

## Workshop on Widening Access to TinyML Network by Establishing Best Practices in Education



3 - 7 July 2023  
An ICTP Meeting  
Trieste, Italy

Further information:  
<http://indico.ictp.it/event/10185/>  
smr3851@ictp.it

# Responsible AI via Sustainable and Privacy Preserving EdgeML



*Brian Plancher*  
Barnard College, Columbia University  
[brianplancher.com](http://brianplancher.com)



# How can we adapt our approach to EdgeML to support **Responsible AI** future?

A voice command starts your TV's recognition, and viewing data is interconnectivity has privacy implications. smart TV spying and how to stop it.

## How to Stop Your Smart TV From Spying on You

FBI warns about snoopy smart TV

## FBI warns about snoopy smart TV

AI is harming our planet: addressing AI's staggering energy cost

Tue, May 24, 2022

The Observer Smart homes  
**How to stop your smart home spying on you**

Everything in your smart home, from the lightbulbs to the

WILL KNIGHT BUSINESS JAN 21, 2020 7:00 AM

## AI Can Do Great Things—if It Doesn't Burn the Planet

The computing power required for AI landmarks, such as recognizing images and defeating humans at Go, increased 300,000-fold from 2012 to 2018.

FORBES > INNOVATION > AI

## Deep Learning's Carbon Emissions Problem

Rob Toews Contributor I write about the big picture of artificial intelligence.

Jun 17, 2020, 11:54am EDT

Follow

Listen to article 13 minutes

This article is more than 3 years old.

2

# Responsible AI via Sustainable and Privacy Preserving EdgeML

1. What is a (**Datasheet** for a) Machine Learning Sensor?
2. **Applications** of TinyML for Sustainability
3. Environmental Footprint of **TinyML Systems at Deployed Scale**

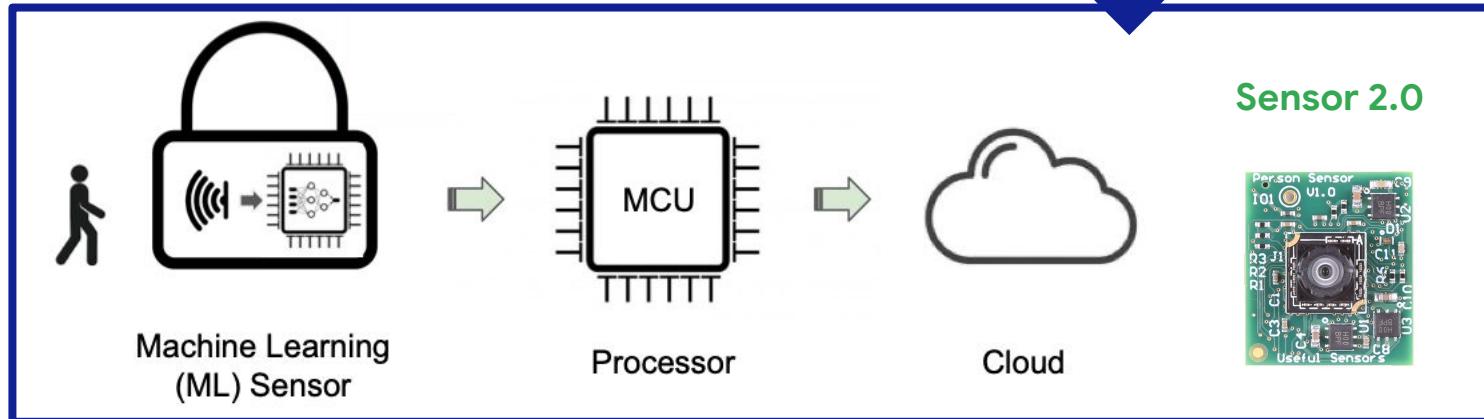
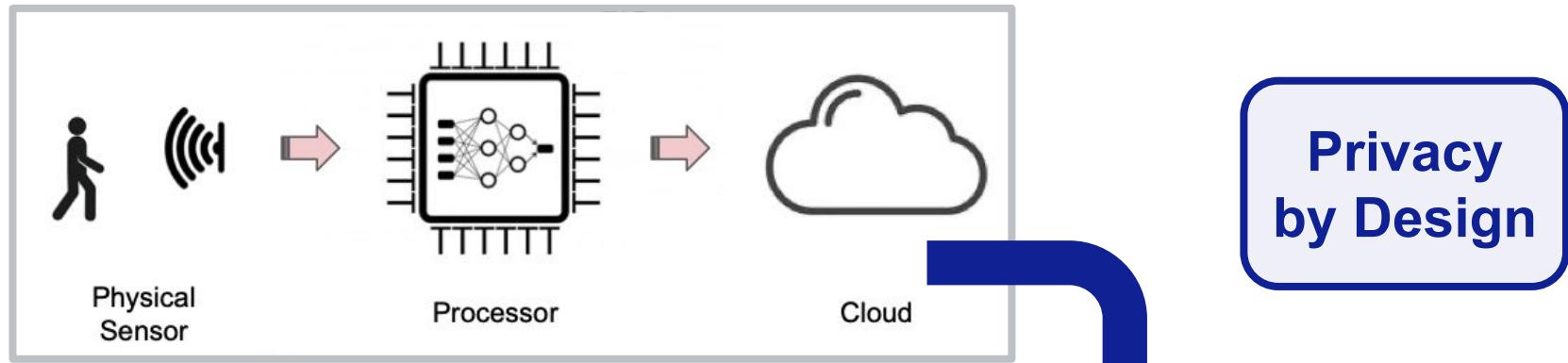
Our Suggested Transparent Paradigm

