Reimagining Building Sensing and Control

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National Renewable Energy Laboratory

Keynote, Sensor Expo & Conference,
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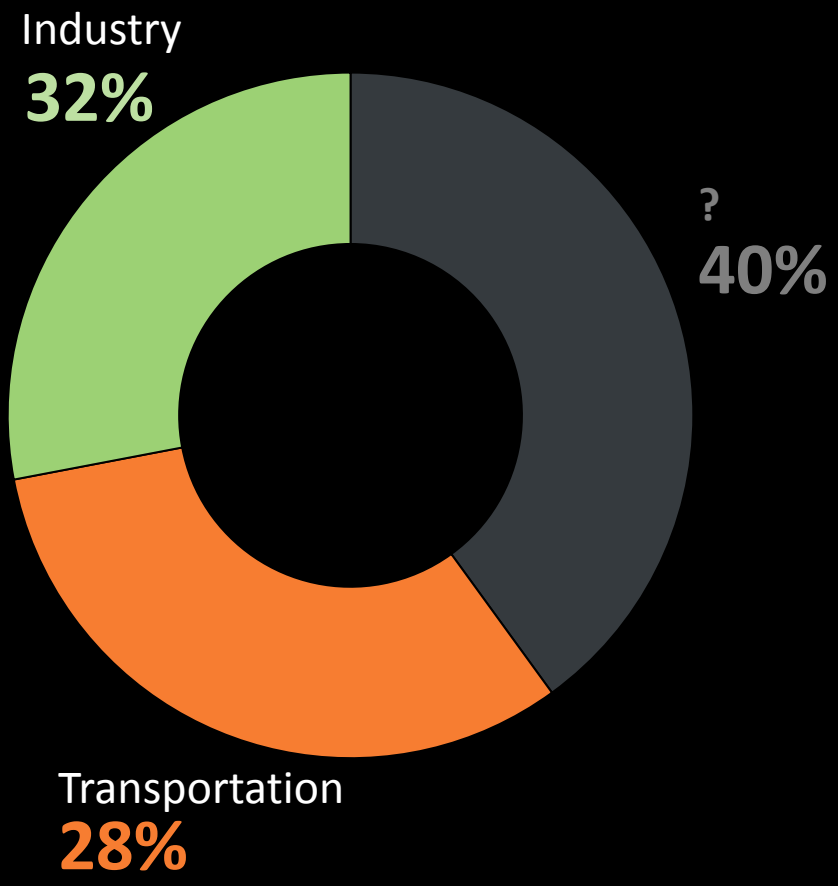
Sensors and The Built Environment

Credits: Dennis Schroeder, NREL 29603; Marjorie Schott, NREL; Abigail Carken, NREL 11348;

Where the US Energy Goes

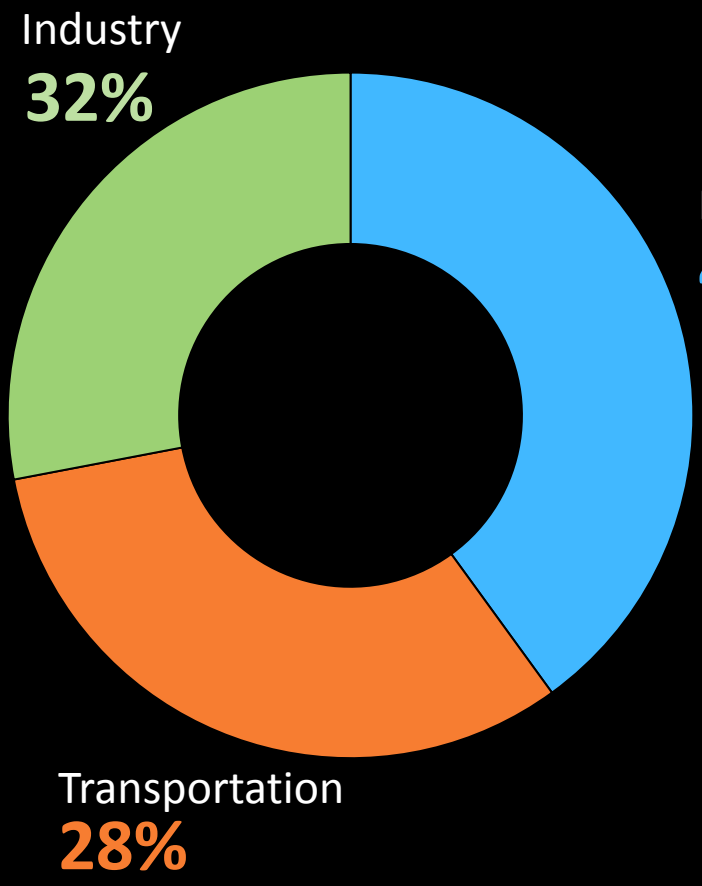


2011 Total Primary Energy Consumption: **98 Quads**

Industry:	31 Qbtu
Transportation:	27 Qbtu

Credits: Jeff Smith, NREL

Where the US Energy Goes

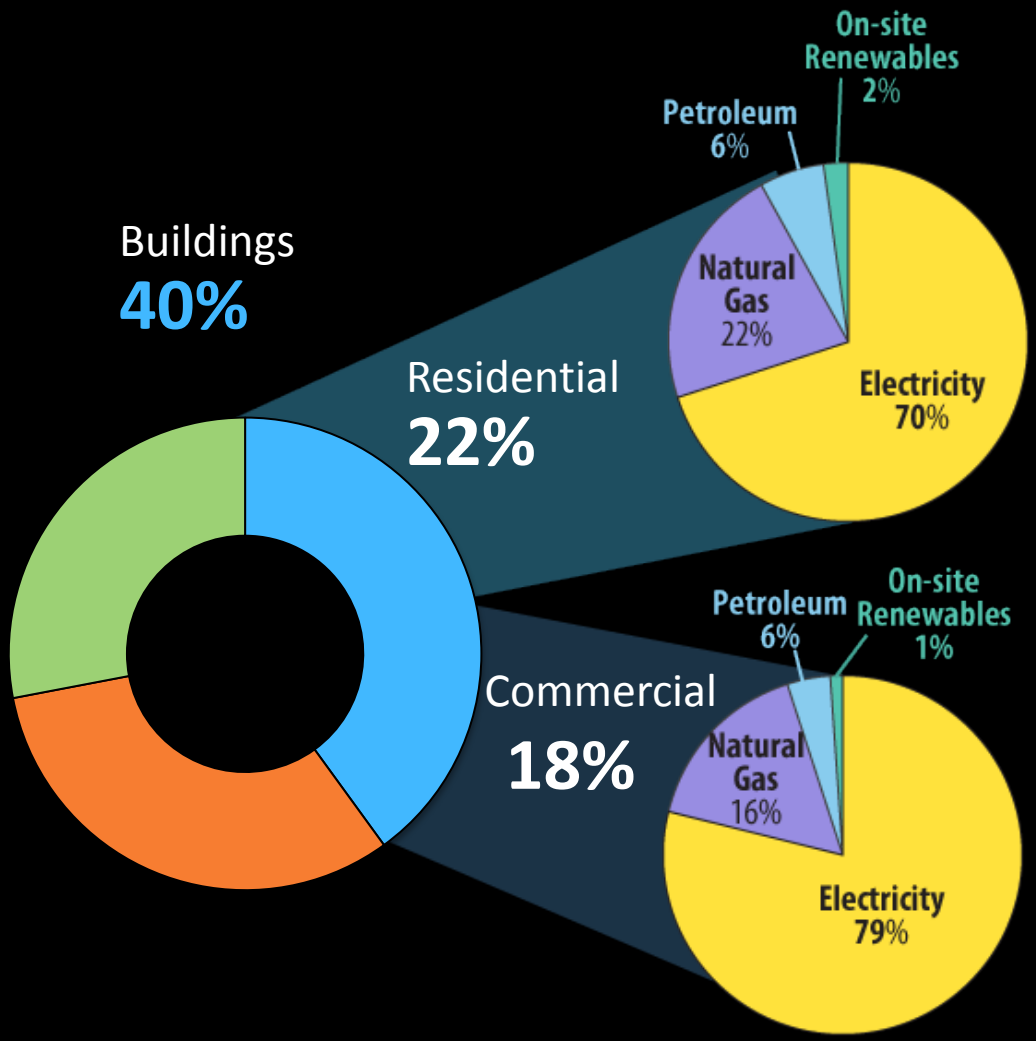


2011 Total Primary Energy Consumption: **98 Quads**

Industry:	31 Qbtu
Transportation:	27 Qbtu
Buildings:	**40 QBtu**

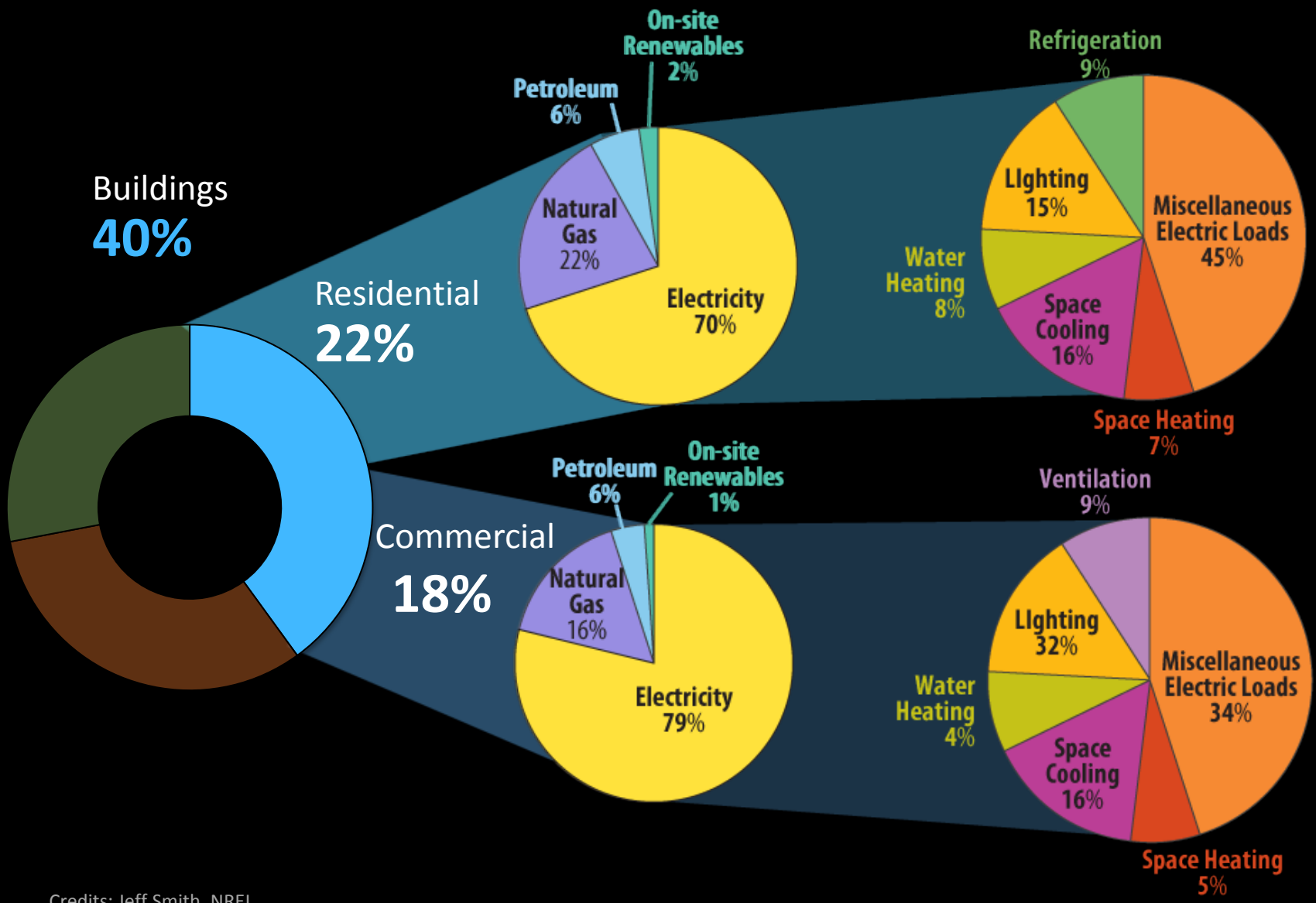
Credits: Jeff Smith, NREL

US Energy Consumption



Credits: Jeff Smith, NREL

US Energy Consumption



Credits: Jeff Smith, NREL

Market Opportunity for Building Sensors

Battlefield:

4.6 M commercial buildings smaller than 50,000 square ft. consume 9.2% of the US primary energy

4.9 M commercial buildings in US

81.1 B square ft. commercial floorspace

Source: DOE EIA CBECS, 2003, http://buildingsdatabook.eren.doe.gov

Market Opportunity

Sensors and controls for Building Energy Management Systems

- Will top $4 billion in 2020
- 18% CAGR worldwide between now and 2020
- Market growth fueled by advanced technologies, price pressure, policy

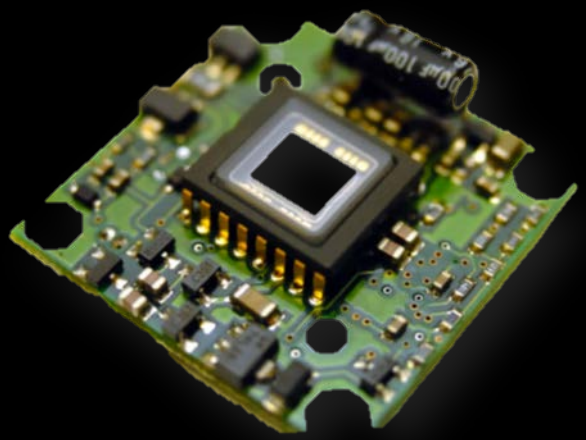
Source: Lux Research, http://www.luxresearchinc.com/news-and-events/press-releases/read/sensors-and-controls-building-energy-management-systems-top-4

Favorable Conditions for Sensors

- The US DOE on a path to boost uptake of building energy efficiency through codes and standards
- The EU on a path with similar aggressive efficiency goals (20% better efficiency by 2020)

