Army Power: Watts, Kilowatts & Megawatts

Money & Technology Beget Capability

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Board on Army Research and Development
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Overview Of Discussion

Watts, Kilowatts & Megawatts

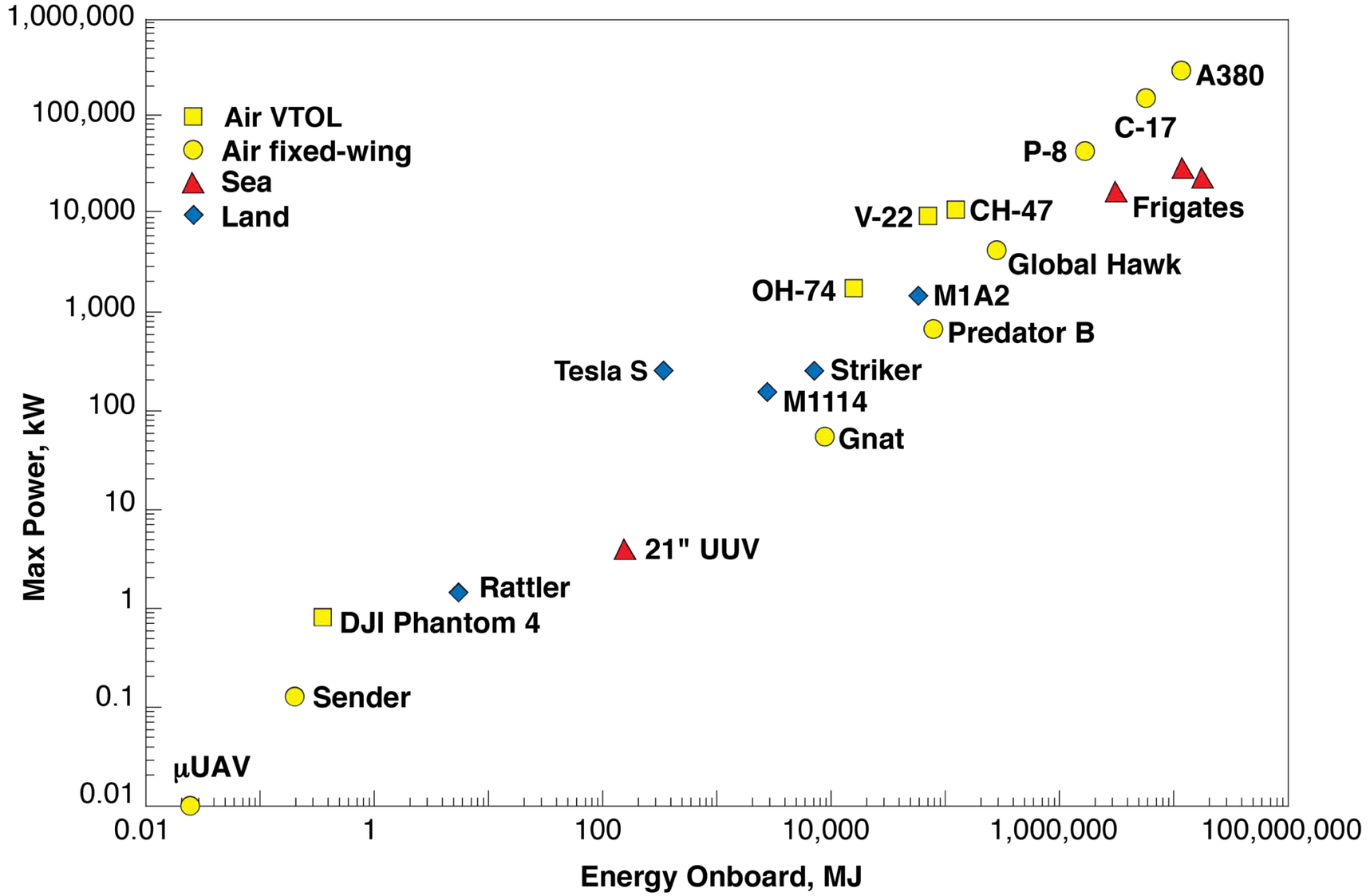
- The Army needs power - mechanical, electric, & thermal - for
  - Mobility on land and in the air
  - Powering electronics, weapons, and armor (maybe)
  - Heating, cooling, & cooking
- Energy on the battlefield is dear
- Consider aviation, ground vehicles, & portable power

The Challenge

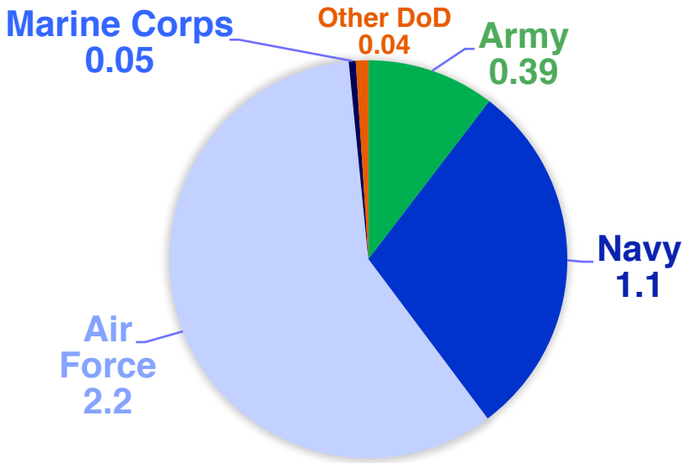
The hard part is the money

- The Army is a very minor player in power & energy
  - There is little demand for many niches important to the Army
- Lots of 6.1-6.3 concepts
  - for generating power, storing energy & reducing its usage
- It's the system that matters, not just the science
- The most important techs are those that can reduce the cost of development & production and/or increase the market

