Natural Gas
Why Now, and What are the Challenges

October 23, 2013

Mike Walser
Executive Vice President & Chief Engineer
Enovation Controls

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Enovation Controls

- $250 million in sales
- >1000 employees worldwide
- Three Major Business Segments
  - Natural Gas Vehicles and Engine Fuel Systems (EControls brand)
  - Natural Gas Production Systems (Murphy brand)
  - Controls and Vehicle Systems (both brands)

Focused in Dynamic Markets

Natural Gas Focused Segments (80%)

CNG / LNG Commercial Vehicles

Natural Gas Vehicles & Engine Fuel Systems

40%

Gas Compression

Natural Gas Production Systems

40%

Engine OEMs

Refinement

Focused in Dynamic Markets

Controls and Vehicle Systems Segment (20%)

Off-Highway

Marine

Control and Vehicle Systems

20%

Gen Sets

Consumer Recreation

Our Global Footprint

Customers Examples

Natural Gas Vehicles & Engine Fuel Systems

Natural Gas Production Systems

Control & Vehicle Systems

AG Equipment Company

MATERIALS HANDLING GROUP, INC.

Natural Gas Vehicles & Engine Fuel Systems

Segment

- Largest provider of natural gas fuel systems for medium and heavy commercial vehicles with over 170,000 systems on the road today
- Installed base of over 1,000,000+ engine control systems
- Engine control systems for CNG, LNG, LPG, gasoline and diesel engines
- Leading alternative-fuel control system manufacturer for on-highway and industrial engines
- Full in-house engine development and emissions certification capability
- Current products meet the most stringent emissions standards in the world
- Market driven design and development