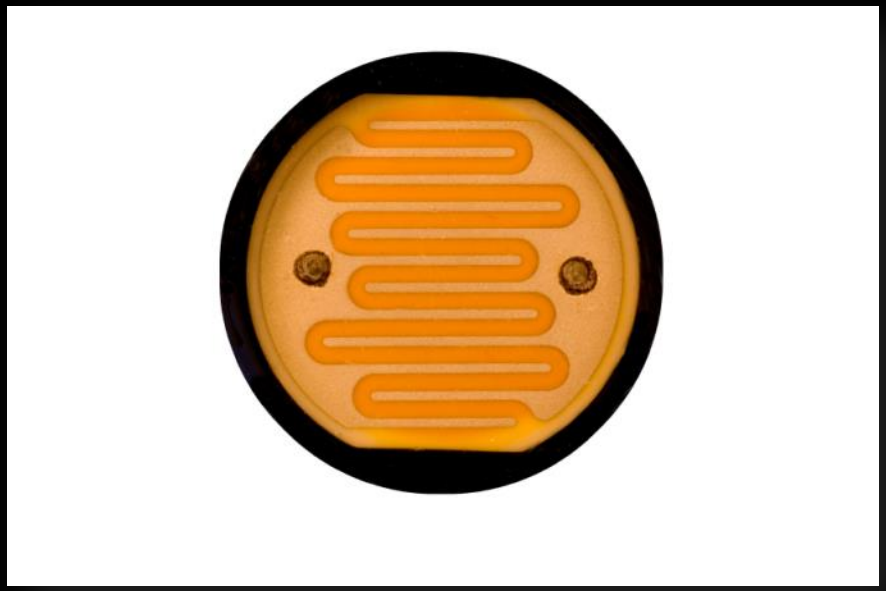
Leveraging the Market Opportunity

- Advanced, smart sensors
- Non-invasive
- Plug-and-play
- Cost effective



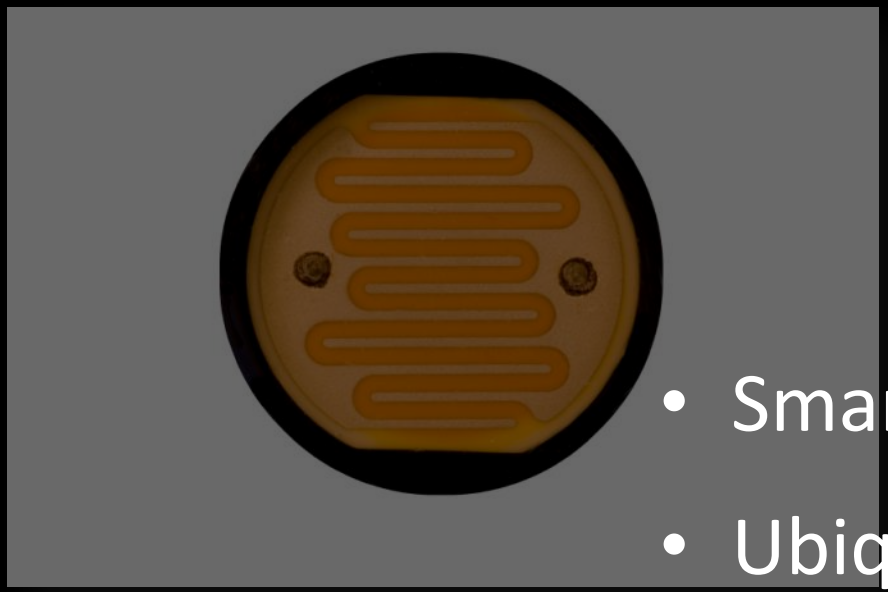
Credit: iStock

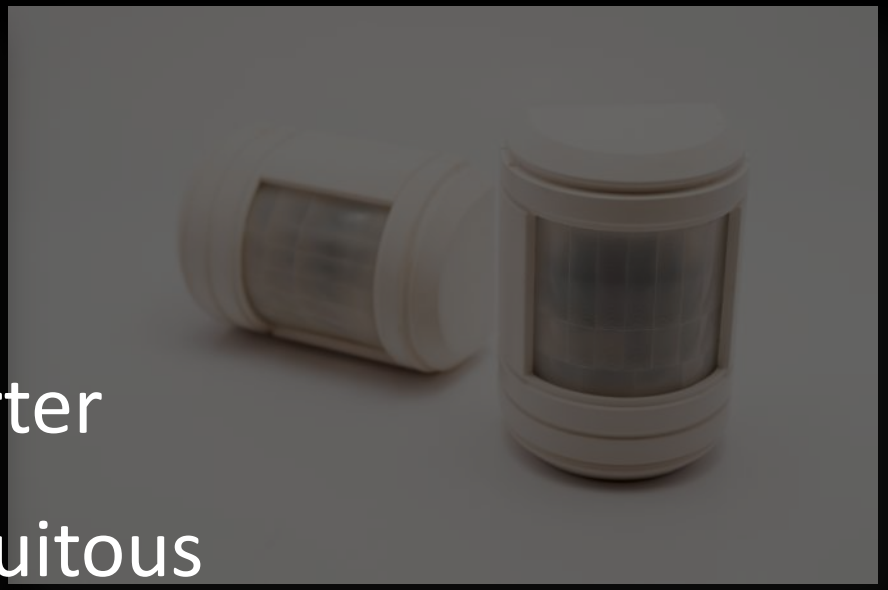
Advancing Building Sensor Technology



Credit: iStock; Credit for bottom right photo: Al Puente, NREL 01320

Advancing Building Sensor Technology

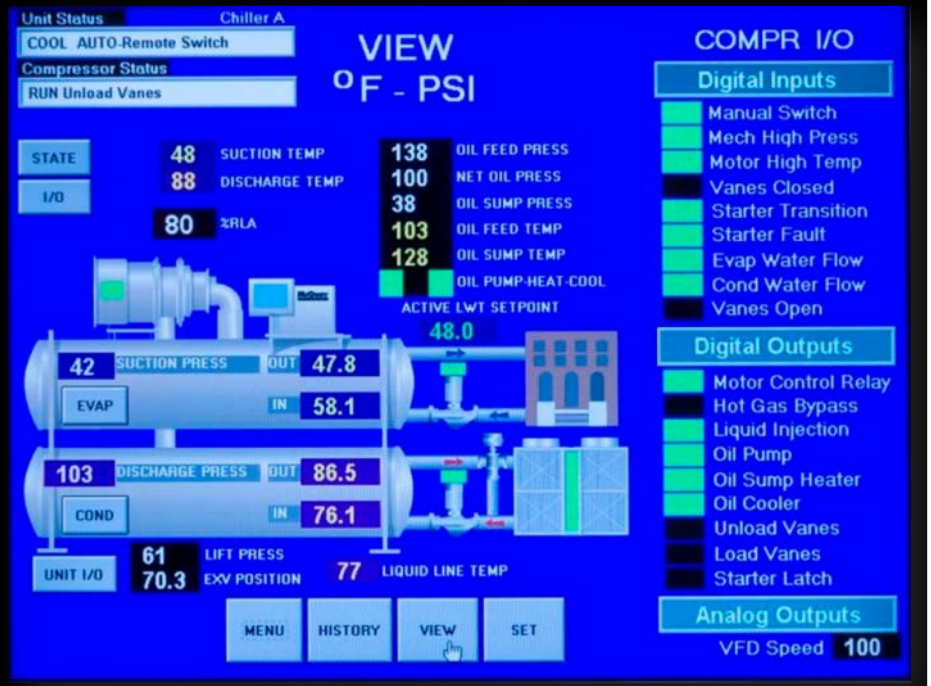




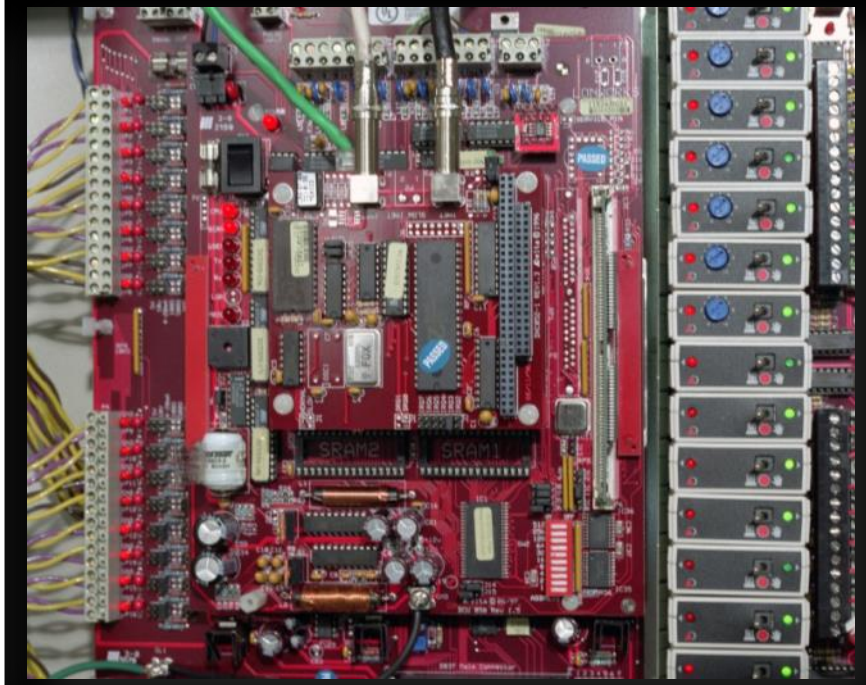
- Smarter
- Ubiquitous
- Networked

Credit: iStock; Credit for bottom right photo: Al Puente, NREL 01320

Advancing Sensor Data Analysis



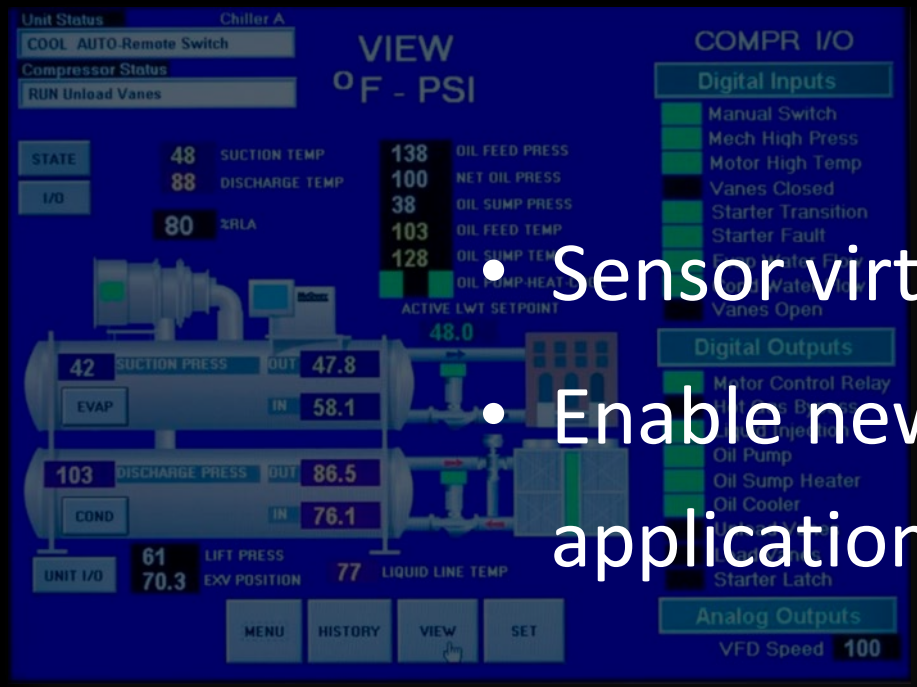
Digital readout of a chiller



Building EMS — where sensors meet controls

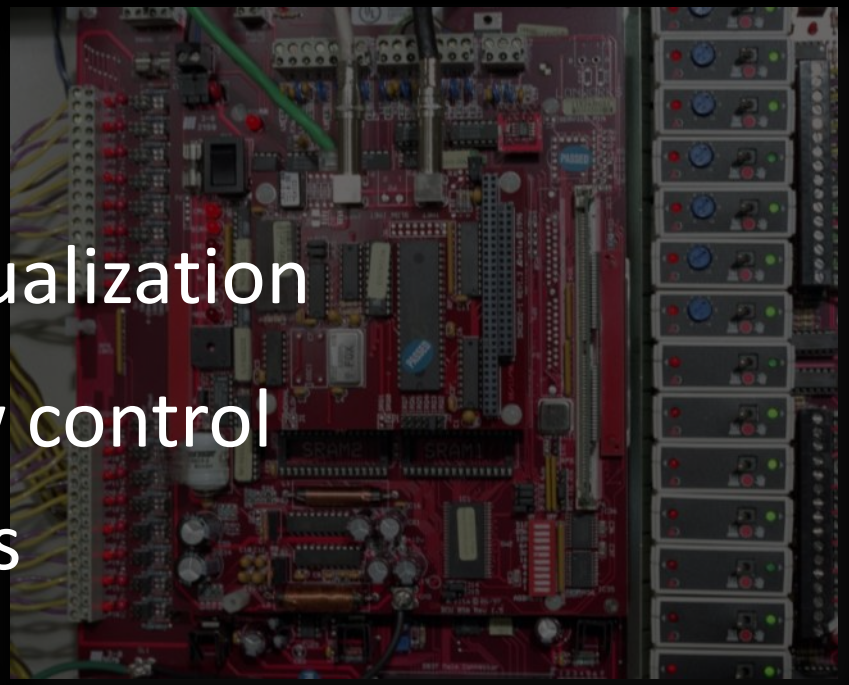
Credit left: Dennis Schroeder, NREL 21736; Credit right: Warren Gretz, NREL 12764

Advancing Sensor Data Analysis



Digital readout of a chiller

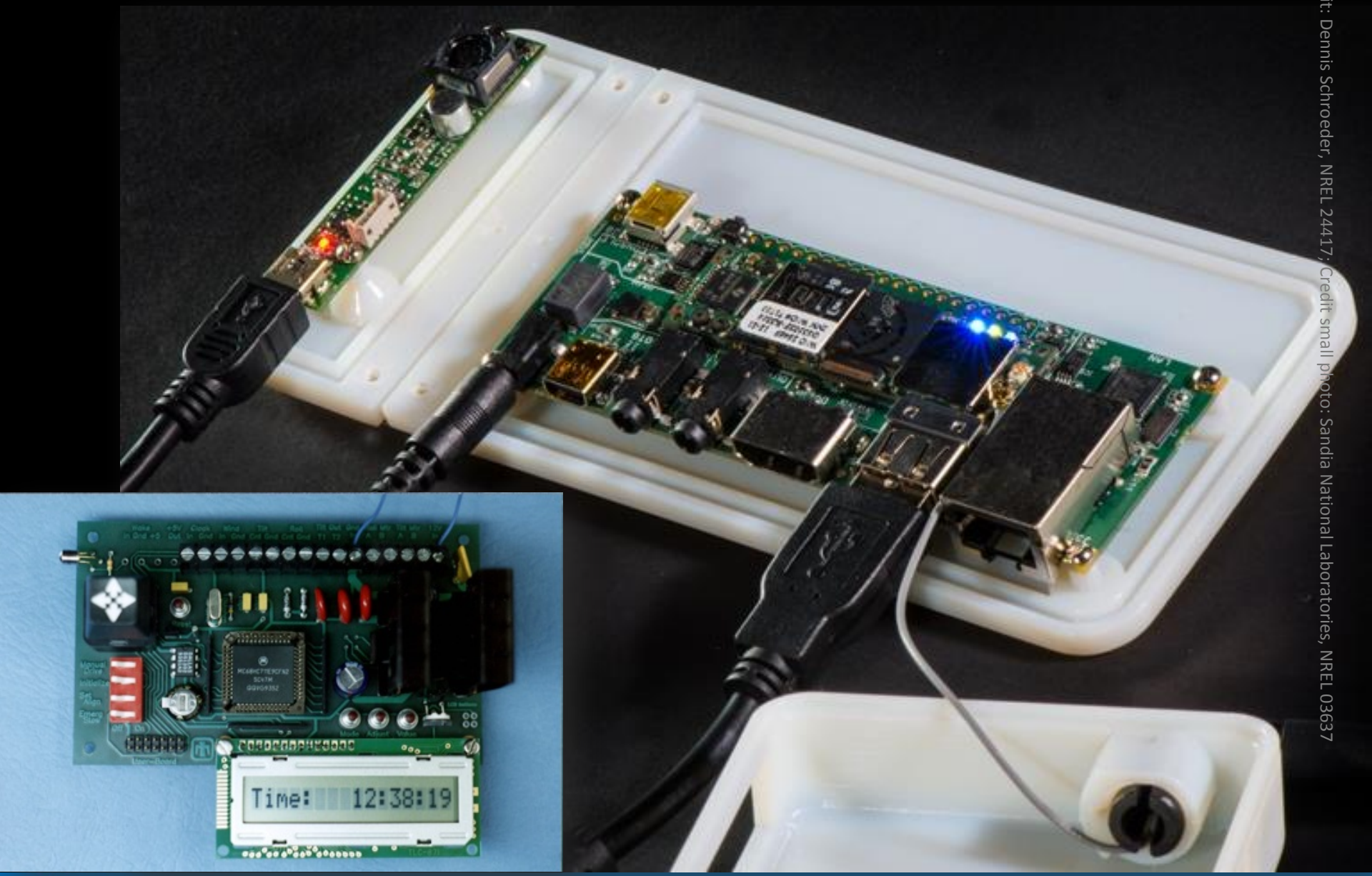
- Sensor virtualization
- Enable new control applications