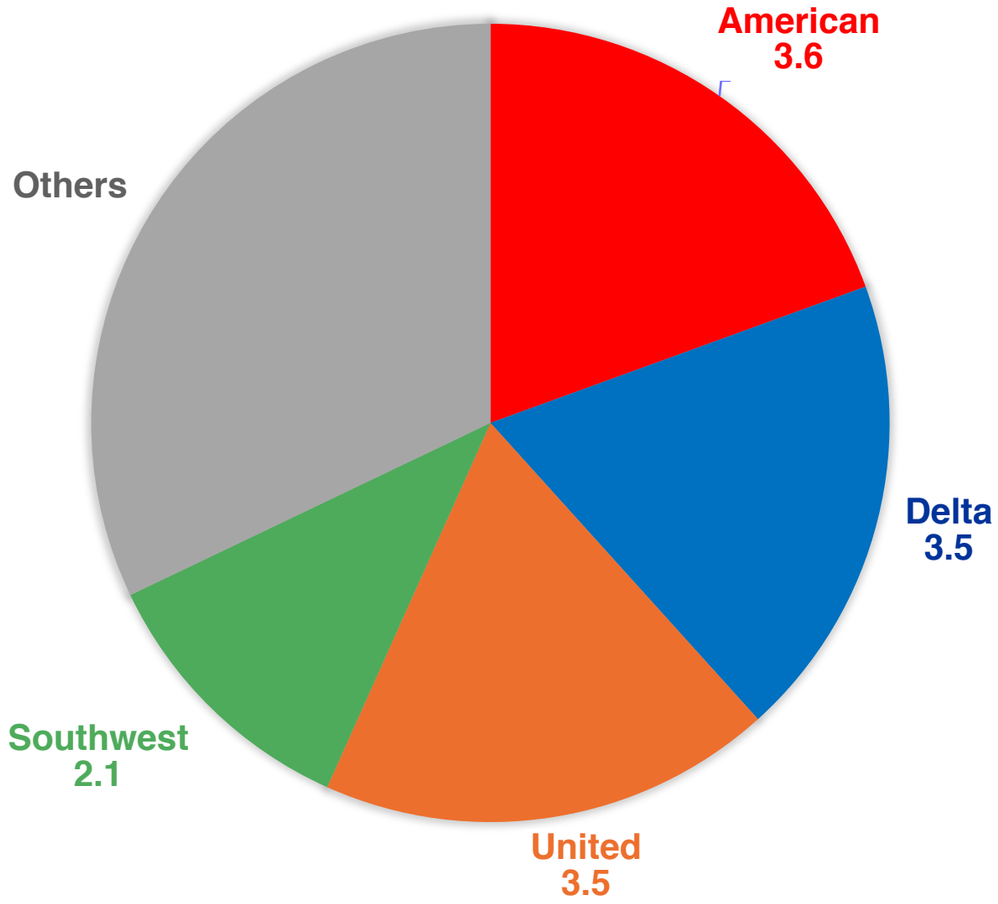
DoD Vehicle Propulsion Energy and Power



Operational Fuel Consumption in 2018



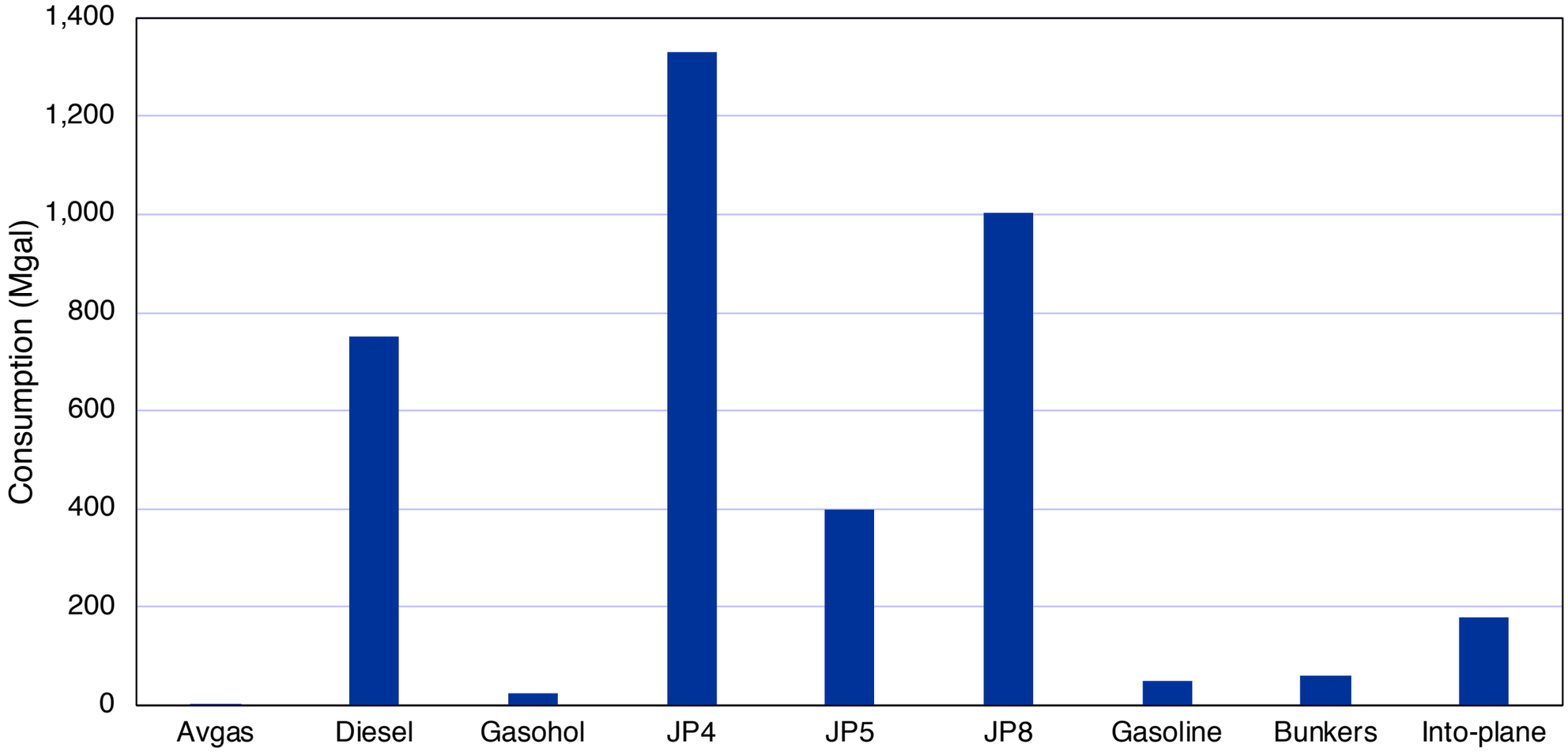
DoD 3.6B gal/yr
$9.1B



US Airlines 18.7B gal/yr
$40.5B

DoD DESC Fuel Sales in FY2019

Direct Expenditures: Army ~$1.2B, Total DoD ~$9.1B



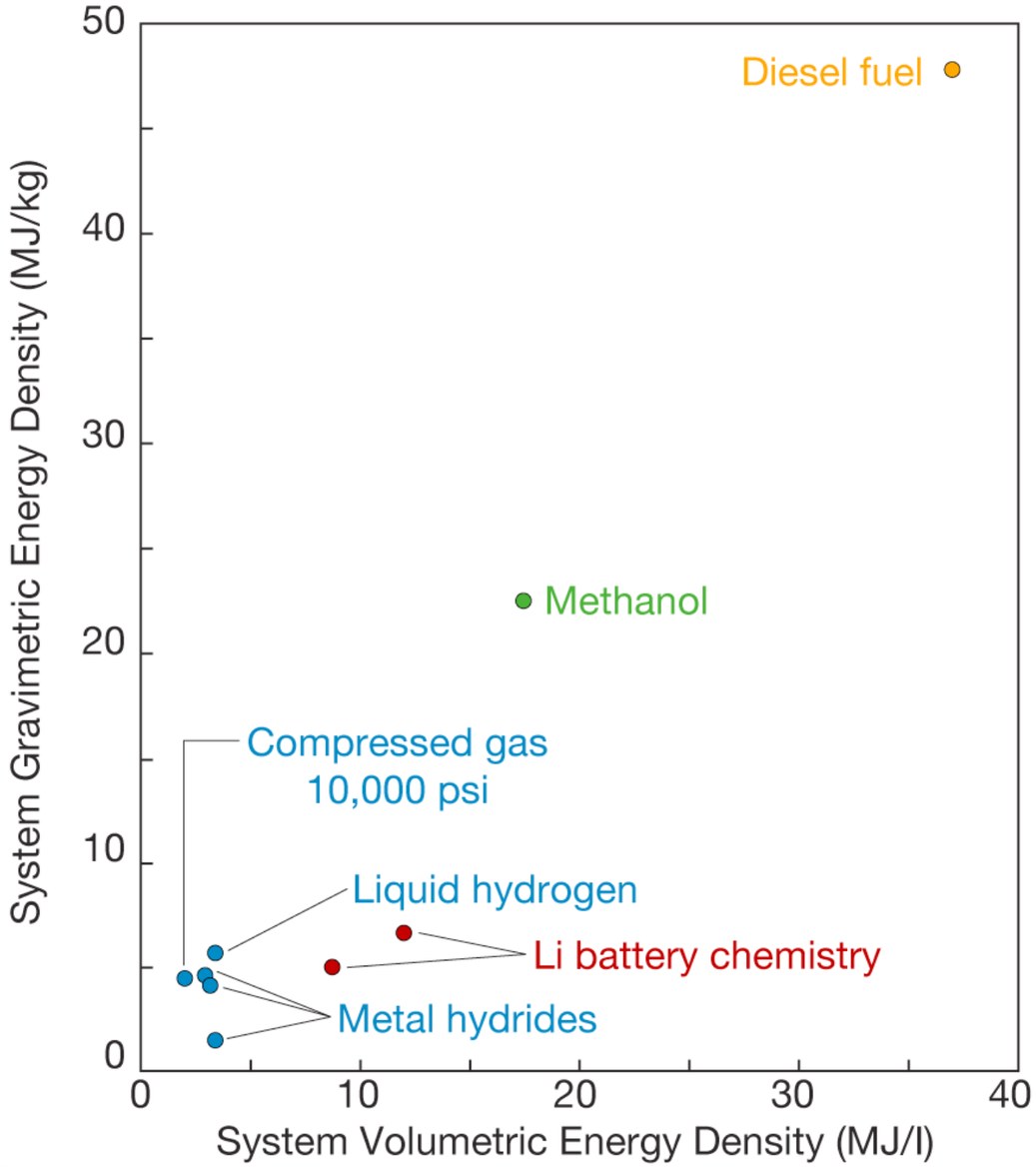
DESC 2019

Fuels For Mobile Energy

	MJ / kg	$ / MJ
Whole Milk	2.8	0.32
Honey	14	0.29
Sugar	15	0.07
Peanut Butter	27	0.15
Bacon	29	0.14
Vegetable Oil	36	0.06
Kerosene	42	0.01
Natural Gas	45	0.005
Hydrogen	117	0.05
Methanol	22	0.03

