FY22 FECM Spring R&D Project Review Meeting
Crosscutting (Sensors & Controls)
2022 May 04

NATIONAL ENERGY TECHNOLOGY LABORATORY

Cyber-Physical Systems as a Power System Development Tool

By

Dr. David Tucker

Solutions for Today | Options for Tomorrow

U.S. DEPARTMENT OF ENERGY

Hyper Gang

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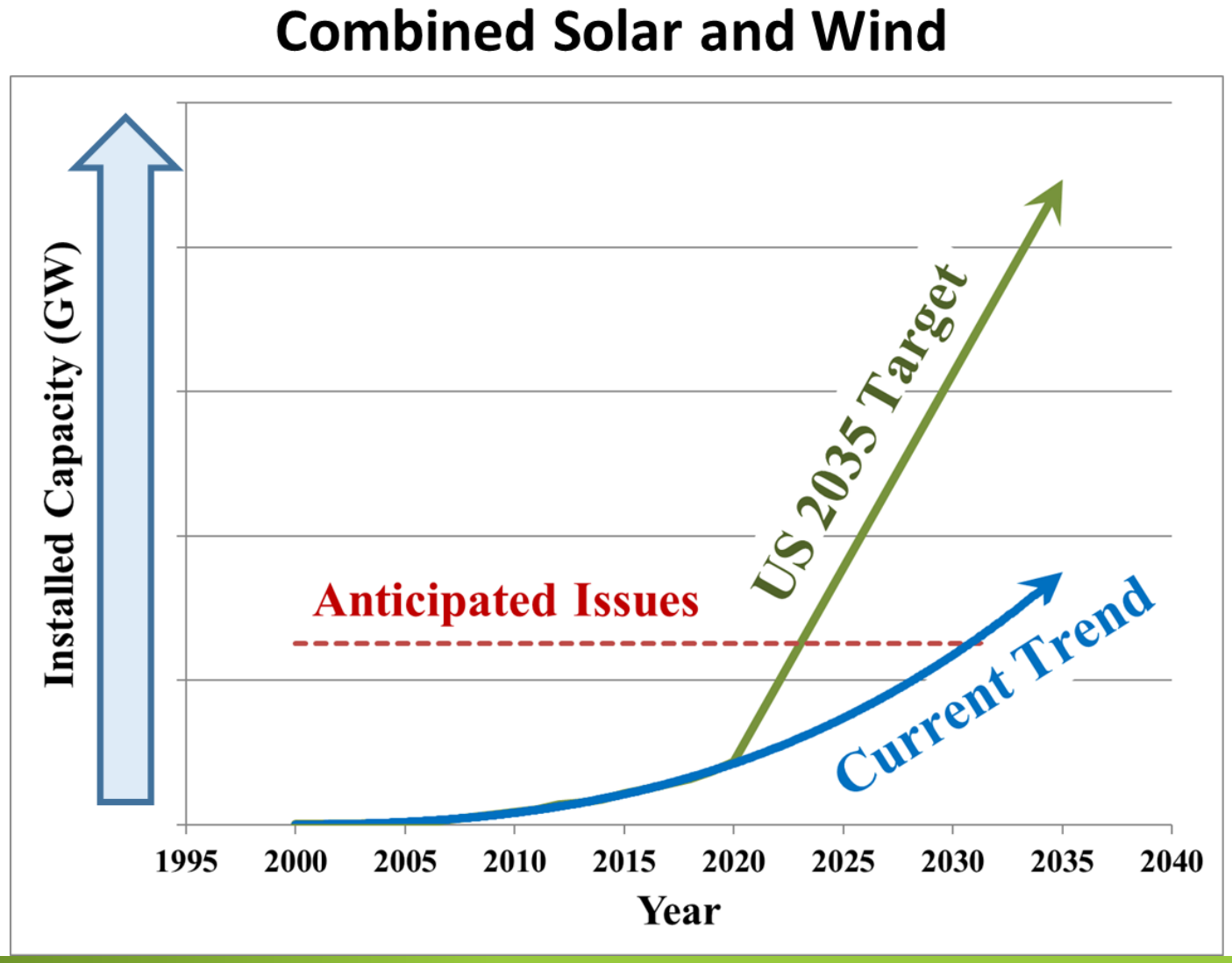
Combining Hardware and Software for Accelerated Technology Development

U.S. Executive Order 14008



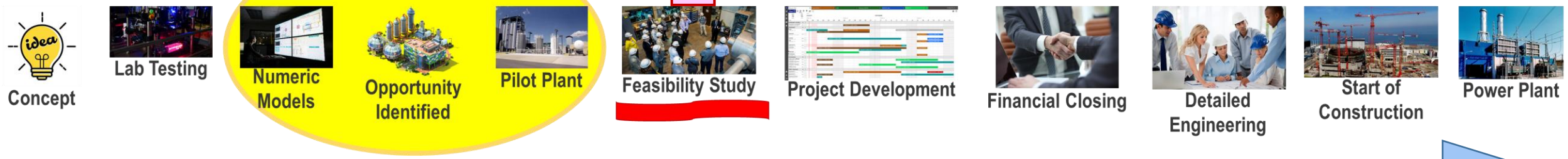
From EO 14008, Sec 205:
"The plan shall aim to use, as appropriate and consistent with applicable law, all available procurement authorities to achieve or facilitate: (i) **a carbon pollution-free electricity sector no later than 2035**"

