The Role of Energy in the Lightweight Cryptographic Profile

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Current view on Profile

Physical characteristics	Performance characteristics	Security characteristics
Area (in GE)	Latency (in clock cycles)	Minimum security strength (bits)
Memory (RAM/ROM)	Throughput (cycles per byte)	Attack models
Implementation type (hardware, software, or both)	Power (μW)	Side channel resistance requirements

Reflects resource cost

Reflects performance and energy cost

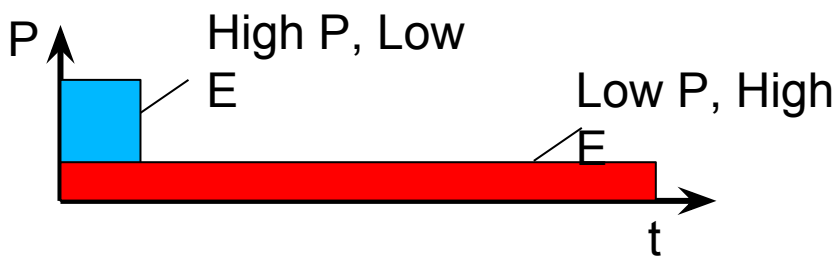
Reflects security

There is a characteristic for power, but what about *energy*?

Energy and Power

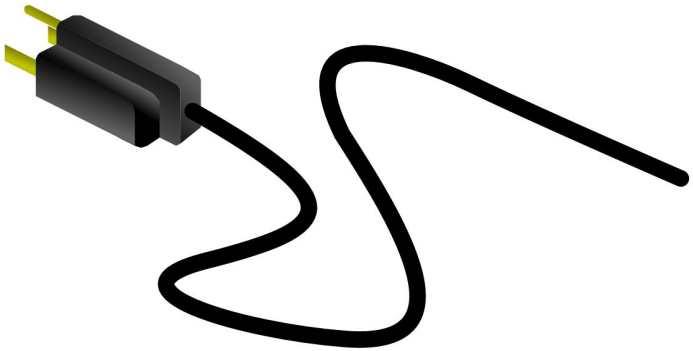
- **Energy equals work (J)**
  - **In crypto = the number of crypto operations**
- **Power equals work per unit of time (J/s)**
  - **In crypto = the number of crypto operations / second**

- **Low power is not the same as low energy**
  - **Energy = Power x Time**

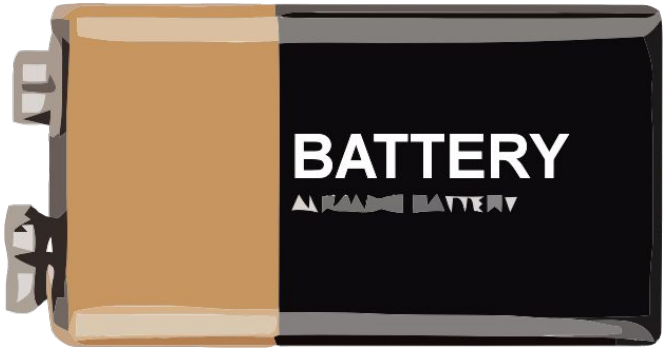


Transitioning to Lightweight

Typical Cryptosystems

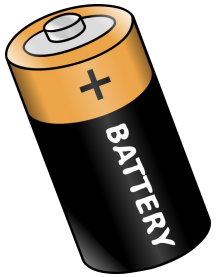


Lightweight Cryptosystems



Continuous Power vs. Limited Power

Design under the current scheme

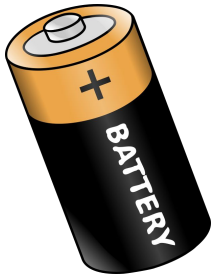


Suppose a system that uses:

- **1 Ahr battery**
- **AES consuming 1 mA of current.**

How long does it last?

Design under the current scheme



Suppose a system that uses:

- **1 Ahr battery**
- **AES consuming 1 mA of current.**

How long does it last?

1000 hours/42 days? Maybe.

Still need to know:

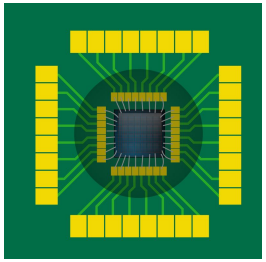
- **How much ciphertext do we process per Joule?**
- **How much ciphertext do we need per day?**

How to answer these questions

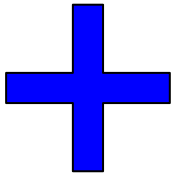
- **Joules per byte?**
- **Bytes per day?**

- Atomic energy cost of a operation
  - Example: Encrypting 1 block costs 12 nano-Joules
  - More precise
  - Energy is a resource

X bytes of memory



Y gates



Z Joules

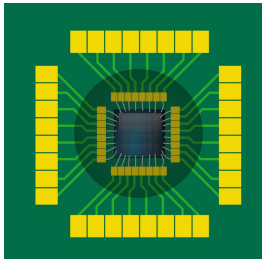
How to answer these questions

- **Joules per byte?**
- **Bytes per day?**

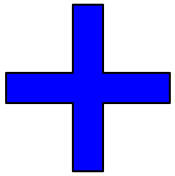
Power / Throughput -- only reflects average case

- Atomic energy cost of a operation
  - Example: Encrypting 1 block costs 12 nano-Joules
  - More precise
  - Energy is a resource

