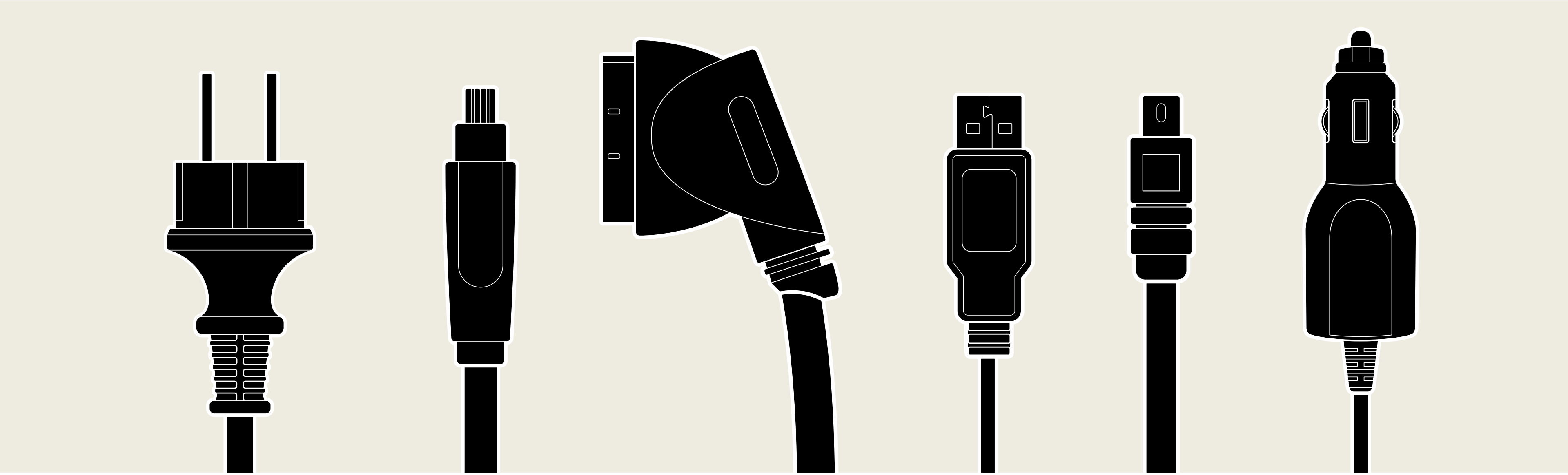
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Energy Design and Scoping Tool for DC Distribution Systems



National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, Colorado State University, Bosch Building Grid Technologies, and PVI Construction Management

PI: Stephen M. Frank, Senior Systems Engineer, NREL (Stephen.Frank@nrel.gov)

Project Summary

Timeline:

Start date: October 1, 2017

Planned end date: December 31, 2020

Key Milestones

1. Preliminary Savings Assessment (FY2018 Q4)
2. Electrical Network Model (FY2019 Q3)
3. DC Design Tool Developed (FY2020 Q3)

Budget:

Total Project $ to Date (Through FY2018 Q2):

- DOE: $56,486
- Cost Share: $0 (not yet documented)

Total Project $:

- DOE: $1,800,060
- Cost Share: $512,584

Key Partners:

Lawrence Berkeley National Laboratory
CSU Fort Collins
Bosch Building Grid Technologies
PVI Construction Management

Project Outcome:

This project will:

- Accurately model AC and DC loads and building electrical distribution systems
- Provide a fair comparison between AC and DC distribution design alternatives
- Facilitate cost/benefit analysis for DC distribution systems

