Mammalian Equivalence

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ROBOTS ARE...

BLIND

DEAF

INSENSITIVE

OVERWEIGHT

WEAK

GLUTTONOUS

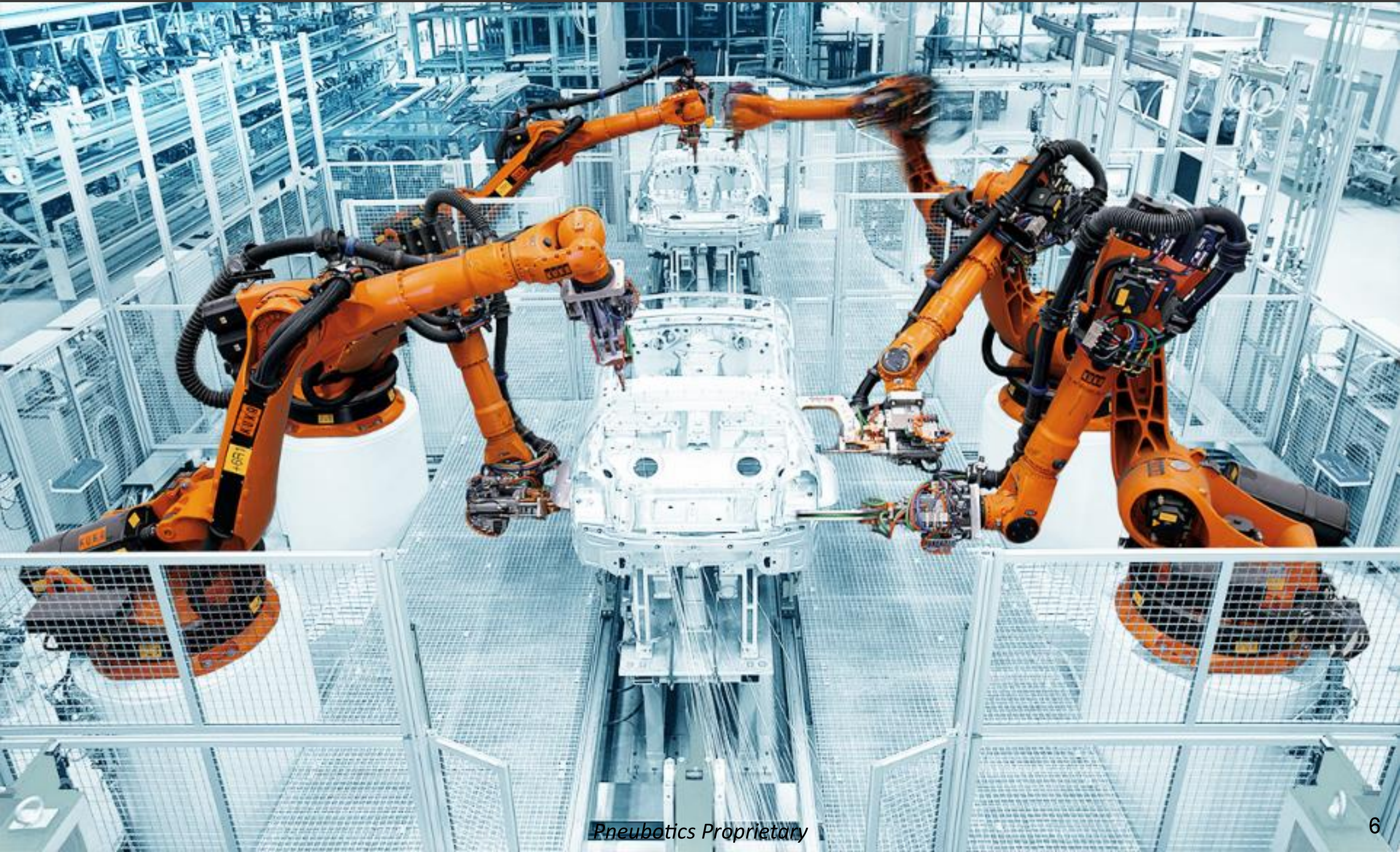
INCOMMUNICATIVE

UNYIELDING

UNCOORDINATED

Rigid robots: Industrial robots

Existing technologies are heavy, expensive, and dangerous



MAMMALIAN EQUIVALENCE

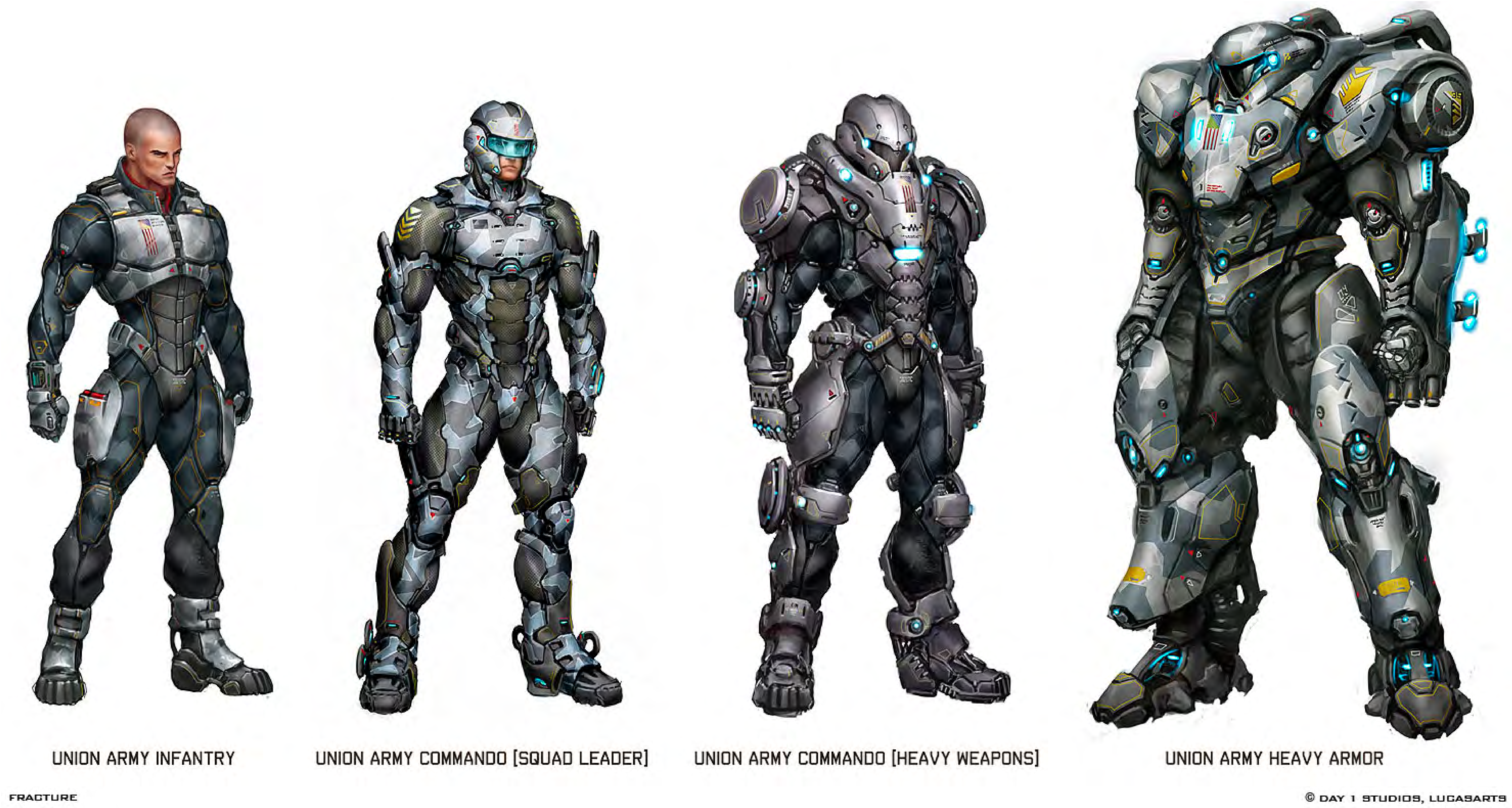
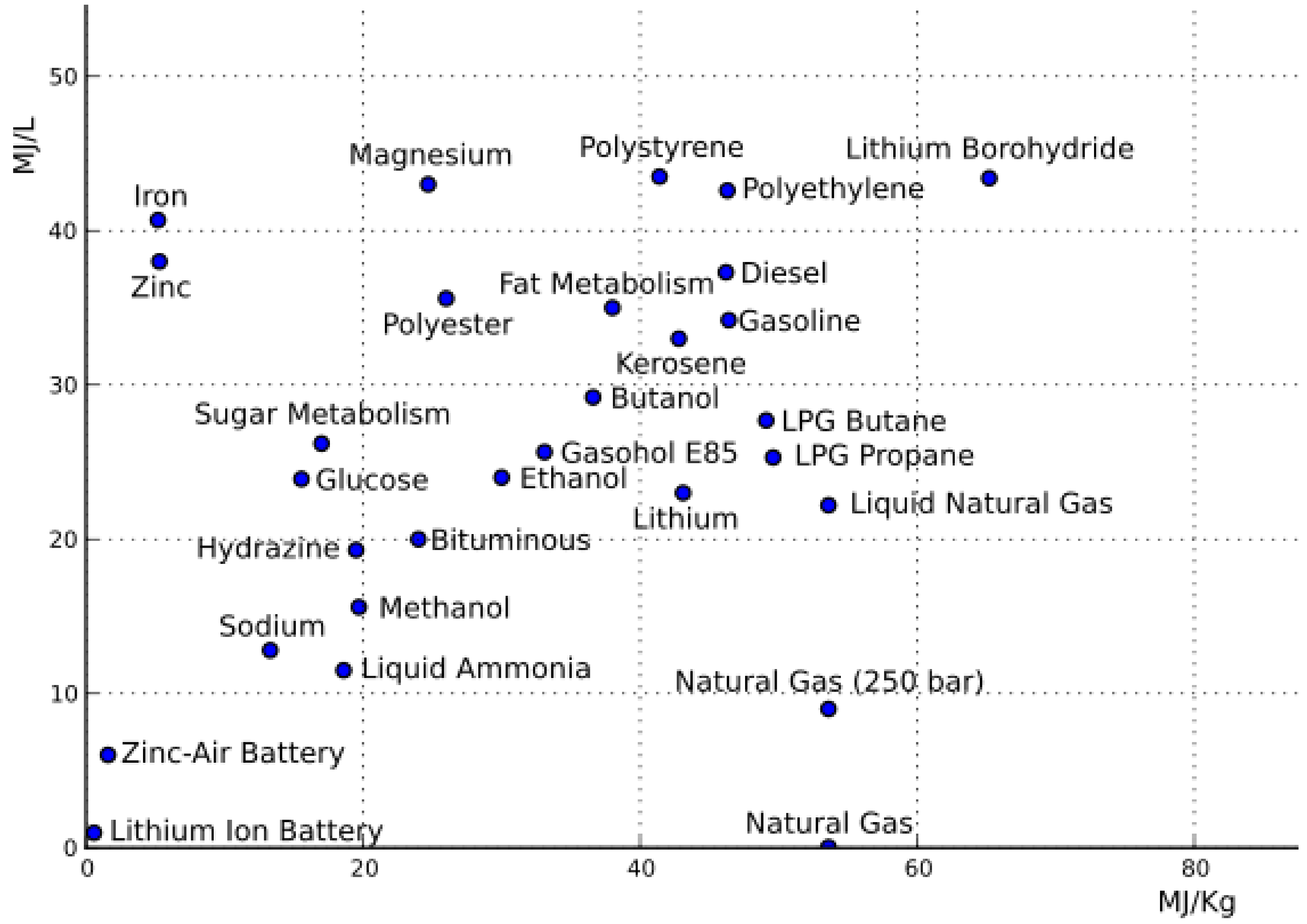


Figure 1: Of the popularized science fiction visions of exoskeletons, which ones are reasonable and or possible?.



