

# Electrifying Mobile Hydraulics

On hybrid- and battery- powered machines

Michael Terzo  
Founder & CEO  
Terzo Power Systems



**TERZO**  
POWER EVOLUTION

| 2022

# OUR MOTIVATION

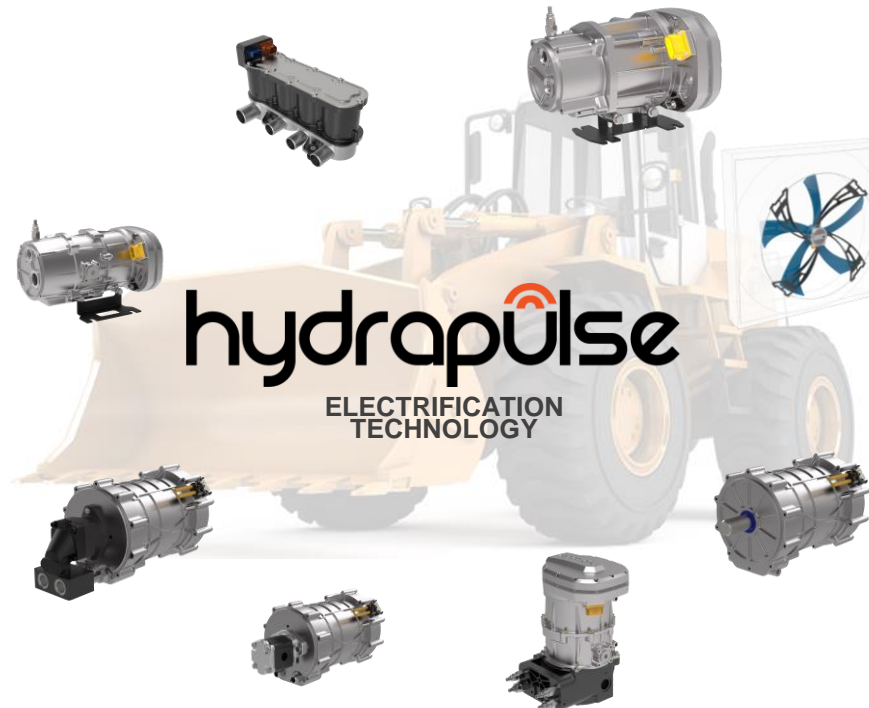
| INNOVATION | EFFICIENCY | SIMPLICITY



## TERZO POWER SYSTEMS, LLC

Terzo Power Systems produces a new, innovative line of electrohydraulic pump systems which provide flexible and easy to use technology designed for on- & off-highway mobile vehicles and industrial applications. Our Hydrapulse® products are fully integrated, economical, energy efficient systems with an electronically controlled motor & pump assembly all contained in a small, compact footprint.

ON-HIGHWAY | OFF-HIGHWAY | INDUSTRIAL



## COMPANY HIGHLIGHTS

- Technology Development & Manufacturing company
- Founded in 2014 by Michael Terzo
- Headquartered in El Dorado Hills, California
- High volume PCB fabrication, assembly, and testing in-house
- Medium-, Heavy-Duty, and Off-highway electrification solutions
- Industrial, Automation, and Motion Control solutions
- Launched the Hydrapulse® product line after 7 years of development.
- High volume final manufacturing in Chicago, IL.

# NEXT GEN SOLUTION | INTEGRATION + INTELLIGENCE |



**RUGGED IP6K9K RATING**



**WIDE VOLTAGE INPUT RANGE**



**CUSTOM MOUNTING OPTIONS**



**QUIET PUMP OPTIONS**



**PRODUCTION READINESS**



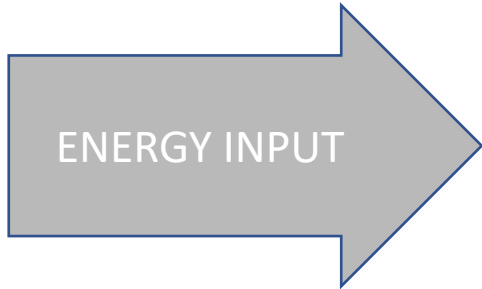
**COMBINED FUNCTIONALITY**



**hydrapulse®**

# CUTTING EDGE EFFICIENCY

# POWER ON DEMAND

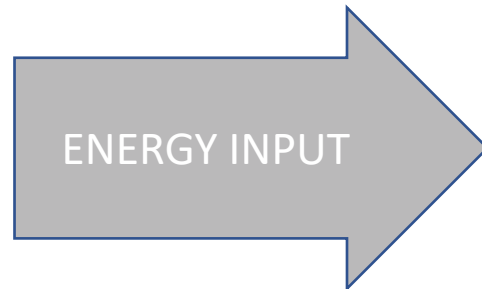


**CONVENTIONAL  
HYDRAULIC SYSTEM**

ENERGY LOST TO HEAT = UP TO 95% LOST\*

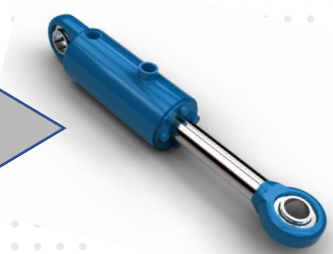
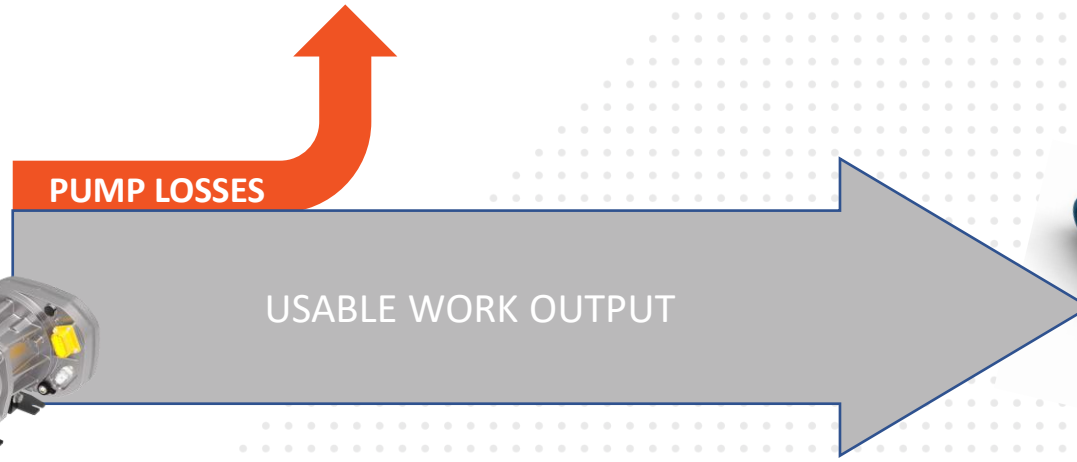