Customers - Heavy-Duty

YUCHAI 玉柴机器

CATERPILLAR®

DETROIT DIESEL CORPORATION

HINO TRUCKS A Toyota Group Company

FAW

中国重汽 SINOTRUK

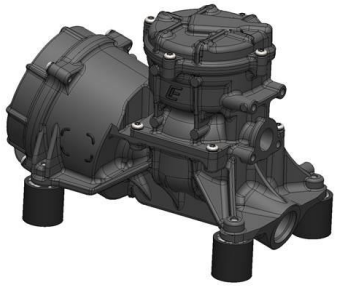
SDEC

Abu Dhabi, UAE. may 2003 Christian Kraut

Complete Engine Control System Provider

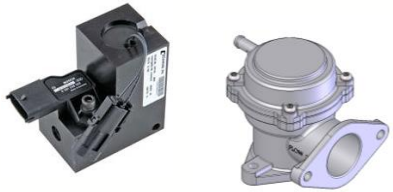
Control Electronics

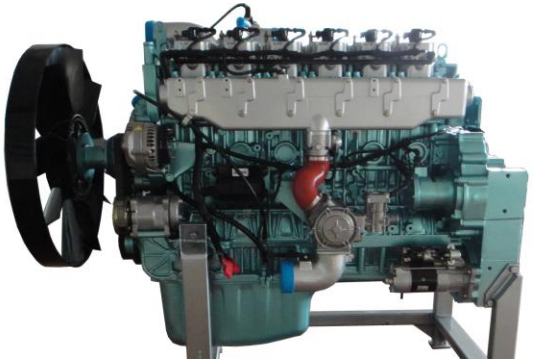
Fuel Metering



Pressure Regulation

Turbocharger Control





Exhaust Aftertreatment

Sensors

Air Control

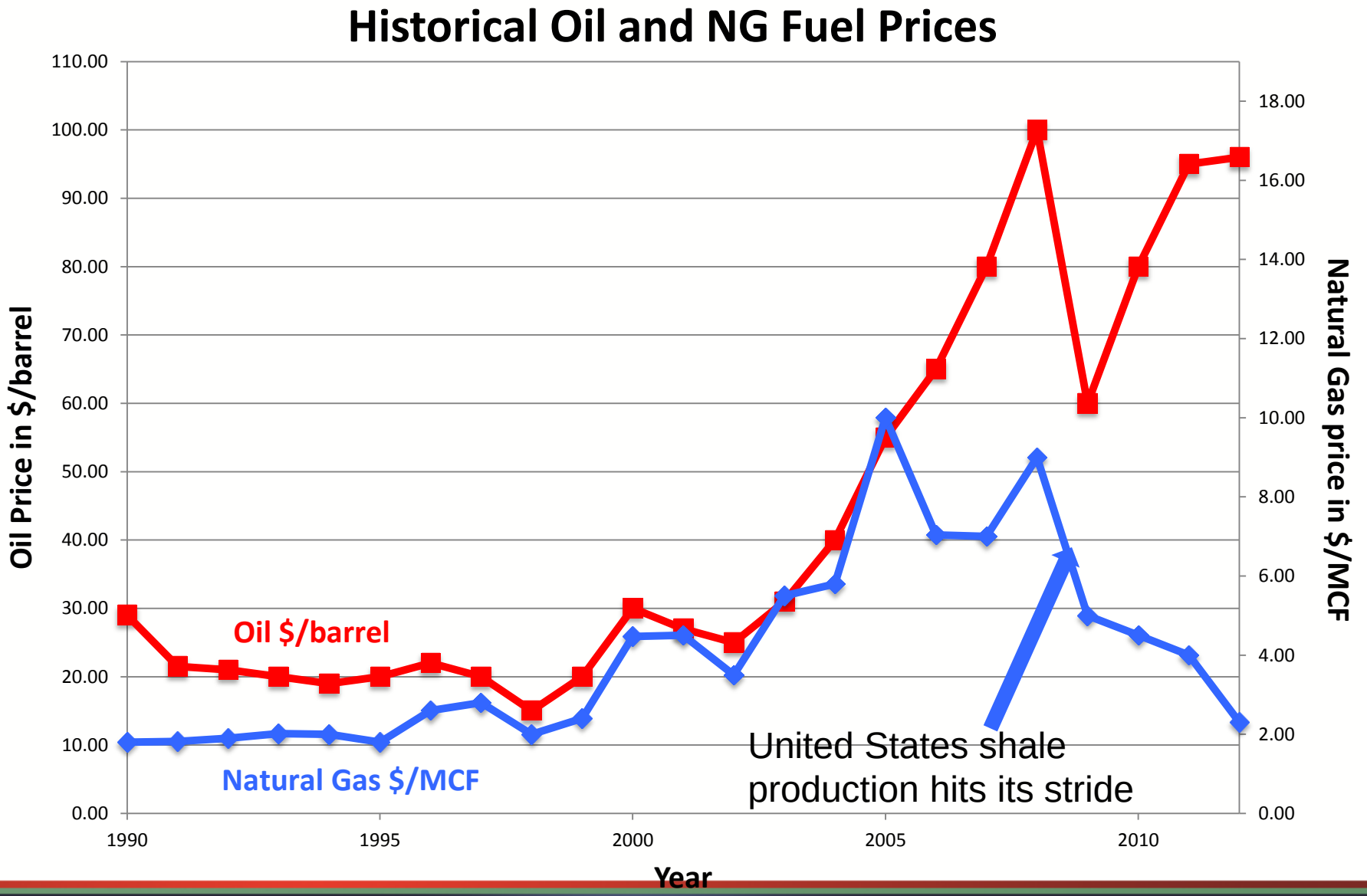
Spark Control

EControls NG Global Experience

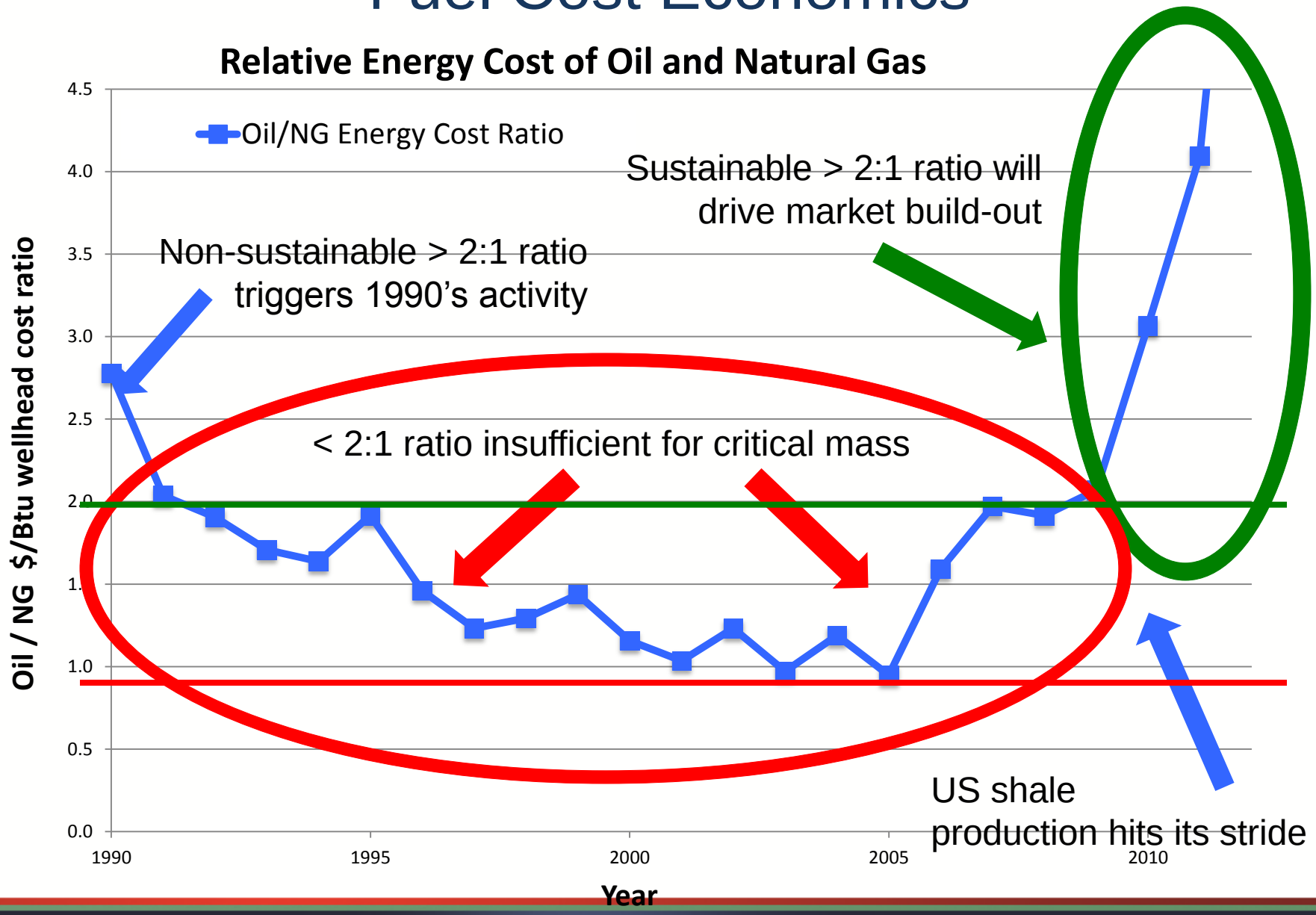
- 170,000+ OEM heavy-duty NG systems on the road today

- 20 Certified production engines for HD/MD
- Dominant supplier in the China HD/MD OEM engine market since 2006
- But... for US HD NG we have been skeptics for 15 years!

Fuel Cost Economics

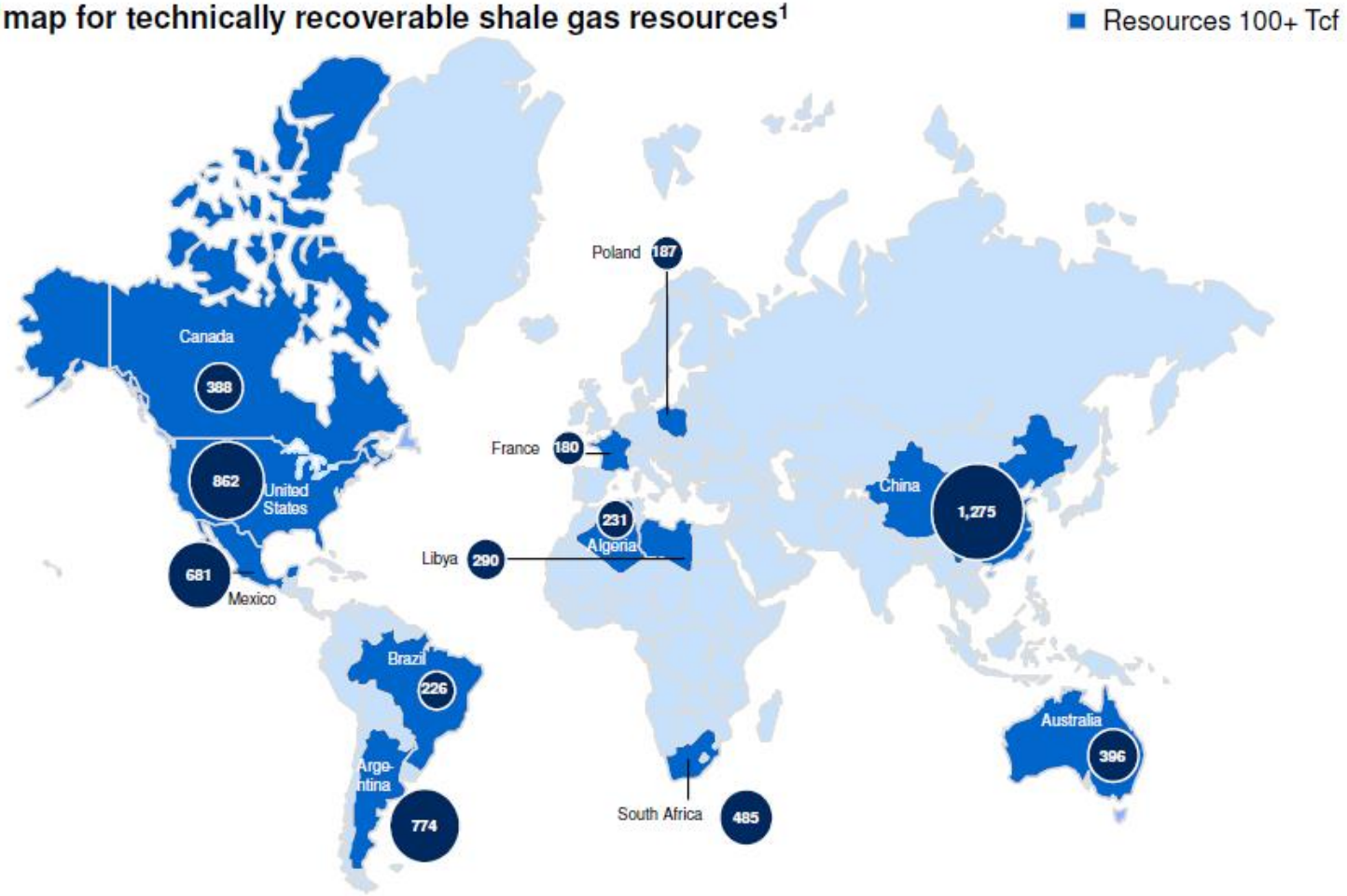


Fuel Cost Economics



McKinsey Report
Where Shale Gas Resources Are

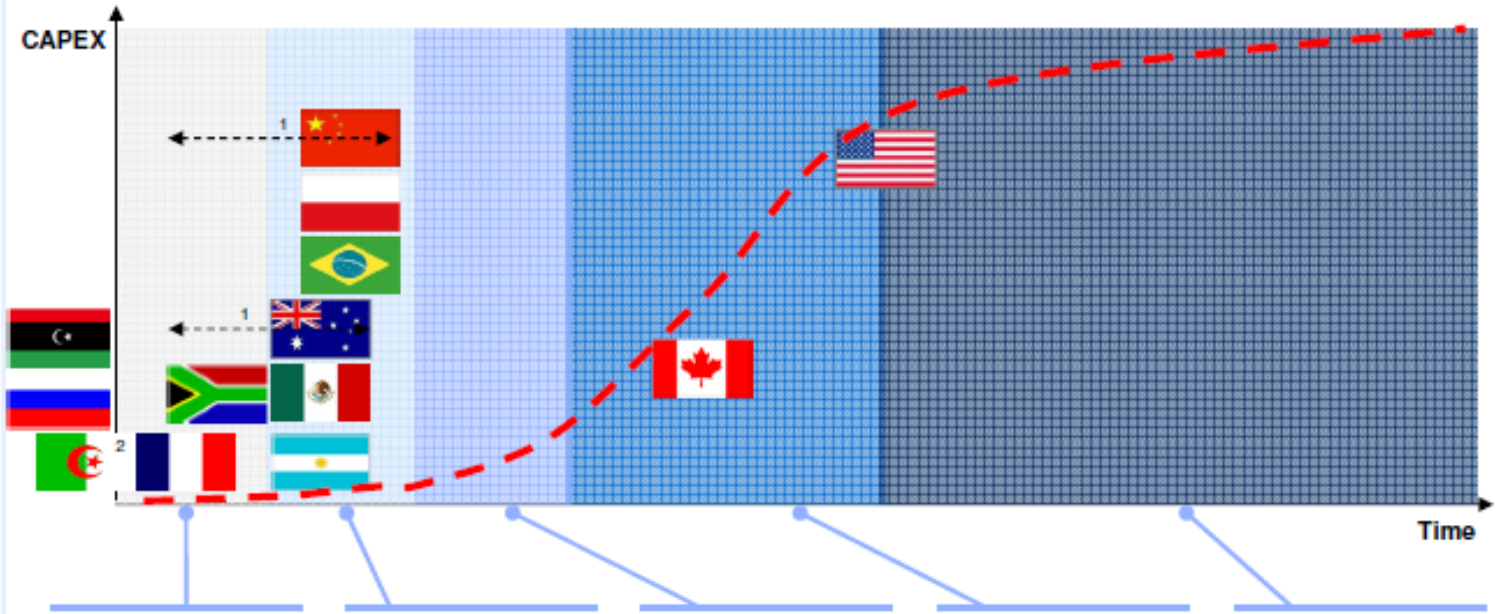
Global map for technically recoverable shale gas resources[1]
Tcf



