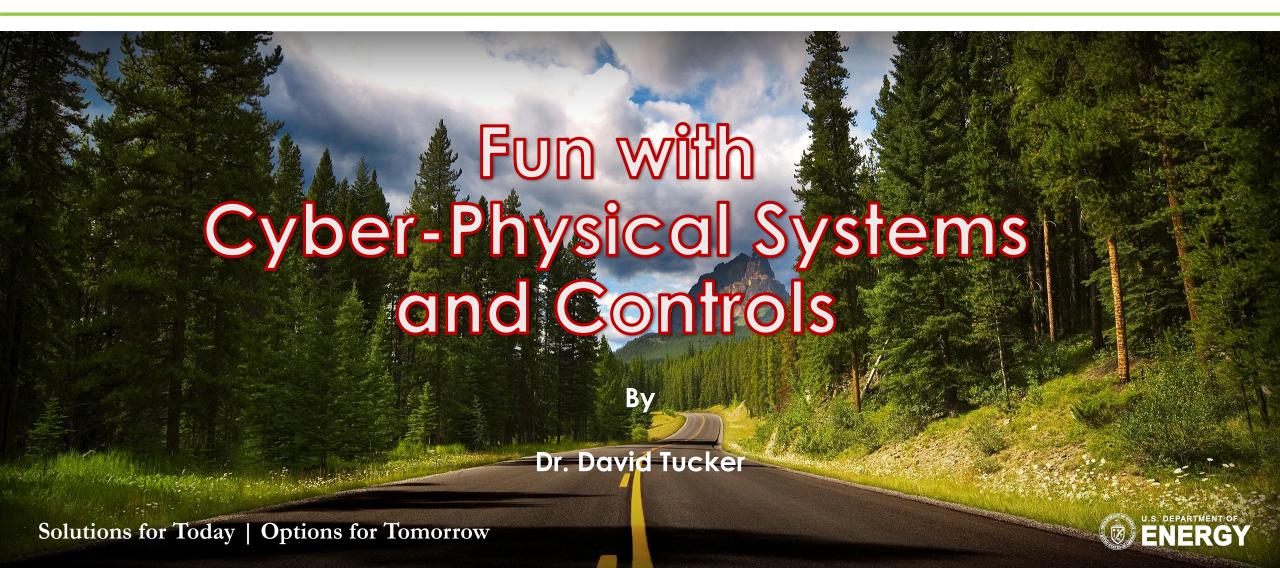
2021 Review Meeting 2021 May 18





Hyper Gang



Combining Hardware and Software for Accelerated Technology Development

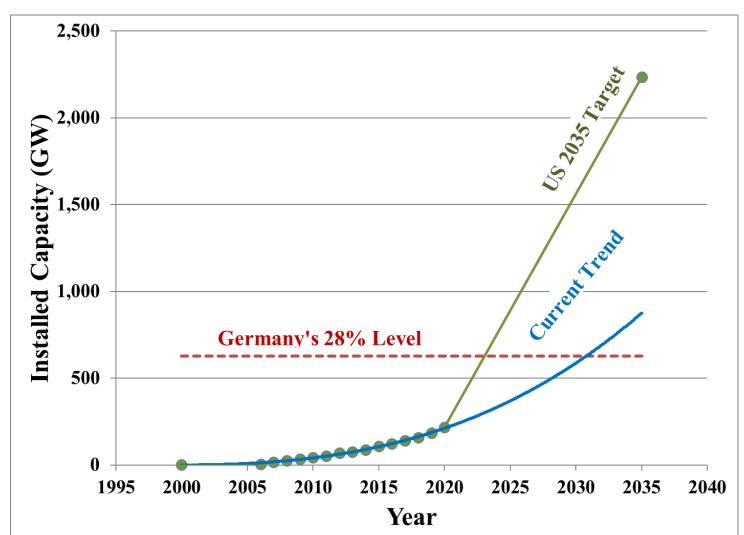




Motivation



Combined Solar and Wind



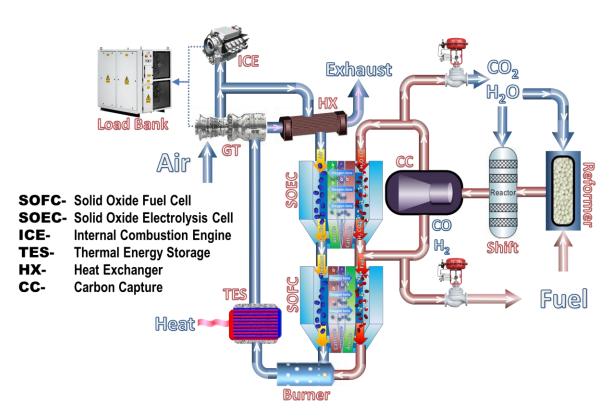
We want to get there fast... real fast

Sources: DOE, EERE WINDExchange Solar Energy Industries Association



Novel Concepts Needed