**ACTUAL WORK  
PERFORMED**



**HYDRAPULSE®  
HYDRAULIC SYSTEM**

ENERGY LOST TO HEAT = LESS THAN 5%\*



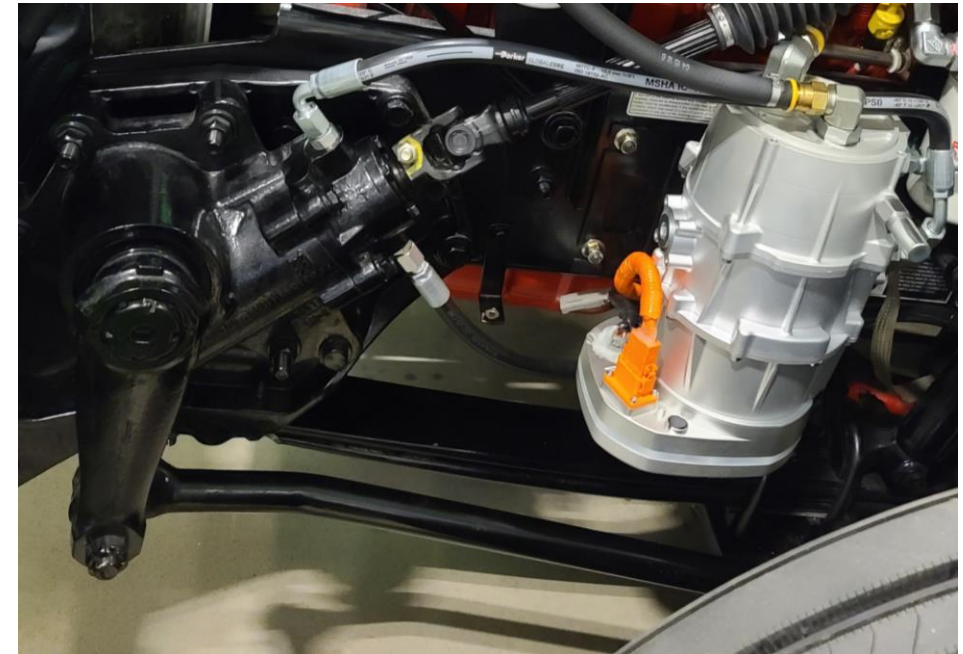
\* DEPENDS ON DUTY CYCLE, FIND OUT HOW WE HAVE PROVEN ENERGY REDUCTION OF UP TO 96% (<https://terzopower.com/over-96-energy-savings-3-year-project-results/>)



# APPLICATIONS – COMMERCIAL TRUCKING

TCO has tipped in favor of ZEV

Will the same happen for off-highway?



**Must Address the Elephant in the Construction site**



# NO

**Construction equipment is not like a car.**

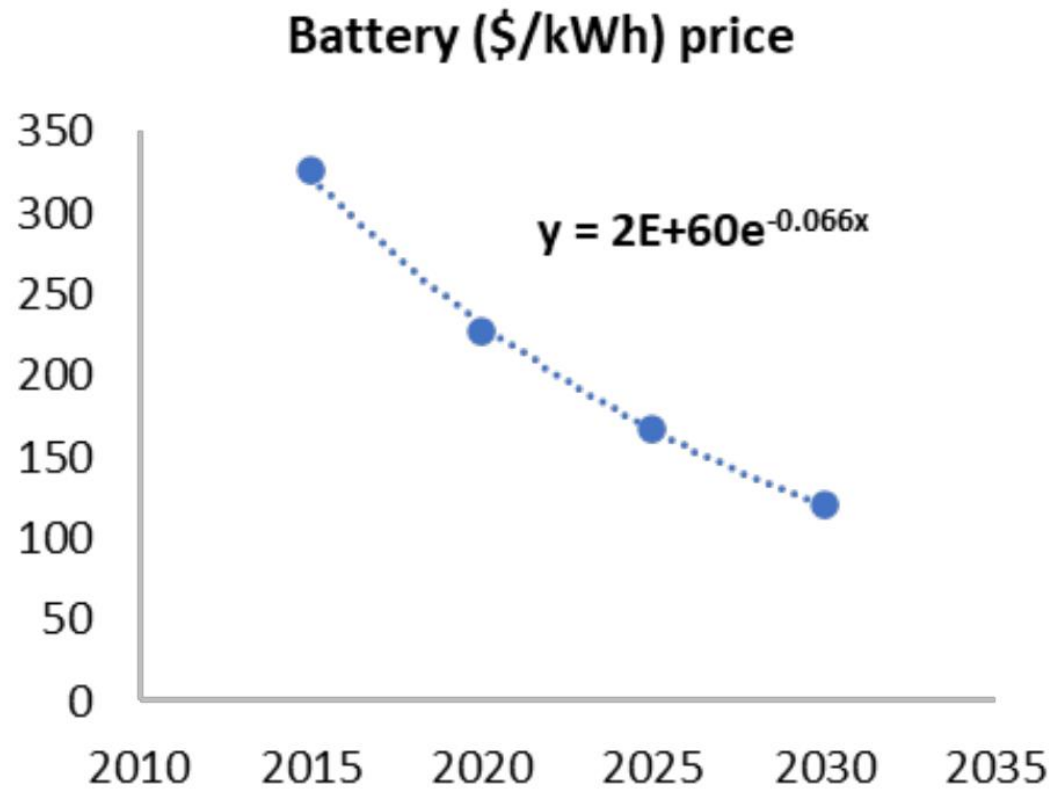
- Batteries are not there yet
- Diversity of duty cycles
- Low volumes