Positive Effects of TinyML

Environmental Footprint at Scale

# What is a (Datasheet for a) Machine Learning Sensor?

# What is a Machine Learning Sensor?



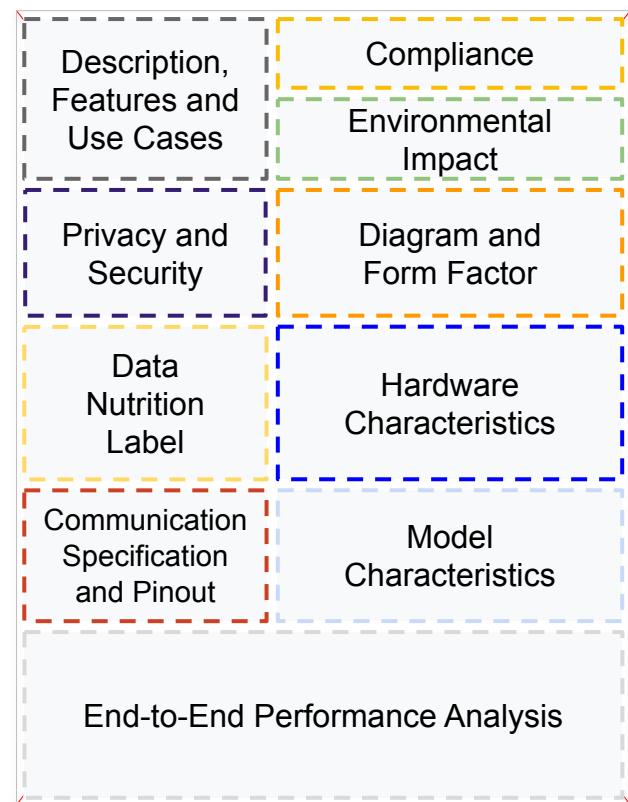
# We suggest **transparency** as a core value to overcome these challenges.

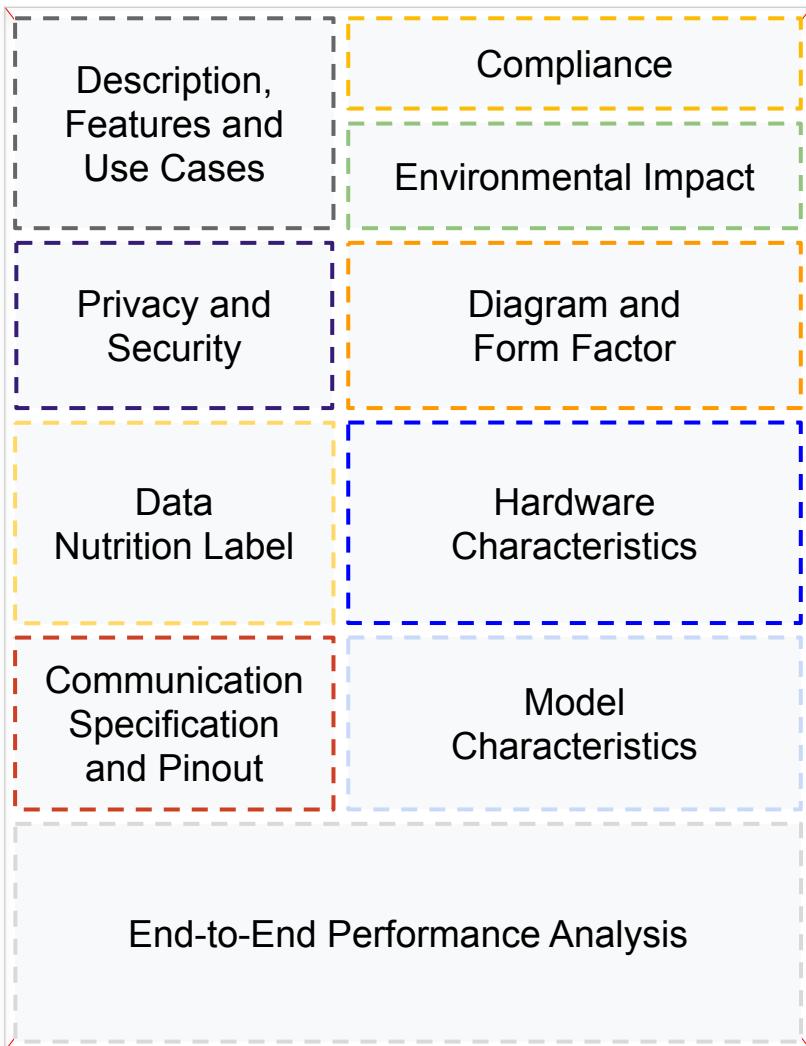
## Datasheets for Machine Learning Sensors

Matthew Stewart<sup>1\*</sup> Pete Warden<sup>2,5</sup> Yasmine Omri<sup>1</sup> Shvetank Prakash<sup>1</sup> Joao Santos<sup>1</sup>  
Shawn Hymel<sup>4</sup> Benjamin Brown<sup>1</sup> Jim MacArthur<sup>1</sup> Nat Jeffries<sup>5</sup> Brian Plancher<sup>3</sup>  
Vijay Janapa Reddi<sup>1</sup>

<sup>1</sup>Harvard University <sup>2</sup>Stanford University <sup>3</sup>Barnard College, Columbia University  
<sup>4</sup>Edge Impulse <sup>5</sup>Useful Sensors

[arxiv.org/abs/2306.08848](https://arxiv.org/abs/2306.08848)