MJ/L
MJ/Kg
0
10
20
30
40
50
0
20
40
60
80
Iron
Zinc
Magnesium
Polystyrene
Lithium Borohydride
Polyethylene
Diesel
Fat Metabolism
Gasoline
Polyester
Kerosene
Butanol
Sugar Metabolism
LPG Butane
Gasohol E85
LPG Propane
Glucose
Ethanol
Liquid Natural Gas
Lithium
Hydrazine
Bituminous
Methanol
Sodium
Liquid Ammonia
Natural Gas (250 bar)
Zinc-Air Battery
Lithium Ion Battery
Natural Gas

$$\eta_{\textbf{fuel to foot}} = \eta_{\textbf{plant}} \times \eta_{\textbf{conversion}} \times \eta_{\textbf{transmission}} \times \eta_{\textbf{actuator}} \times \eta_{\textbf{controls}} \times \eta_{\textbf{exo}} \tag{13}$$

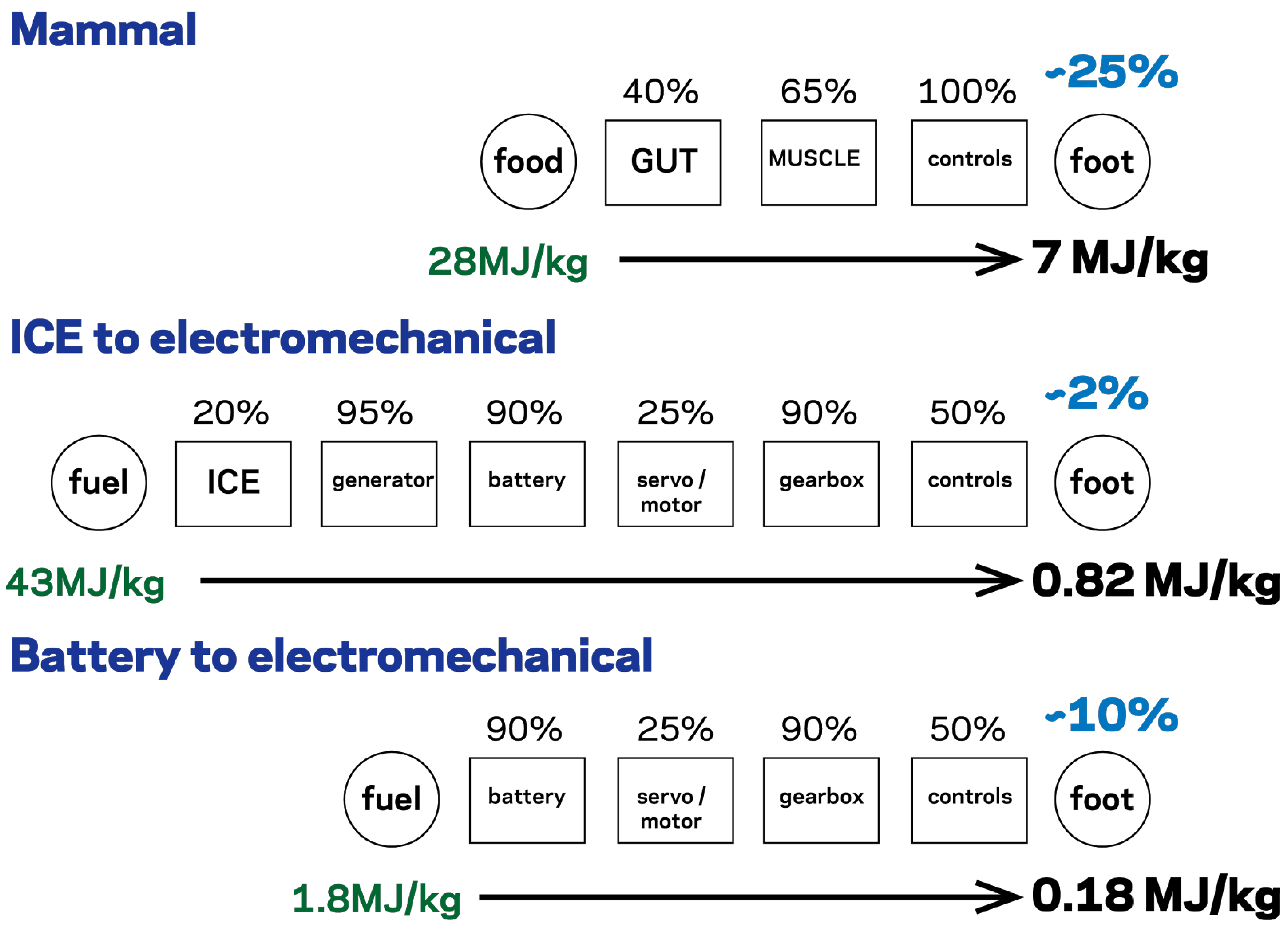
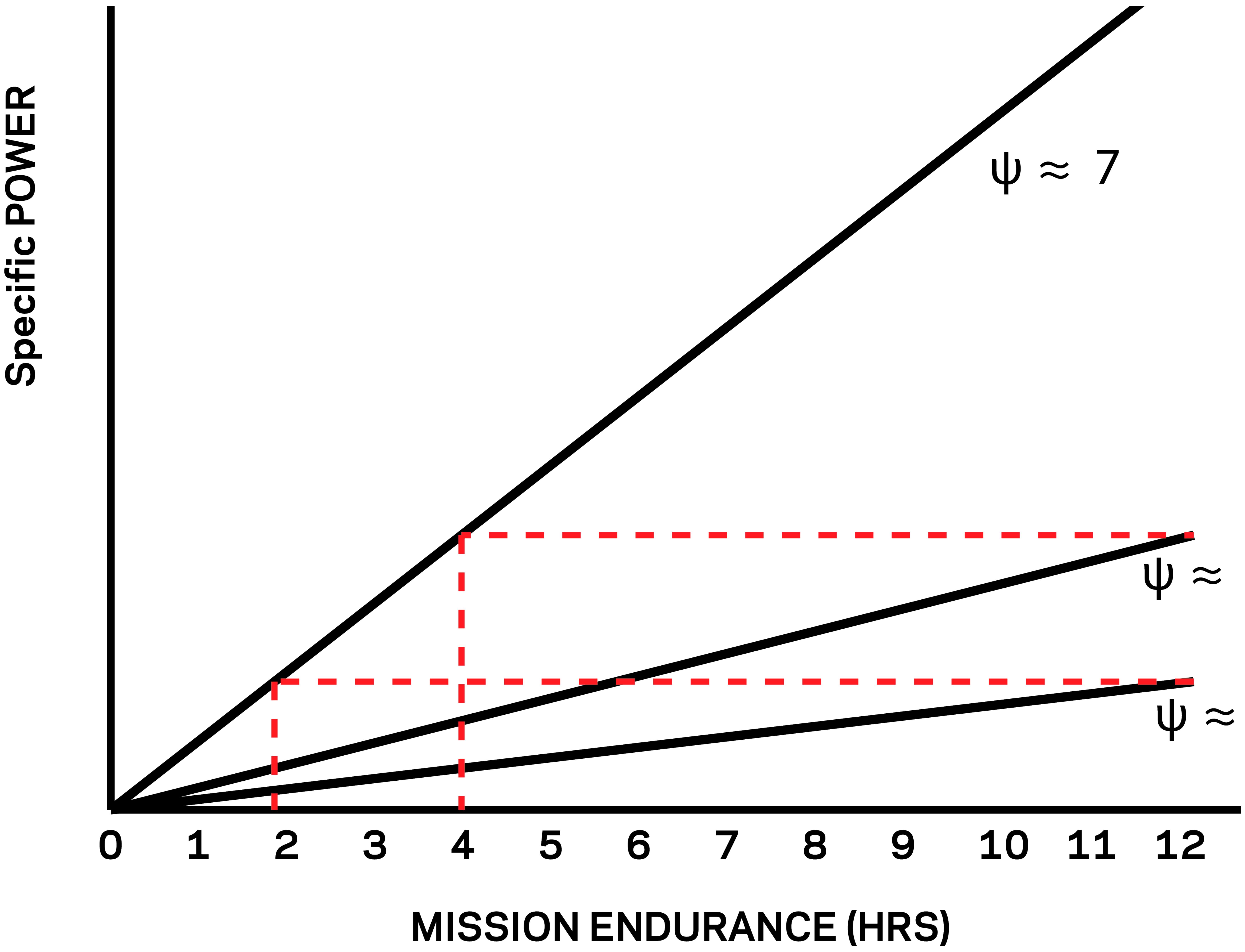
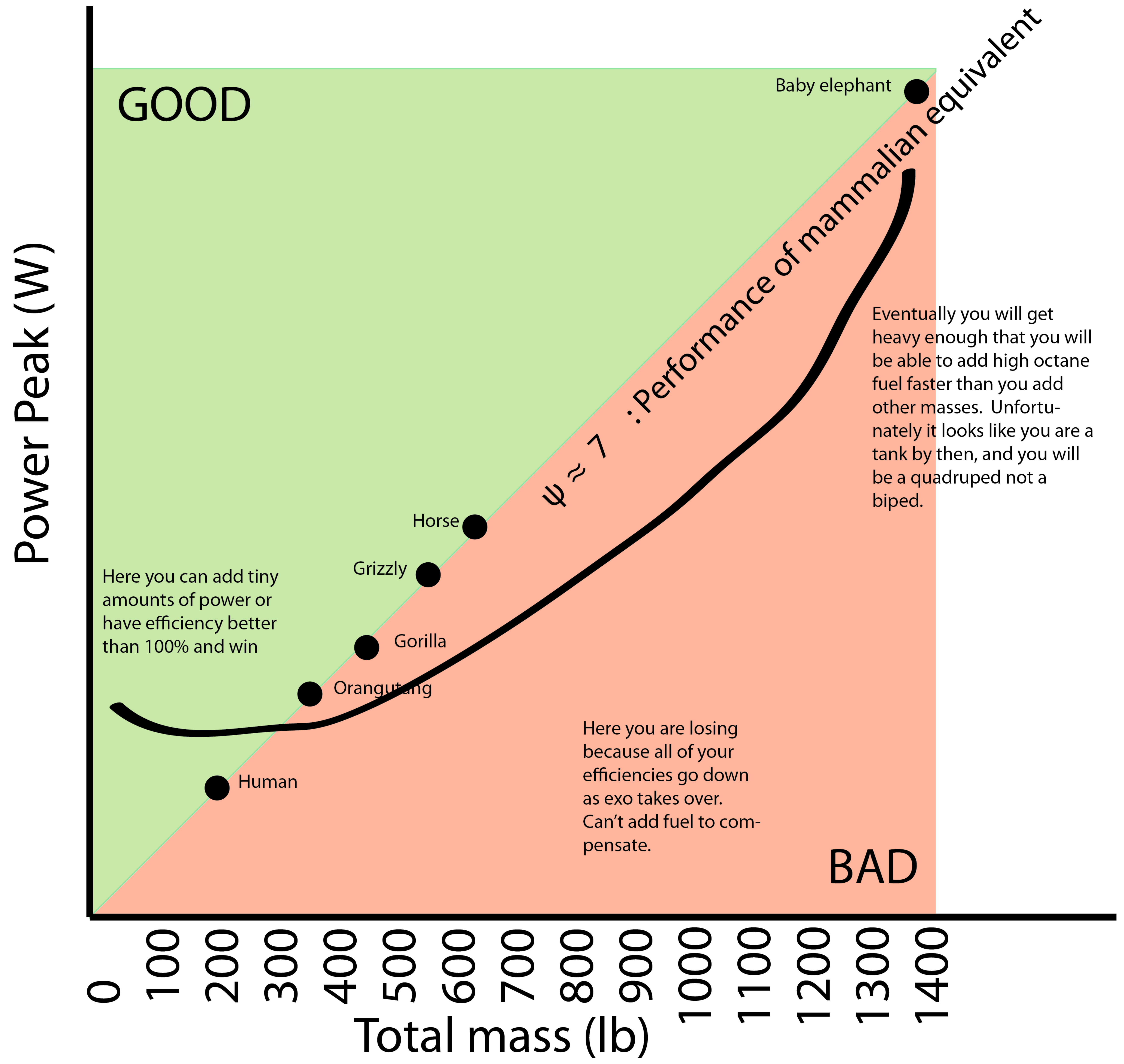