SOURCE: EIA, World Shale Gas Resources

Development of unconventional gas in Europe, Asia and Latin America far behind US and Canada

Country evolution on unconventional s-curve



'Land acquisition'
- No wells drilled
- Largely 'known' basins
- Limited data (quality, productivity)

'De-risking'
- Exploratory drilling
- Focus on reservoir quality and learning rates

'Commercial pilot'
- Secure market access
- Drilling / well design optimization

'Development'
- Manufacturing focus to drive learning curve
- Focus on long term well performance

'Consolidation'
- Consolidation / optimization of basin ownership

1 Flags based on most advanced basins in China (Sichuan basin) and Australia (Cooper basin). Other basins in both countries are still at the land acquisition stage

2 Algerian government has announced its intention to begin shale gas exploration with help from international players

SOURCE: McKinsey oil and gas practice; Expert interviews; CST analysis

Top 10 countries with technically recoverable shale gas resources

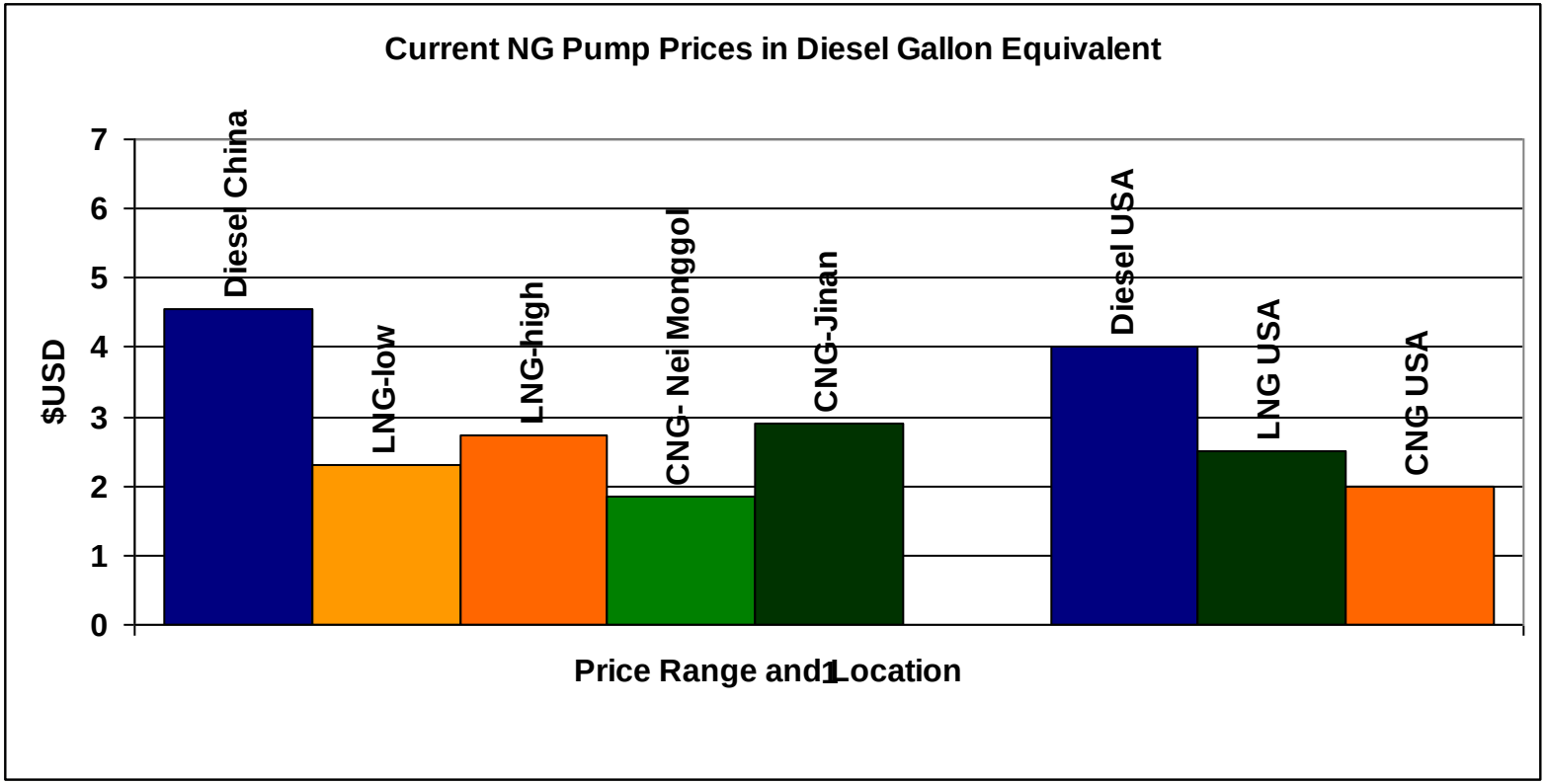
Rank	Country	Shale gas (trillion cubic feet)
1	China	1,115
2	Argentina	802
3	Algeria	707
4	U.S.A	665
5	Canada	573
6	Mexico	545
7	Australia	437
8	South Africa	390
9	Russia	285
10	Brazil	245
	World Total	7,299

EIA estimates

China Challenges for Shale Gas

- Far behind in development of technology
- Gas is deeper and tighter
- Not enough pipeline infrastructure
- Geography not as conducive to exploration
- ***China has the resources to be energy independent with NG***

Current Vehicle Fuel Average Prices in Diesel Gallon Equivalent

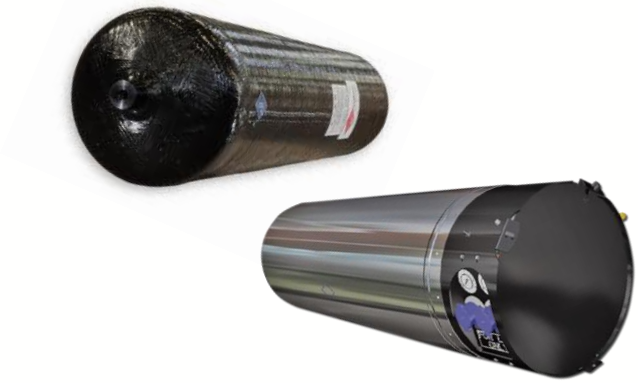


Vehicle Market Challenges

- Infrastructure
  - Asia (China, Thailand, Korea) have the most built out fueling infrastructures in the world for MD/HD applications, but in centralized locations
  - China needs more expansion to continue the large market growth in HD truck
  - The US infrastructure is inadequate currently for HD truck, but developing at a rapid pace. Built by private entities and fuel companies
- Fuel cost concerns
- Durability of engines and systems (mainly an issue in China)
- LNG or CNG decision
  - Not a huge concern in China due to shorter route target customers currently. Is LNG needed for long haul? More stations?
  - Large concern for HD truck in the US as these are mostly long haul. Customers do not know which to purchase even though most believe LNG will win
  - LCNG stations may be needed to eliminate the concern

Critical Fuel System Technologies

- Major Technology Areas:
  - Vehicle fuel storage type
    - CNG = Compressed Natural Gas
    - LNG = Liquefied Natural Gas
  - Engine fuel delivery system
    - Air/Fuel pre-mix
    - Port Injection
    - Direct NG injection
  - Engine ignition system
    - Spark
    - Micro-pilot diesel
    - Standard diesel