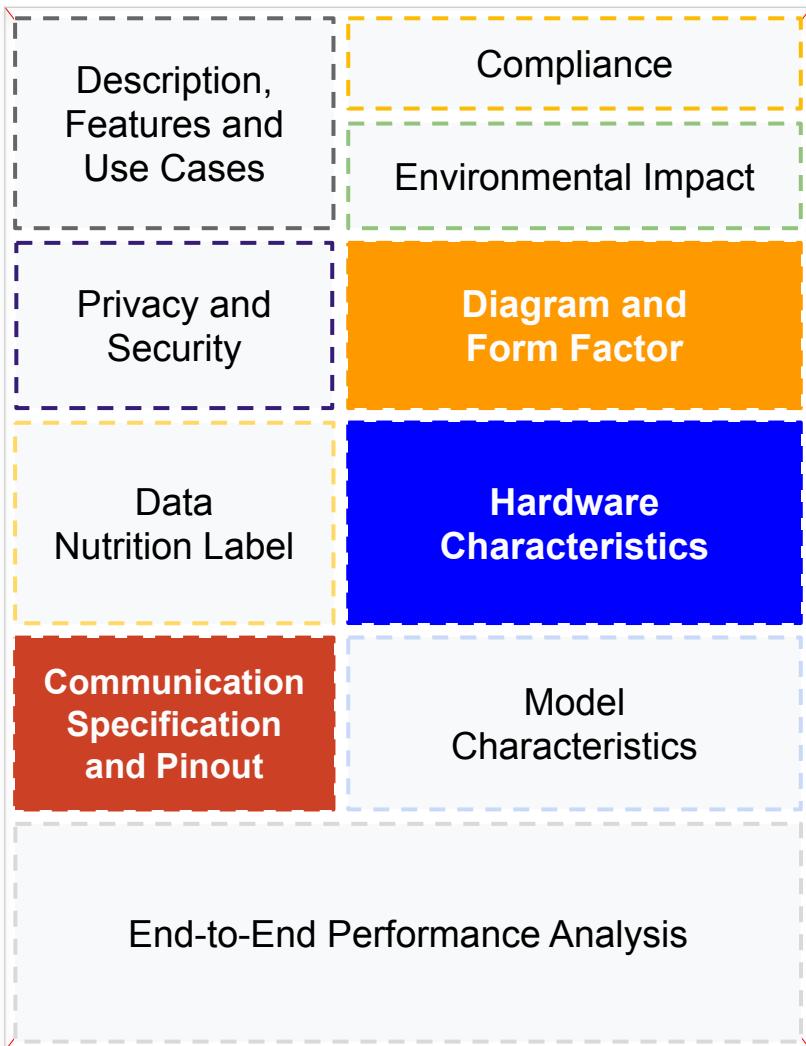




# ML Sensor Datasheets

## Have 3 Goals:

1. Raise the level of **abstraction**
2. Transparent at the **hardware, data, model, and end-to-end layers**
3. Support **Responsible** Use

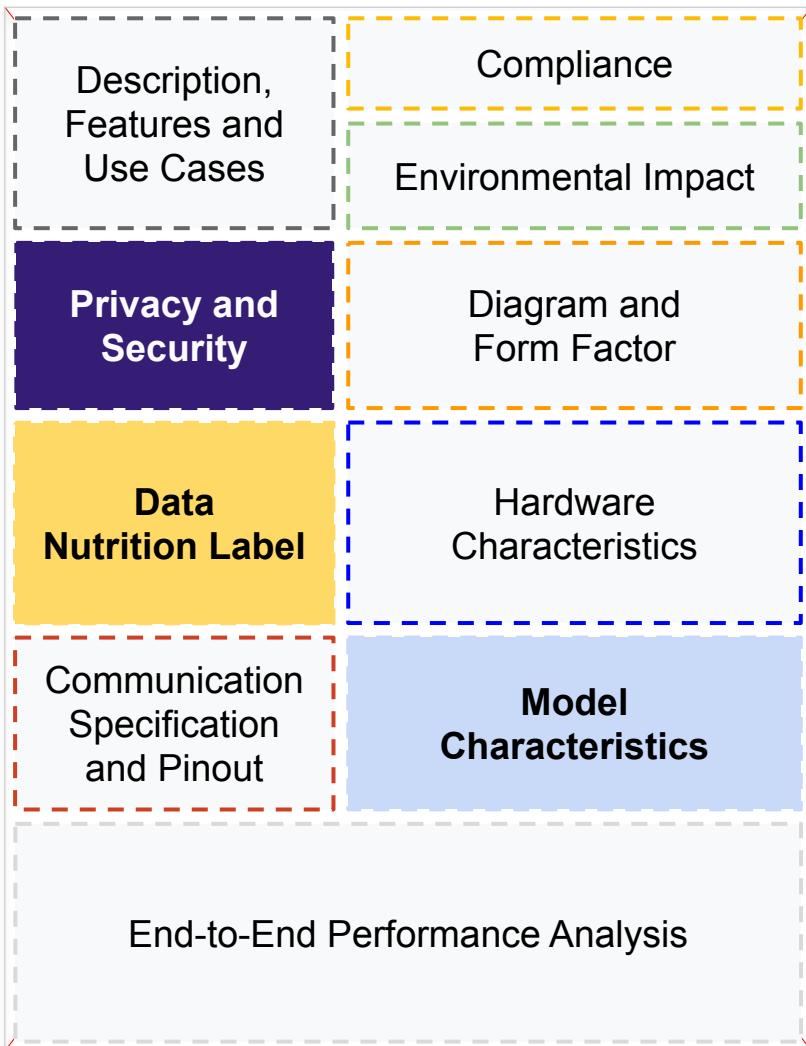


# ML Sensor Datasheets

## Have 3 Goals:

1. Raise the level of abstraction
2. Transparent at the **hardware**, data, model, and end-to-end layers
3. Support Responsible Use

Standard Sensor  
Datasheet



# ML Sensor Datasheets

## Have 3 Goals:

1. Raise the level of abstraction
2. Transparent at the hardware, **data, model**, and end-to-end layers
3. Support **Responsible** Use

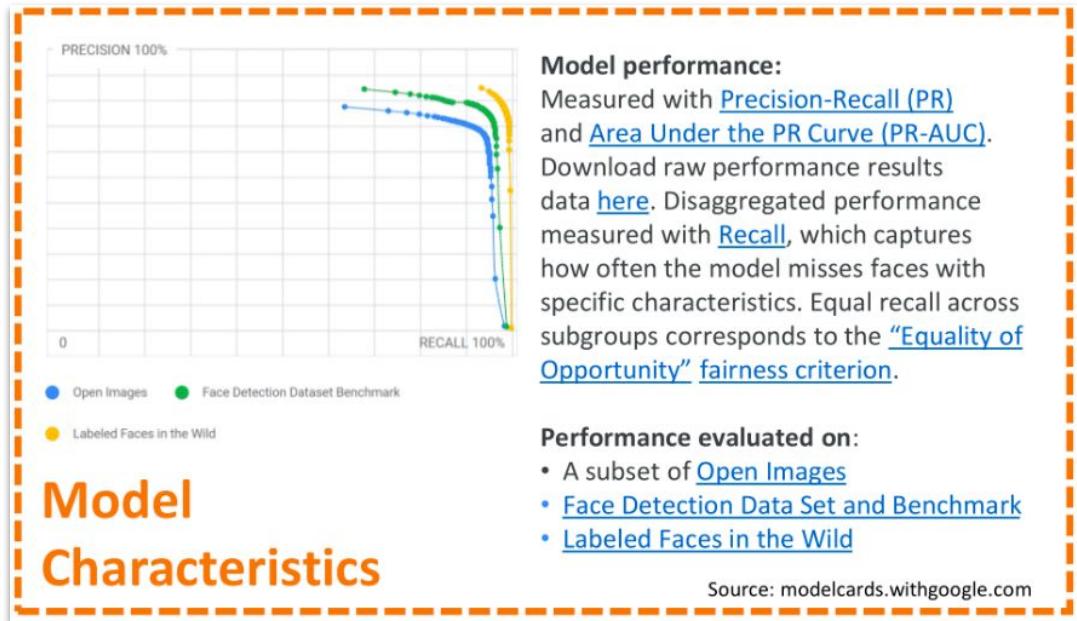
**Responsible  
Machine Learning  
Analysis**