X bytes of memory



Y gates

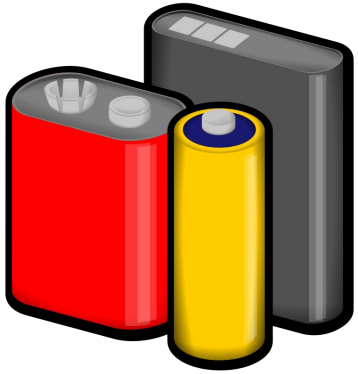


Z Joules

Energy harvesting consideration

Conventional battery

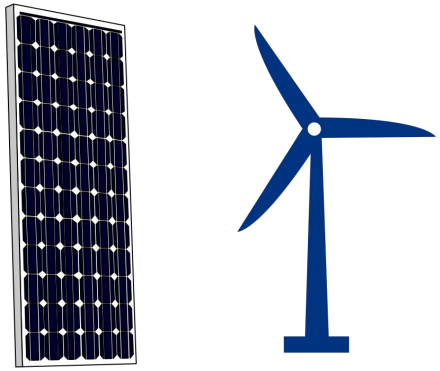
(finite **J**, large J/s)



Cheap
High density
Limited
Servicing cost

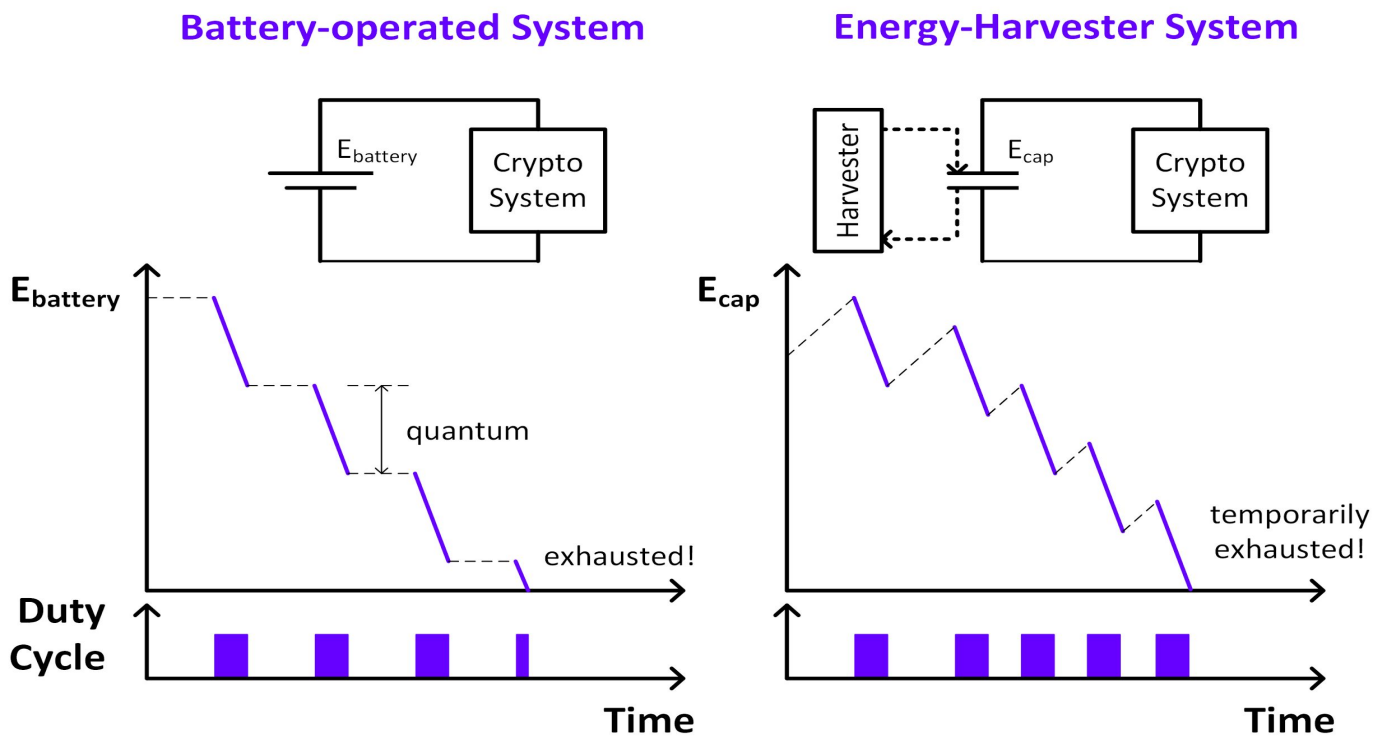
Energy Harvester

(infinite J, finite **J/s**)



