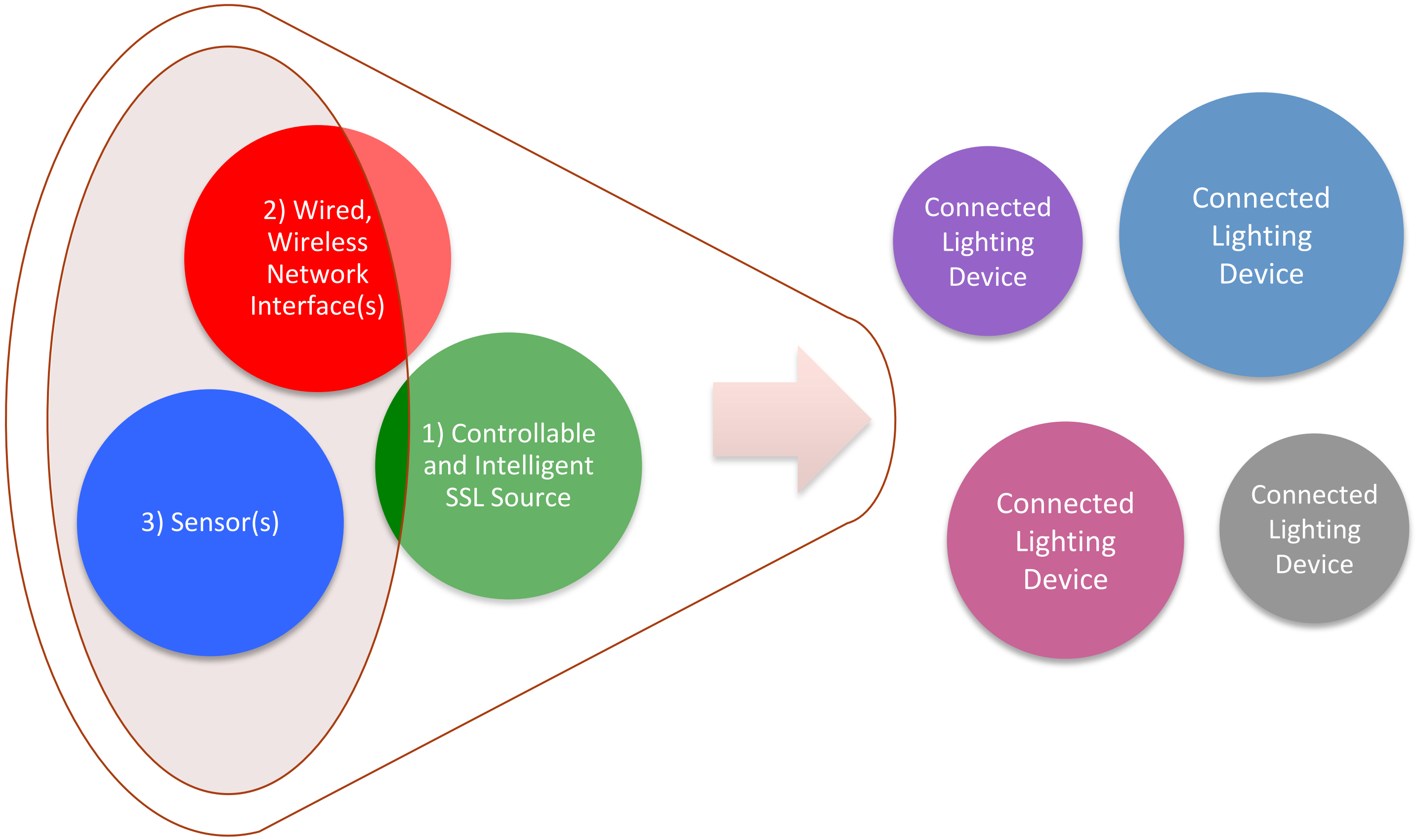
# What Can We Learn in a Connected Lighting Test Bed?

MICHAEL POPLAWSKI

Pacific Northwest National Laboratory

2018 Lightfair

# What is a connected lighting device?




It depends who you ask

- Controllable
- Intelligent
- Connected
- Data consumer <u>and</u> producer
- Many permutations

# What is a connected lighting system?

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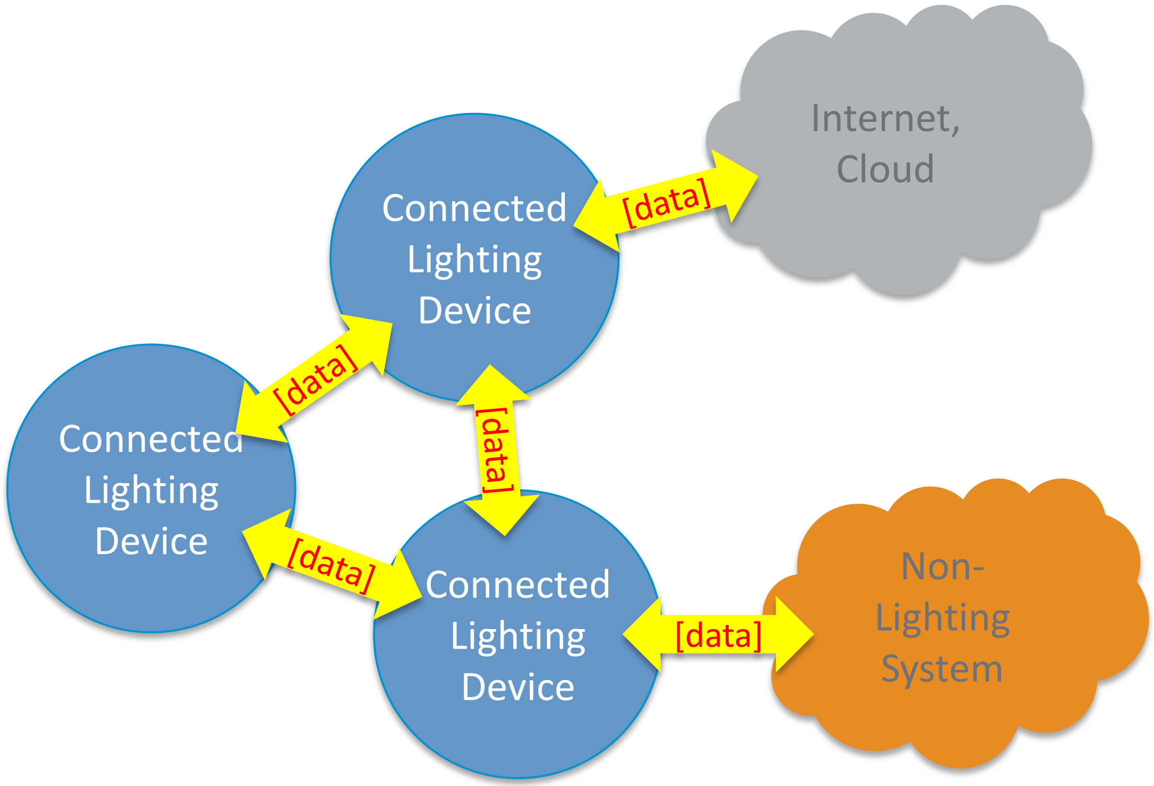
*A data collection platform that also lights spaces*

## Opportunity

Enabling intelligent lighting devices with (the right type and amount of) data can result in reduced energy consumption and improved lighting performance

The collected data may enable other revenue streams that compete with lighting and energy performance

## Threat



# DOE Connected Lighting Systems strategy



## Focus Areas


## Industry Engagement

- Standards Development Organizations (SDO’s)
  - NEMA/ANSI
  - UL
- Industry consortia
  - Open Connectivity Foundation
  - Industrial Internet Consortium
  - Bluetooth SIG
- Technology developers
- System integrators
- Early adopters

# Connected Lighting Test Bed: What and Why?

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## What

- Laboratory
- High-bay and office space
- Indoor and outdoor CLS
- Technical feasibility, not real-world environment

## Why

- System-level testing, active network communication
- Characterize possible range of performance, identify key new features and potential issues
- Contribute to standards, model specification development

## Collaborate with DOE

- Review and comment on reports
- Make recommendations for test methods and studies
  - Types of CLS
  - Attributes to be measured
  - Variables to be controlled (e.g., environmental, operational states)
- Contribute material (e.g., PoE CLS)
  - For use in public studies
  - Direct feedback on relative comparison of key new features, potential issues
  - Direct feedback on targeted topic

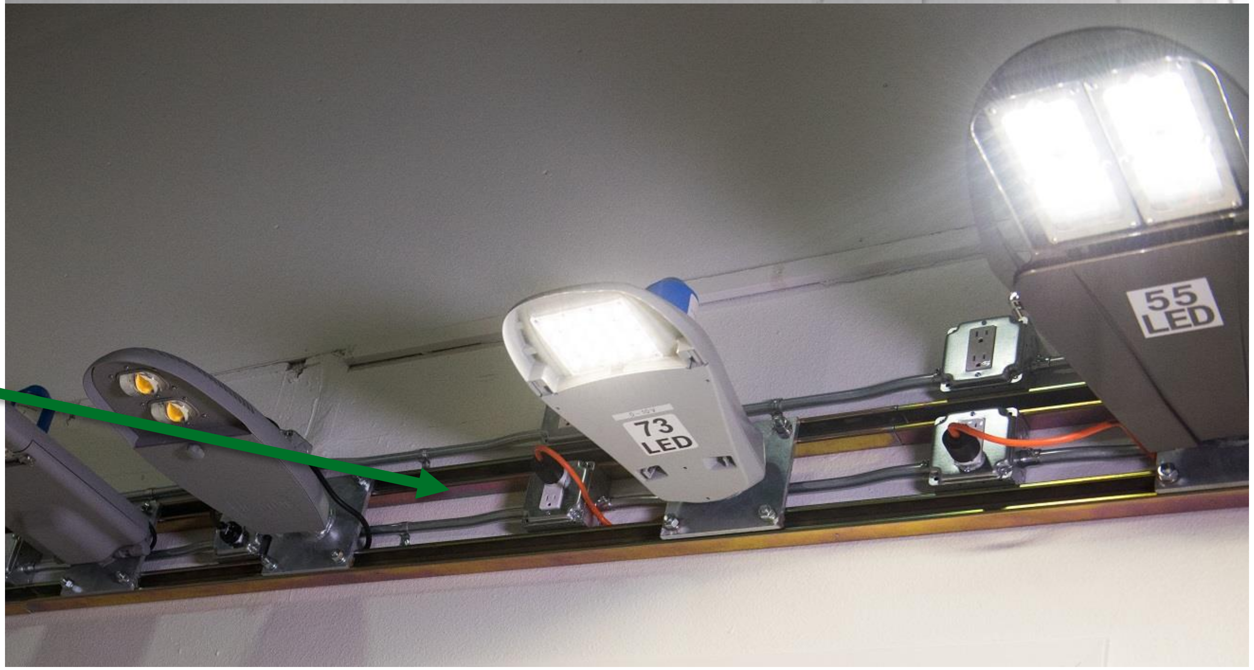
# CLTB indoor lighting infrastructure

- Two 18’x18’ vertically movable lighting trusses with attached suspended ceilings
- Four AC circuits per ceiling with 12 standard duplex receptacle outlets per circuit facilitate plug-and-cord connection of luminaires
- Forty Ethernet cables per ceiling facilitate wired network connectivity and Power over Ethernet for connected luminaires
- Support for 2’x2’ and 2’x4’ troffers and grid-mounted track lighting

# CLTB outdoor lighting infrastructure



- Two rail systems facilitate quick wall-mounting and plug-and-cord connection of streetlights
- System A has 12 standard duplex receptacle outlets split across two AC circuits
- System B has 10 standard duplex receptacle outlets split across two AC circuits
- 2’ spacing between duplex receptacle outlets; 1-2 luminaires between outlets depending on width



# CLS in the CLTB

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PHILIPS

CIMCON Lighting, Inc.