Project Team

Science

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Education

BERKELEY LAB

iUNIT

PVI
DESIGN AND BUILD OF TECHNICAL FACILITIES

ENERGY INSTITUTE
COLORADO STATE UNIVERSITY

BOSCH

THE ALLIANCE CENTER

EMerge ALLIANCE

Industry

Advocacy

Steve Frank
NREL

Rois Langner
NREL

Rich Brown
LBNL

Michael Wetter
LBNL

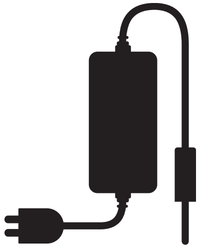
Dan Zimmerle
CSU

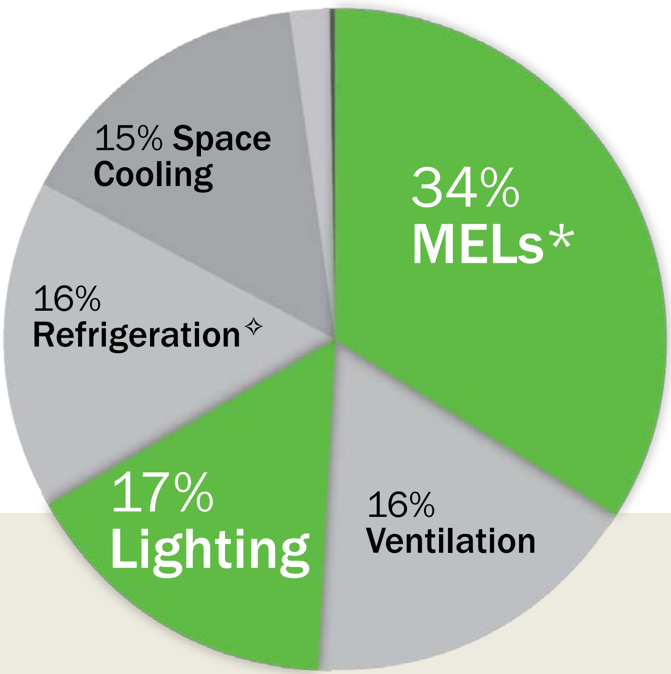
Jim Cale
CSU

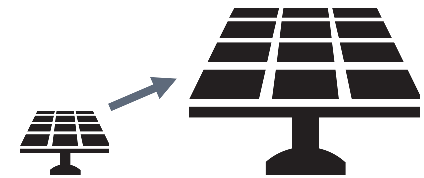
Tim Strunck
Bosch

Sandy Vanderstoep
PVI

The DC Landscape







80%

Electricity will flow through **power electronics converters** by 2030

Predominately DC load

(green pie pieces)

* Includes computers, electronics, and other miscellaneous loads

✧Sometimes included with MELs

14%

Average **AC-DC conversion loss**

2.5x

Growth in PV installations from 2012 to 2017

Sources: DOE Power America website (2018); EIA (2012); Garbesi, Vossos, and Shen (2011); Perea et al. (2018)

Challenge

It’s a Direct Current World Out There

DC distribution systems can **save both energy and money…**

…but **how much?**

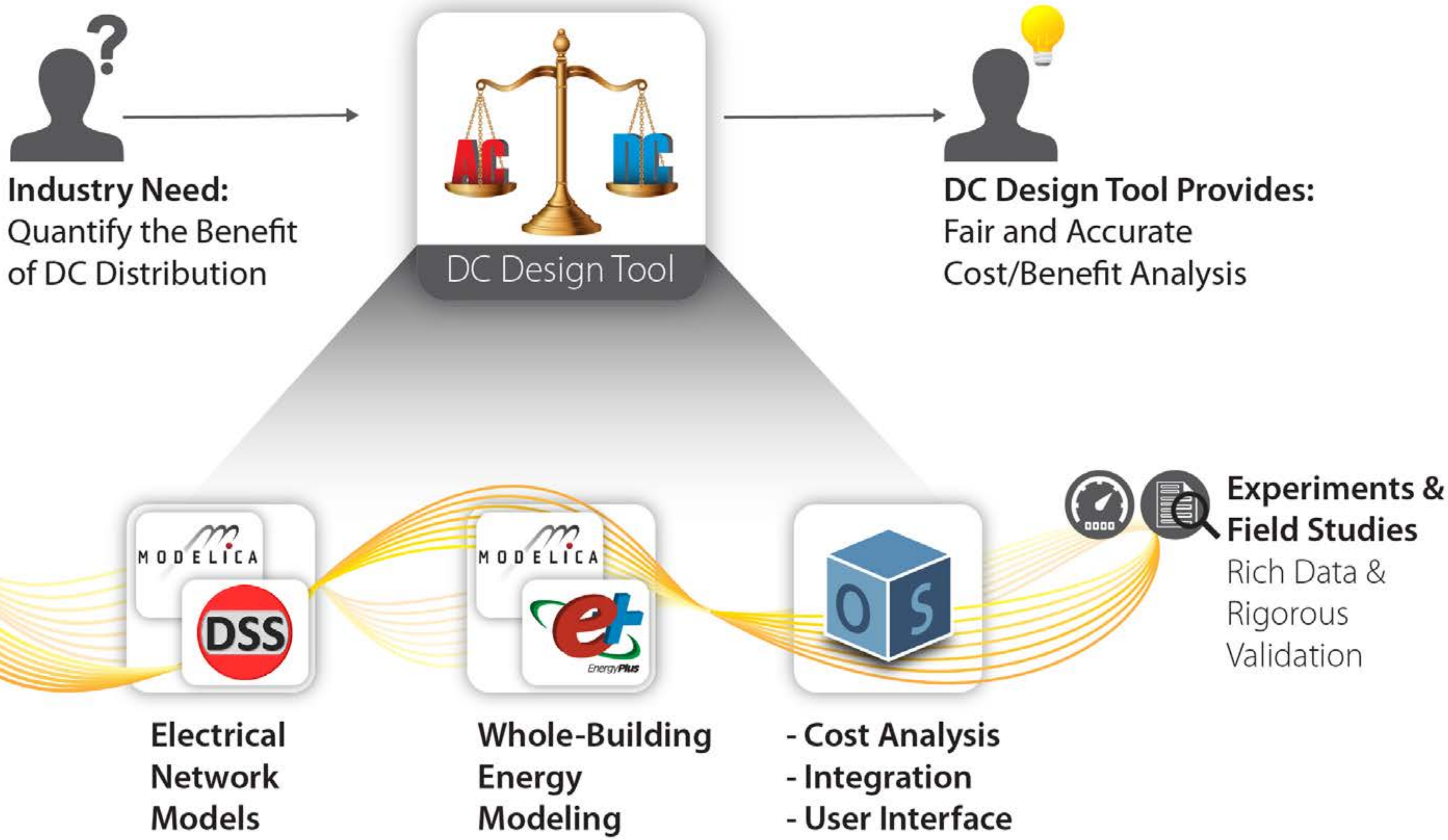
To answer that question, industry needs **rigorous and accurate** analysis tools