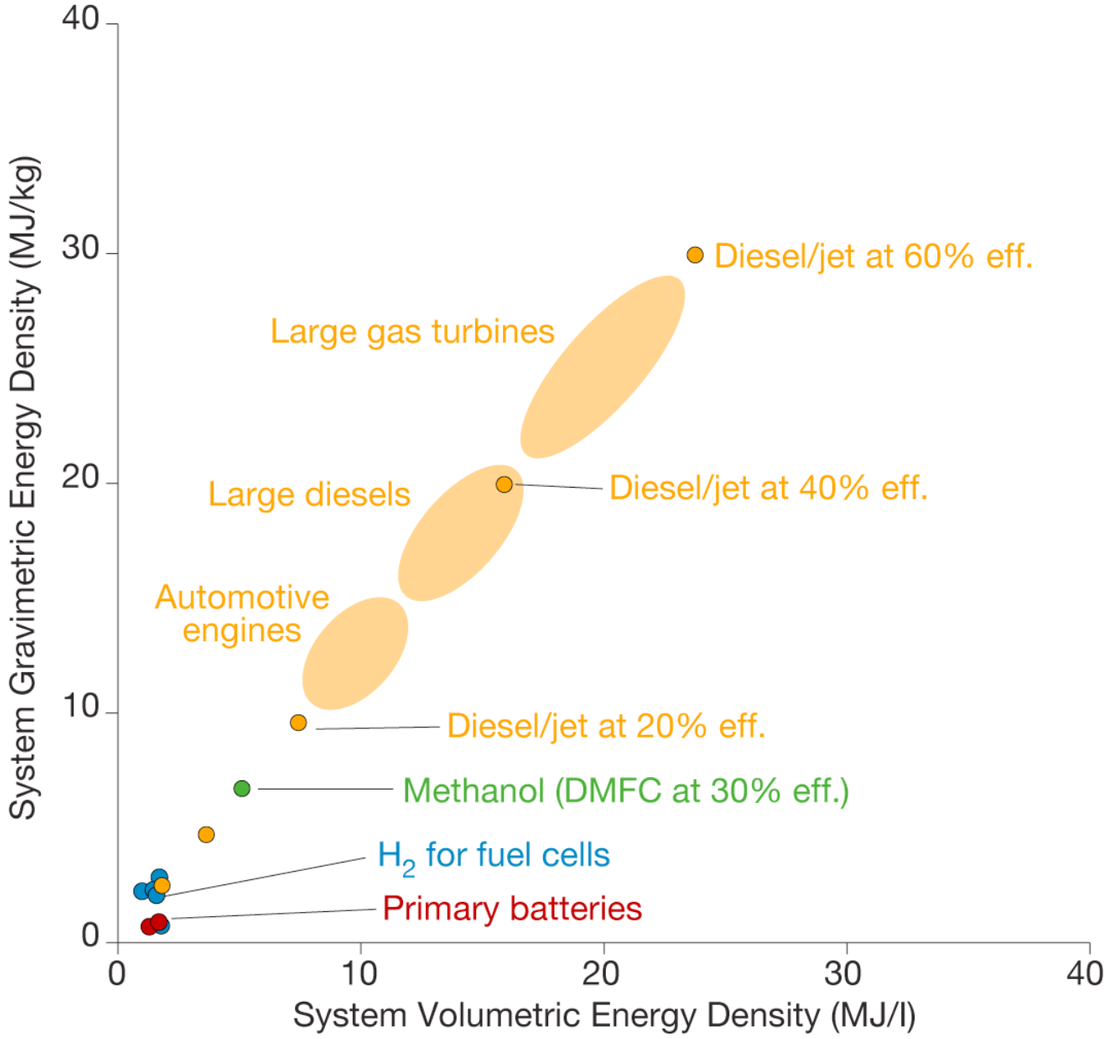
(Adapted from *The Simple Science of Flight*, by H. Tennekes)