Figure 1: The challenge : Existing fuel to electro-mechanical systems fall far short of mammalian

SYSTEM	Q_c (MJ/kg)	η_{plant}	$\eta_{\text{conversion}}$	$\eta_{\text{transmission}}$	η_{actuator}	η_{controls}	η_{Nett}	%	ψ (MJ)/(kg)
MAMMAL	**28**	**0.4**	**1**	**1**	**0.65**	**1**	**0.26**	26	**7.28**
ICE to Electro-Mechanical	40	0.2	0.8	0.85	0.25	0.25	0.009	0.9	0.36
Fuel Cell to pneumatic	30	0.35	0.75	0.90	0.50	0.25	0.0295	2.95	0.89
Battery to electro mechanical	1.8	1	1	0.95	0.25	0.25	0.0594	5.94	0.11
H2 Fuel Cell to Electro	123	0.25	.95	0.95	0.25	0.25	0.0208	2.08	2



Specific POWER
ψ ≈ 7
ψ ≈
ψ ≈
0 1 2 3 4 5 6 7 8 9 10 11 12
MISSION ENDURANCE (HRS)



GOOD
BAD
Power Peak (W)
Total mass (lb)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
Baby elephant
Horse
Grizzly
Gorilla
Orangutang
Human
ψ ≈ 7 : Performance of mammalian equivalent
Here you can add tiny amounts of power or have efficiency better than 100% and win
Here you are losing because all of your efficiencies go down as exo takes over. Can't add fuel to compensate.
Eventually you will get heavy enough that you will be able to add high octane fuel faster than you add other masses. Unfortunately it looks like you are a tank by then, and you will be a quadruped not a biped.