Existing Studies

- Inconsistent assumptions
- Lo-fi models
- Dubious claims
- Conflicting results

Computing Equipment | Consumer Electronics | Motor Drives | Electric Vehicles | Energy Storage | Onsite Generation

Approach



AC
DC
DC Design Tool
Industry Need:
Quantify the Benefit
of DC Distribution
DC Design Tool Provides:
Fair and Accurate
Cost/Benefit Analysis
MODELICA
DSS
MODELICA
EnergyPlus
O
S
Experiments & Field Studies
Rich Data &
Rigorous
Validation
Electrical Network Models
Whole-Building Energy Modeling
- Cost Analysis
- Integration
- User Interface

Knowledge Gaps

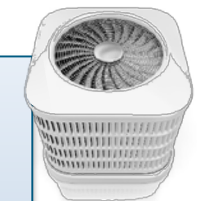
Efficiency of Consumer Power Electronics Converters

Measure device efficiency through experiments and field data collection

Efficiency of Existing Building Electrical Distribution Systems

Develop detailed and accurate electrical models for both AC and DC system components

Effect of DC Distribution on Thermal / HVAC System Performance



Integrate electrical network models with building energy models; validate experimentally

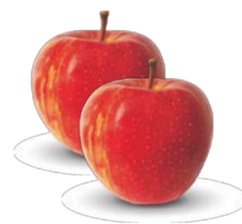
Project Impact

The DC Energy Design and Scoping Tool will…

Fully capture effects of **converter losses** and device **part-load ratios**

Ensure accuracy via thorough **experimental validation**

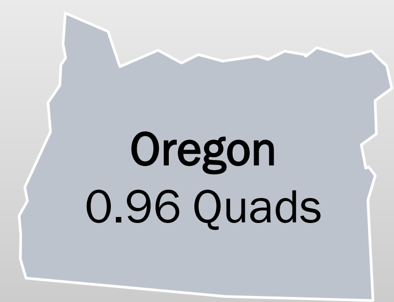
Leverage **whole-building energy modeling tools** to calculate **HVAC impacts**



Provide a **fair comparison** between AC and DC design alternatives

DC Technical Potential Savings in 2030

U.S. buildings primary energy (electricity): 40 Quadrillion BTU
Electricity delivered through power electronics: 80%
Minimum estimated savings per converter: 3%