CREE™

current
powered by GE

Telematics Wireless

enlighted

SoCe

Silver Spring® NETWORKS

Microsoft

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# Test Setup and Method development

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- Test setup: functional requirements
- Test setup implementation: how functional requirements are implemented
- Test method: what is controlled, what is measured
- Limited Releases
  - Device-Level Energy Reporting Accuracy v1 (Jun. 2017)
  - System-Level Energy Reporting Accuracy v0 (Nov. 2017)
  - Cybersecurity Vulnerability v0 (Mar. 2017)

- *Limited release efforts shared with appropriate industry consortia and standards development organizations*
- *Public releases, suitable for use in studies, made available on DOE website*
- *Industry stakeholders experienced in the development and use of such test setups and methods, and willing to provide DOE with feedback and/or suggestions for improvement, are encouraged to request access to the most current version by sending an email to DOE.SSL.UPDATES@ee.doe.gov with their contact information.*

# IIC collaboration on cybersecurity

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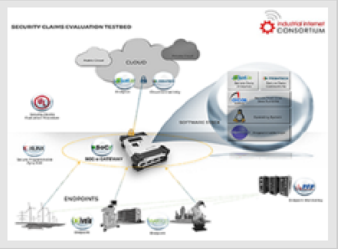
industrial internet CONSORTIUM

HOME | COMMITTEES | INDUSTRIES | RESOURCE HUB | MEMBERSHIP | MEMBERS AREA

## SECURITY CLAIMS EVALUATION TESTBED

SECURITY CLAIMS EVALUATION TESTBED • TESTBEDS



### Testbed in Action

INTELLIGENT SENSOR SECURITY EVALUATION USE CASE

In an Industrial environment setting, monitoring of sensors provides a window into system and operational efficiencies.

Specifically, monitoring key parameters such as temp, vibration, current and voltage provide the operator insight into how whether operation is within normal range, normal failure mode, or indication of a cybersecurity / security breach.

### FAST FACTS

LEAD MEMBERS:

Xilinx, UL (Underwriters Laboratories), Aicas, PrismTech

SUPPORTING COMPANIES:

SoC-e, iVeia, JUXT, PFP Cybersecurity, EyeTech, Algotronix, others pending

MARKET SEGMENT:

Industrial Manufacturing, Smart Grid/Energy, Smart Medical, Automotive, Aerospace & Defense and Communications

CHALLENGE:

Provide a Testbed to allow testing of security claims and other security related testing evaluation.

SOLUTION:

Security Claims Evaluation Testbed – an open and easily configurable cybersecurity platform for evaluation of endpoint, gateway, and other networked components' security capabilities.

HOW IT WORKS:

The security testbed is a comprehensive testbed comprised of three primary tiers: Endpoint, Gateway and Server (Private, Public Cloud). Data sources can include industrial, smart grid/energy, medical, automotive, building automation, and other related endpoints requested for secure operational analysis. Key platform elements of the testbed include:

- Intelligent endpoint monitoring system(s) from PFP Cybersecurity
- Intelligent Gateway from SoC-e
- Real time analytics from Juxt
- Secure runtime Java VM from Aicas
- Private and Public Cloud secure communication from PrismTech

**February 22, 2016**
**11:17 AM Eastern Standard Time**

**INDUSTRIAL INTERNET CONSORTIUM ANNOUNCES FIRST SECURITY CLAIMS EVALUATION TESTBED**

*UL (Underwriters Laboratories), Xilinx, Aicas, and other contributors join forces to provide a security and cybersecurity assessment platform for evaluating endpoint, gateway, and other networked components' security capabilities*

observable networks

SoCe

# Energy Reporting: PoE systems, part 1



## Motivation

- Identify and address high-value and impact market needs for technical explanation, evaluation, communication, and education
- High value and impact criteria
  - New technology
  - High energy savings potential
  - High market impact potential
  - Unfamiliar to one or more industry stakeholder group, possibly resulting in confusion and prone to misrepresentation

## Envisioned impact

- Increased transparency regarding accuracy and applicability of energy data reported by PoE systems;
- Increased prevalence of energy reporting, whether via PoE or other means
- Increased lighting industry awareness and understanding of the diversity/complexity and benefits/limitations of PoE connected lighting systems and standards
- Improved IT industry understanding of lighting needs

# PoE-LED convergence

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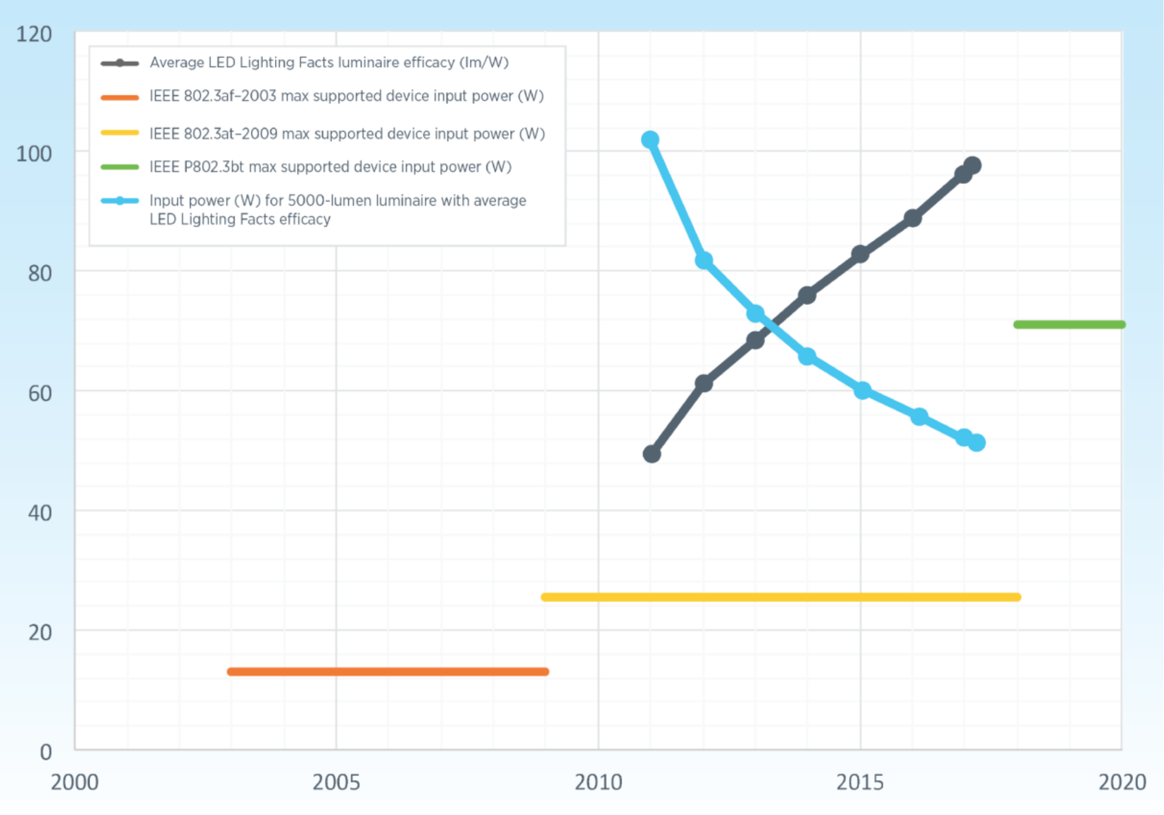
## Standards Progress