Engine Fuel Delivery System

- Air/Fuel Pre-Mix (NG mixed into incoming air stream)
  - Lowest cost and lowest complexity
  - Low fuel pressures at the engine (similar to gasoline)
  - Continuous flow possible = high valve durability
  - Requires throttling = reduced light-load efficiency
  - US example: Cummins ISLG, ISX12G, ISX15G
  - Asia example: All

- Direct NG Injection (NG delivered in-cylinder like diesel)
  - Higher cost and higher complexity
  - High fuel pressures at the engine (cryogenic pumps for LNG)
  - Must be pulsed injection = finite valve cycle life
  - No throttling required = increased light-load efficiency
  - US example: Westport HD 15L

Engine Ignition System

- Spark Ignition (similar to gasoline engines)
  - ⇒ Electronic spark initiates combustion
  - ⇒ Lowest cost and lowest complexity
  - ⇒ Current systems limited to ≈ 21 bar bmep
- Micro-pilot diesel ignition (very small common-rail injection)
  - ⇒ Small diesel quantity initiates combustion
  - ⇒ High cost and high complexity
  - ⇒ Ignition system does not limit bmep
  - ⇒ Engine is not true “dual fuel” (i.e. cannot make >10% torque without NG)
- Standard diesel ignition (standard common-rail injection)
  - ⇒ Diesel injector initiates combustion
  - ⇒ Highest cost and highest complexity
  - ⇒ Ignition system does not limit bmep – but does pose emissions challenges
  - ⇒ Maximum of ≈ ¾ power from NG fuel (remainder from diesel)
  - ⇒ True “dual fuel” (i.e. engine can run full power on diesel)

Vehicle Fuel Storage

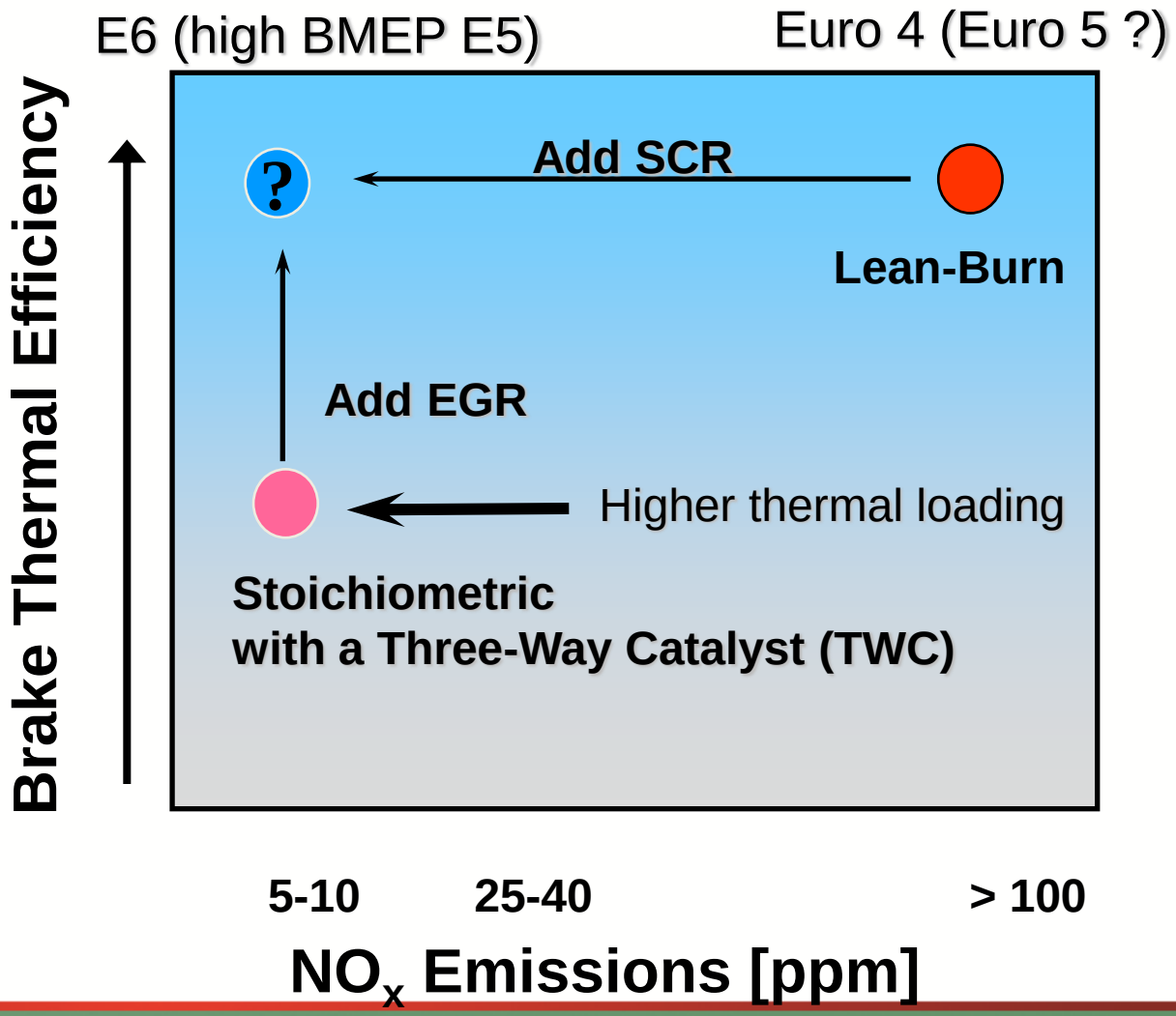
- CNG = Compressed Natural Gas (3000+ psi gas)
  - ⇒ 6:1 tank dimensions for diesel range
  - ⇒ Lower tank price, but more tanks
  - ⇒ Least expensive pump delivery price
  - ⇒ User-friendly filling
  - ⇒ Indefinite fuel storage

- LNG = Liquefied Natural Gas (cryogenic low-pressure liquid)
  - ⇒ 2:1 tank dimensions for diesel range
  - ⇒ Higher tank price, but less tanks
  - ⇒ More expensive than CNG at the pump
  - ⇒ Limited time after filling before tank vents (days to weeks) since tank is essentially a large “thermos” bottle.
  - ⇒ Results in fuel “aging” (higher ethane is result causing knock concern)

Tanks

- Tank cost in the US in much too high currently
  - Most HD trucks currently using type 4 cylinders for CNG
  - Volume and competition is poor
- Tank cost in China is much more reasonable but should improve.
  - Type 1 and 2 cylinders are the only legal selection. Less expensive for CNG
  - Type 2 tanks sizes too small for most efficient storage on HD trucks
  - LNG tank manufacture competition has driven price down over time
  - Production volume

