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Comparative Life Cycle Assessment of Hydrogen Production via Various PV-Assisted Electrochemical Water Splitting Techniques

Achyuth Ravilla
Portland State University

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Achyuth Ravilla
PhD Student
Civil and Environmental Engineering
achyuth@pdx.edu

Portland State University

Hydrogen Production

Steam Methane Reforming	Electrolysis	Biological	Thermochemical	Photoelectro-chemical
• Well-established • Natural gas as a methane sources.	• Electric current as a source • Recently commercially deployed	• Microbes to produce hydrogen • Waste water as a source	• High temperature heat for series of chemical reactions	• Water splitting using semiconductor • Cost-effective

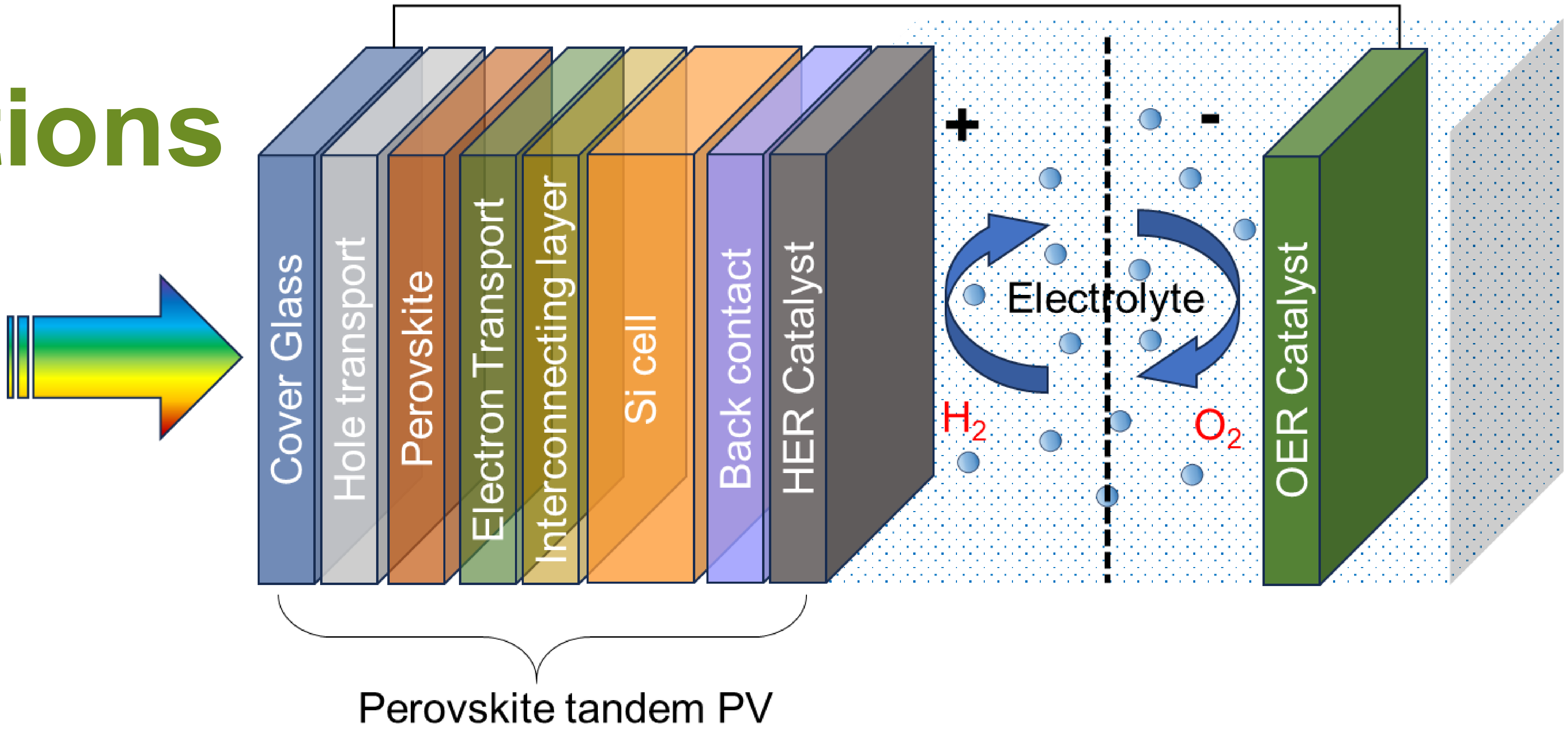
Why Photoelectrochemical Water Splitting?

