“Contemporary Challenges in Exploration Drilling”

Q3 IADC DEC Technology Forum

September 19, 2018

Apply Data Science for Modeling of Dual Fuel Diesel Engine Technology

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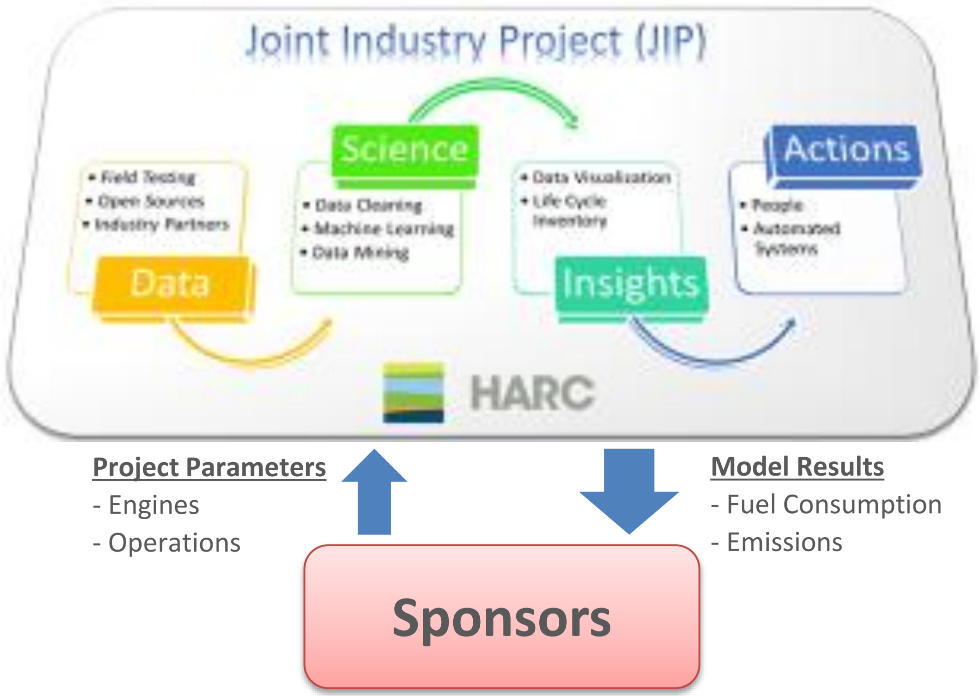
Joint Industry Project
Predictive Model for Dual Fuel Diesel Engines

- **Sponsors**
  Seeking up to 12
  By November 14th
- **Project Cost**
  Total $185,000
  Divided Among Sponsors
- **Duration**
  6-8 months



CONVERTING DATA
Into Insights for Action

SCOPING
What insights are most meaningful?

PREDICTIVE MODEL
Fuel Consumption, Emissions

LESSONS LEARNED
with Data Science shared with Sponsors

Deliverables

- **Interactive Online User Interface**
  - Unlimited User Access for Sponsors
  - 3 Years Hosting
- **Predictive Model Output**
  - Visualized Data and Predictions
  - Diesel & Natural Gas Fuel Consumption & Substitution Ratio
  - Engine Emissions

Dual Fuel Diesel Engines

POWERED BY NATURAL GAS

Hydraulic Fracturing
Variable Load
Speed 1500 to 1950 rpm

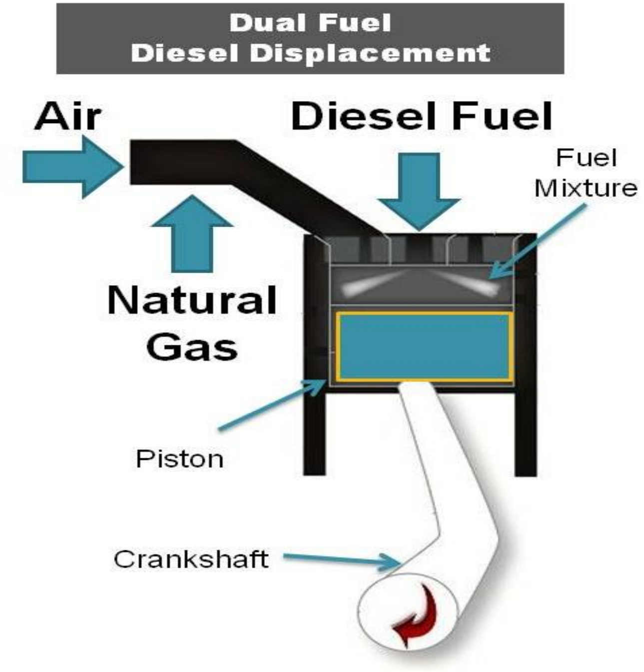
Drilling
Steady + Transient Loads
Speed 1200 rpm