Complex
Low supply
Unlimited
Infinite lifetime

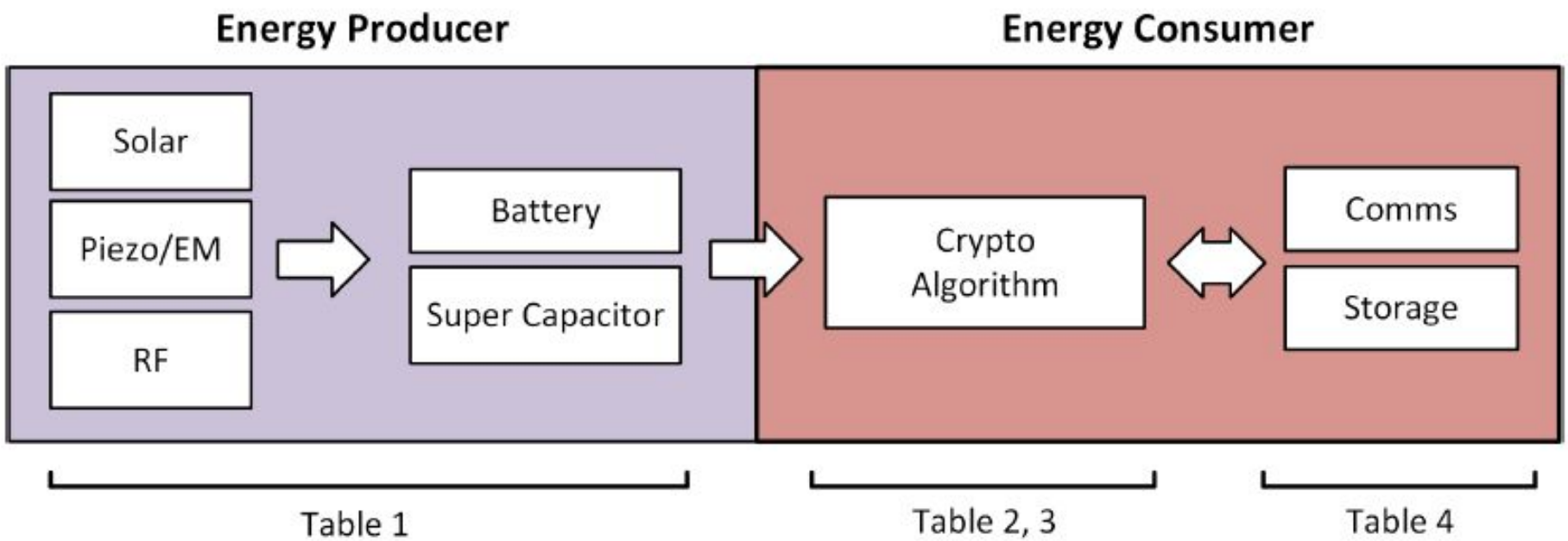
Energy Harvesting vs Battery Operation



- **Under acceptable duty cycle of operation, energy-harvester systems have a *perpetual* lifetime**