Power Technology Development Today

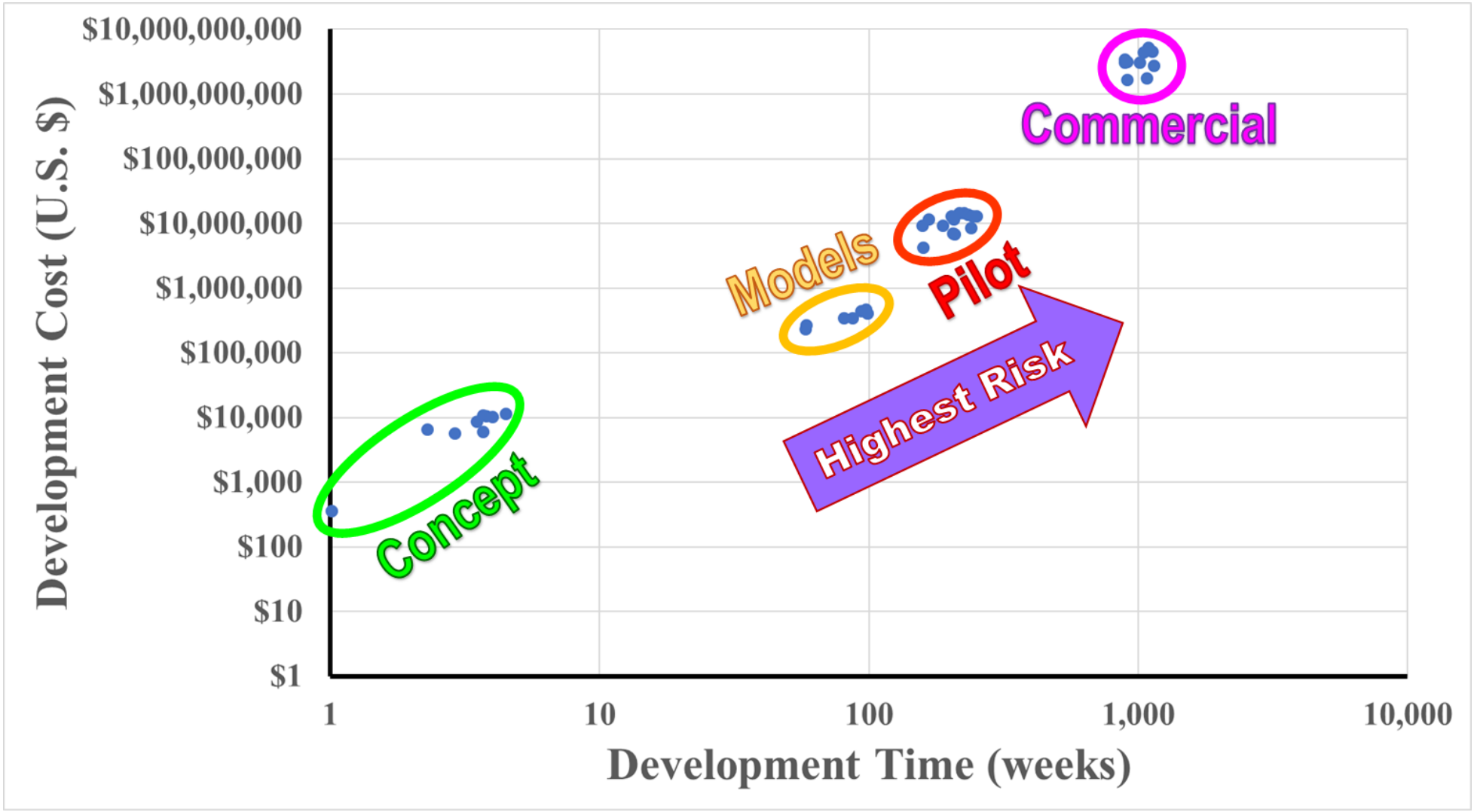
- The current technology paradigm requires two decades
- The highest risk is always associated with pilot development
- Critical Go-No Go relies on a pilot scale technical assessment

1. Conduct Initial Assessments
   a. Engineering
   b. Environmental
   c. Economic
   d. Legal
2. Technical Assessment
3. Conceptual Costs and Schedule
4. Summarize Results
5. Management Direction

1. Fuel Type/Availability
2. Technical Risk
3. Controls Development
4. Uprate Capability
5. Time to Construct
6. Emissions
7. Reliability, Availability, Maintainability
8. Footprint
9. Delivery Schedule
10. Delivery Logistics
11. Cycling Capability
12. Fuel Flexibility
13. Equipment Costs



Power Technology Development Today



Hardware Simulations

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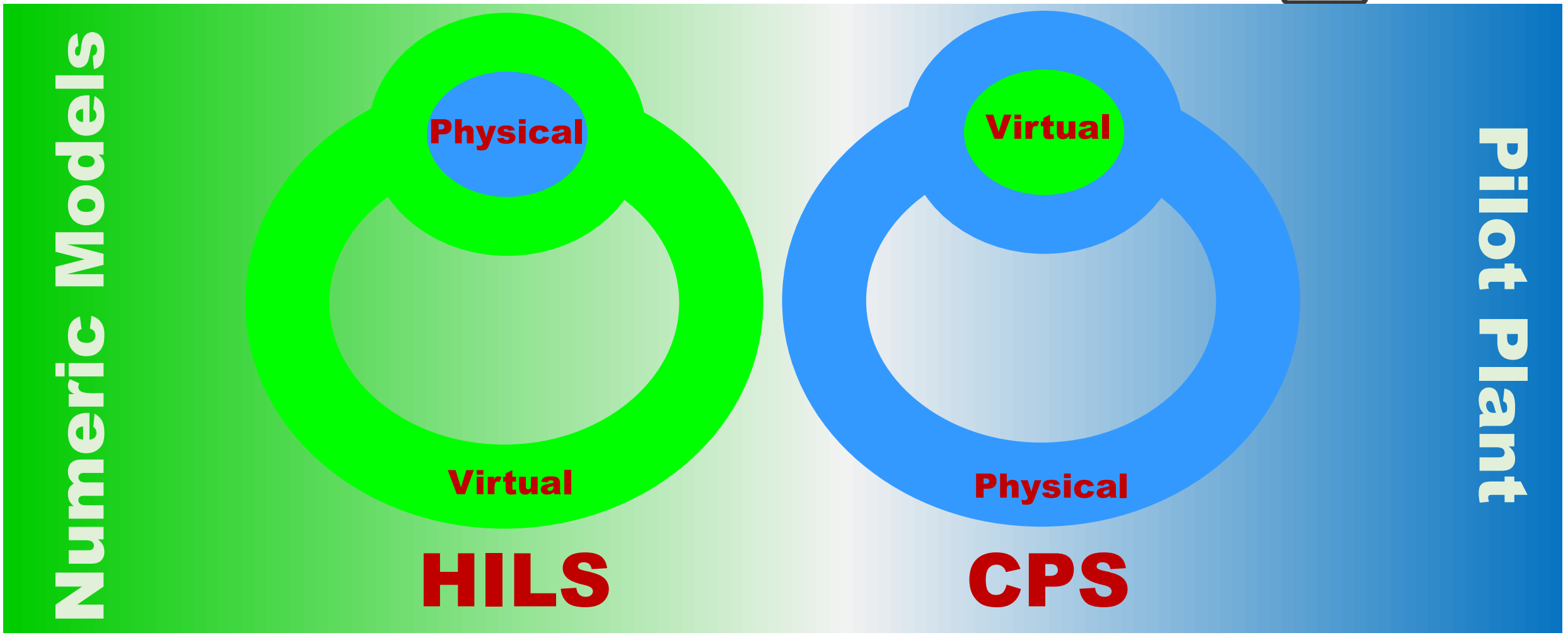
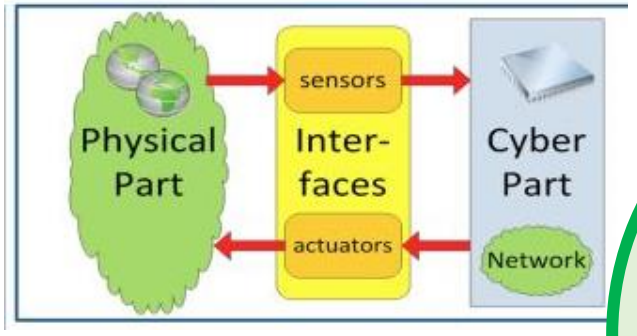
Changing the Paradigm