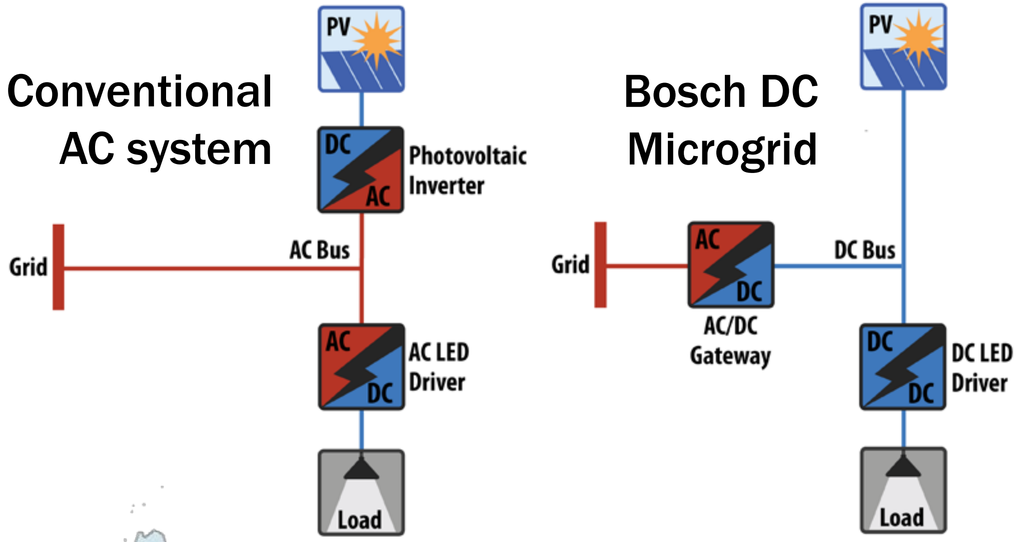


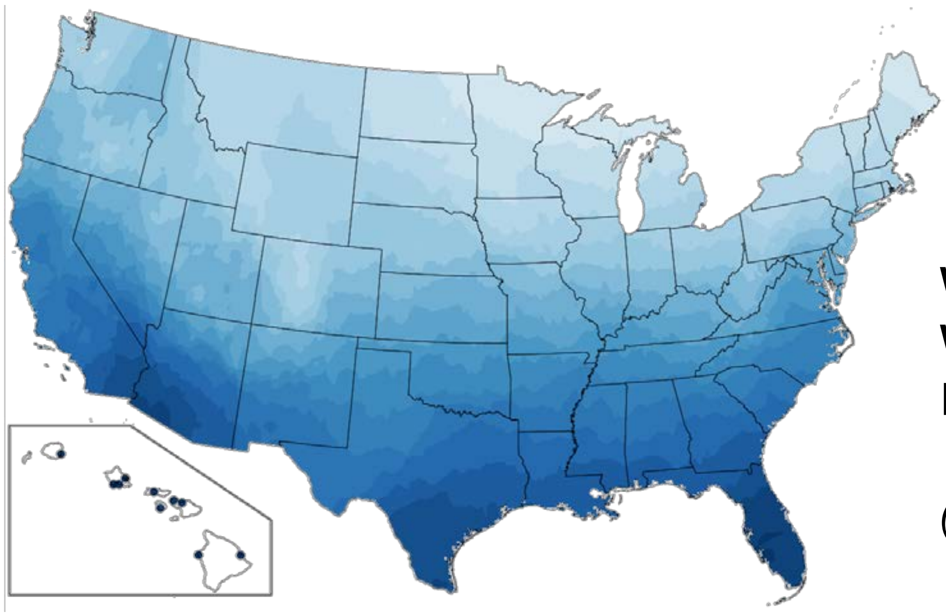
$40 \times 0.8 \times 0.03 = 0.96$ Quads ($19 Billion) per year

Expertise: NREL + Bosch

Modeled energy savings for Bosch DC microgrid for high-bay lighting

- 4 building types
- 554 geographic locations
- Included HVAC impacts





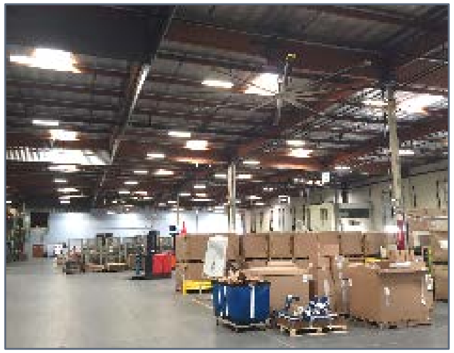
Warehouse: DC Microgrid Whole-Building Energy Savings
Darker Blue = Greater Savings

(Fregosi et al., 2015)

Expertise: Bosch Building Grid Technologies

DC microgrid demonstration at Honda distribution facility in CA

- Total Load: 205 kW
- PV Generation: 287 kW
- Battery: 180 kW / 540 kWh
- Loads include luminaires, fans, forklift chargers



Images: *Courtesy of Bosch Building Grid Technologies*

Expertise: CSU

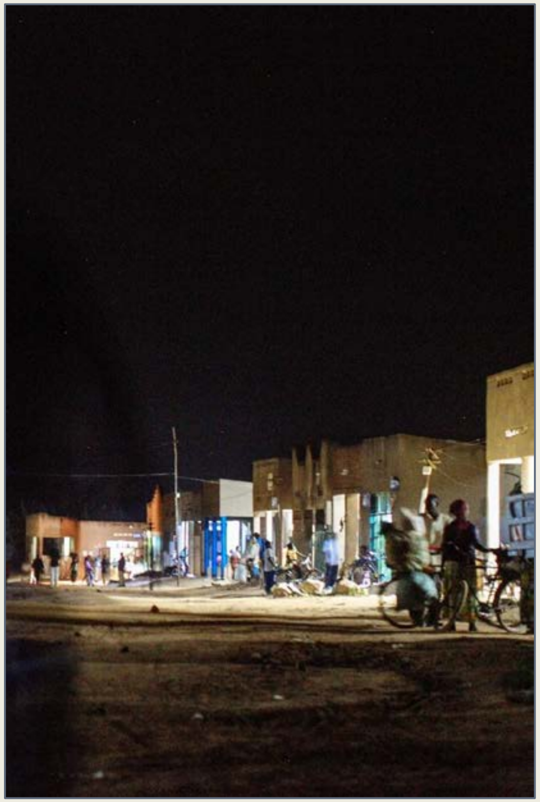
CSU Powerhouse Campus Capabilities:

- 4 x 80 kW equipment test bays
- AC and DC characterization equipment
- Extensive electrical measurement and field test experience

EV Test System

Lithium Ion Battery

DC Test Rack



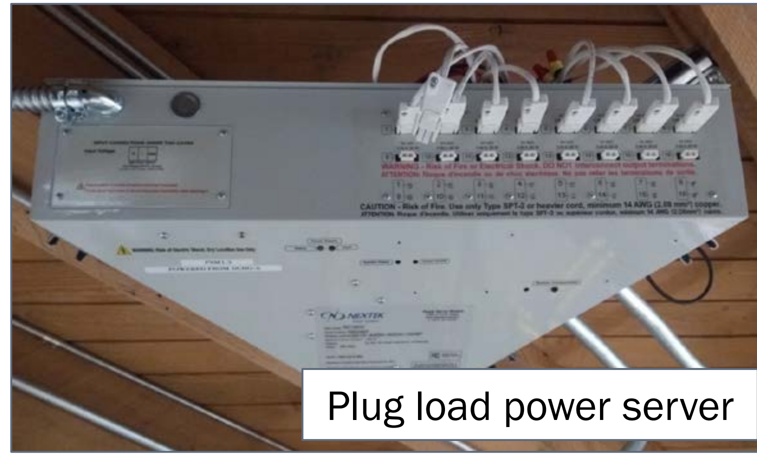
CSU researchers have developed innovative low-power DC microgrids for the developing world

