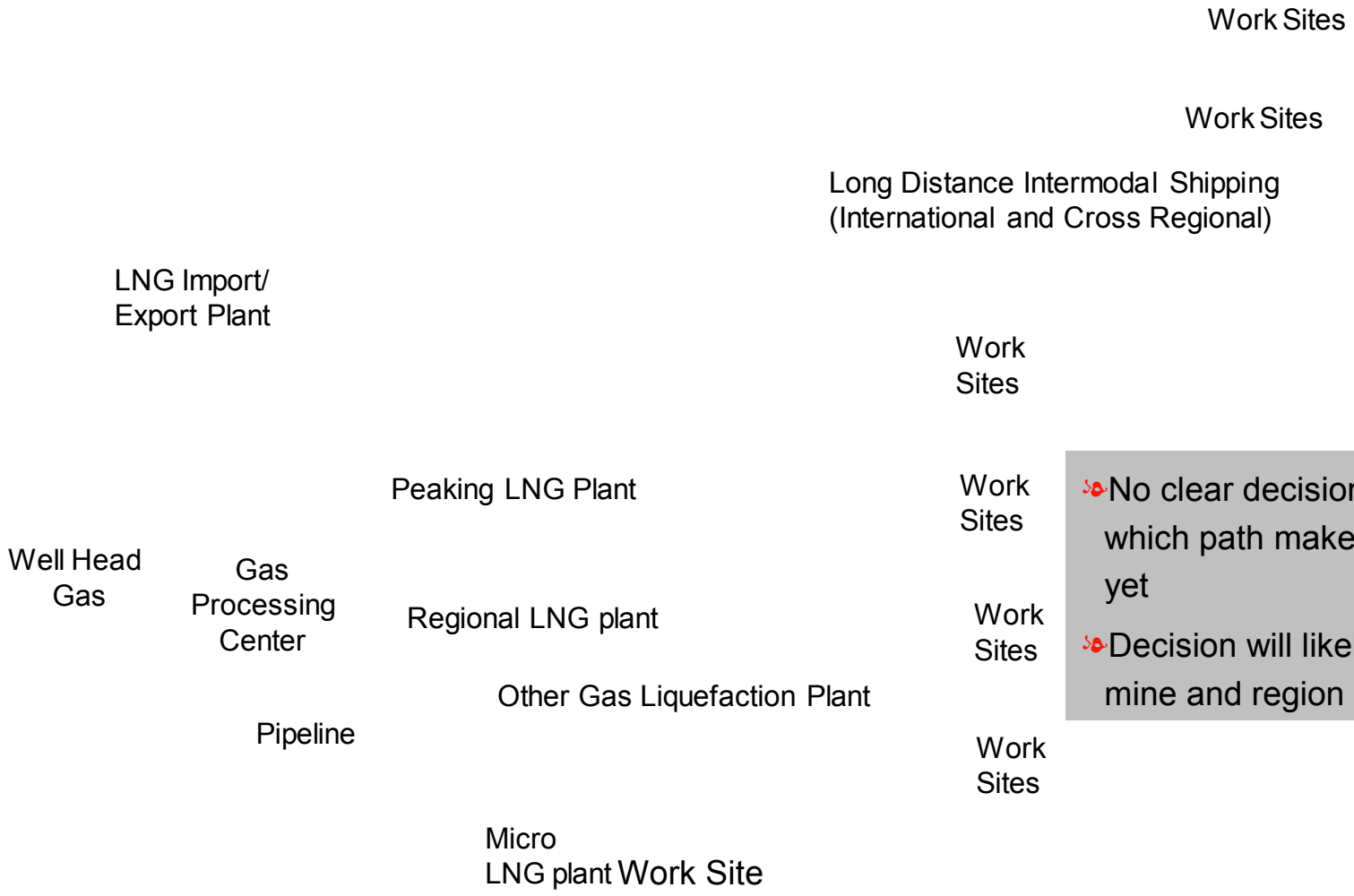
How Do We Prepare For Dual Fuel?







