NREL
NATIONAL RENEWABLE ENERGY LABORATORY





Smart Ports
Technology Advancements in Intermodal Transportation

Brett Oakleaf, NREL - Ports/Airports Collaboration Leader

March 7, 2018

Topics

1) Electrification Progression

- Marine
- Locomotive
- Semi (Class 8) Trucks

2) Electrification Needs

3) Renewable Energy Trends

- Off-Shore Wind
- Solar PV
- Energy Storage

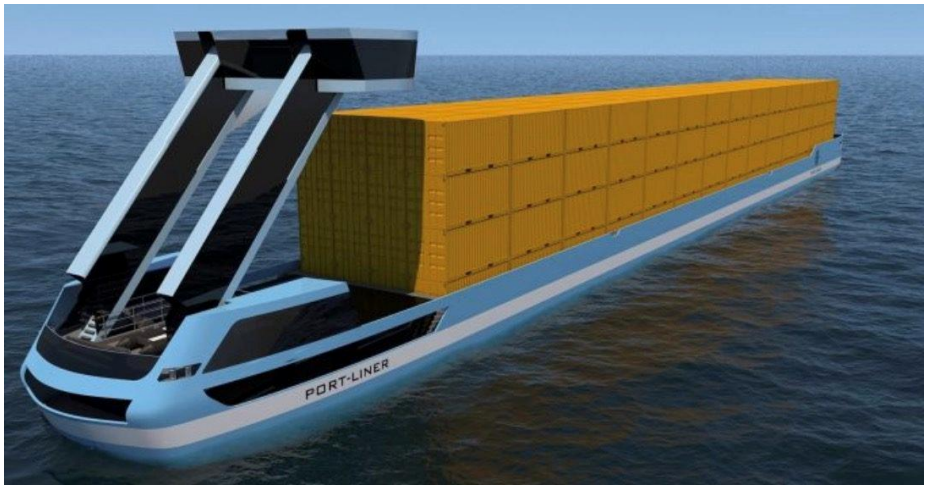
4) NREL's capabilities

- Transportation Group
- Visualization
- Cyber Security

Marine Electrification

Hybrid (Diesel/Electric) propulsion

Easy integration
Greater fuel efficiency
Lower emission
Wartsila, Rolls-Royce, Siemens



All Electric propulsion

Dutch company: Port-Liner
Carrying capacity: 280 containers
ISD: Fall 2018
Routes: Between ports in Europe

Marine Electrification

All Electric propulsion

Hauling up to 2,000 tons of coal
2.4 MWh Battery/Super-Capacitors
~ 24 Tesla Model 100D car batteries
~ 50 Mile range
Maiden voyage – November 2017

All Electric propulsion

Sweden company: HH Ferries
~ 800 ft long/~ 8,500 tons
Projected: 7.4M people/1.9M cars
Routes: ~2.5 miles (Sweden – Denmark)

Marine Electrification

Marine Electrification

Autonomous/Electric

Norwegian: Yara Birkeland
Carrying capacity: 100 – 150 containers
Cost: $25M (3x conventional), but offset by 90% annual operating cost savings
~ 37 Mile range
Maiden voyage – 2018
Transition to full autonomous by 2020

Bottom line:

=> Competitive Advantage to Ports that have these capabilities

Locomotive Electrification

Hybrid Diesel/Electric propulsion

Companies: GE, Toshiba

Limited applications

Yard Shunting, European Passenger

All Electric propulsion

Dutch National Railway

100% Wind powered

Projected: 600K passengers and 5,500 train trips per day

Locomotive Electrification

Electric

India Railway

Goal: 100% Electrification

~ 11,000 kM network

RE Goal: 175 GW of Solar PV by 2022

(1/2 of installed capacity)

Autonomous

Australia

Rio Tinto

100 kM route

Port of Houston – Investigating Autonomous Freight Shuttle System (5 miles – intraport)

Semi (Class 8) Trucks

Natural Gas (LNG/CNG)

Freightliner, Mack

Lower cost fuel

Lower emissions

~500 mile range

Mraesk

Hydrogen Fuel Cell

Toyota, Nikola

Toyota ~ 200 miles

Nikola ~ 1200 miles (2020)

US Department of Energy - SuperTruck Program

Super Truck II
Government-Industry Collaboration

SuperTruck II aims to improve freight efficiency by more than 100% and demonstrate 55% engine brake thermal efficiency.