Image: *Village power image courtesy of MeshPower*

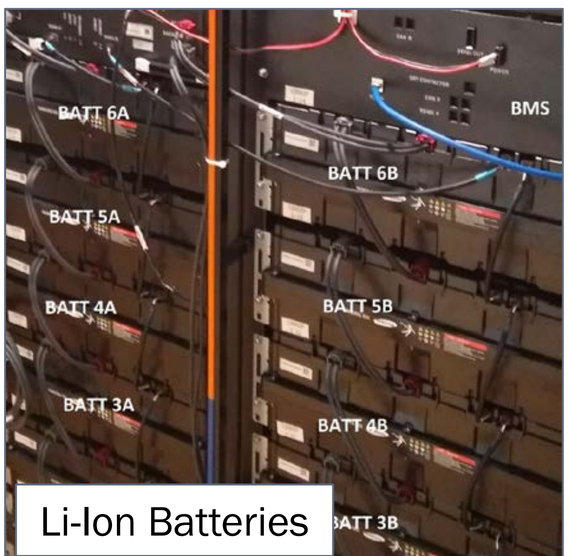
Expertise: PVI / Alliance Center

DC microgrid demonstration at the Alliance Center in Denver, CO

- Multiple voltages: 380 V_{dc}, 24 V_{dc}, 12 V_{dc}, 5 V_{dc}
- Lighting, plug loads, and electric vehicle charging
- Integrates on-site PV generation