Chemical Energy Sources For Mobility



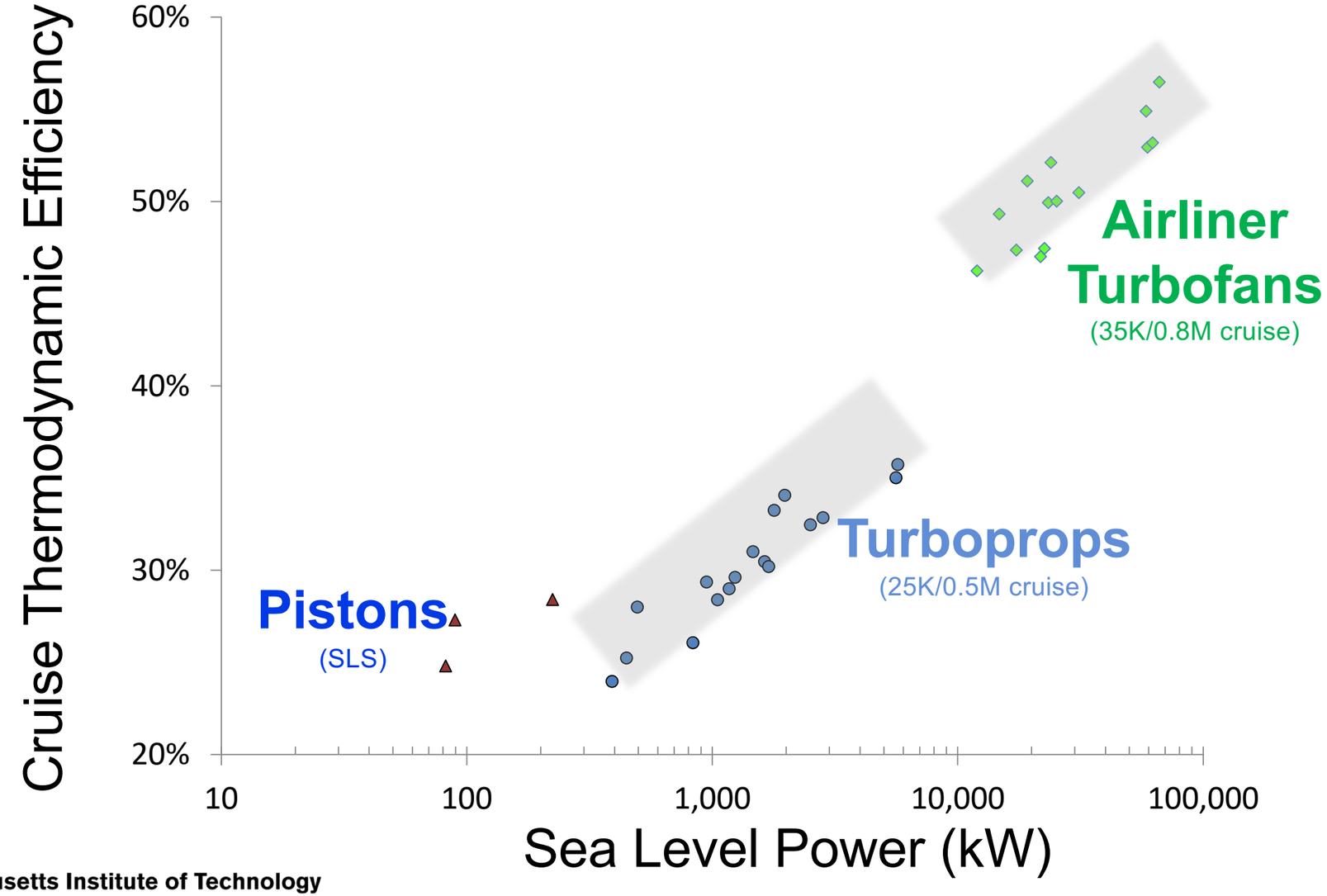
Practical Energy Density Of Fuels

Fuel & Container Only



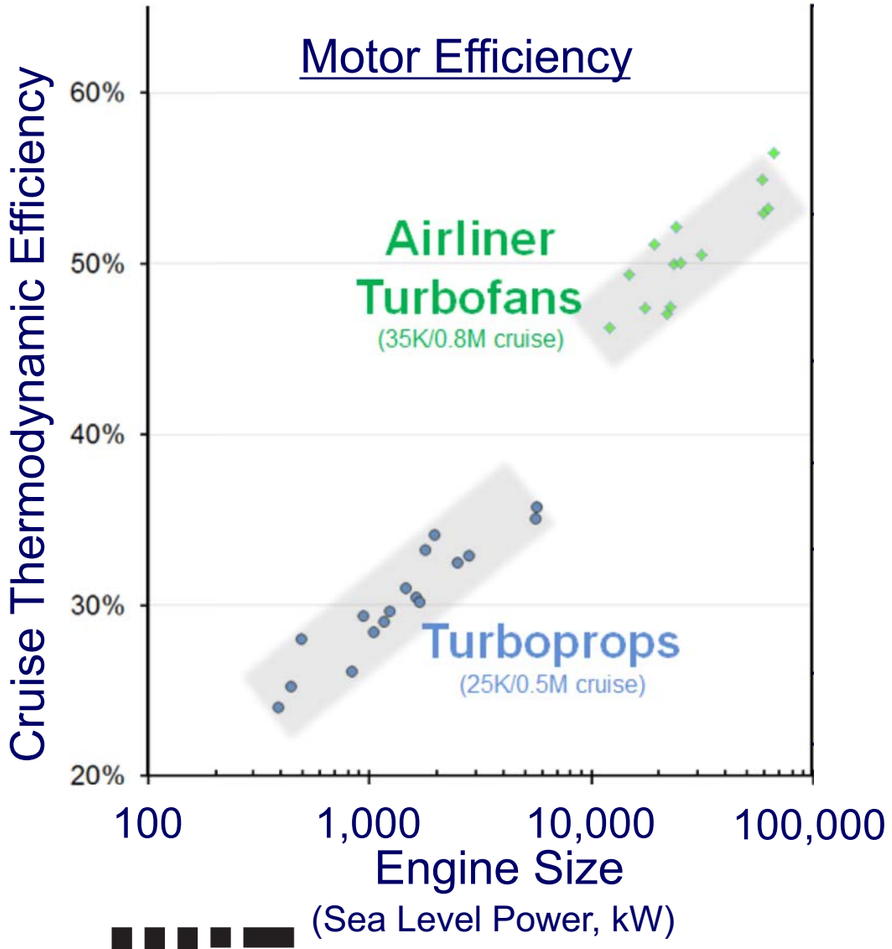
Current Aero Engine Efficiencies

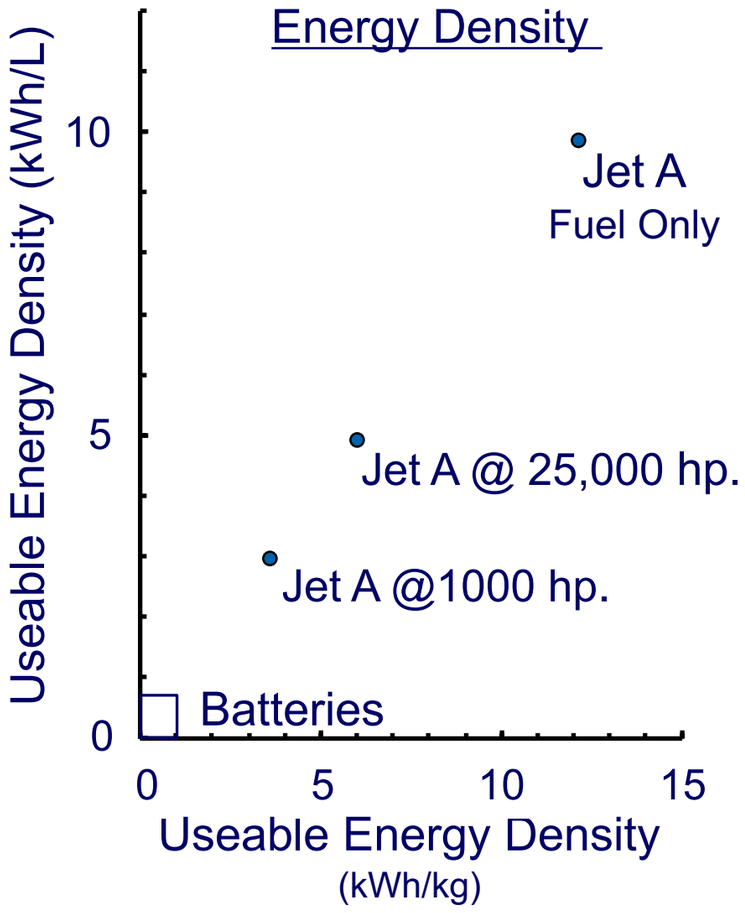
Fuel to shaft power

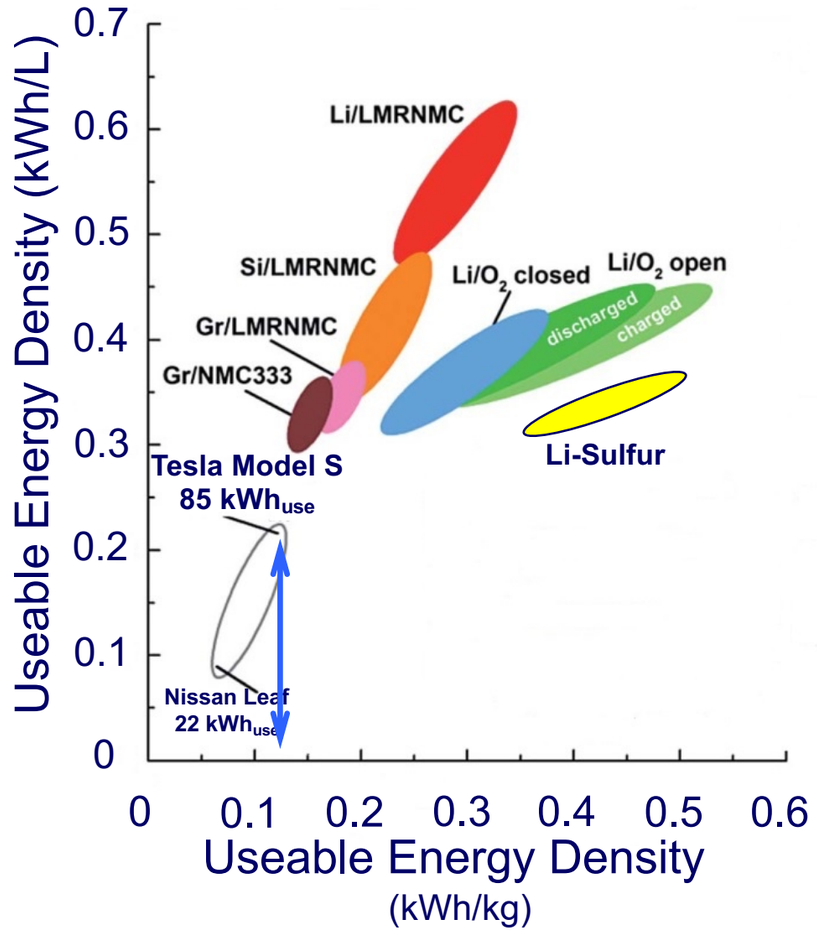


Aviation Energy Density

The challenge for batteries







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Program Challenges for Army Power & Energy

Vehicle propulsion and mobile power

- DoD O&S traditionally considered fuel cheap
  - Propulsion investment motivated by increased capabilities
- SOA propulsion is expensive to develop
- Army is a minor customer/player in
  - Ground vehicles (diesels, hybrids, etc.)
  - Aircraft (large gas turbines)
- Army market is too small for much private investment
  - Rotorcraft *may* be an exception
  - Army is also a major player in small UAV's

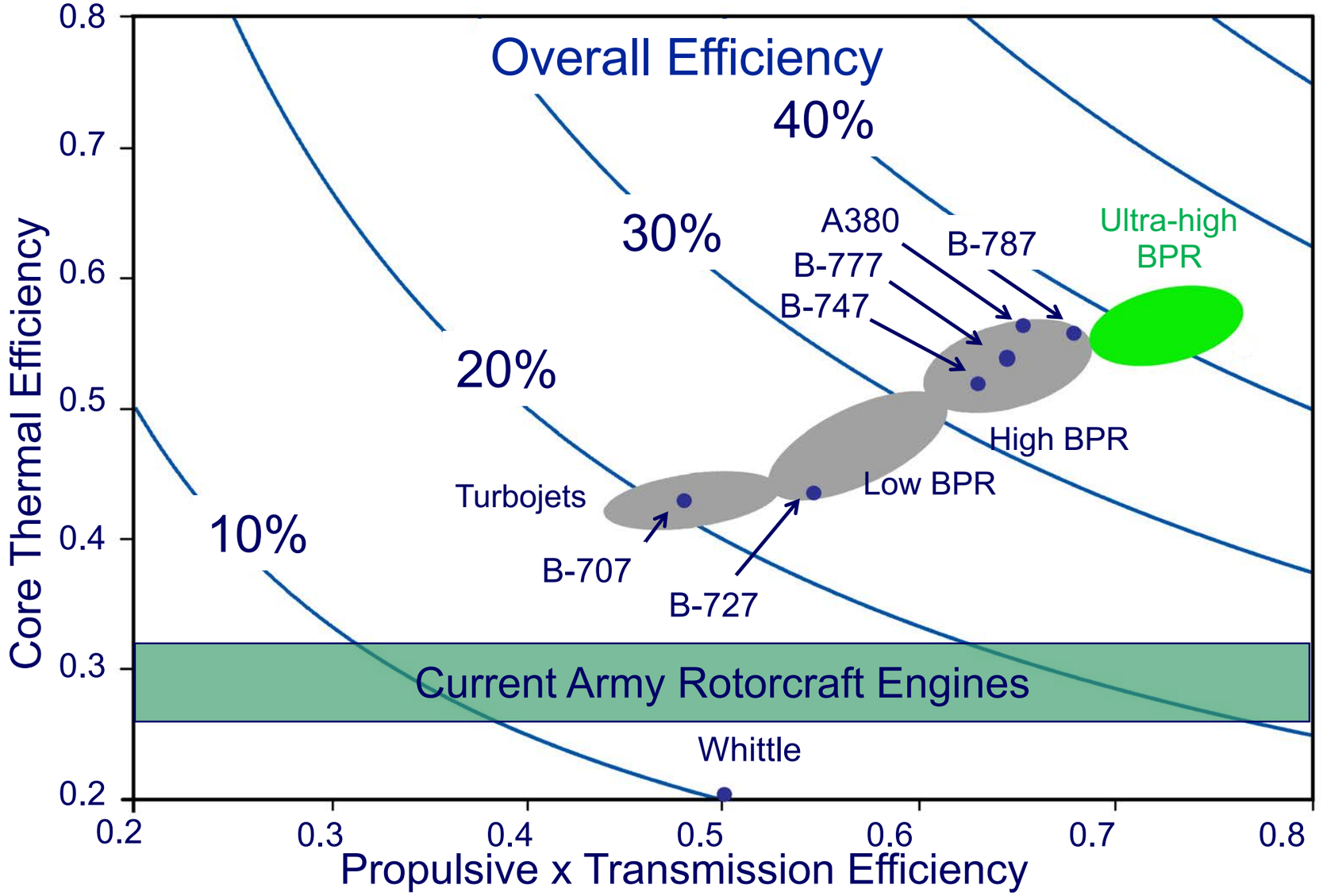
Introduction to Aviation Propulsion

"*The problem of the aviation engine is purely the combination of power and lightness and reliability*"*