HILS vs CPS

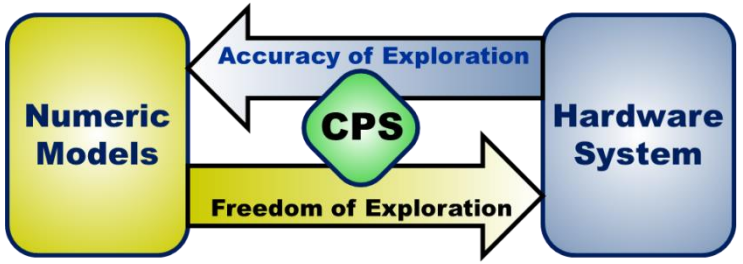

Numeric Models
Physical
Virtual
HILS
Virtual
Physical
CPS
Pilot Plant

Cyber-Physical Systems

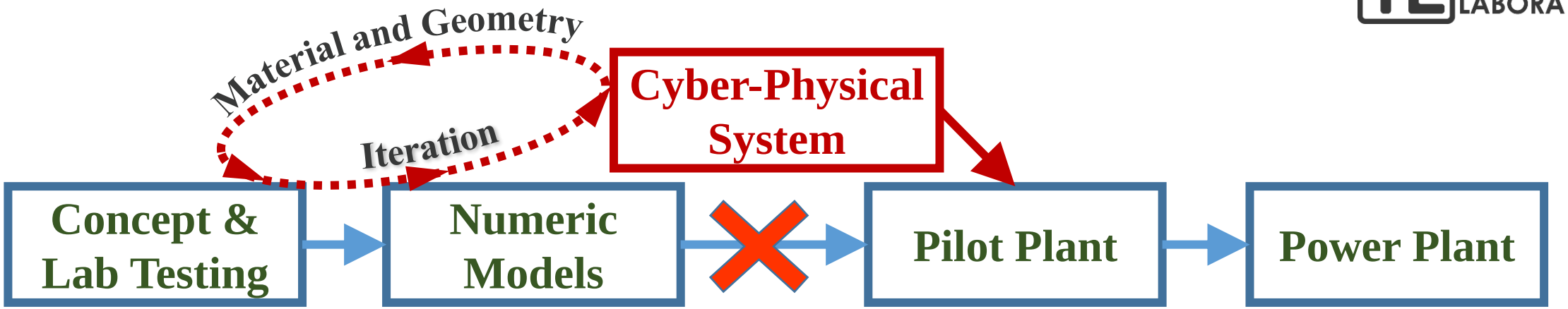


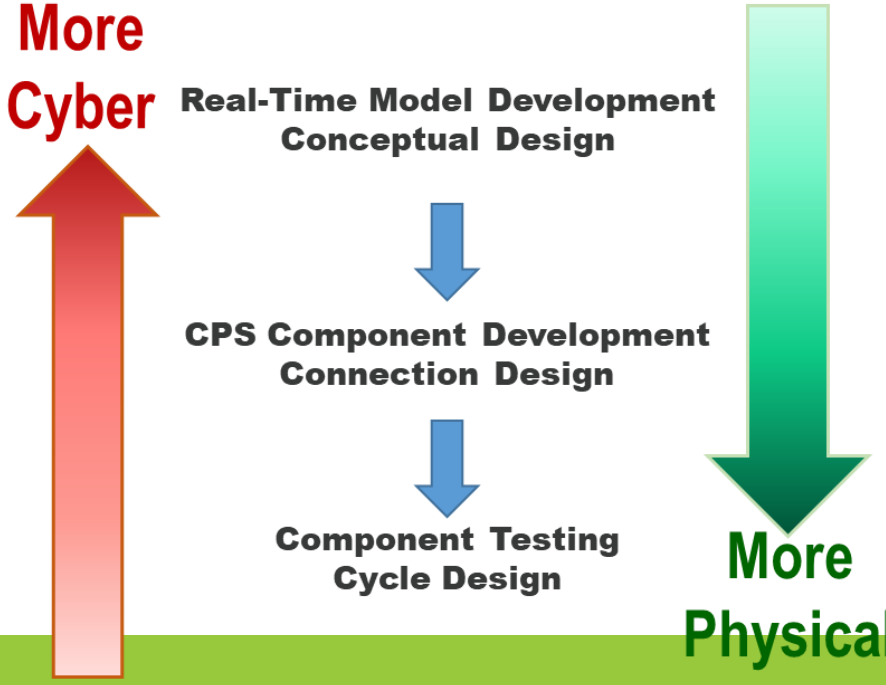
Cyber Physical Systems are used to replace physical systems that:

1. are irreplaceable,
2. are expensive,
3. can't meet performance targets.
4. don't exist…yet



Technology Development Opportunities





Technology Development Tools

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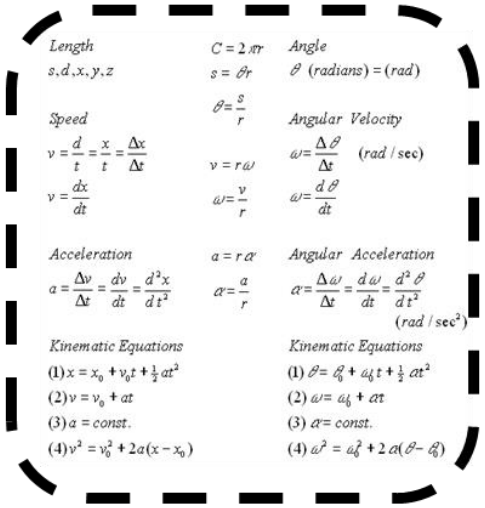
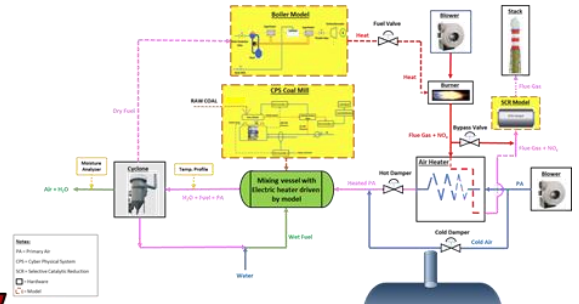
IDAES
Institute for the Design of Advanced Energy Systems

Net-Zero Power Generation Realized

Concept



Numeric Models



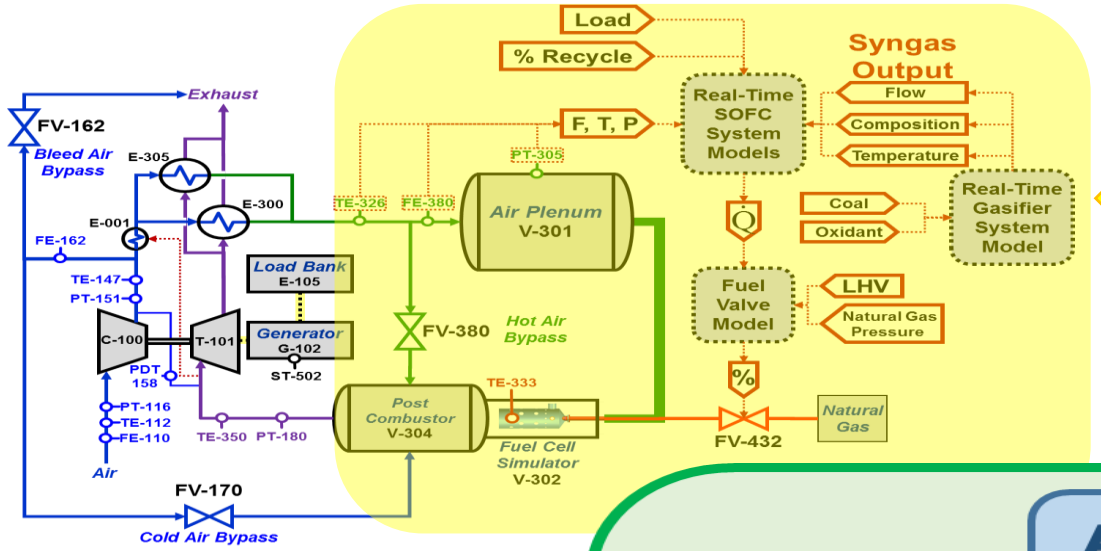
Cyber-Physical Models

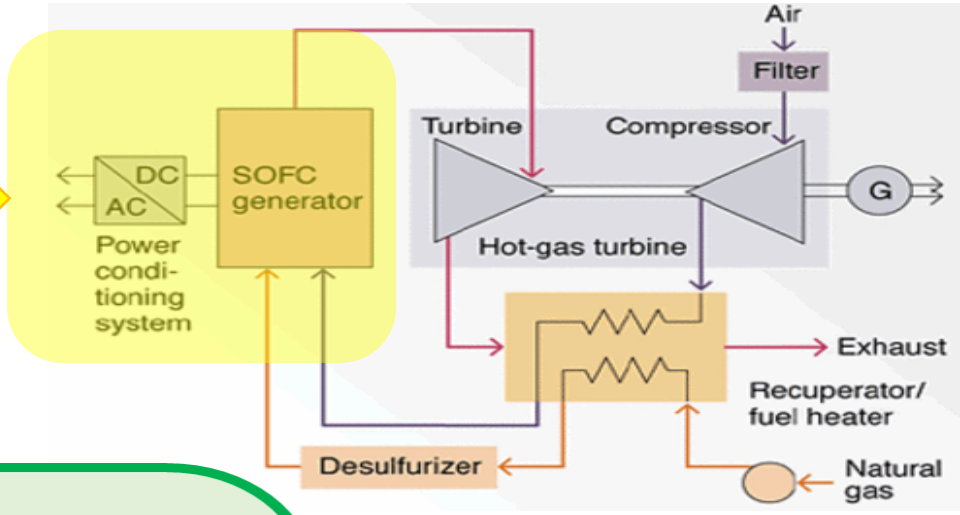
Hyper

Pilot Plants (Physical Models)