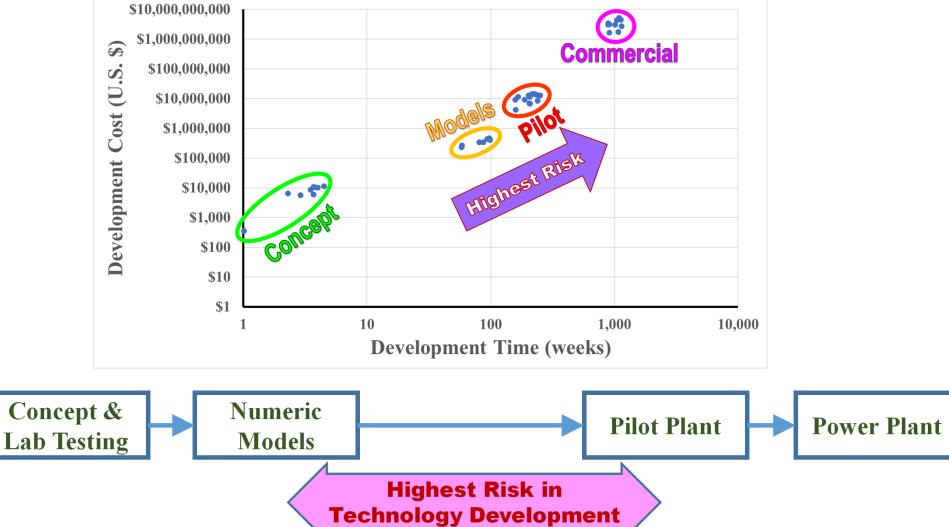
Achieving the highest efficiency and flexibility with the lowest emissions





Technology Development Pardigm







Hardware Simulations

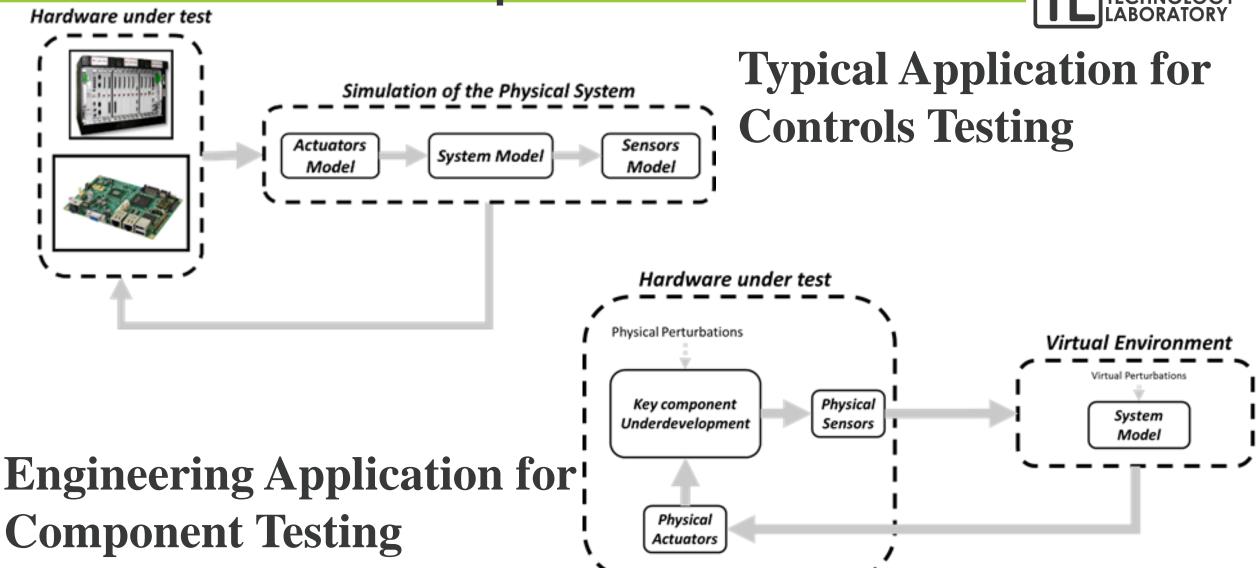


Changing the Paradigm



Hardware in the Loop





<u>Hardware in the Loop</u>

NATIONAL TECHNOLOGY

Automobile **Simulation Model**

Hardware **Under Test**

Length

s,d,x,y,z

C = 2 m

Angle

 \mathscr{G} (radians) = (rad)