**Therefore:**

**Mass adoption of pure electric heavy-duty off-highway vehicles will not happen any time soon.**

# BATTERIES ARE TOO EXPENSIVE

- FAULTY ASSUMPTION THAT BATTERY COSTS WILL CONTINUE DOWNWARD TREND



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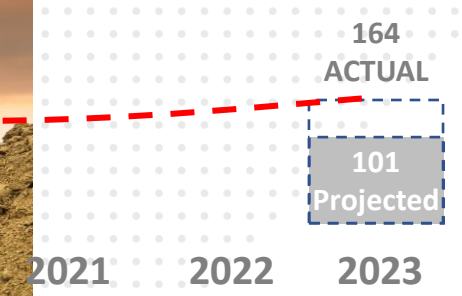
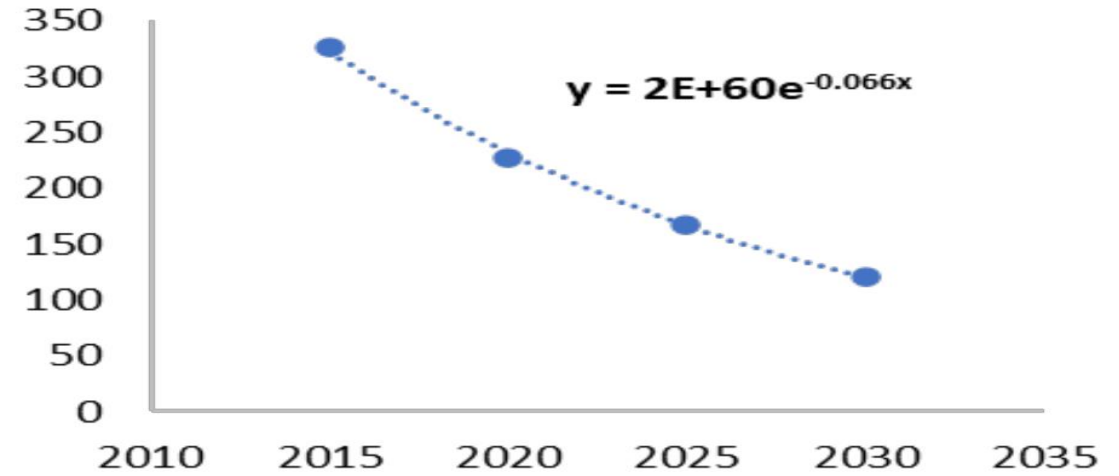




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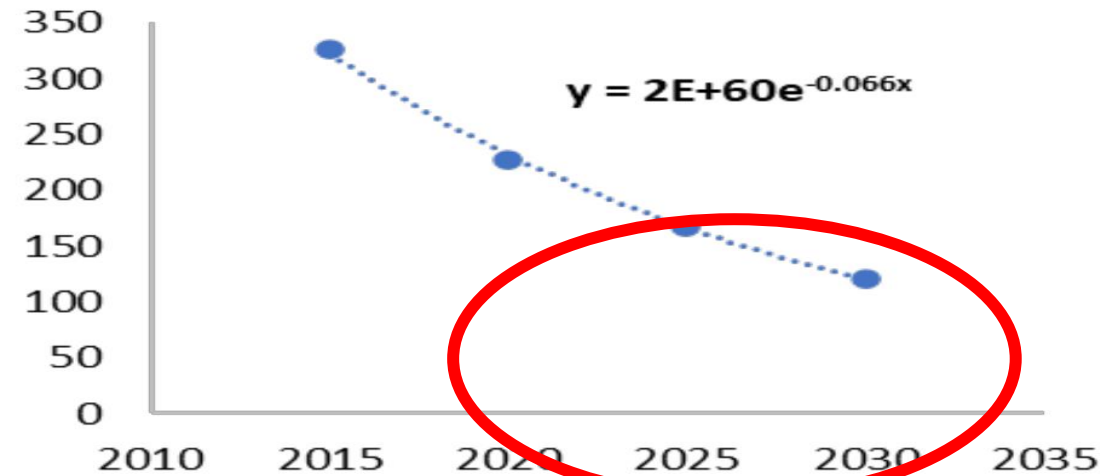
Battery (\$/kWh) price



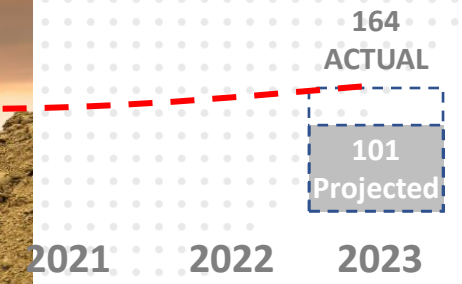
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MOVING THE GOALPOSTS?

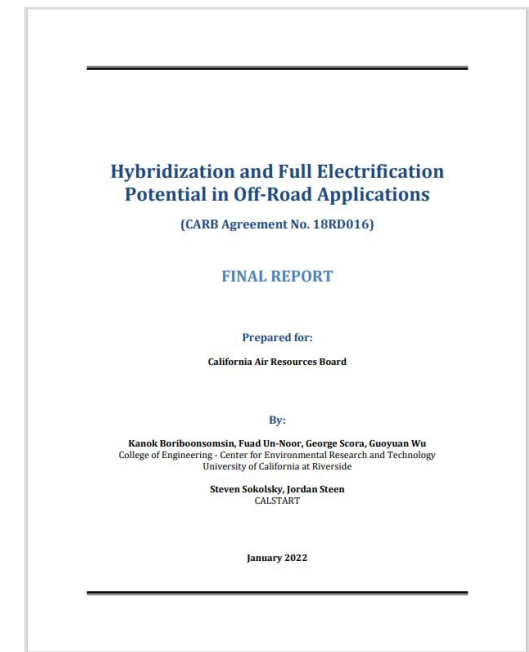


# RESEARCH SHOWS ITS NOT FEASIBLE

## Battery Size by Equipment Type

Equipment Type	Usable Battery Size (kWh)	Actual Battery Size (kWh)	Rounded Actual Battery Size (kWh)
Excavators	420	546	550
Graders	491	638	640
Off-Highway Tractors	2,712	3,526	3,530
Rubber-tired Loaders	604	785	790
Scrapers	1,423	1,850	1,850
Tractors/Loaders/Backhoes	252	328	330

Source: "Hybridization and Full Electrification Potential in Off-Road Application," Boriboonsomsin, 2022



	Excavator	Grader	Off-Highway Tractors	Rubber-tired Loaders	Scrapers	TLB's
<b>Actual Battery Size (kWh)</b>	550	640	3,530 (3.5MWh)	790	1,850 (1.8MWh)	330
<b>Actual Battery Weight kg (lbs)</b>	3,642 (8,030)	4,238 (9,344)	23,377 (51,538)	5,231 (11,534)	12,251 (27,010)	2,185 (4,818)
<b>Actual Battery Cost</b>	\$137,500	\$160,000	\$882,500	\$197,500	\$462,500	\$82,500
<b>Average vehicle purchase price (STANDARD DIESEL VEHICLE)</b>	\$250,000	\$300,000	\$1,000,000	\$200,000	\$600,000	\$120,000

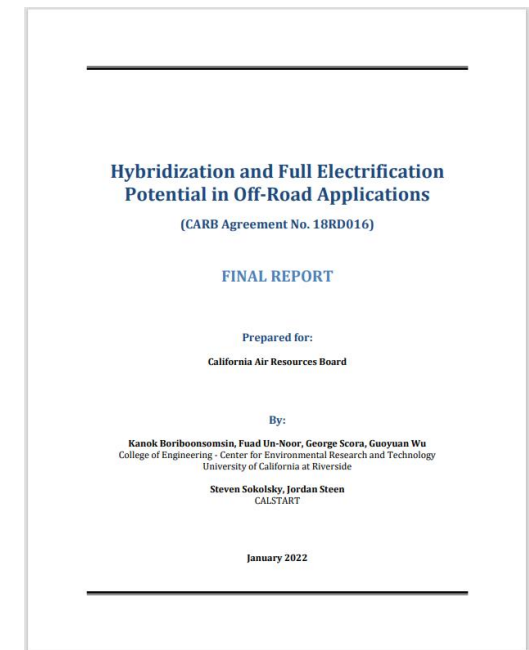
\*References & calculations available. \$250/kWh battery system cost used.