5 Industry Teams Led By:

Volvo
Cummins / Peterbilt
Navistar
Daimler Trucks
PACCAR

Semi (Class 8) Trucks

Electric

Cummins, Thor, Tesla
Lower cost of ownership
No emissions
~300 - 500 mile range

Port Implications

- *Ports implementing Emission reduction plans*
- *Need for regional, nation-wide fast charging network*

Growing Inventory of Port Electric Vehicles

EV Yard Tractors

EV Drayage

Electric Catenary

Automated Guided Vehicles…

Challenges / Opportunities

Charging Infrastructure
Charging Protocols
Charge Management
Battery Secondary Use
Grid Services
Extreme Fast Charging…

Electrification Needs

- *Need for Shore Power*
  - *Not only container, but cruise ships too*
  - *Coordinating infrastructure needs*
- *Load control/growth*
  - *Don't want simultaneous charging (new higher peak demand)*
  - *5x – 8x load growth*
- *Opportunities*
  - *Ship 2 Grid (S2G)*
  - *Opportunities for real time pricing – low cost energy capture*
  - *Reefer units – load control*

Future Power Supply

Where is this power going to come from?

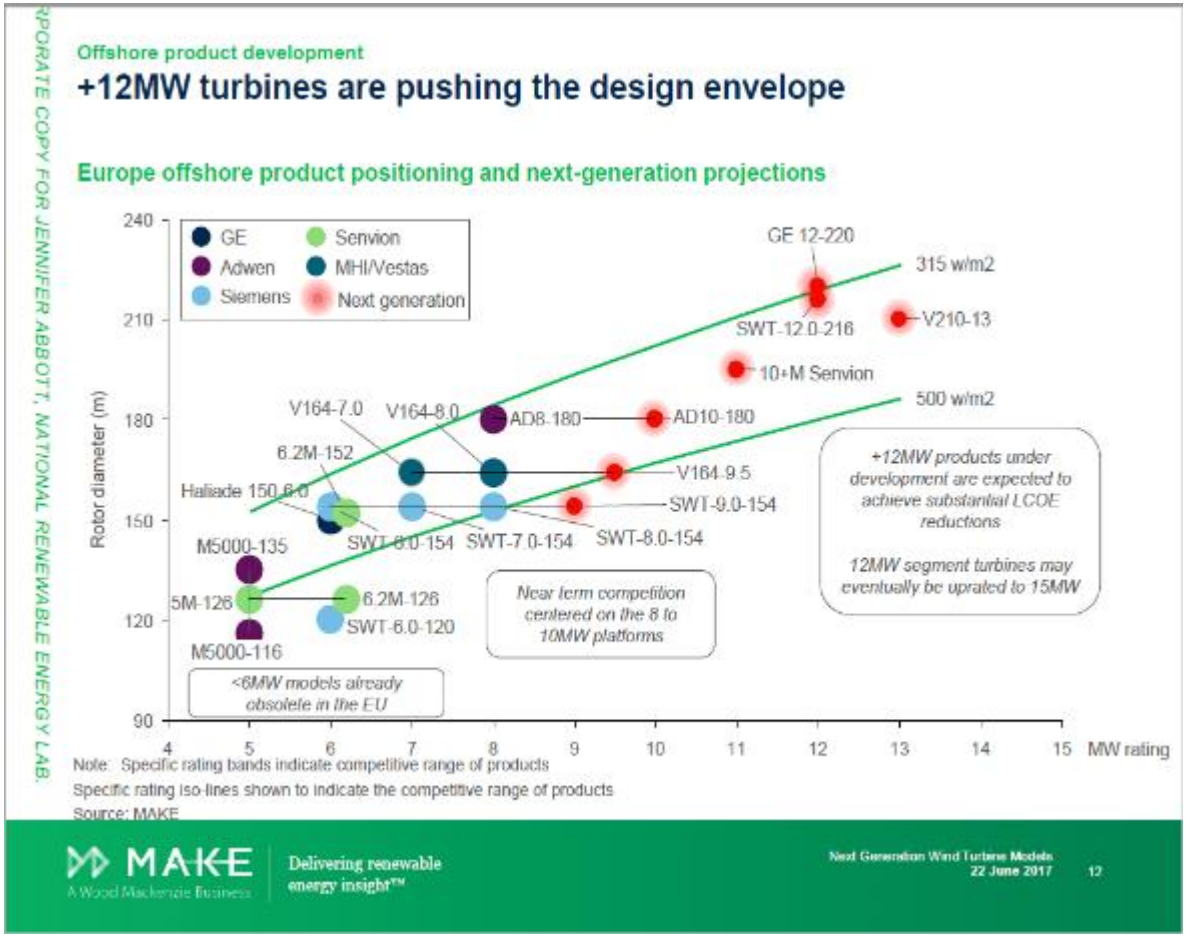
Oil and Gas Experience Helped Accelerate First Generation