Combustion Approaches for Optimum BTE at Low Emissions Levels

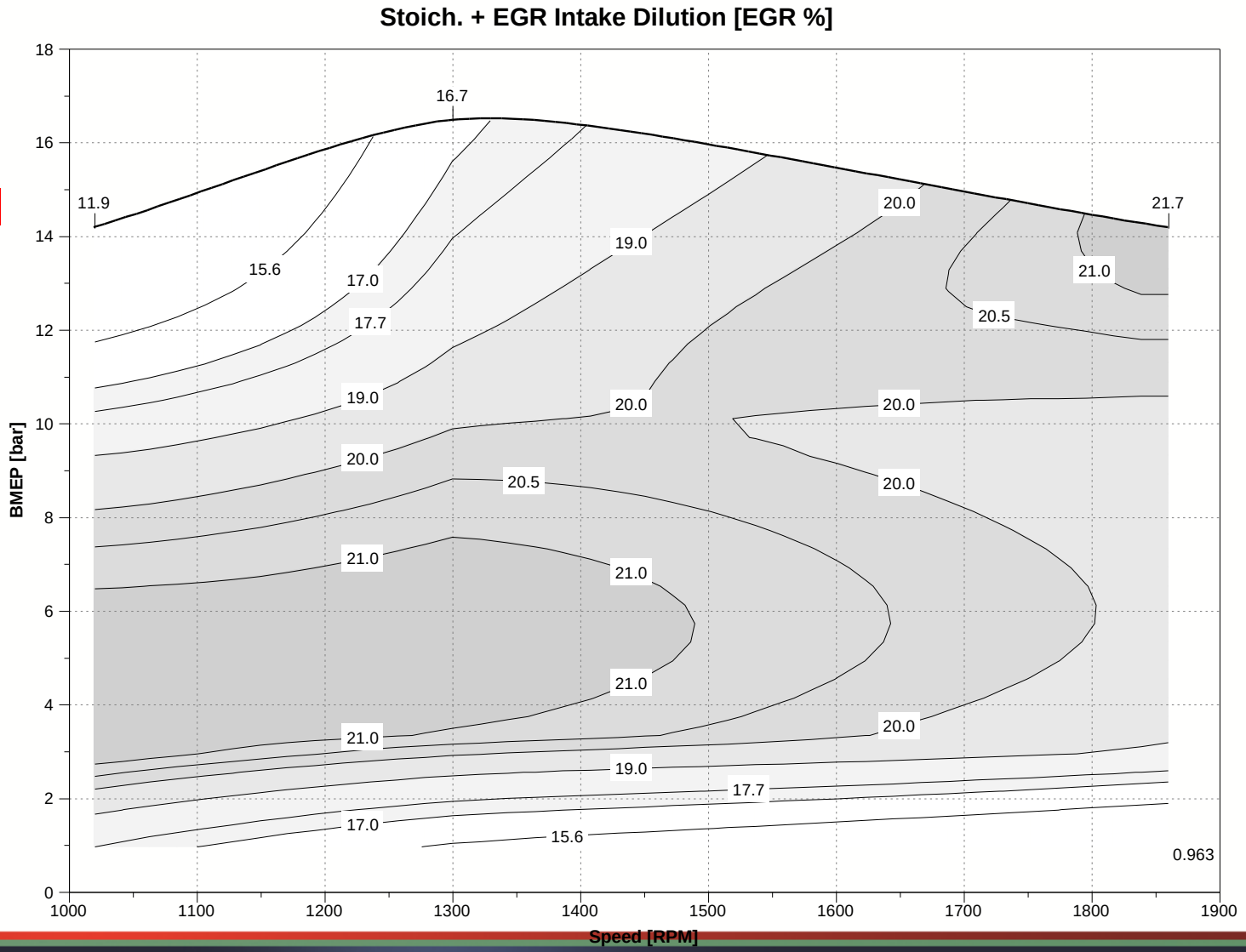


Stoichiometric with High EGR
Spark Ignited

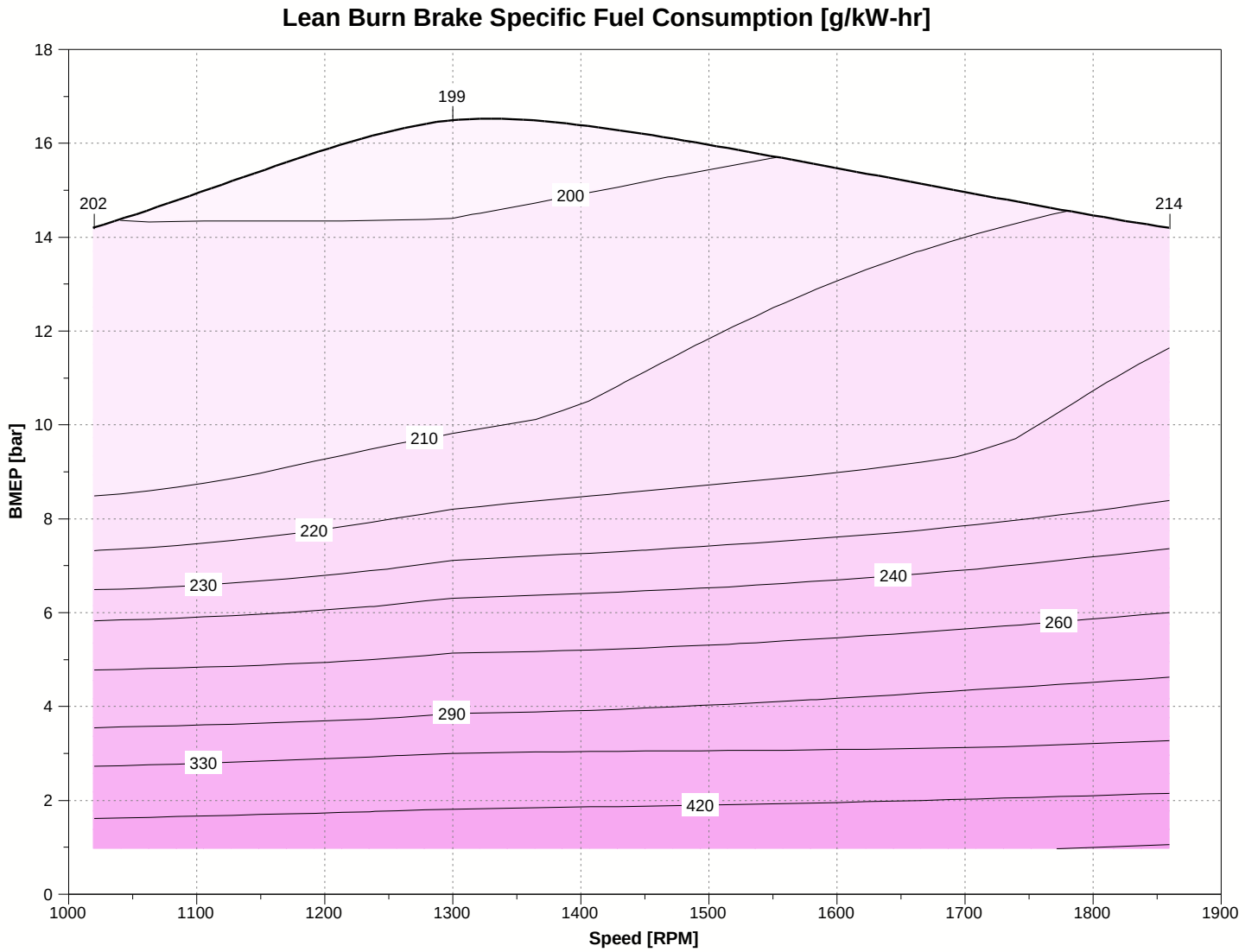
- Allows same efficiency as lean burn (Euro 3)
- Reduces exhaust after-treatment cost greatly ***(lowest cost Euro V and Euro VI solution)***
- Meets current emission regulations worldwide
- Engine durability and temperatures similar to or better than lean-burn