ROBOT v HUMAN

10kW KUKA...
= 80kWh / day (union robot)
= 80 * $0.12
= $9.60 / day

2bN people < $2.00 / day

THE SCORECARD

Blind	3/10	Fast, vision
Deaf	5/10	Fast, voice rec.
Insensitive	1/10	Slow, ideas
Overweight	2/10	Slow, some ideas
Weak	2/10	Medium
Gluttonous	2/10	Slow
Incommunicative	2/10	Medium
Unyielding	3/10	Medium
Uncoordinated	3/10	Fast
Stubborn	10/10	
Obedient	9/10	

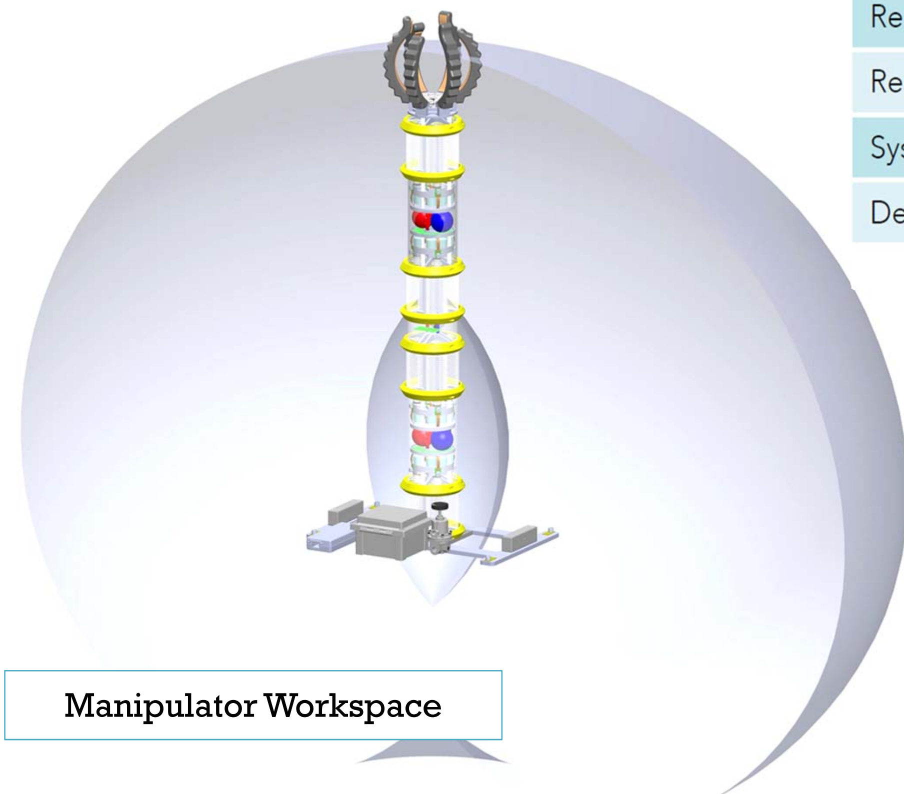
WORKAROUNDS ?

VERY LIGHTWEIGHT

Pneubotics Features

Unparalleled performance and flexibility

Large workspace: 9DOF arm, 4 universal joints, 1 rotational joint at wrist



Manipulator Workspace

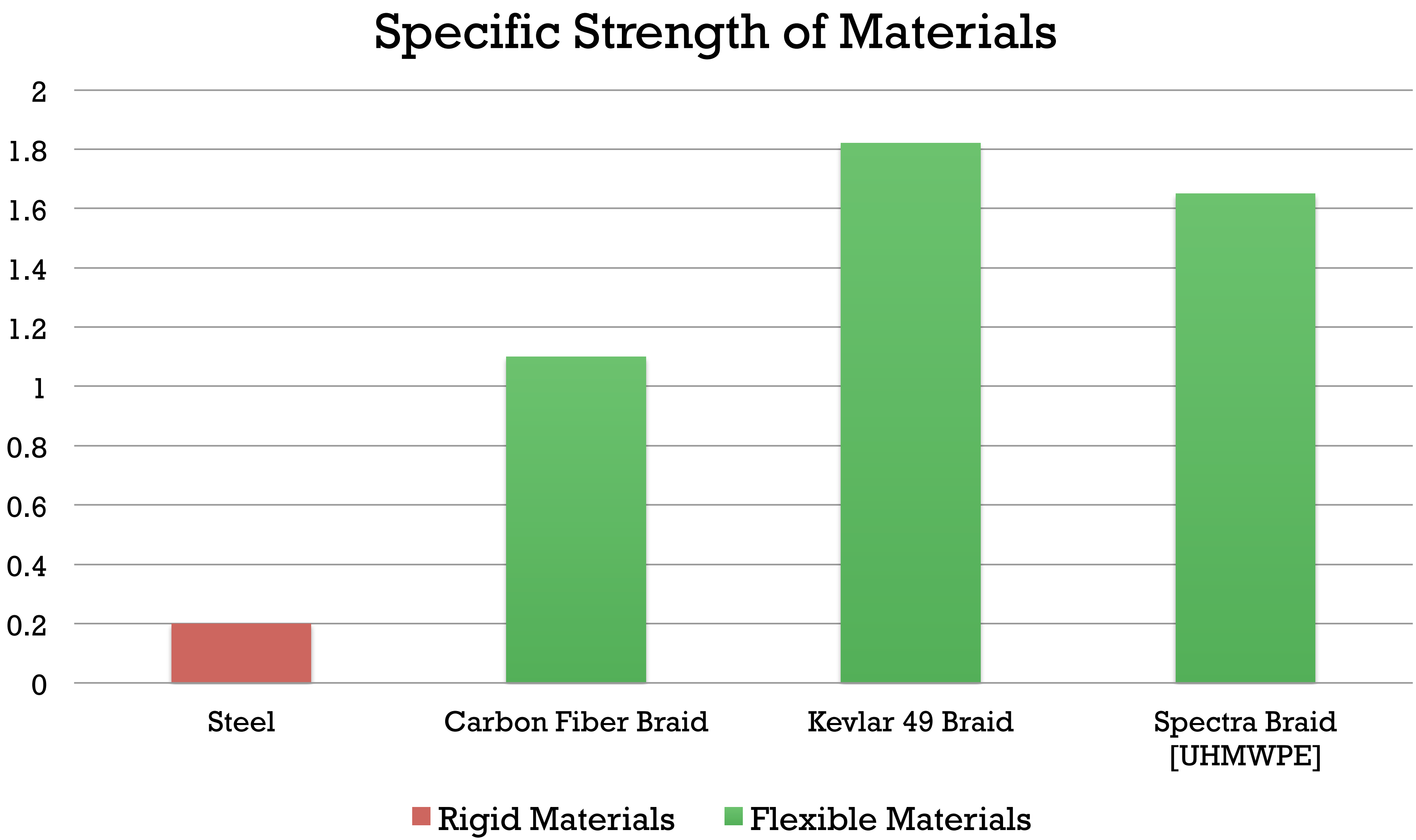
Key Technical Specifications*		
Model	PN15	PN30
Extended Lifting Capacity	15kg @ 1m	30kg @ 1m
Retracted Lifting Capacity	45kg	45kg
Reach	1.4m	1.6m
System mass	18.6kg	26.1kg
Degrees of Freedom	9	9