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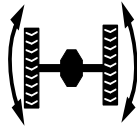
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<b>Actual Battery Cost - \$80/kWh</b>	<b>\$35,200</b>	<b>\$40,960</b>	<b>\$225,920</b>	<b>\$50,560</b>	<b>\$118,400</b>	<b>\$21,120</b>
<b>Average vehicle purchase price (STANDARD DIESEL VEHICLE)</b>	\$250,000	\$300,000	\$1,000,000	\$200,000	\$600,000	\$120,000

\*References & calculations available.

# DIVERSITY OF DUTY CYCLES & APPLICATIONS



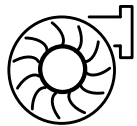
**COOLANT PUMPS  
BATTERY/ENGINE/FUEL CELL**



**HYDRAULIC  
BRAKES | CLUTCHES**



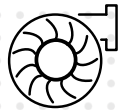
**STEERING ASSIST  
E-STEERING | STEER BY WIRE**



**HYDROSTATIC DRIVE**



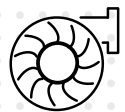
**AXLE STEERING**



**POWER TAKE OFF**



**HYDRAULIC WORK  
FUNCTIONS**



**AUXILLARY FUNCTIONS**

**Duty Cycle | Diverse Applications**



Military



Mining



Agriculture



Utility



Forestry



Construction



## THEN WHY CARE ABOUT ELECTRIFICATION IN HYDRAULIC SYSTEMS?

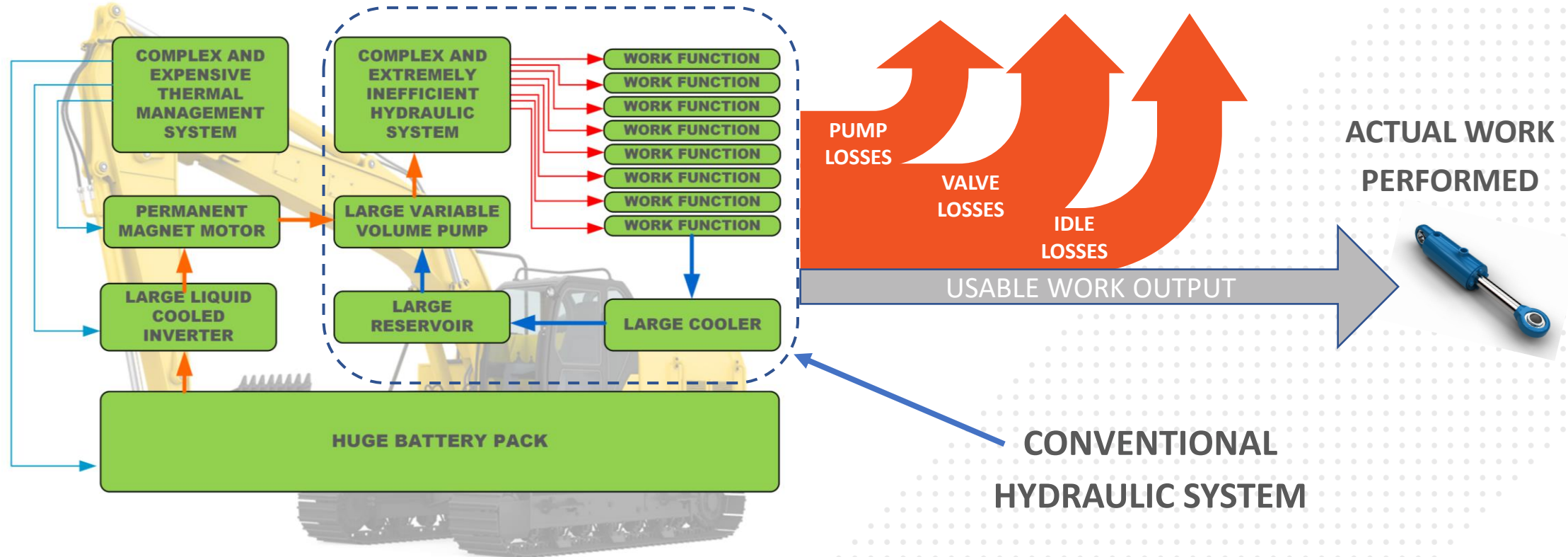
- PERFORMANCE ADVANTAGES
- REGULATORY PRESSURES
- SKILLS SHORTAGES
- NOISE REDUCTION
- FUEL SAVING / TCO REDUCTION