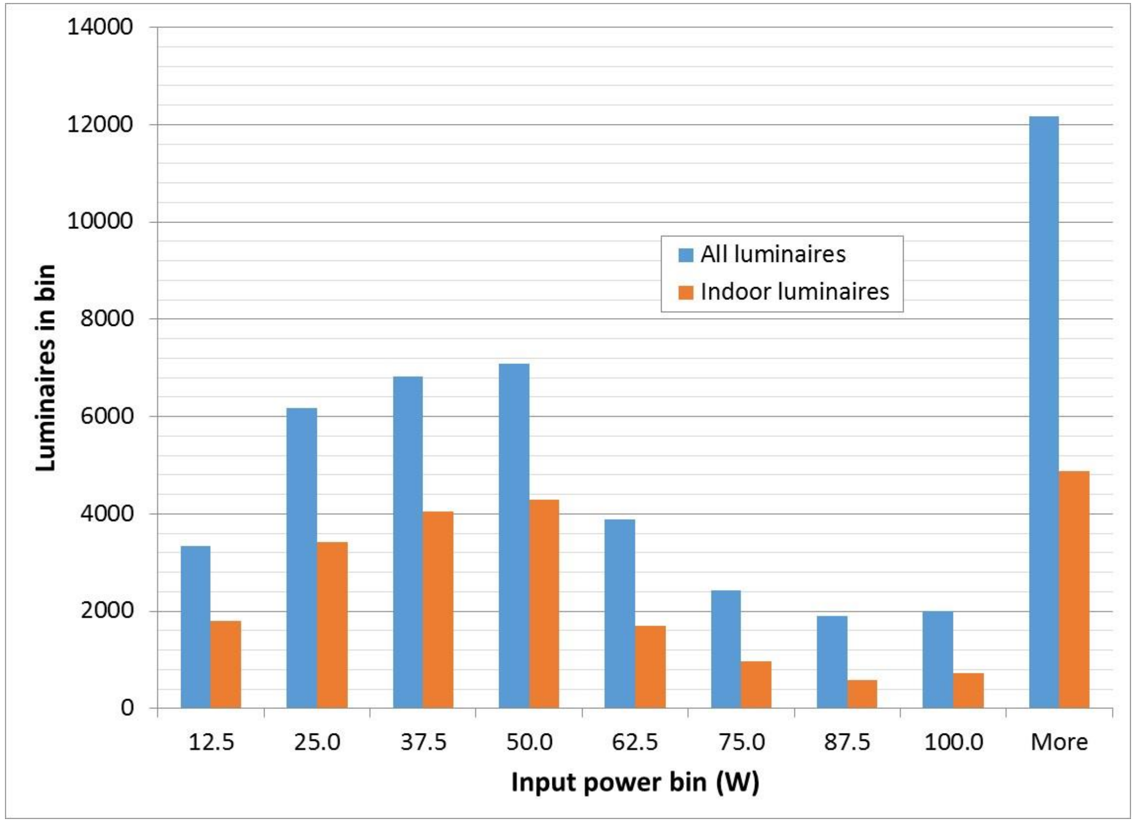
### IEEE 802.3 series



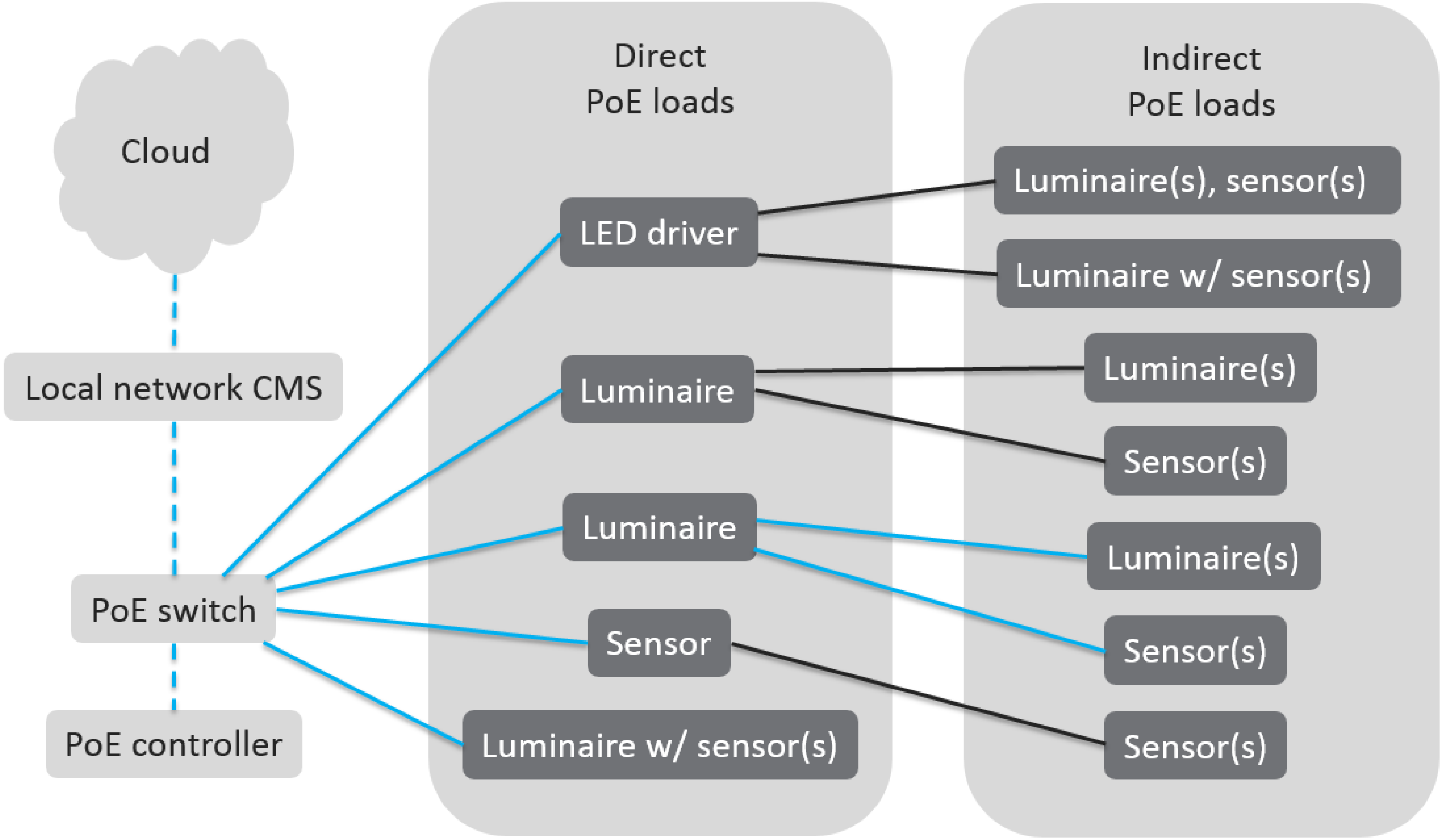

## LED Lighting Facts

### 24% of indoor luminaires ≤ 25.5 W (802.3at Class 4 PD)

### 71% of indoor luminaires ≤ 71 W (P802.3bt Class 8 PD)



# PoE lighting system architectures



# Some PoE lighting systems

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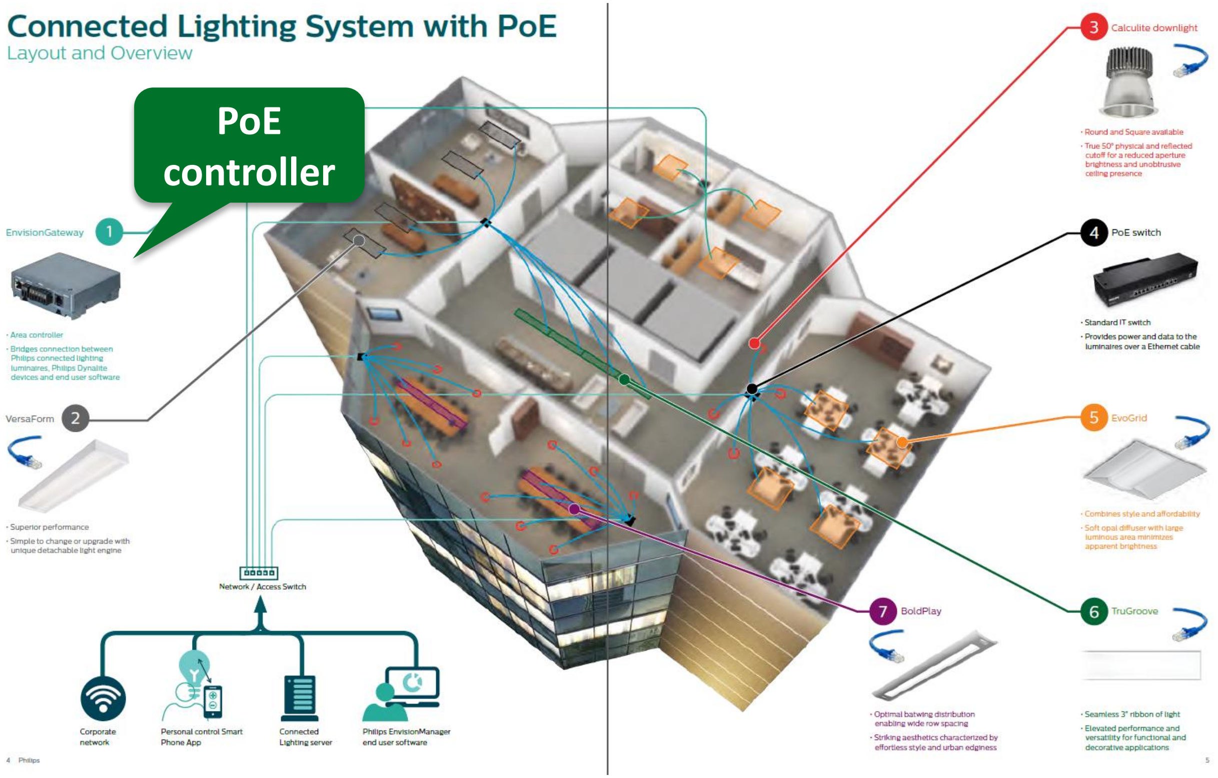
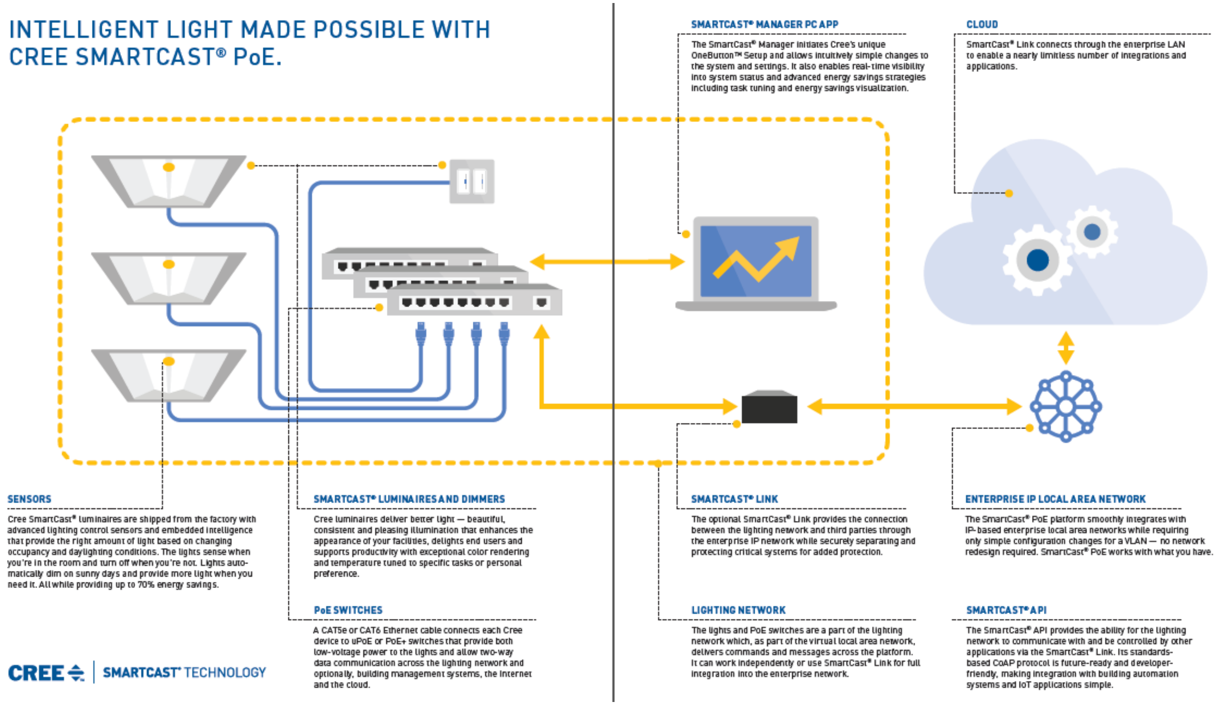
## Philips (2014)