The Hybrid Performance Project Facility

Replacing Components that Don't Exist…Yet





Physical Behavior
Thermal Effluent

Actuators
Fuel Valve (FV-432)

Hardware
Vessels (V-302 & V-304)
Piping

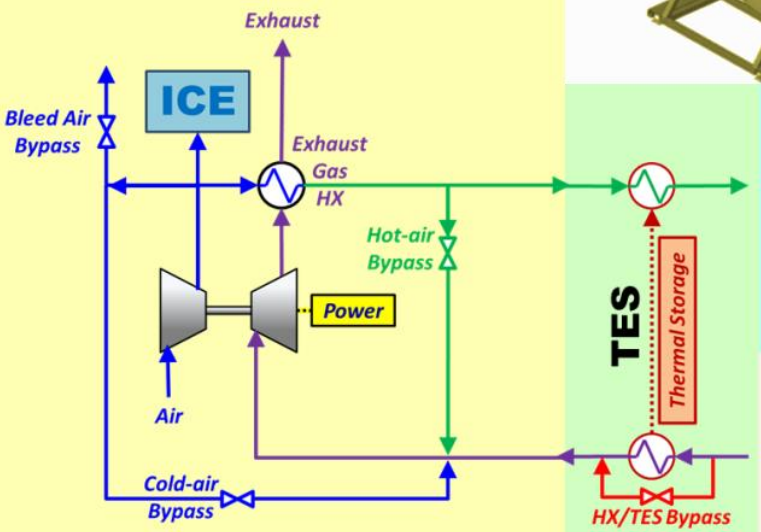
CPS

Models
SOFC System
Air Pre-Heat
Manifold
Fuel Valve

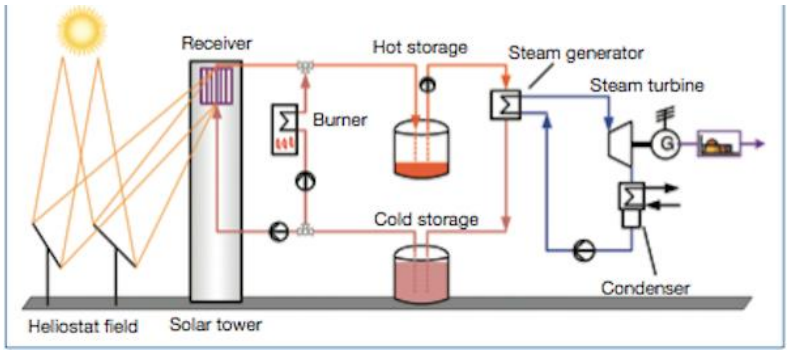
Sensors
Flow (FT-380)
Pressure (PT-305)
Temperature (TE-326)

Stimuli
Turbine Load (P)
Cathode Airflow (P)
Compressor Bleed (P)
HX Imbalance (P)
Fuel Cell Load (V)
Fuel Flow (V)
Fuel Composition (V)
Degradation (V)

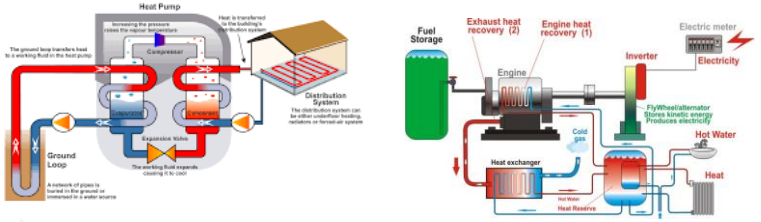
The Hybrid Performance Project Facility



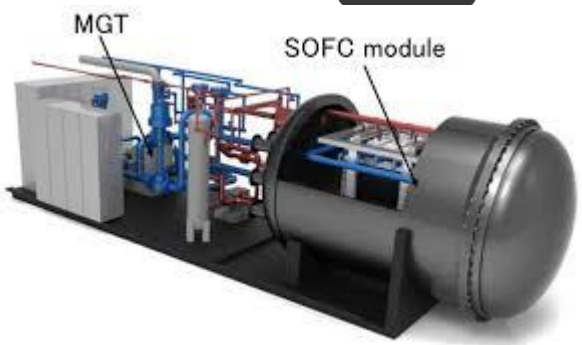
Technology Development Flexibility



CSP/Fossil Hybrid

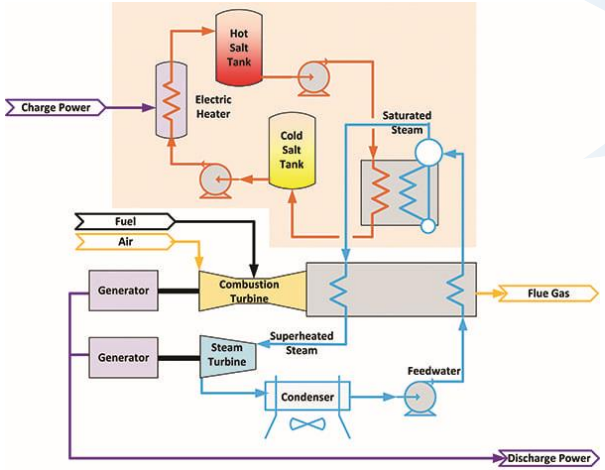


Geothermal & CHP



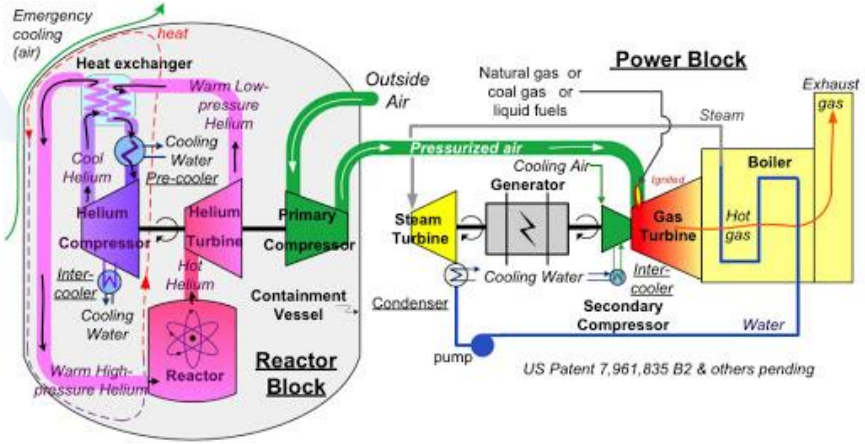
SOFC/GT Hybrid

Hyper Facility



TES/Fossil Hybrid

Reconfigurability



Nuclear/Fossil Hybrid

Technology Development Capital Costs

Siemens Westinghouse pilot demonstration
220kW SOFC/GT Hybrid

Cost: ~$10 M

NETL cyber-physical system
400kW SOFC/GT Hybrid

Cost: ~$1 M

Low Emission Advanced Power (LEAP)