Acceleration

 $a = \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \frac{d^2x}{dt^2}$

Kinematic Equations

(1)
$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

$$(2)v = v_0 + at$$

(3)
$$a = const.$$

$$(4)v^2 = v_0^2 + 2a(x - x_0)$$

 $s = \theta r$

 $a = r\alpha$

Angular Velocity

$$\omega = \frac{\Delta \mathcal{D}}{\Delta t} \quad (rad \mid sec)$$

$$\frac{v}{r}$$
 $\omega = \frac{c}{r}$

Angular Acceleration

$$\alpha' = \frac{\Delta \omega}{\Delta t} = \frac{d \omega}{dt} = \frac{d^2 \mathcal{P}}{dt^2}$$

$$(rad / \sec^2)$$

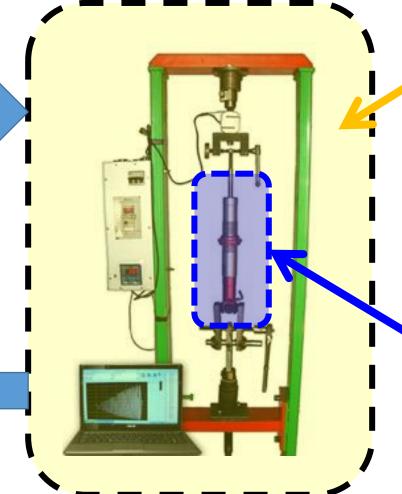
Kinematic Equations

(1)
$$\mathcal{S} = \mathcal{S}_0 + \omega_0 t + \frac{1}{2} \alpha t^2$$

(2)
$$\omega = a_b + \alpha t$$

(3)
$$\alpha = const.$$

$$(4) \omega^2 = \omega_0^2 + 2 \alpha (\mathcal{O} - \mathcal{O}_0)$$



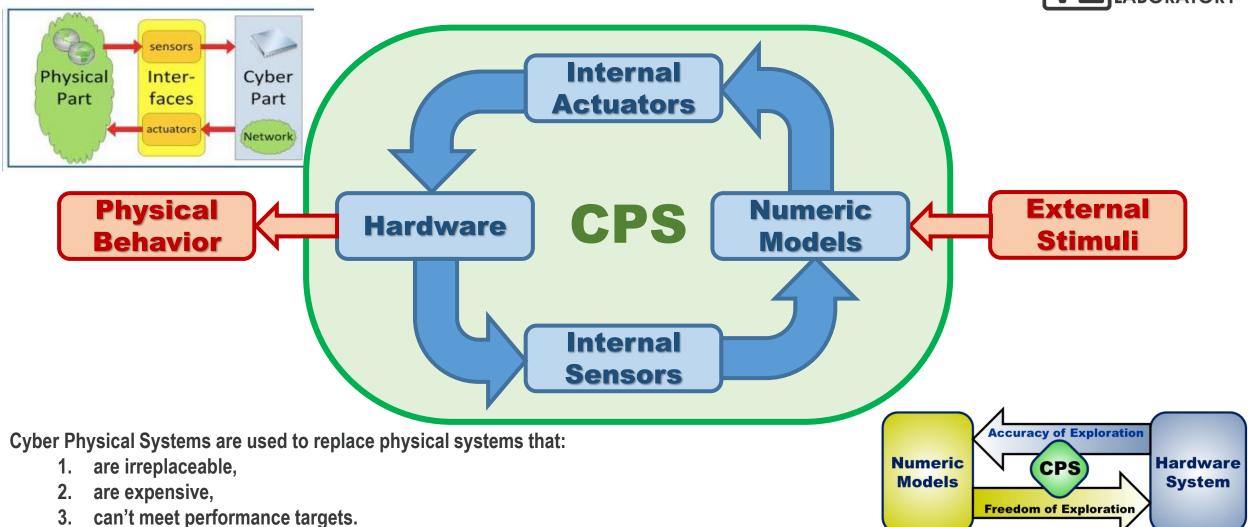
Interface and **Middleware**

Key **Component** Under **Development** (Shock Absorber)