Building EMS — where sensors meet controls

Credit left: Dennis Schroeder, NREL 21736; Credit right: Warren Gretz, NREL 12764

Buildings Sensor Research



Credit: Dennis Schroeder, NREL 24417; Credit small photo: Sandia National Laboratories, NREL 03637

Virtual Sensors

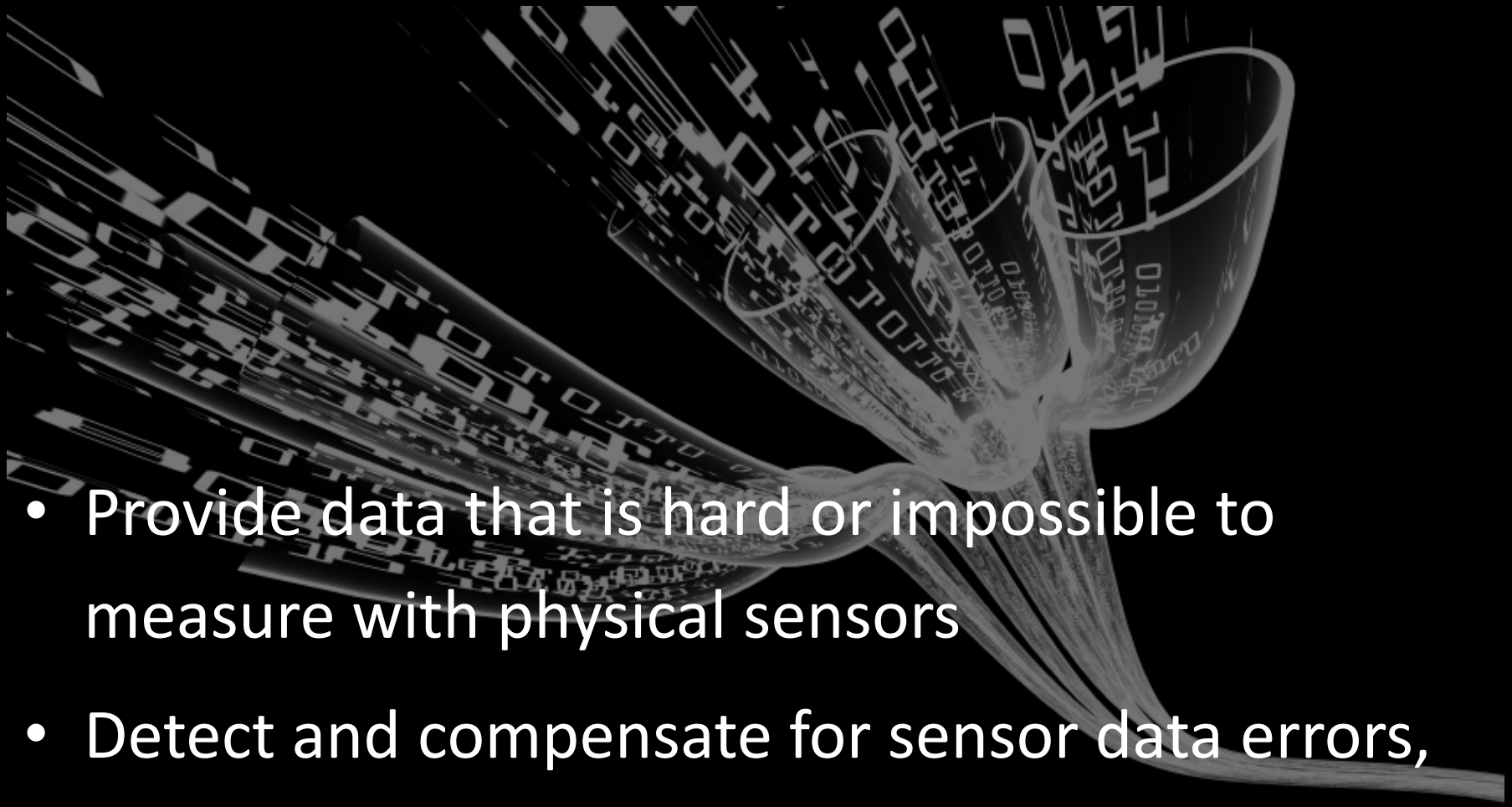


Image credit: iStock

- Provide data that is hard or impossible to measure with physical sensors
- Detect and compensate for sensor data errors, drifts, or faults occurring in harsh operating environments

Virtual Sensors

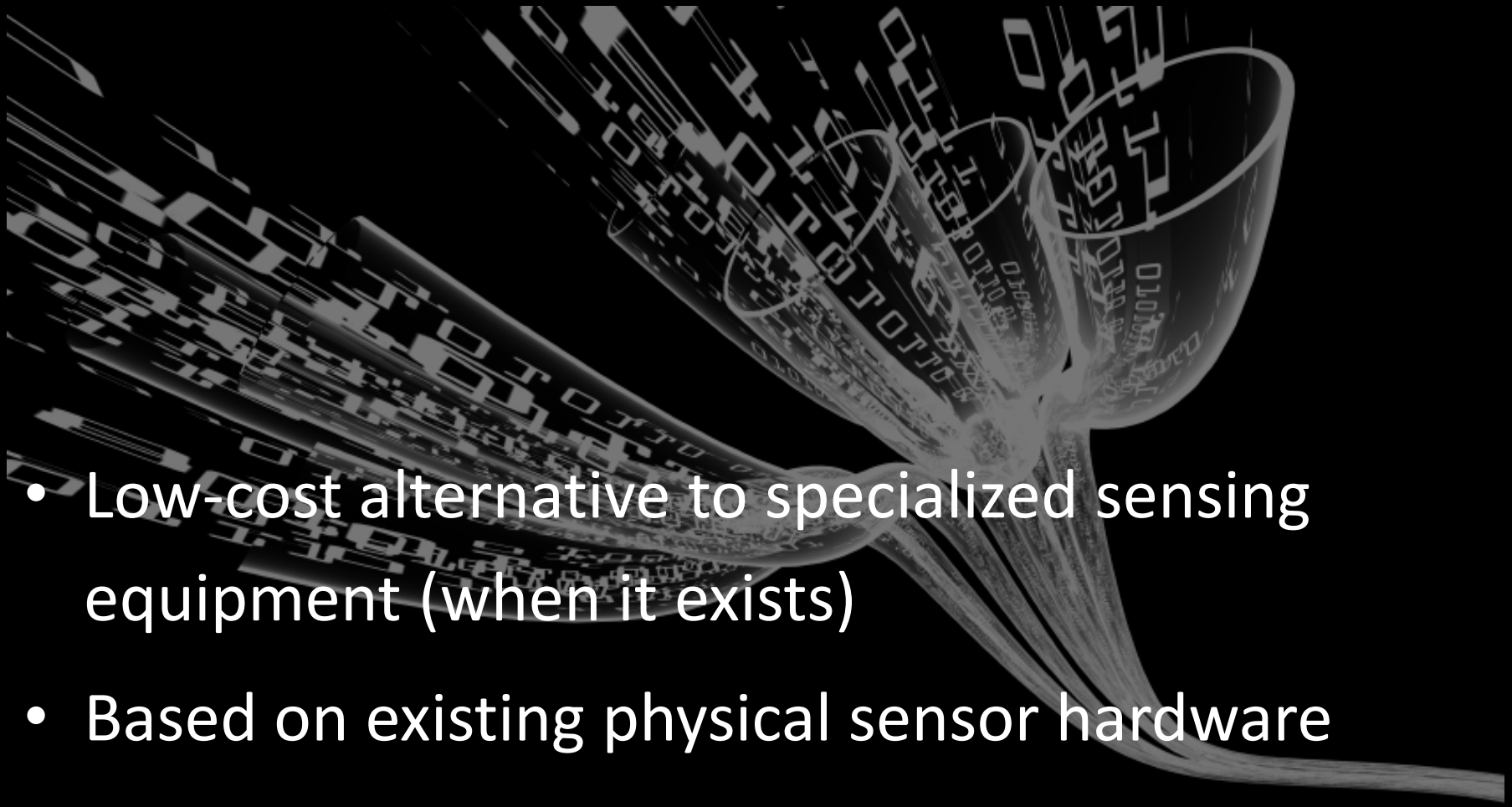
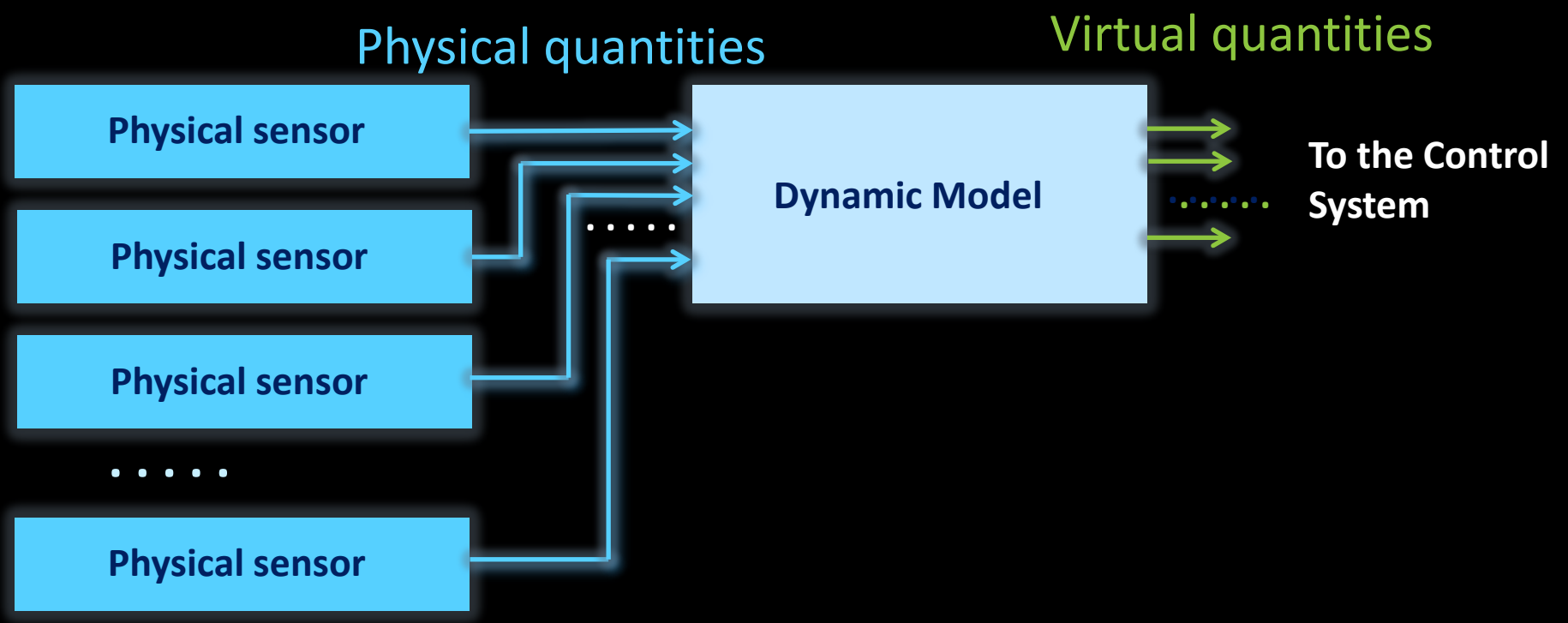