MUST FIT TECHNOLOGY TO THE CORRECT APPLICATION  
ONE SIZE DOES NOT FIT ALL

# THE PROBLEM

# NEW POWER, SAME OLD HYDRAULIC SYSTEM

ENERGY LOST TO HEAT = UP TO 95% LOST\*



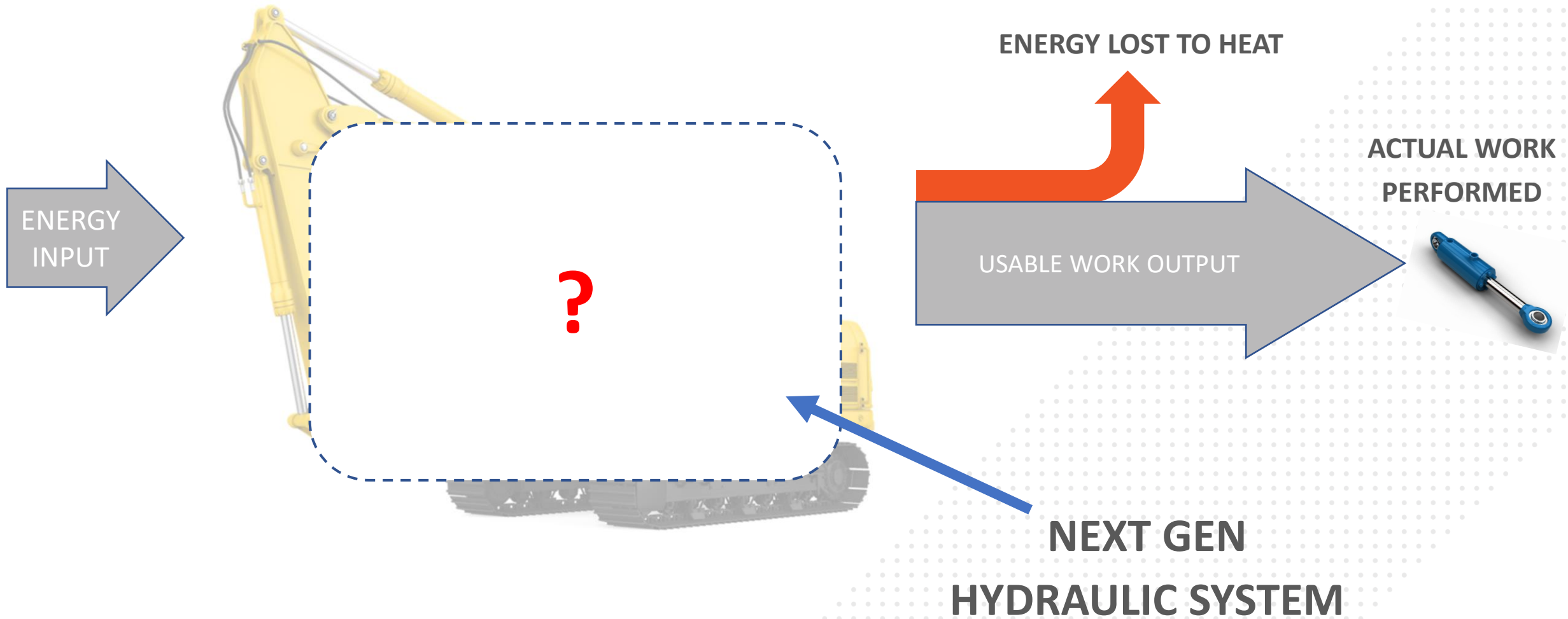
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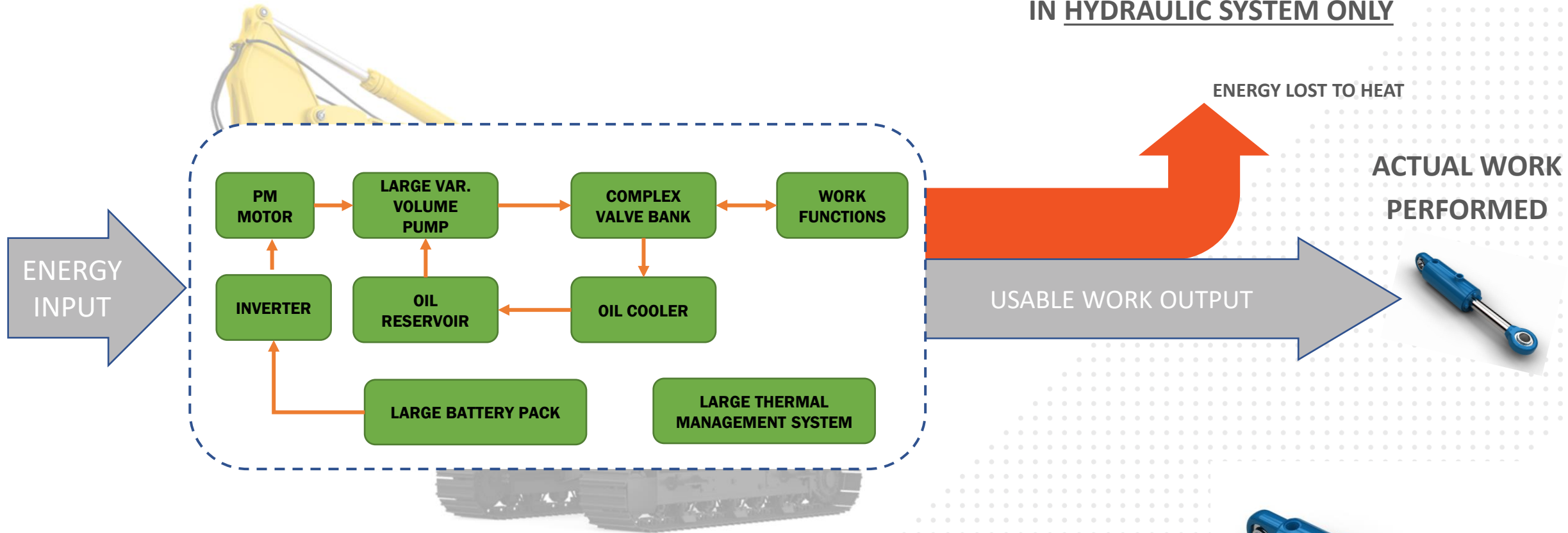