Cyber-Physical Systems



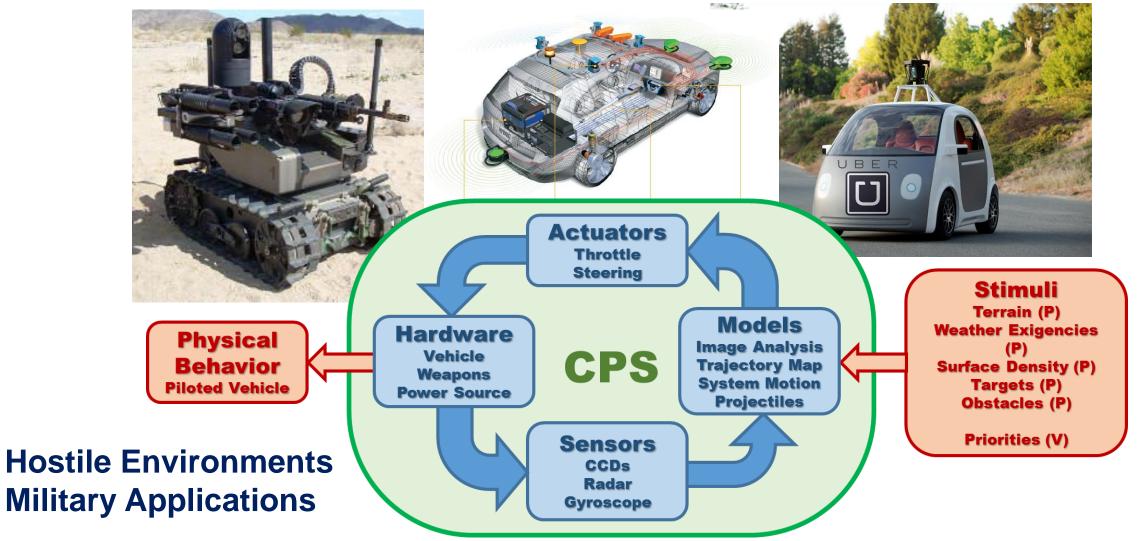




don't exist...yet

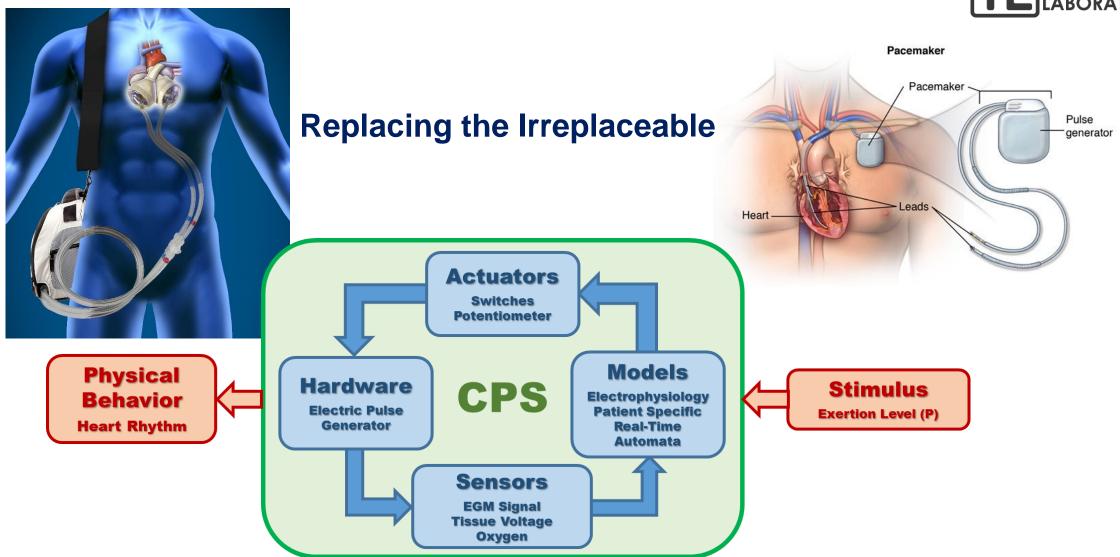
Example: Autonomous Vehicles





Example: Artificial Heart

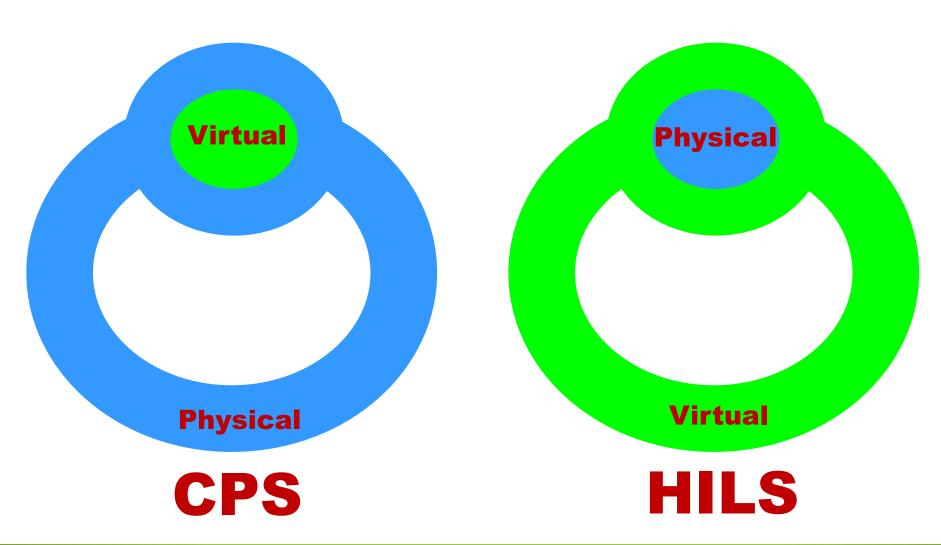






CPS vs HILS



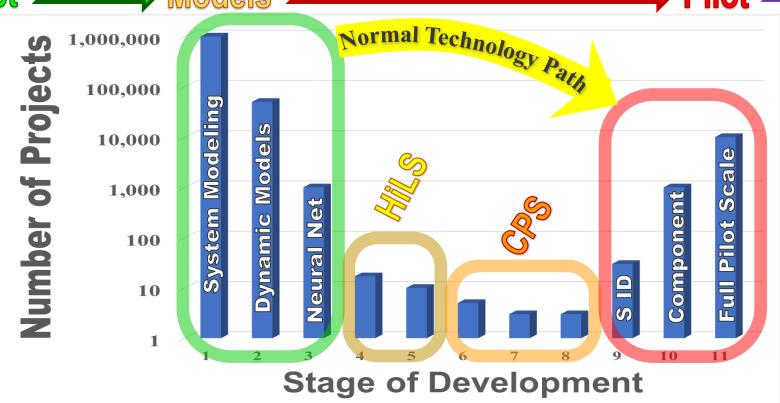




Technology Development Valley of Death







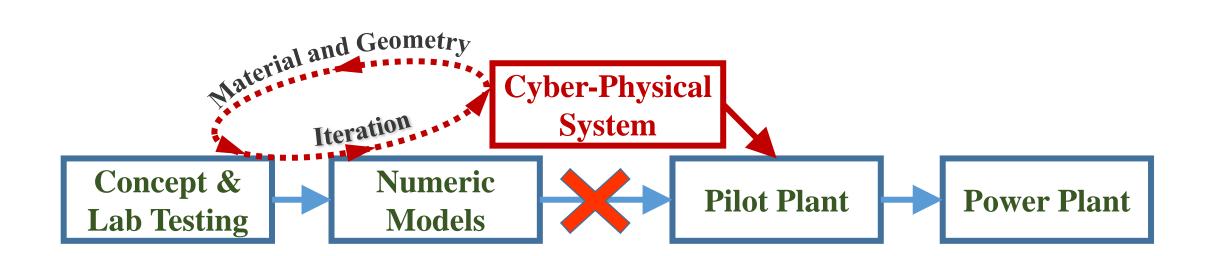


Technology Development NATIONAL TECHNOLOGY Highest Risk in Technology Development Concept Models ▶ Pilot ➤ Commercial **Accuracy of Exploration Numeric Hardware** CPS Models **System** Freedom of Exploration