EGR Dilution Rate at Peak Efficiency

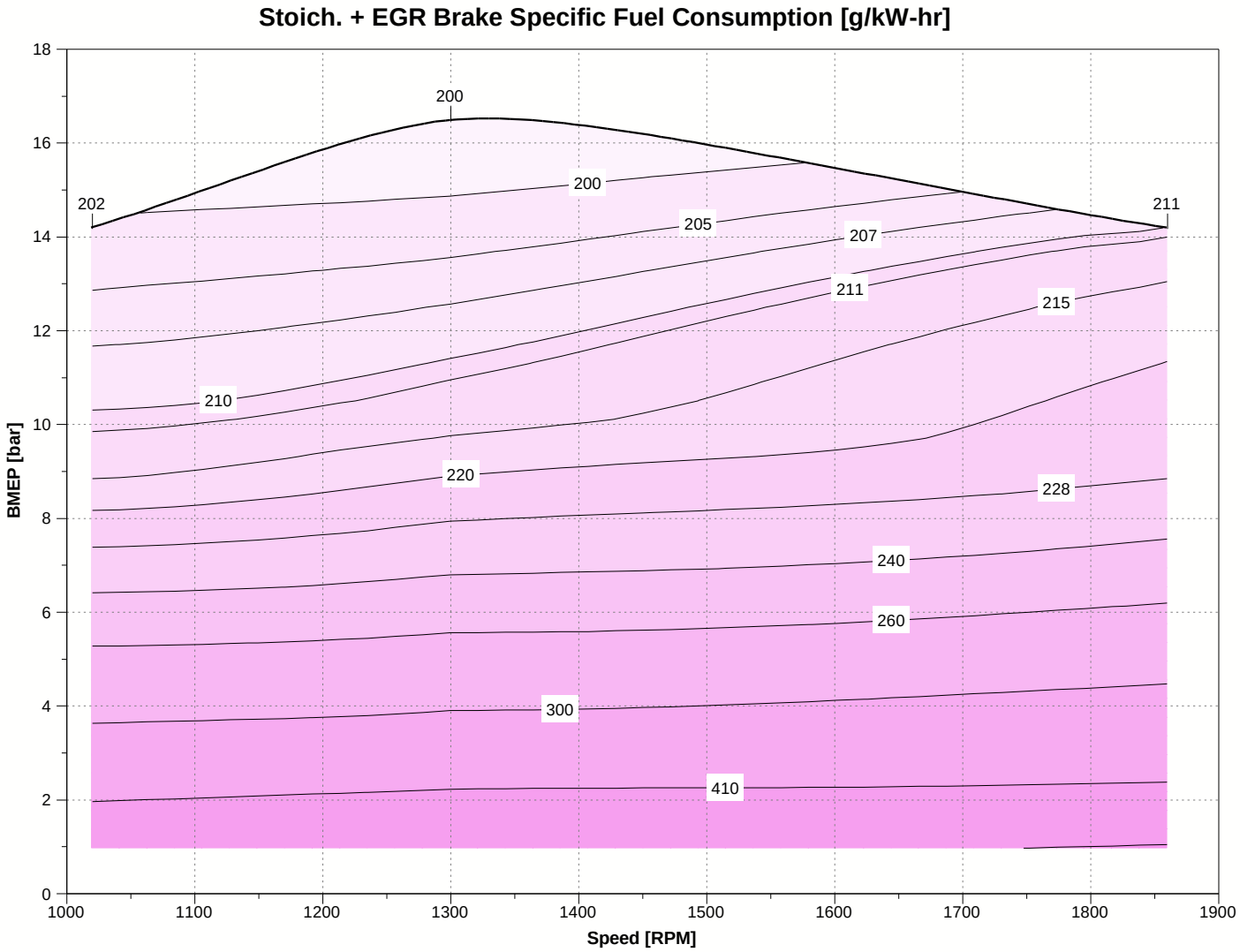
EGR% = Int. CO2 / Ehx. CO2% * 100



Peak Efficiency (no emissions) Combustion Strategy Comparison

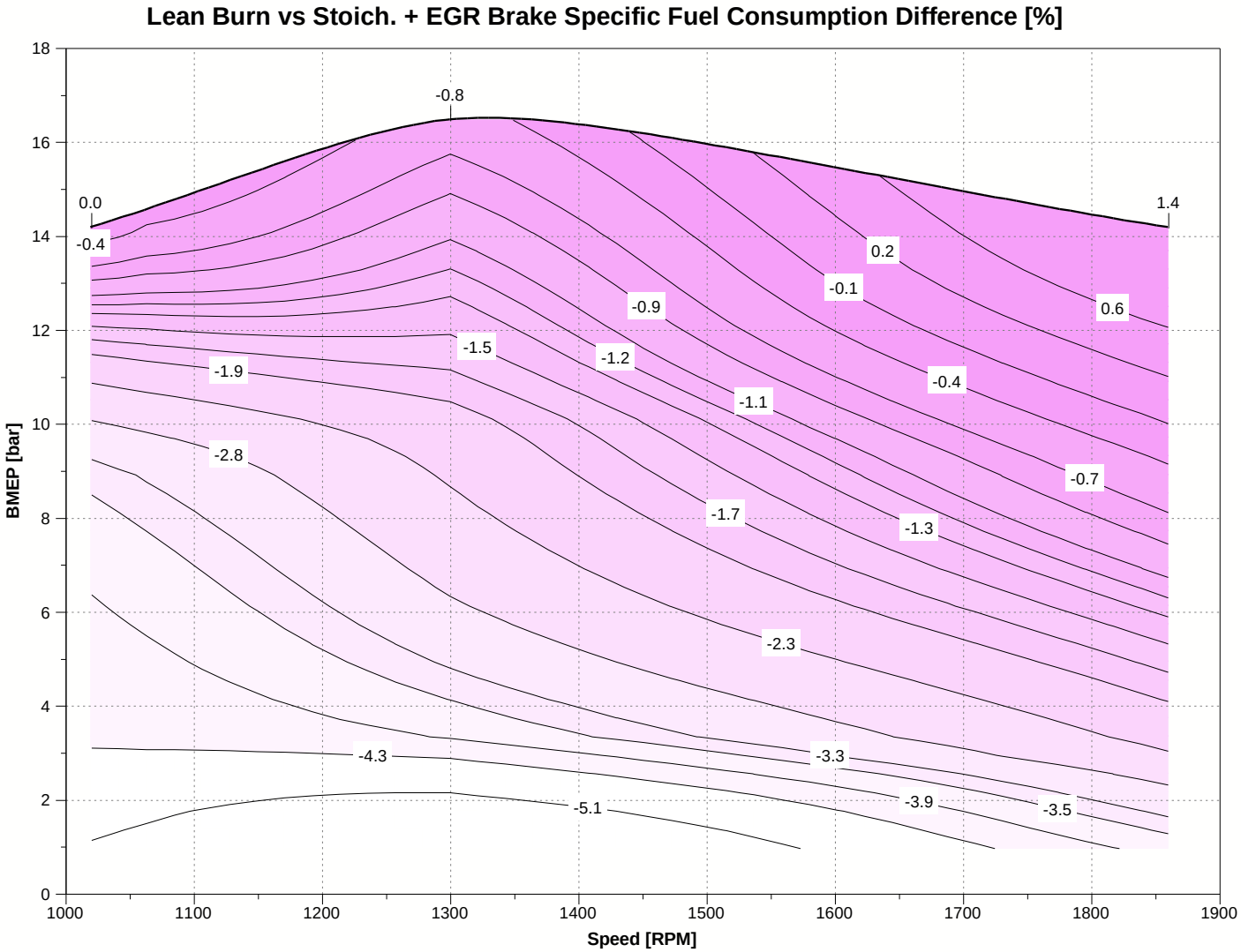


Peak Efficiency (no emissions) Combustion Strategy Comparison



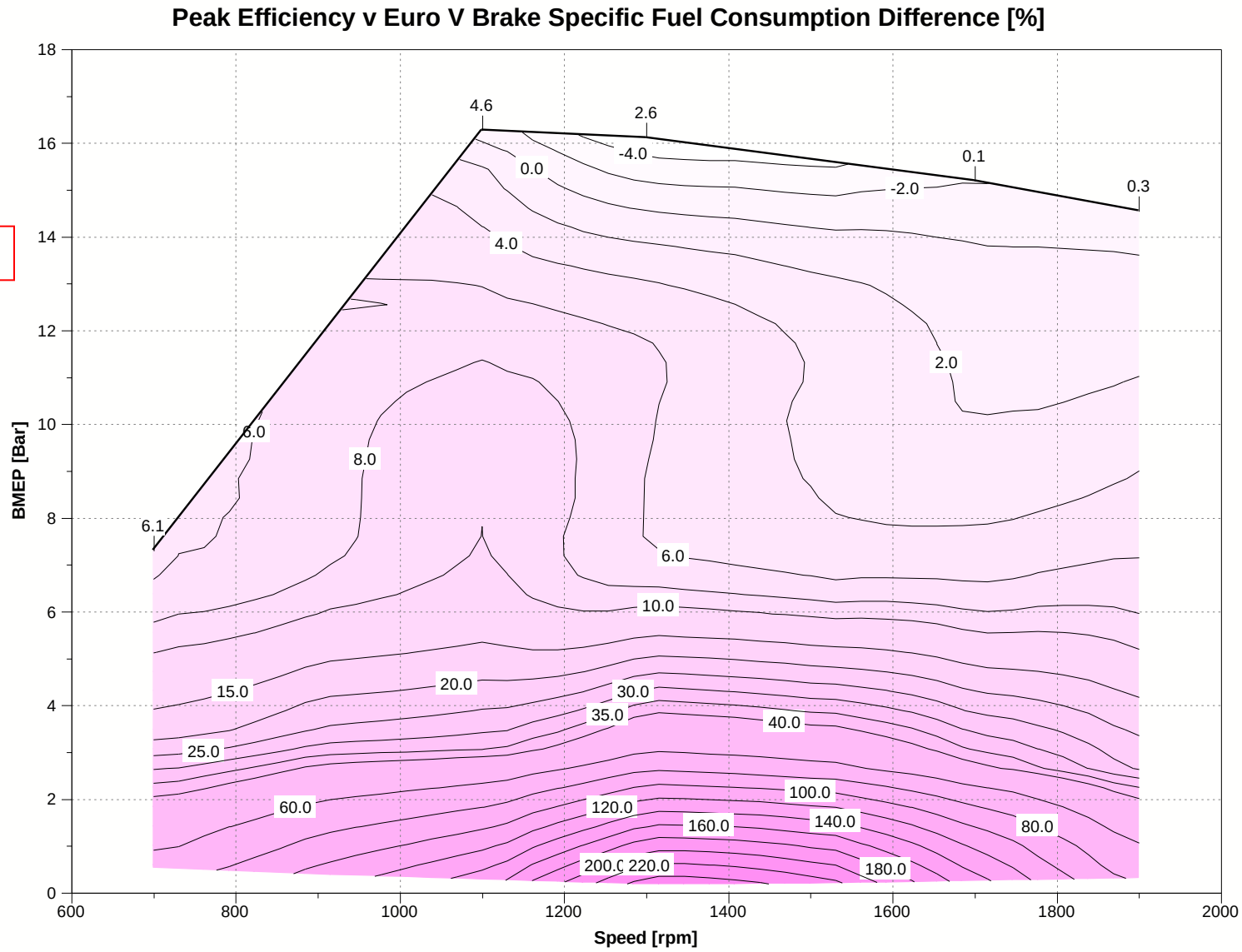
Peak Efficiency (no emissions) Combustion Strategy Comparison

Diff. % = (Lean – EGR)/Lean*100
Negative percentage means higher Stoich. + EGR number.