- For use with 802.3at switches, requires Envision Gateway
- Direct PoE loads: luminaires




## Cree Smartcast PoE (2016)

- For use with 802.3at or UPOE switches
- Direct PoE loads: luminaires and sensors



# Select recommendations

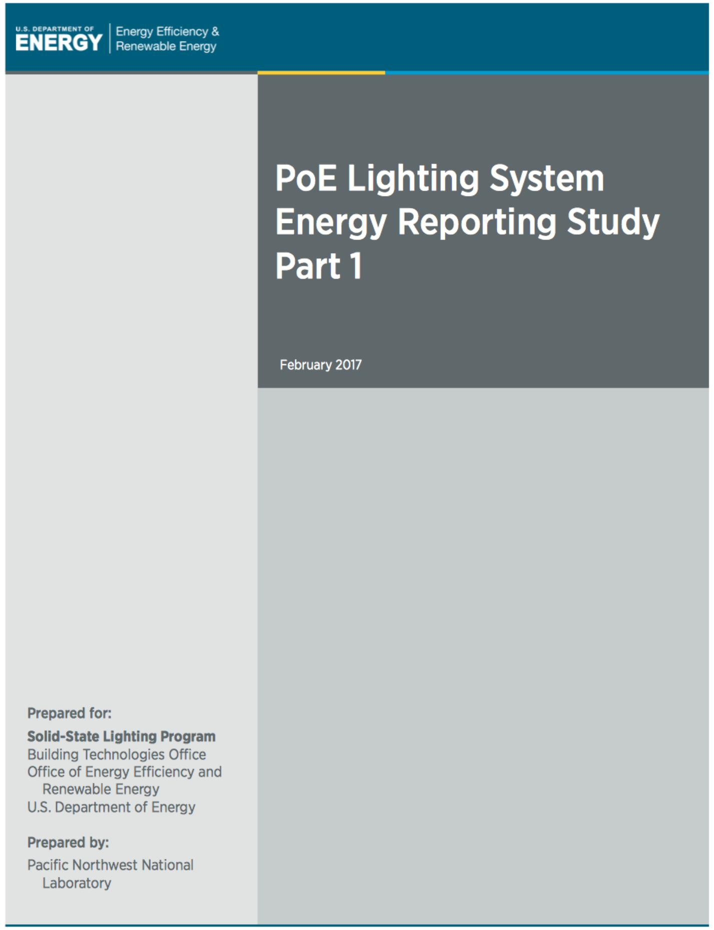


- Manufacturers should develop some minimum required detail describing their PoE system energy reporting capabilities
  - Where energy is reported
  - How energy is reported, e.g., accuracy, information models
- The Industry should develop standards or specifications describing test setups and methods, and performance classes suitable for characterizing PoE system energy reporting accuracy
- The Industry should develop some minimum level of energy reporting capability for PoE devices and systems
  - Where energy is reported
  - How energy is reported, e.g., accuracy, information models

# For more information



1. How prevalent is energy use reporting in commercially-marketed PoE devices and systems?
2. How is energy use being reported in PoE systems?
3. Is energy loss in PoE cables and connections being reported?
4. What energy reporting performance are manufacturers claiming for their commercially-marketed PoE lighting devices and systems?
5. Which existing test setups, test methods, and performance classes appear suitable for PoE lighting devices and systems?
6. What physical, logical, and temporal differences among PoE lighting systems might need to be addressed?
7. What have prior studies found regarding the energy reporting accuracy of commercially marketed PoE lighting devices and systems?


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

PoE Lighting System Energy Reporting Study Part 1

February 2017

Prepared for:
Solid-State Lighting Program
Building Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Prepared by:
Pacific Northwest National Laboratory

# Next steps

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## System-level energy performance

- Comparison, contrast of commercially-marketed PoE CLS
  - Comprising one or more possible PoE system architectures
  - Operating in one or more static system states (e.g., light output, network activity)
  - Operating in one or more or dynamic system states (e.g., implementing an adaptive lighting strategy)
- Characterization of device/system energy reporting accuracy, if applicable

## Collaborate with DOE

- Review and comment on the report; revisions/expansions will be published as appropriate
- Make recommendations (e.g., specific system states to characterize, range of variation to explore)
- Contribute material (e.g., PoE CLS)

# Interoperability: APIs, part 1



## Motivation

- Characterize the interoperable performance of emerging CLS and highlight the benefits of increasing levels of interoperability.
- Qualitatively evaluate the interoperability enabled by consensus industry efforts, and not on whether, or how well, specific devices and/or systems comply with said efforts.
- Identify interoperability issues that are inconsistent with the claims made for a specific industry effort.
- Part 1 study focused on the development and use of APIs to facilitate interoperability.

## Envisioned Impact

- Provide feedback to technology developers on the capabilities and limitations of currently available APIs.
- Educate potential CLS owners and operators on what type of data exchange is enabled by currently available APIs, and the relative effort required to use APIs to realize new features and capabilities facilitated by such information exchange.
- Accelerate the development of interoperability frameworks or platforms, specifications, and standards.
- Educate (non-lighting) IoT stakeholders about the needs of and opportunities offered by CLS.

# Industry engagement



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# API resource trees

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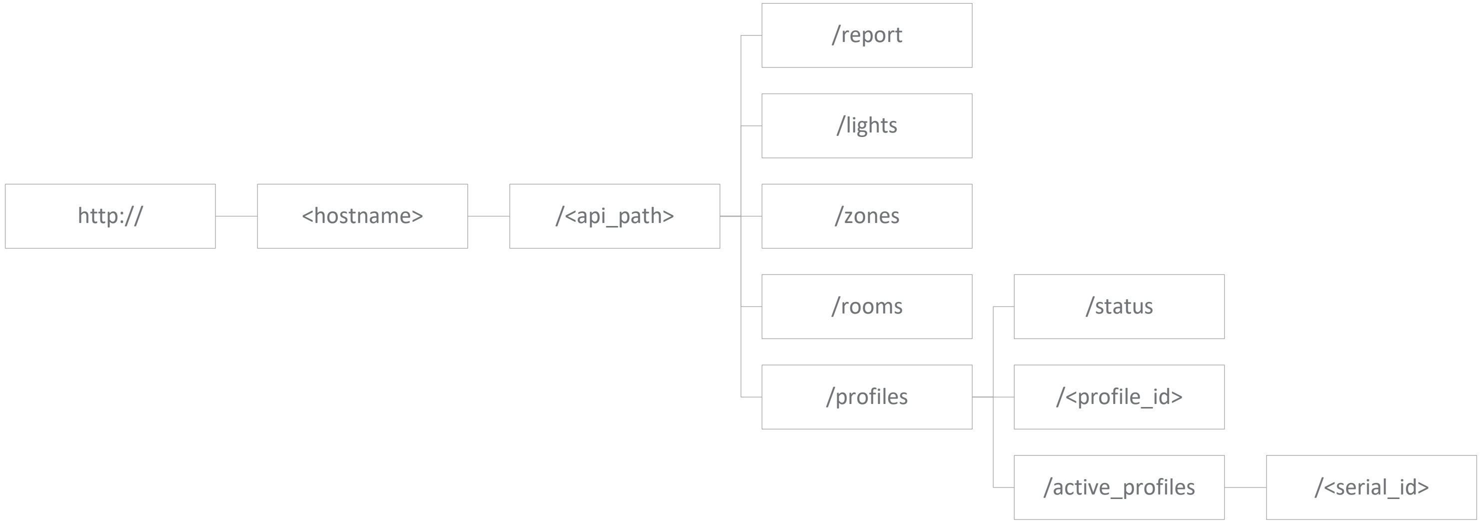
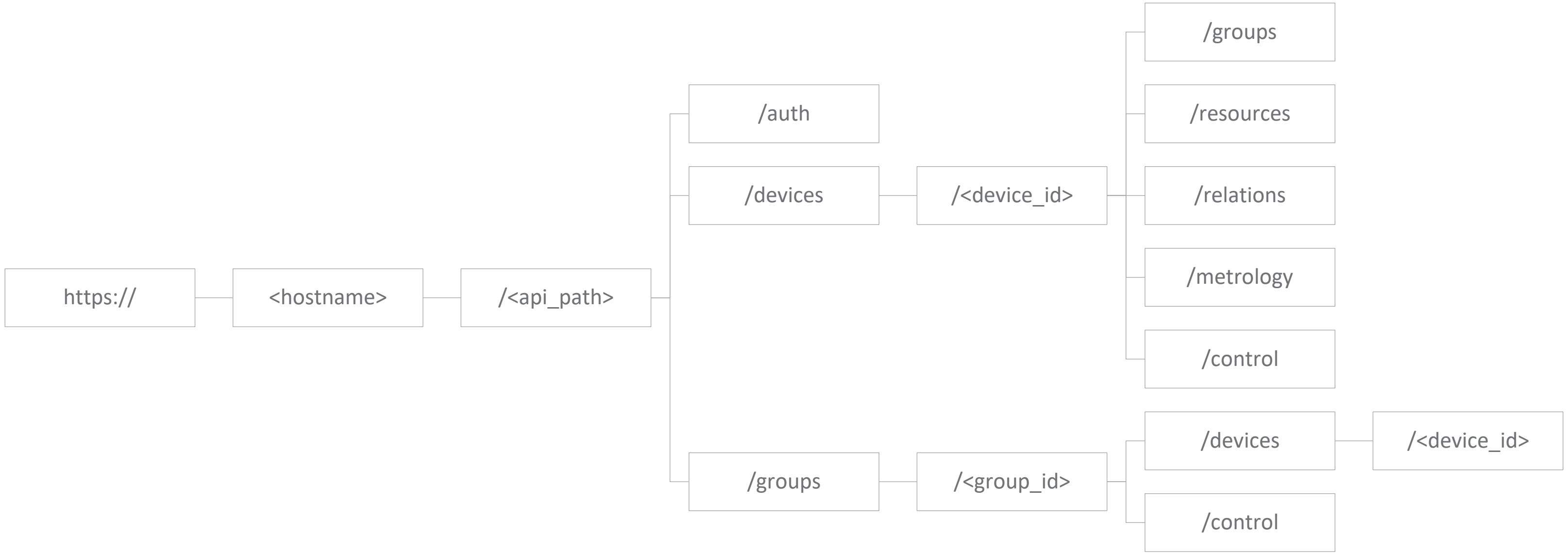
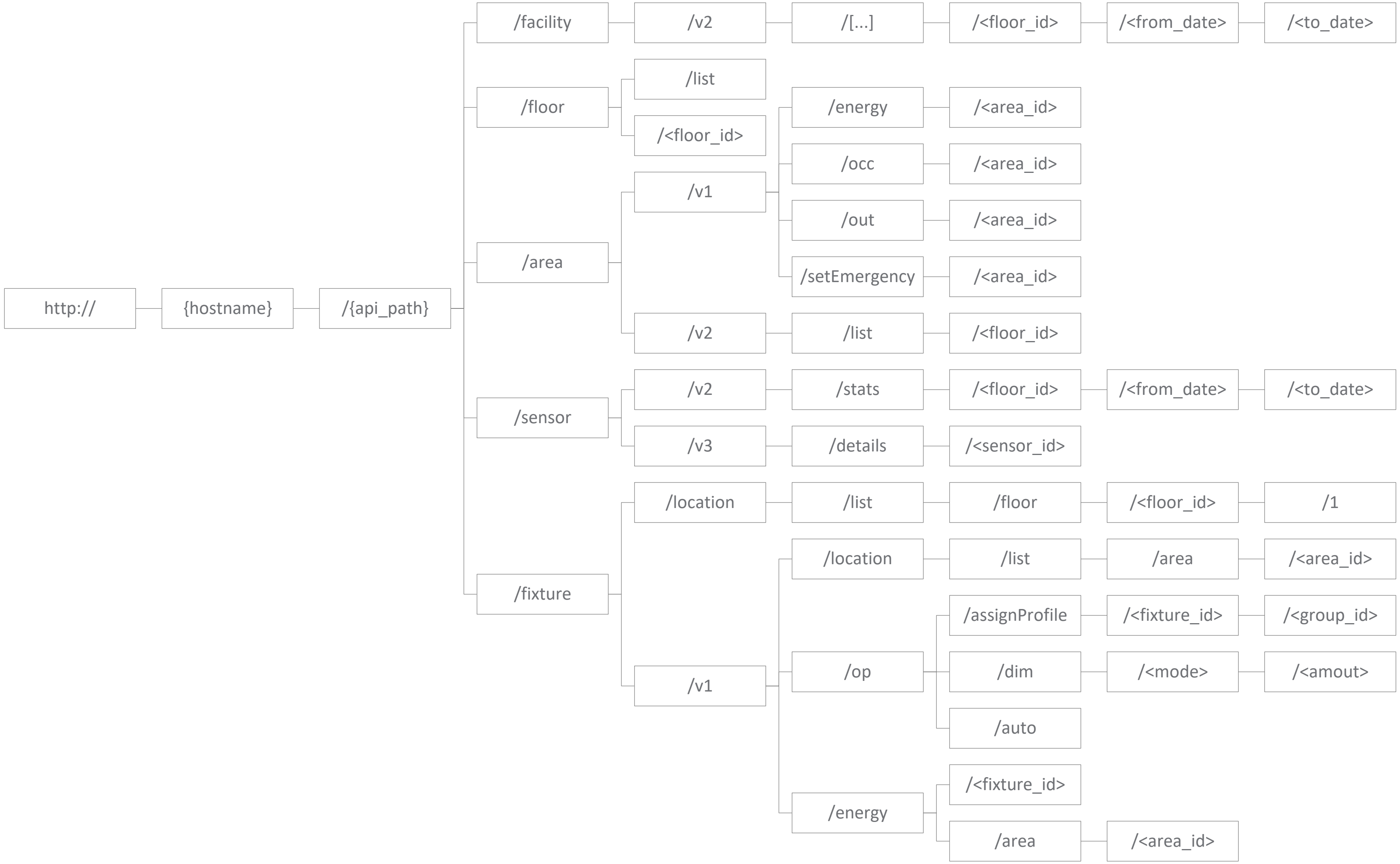