'acceptable' means $E_{harvested} > E_{consumed}$

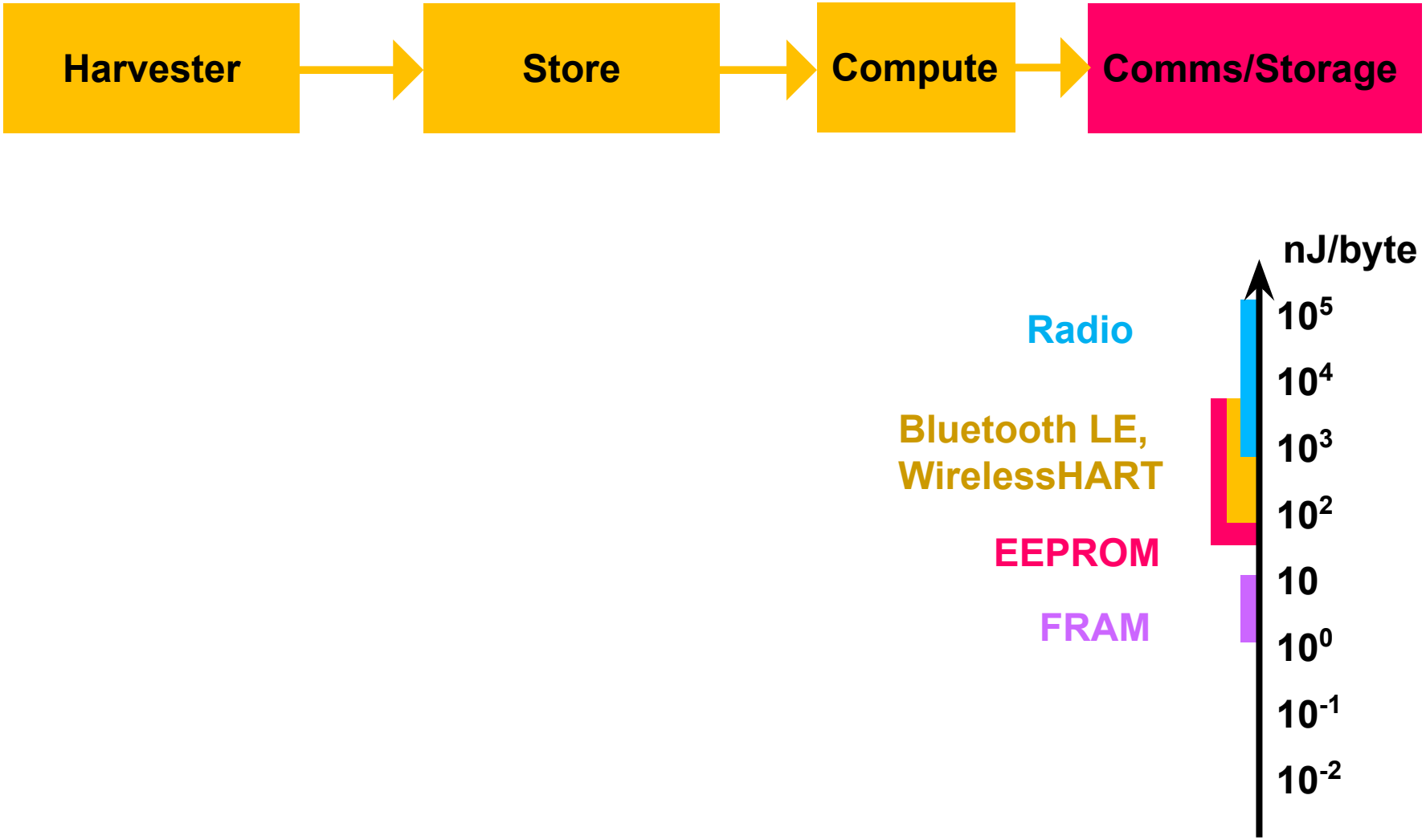
The energy balance



- *Energy Store B (J)*
- *and/ or Energy Influx b (J/s)*

- *Energy Quanta q (J)*
- *Duty cycle d (1/s)*

Energy Harvester Based Design



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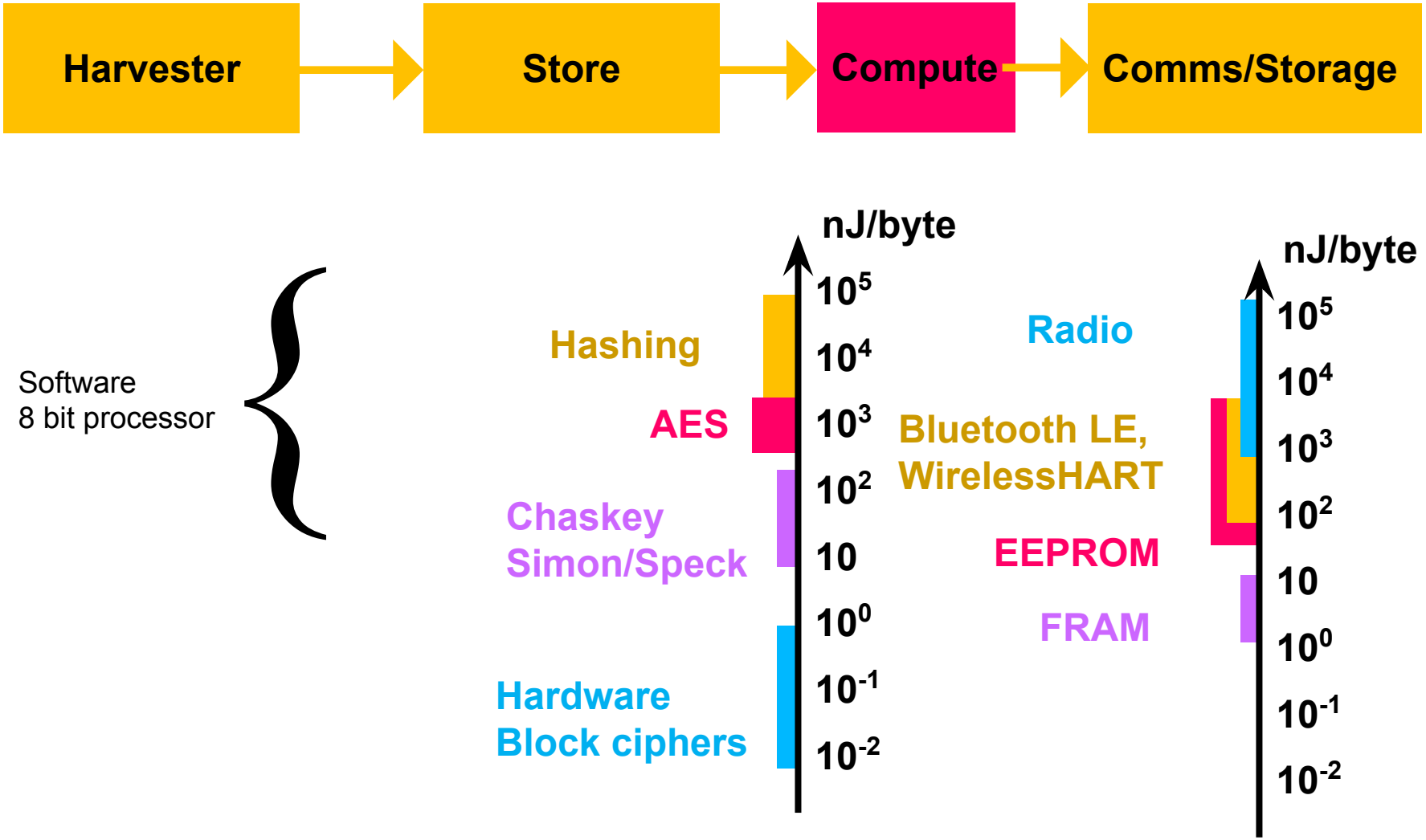