Peak Efficiency Lean-Burn vs. Euro V Lean Burn

Diff. % = (Euro V – Efficiency)/Euro V*100



Fuel Systems

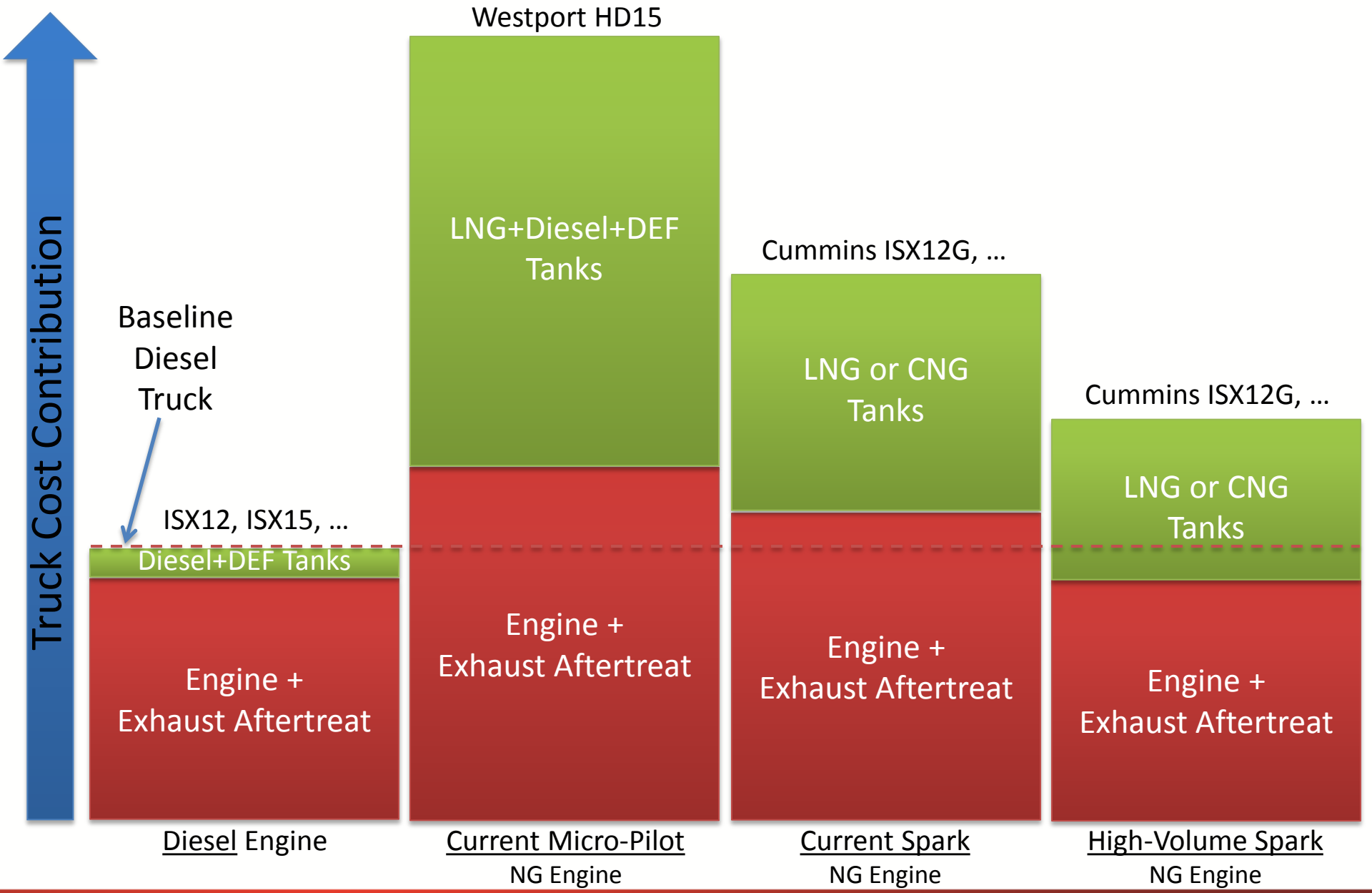
- HPDI (Westport) and dual-fuel
  - Too expensive with two fuel systems and high pressure LNG pumps
  - Exhaust after-treatment more expensive than diesel with SCR
- MPI (Multi-Point Injection)
  - Too much air/fuel variation cylinder to cylinder hurts fuel consumption and emissions
- PWM inj (pulse width modulated on/off CPI)
  - Current injectors not durable enough for HD market on CNG and worse on LNG
- Air fuel pre-mix (Continuous Flow Central Point Injection)
  - Cummins, Yuchai, CNHTC, FAW, etc.
  - ***For the future expect most successful engines to be continuous flow, spark ignited with EGR to meet emission, cost and durability requirements***

US HD NG Engine Availability

Only 3 OEM "Heavy-Duty" NG engines are EPA 2013 certified:

- Cummins ISLG:
  - 9L, 6-cylinder
  - Spark ignition (SI)
  - Standard CNG or LNG tank system compatible
  - Up to 320 bhp, 1000 ft-lbs @ 1300 rpm
- Cummins ISX12G:
  - 12L, 6-cylinder
  - Spark ignition (SI)
  - Standard CNG or LNG tank system compatible
  - Up to 400 bhp, 1450 ft-lbs @ 1200 rpm
- Westport HD15:
  - 15L, 6-cylinder
  - Micro-pilot diesel compression ignition (CI)
  - Requires special LNG tank system with high-pressure cryogenic pump
  - Up to 475 bhp, 1750 ft-lbs @ 1200 rpm
  - Now not being produced since the Cummins ISX12G was released

Initial Truck Cost Considerations



Initial Truck Cost Considerations – The ***Engine***

- **Why are HD NG engines more expensive than diesel???**

They should be cheaper because...

–Spark ignited, pre-mix NG fuel system = HPCR diesel fuel system cost

–Spark ignited NG engine after-treatment is about $1000-$2000 (12L)

–Tier4 diesel after-treatment is about $5000-$8000

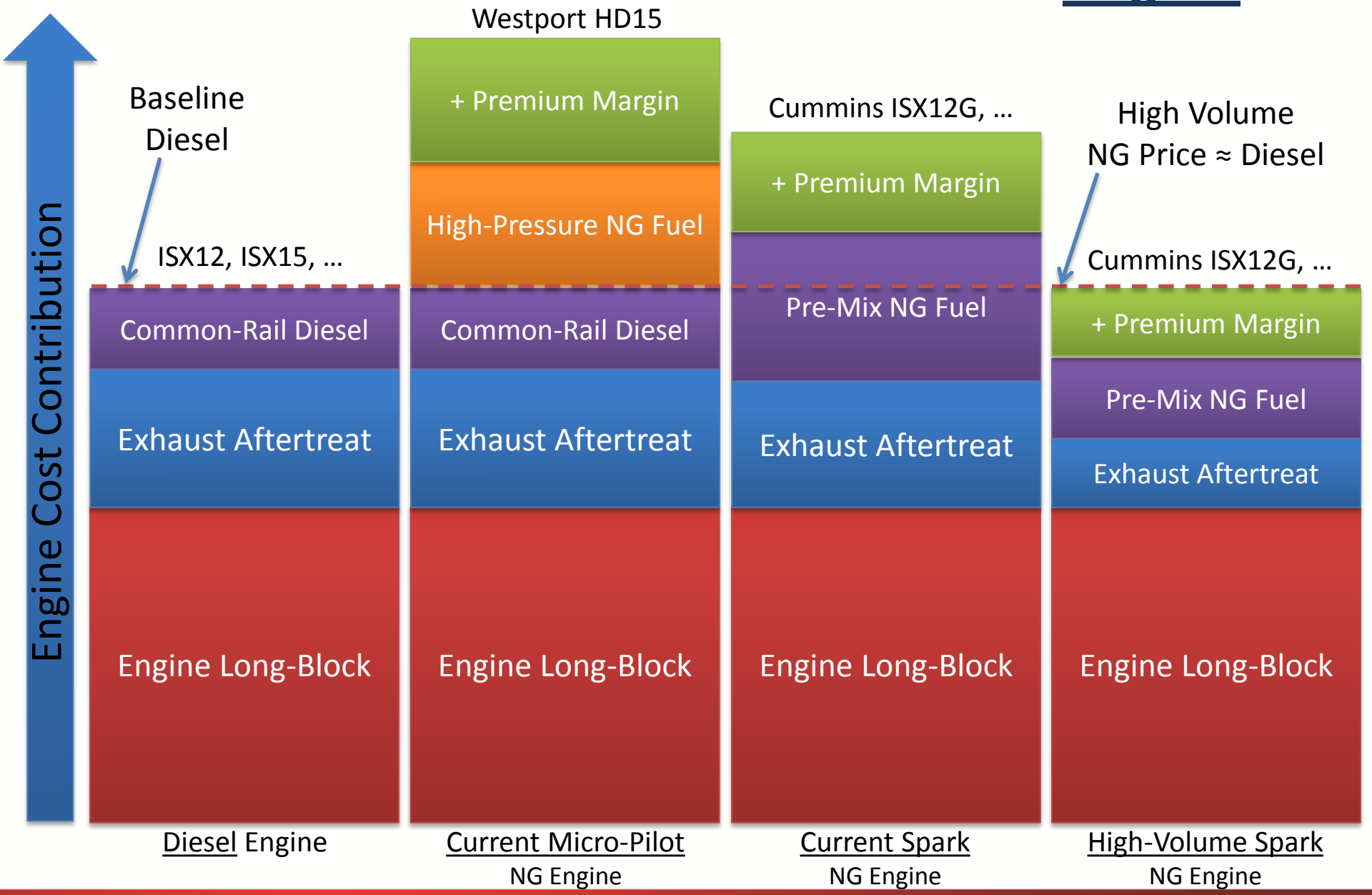
But...