- Floating wind is based on oil & gas technology and reliability criteria that have resulted in successful but expensive designs
- Unit October 2017 there were only 6 utility-scale floating wind systems
- First multi-turbine project: October 2017 in Scotland – 30-MW Statoil
- System engineering approach is needed to lower cost

Knowledge Transfer

Scaling Turbines to 15-MW - New Technology Challenges

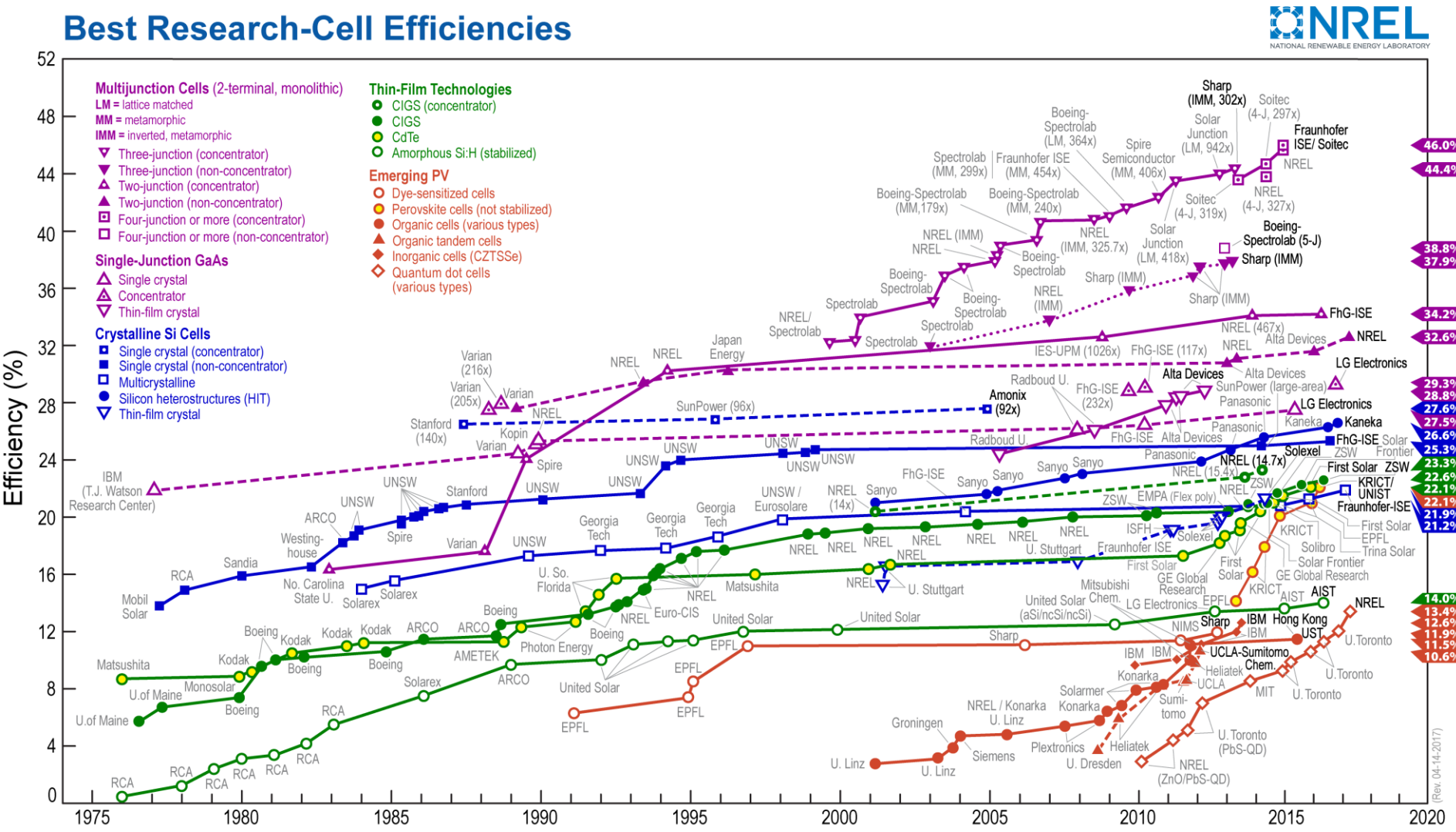
- Key system cost reduction driver is turbine size (5x land-based)
- Component weight minimization a strong imperative; blades, generators, towers, substructures
- 110-m blade lengths: more modular designs, lighter materials, sub-component testing, innovative manufacturing
- Larger test facilities and alternative test methods
- Reduced dependence on vessels