# API resource trees





# API data models

| Request | | |
|---|---|---|
| **Method** | Resource URL | Parameters |
| **GET** | /reports/api/monitoring<br><br>/* Returns an array of metering value descriptors for a given device.<br>(not a comprehensive list of resources) */ | {<br>"methodName": "getDeviceMeteringValueDescriptors",<br>"controllerStrId": "<controller_id>",<br>"idOnController": "<device_id>",<br>"ser": "json"<br>} |

| Response | |
|---|---|
| **Status Code** | Body |
| **200 (OK)** | see below |


```
[
  {'name': 'MainVoltage'     , 'label': 'Mains voltage (V)' , 'type': 'float'  , 'unit': 'V'  , 'labelKey': 'db.meaning.mainvoltage.label'     , [...] },
  {'name': 'VoltageMax'      , 'label': 'Voltage Max'       , 'type': 'float'  , 'unit': None , 'labelKey': 'db.meaning.voltagemax.label'      , [...] },
  {'name': 'VoltageMin'      , 'label': 'Voltage Min'       , 'type': 'float'  , 'unit': None , 'labelKey': 'db.meaning.voltagemin.label'      , [...] },
  {'name': 'Current'         , 'label': 'Mains current'     , 'type': 'float'  , 'unit': 'A'  , 'labelKey': 'db.meaning.current.label'         , [...] },
  {'name': 'MeteredPower'    , 'label': 'Metered power (W)' , 'type': 'float'  , 'unit': 'W'  , 'labelKey': 'db.meaning.meteredpower.label'    , [...] },
  {'name': 'Energy'          , 'label': 'Lamp energy (kWH)' , 'type': 'float'  , 'unit': 'kWh', 'labelKey': 'db.meaning.energy.label'          , [...] },
  {'name': 'PowerFactor'     , 'label': 'Power factor'      , 'type': 'float'  , 'unit': ''   , 'labelKey': 'db.meaning.powerfactor.label'     , [...] },
  {'name': 'Frequency'       , 'label': 'Frequency (Hz)'    , 'type': 'float'  , 'unit': 'Hz' , 'labelKey': 'db.meaning.frequency.label'       , [...] },
  {'name': 'Temperature'     , 'label': 'Temperature'       , 'type': 'float'  , 'unit': ''   , 'labelKey': 'db.meaning.temperature.label'     , [...] },
  {'name': 'LuxLevel'        , 'label': 'Lux level (Lux)'   , 'type': 'float'  , 'unit': ''   , 'labelKey': 'db.meaning.luxlevel.label'        , [...] },
  {'name': 'RunningHoursLamp', 'label': 'Lamp burning hours', 'type': 'float'  , 'unit': 'h'  , 'labelKey': 'db.meaning.runninghourslamp.label', [...] },
  {'name': 'UpTimeInSeconds' , 'label': 'Up time (sec)'     , 'type': 'integer', 'unit': None , 'labelKey': 'db.meaning.uptimeinseconds.label' , [...] },
  {'name': 'supplyLossCount' , 'label': 'Supply losses'     , 'type': 'int'    , 'unit': None , 'labelKey': 'db.meaning.supplylosscount.label' , [...] },
  {'name': 'PhotocellMode'   , 'label': 'Photocell mode'    , 'type': 'boolean', 'unit': None , 'labelKey': 'db.meaning.photocellmode.label'   , [...] }
]
```

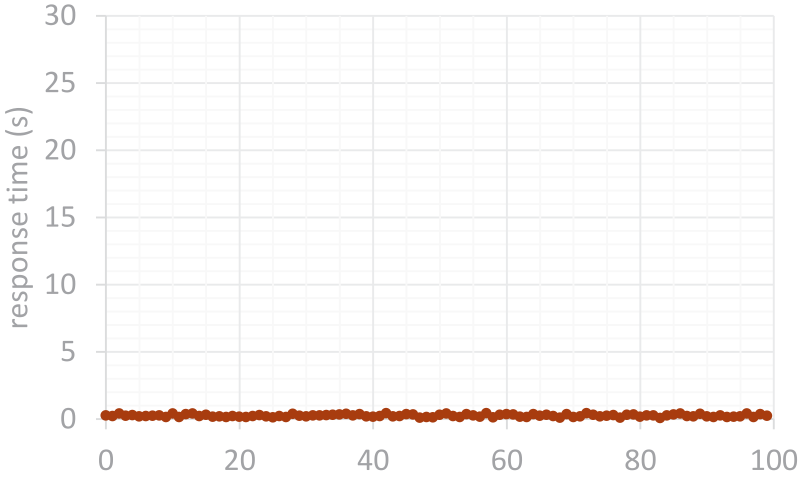
# API data models

| Request | | |
|---|---|---|
| **Method** | Resource URL | Parameters |
| **GET** | /papi/v1.1/devices/<device_id>/resources<br><br>/* Lists the latest resources of a given light fixture, mostly undocumented.<br>Some values are ASCII strings and some base64 encoded. */ | {<br>'Accept': '*/*',<br>'Cookie: 'JSESSIONID=[...]'<br>} |