Dual Fuel Diesel Engine

Diesel Fuel and Natural Gas Used Together

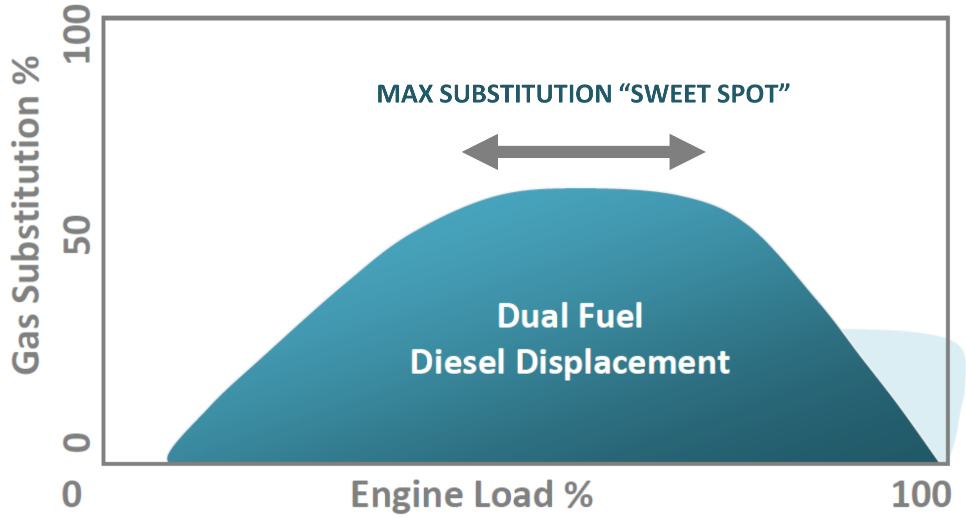
Fumigation Systems

Natural Gas Fuel Introduced Into Engine Air Intake in Vapor Phase



POWERED BY NATURAL GAS

Replace Diesel Fuel with Gas Fuel



Substitution / Diesel Displacement

Maximum Substitution Occurs in the Operating Range known as the "Sweet Spot"

GRAPHICS ADAPTED FROM CUMMINS

Increasing Dual Fuel Diesel Savings

Making the "Sweet Spot" Sweeter

Example of Dual Fuel Diesel Cost Savings with 10% Increased Substitution

A rig that consumes 1,500 gallons of diesel fuel per day could realize an incremental savings of **$177,609** annually by **increasing natural gas substitution from 50% to 60%.**

Diesel Fuel $3.24 / gallon
EIA Diesel Fuel Price Index, June 23, 2018
https://www.eia.gov/petroleum/gasdiesel/

Diesel Fuel Only			Dual Fuel Substitution					
			50%			60%		
Gallons	Daily Cost	Annual Cost	Gallons	Daily Cost	Annual Cost	Gallons	Daily Cost	Annual Cost
1,000	$ 3,244	$ 1,184,060	500	$ 1,622	$ 592,030	400	$ 1,298	$ 473,624
1,100	$ 3,568	$ 1,302,466	550	$ 1,784	$ 651,233	440	$ 1,427	$ 520,986
1,200	$ 3,893	$ 1,420,872	600	$ 1,946	$ 710,436	480	$ 1,557	$ 568,349
1,300	$ 4,217	$ 1,539,278	650	$ 2,109	$ 769,639	520	$ 1,687	$ 615,711
1,400	$ 4,542	$ 1,657,684	700	$ 2,271	$ 828,842	560	$ 1,817	$ 663,074
1,500	$ 4,866	$ 1,776,090	750	**$ 2,433**	**$ 888,045**	600	**$ 1,946**	**$ 710,436**
1,600	$ 5,190	$ 1,894,496	800	$ 2,595	$ 947,248	640	$ 2,076	$ 757,798
1,700	$ 5,515	$ 2,012,902	850	$ 2,757	$ 1,006,451	680	$ 2,206	$ 805,161
1,800	$ 5,839	$ 2,131,308	900	$ 2,920	$ 1,065,654	720	$ 2,336	$ 852,523
1,900	$ 6,164	$ 2,249,714	950	$ 3,082	$ 1,124,857	760	$ 2,465	$ 899,886
2,000	$ 6,488	$ 2,368,120	1000	**$ 3,244**	**$ 1,184,060**	800	**$ 2,595**	**$ 947,248**

Rig using 1,500 gallons of Diesel Fuel per day		
Daily Incremental Diesel Fuel Cost Savings	$	487
Annual Incremental Diesel Fuel Cost Savings	$	177,609

Rig using 2,000 gallons of Diesel Fuel per day		
Daily Incremental Diesel Fuel Cost Savings	$	616
Annual Incremental Diesel Fuel Cost Savings	$	236,812