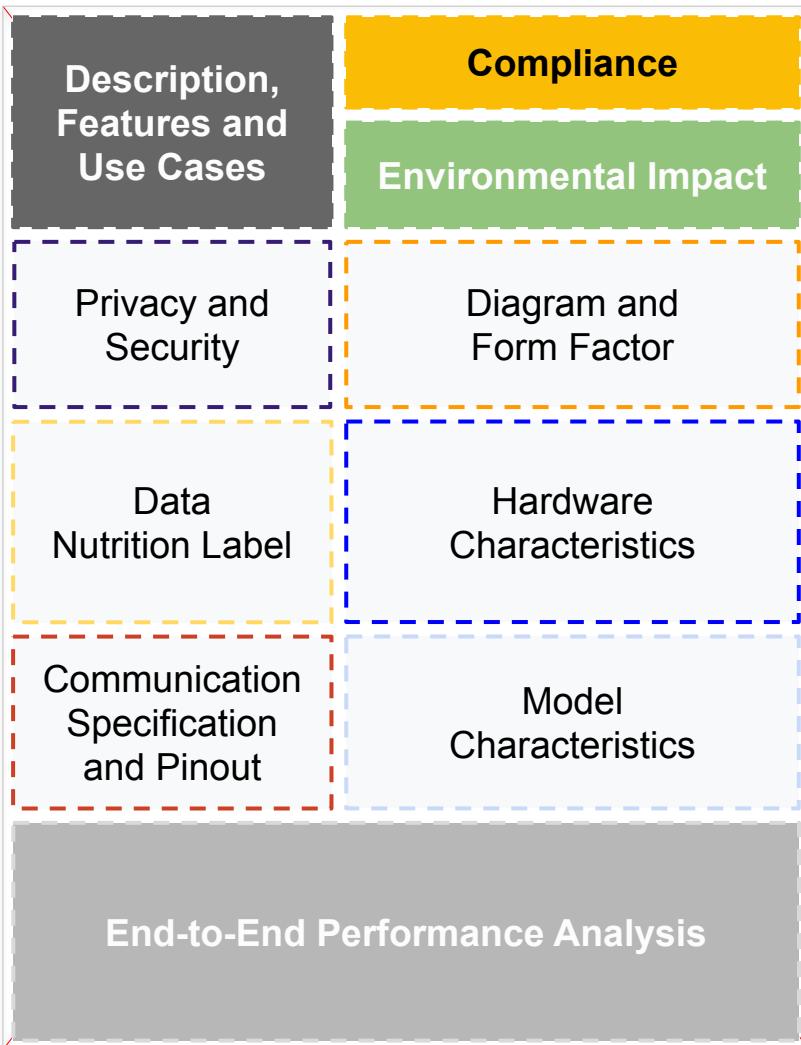
# Responsible Machine Learning Analysis

Source: datanutrition.org



The dashboard features a purple dashed border. Inside, there are two rows of four icons each. The top row includes 'Aggregated Human Data' (person icon), 'Quality Review' (magnifying glass icon), 'Ethical Review' (scales icon), and 'About Humans' (two people icon). The bottom row includes 'Commercial License' (dollar sign icon), 'Multi-source Funded' (hand holding a heart icon), 'Not Actively Updated' (refresh icon), and 'Multi-source Data' (bar chart icon). Below these rows is a large purple title 'Dataset Nutrition Label'.



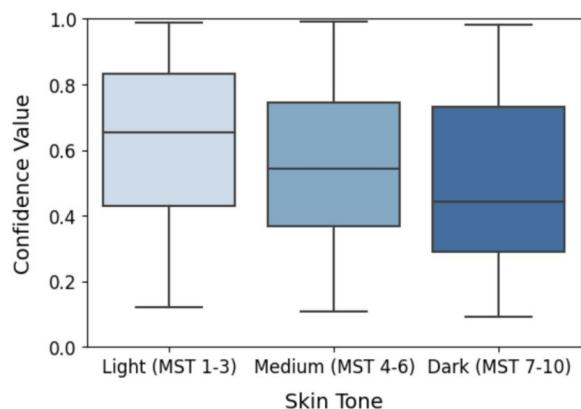
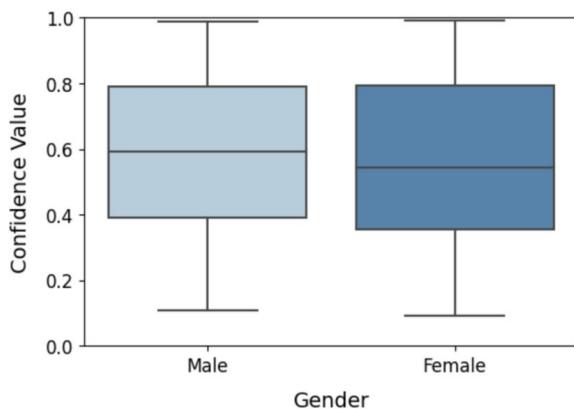
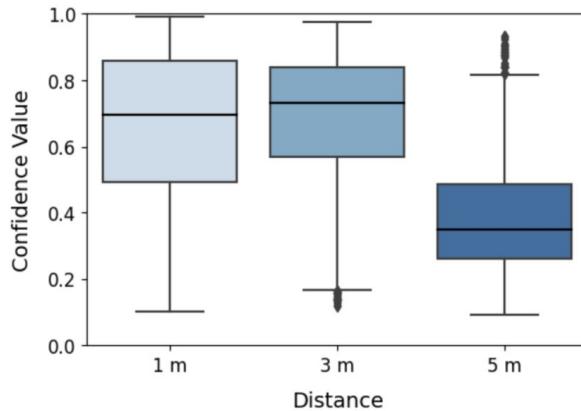
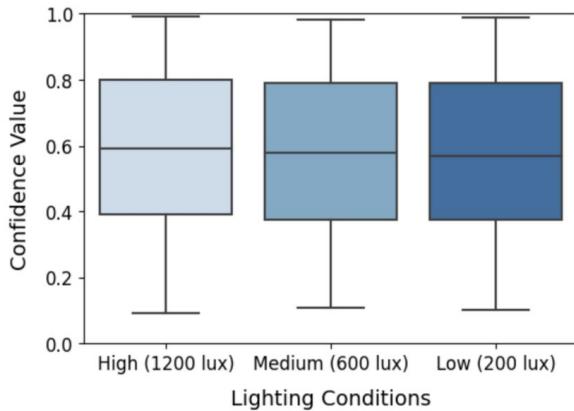