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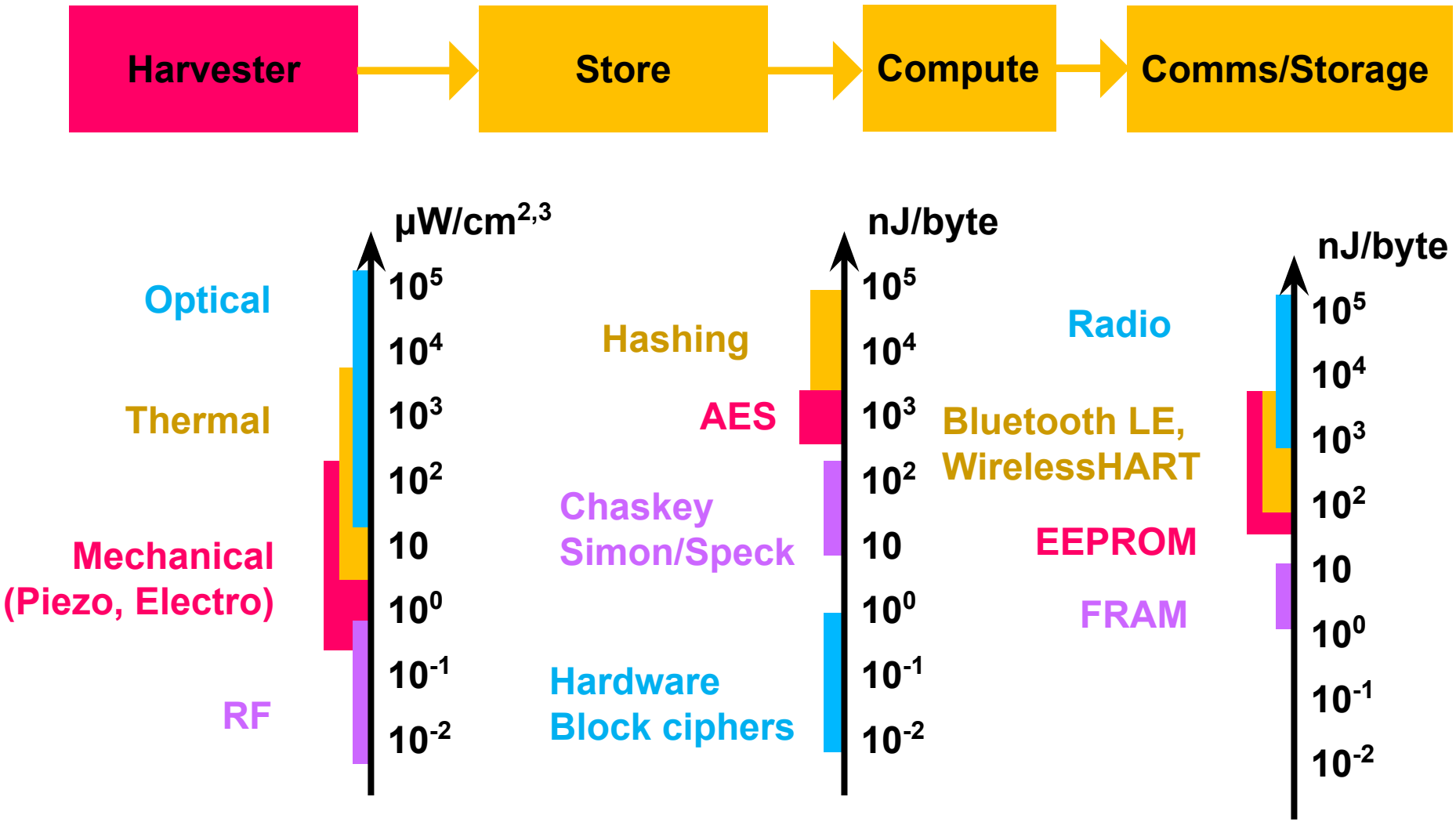
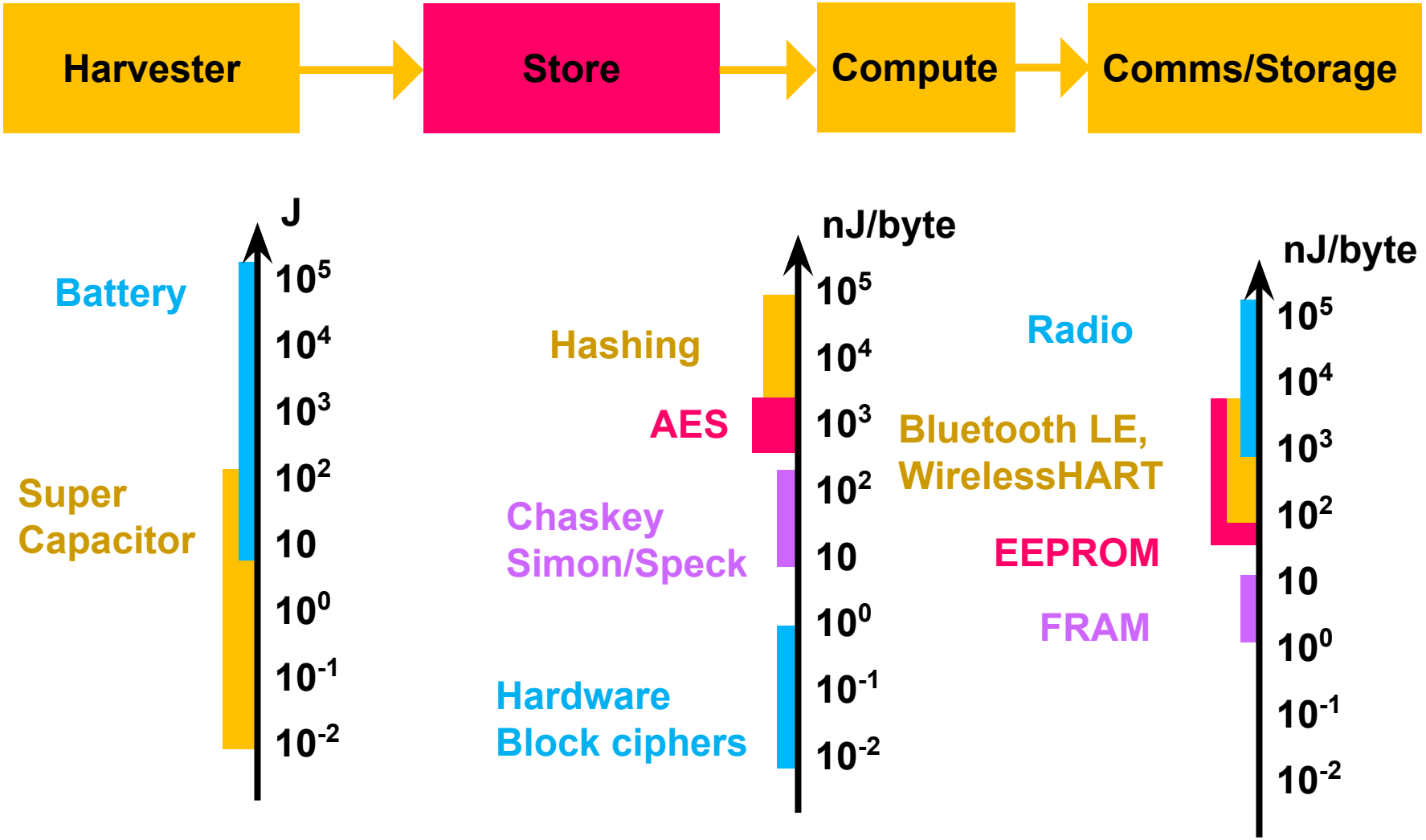