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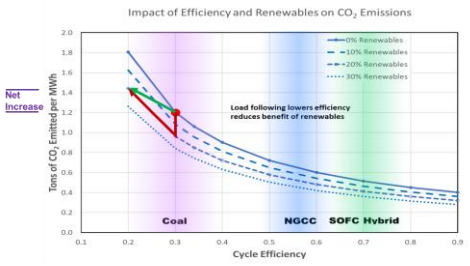
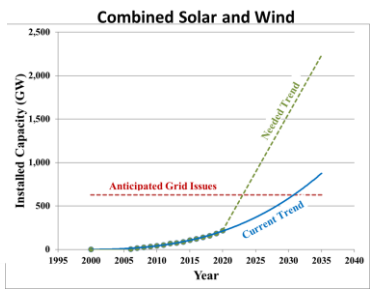
Over 140 leading researchers from 13 countries, 9 national labs, 33 industrial organizations, and 30 universities participated in the event.

Advanced Systems Integration (Monday)



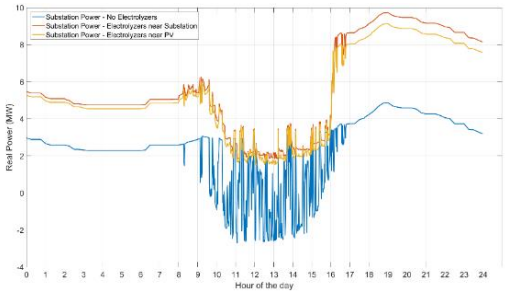


Session 1

Bryan Morreale (NETL), Bhima Sastri (FECM), Sam Thomas (FECM), Aristide Massardo (UNESCO)

Transitioning to net-zero, EO-14008, and social justice

"Getting There" from the U.S. and European perspectives



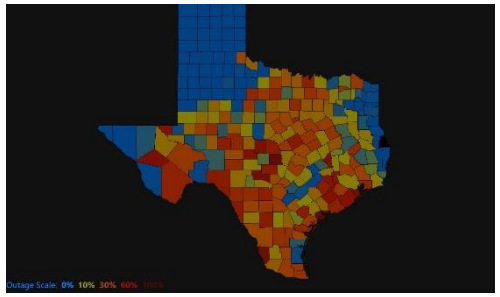
Session 2

Jen Kurtz (ARIES), Rob Hovsapian (NREL)

Renewables, hydrogen, and electric integration with storage

Intermittency, use of electrolysis and electric storage

Need for integration with dispatchable power



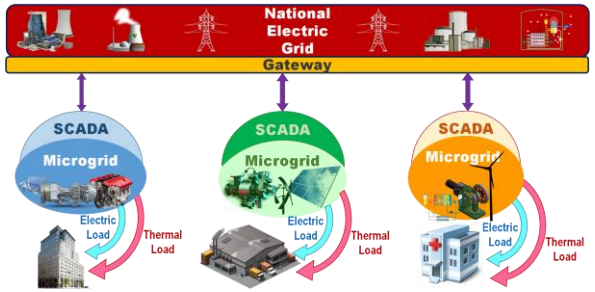
Session 3

EPRI, Southern Co., Exelon

Impact and potential costs

Need for FECM and EERE new technologies in generation and distribution

Advanced Systems Integration (Tuesday)

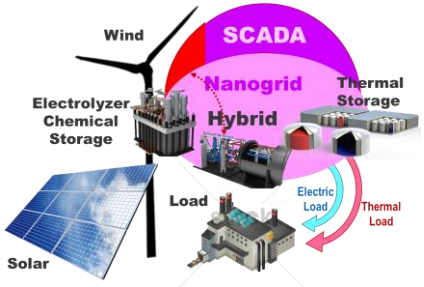


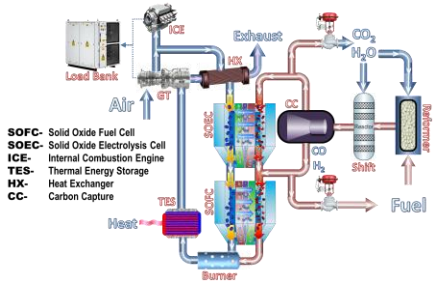
Session 4

Steven Saffel (Pepco), Byron Washom (UCSD), Scott Samuelson (UCI), Stone Edge Farm