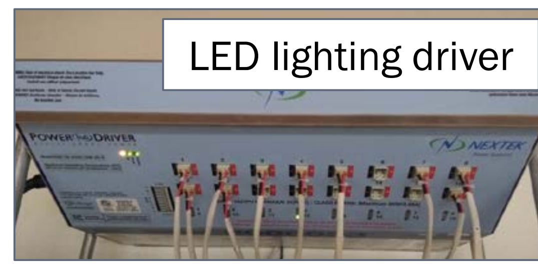


Plug load power server



Li-Ion Batteries

380 V_{dc} Switchgear



LED lighting driver

DC plug load power ports

Images: *Courtesy of EnSync Energy Systems and PVI Construction Management*

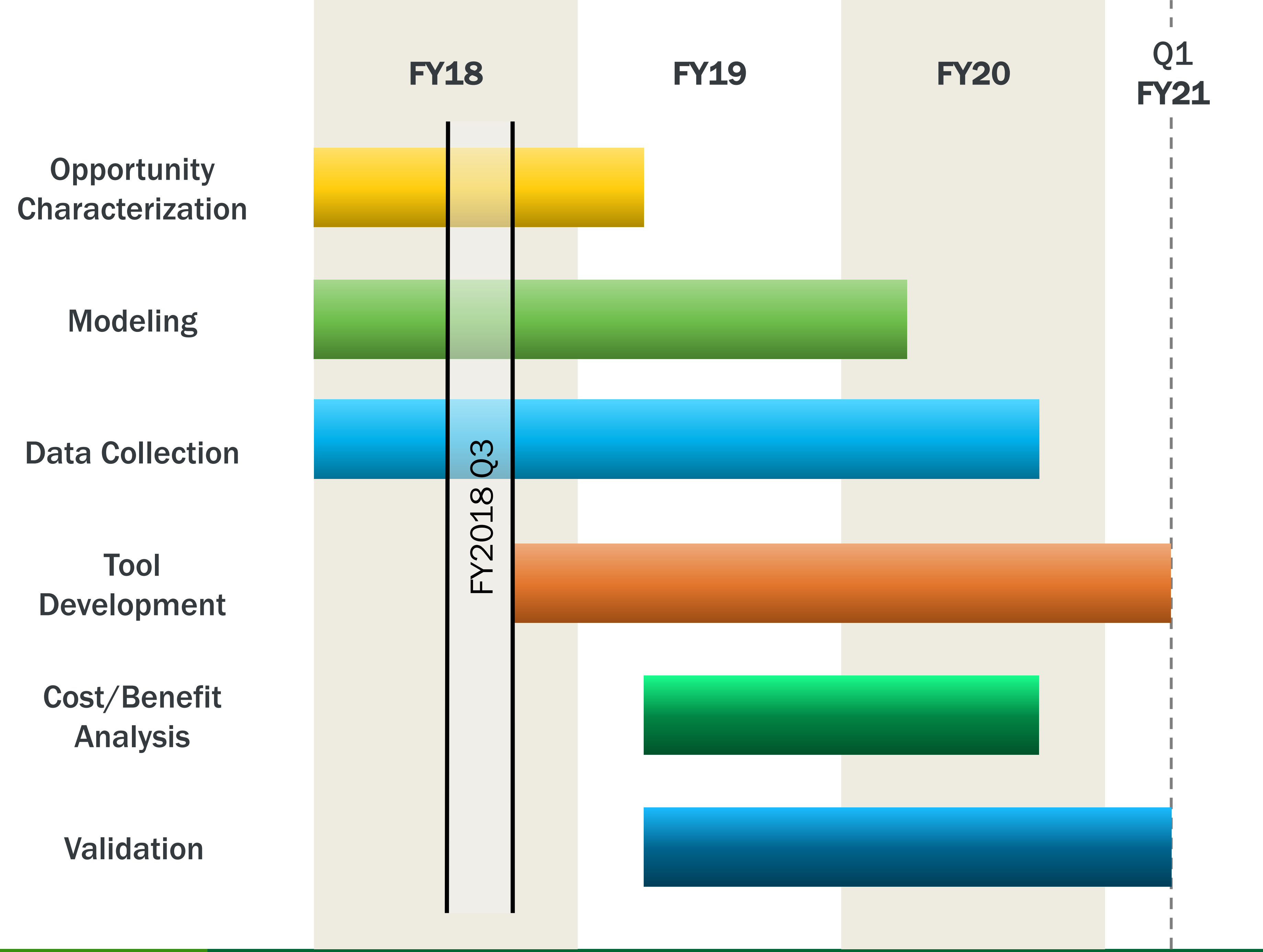
Stakeholder Engagement

1. Technical advisory group to guide project and **ensure industry-relevant outcomes**
2. Work with DC equipment manufacturers to **characterize DC device efficiency**
3. Architect DC design tool to **complement commercial design software products**
4. Perform public beta test to gather user feedback and **refine tool** prior to release

Research Needs

The project team is currently seeking…

1. AC and DC **consumer products** for load characterization experiments
2. **Contacts** familiar with commercial electrical and architectural design tools



FY18
FY19
FY20
Q1
FY21
Opportunity Characterization
Modeling
Data Collection
Tool Development
Cost/Benefit Analysis
Validation
FY2018 Q3

Thank You

National Renewable Energy Laboratory
Lawrence Berkeley National Laboratory
Colorado State University
Robert Bosch LLC
PVI Construction Management

PI: Stephen Frank, PhD
Senior Systems Engineer (NREL)
303-275-4249 / Stephen.Frank@nrel.gov

REFERENCE SLIDES

Project Budget

Project Budget:

Total Budget:	$2,312,644	(By Budget Period: $807K, $757K, $757K)
DOE Portion:	$1,800,060	(By Budget Period: $590K, $605K, $605K)
Cost Share:	$512,584	(By Budget Period: $197K, $157K, $157K)

Variances:

3 month, no-cost extension (brings project duration to 3.25 years)

Spend to Date (through FY2018 Q2): $56,486*

*Does not reflect uninvoiced FY2018 subtier partner costs

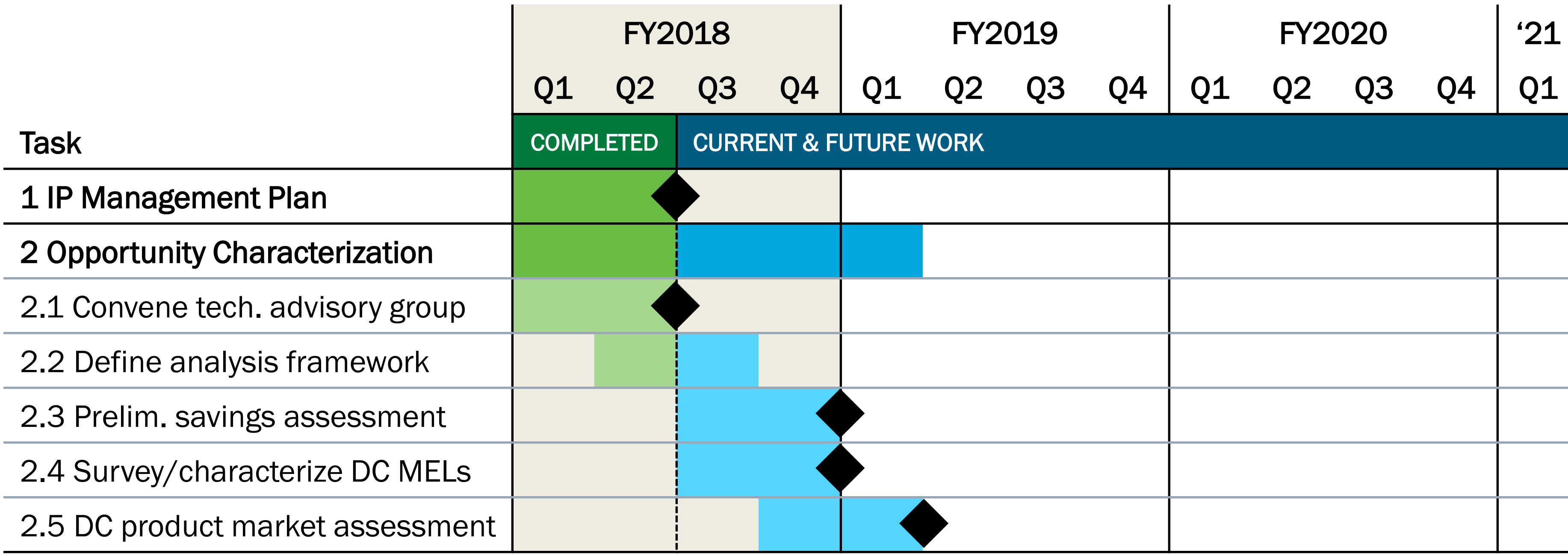
Additional Funding: Cost share from CSU Fort Collins, Bosch Building Grid Technologies, EMerge Alliance, The Alliance Center, and iUnit

Budget History			
FY2018 (current + projected)		FY2019 – Dec 31, 2020 (planned)	
DOE	Cost-share	DOE	Cost-share
$590,000	$197,528	$1,200,000	$315,056

Project Plan and Schedule

Project Start: October 1, 2017

Project End: December 31, 2020



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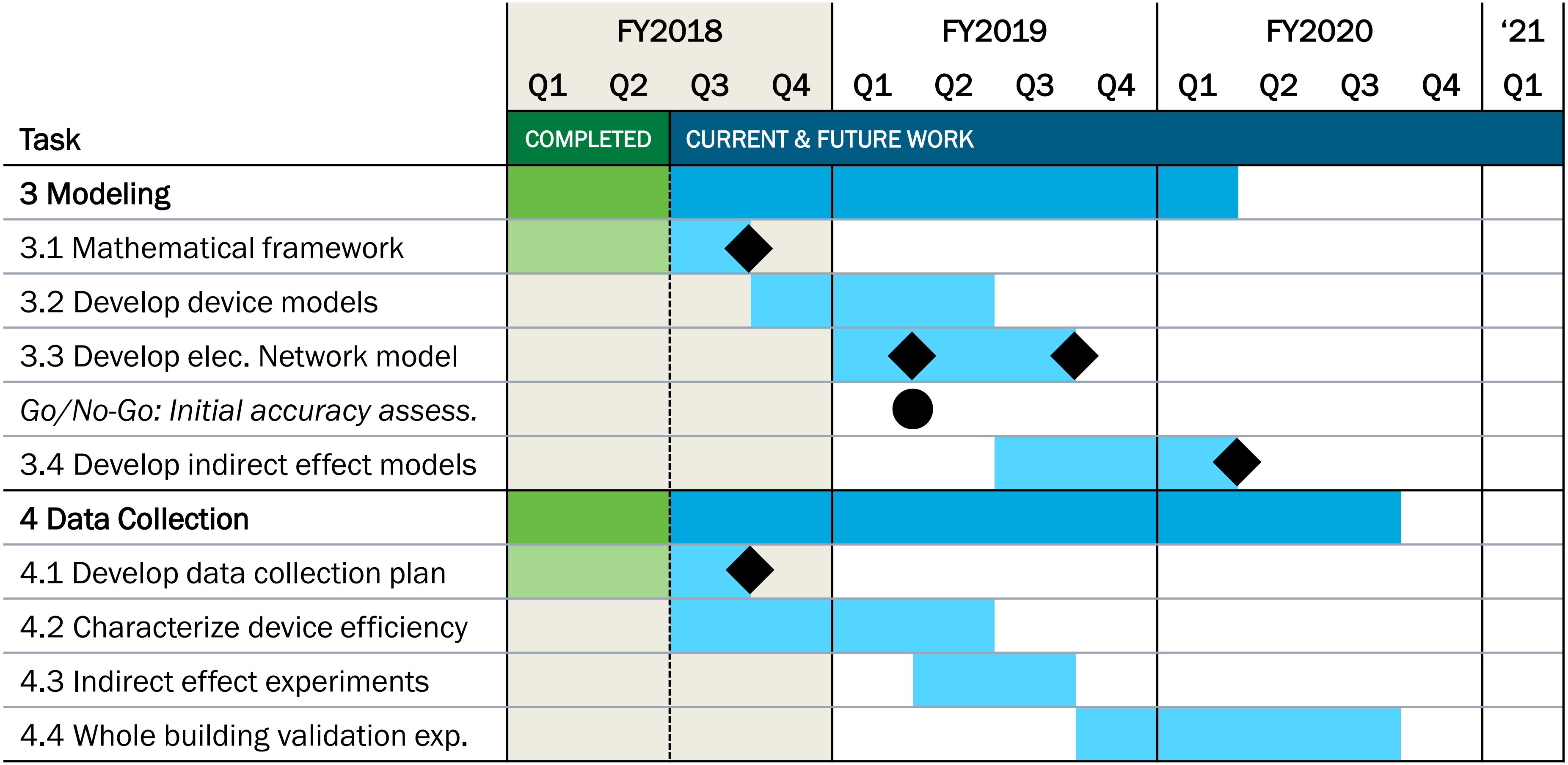
Completed Task/Subtask   Active Task/Subtask   ◆ Milestone   ● Go/No-Go Decision

Project Plan and Schedule (Cont.)



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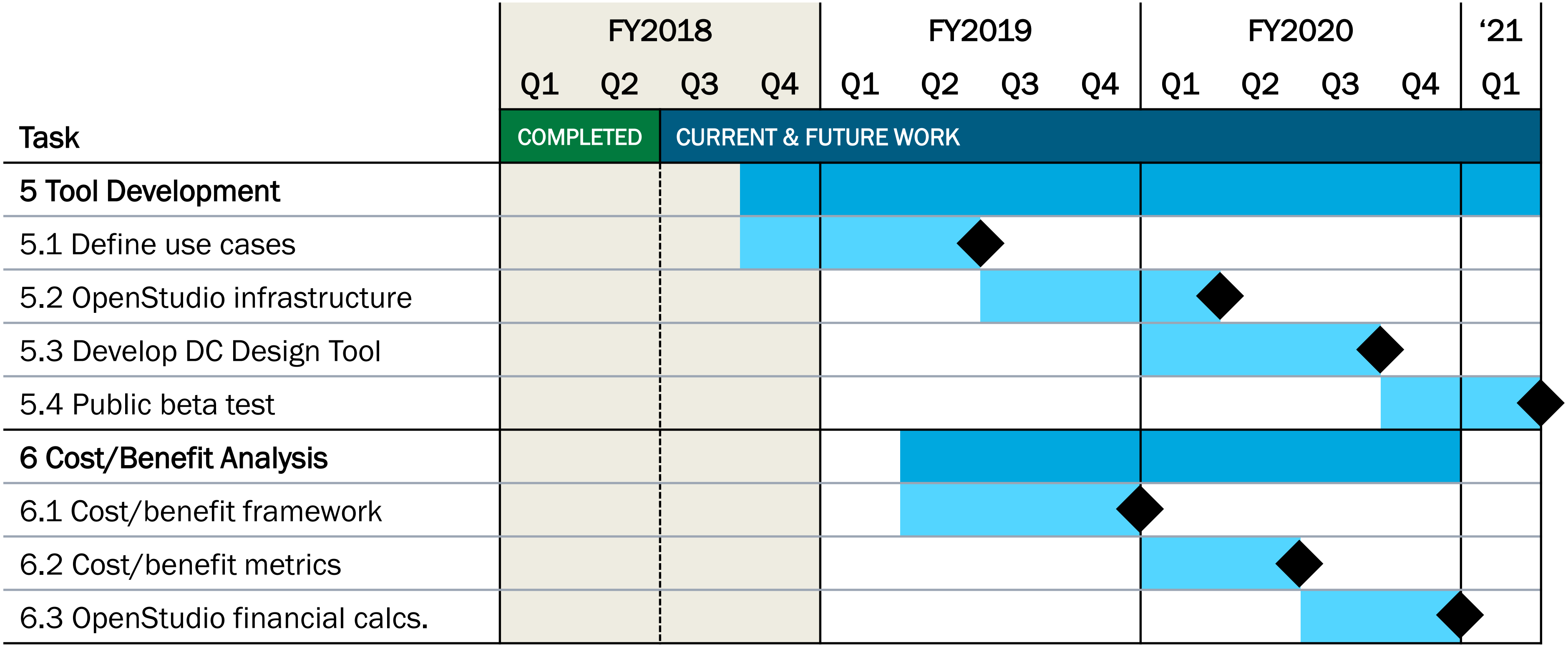
Project Plan and Schedule (Cont.)



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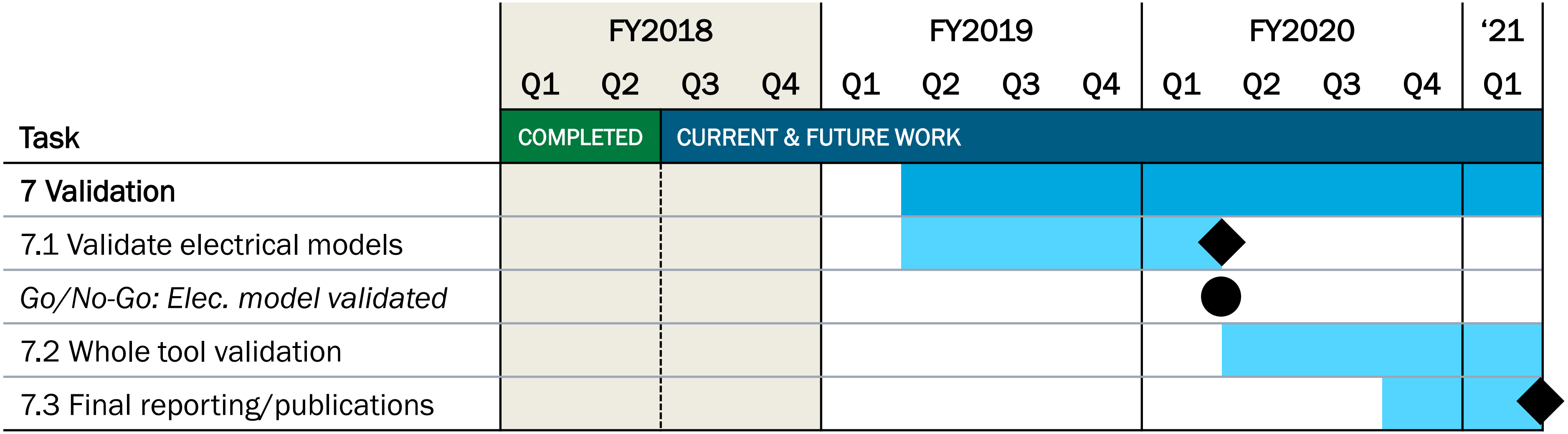
Project Plan and Schedule (Cont.)



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