Illustration Purposes Only

Value Proposition

Increasing Diesel Fuel Savings

Example for Illustration Only

ROI & Payback Period

A rig that consumes 1,500 gallons of diesel fuel per day could save **$177,609** annually by increasing natural gas substitution from 50% to 60% of the diesel fuel typically used, for daily savings of **$488.**

Return on Investment
Annual Fuel Savings $177,609/Sponsorship Fee

Payback in Operating Days
Daily Savings of $488/Sponsorship Fee

Number Sponsors	Sponsorship Fee	ROI	Payback Days
1	$185,000	96%	380
2	$ 92,500	192%	190
3	$ 61,667	288%	127
4	$ 46,250	384%	95
5	$ 37,000	480%	76
6	$ 30,833	576%	63
7	$ 26,429	672%	54
8	$ 23,125	768%	48
9	$ 20,556	864%	42
10	$ 18,500	960%	38
11	$ 16,818	1056%	35
12	$ 15,417	1152%	32

Project Deliverable:
Predictive Model for Dual Fuel Operations

- Diesel Fuel Consumption
- Gas Substitution
- Engine Emissions

Optimize parameters to increase gas substitution for greater diesel fuel cost savings

Confidently address environmental issues of engine emissions

*NOTE: The ROI and Payback Days calculated here consider **only diesel fuel cost savings**. This does not include the cost of natural gas fuel, which can vary considerably based upon supply availability, infrastructure, royalties, and other factors. Furthermore, these calculations do not account for the capital cost for dual fuel equipment. When these factors are considered, actual ROI would be reduced, and the number of Payback Days would increase.

Terms

- No Specialized Hardware
- No Field Measurements - Prediction Only
- Limited Modeling Support
- Background Data Not Shared
- Model Code Not Shared
- Confidentiality / Non-Disclosure
- Subject to Terms & Conditions

Prediction Summary Example

Parameters	Unit	Representative Value*	Best Prediction MARE**	Best Prediction RMSE***
Fuel efficiency	1	0.266	**4.3%**	0.015
Diesel displacement	1	0.604	**7.2%**	0.055
Substitution ratio	1	0.698	**4.8%**	0.044
GHG emission	CO_2e kg/kWh	1.880	**3.9%**	0.095
NMHC+NOx w/o ATS	g/kWh	10.194	**10.4%**	1.15
NMHC+NOx w/ ATS	g/kWh	5.123	**10.4%**	0.61
CO w/o ATS	g/kWh	23.65	**4.8%**	1.36
CO w/ ATS	g/kWh	0.217	**21.4%**	0.063

*Mean value in database
**MARE: Mean Absolute Relative Error
***RMSE: Root Mean Squared Error

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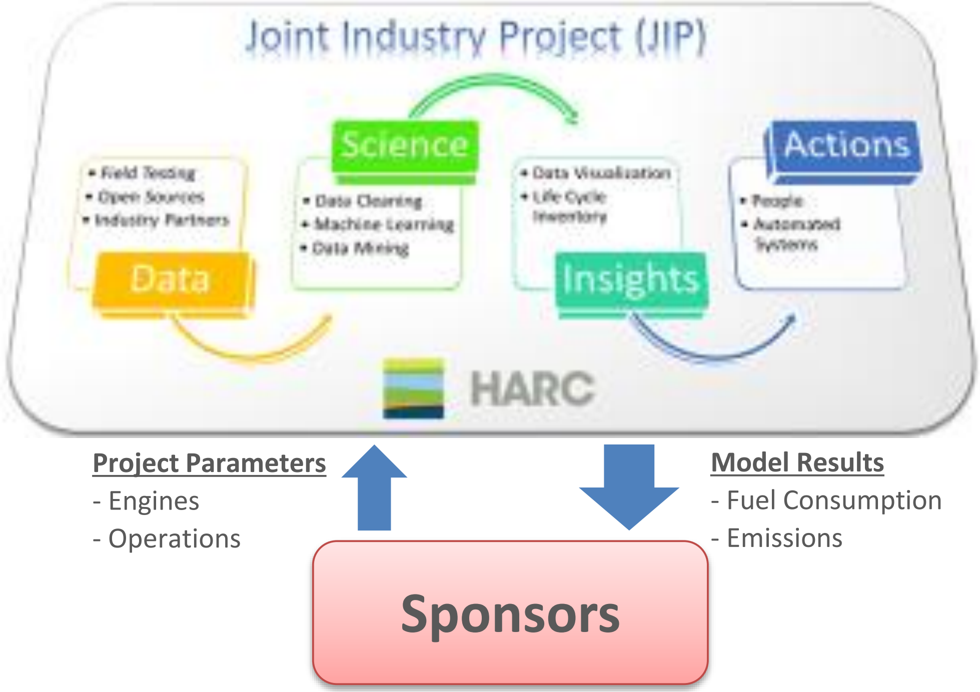

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Thank You

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