- Gas turbines are unsurpassed at sizes above 1MW
  - Most efficient
  - Lightest, by 2-100x
  - Most reliable, by 10-1000x
- Significant engine development continues for large aircraft
- Army is world's largest user of rotorcraft
- Small UAVs growing in importance

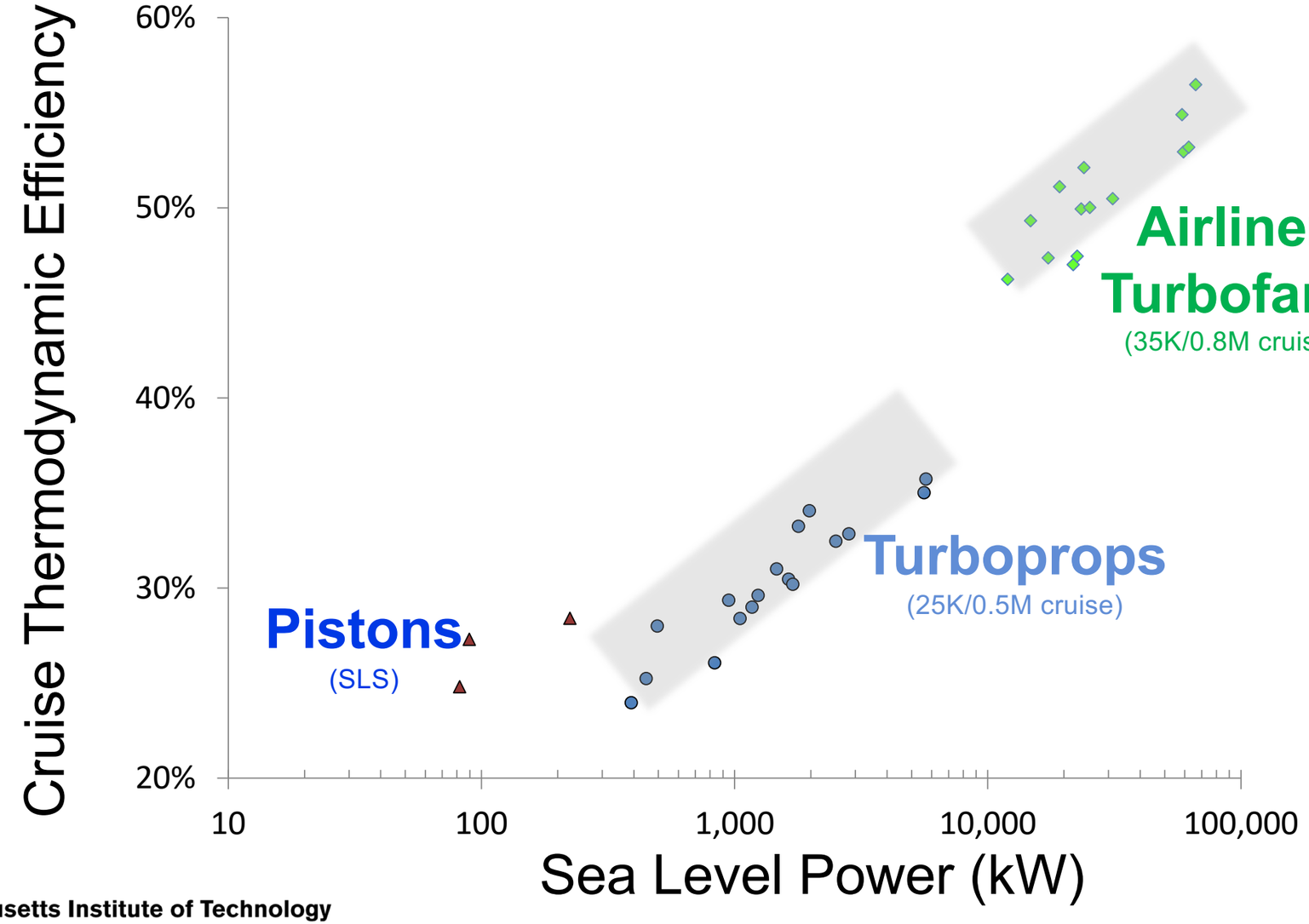
**The Aero*, Jan 1911

Evolution of Gas Turbine Efficiency



Smaller Engines Have Smaller Efficiency

Driven mainly by economics, not physics



VTOL Flight Technology

Trending toward increased power & energy consumption

Today – Conventional helicopters

Future

Faster

Electric

- Higher speeds & electric propulsion will increase Army energy needs -

Air Vehicle Propulsion S&T Opportunities

Focus on Rotorcraft & Small UAV

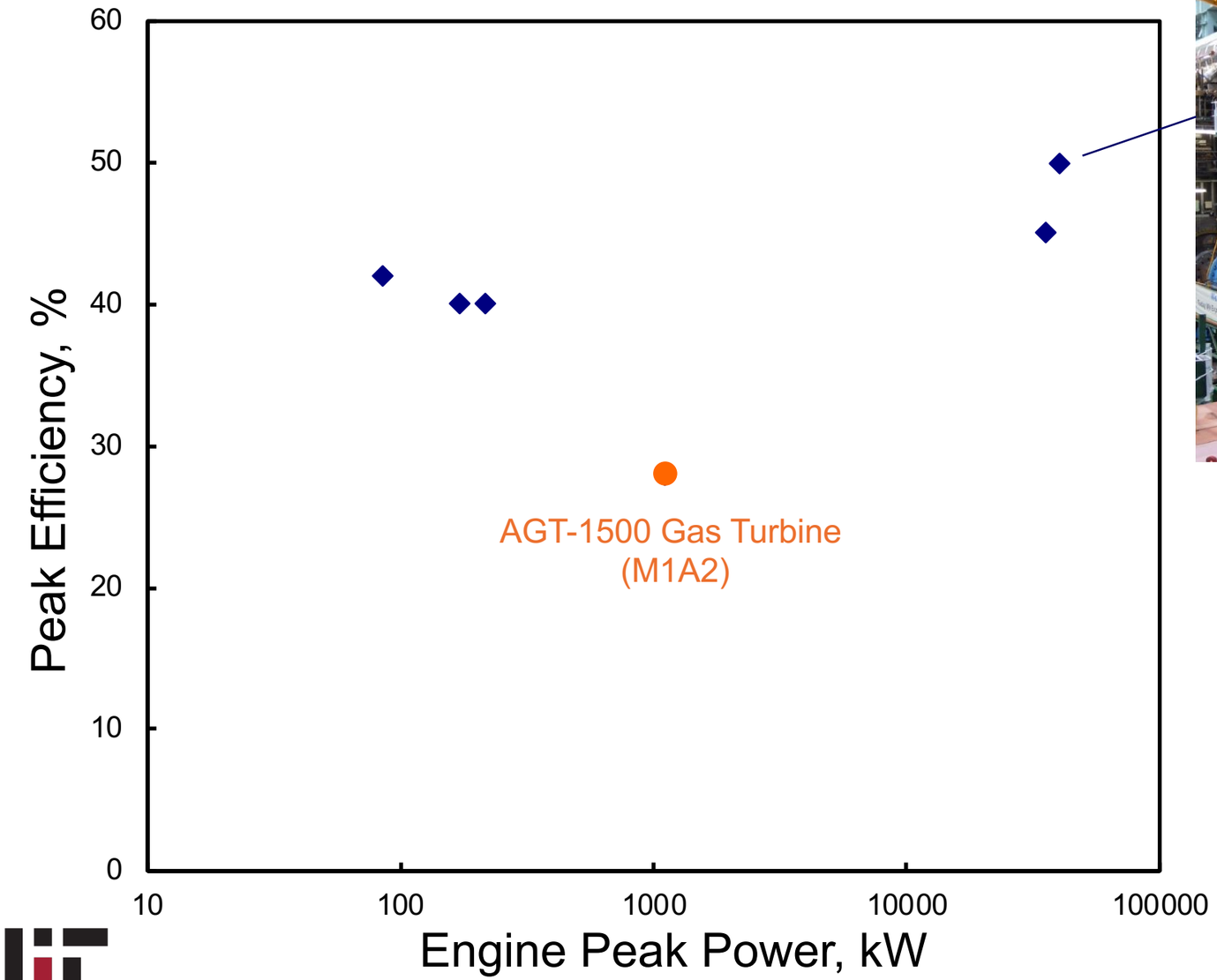
- Current goal increase UH-60 size (3000 hp) eff. by 20%
- Realistic S&T goals at 1000-5000 hp could include
  - Improve eff. by another 20%
  - Increase life by 2-5X
- New approaches can bring this performance down to smaller sizes, 100-1000 hp
- Areas of focus could include
  - Materials (both hot and cold), bearing and gear systems, thermo-fluid mechanics of small turbomachinery, manufacturing tech, mildly hybrid systems, heat exchangers

Introduction to Ground Vehicle Propulsion

- Metrics
  - Integrated efficiency
  - Specific weight and volume
  - Reliability
  - Cost: development, acquisition, maintenance

- Power sources
  - Diesel, gas turbine, spark ignition, hybrid electric, battery electric