- Improved efficiency of semiconductor materials
- Cost effective
- Renewable energy source
- Feasible for all locations

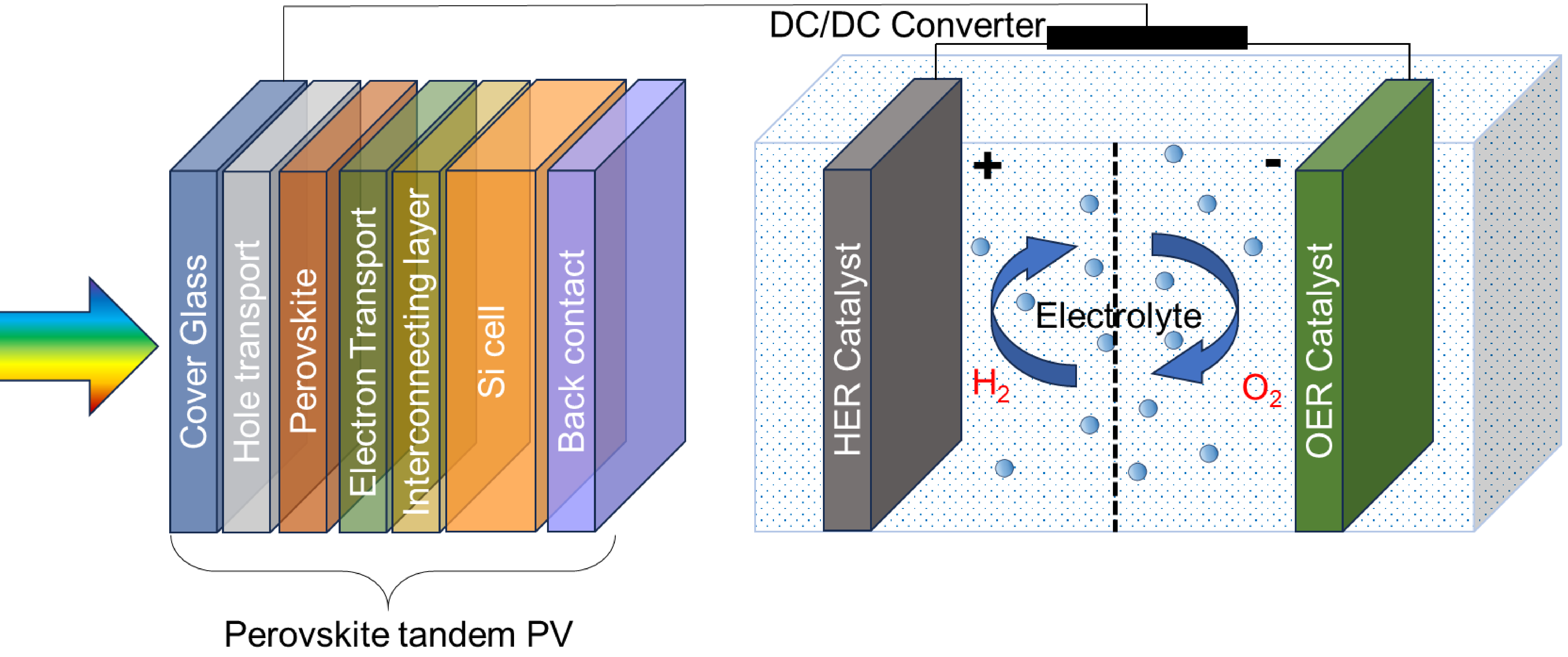
Photoelectrochemical Configurations

Photoelectrochemical (PEC) Water Splitting

- Photovoltaic (PV) material is directly Immersed in water.
- Directly convert sunlight to chemical energy, higher efficiencies.
- No need of external electrical power sources. Simpler design



PEC water splitting



Decoupled PV-EC water splitting

Decoupled Photovoltaic-Electrochemical (PV-EC) Water Splitting

- PV and electrochemical cell is connected in series or parallel.
- Solar energy first converted to electricity. Generated electricity used for electrochemical reactions.
- Complex design. Higher efficiencies than PEC due to improved stability.

Components of Photoelectrochemical Configurations

System Components	
PV panel	Perovskite/Silicon tandem solar cells
Membrane	Perfluoro sulfonic Acid Membrane
HER electrode	NiMo
OER electrode	NiFe
Electrolyte	1M KOH
Chassis	Polypropylene

Earth abundant nickel as catalyst (HER electrode, OER electrode)

Sustainability Status of Photoelectrochemical Water Splitting

U.S. Department of Energy Target for H_2 production is **<$2/kg**

Economic Sustainability

- The cost of hydrogen production using photoelectrochemical water splitting varies from $4 to $10 per kg hydrogen produced.
- Decoupled PV-EC achieved low-cost so far compared to PEC

Environmental Sustainability

- Limited research has been conducted on environmental performance.

Research Questions

Which photoelectrochemical water splitting technique offers better environmental performance?

What are the significant influencing parameters on the environmental performance ?

How to Assess the Environmental Performance?