*Design Specs

- **High Strength**: 1:1 payload to arm weight ratio.
- **Flexible**: Stiffness directly controlled with air pressure
- **Robust**: Entirely sealed, non-corrosive components for harsh environments

Soft and strong

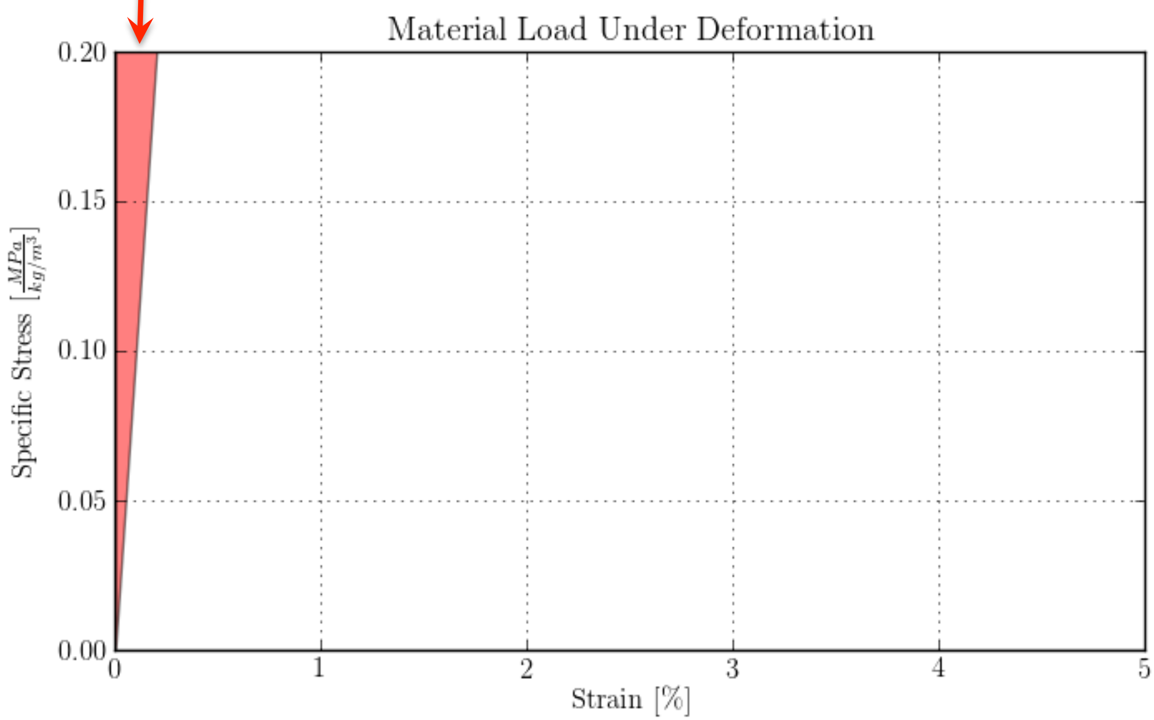
The highest performance materials are softer than steel



Uncharted territory

Moving beyond the limits of rigid metal design

Metals:
Steel, Aluminum, etc.
Expensive/Heavy



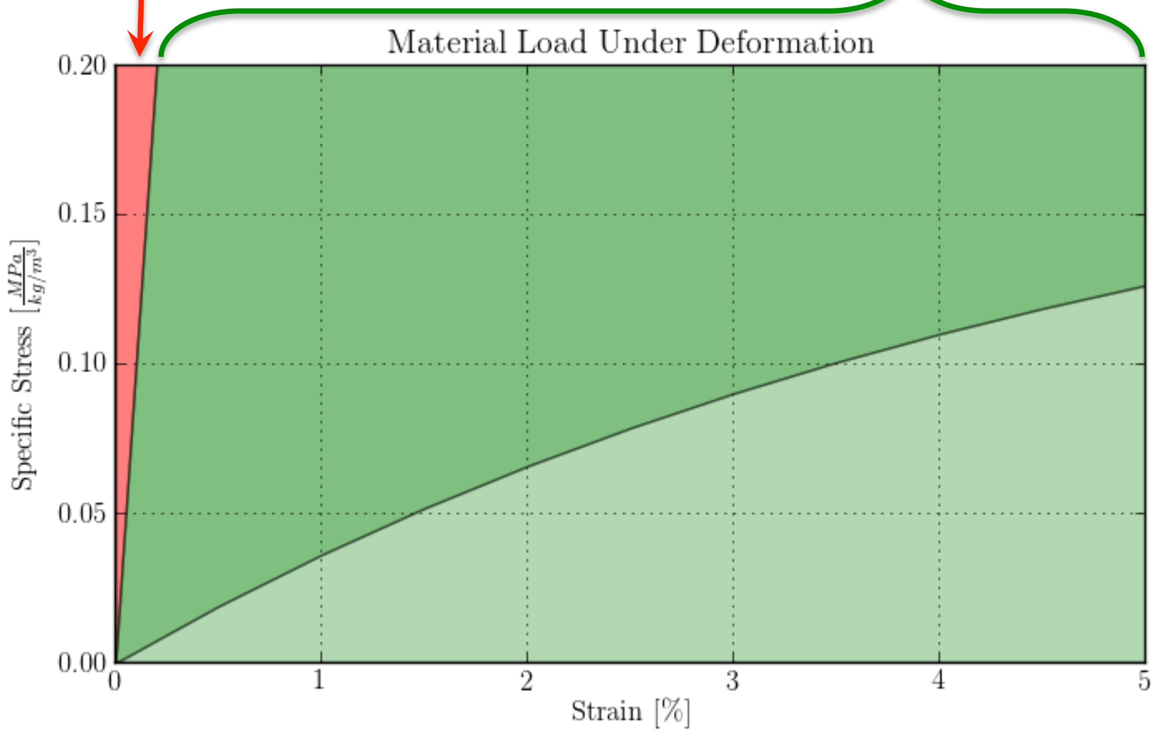
Traditional engineering design is restricted heavy rigid materials