Diesel Engine Efficiency



680 tonnes

Ship Diesel

Same power

1.6 tonnes

Gas Turbine

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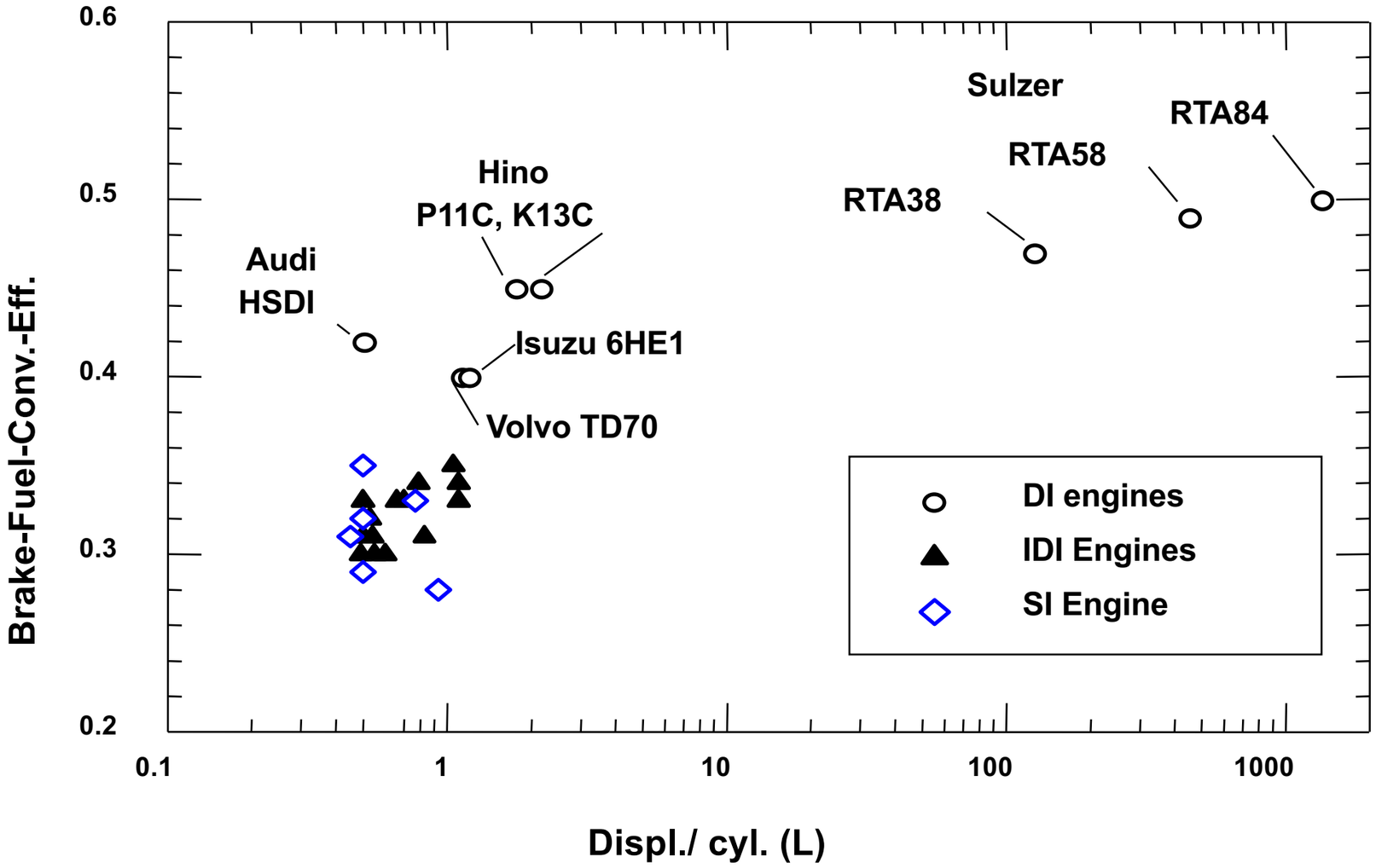
Effect of IC Engine Size on Efficiency

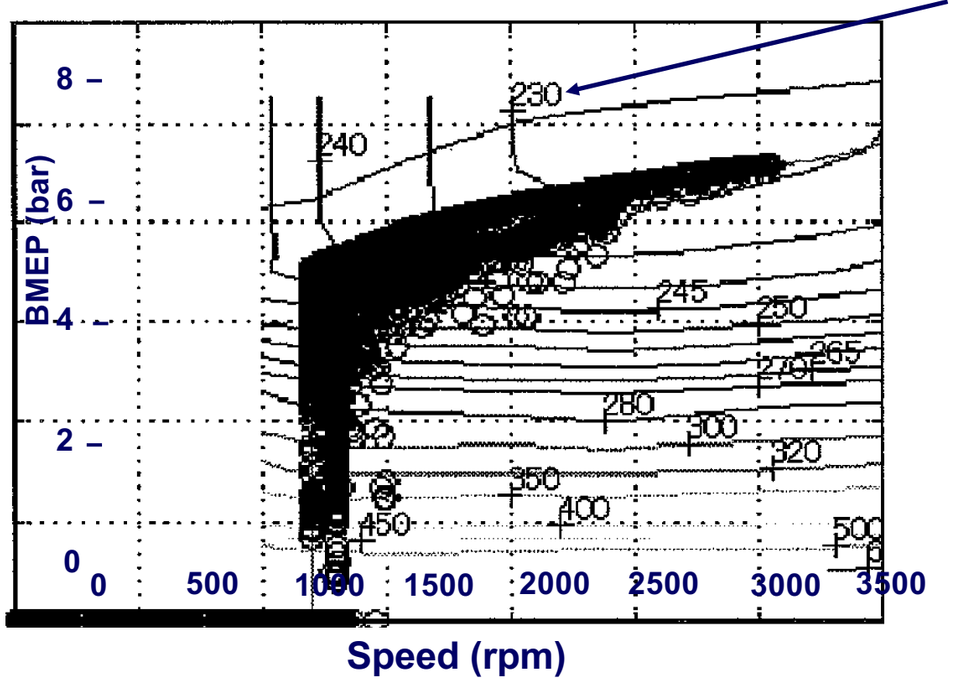
Best efficiency points of engine map



Courtesy W. Cheng, MIT

Engines Rarely Operate at Peak Efficiency

Operating map in LA4 driving cycle



Toyota Prius engine map
Operating points are for each second of
FTP drive cycle for the hybrid vehicle

For gasoline, sfc = 230 g/kW-hr
Corresponds to $\eta_{f,brake}$ = 36%

Why hybrid electric combat vehicles
- Energy consumption, peak vs. average power needs
- Synergy between propulsion & weapons
- Silent watch

Some challenges
- System volume
- Component power level and cost

Ground Vehicle Propulsion

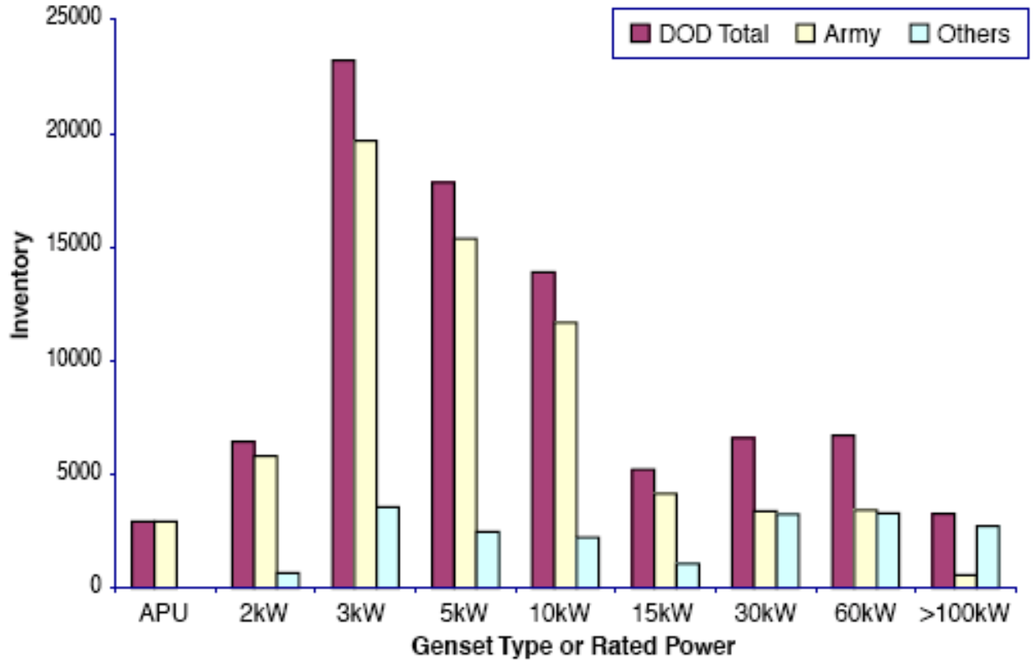
*Technical possibilities to reduce fuel consumption**

- Increasing peak diesel efficiency
  - Tech to improve emissions ~10%
- Improving the driving cycle
  - Hybrid propulsion?
  - Large vehicles ~ 20-30%
  - Very small vehicles ~ 50-100%
- Reducing vehicle weight with improved materials
  - Adiabatic diesel to eliminate cooling system
  - Advanced gas turbines with APU's
  - Armor? Other?