–Low volume production by US manufacturers = higher cost

–Extremely limited US engine competition = higher cost

–US market will currently bear a higher price because NG vehicle buying decisions are driven by fuel cost advantages – not engine cost

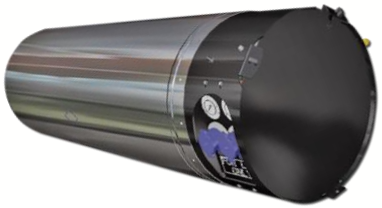
Initial Truck Cost Considerations – The ***Engine***



Initial Truck Cost Considerations – The ***Tanks***

- **What does the fuel tank system cost???**

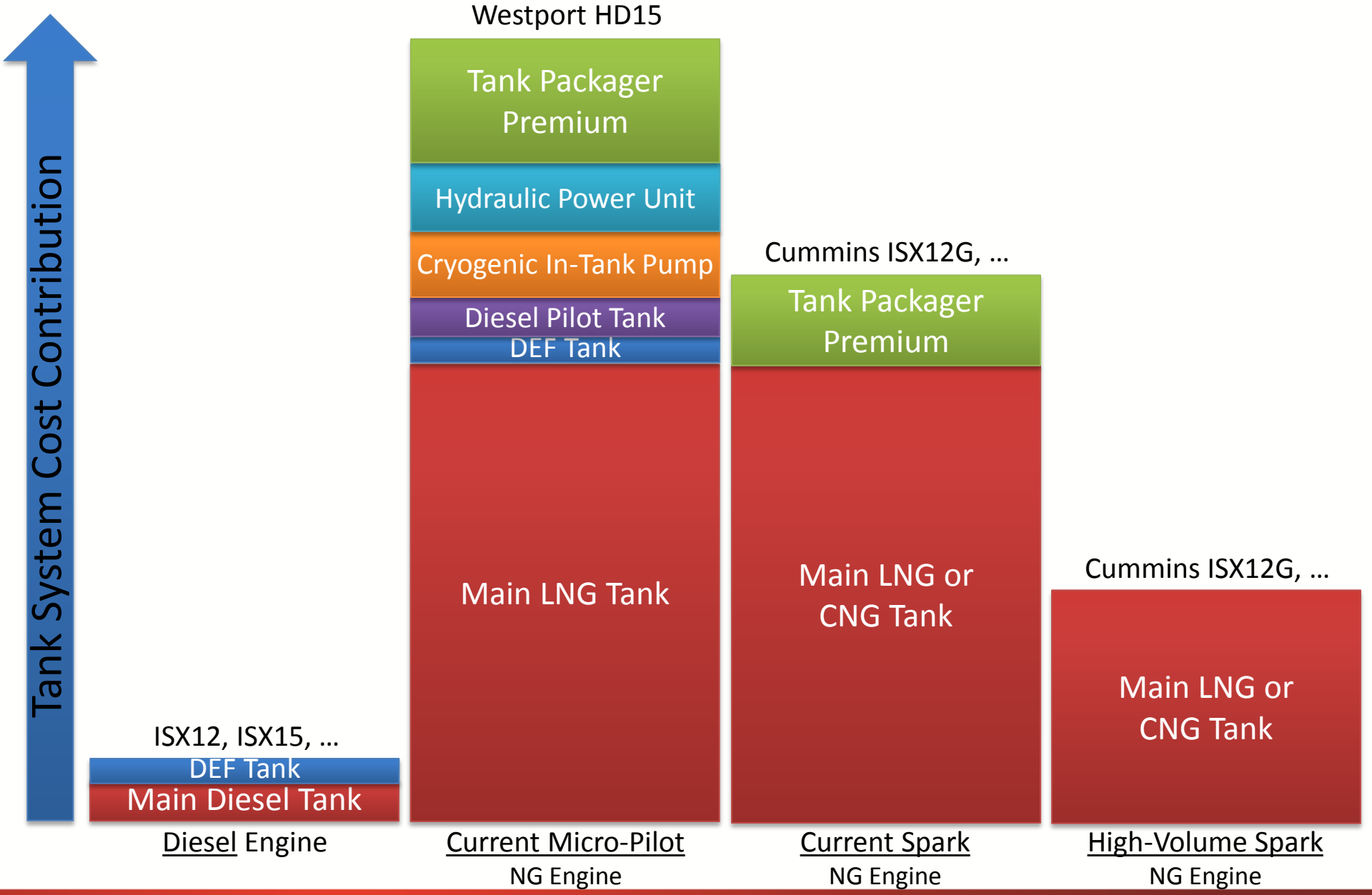
  - In the US Both CNG and LNG tankage are currently ≈ $300 / DGE – This is too high!
  - In high-volume (i.e. mature market), both CNG and LNG should be ≈ $100 / DGE – Asia
  - Mounting brackets and tank to engine plumbing are more expensive than diesel
  - Fuel heat exchangers required on LNG systems, may also be used with some CNG systems



  - No SCR required for spark-ignited systems means no DEF related tankage
  - The Westport HD15 requires an extremely expensive special LNG tank with a high-pressure in-tank cryogenic hydraulic pump costing ≈ $500 / DGE

*DGE = Diesel Gallon Equivalent

Initial Truck Cost Considerations – The ***Tanks***



Fuel Cost Operating Advantages

Basic Assumptions:		
Truck miles per year	100,000	miles
Diesel cost	4.00	$/gallon
LNG cost per DGE	2.50	$/DGE
CNG cost per DGE	2.00	$/DGE
Diesel fuel economy	7.0	miles/DGE
NG fuel economy - CI	7.0	miles/DGE
NG fuel economy - SI	6.3	miles/DGE

Fuel Operating Cost Advantage Analysis:

Engine Platform	Truck Premium (Initial $)	Diesel Fuel Cost ($ / Year)	NG Fuel Savings ($ / Year)	Payback (Months)	ROI - 5 year (avg % / year)
Westport HD15 (LNG)	$90,000	$57,143	$21,429	50	3.8%
Cummins ISX12G (CNG) - Current	$45,000	$57,143	$25,397	21	36.4%
Cummins ISX12G (CNG) - Future/Mature	$23,000	$57,143	$25,397	11	90.4%
Yuchai 6112 (CNG) – Current	$18,000	$57,143	$25,397	9	121.1%

How Can We Accelerate US HD NG Buildout?

- Broad-based availability of HD ready CNG (or LCNG) refueling stations
- Create engine competition against Cummins by encouraging truck manufacturers to develop NG engines or bring in foreign competition
- Drive tank pricing down toward high-volume levels through competition and truck manufacturer integration assistance
- Work with CNG based refueling stations to negotiate industrial NG pricing (instead of commercial)
- ***Most HD industry experts believe NG will power >20% of the fleet in 5-10 years in the US***