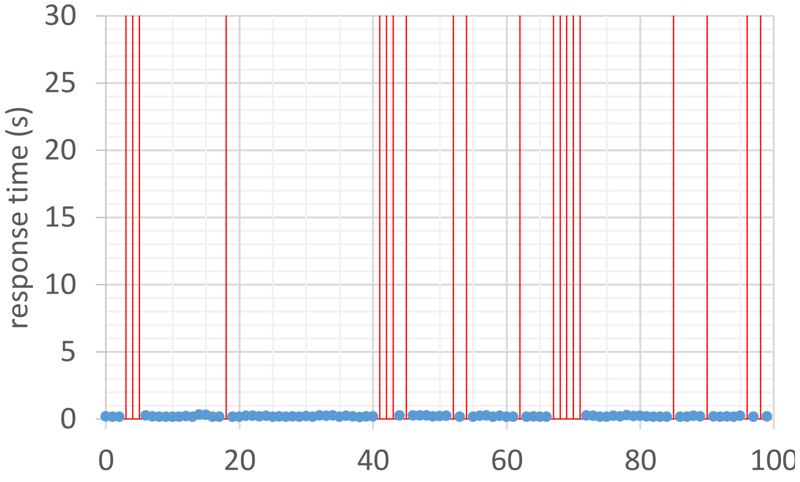
| Response | |
|---|---|
| **Status Code** | Body |
| **200 (OK)** | [<br>{{'timeMeasured': '2017-02-08 20:37:37.924', 'name': '/fw_ota_progress/download_status' , 'value': '0' },<br>{'timeMeasured': '2017-02-08 20:37:37.924', 'name': '/fw_ota_progress/image_crc' , 'value': '0' },<br>{'timeMeasured': '2017-02-08 20:37:37.924', 'name': '/fw_ota_progress/ota_progress' , 'value': '0' },<br>{'timeMeasured': '2017-02-08 20:37:37.924', 'name': '/fw_ota_progress/ota_status' , 'value': '0' },<br>{'timeMeasured': '2017-02-08 20:37:37.924', 'name': '/fw_ota_progress/upload_status' , 'value': '0' },<br>{'timeMeasured': '2017-03-08 19:49:24.0' , 'name': '/gps/fix' , 'value': '1' },<br>{'timeMeasured': '2016-10-13 17:29:22.0' , 'name': '/gps/lat' , 'value': '[...]' },<br>{'timeMeasured': '2016-10-13 17:29:22.0' , 'name': '/gps/lng' , 'value': '[...]' },<br>{'timeMeasured': '2017-03-08 19:49:24.0' , 'name': '/lt/0/ctr' , 'value': '1' },<br>{'timeMeasured': '2017-03-08 19:49:24.0' , 'name': '/lt/0/dim' , 'value': '100' },<br>{'timeMeasured': '2017-03-08 19:49:24.0' , 'name': '/lt/ontime' , 'value': '2323.44' },<br>{'timeMeasured': '2017-03-07 22:49:40.0' , 'name': '/nw/eripaddr' , 'value': '[...]' },<br>{'timeMeasured': '2017-03-07 22:49:40.0' , 'name': '/nw/ipaddr' , 'value': '[...]' },<br>{'timeMeasured': '2017-03-07 22:49:40.0' , 'name': '/nw/macaddr' , 'value': '[...]' },<br>{'timeMeasured': '2017-03-07 22:49:40.0' , 'name': '/nw/pipaddr' , 'value': '[...]' },<br>{'timeMeasured': '2017-03-07 22:49:40.0' , 'name': '/nw/sipaddr' , 'value': '[...]' }<br>] |

# Use-Case: broadcasting a lighting command

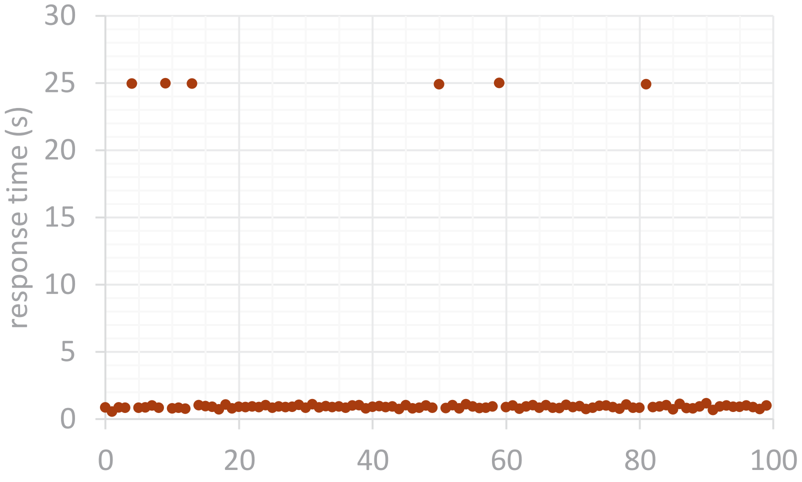




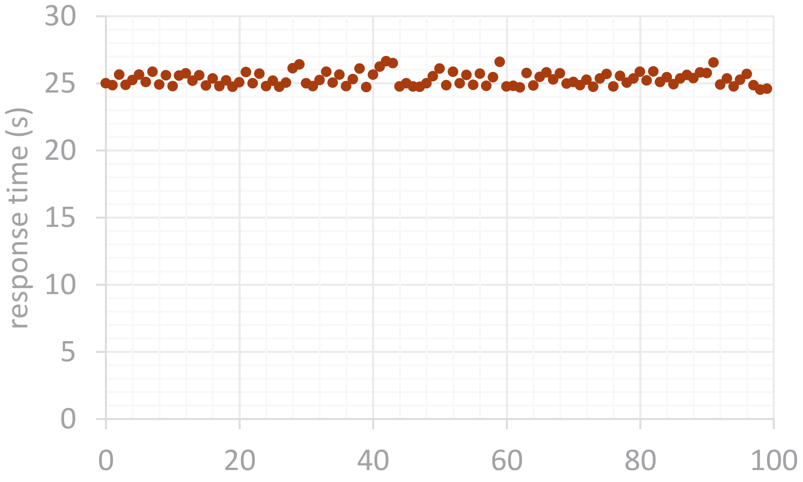

*ρ = 100% / μ = 0.24s / σ = 0.09s*



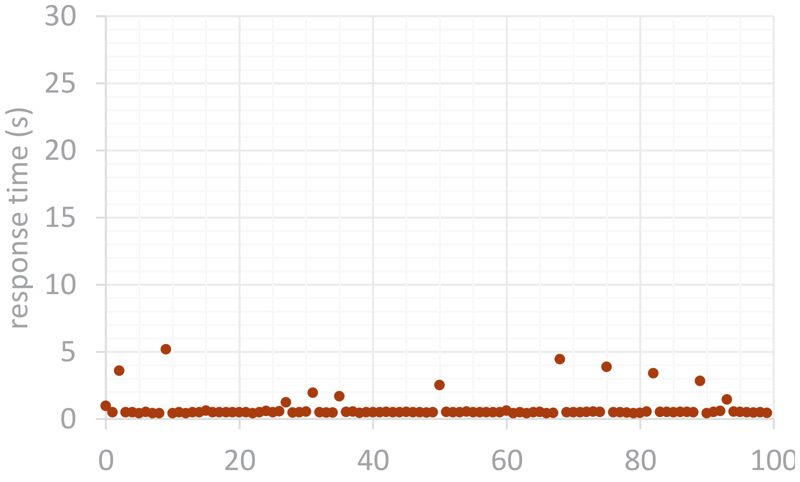

*ρ = 80% / μ = 0.19s / σ = 0.04s*



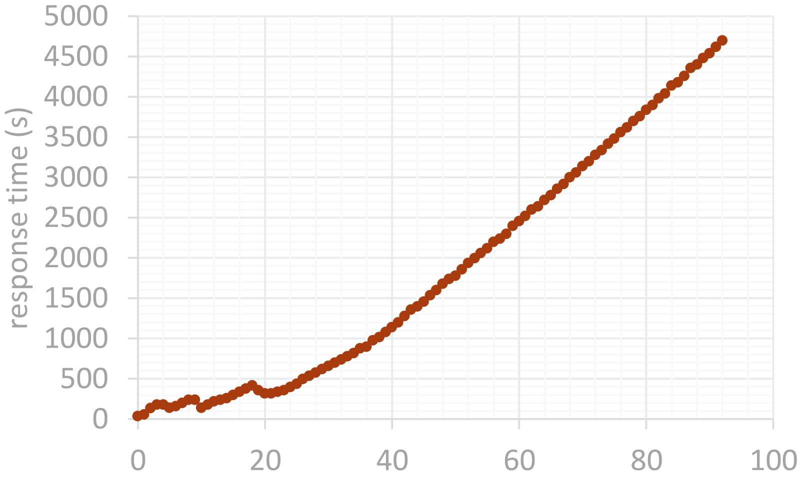

*ρ = 100% / μ = 2.33s / σ = 5.74s*




*ρ = 100% / μ = 25.29s / σ = 0.50s*




*ρ = 100% / μ = 0.76s / σ = 0.87s*




*ρ = 100% / μ = 1825.91s / σ = 1465.27s*

*Response time for each of the six CLS, measured and plotted sequentially 100x for statistical analysis*

# Select recommendations



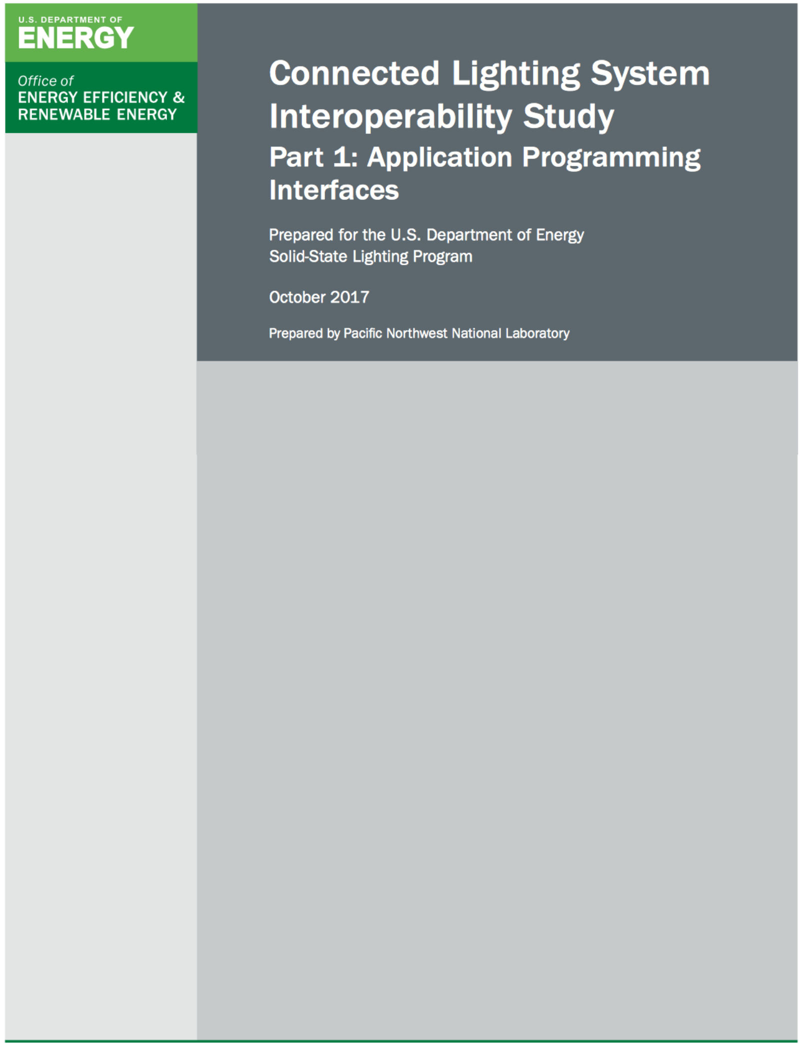
- CLS developers should make their APIs readily available and ensure that documentation is synchronized with software updates.
- CLS developers should name and organize API resources in readable, logical, and consistent ways.
- CLS developers should fully document API data models, including reporting unit (when applicable), data type, resolution, and accuracy.
- API developers should consider the implementation of override or prioritization schemes that support adaptive control of configurable system devices.
- API developers should consider providing support for multiple measurement units and time aggregations for reported data, and support for controls schemes beyond switching between or pushing out of new device profiles.
- The lighting industry should consider developing and adopting:
  - well-thought-out, maintained common information and/or data models
  - a well-thought-out, modern, and evolving common resource organization scheme
  - a common approach to authentication, with some minimum level of resistance to cybersecurity vulnerabilities

# For more information



## Research questions

1. How do API implementation and information models currently found in commercially available CLS vary?
2. What type of effort is required to exchange information between – or, more fundamentally, to integrate – heterogeneous and asynchronous resources residing in different CLS, via their APIs, into a single interoperable platform?
3. How might the implementation of real-life use-cases effectively characterize the level of interoperability found in CLS?