(*although not necessarily good investments)

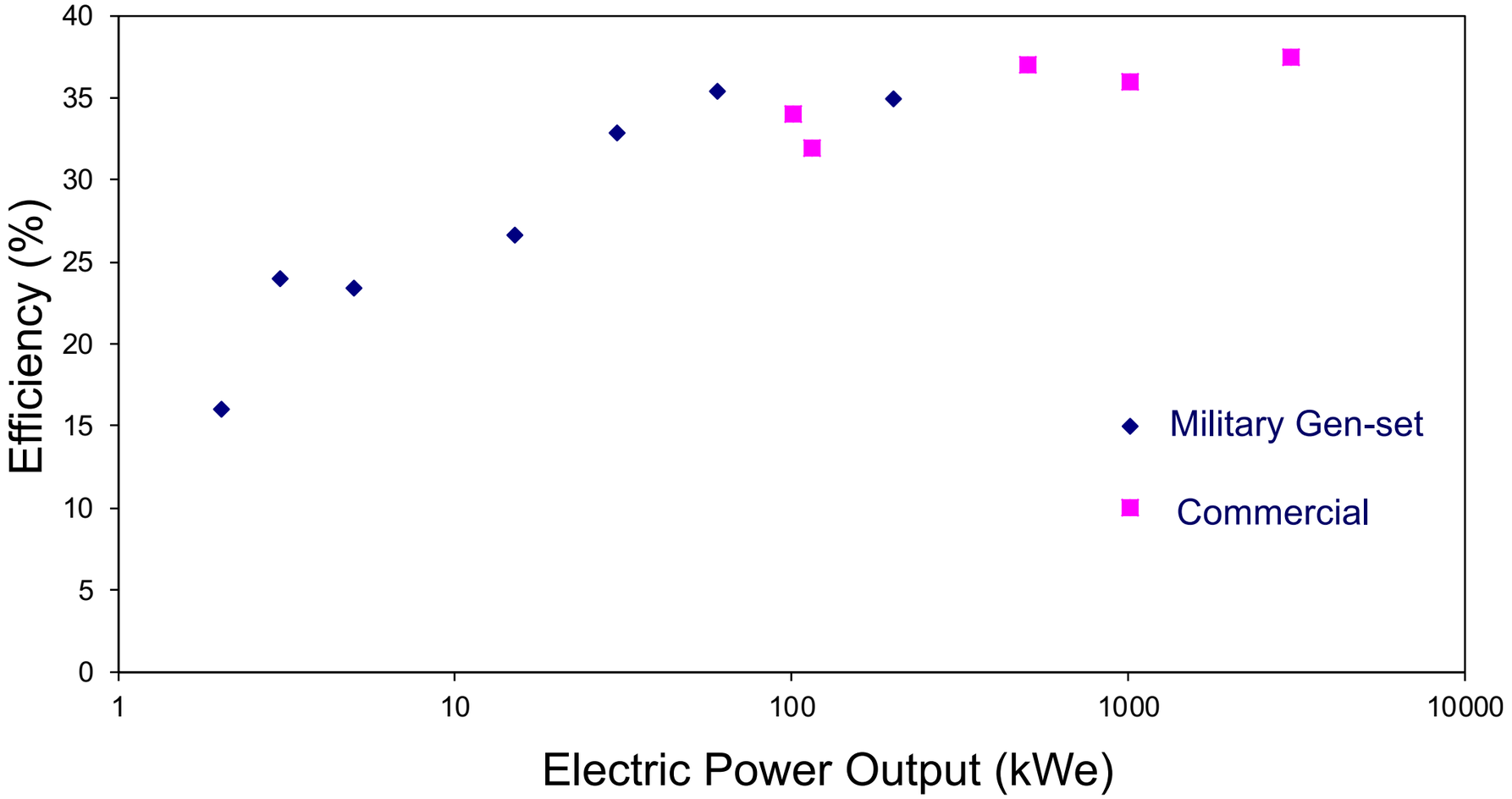
Introduction to Army Portable Electric Power

- More than 50,000 generators in inventory
- 2 kW to 50kW
- Average 200 hr/year utilization in peace time
- 50 hr mean time between maintenance
- Metrics
  - Logistics fuel (e.g. diesel)
  - Efficiency
  - Noise and vibrations
  - Weight (especially at small sizes)
  - Reliability/availability
  - Cost



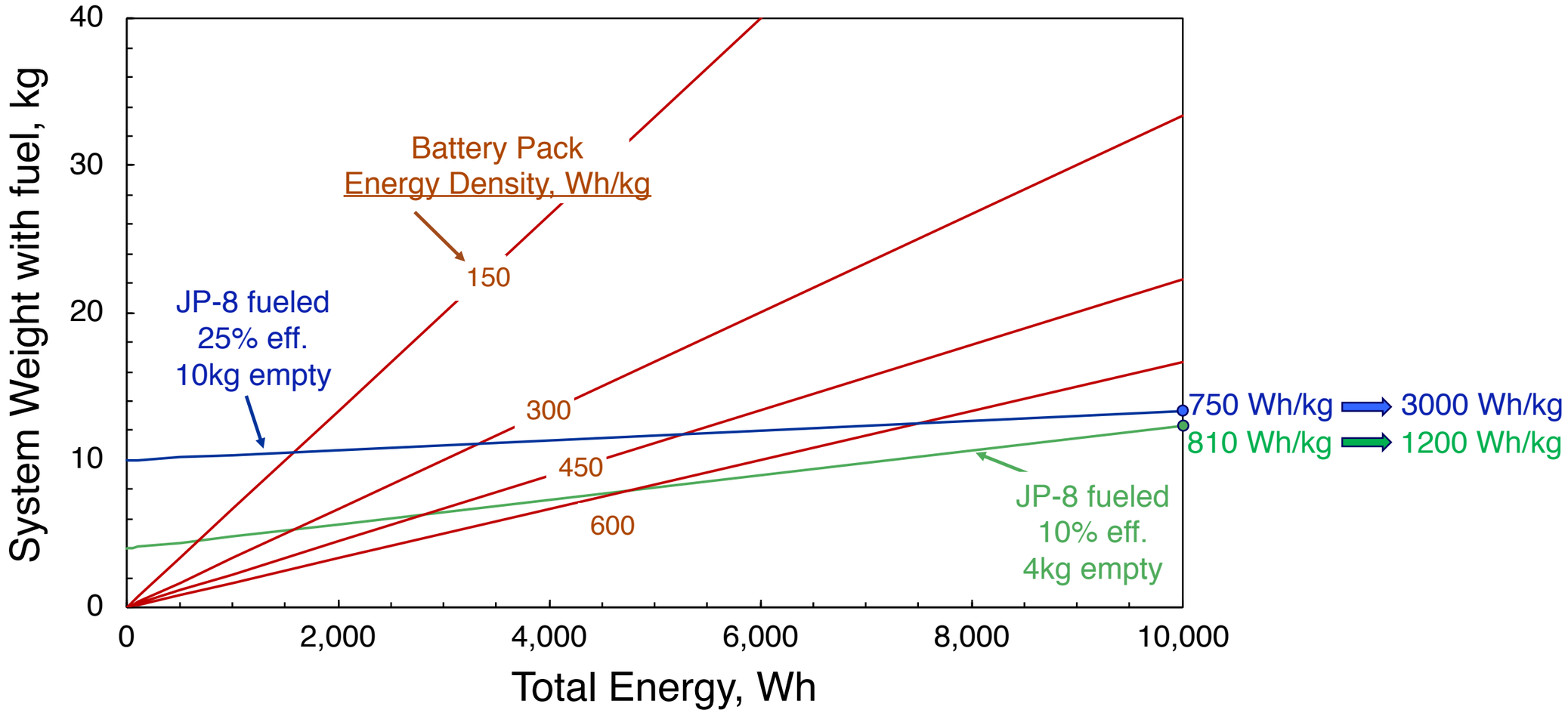
Diesel Gen-set Efficiency

At rated power



Total Weight for Battery & Fueled Systems

Sensitive to empty weight vs. energy requirement



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Observations on Army Gen-sets

Small tactical generators, 2,3,5 kW

- Gen-sets spend much of their time at part power
  - Increases maintenance needs
  - Reduces efficiency

- Smallest units, 2 kW and 3 kW
  - Very heavy
  - Poor fuel consumption
  - Do not meet noise requirements/needs

Lots of Prototypes

20 Watt DMFC
22% eff

25W Reformed Fuel Cell
24% eff on Methanol

20 Watt SOFC
30% eff on propane

Nectar
Butane

250 W SOFC

160W Stirling Engine
20% eff on Propane

Getting Beyond the Prototype Stage

Stuff you can buy (or almost)