Technology Development Opportunities



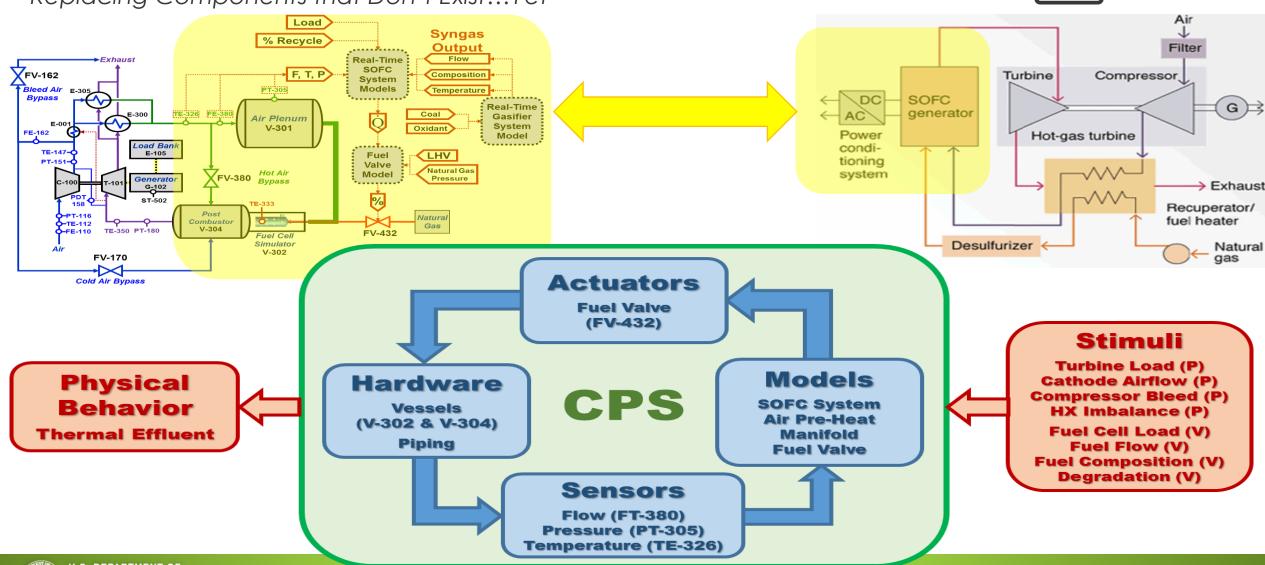




The Hybrid Performance Project Facility

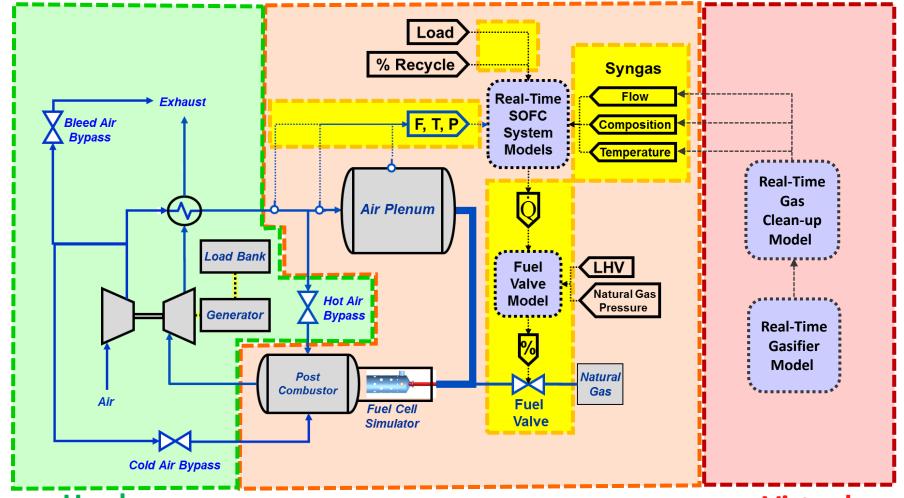


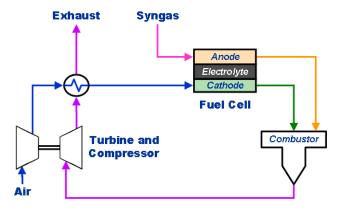
Replacing Components that Don't Exist...Yet