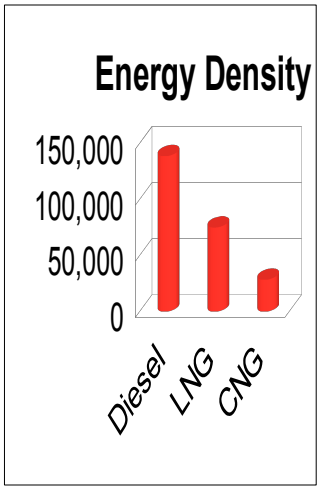
LNG Supply Chain Options



- No clear decision on which path makes sense yet
- Decision will likely vary by mine and region

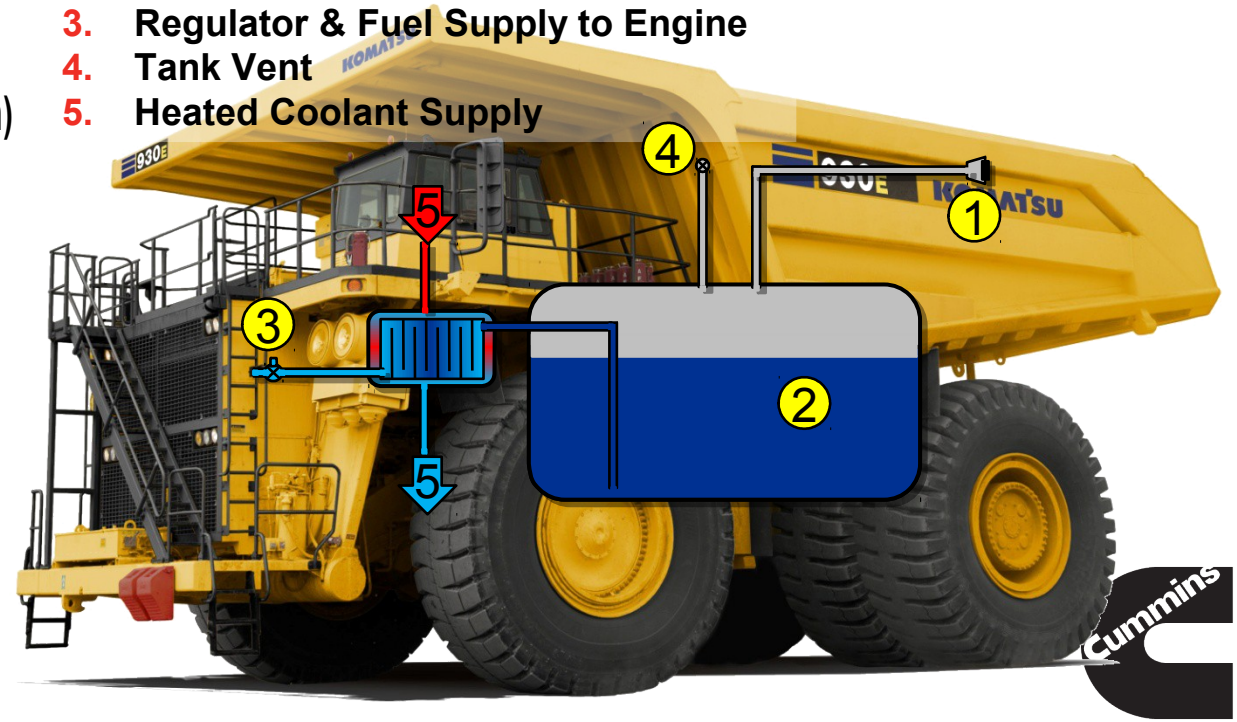
LNG Vehicle Fuel System

- LNG expected to be dominant choice for mobile applications due to storage constraints due to energy density
  - LNG energy storage is about twice that of CNG, but about half of diesel.



Vehicle LNG System

1. LNG Fill
2. Cryogenic Fuel Tank
3. Regulator & Fuel Supply to Engine
4. Tank Vent
5. Heated Coolant Supply



End User Requirements For LNG Vehicles

- Operator & Technician Training
  Care and handling of LNG
- Fuel Supply & Storage
  Large cryogenic tanks and lines
- Vehicle Refueling Equipment
  Cryogenic pumps and nozzles
- Vehicle Service Bays
  Processes and equipment to manage venting natural gas

Summary: Dual Fuel Opportunity

- Dual fuel provides a large fuel cost saving opportunity with a manageable impact at a mine site
- Requires capital investments for LNG storage and refueling
- Dual fuel equipment performance will match diesel equipment

Dual fuel technology is a major tool for cost efficient mine operations

Thank you for your time