3,000 Watt DMFC
122 kg, 24% eff
41 kg/kW empty wt

2,600 Watt Gas Turbine
65kg, 5% eff
25 kg/kW empty wt

105 Watt DMFC
8.5 kg, 17% eff
81 kg/kW empty wt

1,000 W SOFC
23kg, 23% eff on Propane
23 kg/kW empty wt

IHI* Micro Gas Turbine Gensets

Extremely quiet, light, low emissions compared to diesels

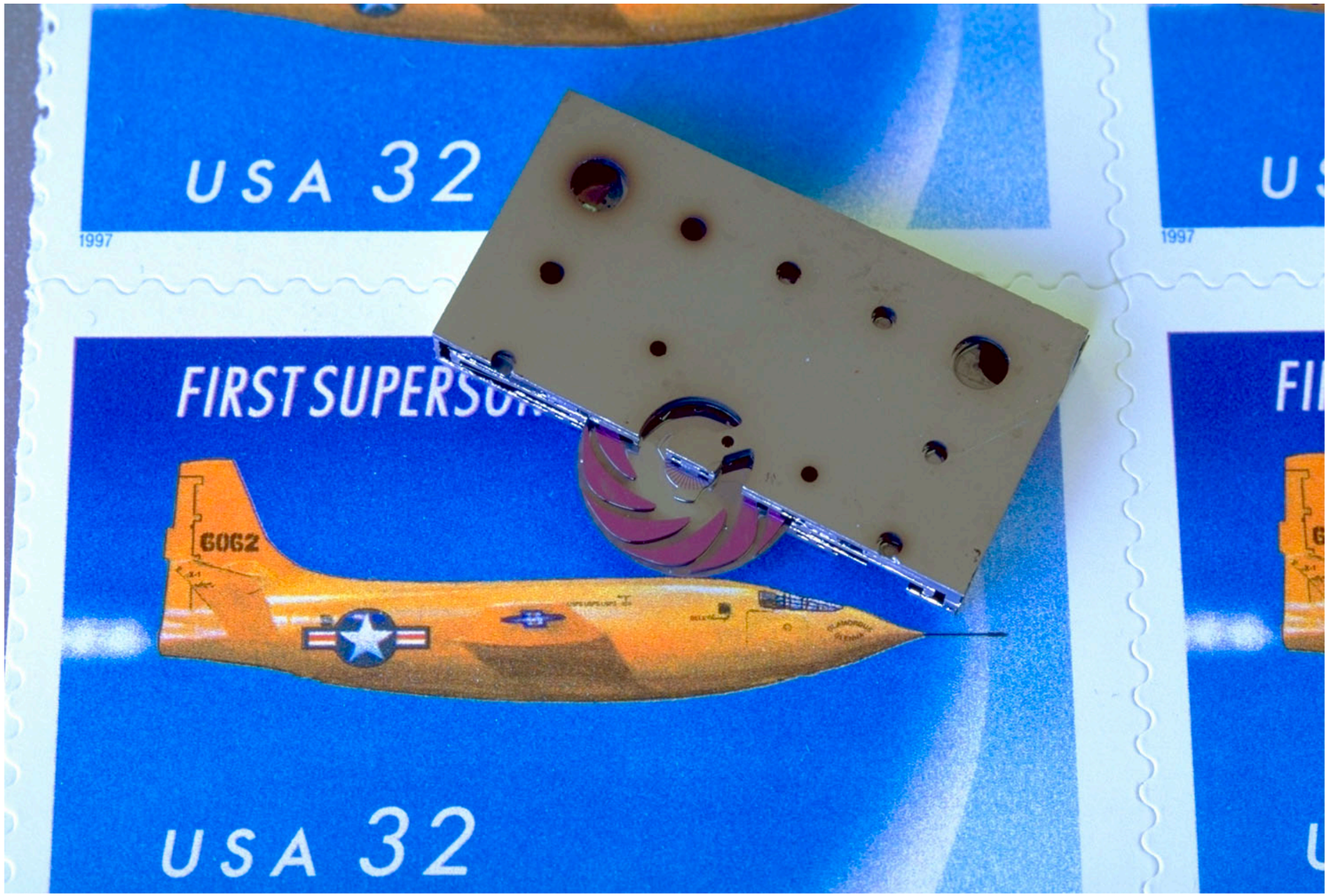
2.6kW, Dynajet
65 kg, 5% eff. on JP-8
Produced 1996-2007

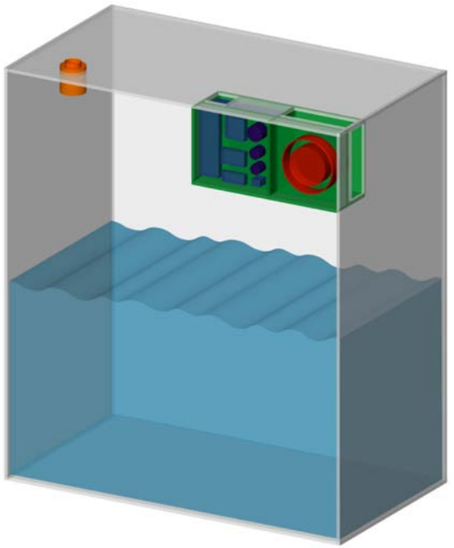
400 W
Simple Cycle: 9.5kg, 7% eff.
Recuperated: 12 kg, 13% eff.

2 kW
Simple Cycle:12 kg, 10% eff.
Recuperated: 19 kg, 25% eff.
9.5 kg/kW empty weight

* Now: Powart Japan

MIT Micro Gas Turbine Generator





50W Microengine
in a BA-5590 package

Portable Electric Power S&T Opportunities

- Army can be a player at the low end (1-10kW)
  - Efficiencies are low due to low investment
  - Weight, noise, efficiency, fuel choice are tactical considerations
  - Unit cost is a less dominant issue for the Army
  - Commercial world may not be interested

- Significant opportunities at 1~10 kW
  - Hybrid micro grid solutions
  - Gas turbines & diesels with new materials & approaches
  - Small solid-oxide fuel cells
  - Synergy with some small UAV applications
  - These are hard engineering problems, need substantial investment

The Challenge for a New Energy Product

Cost, cost, cost

UTC Fuel Cell Bus

- Extensively tested by several transit authorities
- Proved quiet, reliable & efficient
- Too expensive

Honeywell Parallon 75 kW Gas Turbine Generator

- Intended for microgrids & standalone small businesses
- Extensively tested by utilities, very low emissions
- Proved reliable & efficient
- Too expensive to produce relative to market

Attacking the Demand Side at the Base

Consider system level solutions rather than piece parts

- Generators, coolers assembled from commercial components
  - Specs favor compactness over efficiency

Container Cooler, COP=2

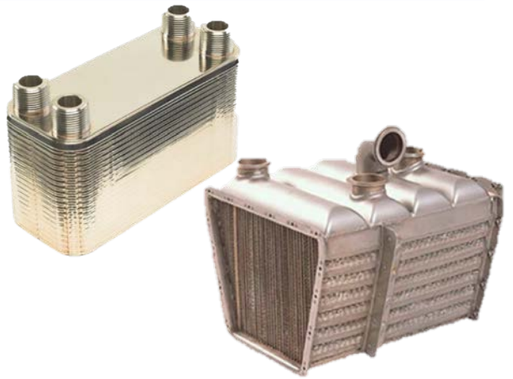
3kW QTG

- System level integration example
  - Cooling & heating from generator waste heat
  - Water from engine exhaust and atmospheric condensation, 2 kg H_2O for each 1 kg fuel
  - Perceived water quality must be addressed
  - This is an engineering and cost challenge, not a science one

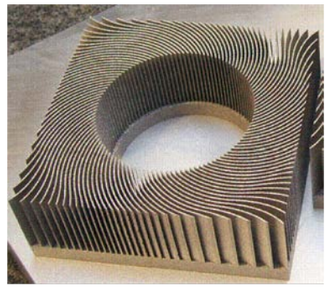
- Requires working across Army stove pipes

Comments on Heat Exchangers

Old tech but really important



- Thermal devices must reject heat
  - Needed for engines, SOFCs, power electronics, coolers, etc.
  - Heat exchanger are often the bulkiest and most expensive component
  - Generally poor reliability & high maintenance cost
  - Army appropriate tech needed (harsh environment)
- Appropriate 6.1, 6.2, 6.3 investment could help



Army Power: Watts, Kilowatts & Megawatts

Observations

- For commercial products
  - “Good enough” is the enemy of “better” (cost, cost, cost)
- Batteries & JP-8
  - Battery tech will improve by 2-4X, driven by commercial opportunities
- Stick with logistics fuel, i.e. JP-8
  - Invest in JP-8 compatible solutions
- It’s the system, not just the apparent high tech stuff
  - Understanding the system limiters can help focus tech investment

Army Power: Watts, Kilowatts & Megawatts

Summary - money, technology, and capability

- Money
  - Military increasingly dependent on civil investment & volume
  - The Army market is relatively a very, very small market for most items
  - That reality should influence 6.1, 6.2, 6.3 investment decisions
- Technology
  - JP-8 is the Army energy source for the next few decades
  - Focus on JP-8 compatible approaches, e.g. small turbines, SOFC
- Capability
  - Requires moving tech to the field, economics is the hardest part

Backup