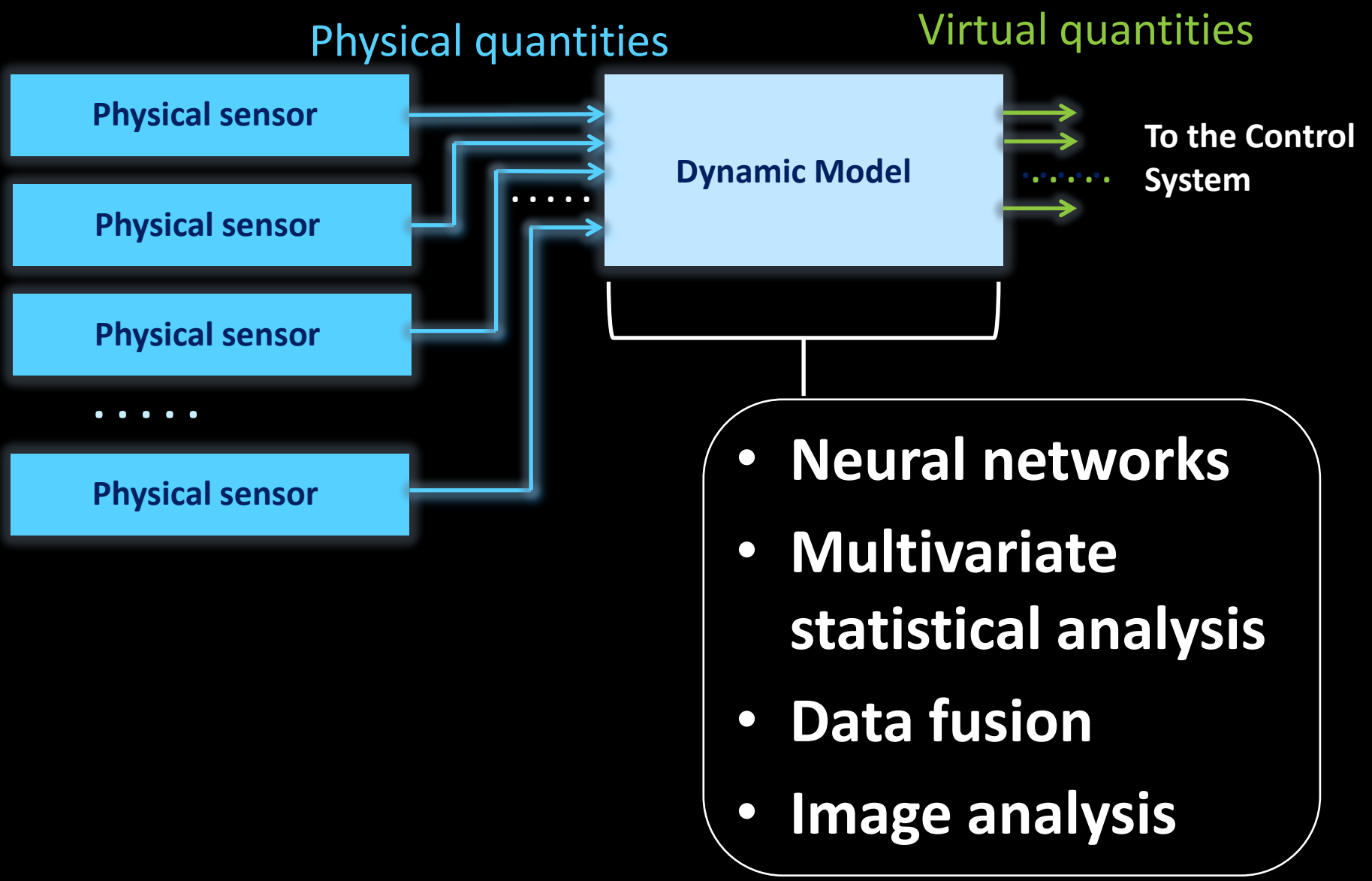
Image credit: iStock

- Low-cost alternative to specialized sensing equipment (when it exists)
- Based on existing physical sensor hardware
- Can provide real-time outputs even if physical sensors provide delayed responses

Model


Physical quantities
Virtual quantities
Physical sensor
Physical sensor
Physical sensor
Physical sensor
Dynamic Model
To the Control System

Model


Physical quantities
Virtual quantities
Physical sensor
Physical sensor
Physical sensor
Physical sensor
Dynamic Model
To the Control System
• Neural networks
• Multivariate statistical analysis
• Data fusion
• Image analysis

Ventilation & Indoor Air Quality

Credit: iStock

Ventilation & Indoor Air Quality

Credit: iStock

- Conventional CO_2 sensors expensive, slow, error prone
- Solution?

Ventilation & Indoor Air Quality

Credit: iStock

- **Conventional CO_2 sensors expensive, slow, error prone**
- **Solution?** A CO_2 virtual sensor

CO_2 Virtual Sensor

Sensors: the building Wi-Fi access points and routers infrastructure

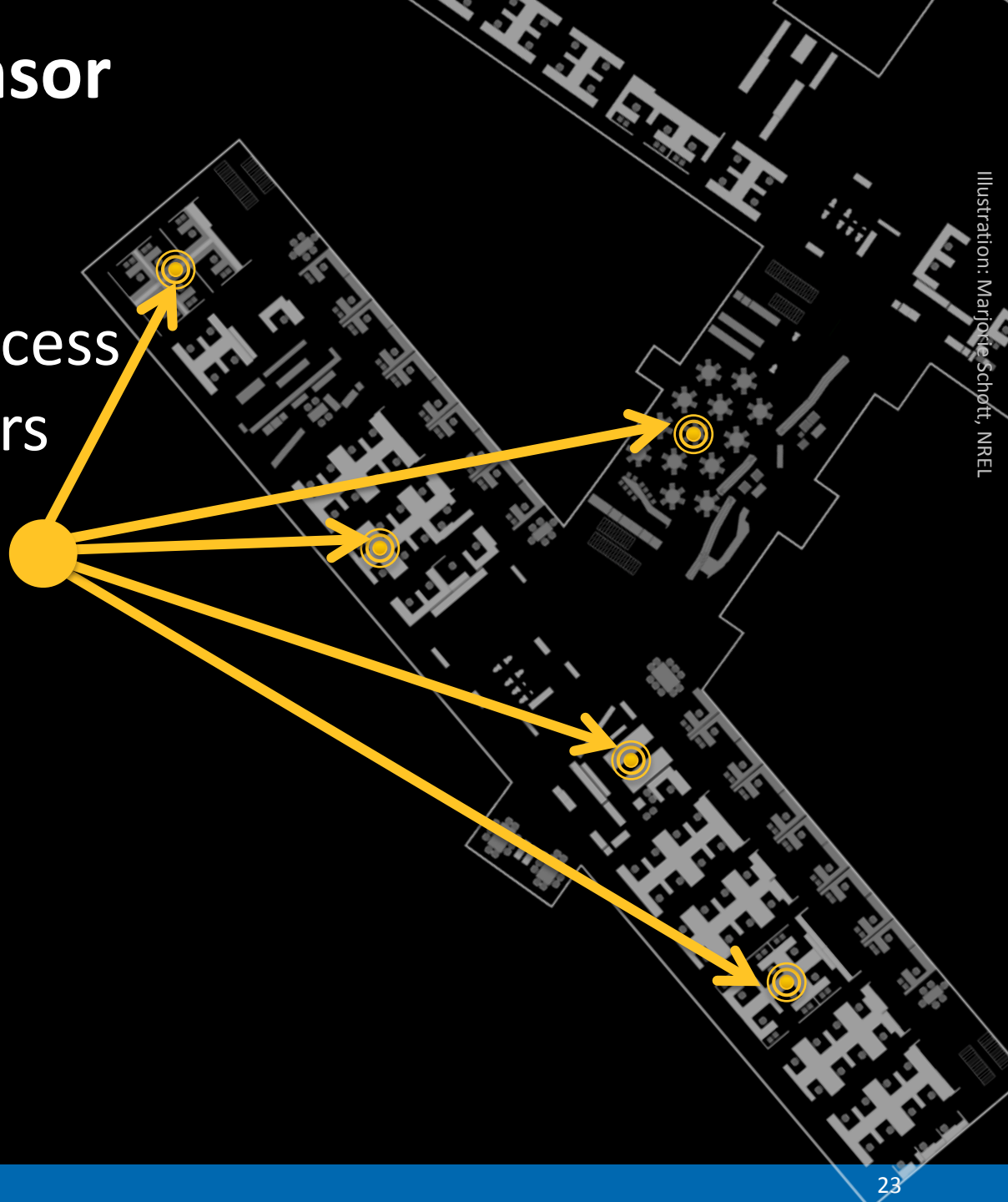
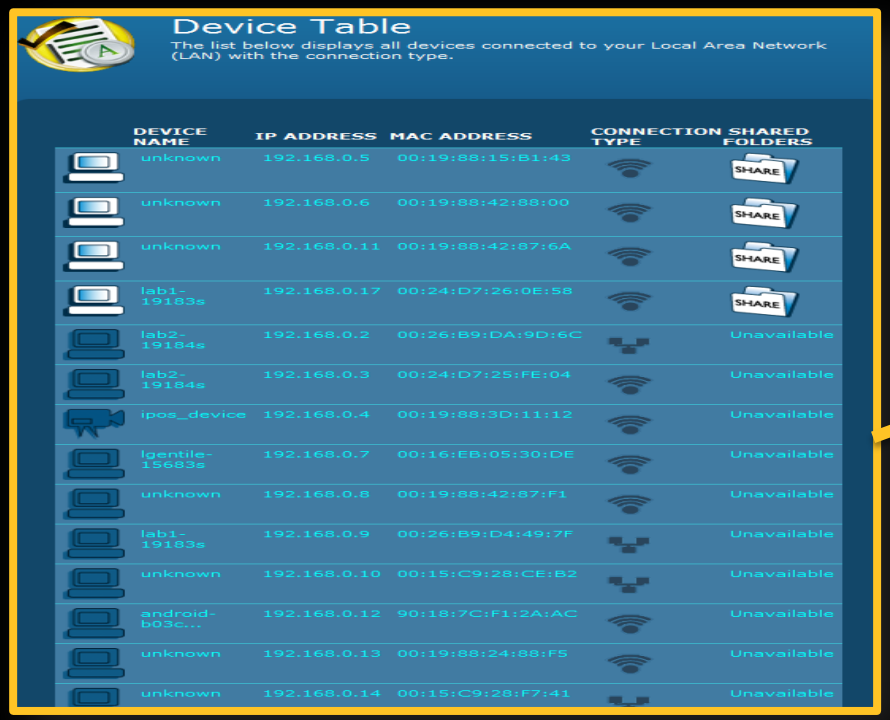


Illustration: Marjorie Schott, NREL

CO_2 Virtual Sensor

Sensors: the building Wi-Fi access points and routers infrastructure



Device Table

The list below displays all devices connected to your Local Area Network (LAN) with the connection type.

DEVICE NAME	IP ADDRESS	MAC ADDRESS	CONNECTION TYPE	SHARED FOLDERS
unknown	192.168.0.5	00:19:88:15:B1:43		SHARE
unknown	192.168.0.6	00:19:88:42:88:00		SHARE
unknown	192.168.0.11	00:19:88:42:87:6A		SHARE
lab1-19183s	192.168.0.17	00:24:D7:26:0E:58		SHARE
lab2-19184s	192.168.0.2	00:26:B9:DA:9D:6C		Unavailable
lab2-19184s	192.168.0.3	00:24:D7:25:FE:04		Unavailable
ipos_device	192.168.0.4	00:19:88:3D:11:12		Unavailable
lgentile-15683s	192.168.0.7	00:16:EB:05:30:DE		Unavailable
unknown	192.168.0.8	00:19:88:42:87:F1		Unavailable
lab1-19183s	192.168.0.9	00:26:B9:D4:49:7F		Unavailable
unknown	192.168.0.10	00:15:C9:28:CE:B2		Unavailable
android-b03c...	192.168.0.12	90:18:7C:F1:2A:AC		Unavailable
unknown	192.168.0.13	00:19:88:24:88:F5		Unavailable
unknown	192.168.0.14	00:15:C9:28:F7:41		Unavailable

Illustration: Marjorie Schott, NREL; picture at left: Luigi Gentile Polese, NREL

CO_2 Virtual Sensor

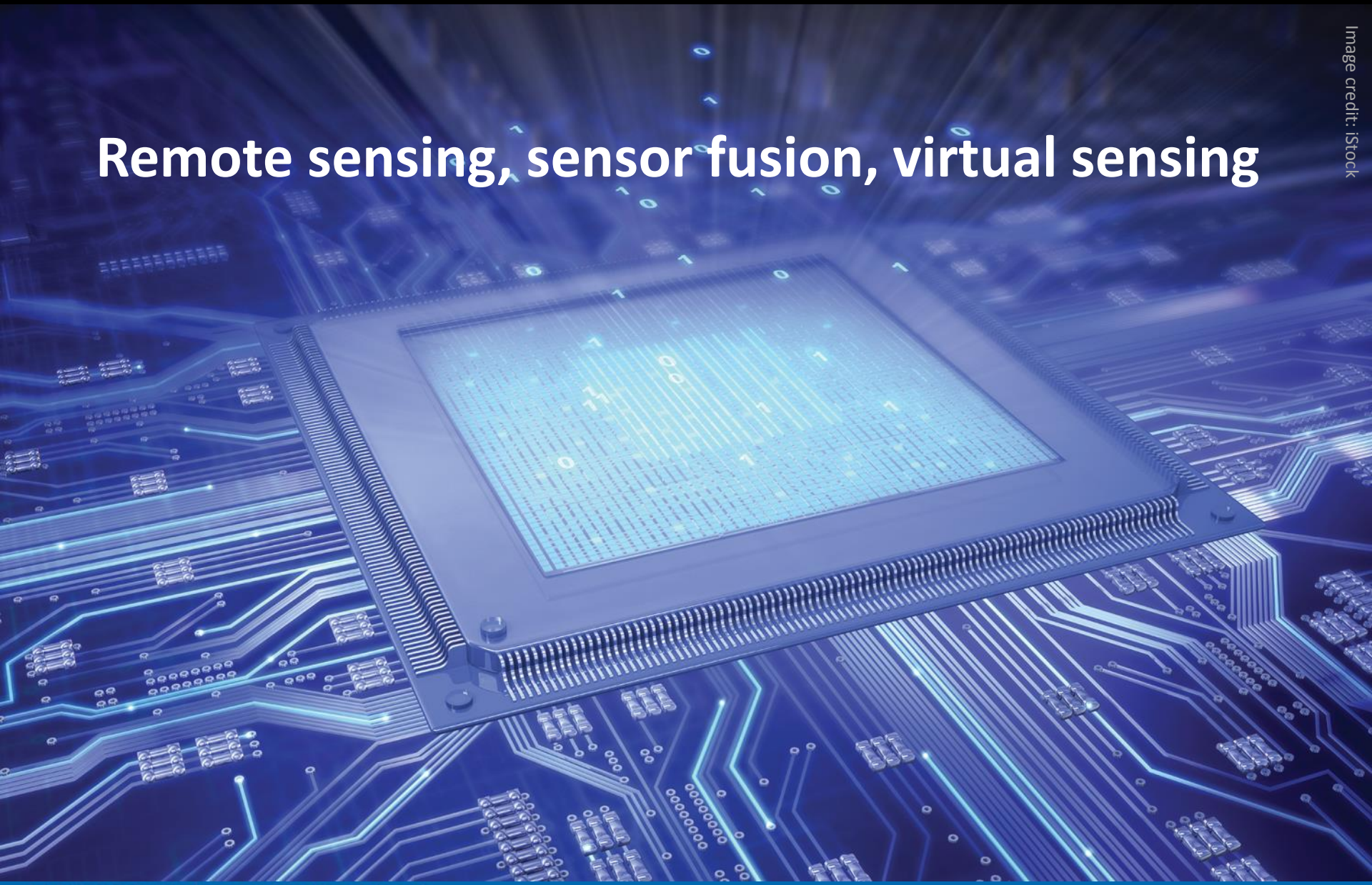
Sensors: the building Wi-Fi access points and routers infrastructure