# ML Sensor Datasheets

## Have 3 Goals:

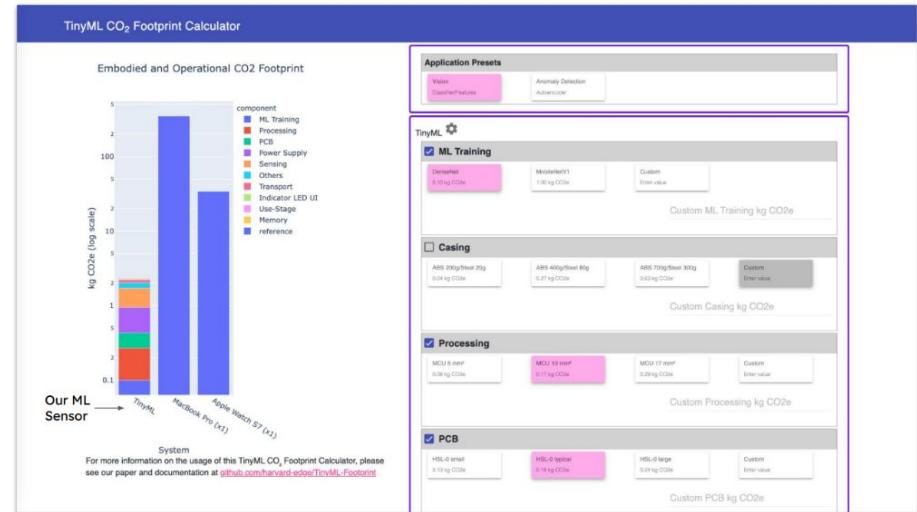
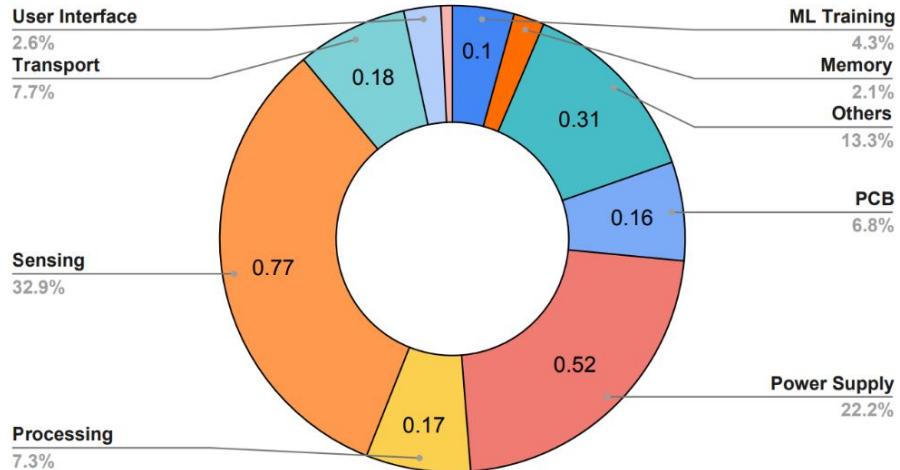
1. Raise the level of **abstraction**
2. Transparent at the hardware, data, model, and **end-to-end layers**
3. Support **Responsible Use**

Overall System  
Analysis



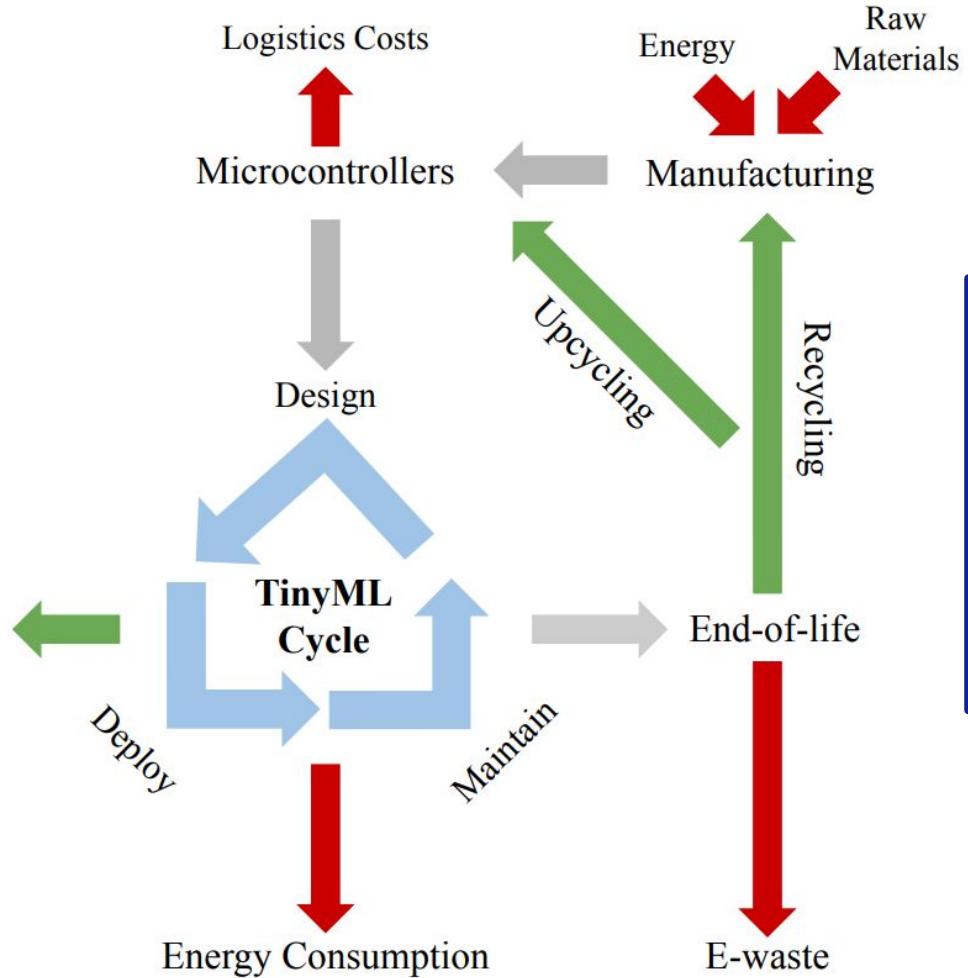
# End-to-End Responsible Performance Analysis

# Environmental Impact



Lets Explore this Impact  
in More Detail

## Sustainable Development Goals



TinyML can support the SDGs but comes with costs. **What is the net impact?**

# Applications of TinyML for Sustainability

# Zero Hunger & Good Health and Well-Being (SDG #2 & #3)



Credit: PlantVillage Nuru

Nuru, an ML app more accurate than humans at detecting plant diseases. Increased a farmer's sales by 55% & **yields by 146%**.