# THE PROBLEM | NEED A NEW SOLUTION |



# SOLUTION 1 | ELECTRO-HYDRAULIC |

UP 10% EFFICIENCY IMPROVEMENT  
IN HYDRAULIC SYSTEM ONLY

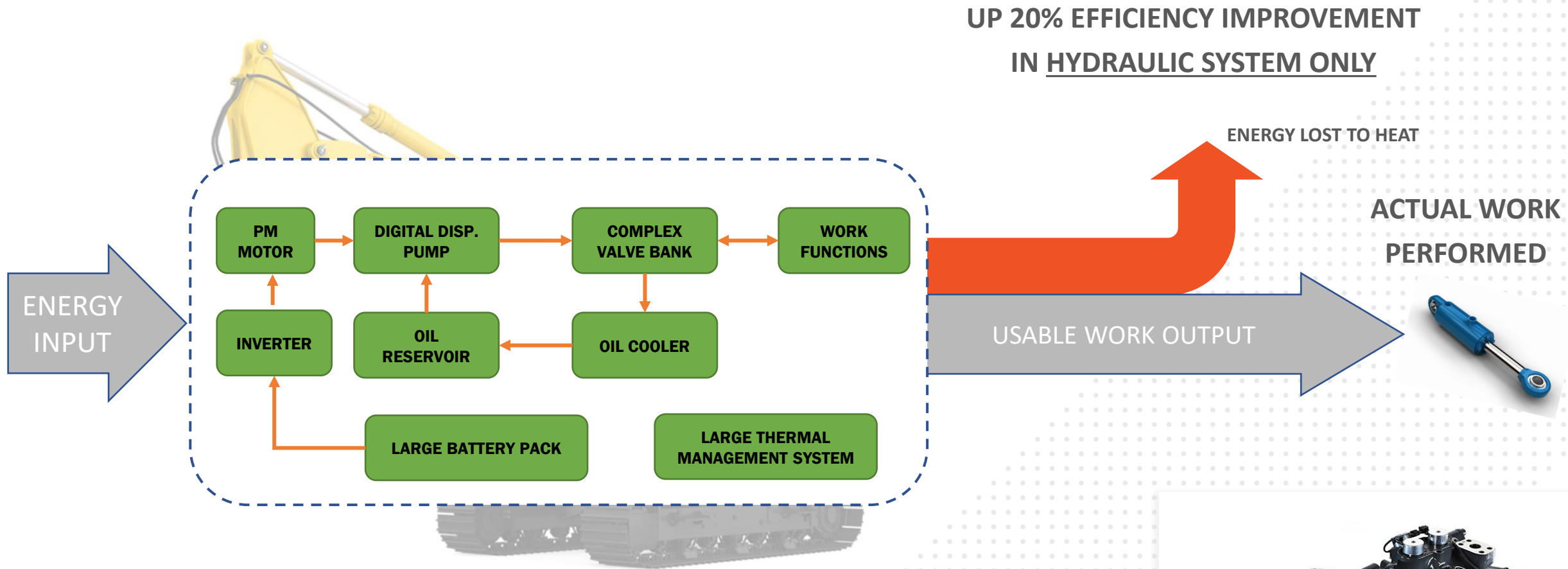


- CAN IDLE MOTOR BUT CANNOT RUN TRUE POWER-ON-DEMAND
- STILL HAS SIGNIFICANT PUMP & VALVE LOSSES BUT WITH REDUCED IDLE LOSSES



# SOLUTION 2 |

# ELECTRO-HYDRAULIC WITH DIGITAL PUMP |



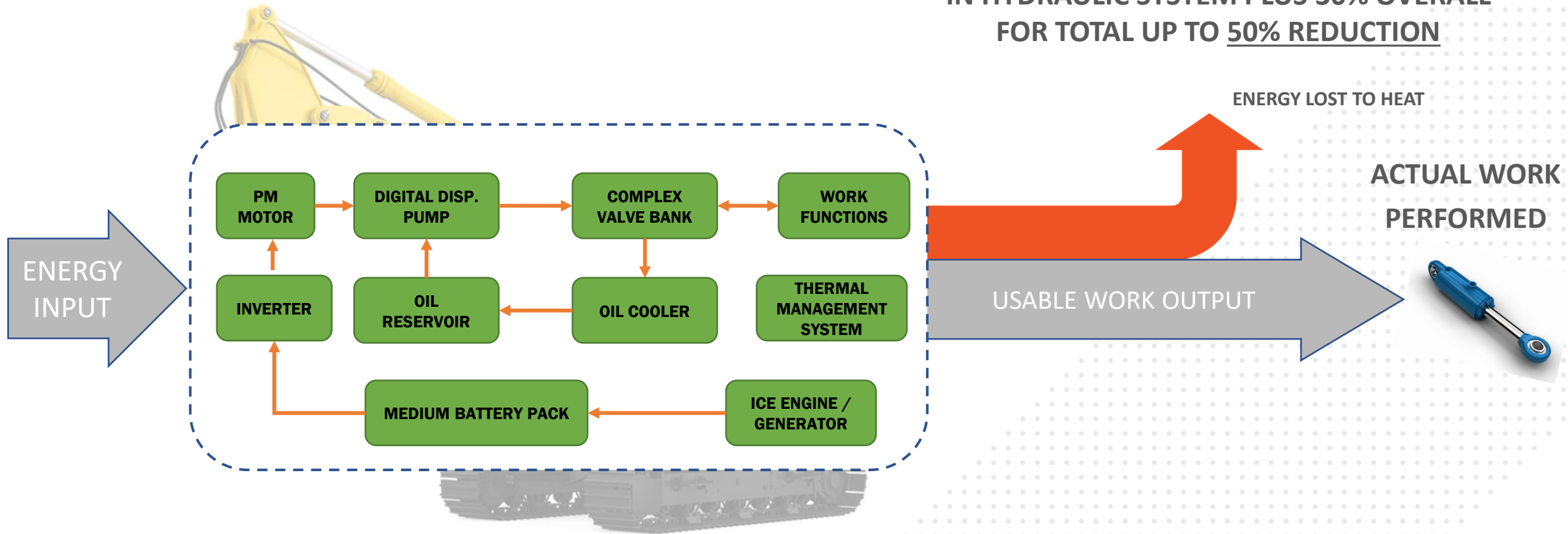
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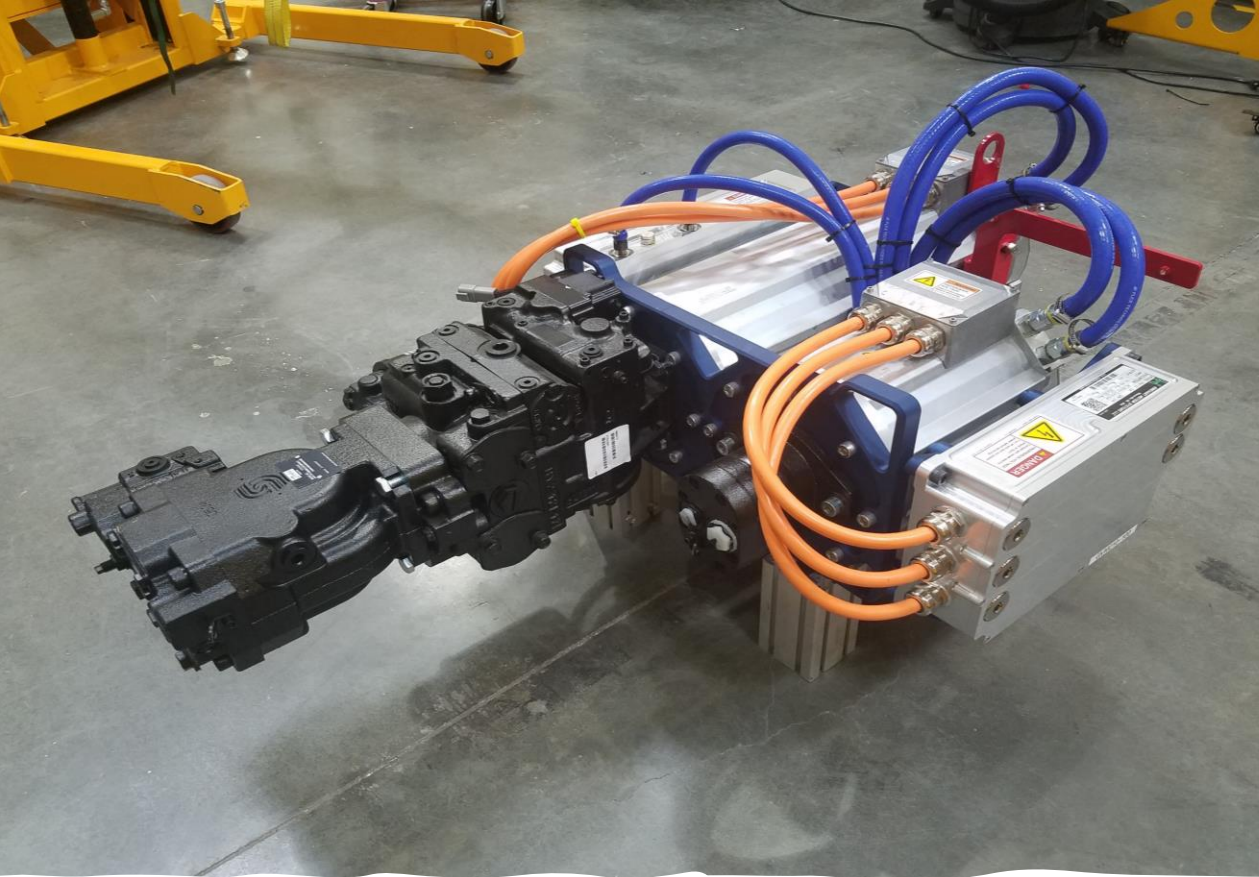
# SOLUTION 3 |