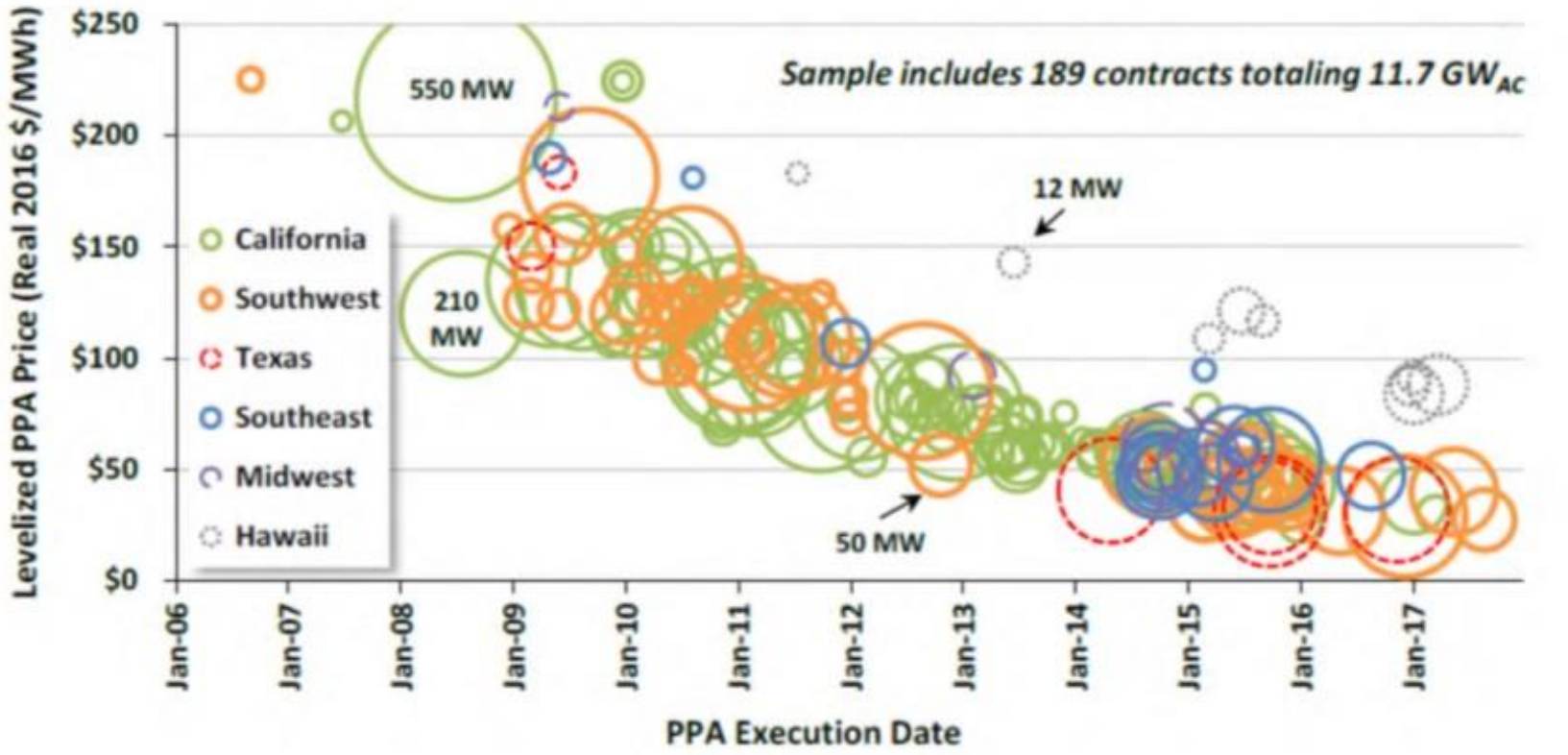
Data Source: MAKE Consulting 2017

Will mature large-scale offshore wind turbines be adapted for future land-based wind plants?