Credit: Crop Angel Ltd

Tiny drones can provide targeted pesticide applications that **reduce use to 0.1%** of conventional blanket spraying.



Credit: Sinhyu/Getty Images

Using Edge Impulse, a system was prototyped to identify mosquitoes by wing beats sounds with **88.3% accuracy**.

# Life on Land & Below Water

## (SDG #14 & #15)



Credit: Rainforest Connection

Rainforest Connection uses **recycled smartphones** for **solar-powered** listening devices to warn of **deforestation** efforts



Credit: RESOLVE and Bivash Pandav

RESOLVE's AI camera transmits notifications of elephant detection and can **run for more than 1.5 years** on a single battery.



Credit: Tim Cole

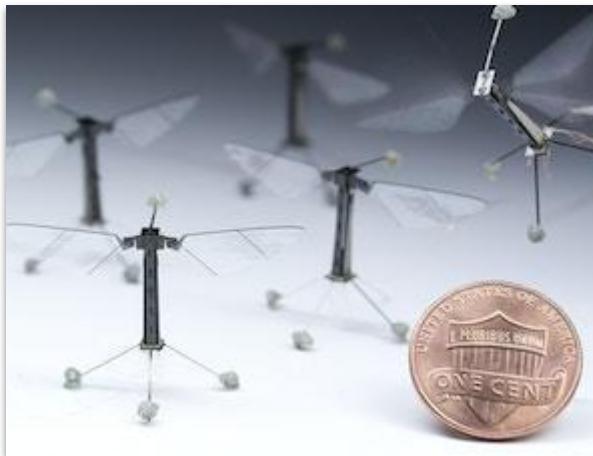
To prevent collisions with whales in busy waterways, Google deployed a TinyML model on hydrophones to alert ships.

# Climate Action (SDG #13)



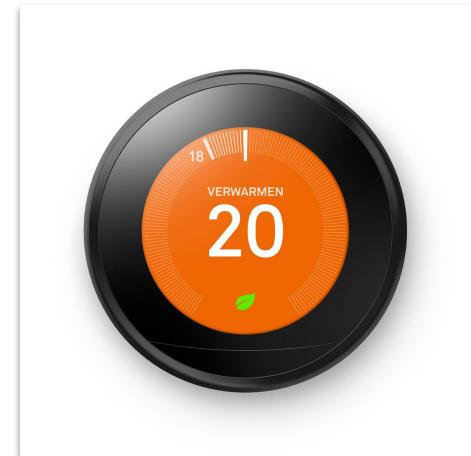
Credit: Ribbit Network

Ribbit Network is **crowdsourcing world's largest greenhouse gas emissions dataset** through distributed intelligent sensors



Credit: Wyss Institute at Harvard University

TinyML can help provide intelligence to **tiny robots like the Robobee** that can be used as artificial pollinators.

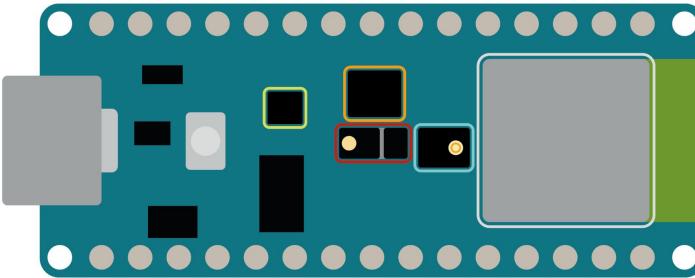


Credit: Google Nest

Smart HVAC systems show a **20-40% reduction in building energy usage**.

# Environmental Footprint of TinyML Systems

# Real TinyML Systems are more than just an MCU!

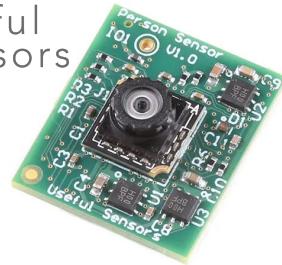


- ◆ Color, brightness, proximity and gesture sensor
- ◆ Digital microphone
- ◆ Motion, vibration and orientation sensor
- ◆ Temperature, humidity and pressure sensor
- ◆ Arm Cortex-M4 microcontroller and BLE module