The Hybrid Performance Project Facility







Interface and Middleware

Hardware components

Accuracy

Cyber-physical components

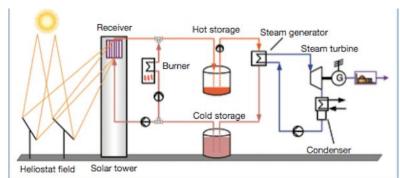
Flexibility

Virtual

components

Technology Development Flexibility

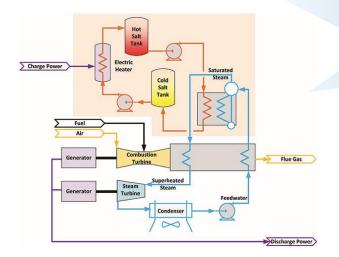




SOFC module

SOFC/GT Hybrid

CSP/Fossil Hybrid



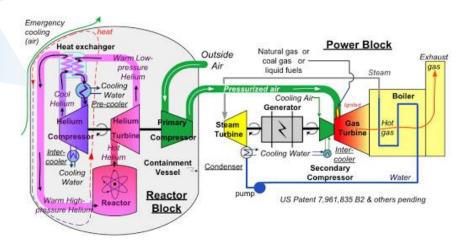
TES/Fossil Hybrid



Geothermal & CHP

Hyper Facility

Reconfigurability



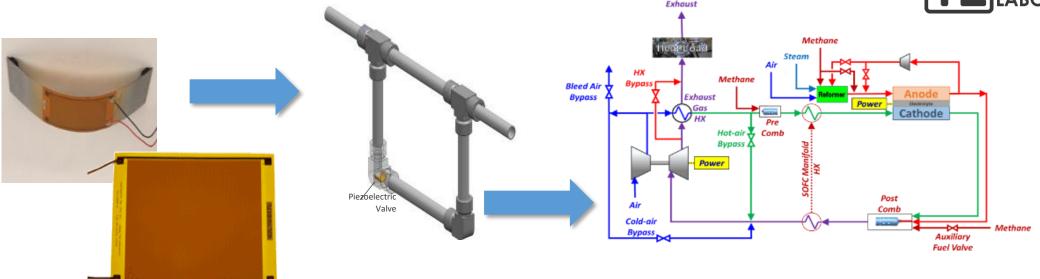
Nuclear/Fossil Hybrid



Cyber-Physical CHP EERE AMO



System Progression



Technology -----



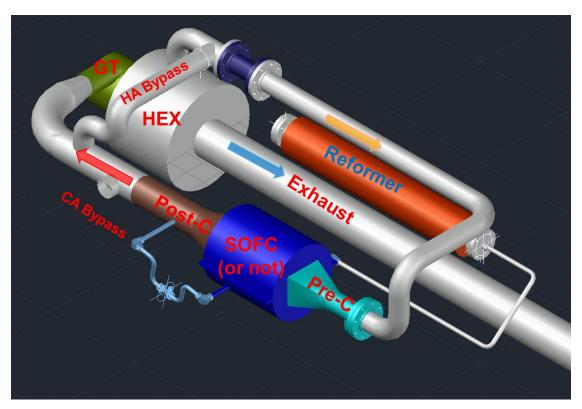
Component