# ELECTRO-HYDRAULIC WITH DIGITAL PUMP & HYBRID |

UP 20% EFFICIENCY IMPROVEMENT  
IN HYDRAULIC SYSTEM PLUS 30% OVERALL  
FOR TOTAL UP TO 50% REDUCTION



- CAN IDLE MOTOR BUT CANNOT RUN TRUE POWER-ON-DEMAND
- STILL HAS SIGNIFICANT VALVE LOSSES BUT WITH REDUCED PUMP AND IDLE LOSSES
- MEETS RUN TIME AND SIZING BUT PRETTY EXPENSIVE



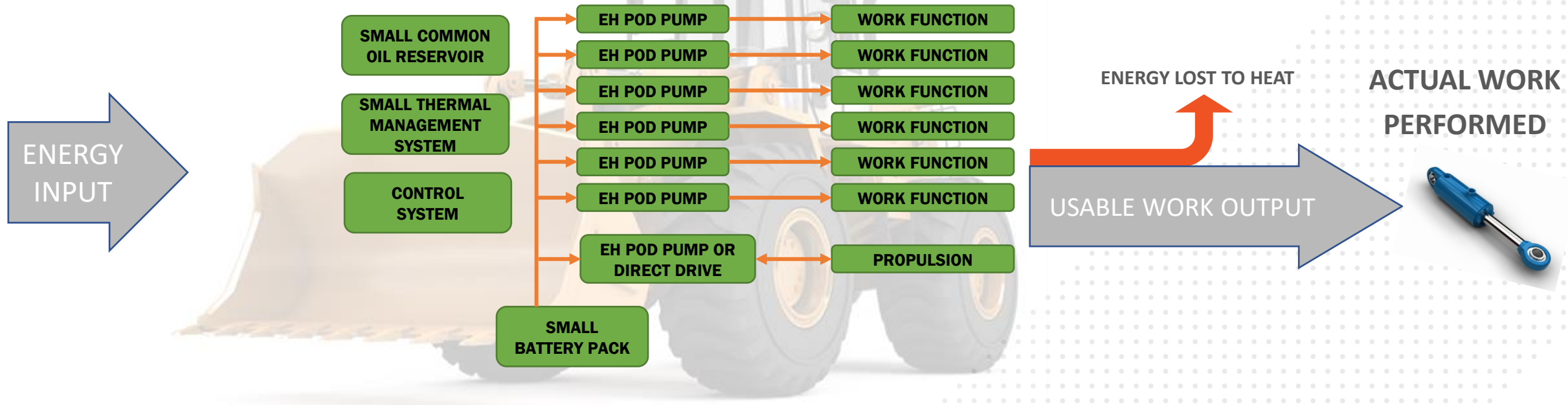
## SOLUTION LIES IN FLUID POWER

### HYDRAULIC OPPORTUNITY

- MOST OFF-HIGHWAY EQUIPMENT IS EXTENSIVELY DEPENDANT ON HYDRAULICS
- PROVEN TECHNOLOGIES AND SOLUTIONS – MUST BE ADAPTED
- GREATER THAN 50% IMPROVEMENT REQUIRED
- RULES OUT MANY TECHNOLOGIES AND SYSTEM ARCHITECTURES
- THE GREATER UTILIZATION OF HYDRAULIC ON THE MACHINE, THE BETTER THE USE CASE FOR ELECTRIFICATION