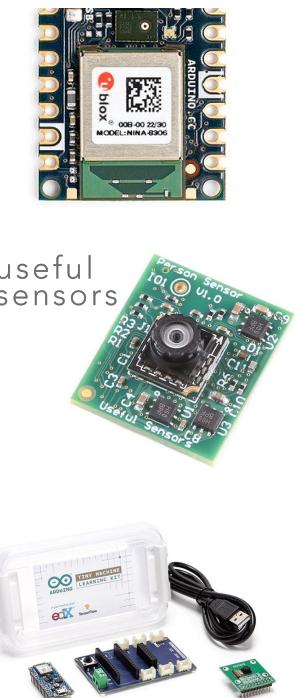
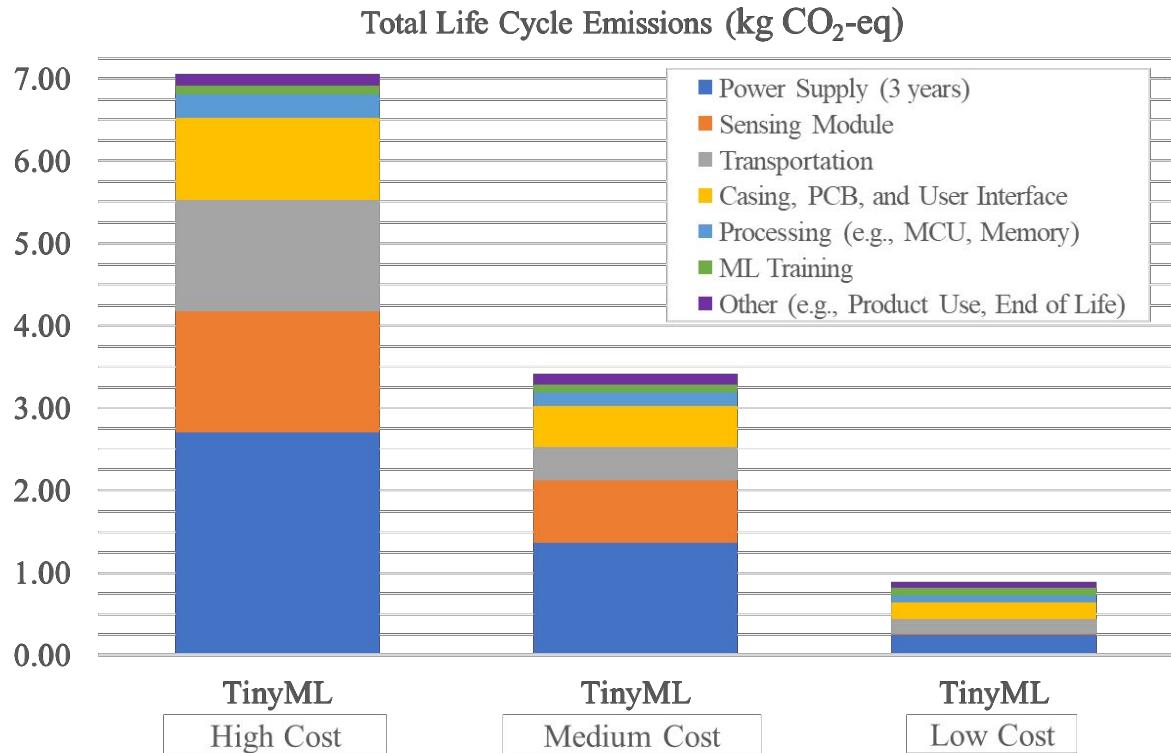


# Building Representative Systems

Cost Level	High Cost	Medium Cost	Low Cost
Application	Image Classification		Keyword Spotting
Size	Large	Compact	Compact



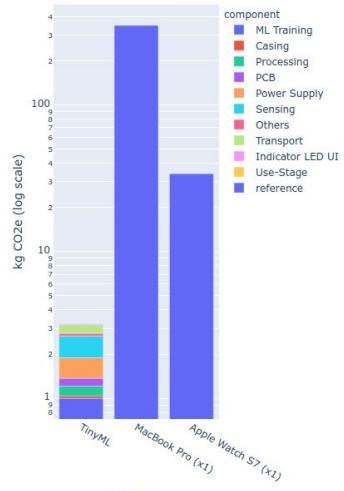
# Building Representative Systems



# [harvard-edge.github.io/TinyML-Footprint/](https://harvard-edge.github.io/TinyML-Footprint/)

## TinyML CO<sub>2</sub> Footprint Calculator

Embodied and Operational CO<sub>2</sub> Footprint



For more information on the usage of this TinyML CO<sub>2</sub> Footprint Calculator, please see our paper and documentation at [github.com/harvard-edge/TinyML\\_Footprint](https://github.com/harvard-edge/TinyML_Footprint)

Application Presets

Vision  
Classifier/Features      Anomaly Detection  
Autoencoder

**TinyML**

**ML Training**

DenseNet 0.10 kg CO <sub>2</sub> e	MobileNetV1 1.00 kg CO <sub>2</sub> e	Custom Enter value
---------------------------------------	--	-----------------------

Custom ML Training kg CO<sub>2</sub>e

**Casing**

ABS 200g/Steel 20g 0.04 kg CO <sub>2</sub> e	ABS 400g/Steel 80g 0.27 kg CO <sub>2</sub> e	ABS 700g/Steel 300g 0.63 kg CO <sub>2</sub> e	Custom Enter value
---	---	--	-----------------------

Custom Casing kg CO<sub>2</sub>e

**Processing**

MCU 5 mm* 0.08 kg CO <sub>2</sub> e	MCU 10 mm* 0.17 kg CO <sub>2</sub> e	MCU 17 mm* 0.29 kg CO <sub>2</sub> e	Custom Enter value
--	---	---	-----------------------

Custom Processing kg CO<sub>2</sub>e

**PCB**

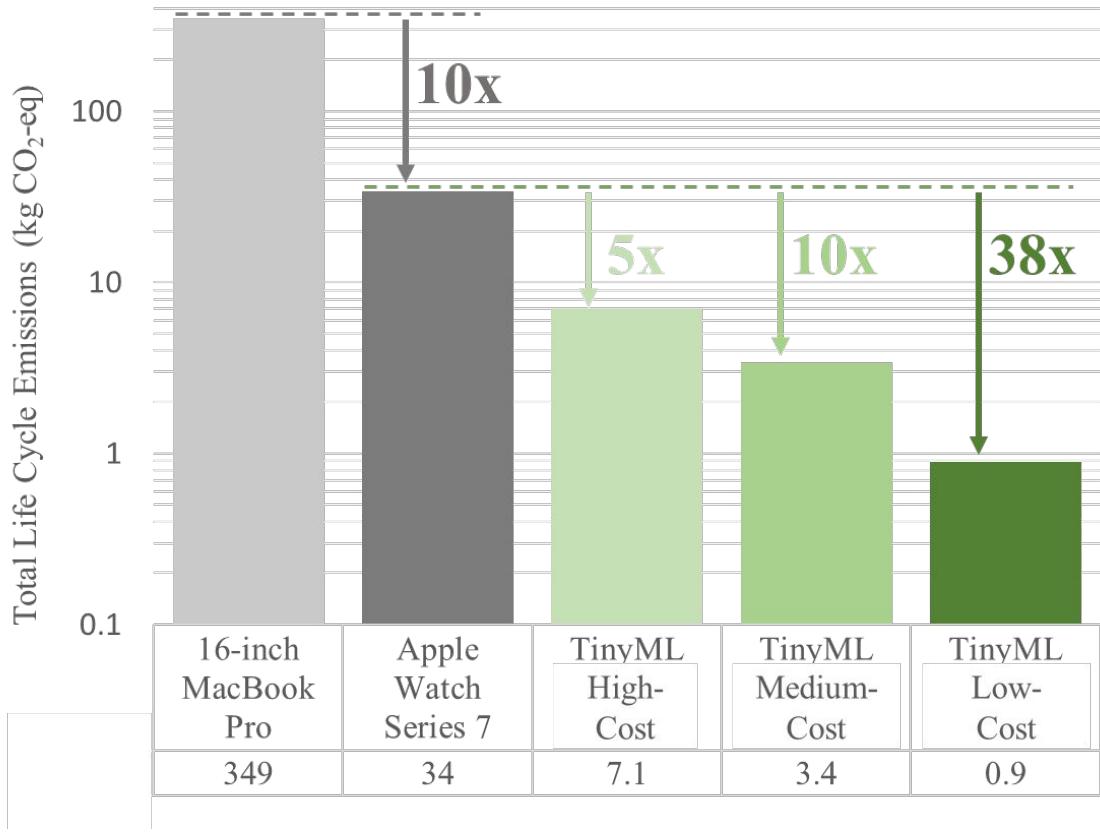
HSL-0 small 0.13 kg CO <sub>2</sub> e	HSL-0 typical 0.16 kg CO <sub>2</sub> e	HSL-0 large 0.24 kg CO <sub>2</sub> e	Custom Enter value
--	--	--	-----------------------