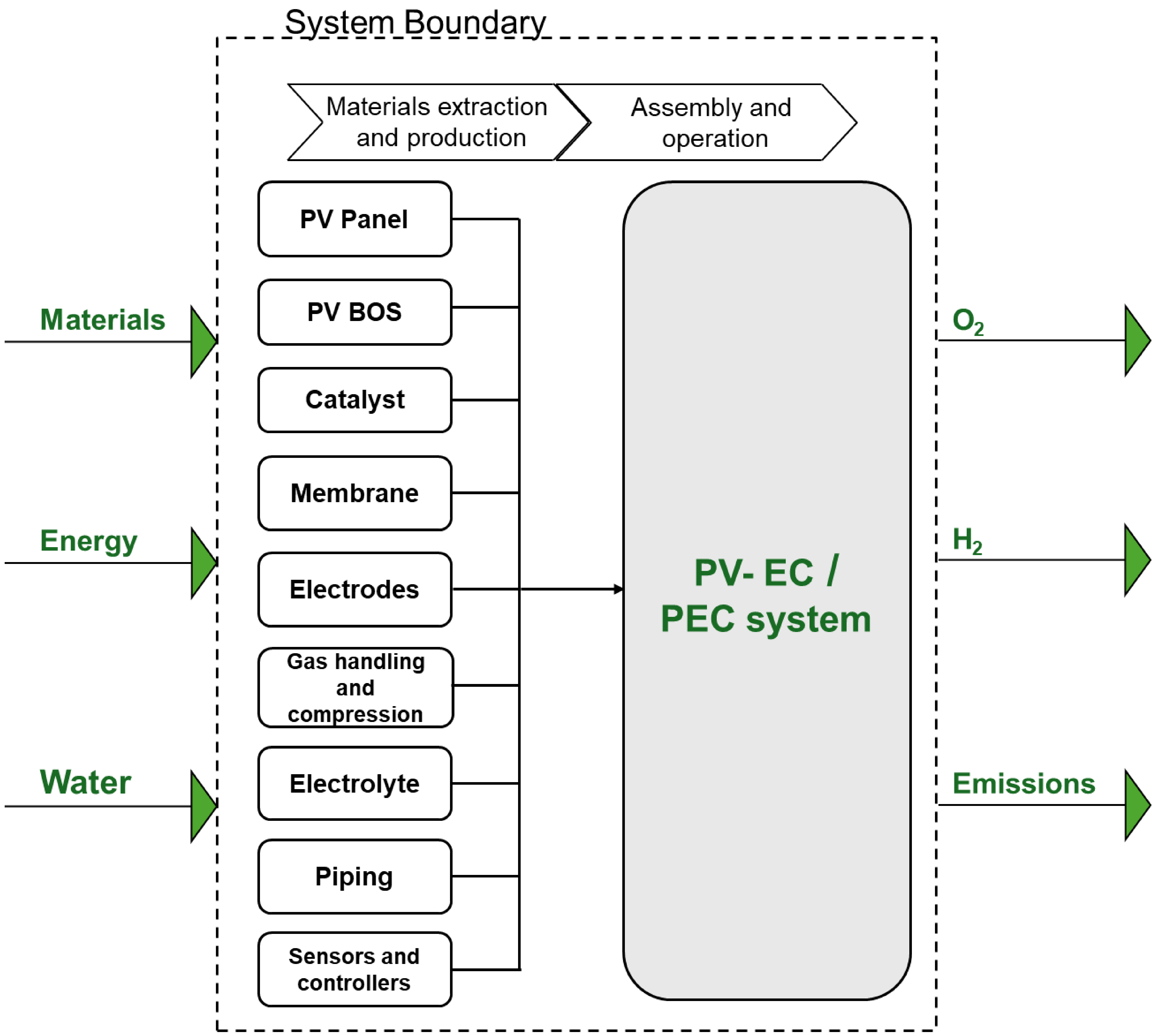
Life Cycle Assessment (LCA)