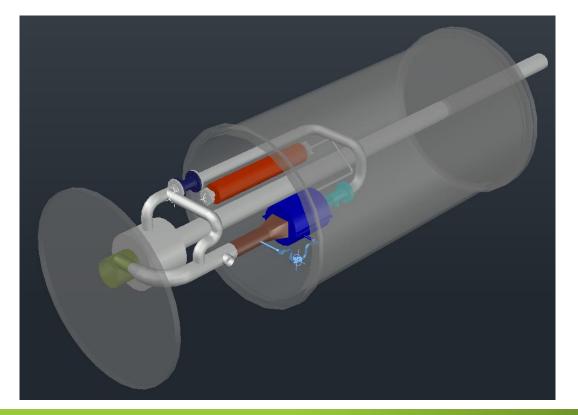
Cyber-Physical Reformer ARPA-E



CPS Reformer and SOFC Pressure Test (ARPA-E INTEGRATE)

The test facility is under design for a 20 kW demonstration of an SOFC/GT automated Hybrid The facility will also represent a pressurized Cyber-Physical reformer platform Under ARPA-E INTEGRATE, the facility will be used for pressure testing 10 kW SOFC Stacks



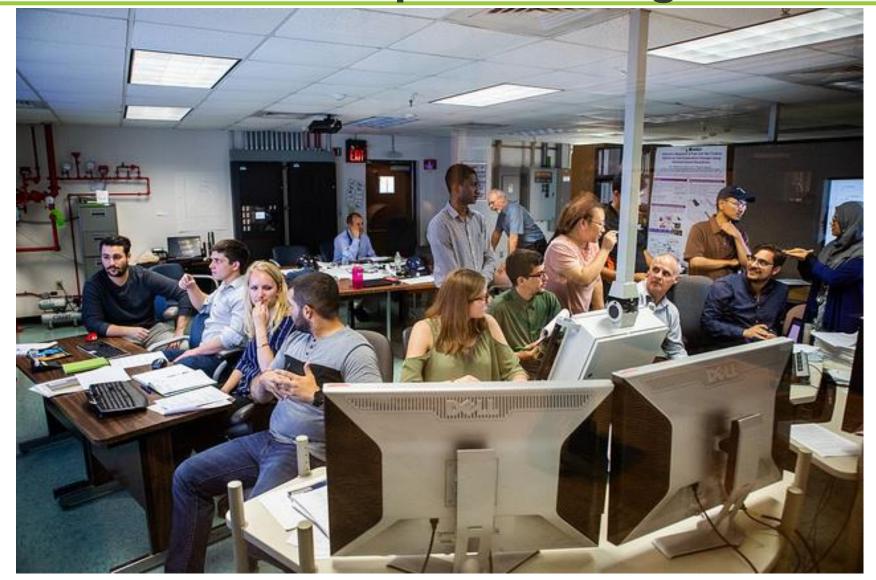






Controls Development using CPS



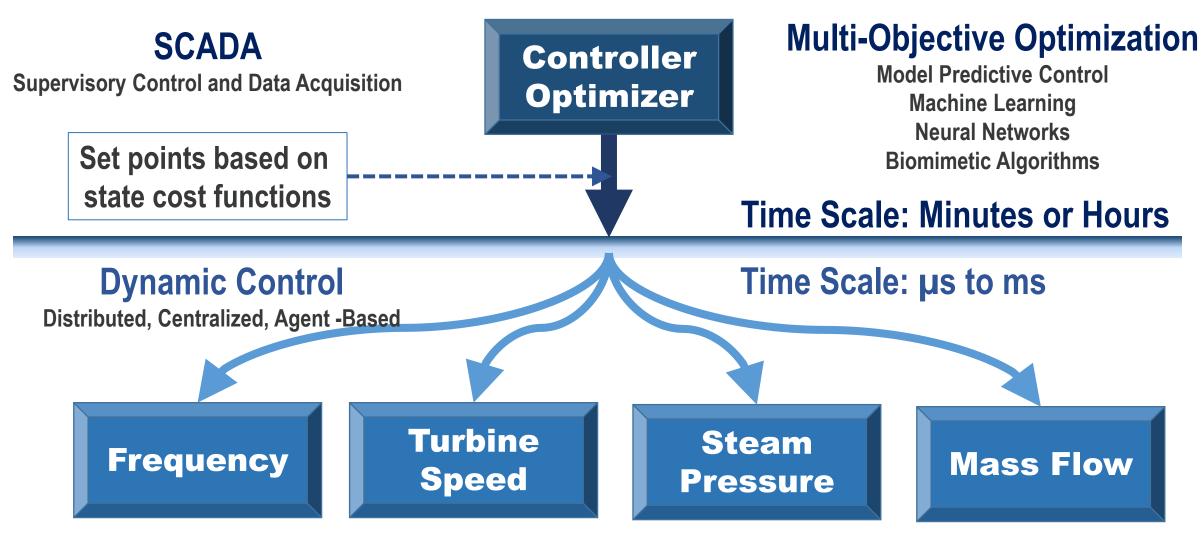


Working toward the development of dynamic controls to achieve the highest degree of disturbance rejection, enabling novel cycles commercialization