# A NEW APPROACH | TRUE POWER-ON-DEMAND |

UP 95% EFFICIENCY IMPROVEMENT  
IN HYDRAULIC SYSTEM

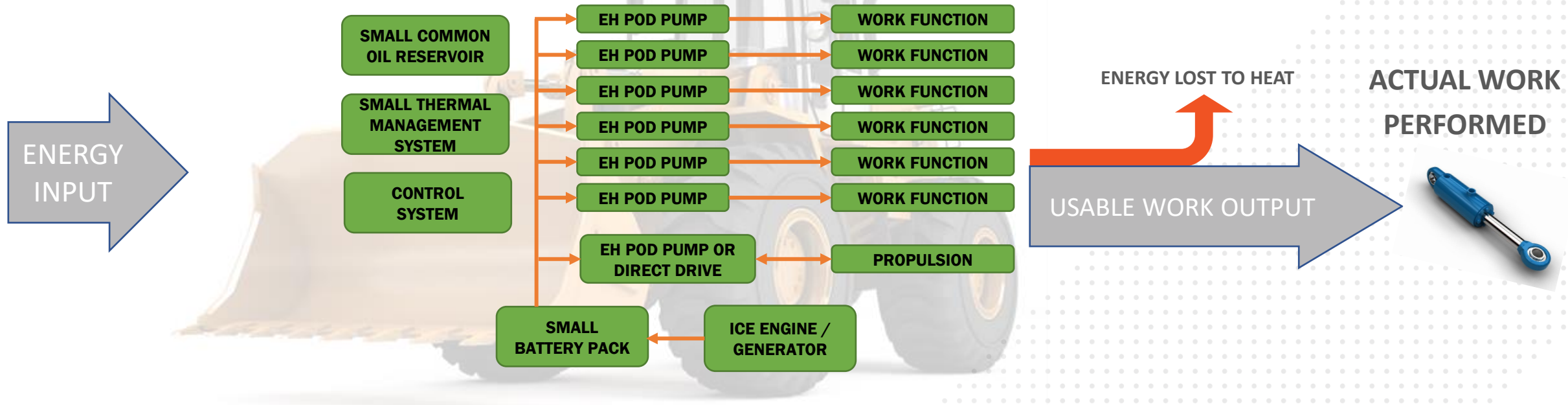


## EH POD BEV SYSTEM

EXTREME ENERGY EFFICIENCY / COST PARITY / NOT COMPLEX

# A NEW APPROACH | TRUE POWER-ON-DEMAND |

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IN HYDRAULIC SYSTEM



## EH POD HEV SYSTEM

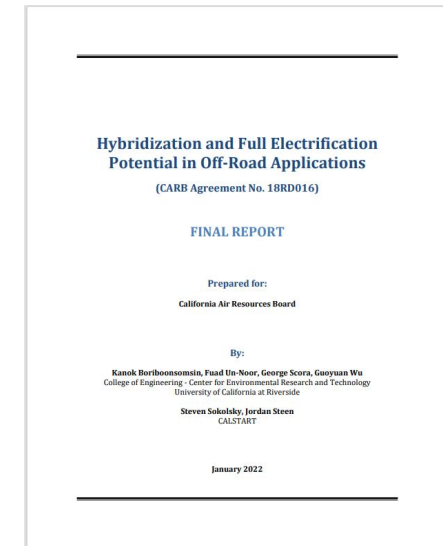
EXTREME ENERGY EFFICIENCY / COST PARITY / NOT COMPLEX

# WHAT'S POSSIBLE TODAY – BEV / HEV FEASIBILITY

## Battery Size by Equipment Type

Equipment Type	Usable Battery Size (kWh)	Actual Battery Size (kWh)	Rounded Actual Battery Size (kWh)
Excavators	420	546	550
Graders	491	638	640
Off-Highway Tractors	2,712	3,526	3,530
Rubber-tired Loaders	604	785	790
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Source: "Hybridization and Full Electrification Potential in Off-Road Application," Boriboonsomsin, 2022



	Excavator	Grader	Off-Highway Tractors	Rubber-tired Loaders	Scrapers	TLB's
<b>Adjusted Battery Size (kWh)</b>	135	400	2,870 (2.8MWh)	553	1,433 (1.4MWh)	145
<b>Actual Battery Weight kg (lbs)</b>	891 (1,971)	2,640 (5,840)	18,942 (41,902)	3,650 (8,073)	9,457 (20,921)	957 (2,117)
<b>Adjusted Battery Cost (\$250 kWh)</b>	\$33,750	\$100,000	\$717,500	\$138,250	\$358,250	\$36,250
<b>Adjustment based on hydraulic %</b>	100%	50%	25%	40%	30%	75%
<b>Adjusted Battery Cost (\$150 kWh)</b>	\$20,250	\$60,000	\$430,500	\$82,950	\$214,950	\$21,750
<b>Adjusted Battery Cost (\$80 kWh)</b>	\$10,800	\$32,000	\$229,600	\$44,250	\$114,640	\$11,600
<b>Average vehicle purchase price (STANDARD DIESEL VEHICLE)</b>	\$250,000	\$300,000	\$1,000,000	\$200,000	\$600,000	\$120,000

BEV / HEV

HEV

HEV

BEV / HEV

HEV

BEV / HEV



# WHAT THIS MEANS FOR THE INDUSTRY | **ENGINE SIZE REDUCTION** |



**CONVENTIONAL  
DIESEL SYSTEM**

**50% SIZE  
REDUCTION  
MINIMUM**



**HYBRID  
DIESEL SYSTEM**

# ELECTRIFICATION = POWERFUL SOLUTION

## | MAKES BUSINESS CASE

1. Purchase Cost
  2. Operating Cost
  3. Maintenance Cost
  4. Resale Value
  5. Productivity & Performance
  6. Durability / Longevity
  7. Noise
  8. Flexibility
  9. Size
  10. Weight
  11. Features (i.e. operator comfort, options, etc.)
  12. Environmental Impact / Emissions
- TCO
- 

## | MEETS TRENDS

1. Carbon-based Fuels
2. Renewable Energy
3. Compact Equipment
4. Connectivity
5. Autonomous Machinery
6. Sensors
7. Workers
8. Business Models
9. Construction Data

## | REGULATORY / ESG COMPLIANCE

1. Allows ZEV for many platforms
2. Allows HEV for all platforms
3. Reduces hydraulic oil hazards
4. Reduces noise
5. Not dependent on battery cost reduction
6. HEV allows non-diesel fuels
7. Reduces dependency on incentives
8. Extreme PM & GHG reduction

# COST BENEFIT ANALYSIS



	Future BEV Excavator	Future HEV Excavator	John Deere 210G LC	John Deere 210G LC (if electric)	CAT 323 Next Generation	CAT 323 Next Generation (if electric)
<b>Purchase Price</b>	\$275,000	\$300,000	\$232,000	\$370,000	\$299,000	\$436,000
<b>Vehicle Weight</b>	50,200 lbs.	48,500 lbs.	52,097 lbs.	62,500 lbs.	56,200 lbs.	62,900
<b>Power Option</b>	Battery (\$250/kWh)	Diesel / Gas / LP / NG	Diesel	Battery (\$250/kWh)	Diesel	Battery (\$250/kWh)
<b>Net Power (KW)</b>	300	300	119	150	128	150
<b>Fuel Cost per yr. <sup>1</sup></b>	\$4,950	\$3,350	\$19,000	\$9,000*	\$16,000	\$7,500*
<b>Maintenance per yr. <sup>2</sup></b>	\$2,750	\$3,150	\$5,380	\$3,000*	\$6,470	\$3,000*
<b>Cost to operate (7 yrs.) <sup>3</sup></b>	\$53,900	\$45,500	\$170,660	\$84,000	\$157,290	\$73,500
<b>TC Operate Reduction</b>	68%	73%	0%	51%	7.8%	56%
<b>Battery Weight . <sup>4</sup></b>	4,176 lbs.	870 lbs.	N/A	10,440 lbs.	N/A	8,700 lbs.

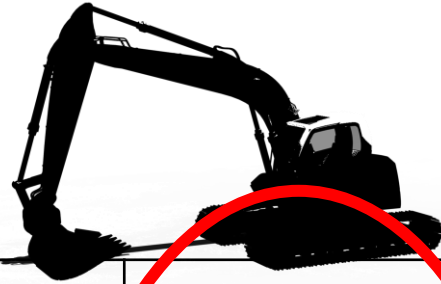
1. Based on national average electric cost per Kwhr and diesel cost per gallon (Q12021). Includes DEF cost @ \$3/gallon (Approx. \$1/hr.)

2. Includes both wear items (daily lubricants, tracks, & consumables) and routine maintenance

3. Minus taxes, insurance, fees, depreciation, and interest. Also does not include labor cost of operator.

4. Based on 8 hr. run time

# COST BENEFIT ANALYSIS



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# TAKE-AWAYS

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1. BATTERIES ARE NOT THE SILVER BULLET
2. SOLID BUSINESS CASE FOR ELECTRIFICATION
3. HYBRIDIZATION IS THE FUTURE
4. ENGINES WILL BE SMALLER





# THANK YOU!

Michael Terzo  
Founder & CEO  
Terzo Power Systems

**TERZO**  
POWER EVOLUTION

| 2022