Custom PCB kg CO<sub>2</sub>e

**Power Supply**



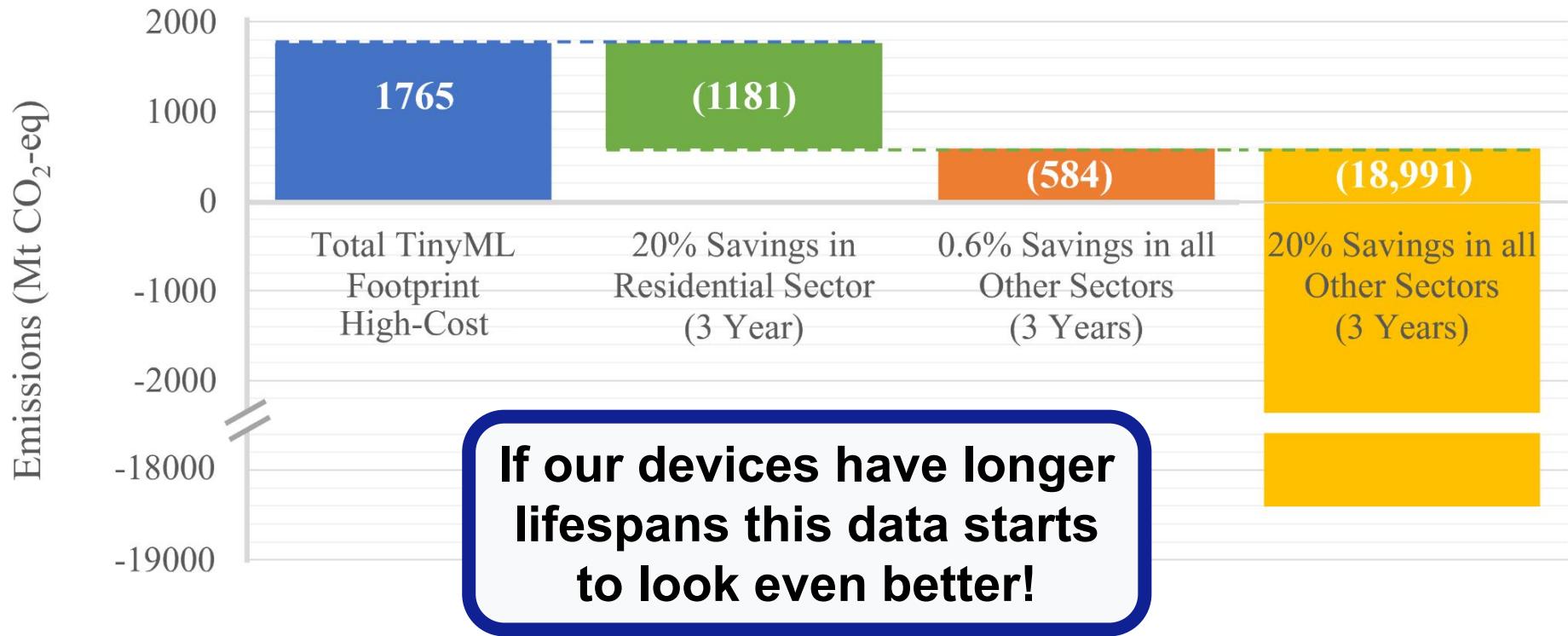
# TinyML Systems in Context



**5x to 38x  
Savings  
over a  
3-year  
lifespan!**

# Environmental Footprint of TinyML Systems at Deployed Scale

# What if we scale to 250bn devices?



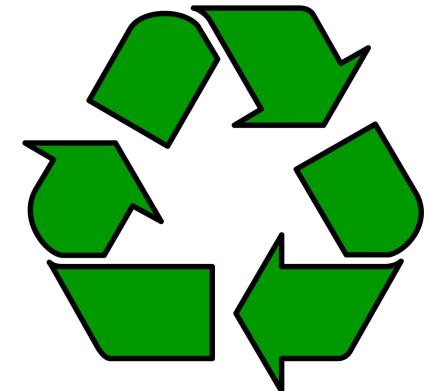
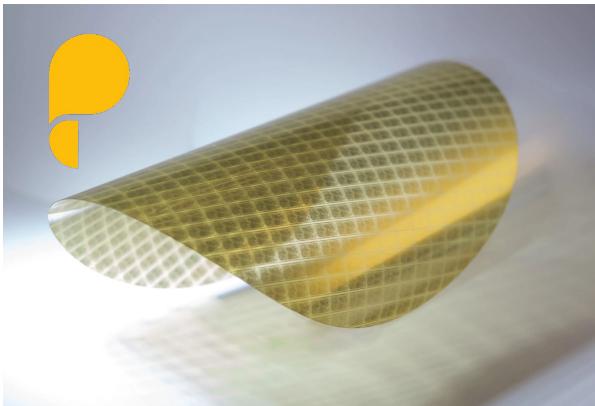
# Limitations and Areas for Future Study

What about the net impact  
of factors **beyond carbon**?

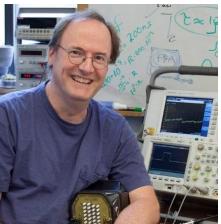
What about  
Jevons' Paradox?

What about the  
**human costs**?

How can **emerging**  
technologies help?



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