Sense what? mobile devices

Credit: NREL 24505

Illustration: Marjorie Schott, NREL

Image Sensors



Market Opportunity

Image credit: iStock

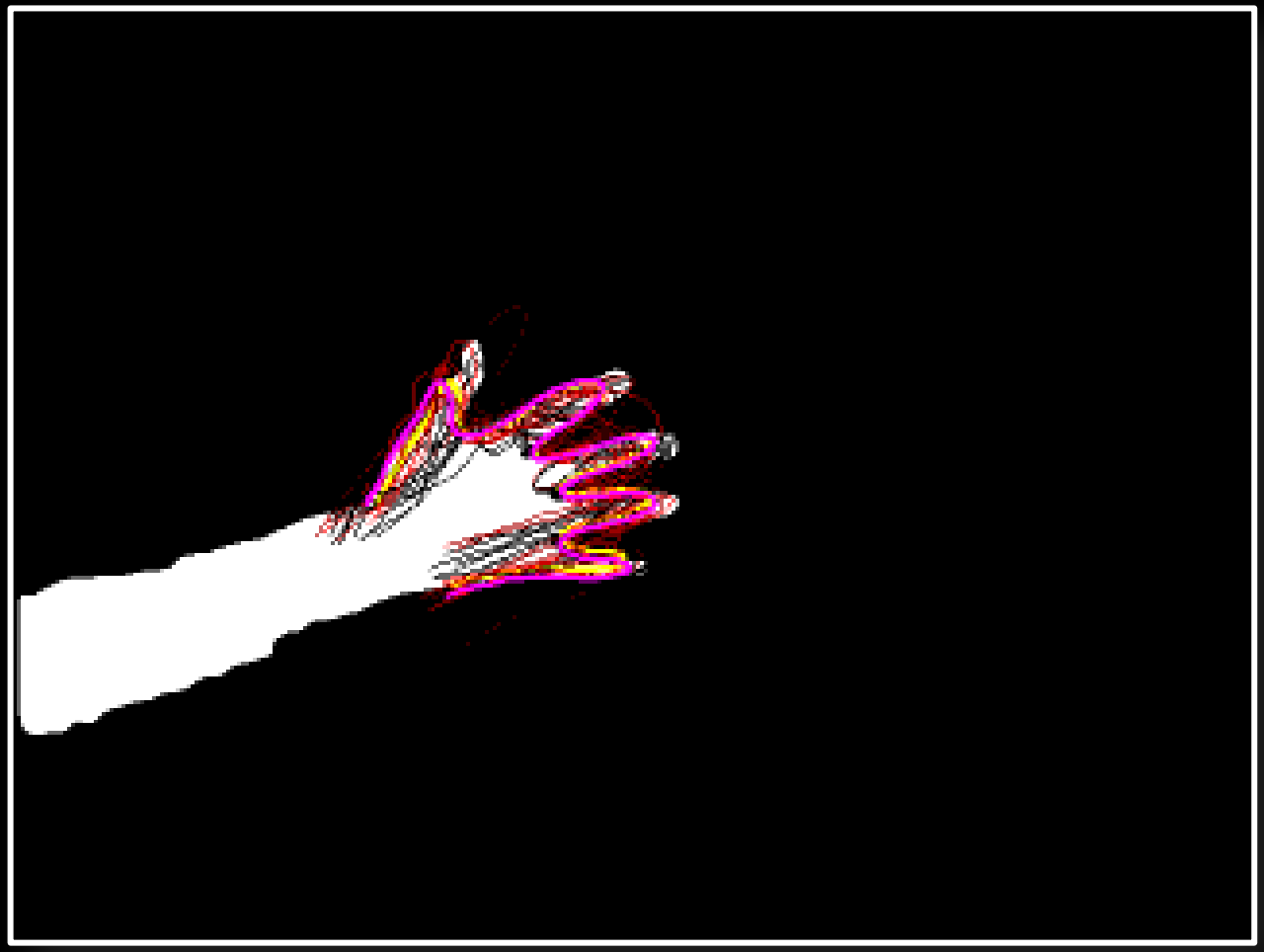
Automotive:

- Lane Assist
- Self Parking
- Drowsiness Alert
- Customized Driver Settings (seat, rear & side mirrors, …)

Gesture Recognition Sensors

Image credit: iStock

Gesture Recognition Sensors



Credit: Roy Shilkrot, MIT Media Lab
http://www.morethantechnical.com/2013/05/26/extending-the-hand-tracker-with-snakes-and-optimizations-w-code-opencv/

Augmented Reality Sensors

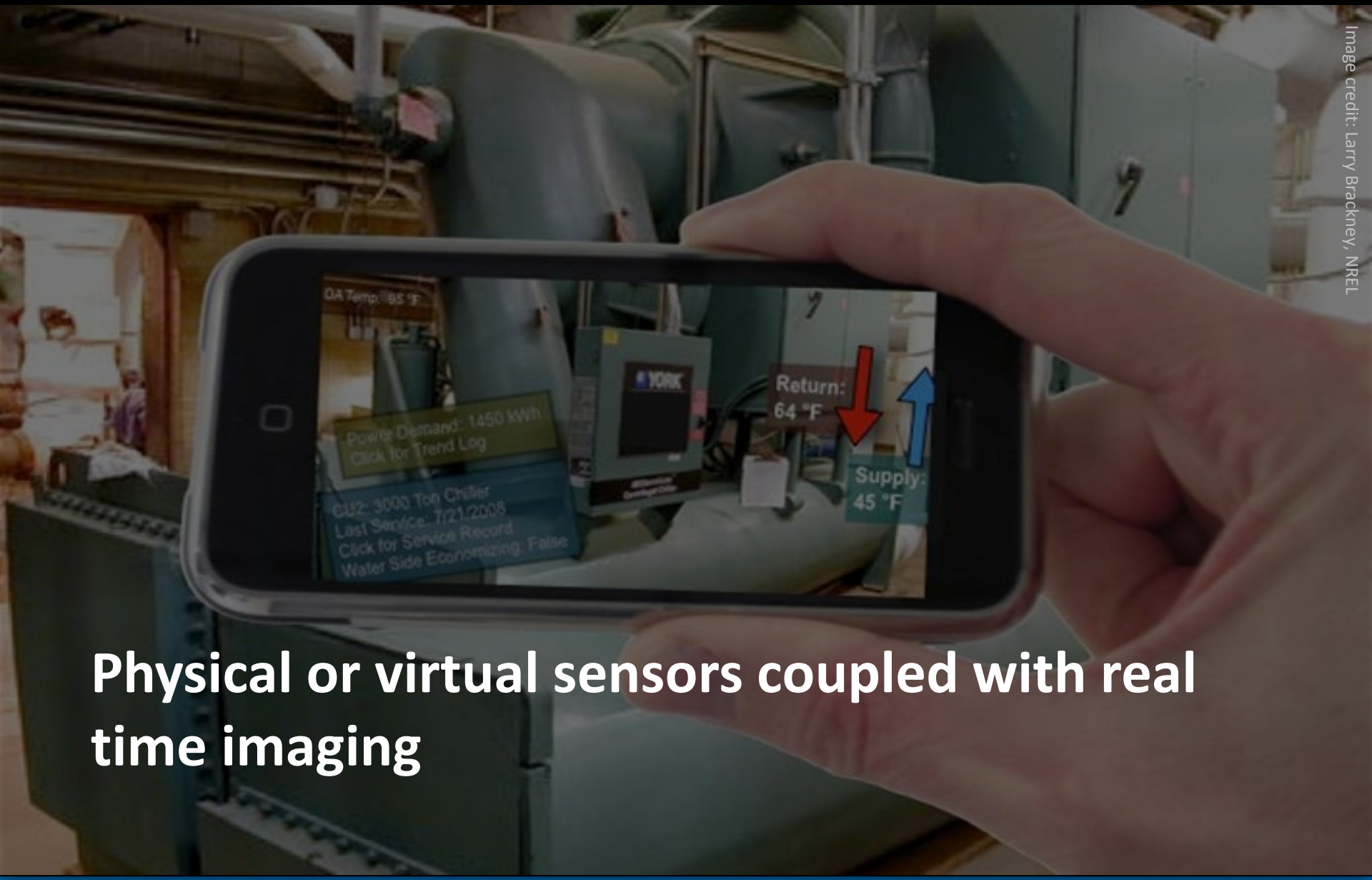


Image credit: Larry Brackney, NREL

Physical or virtual sensors coupled with real time imaging

Lighting System M&V

Image credit: Larry Brackney, NREL

Ventilation Flow Diagnostics

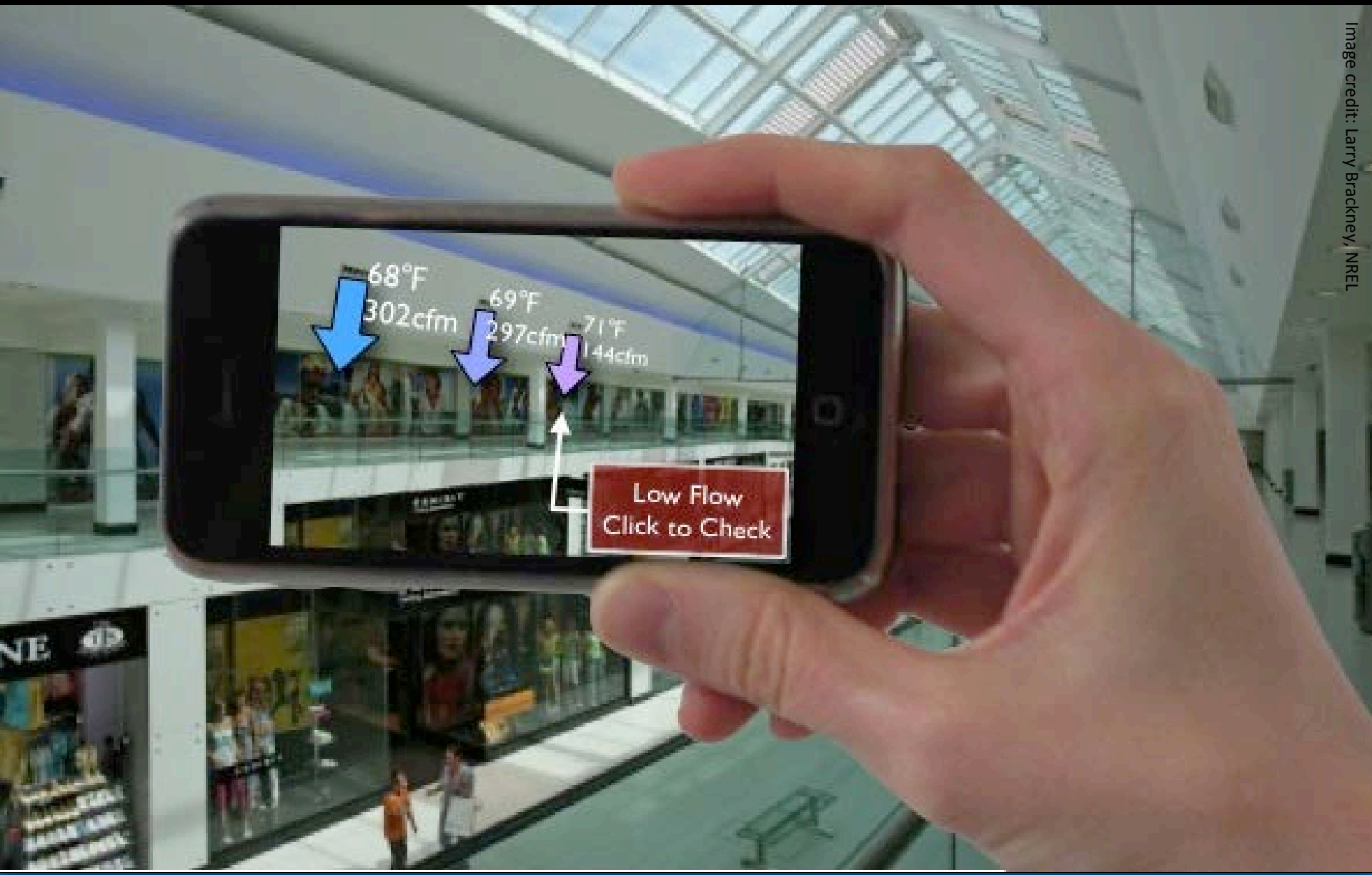
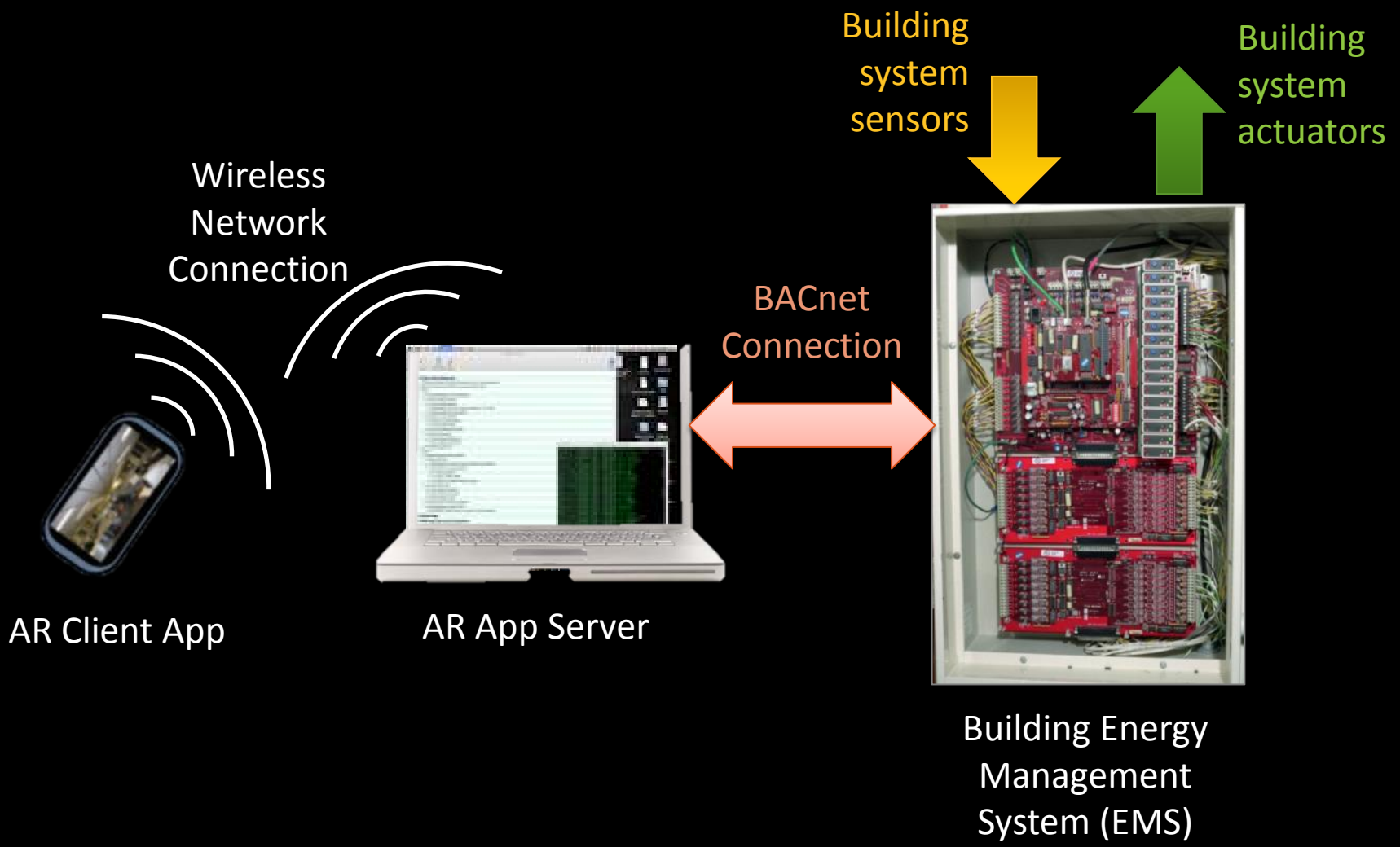