U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

Connected Lighting System Interoperability Study

Part 1: Application Programming Interfaces

Prepared for the U.S. Department of Energy
Solid-State Lighting Program

October 2017

Prepared by Pacific Northwest National Laboratory

# Next steps



## Research studies

- Continued focus on API's
  - ✔ Real-world early adopter use cases
  - ✔ Integration via emerging IoT platforms (e.g., Azure, AWS, Thingworx)
- Key new features enabled by interoperability and/or system integration
  - ✔ Streetlight asset information retrieval
  - ✔ Streetlight occupancy sensor integration
- Interoperability claims made by emerging technology platforms with significant manufacturer adoption
  - e.g. PoE, Bluetooth Mesh
  - Multiple use-cases

## Collaborate with DOE

- Review and comment on the report; revisions/expansions will be published as appropriate
- Make recommendations
  - Characterization topics
  - Integration approaches
  - Use-cases to explore and estimates of their relative value
- Contribute material
  - CLS with APIs
  - Access to non-lighting (e.g., asset management) systems with APIs

# PoE cable energy losses, part 1



## Motivation

- Explore the impact of cable selection on PoE lighting system energy efficiency
- Evaluate the effectiveness of cable selection guidelines recently introduced by the American National Standards Institute (ANSI) C137 Lighting Systems Committee

## Anticipated impact

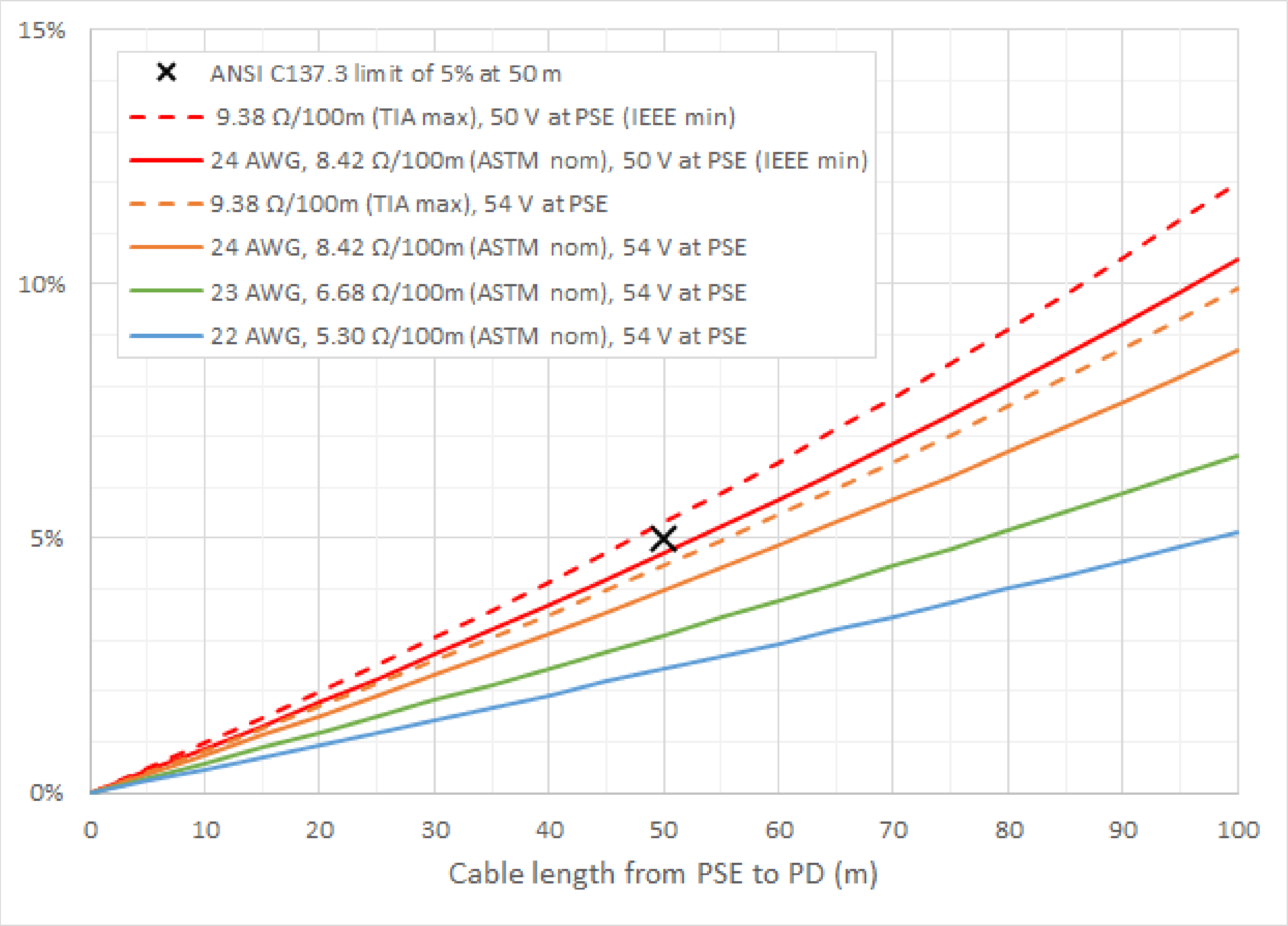
- Contribution to industry discussion on how the energy efficiency of PoE lighting systems might be predicted during design and/or validated once installed
- Validation of the effectiveness of ANSI C137.3, or recommendations for its improvement

# Specifying PoE cable resistance



- Cutsheets typically indicate compliance with standards that specify maximum cable resistance
  - In some cases, nominal and/or maximum DC resistance (DCR) in ohms (Ω) per 100 meters is indicated as well
  - Conductor resistance can vary due to actual diameter, twist rate, etc.
- Clause 33 of IEEE 802.3-2015 (802.3at) references Telecommunications Industry Association (TIA) specs
  - ANSI/TIA-568-C.2 for Category 5e or better cabling
    - References ANSI/NEMA WC 66/ICEA S-116-732-2013 for Category 6 and 6A
  - ANSI/TIA/EIA-568-A for Category 5 cabling
    - ANSI/ICEA S-90-661-2012 covers Category 3, 5, and 5e