Microgrids

Coupling non-dispatchable with dispatchable generation



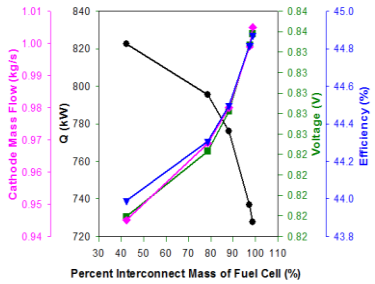


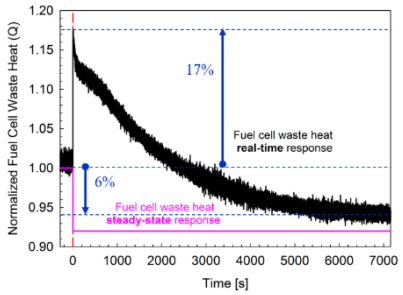
Session 5

Alberto Traverso (TPG), NETL, NREL, INL, Sandia

Thermally/chemically integrated systems

SOFC/SOEC/GT/ICE/TES/CCS/CSP/NE/etc. and other crazy ideas





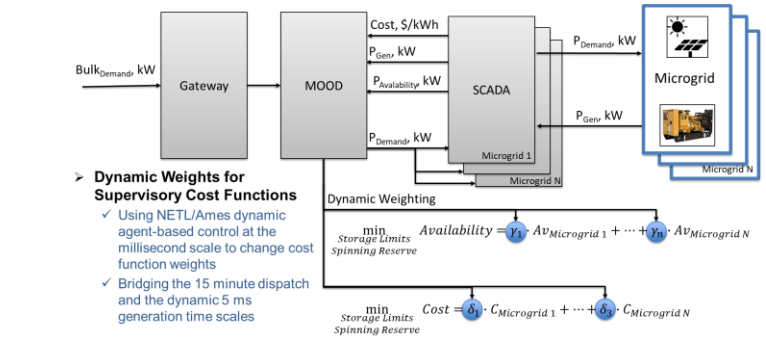
Session 6

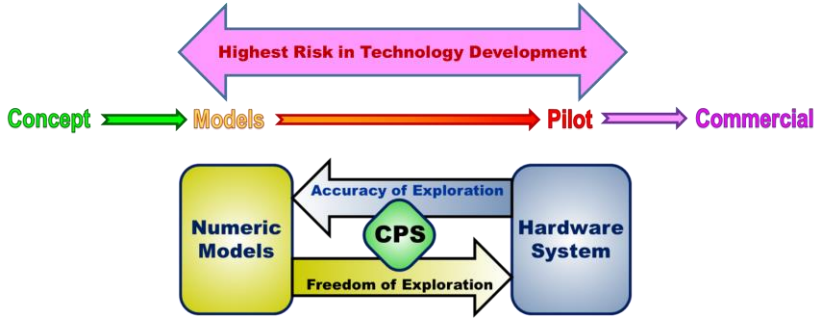
Jack Brouwer (UCI NFCRC), NETL, UNIGE, WVU

Part load and dynamics for hybrid power systems

Challenges for highly coupled systems, non-linear interactions, control issues

Advanced Systems Integration (Wednesday)





Session 7
David Tew (ARPA-E)

ARPA-E paths to commercialization

Commercialization of integrated energy systems for hybrid electric power in INTEGRATE and REEACH

Session 8
Paolo Pezzini (Ames), Emerson, ABB, NETL, NREL, INL

Controls for integrated energy systems and novel concepts

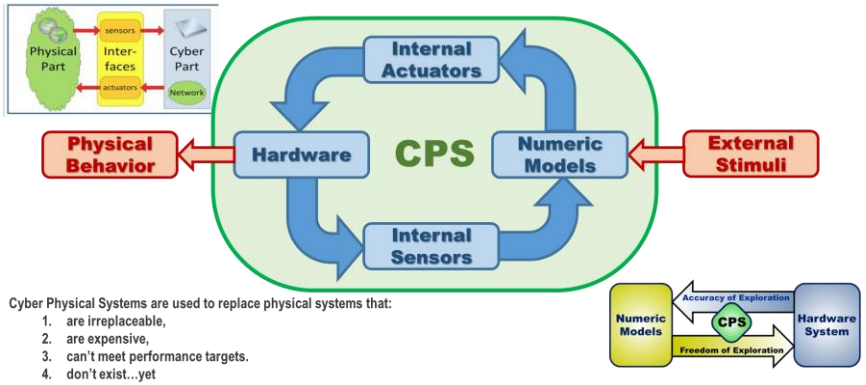
Need for high-speed coordination of dynamic control with supervisory control, agents, MIMO, MOOD

Session 9
All Speakers,

Conclusion and summary of results

Need for a new paradigm in technology development, simultaneous co-design of components, systems, and control

Cyber-Physical Modeling (Thursday)



Session 10

Mark Bryden (Ames), Nathan Johnson (ASU), Sydni Credle (NETL), Mario Ferrari (TPG), Melanie Herbst (DLR)

Introduction to Cyber-Physical Modeling

The energy sector and net-zero carbon generation

Energy: A quickly changing landscape

The need and challenge of reaching a net zero carbon energy system

Breakout Sessions for discussion

Session 11

Scott Ferguson (NCSU)

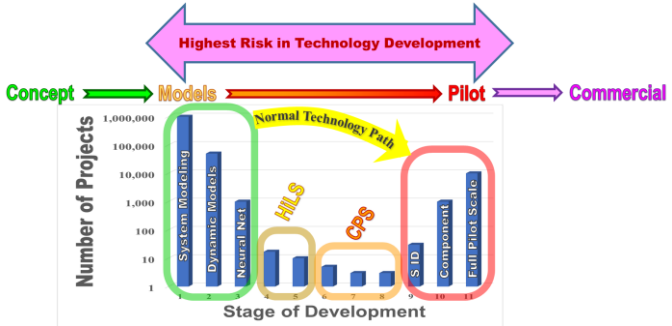
Cyber-physical modeling and energy system design

Rethinking traditional design strategies for energy systems

Building a CPM community for energy systems development

From cyber-physical modeling to intelligent systems

Breakout Sessions for discussion



Session 12

Michael Shelton (ACTS), Comas Haynes (GTRI), Paolo Pezzini (Ames)