Image credit: Larry Brackney, NREL

AR Sensor Architecture for Buildings Apps

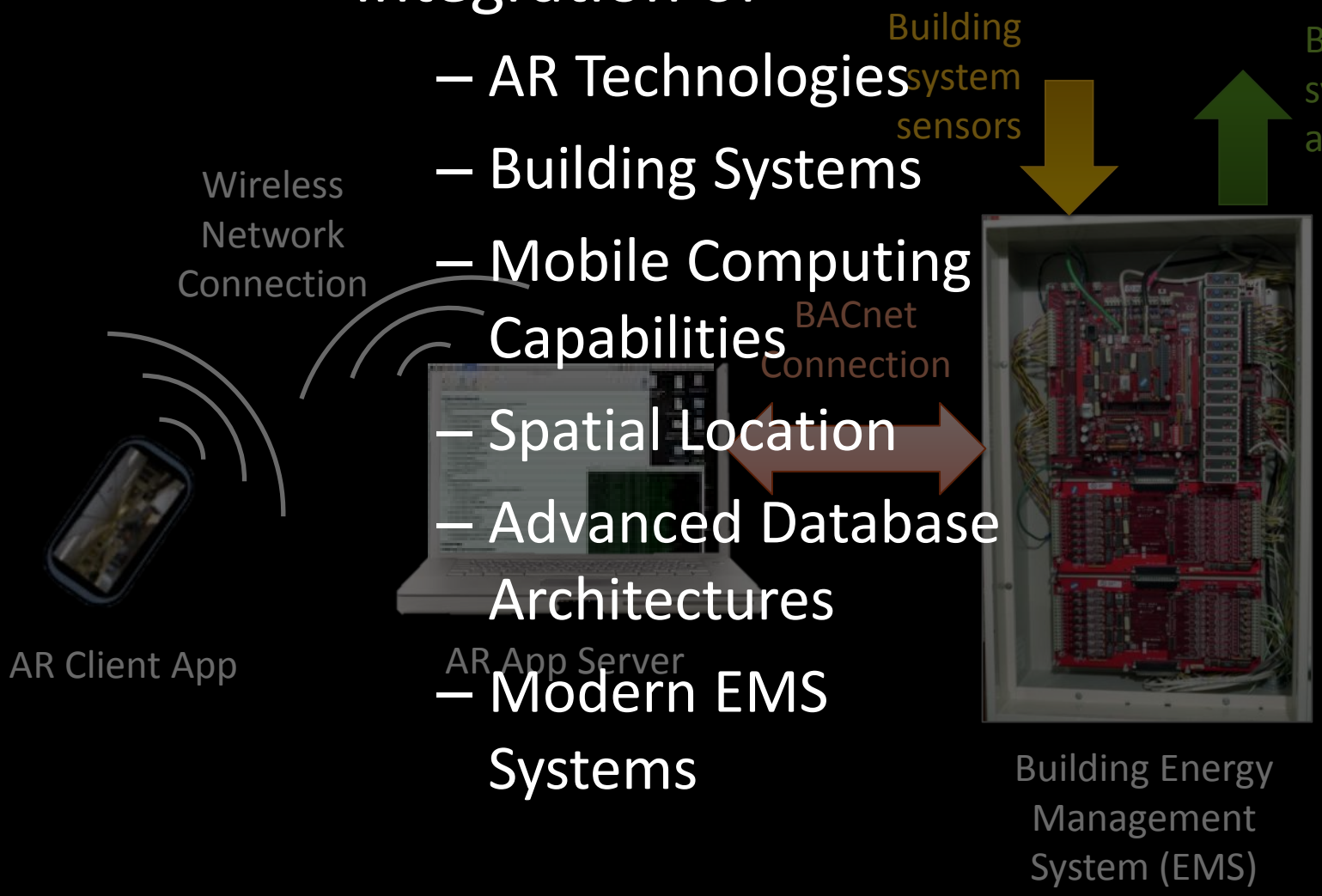


Phone Image: Larry Brackney, NREL; Computer: iStock; Control Panel: Warren Gretz, NREL 12762

AR Sensor Architecture for Buildings Apps

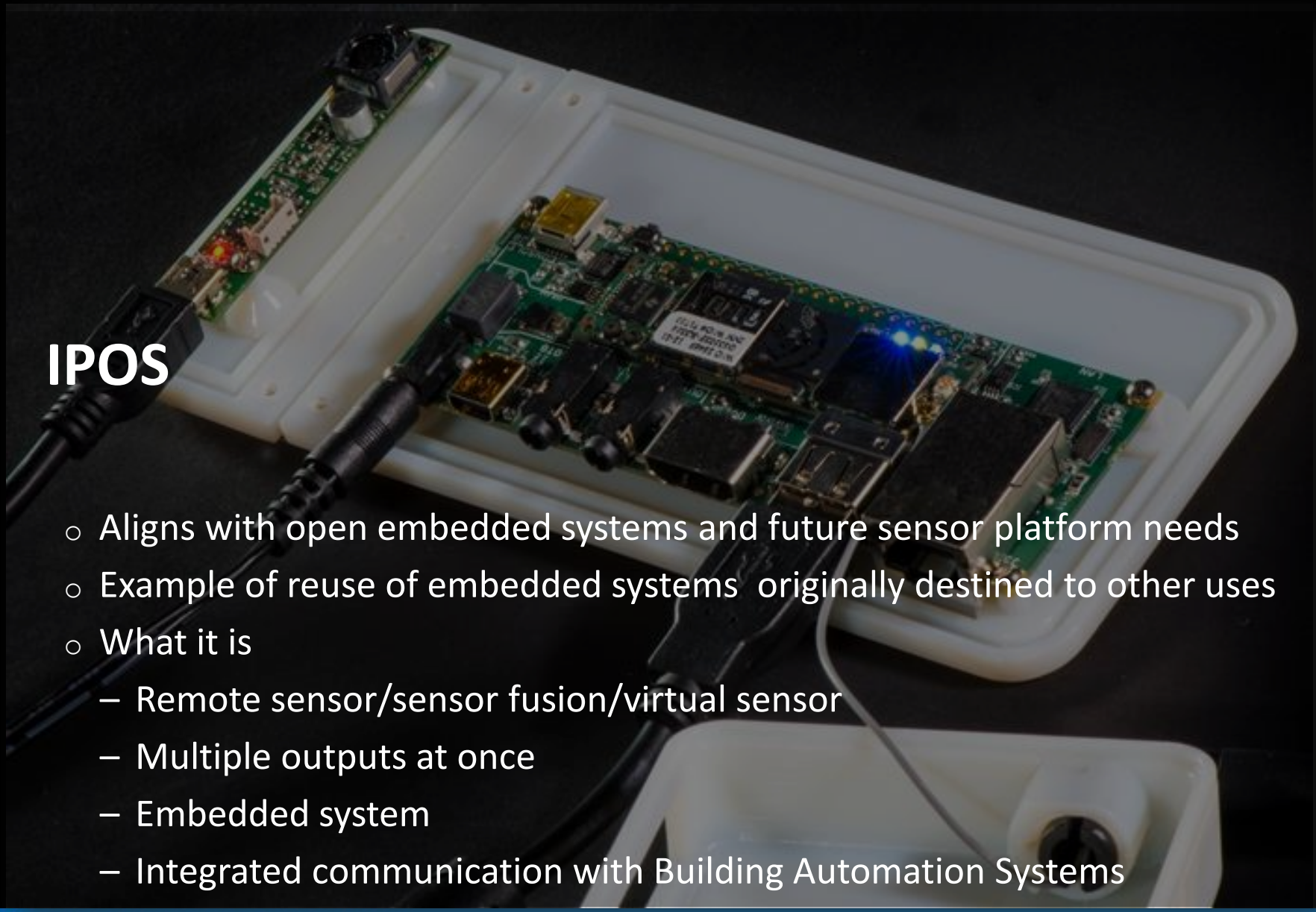
Integration of

- AR Technologies
- Building Systems
- Mobile Computing Capabilities
- Spatial Location
- Advanced Database Architectures
- Modern EMS Systems



Phone Image: Larry Brackney, NREL; Computer: iStock; Control Panel: Warren Gretz, NREL 12762

Image Processing Occupancy Sensor



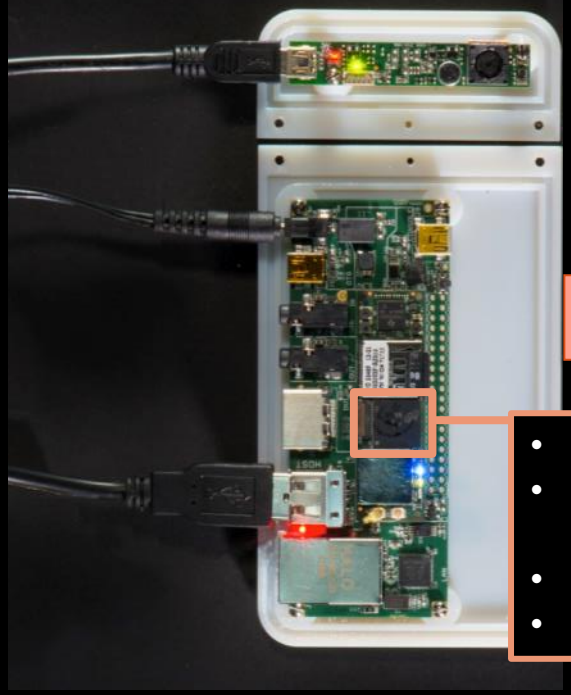
Credit: Dennis Schroeder, NREL 24417

IPOS

- Aligns with open embedded systems and future sensor platform needs
- Example of reuse of embedded systems originally destined to other uses
- What it is
  - Remote sensor/sensor fusion/virtual sensor
  - Multiple outputs at once
  - Embedded system
  - Integrated communication with Building Automation Systems

Image Processing Occupancy Sensor

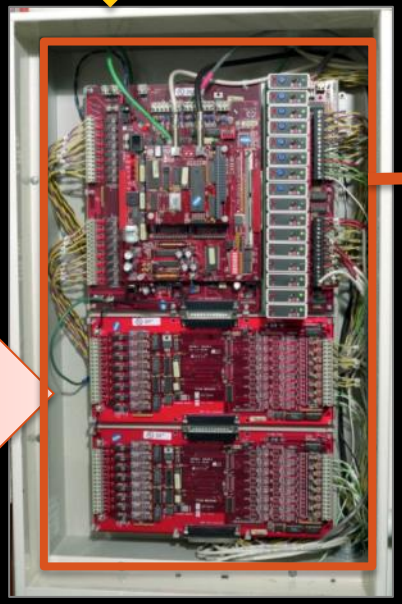
IPOS



- Open Embedded OS
- OpenCV Computer Vision Library
- Open BACnet Comms
- IPOS Algorithms

Building system sensors

Building system actuators



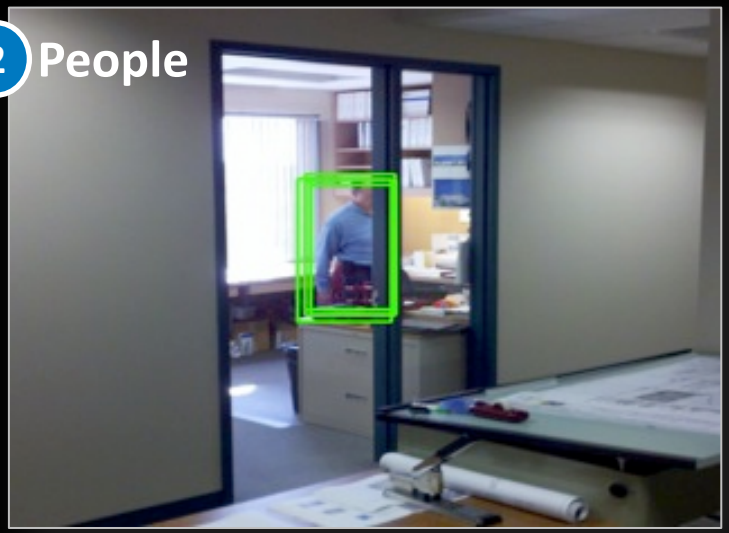
Building Energy Management System (EMS)

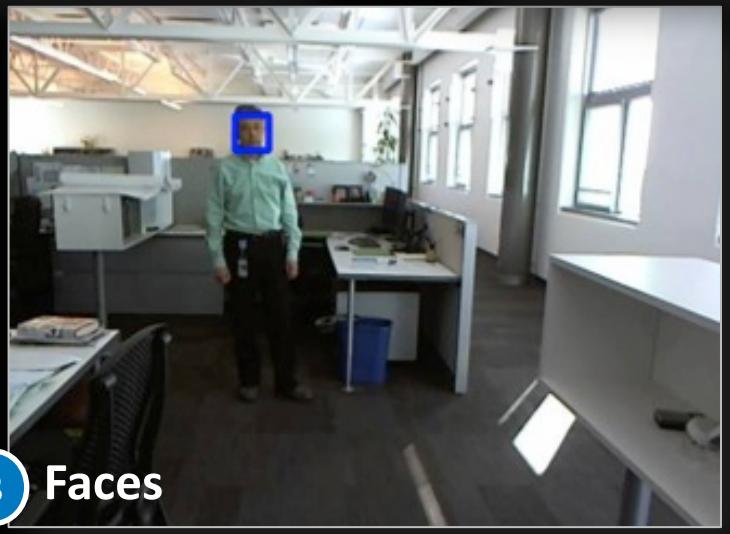
Robust Algorithms for Finely Grained:

- Lighting Controls
- Daylighting
- Set Point Management
- Demand Controlled Ventilation

Top and bottom left: Dennis Schroeder, 24420, 24418 NREL; Control Panel: Warren Gretz, NREL 12762