# Expected PoE cable energy loss as % of PoE system energy



# Industry engagement

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COMMSCOPE®

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General Cable

# Test samples

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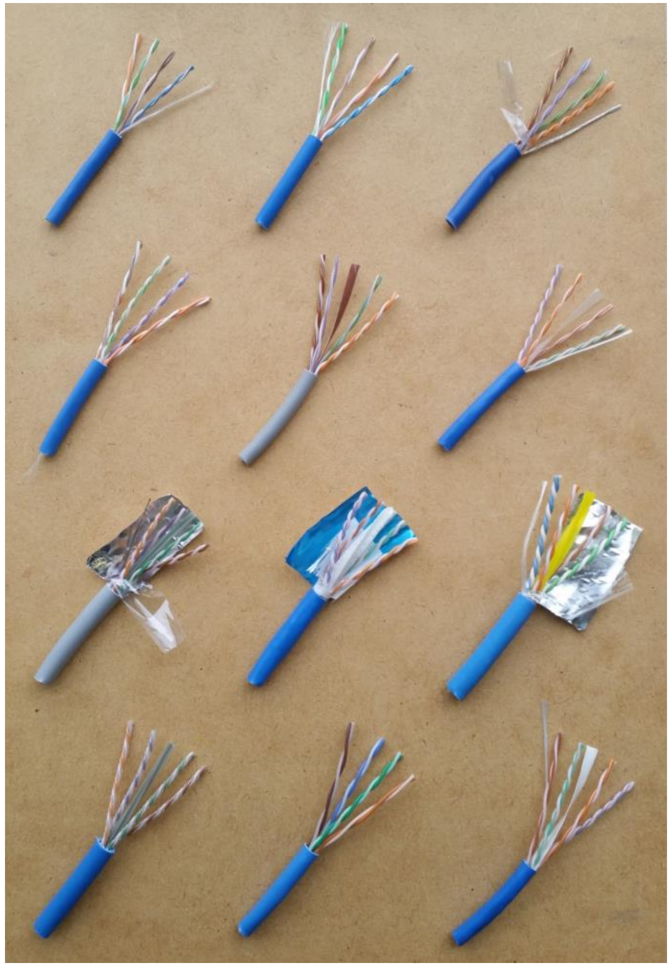
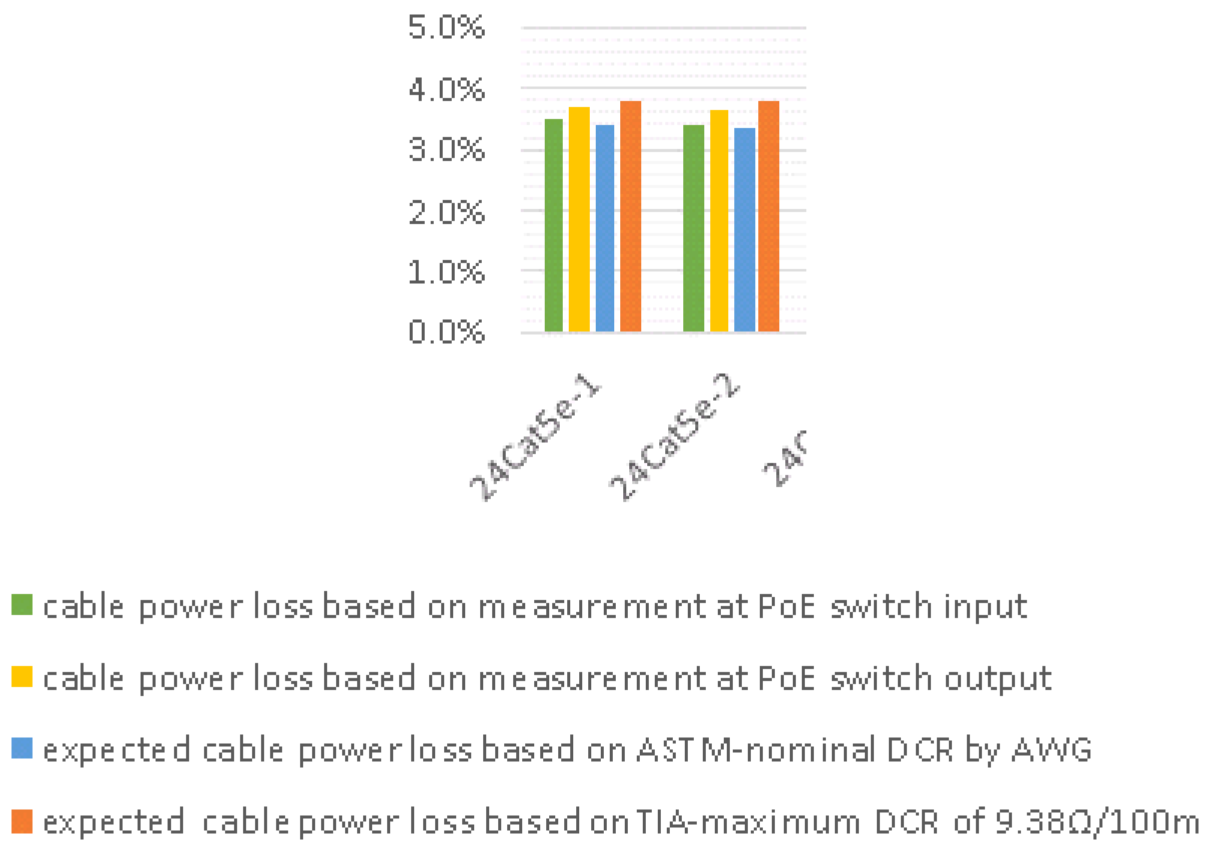
| Test ID | AWG | Category | Shielding | Fire rating | DCR |
|---|---|---|---|---|---|
| 24Cat5e-1 | 24 | 5e | U/UTP | CMP | ≤ 9.38 |
| 24Cat5e-2 | 24 | 5e | U/UTP | CMP | ≤ 9.38 |
| 24Cat5e-3 | 24 | 5e | F/UTP | CMP | ≤ 9.38 |
| 24Cat6-1 | 24 | 6 | UTP | CMP | ≤ 9.38 |
| 23Cat6-1 | 23 | 6 | U/UTP | CMP | ≤ 8.00 |
| 23Cat6-2 | 23 | 6 | U/UTP | CMP | 7.0 |
| 23Cat6-3 | 23 | 6 | F/UTP | CMP | ≤ 9.38 |
| 23Cat6A-1 | 23 | 6A | U/UTP | CMP | < 9.38 |
| 23Cat6A-2 | 23 | 6A | UTP | CMR | ≤ 9.38 |
| 23Cat6A-3 | 23 | 6A | U/UTP | CMP | ≤ 7.61 |
| 22Cat5e-1 | 22 | 5e | U/UTP | CMP | N/A |
| 22Cat6-1 | 22 | 6 | U/UTP | CMP | 6.5 |



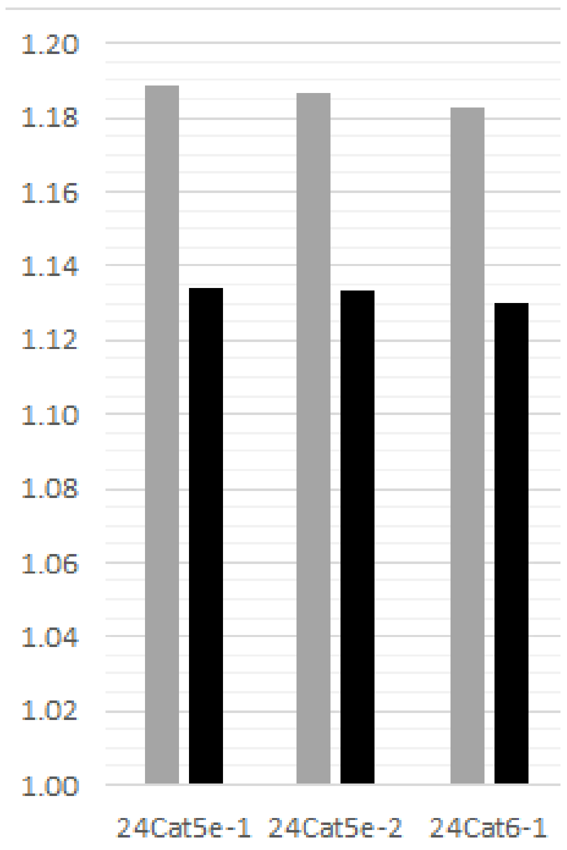
# Sample results



## Cable loss as a % of system energy




## System power relative to luminaire power



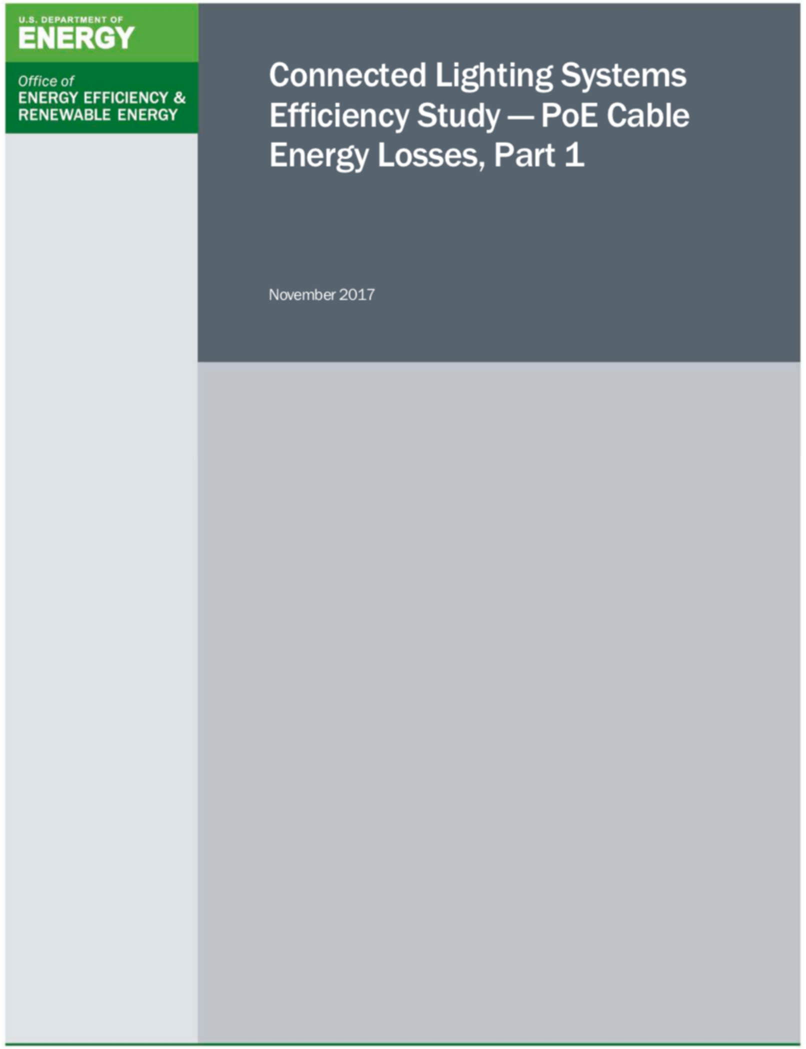
# Select recommendations

- Manufacturers of PDs and PoE switches should very clearly state in product documentation which types of Ethernet cabling (e.g., F/UTP) are compatible and incompatible.
- PoE switch manufacturers should state measurement accuracy for switch-reported PSE output power in product documentation.
- Lighting PD manufacturers should design their products such that input power and light output do not vary with cable length, or describe in product documentation how these attributes vary with cable length.
- Ethernet cable manufacturers should publish rated DCR values specific to each product.
- PoE lighting system designers should specify ANSI C137.3 minimum AWG as a function of luminaire input power.
- PoE lighting system designers/suppliers/installers should publish statistics for PoE cable lengths used on each project (e.g., minimum, maximum, mean, median), along with information on each model used (e.g., AWG, Category, fire rating, shielding).

# For more information

## Research questions

1. To what extent do power losses vary between models of cable differing in AWG, Category, fire rating, shielding, or manufacturer?
2. Is the ANSI C137.3 guidance effective in limiting power losses to less than 5% in a 50m cable from PSE to PD?
3. What is the range of maximum and nominal DCR values claimed for relevant Ethernet cables, and how does this compare with standard values?
4. Can cable power losses be determined from values reported by PSE or PD?
5. What have prior studies found regarding PoE cable energy losses?


U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Connected Lighting Systems Efficiency Study — PoE Cable Energy Losses, Part 1

November 2017

# PoE cable energy losses, part 2



## Scope currently in development

- Shielded cable
- More cable makes/models
- Physical installation characteristics
- Enhanced test setup

## Collaborate with DOE

- Review and comment on the report
- Make recommendations (e.g., specific physical characteristics to characterize, range of variation to explore)
- Contribute material (e.g., PoE cable, switches)

# Other studies in progress or development



## Energy reporting accuracy

- Connected outlets
- Connected street lighting controllers


## Key new features

- Feature characterization and performance
- Sensor characterization and performance
- Sensor integration and interchangeability


DALI 2

# New focus area: Grid Integration



- CLS integration examples
  - Electric grid systems with known issues (e.g., due to aging infrastructure, or outdoor infrastructure subject to environmental events)
  - Application-specific modifications to traditional electric grid systems
- Experimental scope examples
  - Whether CLS are compatible with the targeted grid system
  - Whether integration aids in managing and maintaining the grid system, thereby increasing the value of the CLS
- Evaluation and characterization examples
  - Outdoor CLS immunity to transient electrical disturbances when integrated with aging above-ground electrical infrastructure
  - Indoor CLS immunity to electromagnetic pulse (EMP)
  - CLS performance when tightly integrated with a renewable energy source and a associated backup devices in both on-grid and off-grid environments
  - CLS ability to adapt to grid events ranging from AC frequency reduction to pricing or other demand-response signals

# Questions?

MICHAEL POPLAWSKI

Pacific Northwest National Laboratory

2018 Lightfair