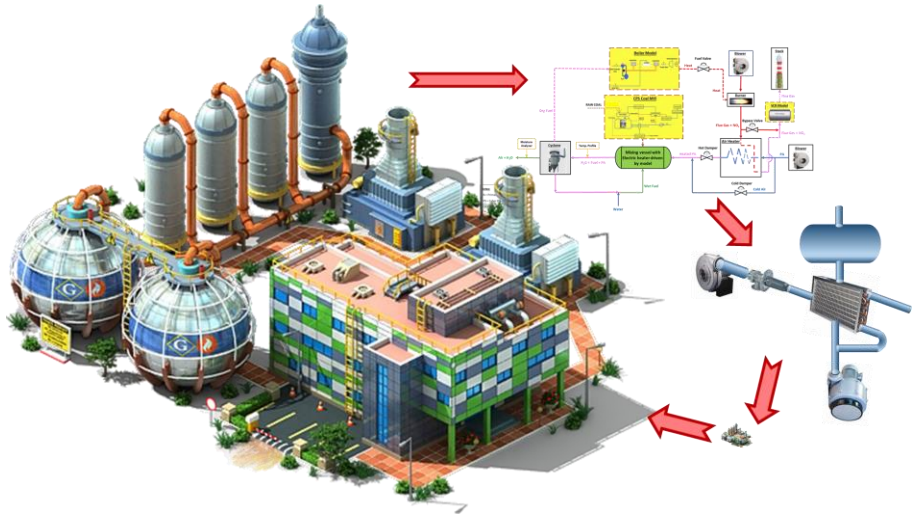
Building cyber-physical energy system models

Hardware and software needs to support CPM in the future

Developing continually adaptive cyber-physical systems

Breakout Sessions for discussion

Cyber-Physical Modeling (Friday)



Session 13

Scott Ferguson (NCSU)

Intelligent, reconfigurable, adaptive energy systems

Adaptive design for a changing world

A cyber-physical modeling energy system development process: creating intelligent, reconfigurable, adaptive energy systems

Breakout Sessions for discussion

Session 14

All Speakers led by Ames and NETL

Next steps in cyber-physical modeling of energy systems

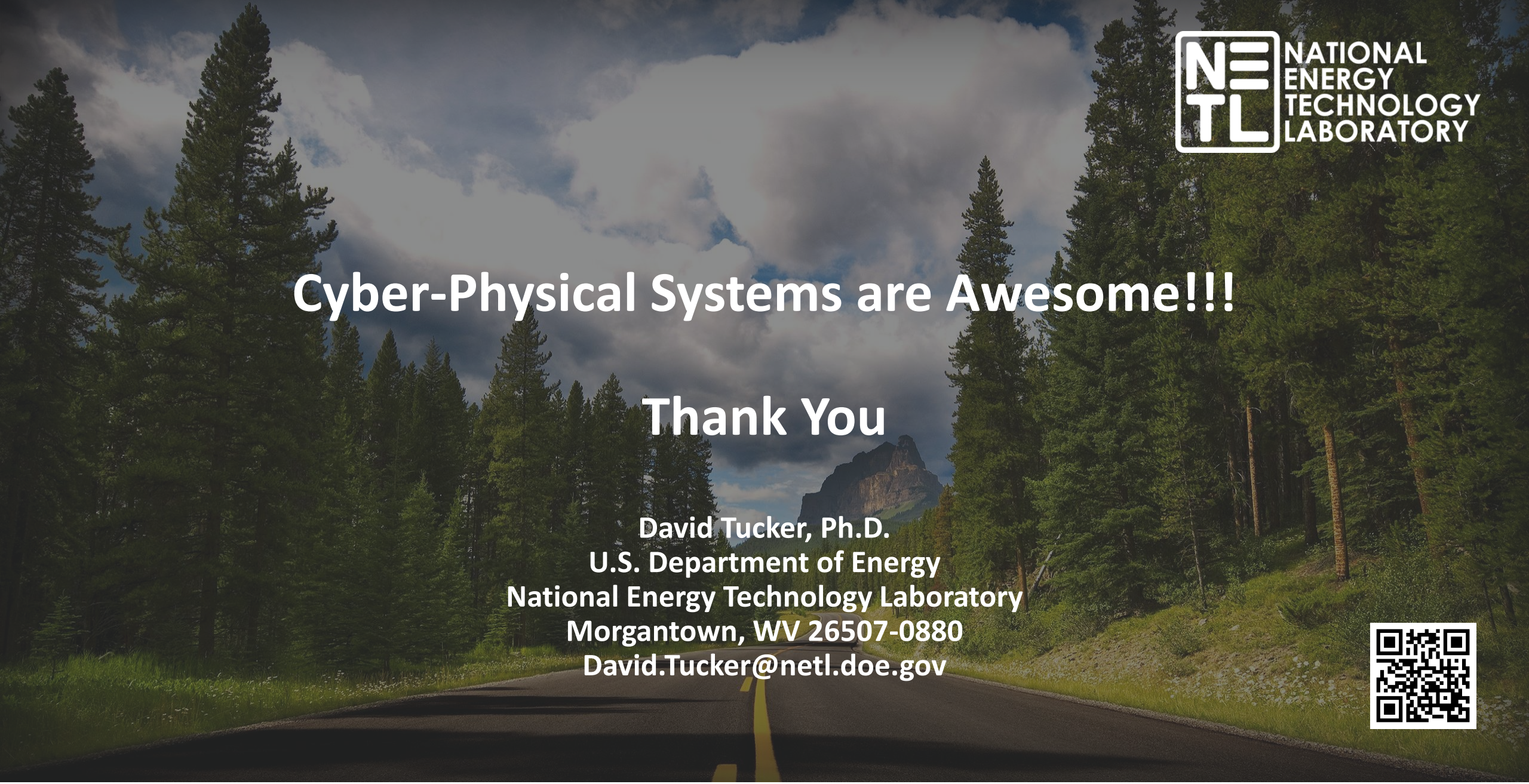
Open invitation to participate in developing a CPM community

Summary

- New technologies will be required for transition to economically viable renewable generation assets
- Key dynamic interactions need to be characterized/quantified
- Cyber-physical systems can enable exploration of highly integrated systems at lower cost
- World leaders participated in the virtual LEAP workshop focused on integration issues and Cyber-Physical Modeling
- A systematic approach to CPS is essential

Acknowledgements and Disclaimer

- **This material is based upon work supported by the Department of Energy Advanced Sensors and Controls, FWP-1022427**



Cyber-Physical Systems are Awesome!!!

Thank You

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