LNG as a Fuel for Demanding High Horsepower Engine Applications: Technology and Approaches

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The Opportunity
Industries in Transition
Technology Solutions
The Opportunity

Industries in Transition

Technology Solutions
Customers with work to do

Demanding high horsepower applications:

- **Rail**
- **Marine**
- **Mining**
- **Oil & Gas**

Small number of dominant engine platforms from major OEMs:
Massive concentrated market opportunity

Global High-Horsepower Fuel Consumption

- Oil & Gas: 5.54 billion US gallons of diesel fuel per annum
- Mining: 5.90 billion US gallons of diesel fuel per annum
- Rail: 8.96 billion US gallons of diesel fuel per annum
- Marine: 13.97 billion US gallons of diesel fuel per annum

LNG Equivalent: 4 billion mmBTU 80 mtpa

Source: UN Energy Statistics Database, Westport analysis
Why LNG for these markets?

**Economics**
- Fuel price
- Cheaper way to meet emissions standards

**Practicality**
- Range
- Rapid refueling
- Efficient injection pressure
- The Opportunity
- Industries in Transition
- Technology Solutions
MACK PRESENTS

DIESEL

power

Mack diesels

From war... to peace

New "Jimmy" Diesel
gets a big O.K.

New GM "71E" Diesel produces lower cost miles than before. Now available for any make of truck, 28,000 miles per

INTERNATIONAL TRUCKS
WORLD'S MOST COMPLETE LINE

"We know we've got America's No. 1 Diesel"

The country's leading haulers checked fleet records topping 250,000 miles per truck on their GMC 8680's. Their verdict:

Diesels that weigh less, do more to cut costs!

New lightweight compact-engine design enables you to carry more freight... save money every trip... and save money on fuel... cut wear and tear on the whole truck, engine, transmission and differential... save freight charges... save over in many ways! A long way to go, but don't you think it's worth every inch?...
Diesel trucks dominate

Diesel’s share of new sales of Class 8 trucks in the U.S.

Source: MacKay & Co., & Wards Auto Group, a division of Penton Media, Inc.
The steam to diesel transition

Harrisonburg, Virginia, 1947
NMAH, Transportation Collections, McBride photos
A NEW DAY DAWNS IN RAILROADING

Throughout history, wars have set up new milestones of transportation progress. And with this war, it is the General Motors Diesel Locomotive that is ushering in the new era. What advances the future will bring are already apparent in the present performance of these locomotives and the way they are helping to meet the abnormal demands upon the railroads today.

KEEP AMERICA STRONG • BUY MORE BONDS

Every 3 days a new diesel joins the Santa Fe fleet!

A 10-year record of “building new” on the Santa Fe

Chosen with California champagne, Santa Fe’s first multiple-unit diesel locomotive rolled out of Chicago on Tuesday, May 12, 1936.

It possessed the first “Super Chief”, 1000 “horses” here it rolled into Los Angeles—and the new age in railroading was here. There were 5000 “horses” in that one. Five years later, the first multiple-unit freight diesel rolled on Santa Fe rails.

There were 5000 “horses” in that one. Today, there is more than 2,100,000 diesel horsepower on the Santa Fe—1500 mighty diesel units.

PROGRESS THAT PAYS ITS OWN WAY

Westport
Steam locomotives totally replaced Diesel Powered Locomotives, North America

Natural gas power generation

Current (2010) capacity by initial year of operation and fuel type

gigawatts

Current (2010) U.S. capacity

- natural gas
- nuclear
- other
- petroleum
- wind
- coal
- hydro

EIA (Energy Information Administration)

Westport
Aerospace technology introduced

From October 2002 | ASME Power Division Special Section
The familiar S-curve

Natural Gas share of new U.S. power plant construction

The ingredients for change

Favourable Economics + Technology Solution = Rapid Transformation
- The Opportunity
- Industries in Transition
- Technology Solutions
Transforming the refuse truck market

- Cummins Westport ISL G 9L engine
- Stoichiometric combustion with EGR
- Three way catalyst
80% market share within 5 years

Natural gas share of U.S Refuse Truck Sales

Source: Cummins Westport
The Westport HPDI System for Heavy Haul Trucking

Natural gas engines with diesel-equivalent performance, range and efficiency.
Over 800 trucks on the road already
Tank system for regional and vocational trucks

- Pumped LNG responds to engine demands
- Cold unsaturated fuel increases range and eliminates fuel venting
- 450 miles on a single tank of LNG
The ingredients for change

Favourable Economics + Technology Solution = Rapid Transformation
FOR IMMEDIATE RELEASE

Westport and Caterpillar Announce Agreement to Develop Natural Gas Technology for Off-Road Equipment

The two companies are positioned to be the first to offer Westport™ HPDI technology in the high horsepower off-road market; initial focus on mining trucks and locomotives;
Westport technology solutions being deployed

- **High Pressure Direct Injection (HPDI)** of natural gas in 4,000+ hp engines
- **LNG pump systems** for mobile applications capable of delivering 4,000 psi fuel at over 650 kg / hour
- 1,000+ gallon **LNG tanks** for a mining environment
- Rail **tender cars** to provide mainline locomotives with increased range
The result - global high horsepower LNG market

By 2025:
- $20 billion in annual customer savings
- 2 billion mmBTU of gas consumed annually
- 40 million tons per annum of LNG liquifaction capacity required

Projection: 50% market penetration within 10-15 years