Functional Unit

1kg hydrogen generation from each system in 10 years lifetime

Software for LCA

openLCA



LCA Framework

Life Cycle Inventories → Data from literature and Ecoinvent database

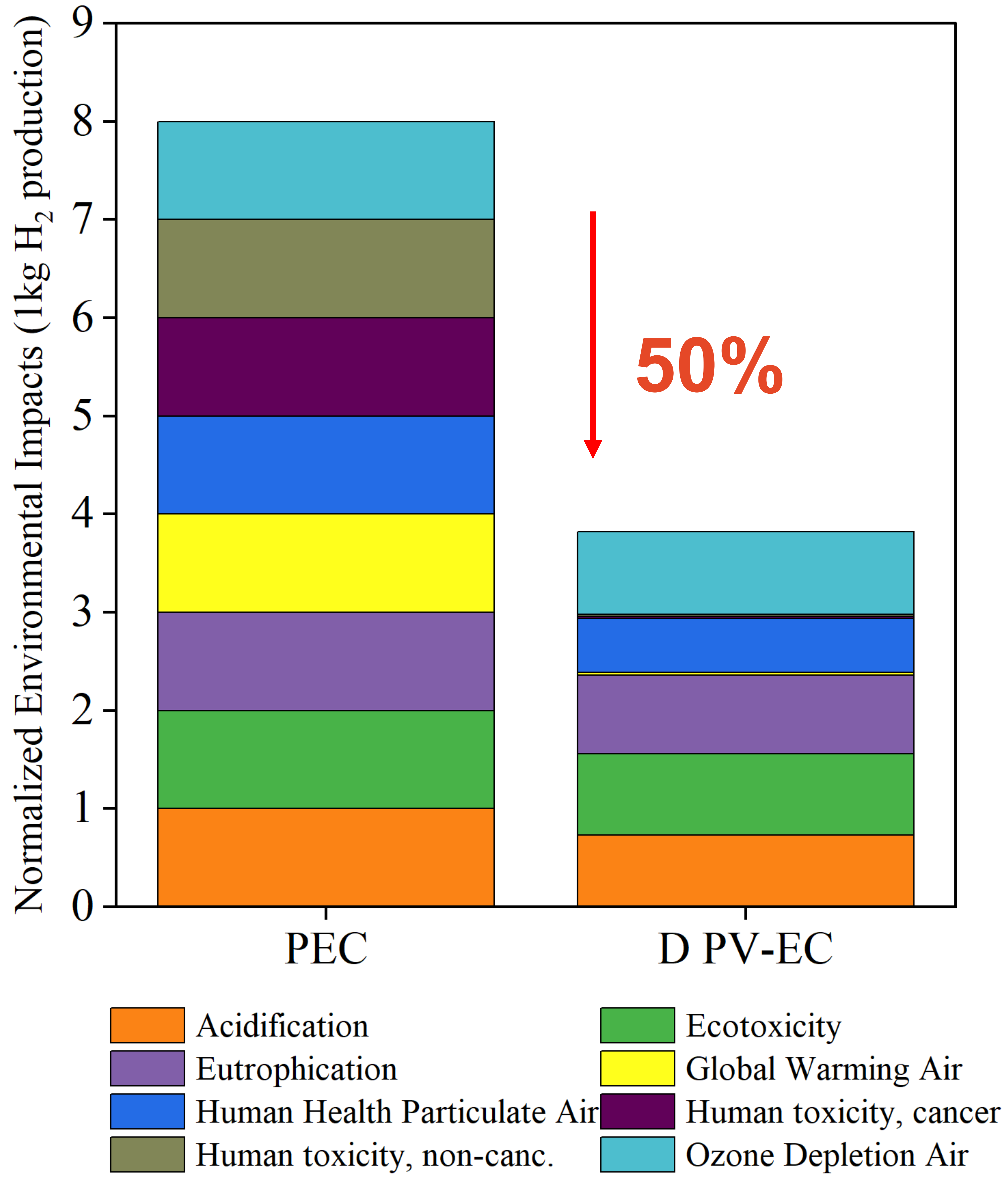
Impact Assessment → TRACI 2.1 by U.S. Environmental Protection Agency →

Acidification (kg SO_{2eq}.),
Ecotoxicity (CTUe),
Eutrophication (kg N_{eq}),
Global Warming Potential (kg CO_{2eq}),
Human toxicity (CTUh), cancer and non-cancer,
Human health particular air (kg $PM_{2.5\text{-}eq}$),
Resources-fossil fuels (MJ surplus energy),
Ozone depletion (kg $CFC11_{eq}$),
Cumulative energy demand (CED)

Analysis

Results

Impact Category	Units	PEC	D PV-EC
Acidification	kg SO2-Eq	7.08E-03	5.16E-03
Ecotoxicity	kg N-Eq	4.85E+01	4.01E+01
Eutrophication	kg $CO_{2\text{-}Eq}$	7.19E-03	5.76E-03
Global Warming Air	CTUe	7.99E+01	2.10E+00
Human Health Particulate Air	kg CFC-11-Eq	2.73E-03	1.52E-03
Human toxicity, cancer	kg PM2.5-Eq	3.60E-03	6.01E-05
Human toxicity, non-canc.	CTUh	3.60E-04	6.60E-06
Ozone Depletion Air	CTUh	1.14E-07	9.61E-08



Conclusions

Decoupled PV-EC configuration has 50% lower environmental impacts compared to PEC water splitting for 1 kg of H_2 generation

Most of the environmental impacts in both water splitting configurations are due to operation and maintenance

Future Work

- Conducting sensitivity analysis for various efficiencies and lifetimes.
- In my Summer 2024 internship at the National Renewable Energy Laboratory (NREL), I will upscale these configurations by gathering real time data.

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Questions?