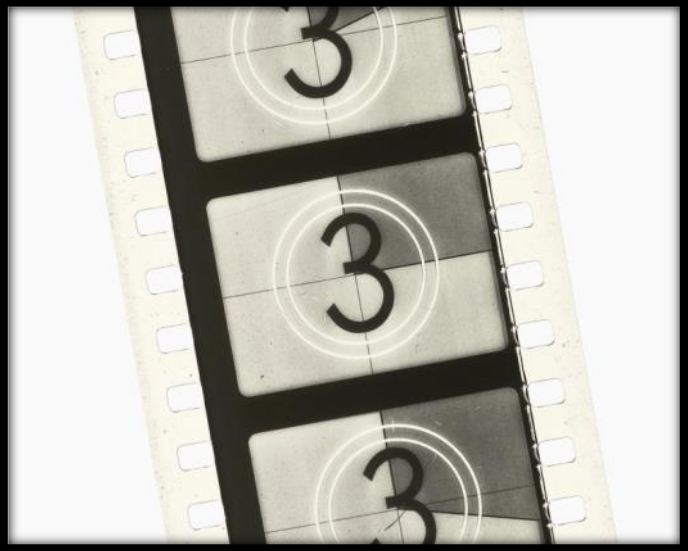
IPOS: Fusion of Image Sensing





Top images: Alex Swindler, NREL; Bottom image: Luigi Gentile Polese, NREL

Motion Analysis

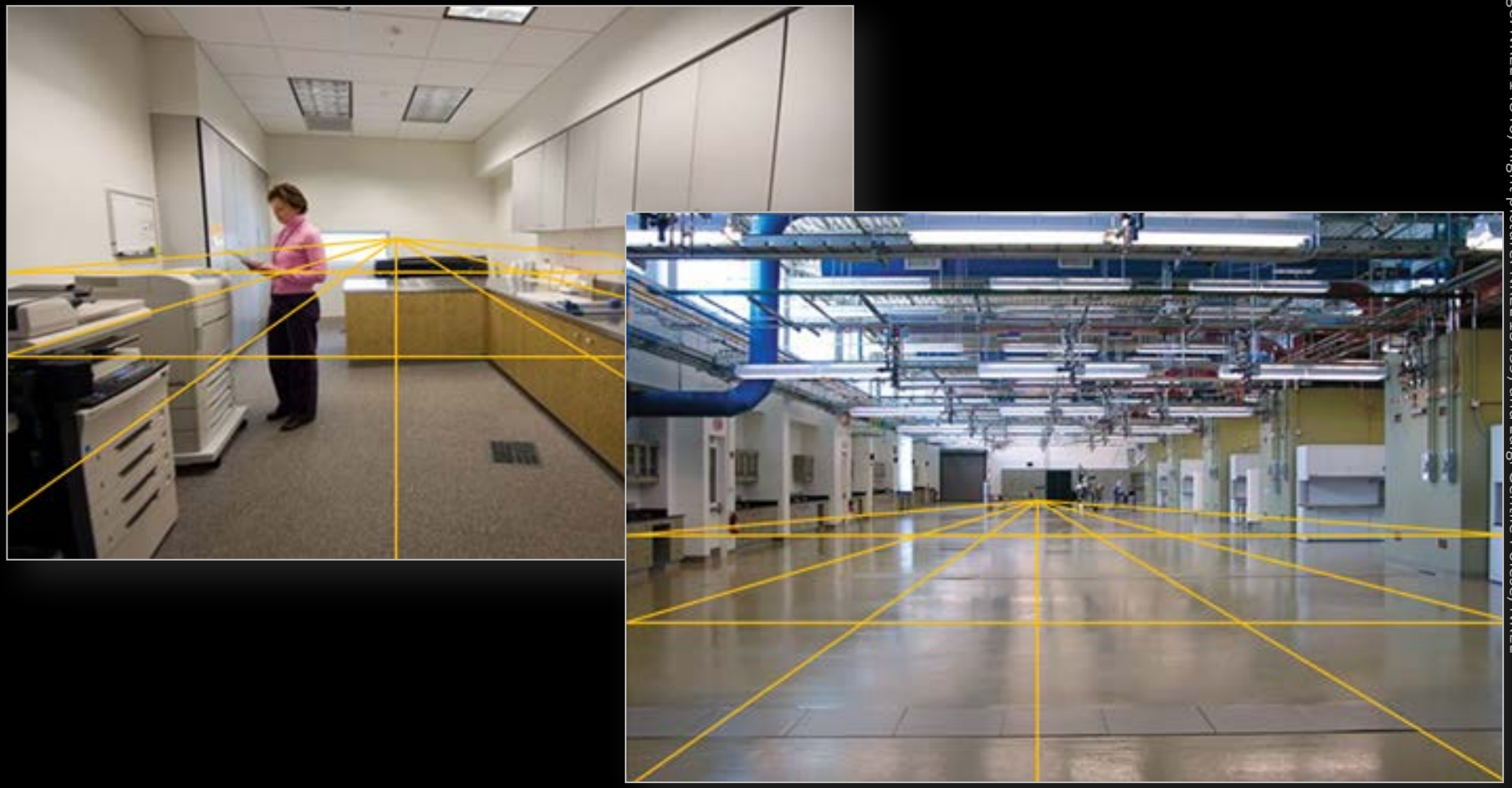


Illuminance and Location Awareness

Credits: Luigi Gentile Polese, NREL

Sensor in a Sensor

IPOS Image segmentation/multiple zones
Simultaneous virtual sensing

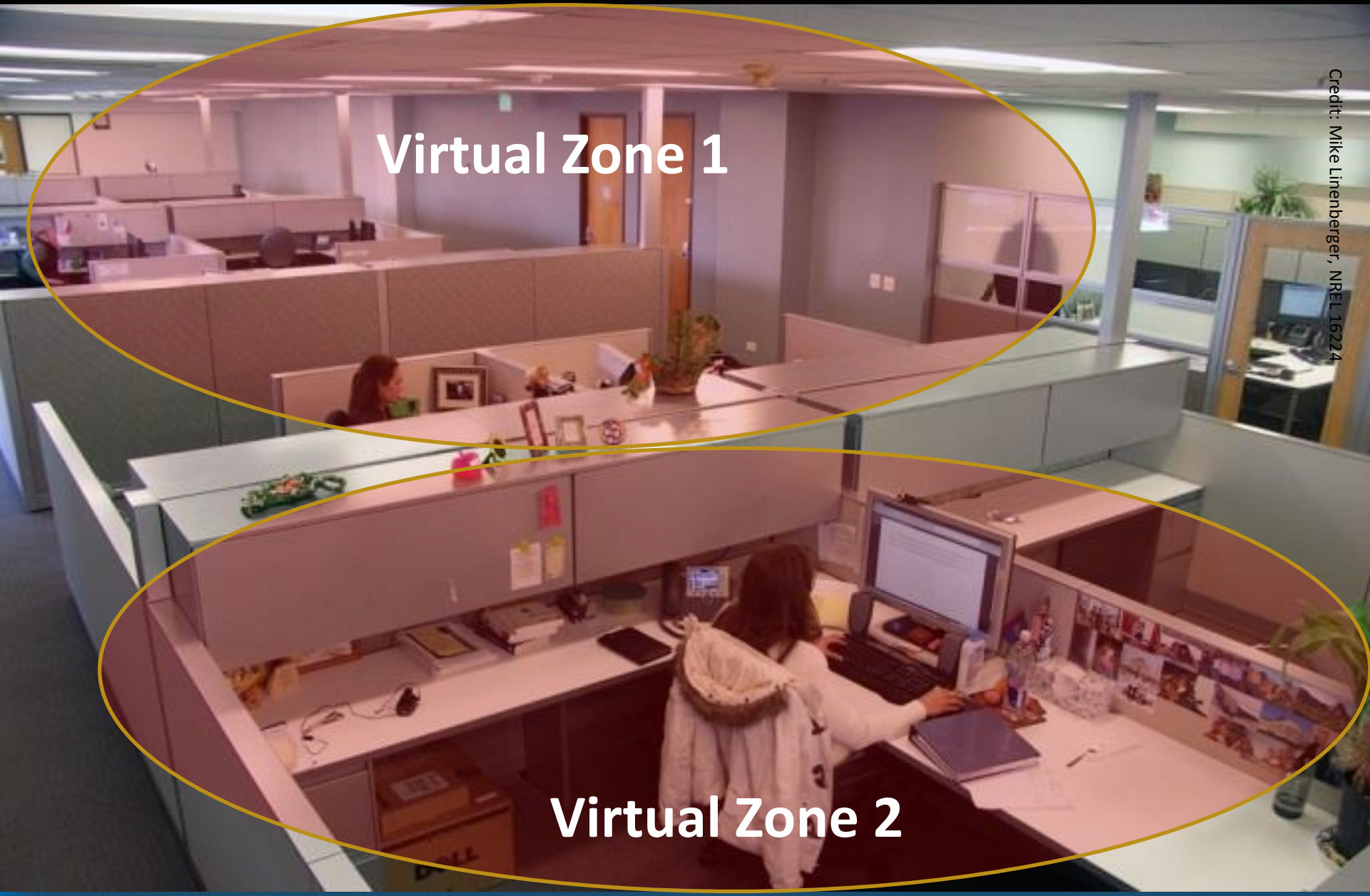


Credits: Left image: NREL 14840; Right picture: NREL 15439; and Luigi Gentile Polese, NREL

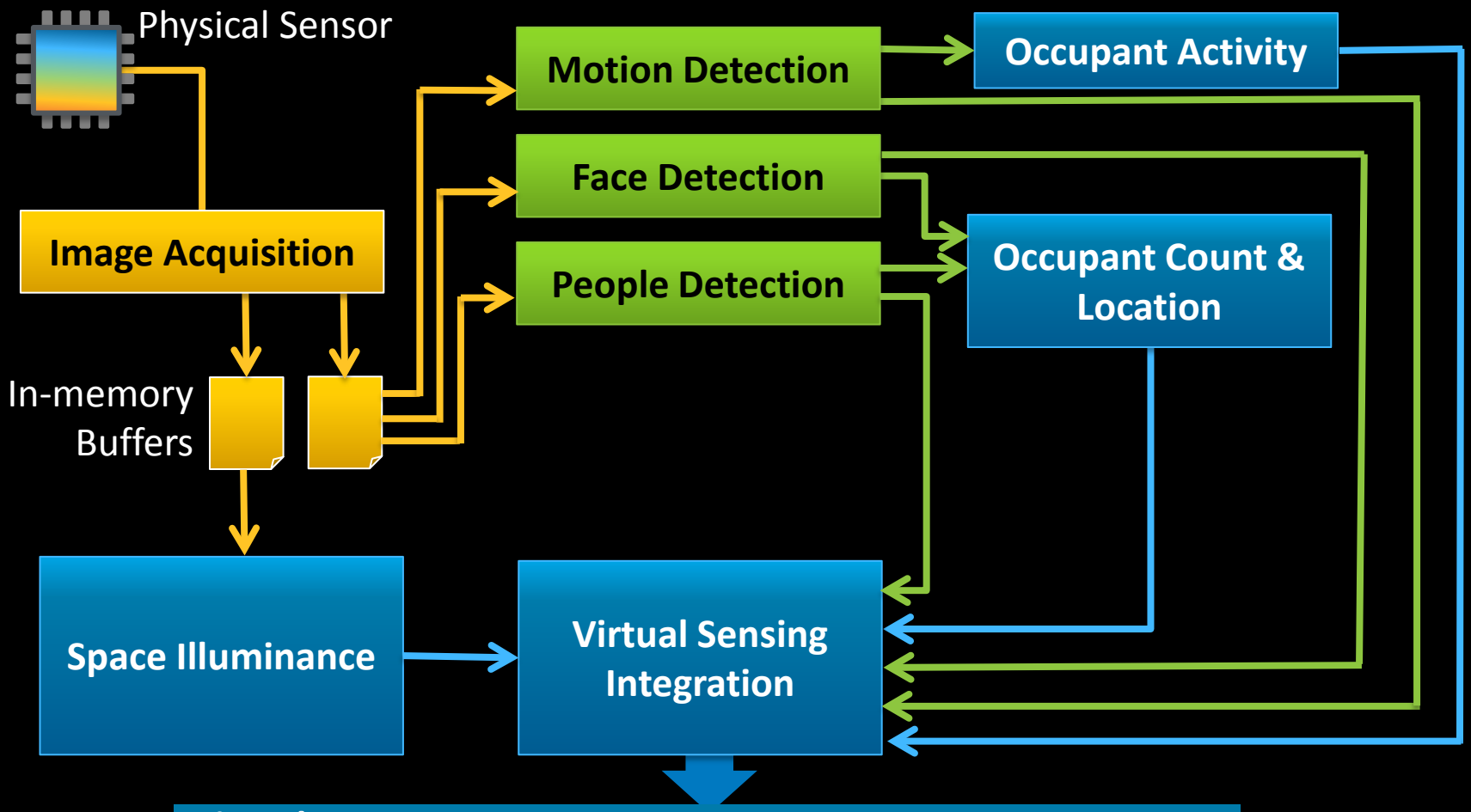
IPOS Sensor Commissioning

Credit: Mike Linenberger, NREL 16224

IPOS Sensor Commissioning



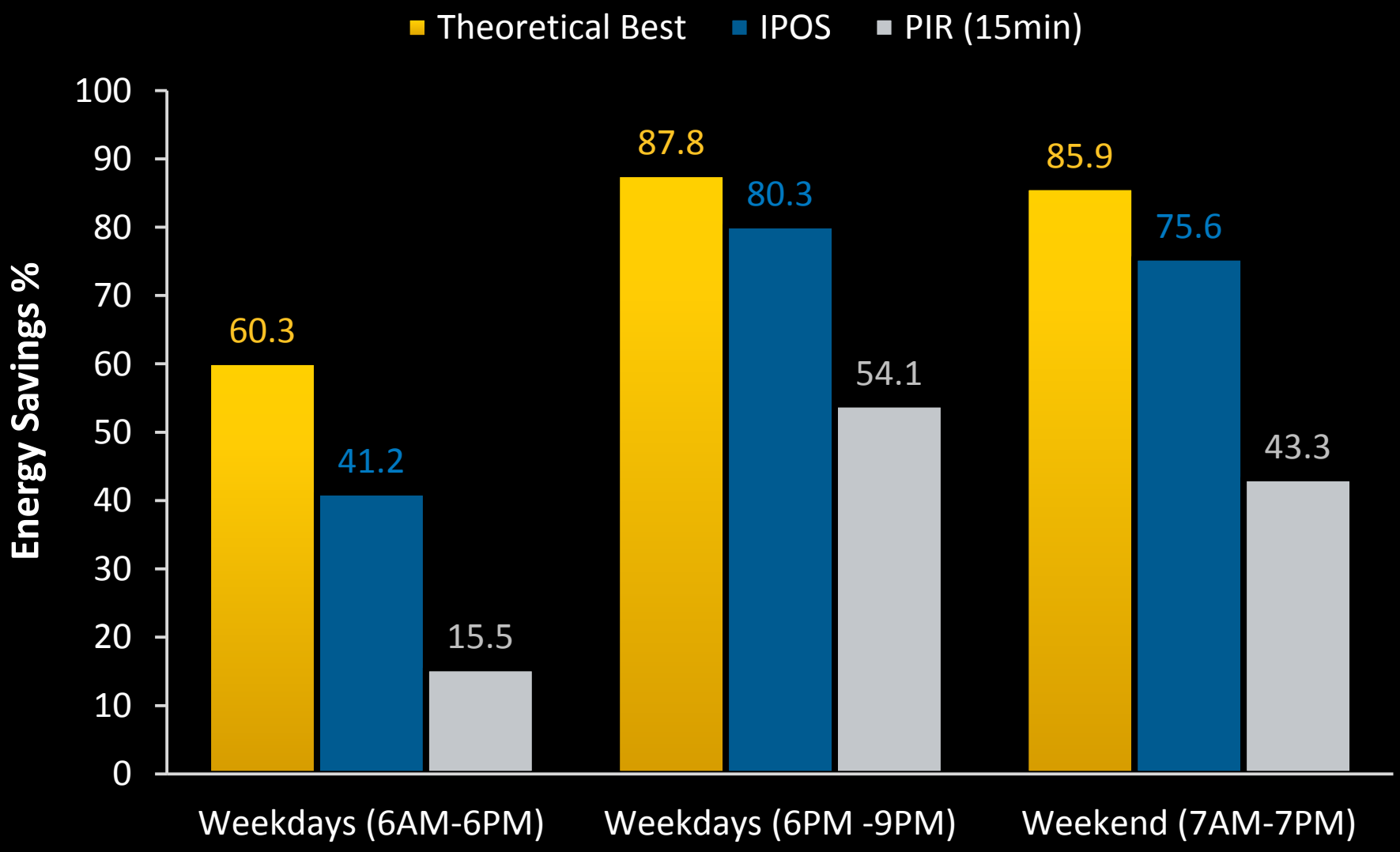
IPOS Virtual Sensor Model



Virtual Outputs

- Human Occupancy
- Confidence Levels
- Number & Location of Occupants
- Occupant Activity Levels
- Illuminance/Light Meter
- Light Dimming Power Levels
- Multiple Zones Outputs

Higher Accuracy = Higher Energy Savings



Sensors Needs

What will the future sensors have in common?