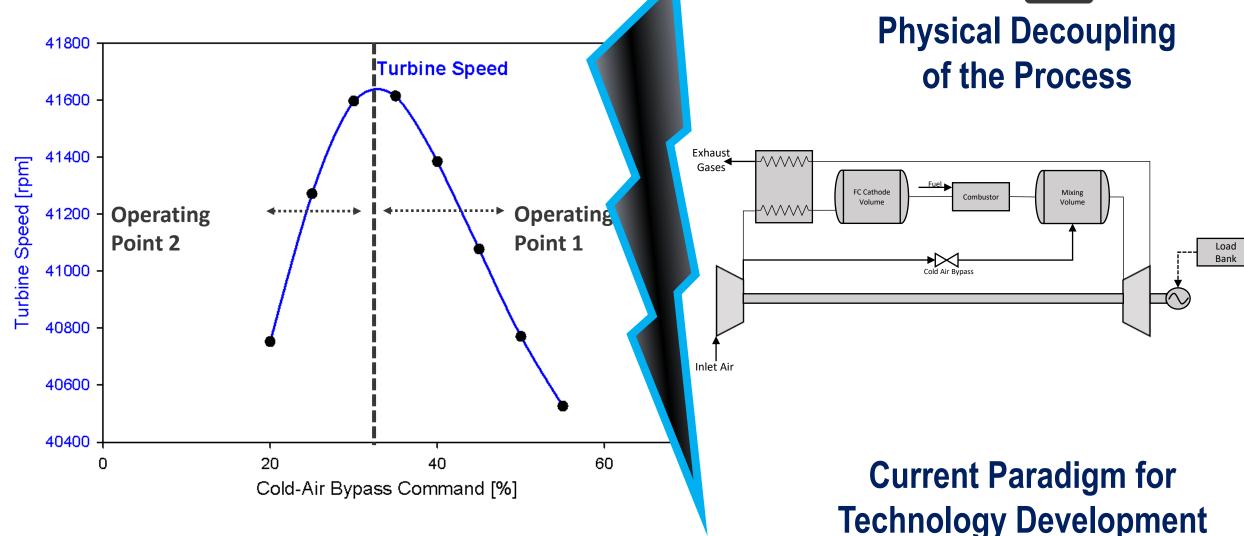
Technology Development Hyper Focus





Technology Development Hyper Focus



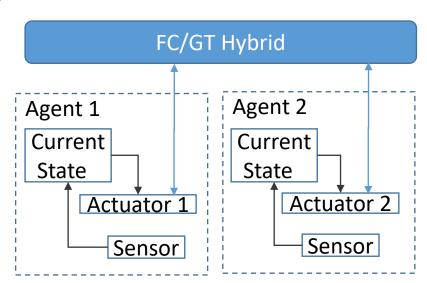


Technology Development Hyper Focus

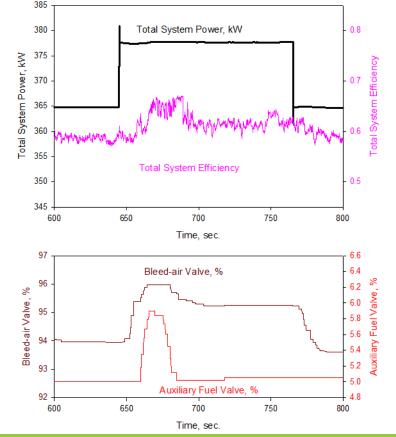


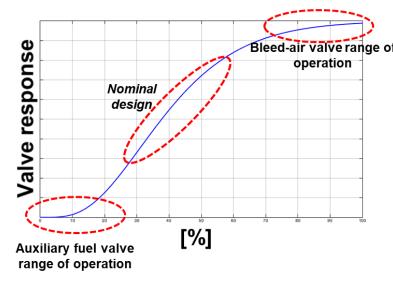
Agent Based · R

- Reconfigurable on different power plants
- Multi-agents emulate intelligent control
- Agents can coordinate their behavior to achieve multiple objectives
- Load following was achieved while minimizing the transient impact on efficiency



Two (2) agent controller demonstrated on laboratory power equipment in the Hyper facility





Valve are saturated when fully closed making conventional control unstable



Summary



- New fossil technologies will be required for transition to economically viable renewable generation assets
- > Integrated energy systems will be needed to meet the flexibility demands
- Key dynamic interactions need to be characterized/quantified
- > Cyber-physical systems can enable exploration of highly integrated

systems at lower cost

- Co-design will be essential in future power systems
- ➤ Any power system that cannot be controlled is not technically feasible, economically viable, and has no market
- > A new paradigm for controls development is required to meet future power needs
- A systematic approach to CPS is essential





Acknowledgements and Disclaimer



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