Energy Harvester Based Design



Energy Harvester Based Design

Harvester → Store → Compute + Comms

μW/cm²

Optical

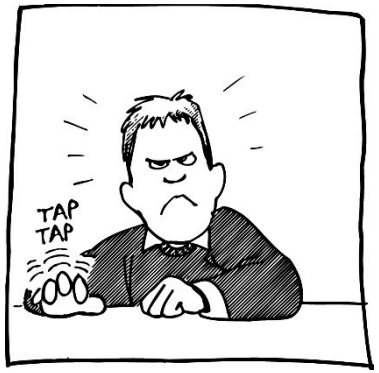
Thermal

Mechanical (Piezo, Electro)

RF

10^5
10^4
10^3
10^2
10
10^0
10^{-1}
10^{-2}

1 block = 20 uJ
=
1 μW x 20 sec



nJ/byte

Hashing

AES

Chaskey, Simon/Speck

Hardware Block ciphers

10^5
10^4
10^3
10^2
10
10^0
10^{-1}
10^{-2}

Based on data from TI, Penella-Lopez, Mitcheson

Energy Harvester Based Design

Harvester → **Store** → **Compute + Comms**

	$\mu W/cm^2$
Optical	10^5
	10^4
Thermal	10^3
	10^2
Mechanical (Piezo, Electro)	10
	10^0
	10^{-1}
RF	10^{-2}

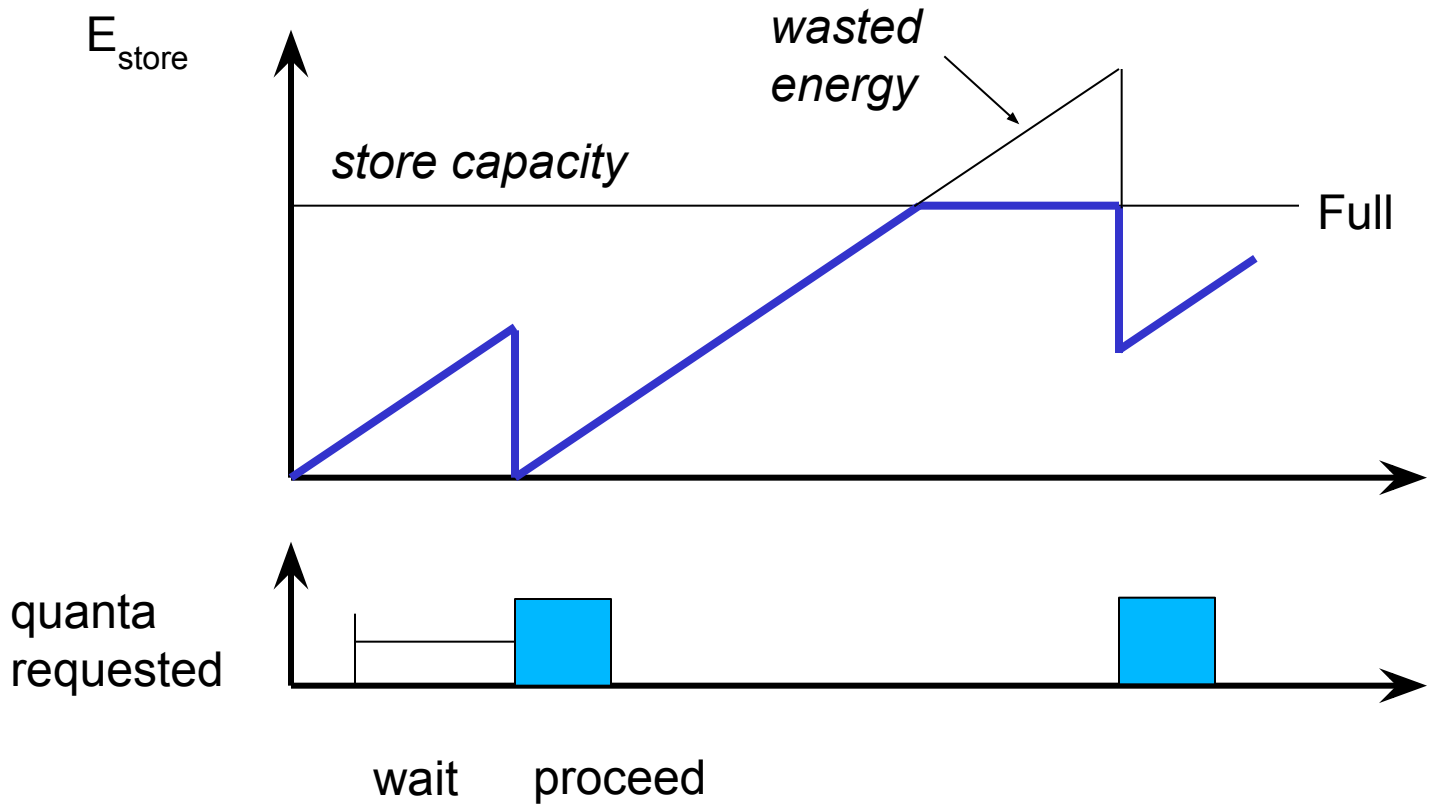
1 block = 20 uJ
=
4320 blocks / day

	nJ/byte
	10^5
Hashing	10^4
AES	10^3
	10^2
Chaskey, Simon/Speck	10
	10^0
Hardware Block ciphers	10^{-1}
	10^{-2}