Open embedded system platforms as a need for advanced sensor products

- Multi-function, modular
- Open source, open license
- Embedded signal processing
- Interoperable, can be easily integrated into applications
- Integrates with other sensors and control systems
- Standard communication systems

Business & market opportunities

- Robustness, aggregation, multi-function, enables virtual sensing, localized intelligence
- Cost effective
- New capabilities and advanced applications
- Better/more energy efficiency enabler

Credit: Dennis Schroeder, NREL 24417

Challenges Ahead

Conflicting requirements: Higher Complexity, Higher Sensor Density, Computation-Intensive vs. Low-Power Consumption

Credit: Michael Sheppy, NREL

Challenges Ahead

A new/different workforce skillset for sensor manufacturers

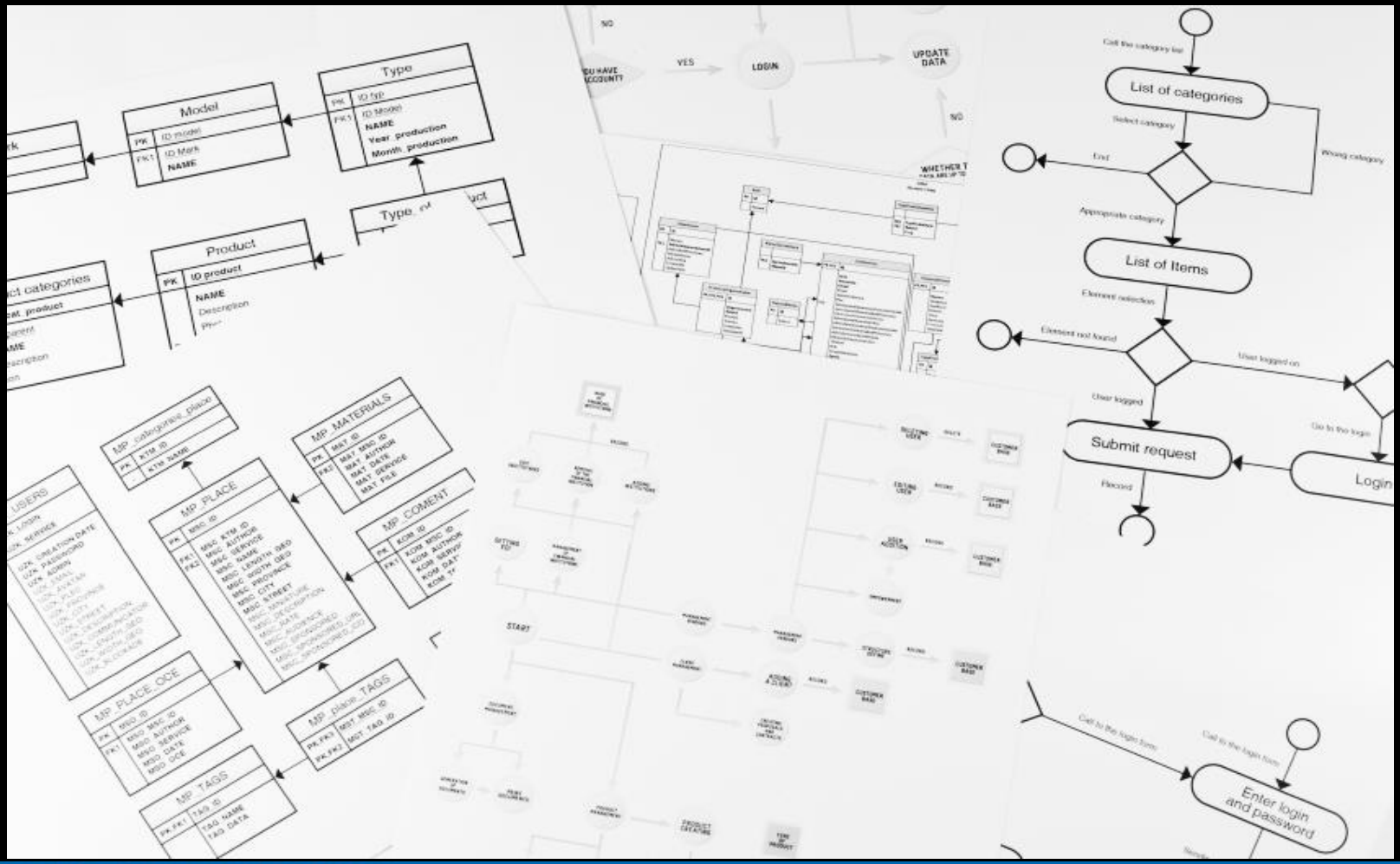


Image credit: iStock

Challenges Ahead

Image credit: iStock

Opportunities from Future Sensors

First photo: Dennis Schroeder, 21482; Second photo: SunPower, NREL 13339

Better energy efficiency: Renewables adoption more favorable/more cost effective

What's Ahead?

- Self-Organizing sensor networks
- Self-Commissioning – Optimal energy efficiency over building lifetime & Lower operational costs
- Self-Cooperating sensors
- Self-Decision-Making
- Self-Diagnosing, Self-Recovering, Self-Reporting – Lower maintenance costs
- Open, embedded sensor platforms

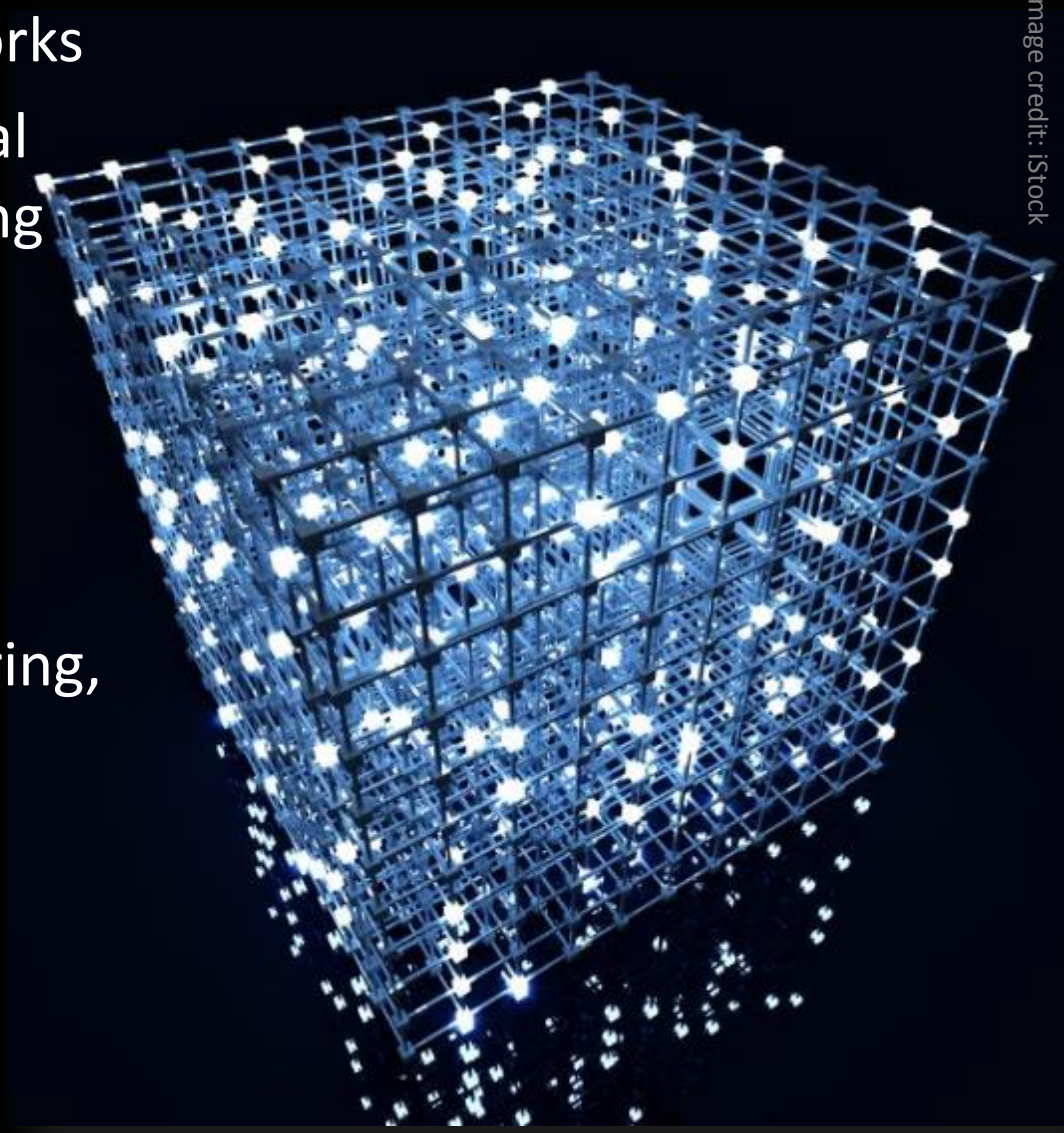


Image credit: iStock

What's Ahead?

Smarter, digital, networked, secure sensing

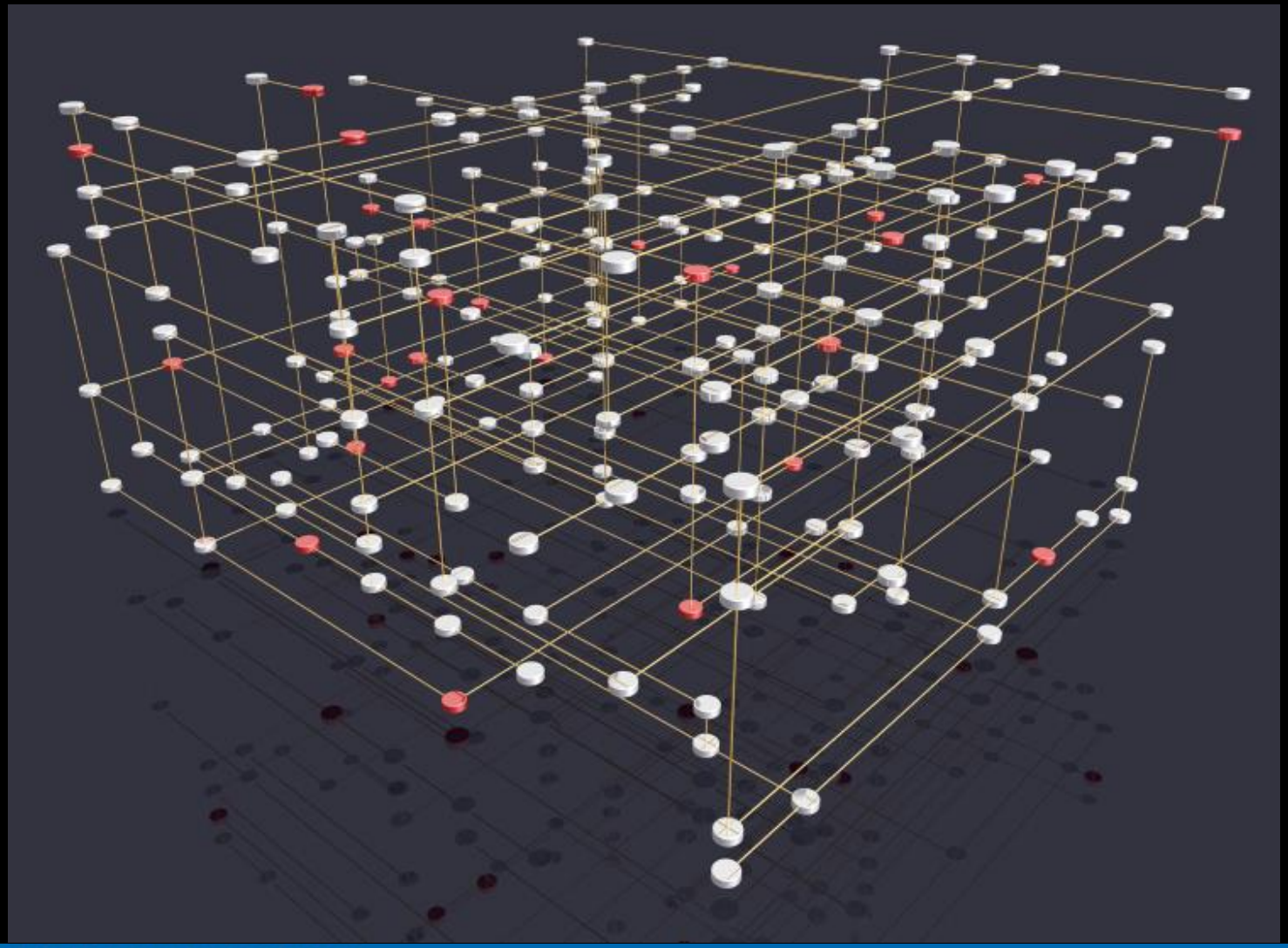


Image credit: iStock

Thank you!

luigi.gentile.polese@nrel.gov