Uncharted territory

Moving beyond the limits of rigid metal design

Metals:
Steel, Aluminum, etc.
Expensive/Heavy

Polymers:
PET, E-Glass, Nylon, etc.
Inexpensive/Light

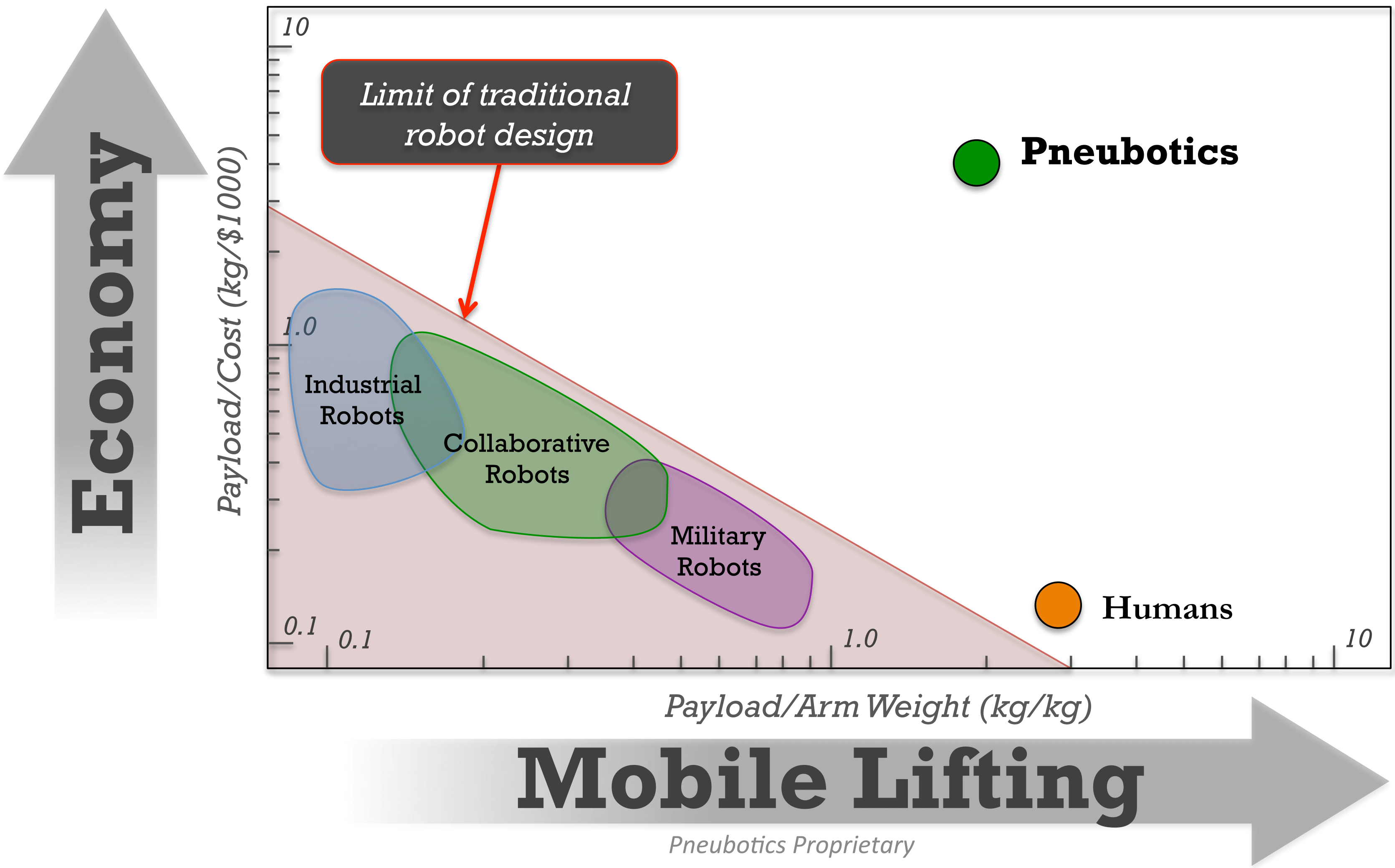


We can now trade off material weigh, cost, and complexity for inexpensive computation and sensing