Based on data from TI, Penella-Lopez, Mitcheson

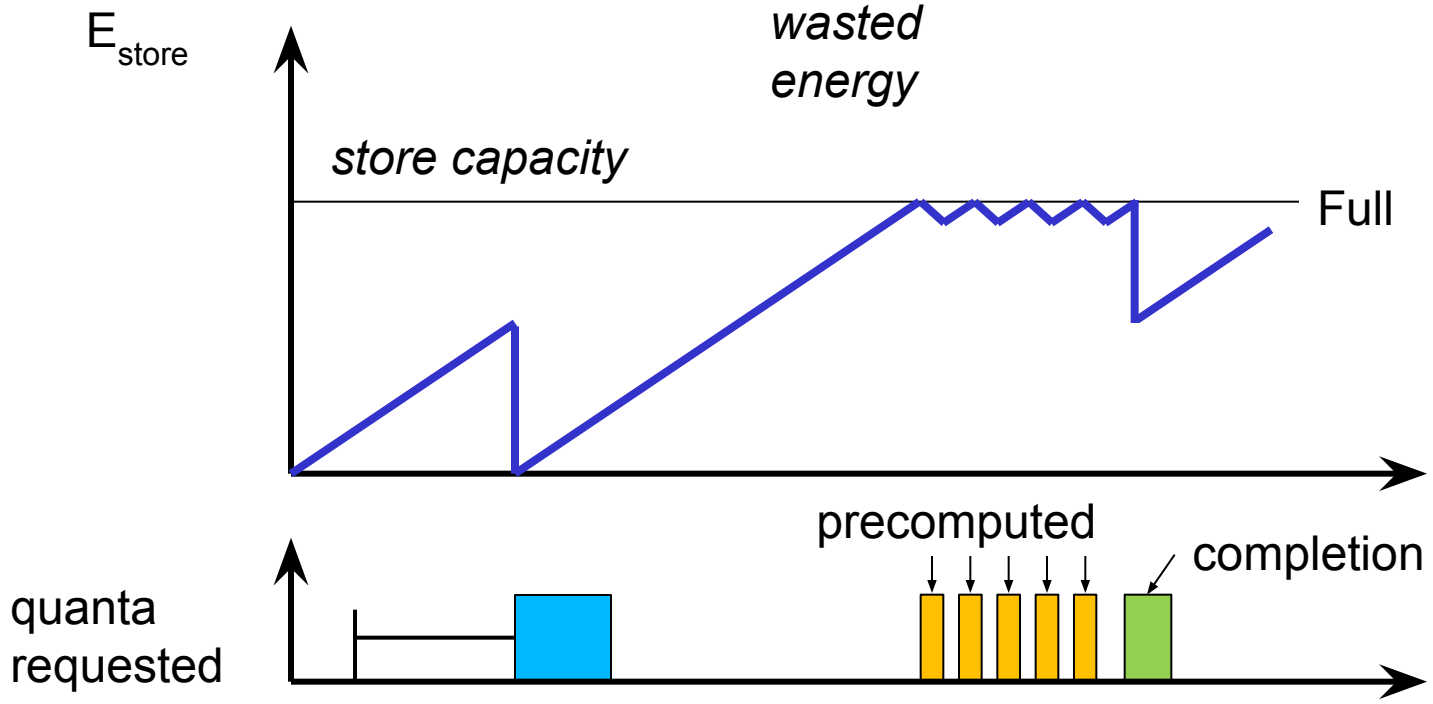
Energy Harvester Based Design

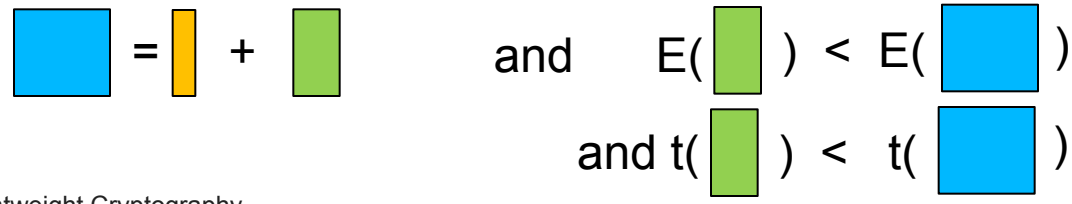
Traditional design - atomic algorithm execution