PV Record Cells – Current Status



PV Costs – Falling Rapidly

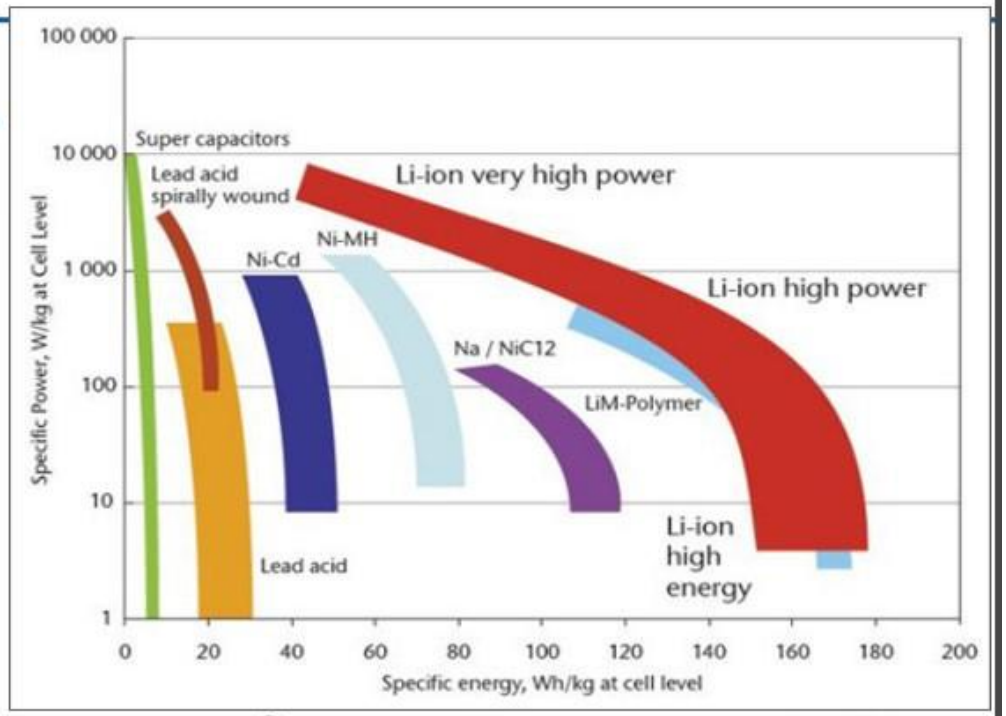


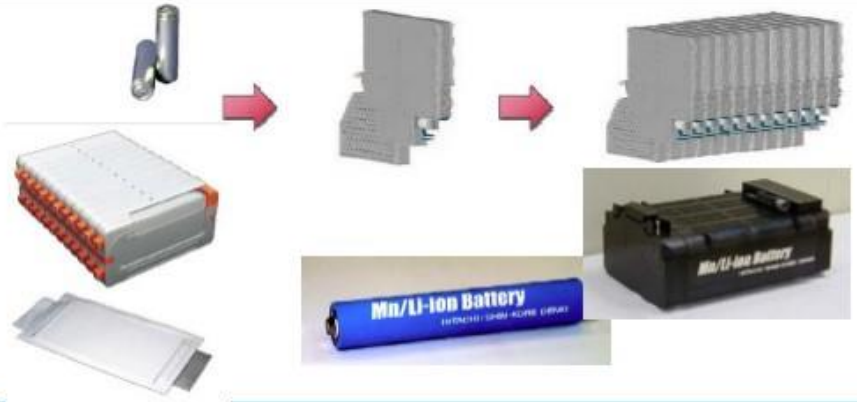
- There has been a strong, steady downward PPA price trend since 2006, with an average levelized price signed in 2016 of ~$35/MWh.
- The median unsubsidized LCOE of utility-scale PV projects built in 2016 was below the DOE 2020 SunShot target of 6 cents/kWh.

Source: Bolinger, M. , J. Seel, K. H. LaCommare. 2017. *Utility-Scale Solar 2016:An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States*. Berkeley, CA: Lawrence Berkeley National Laboratory.