Competitive landscape

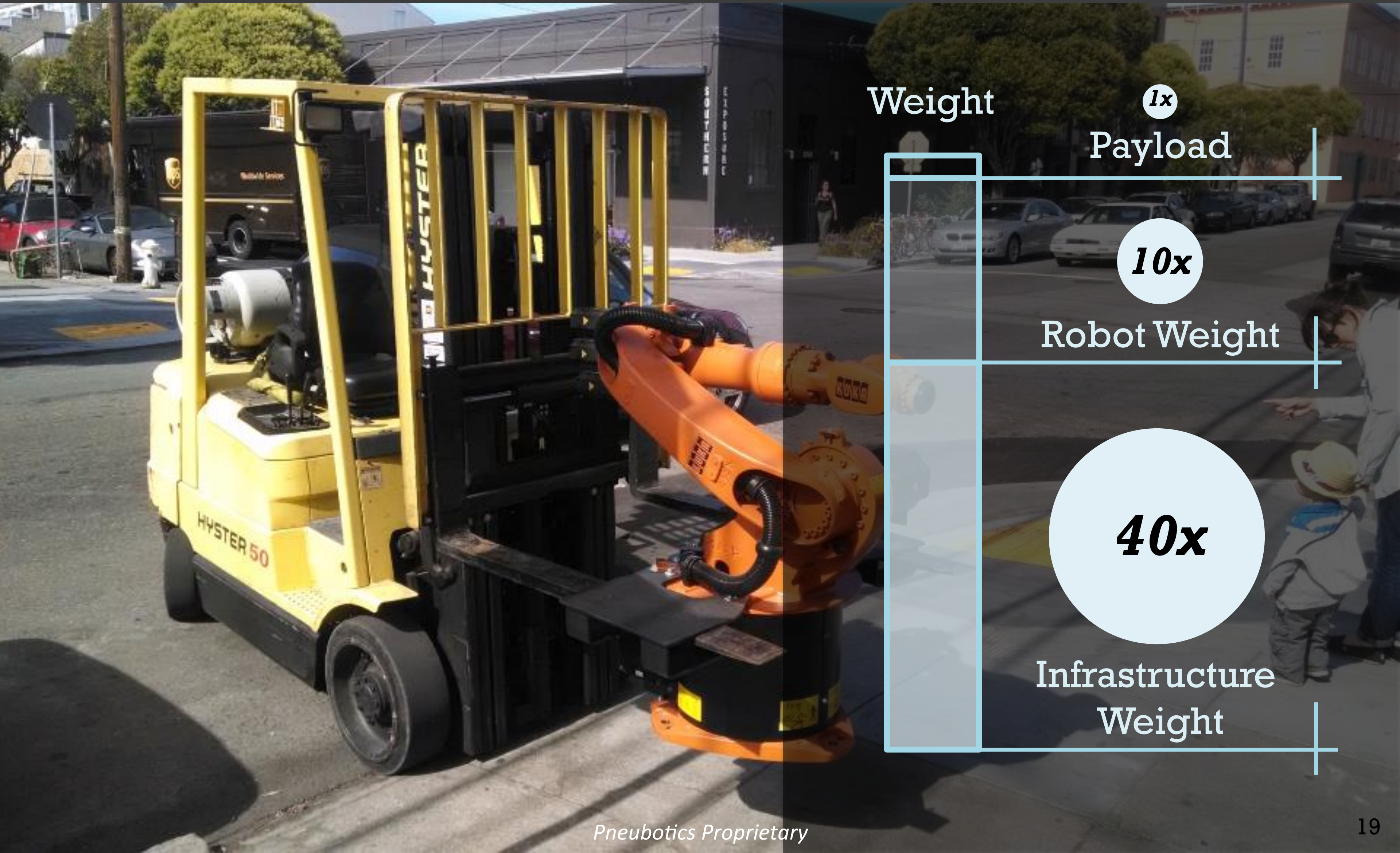
The world's first robot with the mobile lifting capacity of humans

Economy vs. Mobile Lifting Capacity



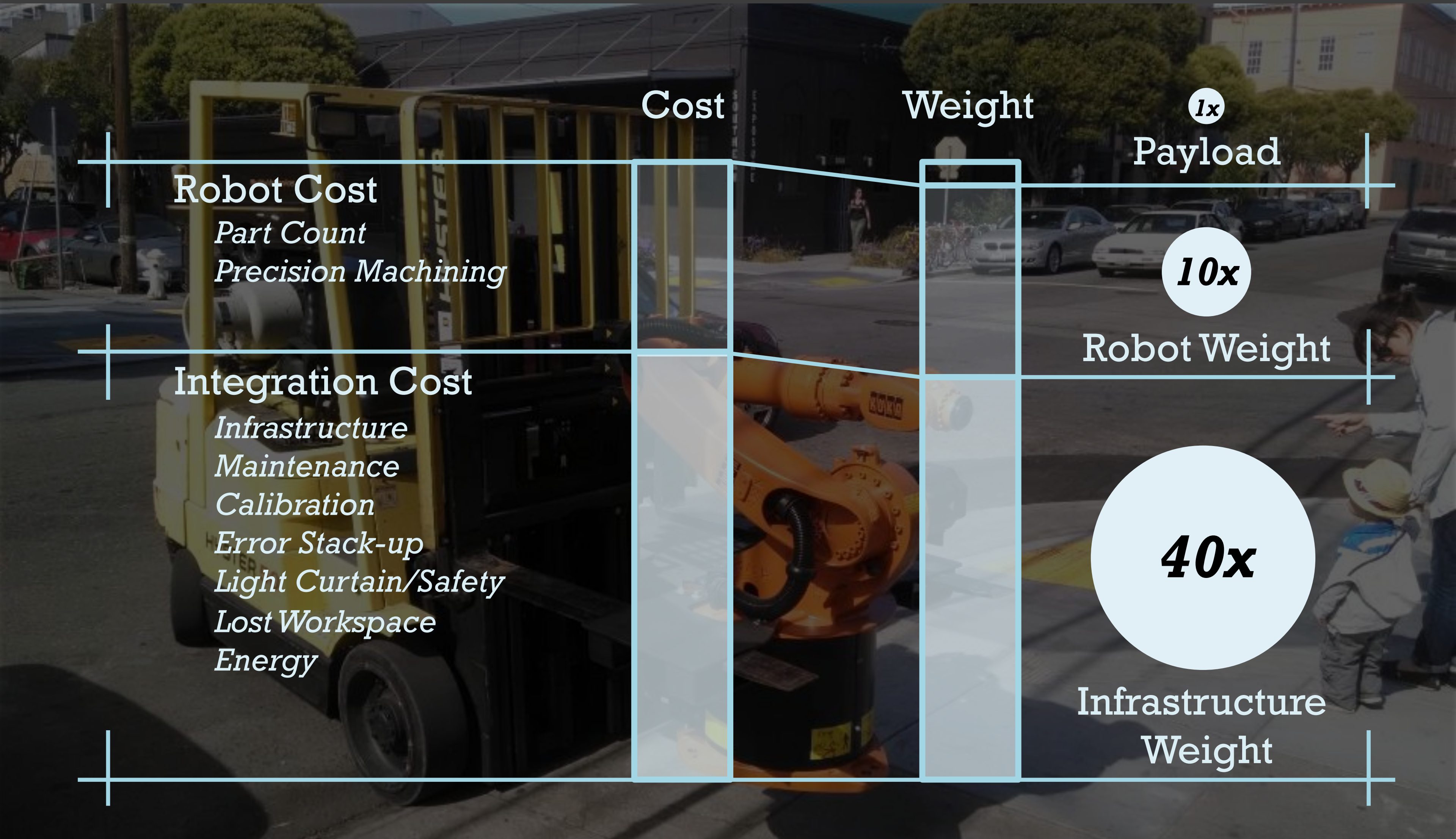
Cascading weight effect

Rigid design relies on weight and material cost for performance



The price of weight

Existing technologies are heavy, expensive, and dangerous



WHEELS

STRUCTURED ENVIRONMENT

RESEARCH QUALITY PROBLEMS:

VISION

ACTUATORS beyond electromechanical

SKIN
touch
proprioception

COMPLIANCE
human
safe

BATTERIES

CONTROLS

closed loop at end effector

UI / UX


Thank you