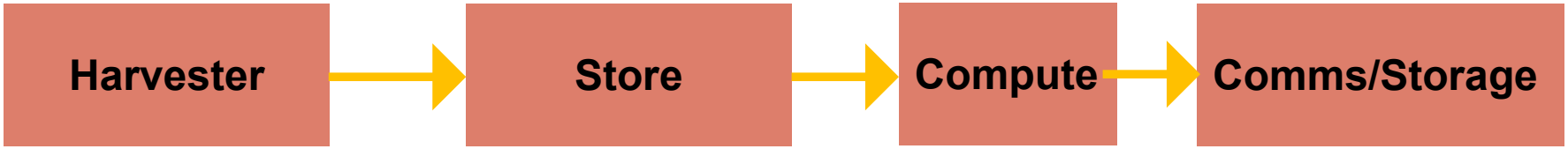
Energy Harvester Based Design

Improved design - precomputed execution

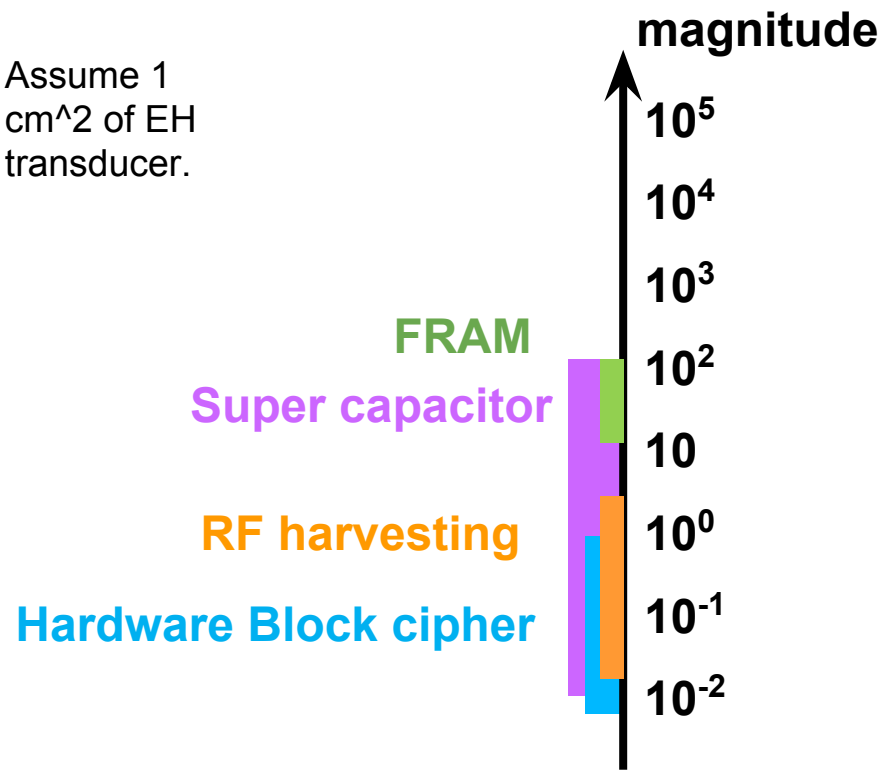




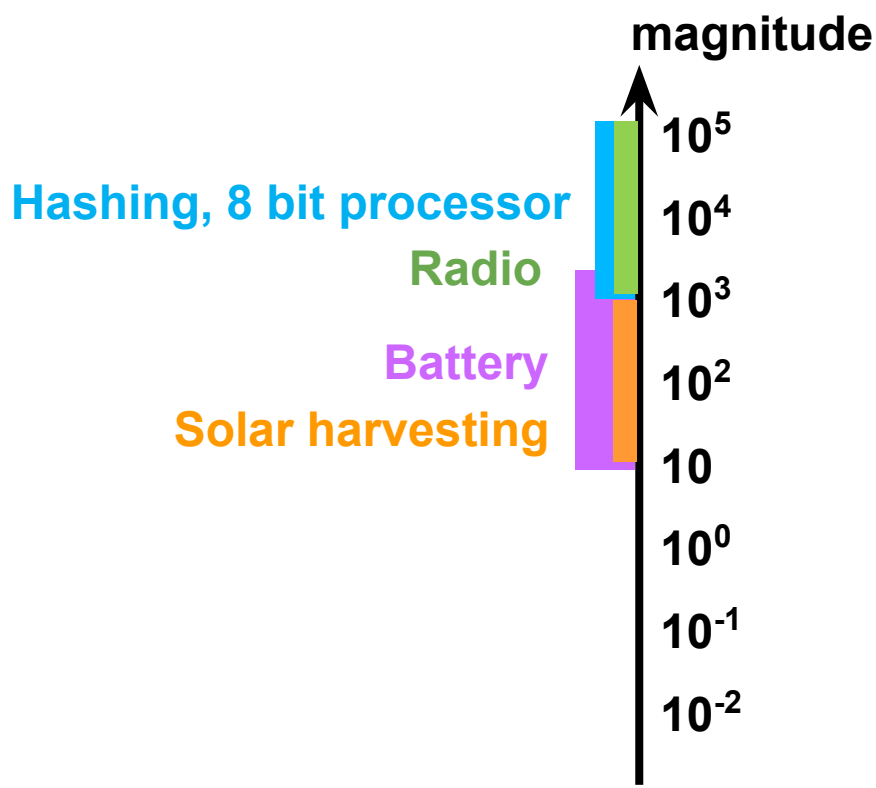
Putting it all together



Assume 1 cm^2 of EH transducer.



Potential of **1.5 MB** per day



Potential of **1.5 MB** per day

We need better energy metrics

- **Joules per byte (J/byte)**
- **Hard to compare HW implementations**
  - **Different hardware implements of same cipher will vary in magnitudes for J/byte.**

- **Relativeness of cipher J/byte seems to hold.**
- **It would be best for authors to report J/byte relative to another cipher on same platform.**

What we did

- **Approximate:**
  - **Energy = K * (Power * throughput / block-size)**

- **K = technology constant, units: CV^2/2 J/gate)**

- **Provides results not useful for design, but may work for comparison.**

Conclusion

Physical characteristics	Performance characteristics	Security characteristics
Area (in GE)	Latency (in clock cycles)	Minimum security strength (bits)
Memory (RAM/ROM)	Throughput (cycles per byte)	Attack models
Implementation type (hardware, software, or both) **Energy**	Power (μW)	Side channel resistance requirements

- **Energy harvesting -- new LWC paradigm.**
- **J/byte -- crucial metric for engineers and designers.**
- **Secure LW design involves a lot of balancing.**