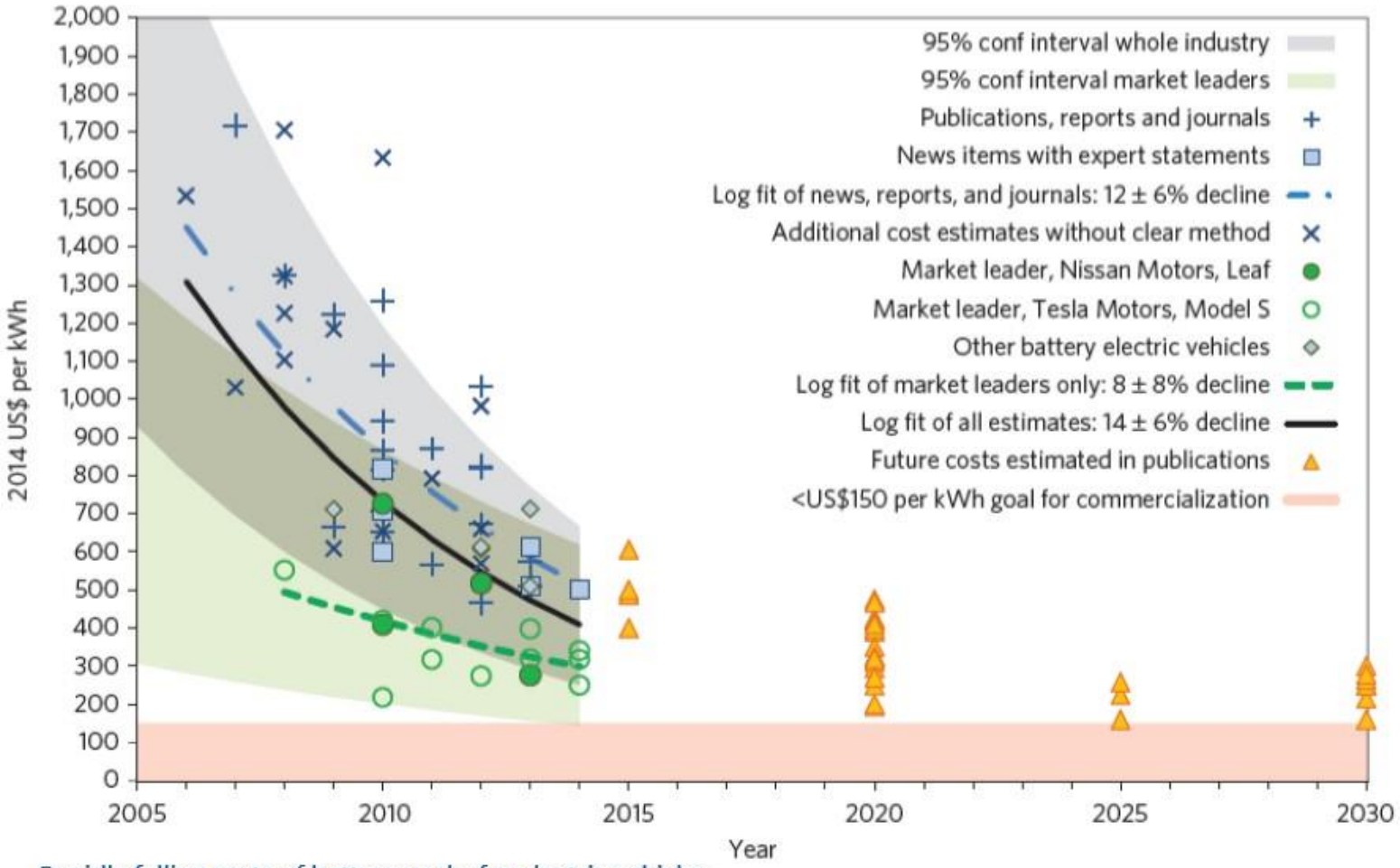
Li-Ion Batteries

- Lithium-ion battery technology is expected to be the energy storage choice for (xEVs and grid storage) in the coming years
- Better (energy & power) performance than other existing technologies
- Trends toward large format cells
  - Higher volume &weight efficiencies and packaging
  - Lower # of connections and components
  - Lower system cost





Li-Ion Battery Cost is Falling



Rapidly falling costs of battery packs for electric vehicles
Björn Nykvist and Måns Nilsson (Nature Climate Change, March 2015)

Bringing analytic resources to the table for novel research outcomes

Vision: a systems approach to integration with near real time analytics


asecase, Energy:Basecase
$3M
$2.5M
$2M
$1.5M
$500K
$500K
O&M Costs
Capital Costs
Demand Cost
Energy Cost
Energy Savin
Demand Savi
Saturday, April 02, 2016 08:30
0.26 MW
kW
5000
3000
1600
SAT
MON
THU
South (35 kW)
South (10 kW)
Garage (270 kW)
East (1,153 kW)

Unique Value Proposition of NREL's Cyber Security team

- **Deep expertise** in:
  - Power systems Supervisory Control and Data Acquisition (SCADA)
  - Cybersecurity
  - Networking
  - Distributed energy resources (DERs).

- **Advanced research capabilities** at the Energy Systems Integration Facility's (ESIF's) Systems Performance Laboratory, including:
  - Complete test bed with modular power systems, communications, and cybersecurity capabilities
  - Vendor and technology agnostic perspective
  - Ability to pen test at interface, component, or systems level.

- **Flexibility** to expand to water, oil and gas, and thermal systems testing for cybersecurity and resilience.

NREL, 35452

NREL, 35445

Summary

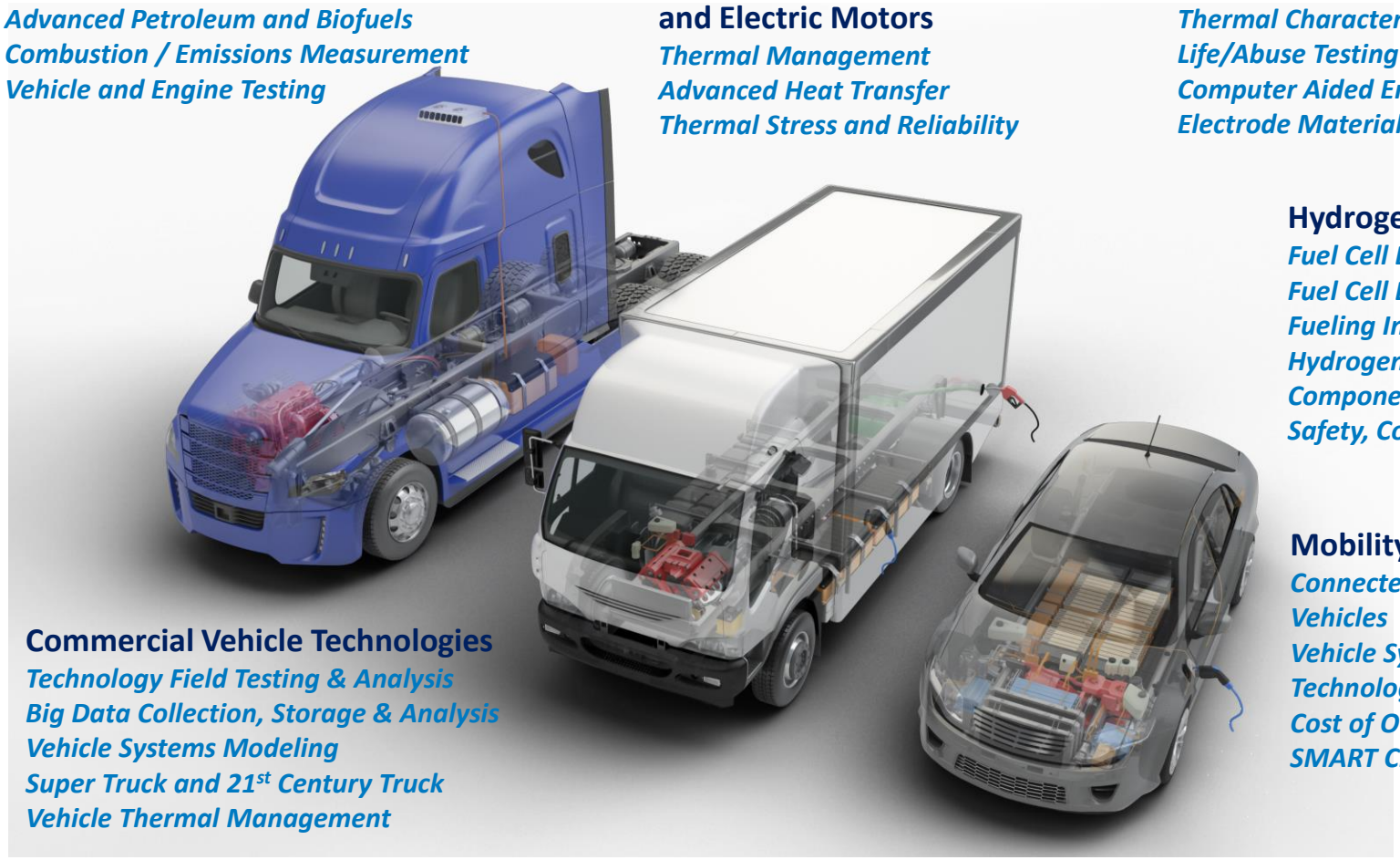
- *Growing reliance/need for coordination between IT & energy systems*
  - *Energy systems & infrastructure often overlooked*
  - *Vulnerabilities growing (IoT), metering, controls, etc*
- *Growing vehicle electrification & autonomy*
  - *Growing collaboration/interdependency between Port, City, and regional freight movement*
- *Could Port become virtual power plant?*
  - *Solar PV (Perovskites)*
  - *Large amount of energy storage*

NREL Transportation and Vehicle RD&D Activities

Advanced Combustion / Fuels
Advanced Petroleum and Biofuels
Combustion / Emissions Measurement
Vehicle and Engine Testing

Advanced Power Electronics and Electric Motors
Thermal Management
Advanced Heat Transfer
Thermal Stress and Reliability

Advanced Energy Storage
Thermal Characterization / Management
Life/Abuse Testing and Modeling
Computer Aided Engineering
Electrode Material Development



Hydrogen and Fuel Cells
Fuel Cell Electric Vehicles
Fuel Cell Buses
Fueling Infrastructure
Hydrogen Systems and Components
Safety, Codes and Standards

Mobility Systems
Connected and Autonomous Vehicles
Vehicle Systems Modeling
Technology Adoption
Cost of Ownership Modeling
SMART Cities Columbus

Commercial Vehicle Technologies
Technology Field Testing & Analysis
Big Data Collection, Storage & Analysis
Vehicle Systems Modeling
Super Truck and 21st Century Truck
Vehicle Thermal Management

Infrastructure and Impacts Analysis
Vehicle-to-Grid Integration
Integration with Renewables
Charging Equipment & Controls
Fueling Stations & Equipment

Vehicle Deployment / Clean Cities
Guidance & Information for Fleet Decision Makers and Policy Makers
Technical Assistance
Online Data, Tools, Analysis

Regulatory Support
EPAct Compliance
Data & Policy Analysis
Technical Integration
Fleet Assistance

Thank you

www.nrel.gov

Brett Oakleaf
Brett.oakleaf@nrel.gov
Phone # (303) 275-3771

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY