ASU®

The Future of Sustainable Transportation Fuels Series

Challenges and Opportunities in Designing Good Metrics to Assess Promise

September 22, 2015

LightSpeed Solutions
Secure Energy · Sustainable Fuels

Introduction

Future of Sustainable Transportation Fuels

Ellen B Stechel
Deputy Director,
ASU LightWorks
Managing Director,
Light*Speed* Solutions

Light*Speed* Solutions, an initiative of Arizona State University LightWorks in partnership with the Security and Sustainability Forum is hosting **The Future of Sustainable Transportation Fuels Forum**, a free four webinar series to engage the range of future fuels stakeholders in online conversations about the future of sustainable transportation fuel production and use.

Edward Saltzberg
Managing Director,
Security & Sustainability Forum

LightSpeed Solutions
Secure Energy • Sustainable Fuels

ASU LightWorks
ARIZONA STATE UNIVERSITY

SECURITY & SUSTAINABILITY FORUM
Convening Global Experts to Guide Decision Making

Supporting Partners

LightSpeedSolutions.org

LinkedIn

The Future of Sustainable Transportation Fuels Group

Promotional partners

ENVIRONMENTAL LAW • INSTITUTE®

CAAFI® COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

NASEO National Association of State Energy Officials

ASERTTI

frontiers

ACORE American Council On Renewable Energy

SOFI Solar Fuels Institute

SERC SOLAR ENERGY RESEARCH CENTER

the center for negative carbon emissions

Moderator

Dr. Gary Dirks is the Director of the Julie Ann Wrigley Global Institute of Sustainability and of LightWorks, an Arizona State University initiative that capitalizes on ASU's strengths in solar energy and other light-inspired research. Before joining ASU, Dr. Dirks was the President of BP Asia Pacific and the President of BP China.

Agenda

1. Overview and Introductions: **Gary Dirks**
2. Presentations
   a) **Louise Vickery & James Hinkley,** Manager of renewable futures at the Australian Renewable Energy Agency and senior research scientist at the Commonwealth Scientific and Industrial Research Organization (respectively
   b) **Cheryl Martin**, Founder, Harwich Partners and previous Deputy Director for Commercialization of the Advanced Research Projects Agency - Energy (ARPA-E) at the US Department of Energy
   c) **Eric Miller**, Program manager for hydrogen production delivery at the US Department of Energy)
   d) **Andrew Maynard,** Professor in the School for Future of Innovation in Society at Arizona State University
3. Panel Discussion & Audience Questions (Submit questions through side panel)

Please take the exit questionnaire about keeping the conversation going.

Webinar series goals

To further the conversation on achieving a sustainable low net carbon transportation future

- To accelerate the transition and promote economic efficiency
- To convey that technical advances and better understanding are opening up opportunities to consider a broader range of options

To stimulate additional conversation and prove to be a starting point on exploring alternatives

- To offer a range of viewpoints, but won’t be comprehensive and we are not going to provide “the answer” nor debate perspectives
- To further innovation and to further the conversation from a wide range of viewpoints and expertise
- To provide useful guidance for decision-makers, including policy makers and regulators

Available Webinars

- **Webinar 1 Video:** Anchoring Themes
- **Webinar 2 Video:** Coupling the Electric Power and Transportation Sectors - Electric Vehicles and Beyond
- **Webinar 3 Video:** Recycling CO_2 to Liquid Hydrocarbon Fuels

Watch the recordings at

www.light*speed*solutions.org

Conversations Started

- **<u>Supportive Policies</u>:** Meeting ambient CO_2 concentration goals requires moving to low carbon transportation but policies to offset competitive limitations with fossil options are needed, such as a carbon tax.

- **<u>Grid Decarbonizing</u>:** Decarbonizing both electric grids and natural gas (with e.g., biogas or synthetic gas) fast enough can enable decarbonizing some of transportation with electric, natural gas, and hydrogen vehicles.

- **<u>Preserving the advantages of carbon-based fuels</u>:** Fleet turnover rates, infrastructure and scalability for renewables argue for low carbon petroleum alternatives (drop-in fuels) and continued investment in bio-based fuels, carbon capture and utilization (CCU), and solar fuels.

- **<u>CO_2 as a feedstock</u>**: Most likely affordable technologies to remove CO_2 from the air will be needed for both negative emissions and a benign carbon source. With air capture, CO_2 fed alternatives (e.g., algal and carbon-based solar fuels) can close the carbon cycle. Carbon capture from fossil sources can serve as a valuable *interim* step to source that carbon on path to *eventually* weening completely off of fossil.

Webinar panelists

Cheryl Martin, Founder, Harwich Partners and previous Deputy Director for Commercialization of the Advanced Research Projects Agency - Energy (ARPA-E) at the US Department of Energy

Eric Miller, Program manager for hydrogen production delivery at the US Department of Energy

James Hinkley, Research Scientist at CSIRO in solar thermal technologies for power and fuels in Australia

Andrew Maynard, Professor in the School for Future of Innovation in Society at Arizona State University

Australian Government
Australian Renewable Energy Agency

Solar Transport Fuels

Louise Vickery

General Manager – Renewable Futures Projects Group
Australian Renewable Energy Agency (ARENA)
September 2015

Jim Hinkley

Project Leader: Solar Fuels Roadmap
Commonwealth Scientific and Industrial
Research Organisation (CSIRO)

ARENA

Solar Fuels as Part of Future Energy Systems

- The world is transitioning to low emission energy solutions that are cost effective
- Role of Government is to manage the transition through policies / programs that balance economic, social and environmental outcomes
  - facilitating awareness, uptake and investment in commercial low emission reliable renewable energy solutions
- Solar Fuels could play an important role in the transition
- Developing the right solar fuel solutions requires a clear understanding of:
  - what is the problem that solar fuels are seeking to address?
    - What energy service are we hoping to provide and to whom
  - what are the market opportunities ?
  - what are the key technical challenges?
  - what are the economic costs and benefits?
  - what is required to facilitate the necessary industry investment
- ARENA has funded the Solar Fuels Roadmap Project to address these issues.

ARENA

Solar Fuels Roadmap Project

- 3.5 year project concluding 30/11/15
  - Fuel security and high oil prices key concerns at start of project
  - Solar thermal processes for fuel production
    - Solar fossil hybrids: solar steam reforming, solar gasification
    - Redox cycles: fully renewable
- Roadmap project engages with international experts and local stakeholders to:
  - summarise the state of the art of solar thermal technologies for fuel production
    - Include synthesis options – syngas to H_2, gasoline, diesel, methanol, NH_3
  - conduct techno-economic evaluations to understand cost, maturity etc.
  - establish a roadmap to map out the research, development and demonstration priorities to establish a solar fuels industry in Australia
- Significant cost reduction in PV meant that scope was expanded to include an assessment of PV & Electrolysis for H_2

ARENA

Observations on the Project

- Challenges
  - Multiple technologies, multiple feedstocks, multiple products
  - Many technologies at low TRL
    - Difficult to estimate current & future costs
  - Market identification as important as technology development
    - Initial expectation: liquid transport fuels for energy security and export
    - Subsequently: hydrogen for Japan, methanol for China and ammonia
  - Externalities affect value proposition (oil price, CO_2 tax etc.)
  - Researcher world view is not the same as an industrial company
    - Key issues for companies: risk, risk, risk and payback
    - Research perspective: levelised cost of fuel
    - Industry perspective: return on investment (now and into the future)
- Metrics:
  - TRL, research intensity, difficulty of unsolved hurdles
  - Levelised cost of fuel useful for comparing technologies ($/GJ)
  - Return on investment for specific cases: more interesting for companies (assumptions)

ARENA

Key Project Findings

- Expect that solar fuels can be competitive with oil derived fuels (at $100-$140/bbl)
  - Time frame: 2020-2025 (assumes ongoing investment and CSP deployment)

- Range of solar thermal technologies, trade off between maturity and carbon reduction, progressive de-carbonisation
  - Solar-fossil hybrids closest to commercial success
    - + transitional technologies with cost benefits of fossil fuels but reduced emissions
  - Medium term: gasification of coal and or biomass
  - Longer term: redox cycles for fully renewable fuels (2025+)

- Preliminary estimates of PV and electrolysis based on DoE data suggests will be 2-3 times more expensive than solar fossil hybrids
  - Issues: utlisation of electrolyser, unknown durability under intermittent load (PEM)

- Delivering a high capital process to market requires sustained investment
  - Challenging when the next investment is $10-15 million
  - Reality is need bankable (demonstrated) technologies
  - Need to identify high value niche markets for early uptake

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Summary

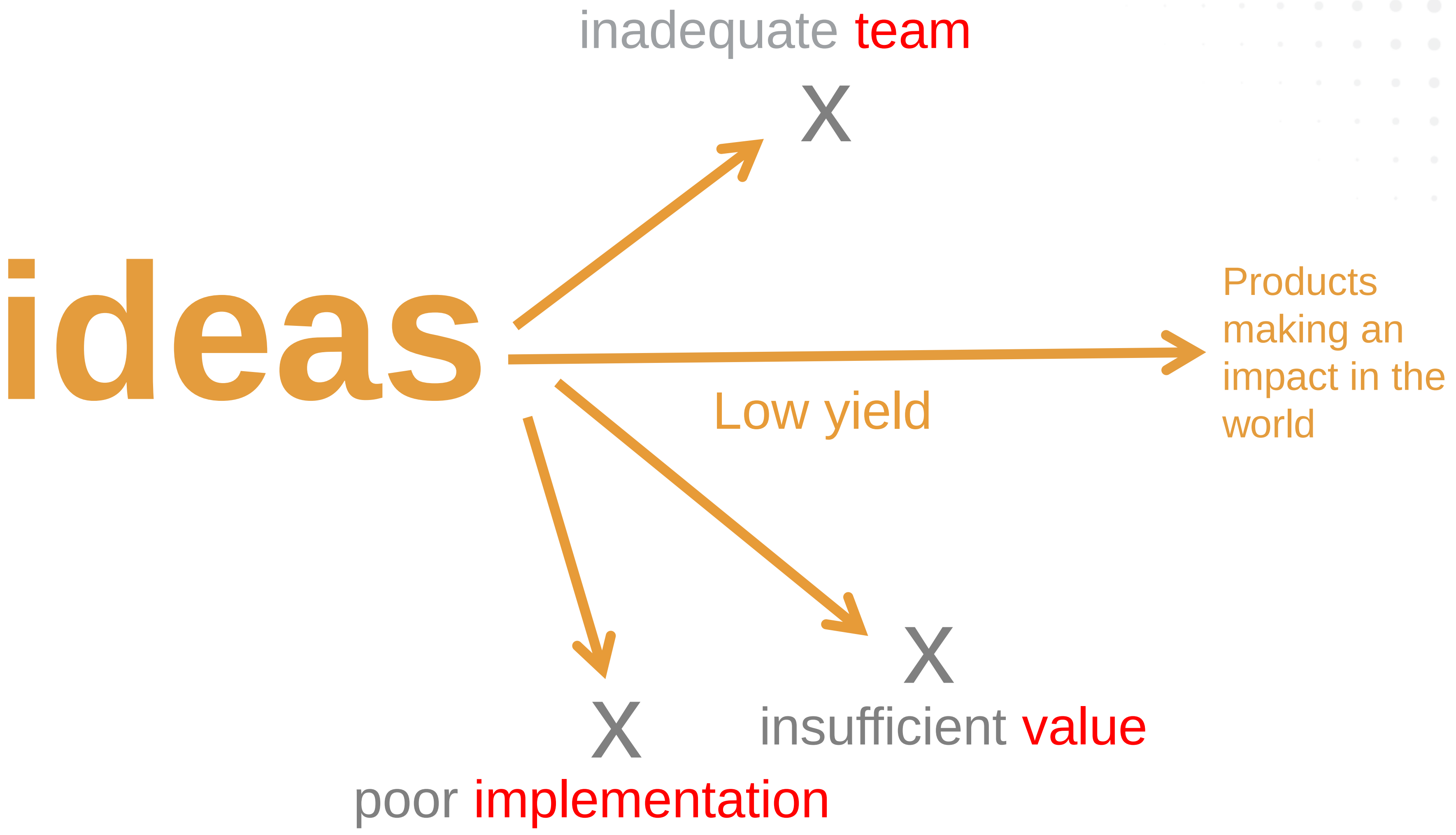
- The World will transition to a low carbon future
  - the speed of the transition and the mix of future energy technologies is yet to be determined
- Solar Fuels could be part of the future energy mix, however there is still a need to understand the problem that solar fuels seek to address
- This will allow for better identification of the solar fuels market and what the competition is.
- The metrics used should reflect and communicate the metrics understood by the market
- It will require close engagement with industry to develop solar fuel solutions that mitigate risk and provide the greatest likelihood of return on investment.
- Significant markets exist for solar fuels, whether for transport or storage.
  - Domestic and international collaborations across researchers, government and industry will ensure that market opportunities are identified and captured quickly.

ARENA

Technology to Market Challenges in Liquid Fuels

Cheryl Martin
Harwich Partners

Improving the Yield



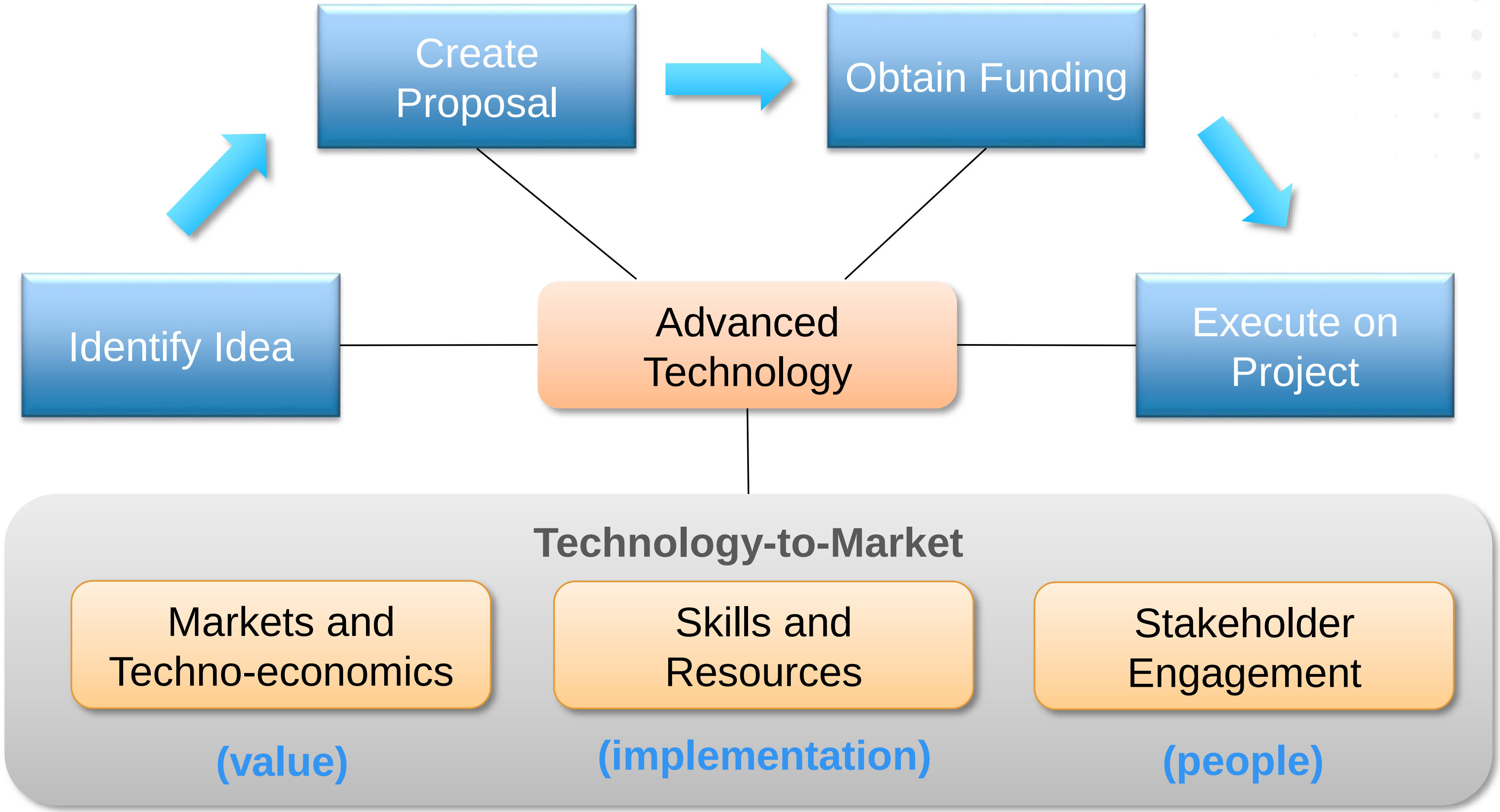
Changing the Model

ideas

+ value
+ team
+ implementation

Products making an impact in the world

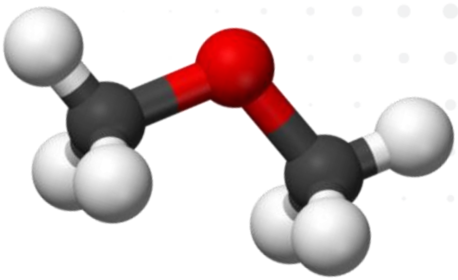
Changing the Model



"What Matters" for Liquid Fuel Success

- Technical Challenges
  - Energy Density, Catalysts, Conversion Efficiency etc…
  - Scale-up
- Infrastructure
  - Compatibility
- System Level Cost and Safety
- Regulation
- End Markets
- Financing
- Partners and Networks

DME Dimethyl Ether



Simple Fuel

- Diesel-like performance
- Clean burning, no soot generated
- Made from methane and carbon dioxide

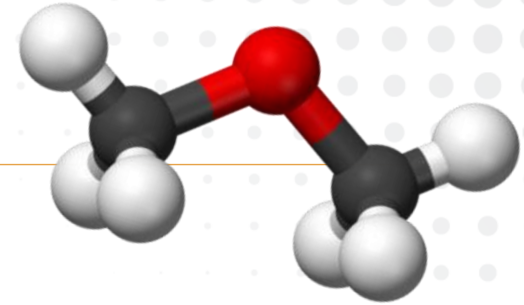
Simple Engine

- Efficiency & torque of diesel engine with no soot produced
- Remove significant amount of after-treatment equipment

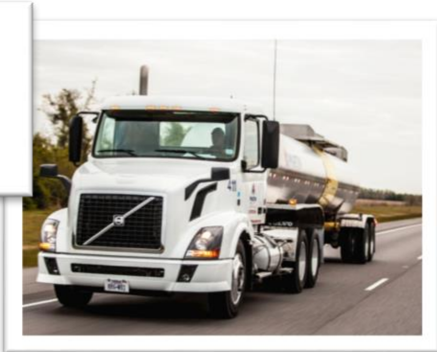
Simple Infrastructure

- Propane-like Handling (cylinders/tank, only change seal)

Oberon Fuels



- **Founded in November 2010**
- **Technology acquired from failed startup**
  - Benchtop-scale conversion of wastewater treatment gas to gasoline, pivoted to DME
- **Key Development Milestones**



2013 Oberon DME pilot plant online. Fuels Volvo's US-based demonstrations.

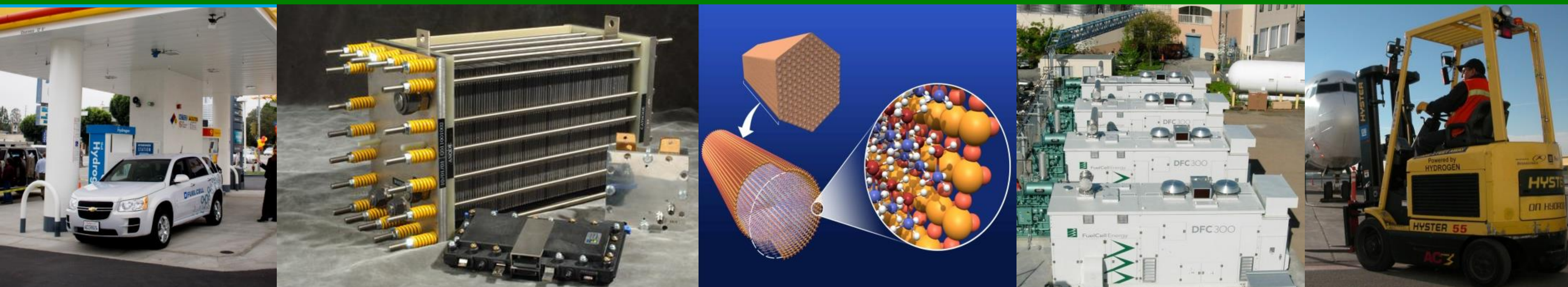
2013 Volvo Oberon Partnership to Commercialize DME

2015 With CA's change in their Code of Regulations, DME can now be legally sold in all 50 states.

Thank You

cheryl@harwichpartners.com

U.S. DEPARTMENT OF
ENERGY



Critical Metrics and Analyses: Addressing the Fundamental Challenges for Hydrogen and Fuel Cell Technologies

Eric L. Miller

U.S Department of Energy
Office of Energy Efficiency & Renewable Energy
Fuel Cell Technologies Office

Security and Sustainability Forum Panel

22 September, 2015

Sustainable TRANSPORTATION

Renewable ELECTRICITY GENERATION

Energy Saving HOMES, BUILDINGS, & MANUFACTURING

Sustainable Transportation Sector

Sustainable TRANSPORTATION

- Transportation Efficiency
- Diverse Fuel Sources
- Domestic & Renewable

Hydrogen and Fuel Cells

Vehicles

Bioenergy

National Energy Goals & Climate Action Plan

Net Oil Imports
↓ 50% by 2020

GHG Emissions
↓ 17% by 2020
>80% by 2050

Fuel Cell Vehicles are on U.S. Roads Now!

Just Announced Publicly- Toyota Mirai FCV

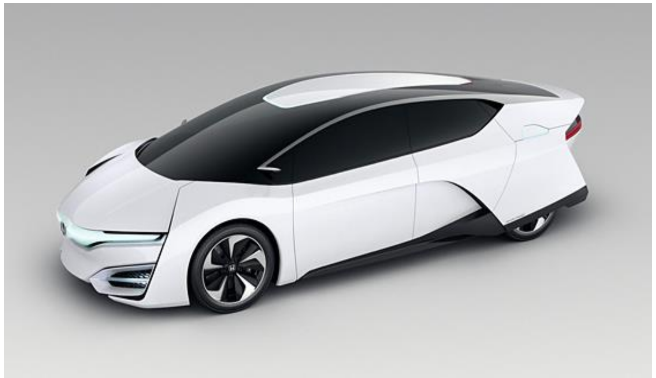
1st commercially available FCEV for sale in the US

Toyota Mirai Fuel Cell Vehicle

Now Leasing…

Hyundai Tucson Fuel Cell SUV

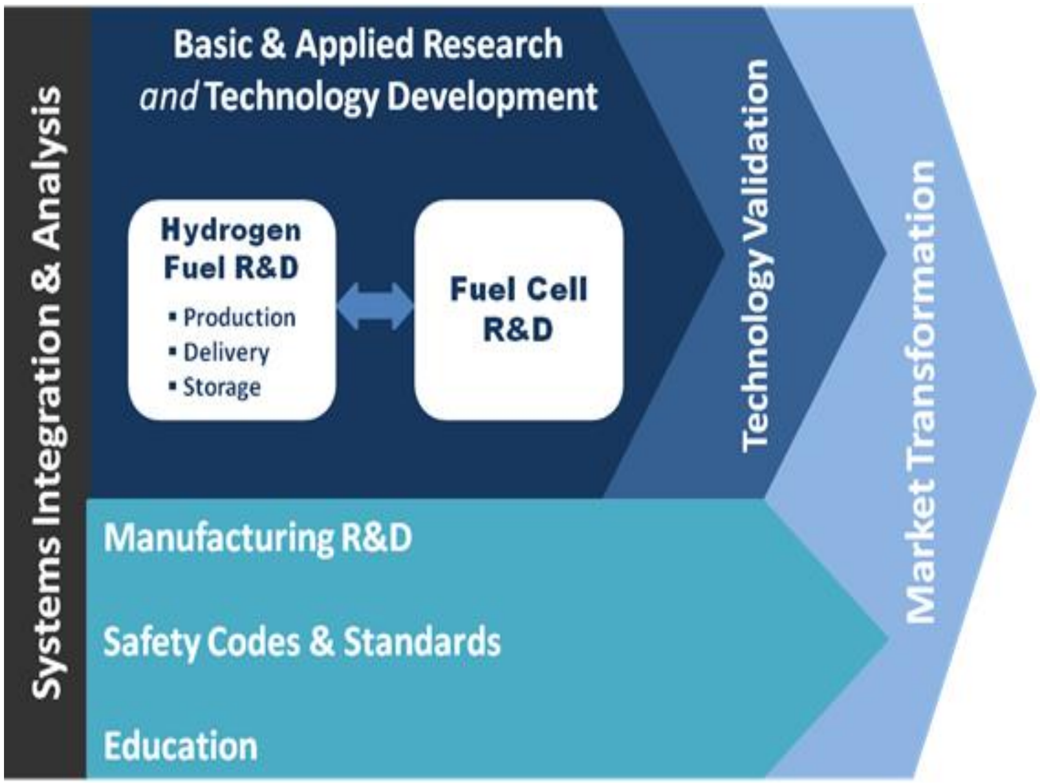
In Auto Shows…



Honda Fuel Cell Electric Vehicle

OEMs bringing fuel cells to showrooms and driveways:
Cost reductions needed in fuel cells, and H_2 production, storage & delivery

Mission: Enable widespread commercialization of a portfolio of H_2 and fuel cell technologies through basic and applied research, technology development and demonstration.



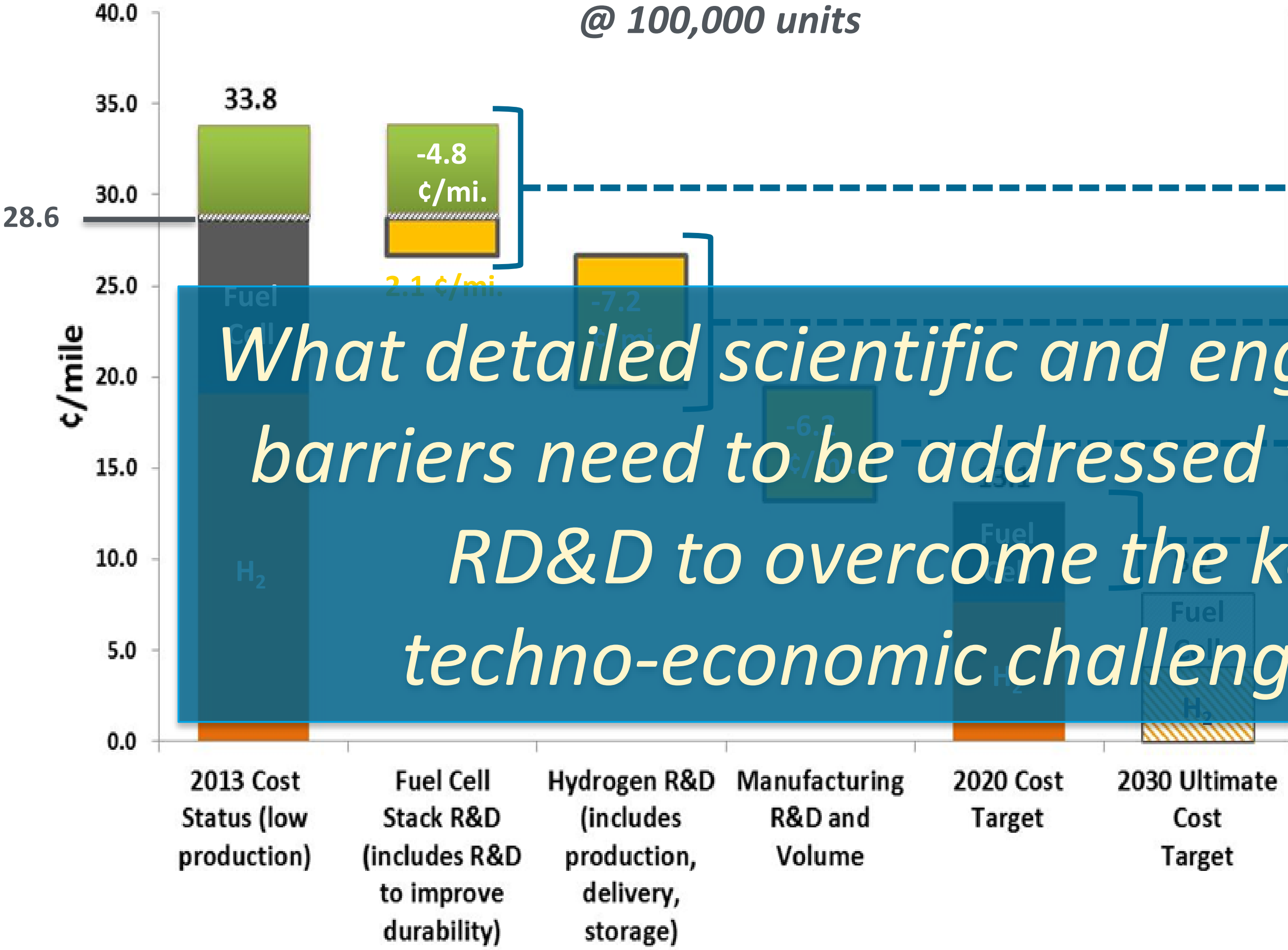
Fuel Cell Cost	$40/kW	$1,000/kW* $1,500/kW**
Durability	5,000 hrs	80,000 hrs
H_2 Storage Cost (On-Board)	$10/kWh	
H_2 Cost at pump	<$4/gge	

*For Natural Gas
**For Biogas

The Program includes a comprehensive portfolio of activities to address the techno-economic challenges in fuel cells and hydrogen fuel

FCEV Cost Reduction Pathways

@ 100,000 units



RD&D Needs

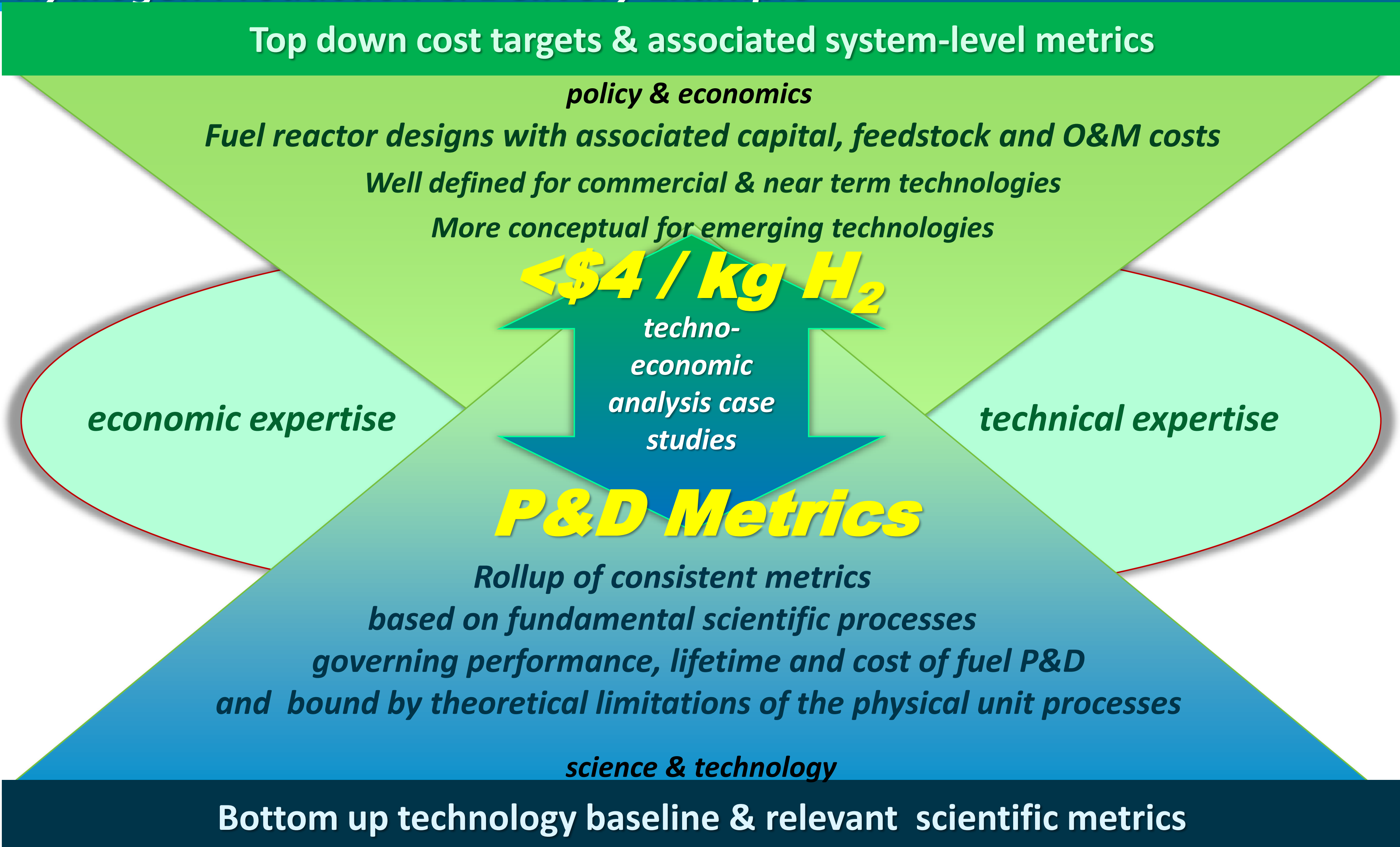
- Catalysts, membranes, electrodes, BOP and increase in durability
- H_2 Production, delivery and storage
- Manufacturing RD&D and processes, QC and high volume fabrication
- Additional progress needed for ultimate targets

What detailed scientific and engineering barriers need to be addressed through RD&D to overcome the key techno-economic challenges?

Represent additional costs assuming a higher platinum cost of $2000/tr. oz. – reductions shown represent RD&D of low-Pt catalysts

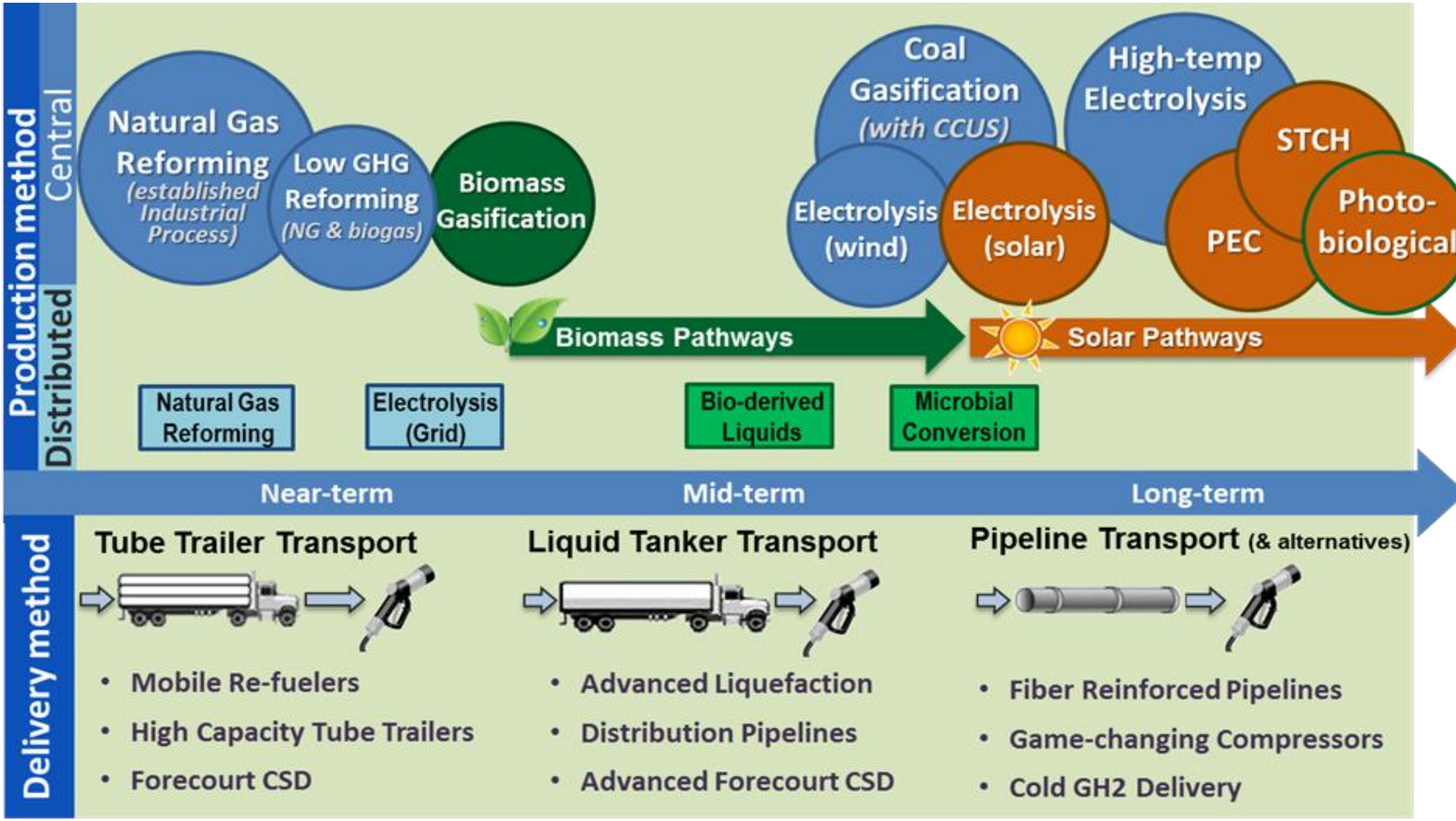
Total cost of ownership analysis identifies key RD&D needs for FCEVs to be competitive with incumbent and other advanced technologies

Techno-economic Push and Pull:
Hydrogen Production & Delivery Example



Connecting the TOP DOWN and BOTTOM UP metrics is critical

Diverse H_2 Production & Delivery RD&D Portfolio

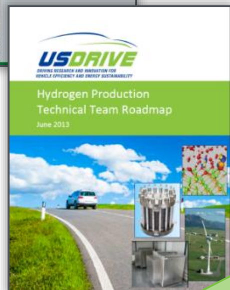


Addressing the near-term infrastructure rollout needs as well as the longer-term transition from incumbent technologies to large-scale renewable hydrogen

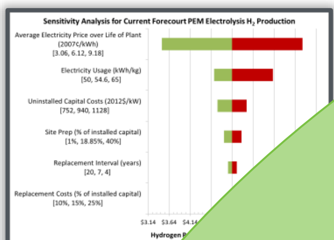
RD&D Portfolio Development Approach

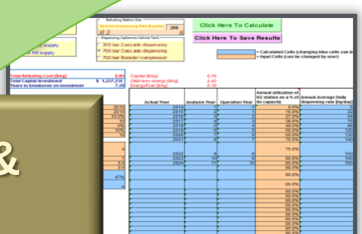
Workshops

U.S. DRIVE Tech Team Roadmaps



H2A





HDSAM

Analysis & Studies

Stakeholder Input

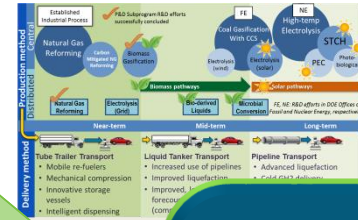
Collaboration & Coordination

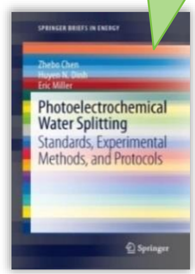
SBIR / STTR
Small Business Innovation Research
Small Business Technology TRansfer

Engineering Directorate
Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET)
NSF 14-511: NSF/DOE Partnership On Advanced Frontiers in Renewable Hydrogen Fuel Production via Solar Water Splitting Technologies

H_2FIRST
Hydrogen Fueling Infrastructure Research and Station Technology

H_2USA





Pathway Working Groups

RD&D Portfolio
priorities, metrics, targets

Characteristics	Units	2011 Status	2015 Target	2020 Target	Ultimate Target
Solar-Driven High-Temperature Thermochemical Cycle Hydrogen Cost [b]	$/kg	NA	14.80	3.70	2.00
Chemical Tower Capital Cost (installed cost) [c]	$/TPD H_2	NA	4.1MM	2.3MM	1.1MM
Annual Reaction Material Cost per TPD H_2 [d]	$/ yr.-TPD H_2	NA	1.47M	89K	11K
Solar to Hydrogen (STH) Energy Conversion Ratio [e,f]	%	NA	10	20	26
1-Sun Hydrogen Production Rate [g]	kg/s per m^2	NA	8.1E-7	1.6E-6	2.1E-6

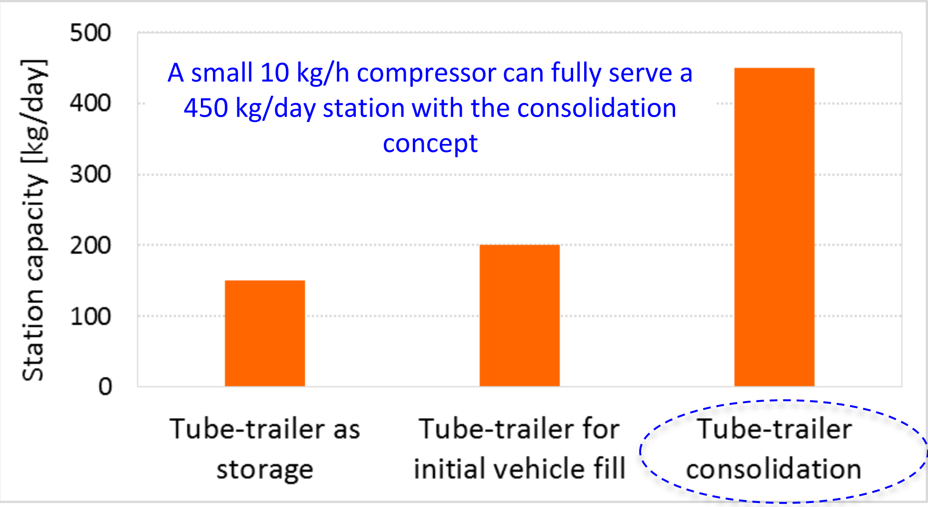
Table 3.1.7 Technical Targets: Solar-Driven High-Temperature Thermochemical Hydrogen Production [a]

FCTO MYRD&D Plan for Meeting Cost Goals

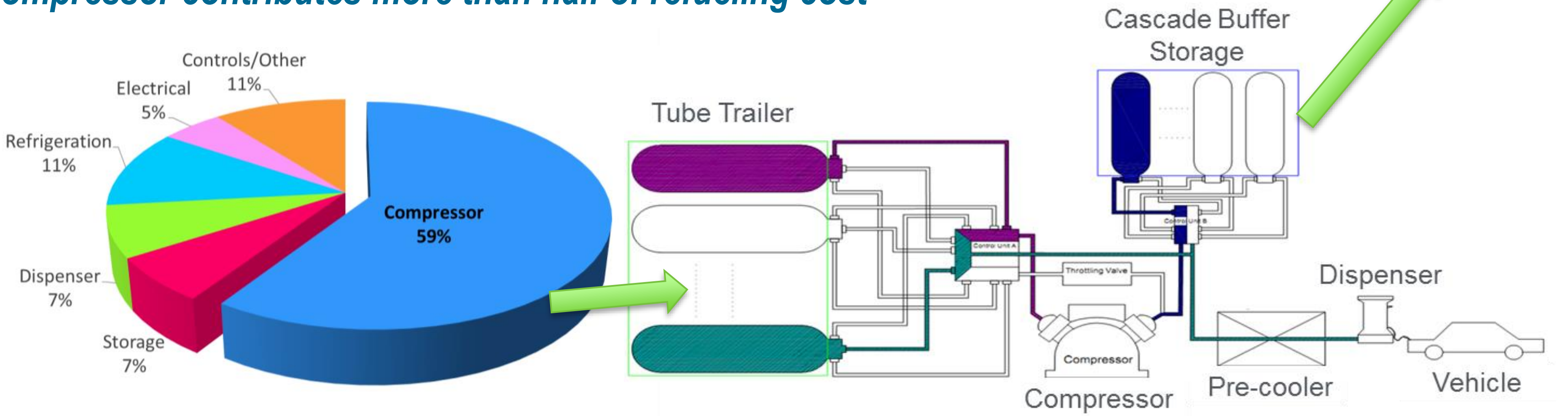
Techno-economic analyses & stakeholder input inform programmatic decisions & priorities for portfolio of pre-competitive RD&D

Advancing Near-Term H_2 Station Technologies

- By using the compressor to consolidate the remaining hydrogen on board the tube trailer during off peak hours a smaller compressor can be used at the forecourt to meet the same demand.
- This greatly reduces the cost of the compressor and this lowers the station cost contribution.

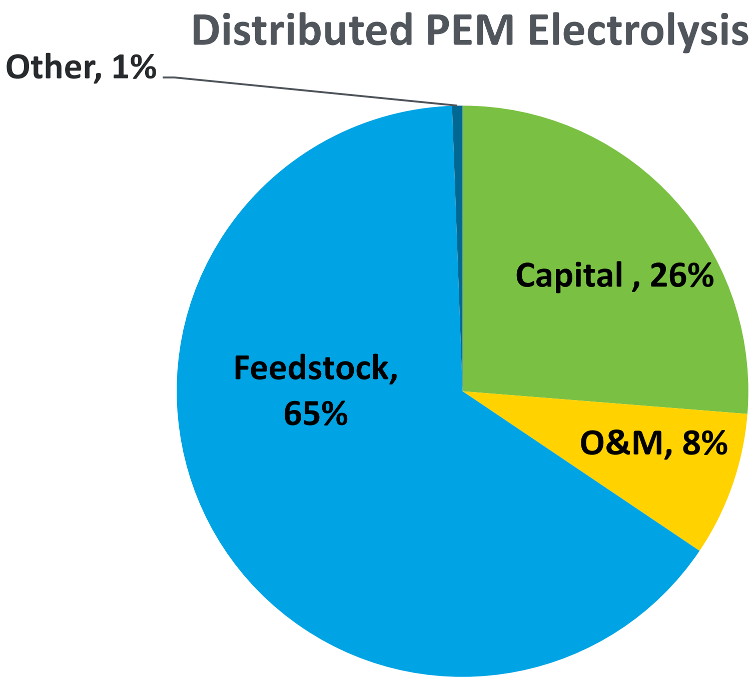


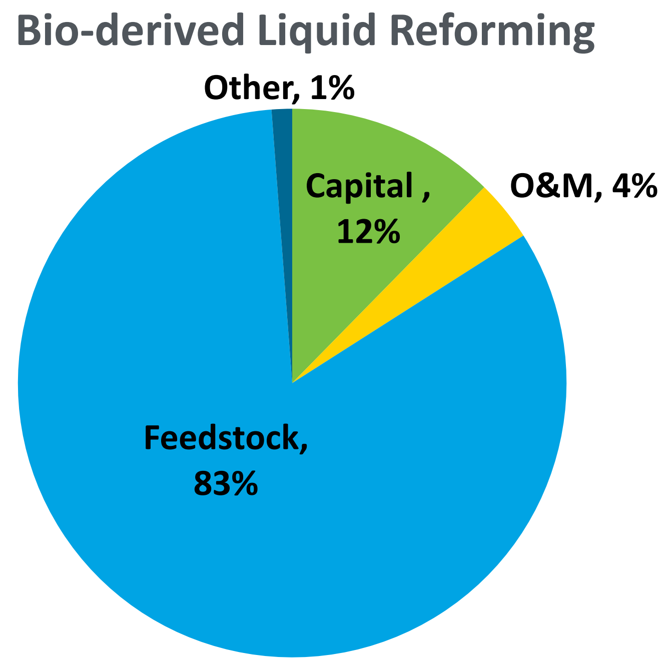
Compressor contributes more than half of refueling cost



Economic pull clearly linked with technical push at the component, systems and systems integration levels to guide innovation

Near-term Renewable Hydrogen Options



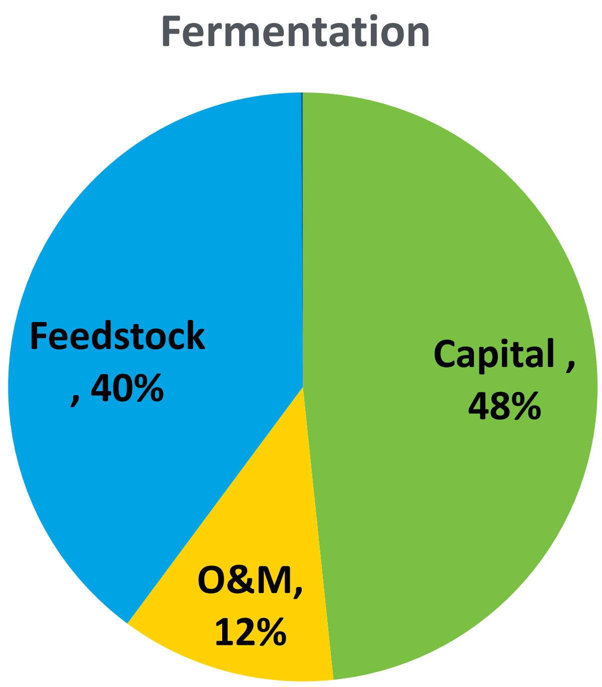


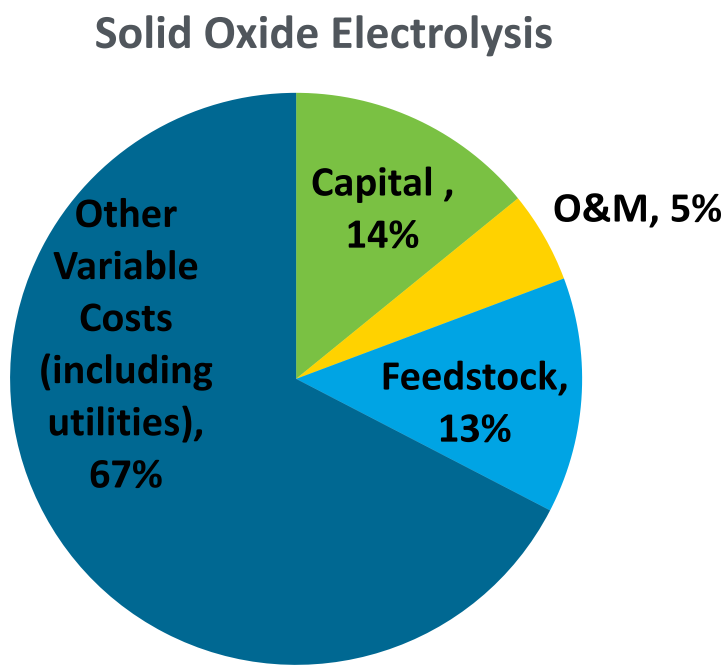
Current projected "high-volume" costs of near-term renewable H_2 options

Current H_2 Production Cost [6]	LOW $/kg	BASELINE $/kg	HIGH $/kg
Distributed Pathways			
Distributed PEM Electrolysis	3.40	5.10	6.60
Distributed Bio-Derived Liquids	3.20	6.60	7.90
Central Pathways			
Central PEM Electrolysis	3.40	5.10	6.50
Central Biomass	2.10	2.50	4.20

Renewable feedstock costs have major impact on H_2 costs;
There is still some room for cost reduction through technology advances

Emerging Technologies for Renewable H_2 Production



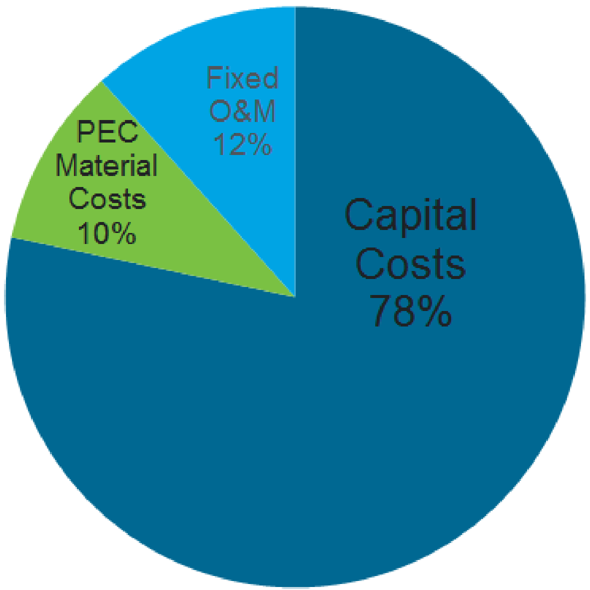


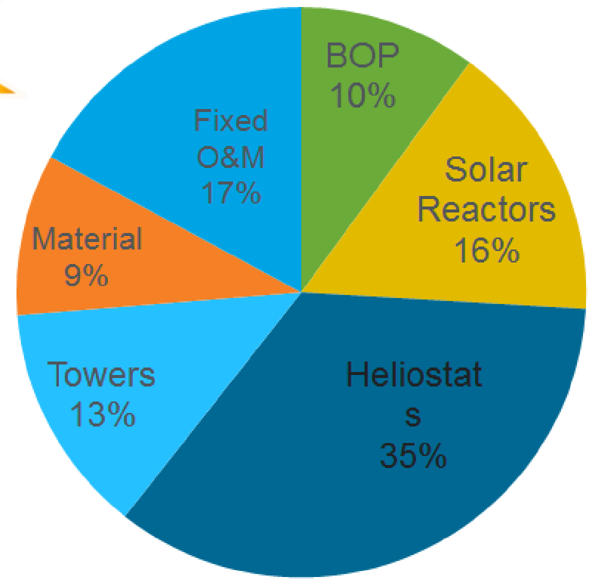
Technology Readiness Level impacts quantity and quality of stakeholder involvement, data/metrics for analysis input as well as how results are used to guide RD&D efforts

Non-feedstock technology cost drivers have been identified; Technology and investment barriers remain to meeting cost targets

Longer Term Solar to Hydrogen Pathways

High-impact/high-risk technologies need to be guided by metrics & benchmarking





PEC
Photoelectrochemical

STCH
Solar-thermochemical

Solar-to-hydrogen conversion efficiencies over 30% may be needed to meet cost targets.

To date, lab-scale prototype demos have achieved ~1-12% STH for limited periods.

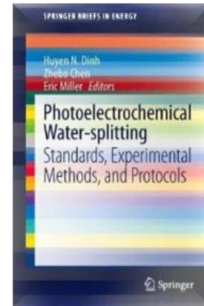
Major cost drivers relate to efficiency & durability, determined by Thermodynamics & Kinetics of Materials Systems

Sustainable Fuel Challenges & Opportunities

Advances continue in all the sustainable fuel pathways, but to achieve such aggressive targets the RD&D communities must keep considering:

- What are the **THEORETICAL** limits?
- What are the **PRACTICAL** barriers?
- What **FUNDAMENTAL RD&D** is needed?
- What **ENGINEERING RD&D** in needed?
- What other barriers must be addressed?
- What RD&D trajectories are possible? (how to minimize the 'overpotential'?)

**model for success in the PEC community*



JCAP

International Energy Agency (iea) H I A

~25-30% STH

- Unit sub-processes must be clearly defined with quantitative metrics and limits.
- Relationships of unit processes to system performance must be clearly mapped.
- **STANDARDIZED PROTOCOLS*** are critical.
- **UNTAPPED SYNERGIES** across sustainable fuels pathways must be exploited.

~1-12%STH

solar hydrogen example

Advances across sustainable fuel technologies can be enabled by clear and common definitions and benchmarking standards for techno-economic performance metrics

Discussion Questions:

- What are the key analyses, technical metrics, benchmarking procedures and reporting standards a given technology? How well are they defined and are they used consistently by the RD&D community to identify and address the key barriers to commercialization?
- What advances and learnings can be leveraged to avoid re-inventing the wheel? How can established procedures and lessons learned from commercial- and near-commercial technologies be best leveraged to accelerate development of emerging technologies?
- What are the specific collaborative opportunities for technical cross-cuts in the sustainable energy space, including fuel cells, batteries, flow batteries, H_2 production, solar cells, etc., all facing technical challenges in functional materials and interfaces?

Thank you!

eric.miller@ee.doe.gov

http://energy.gov/eere/fuelcells/fuel-cell-technologies-office

NAVIGATING AN UNCERTAIN FUTURE

Risk, responsibility, and technology innovation

Andrew Maynard
Director, Risk Innovation Lab

Sustainable Transportation Fuels – *Challenges and Opportunities for Designing Good Metrics to Assess Promise. September 22 2015*

SCHOOL FOR THE FUTURE of Innovation in Society
ARIZONA STATE UNIVERSITY

PRESENT

RISK

FUTURE

You want to be here

You are here

RISK

PRESENT

FUTURE

You want to be here

Perceptual Risk

Technical Risk

Environmental Risk

Social Risk

Goals Risk

Political Risk

Regulatory Risk

You are here

Health Risk

Financial Risk

(You may need to be to be here)

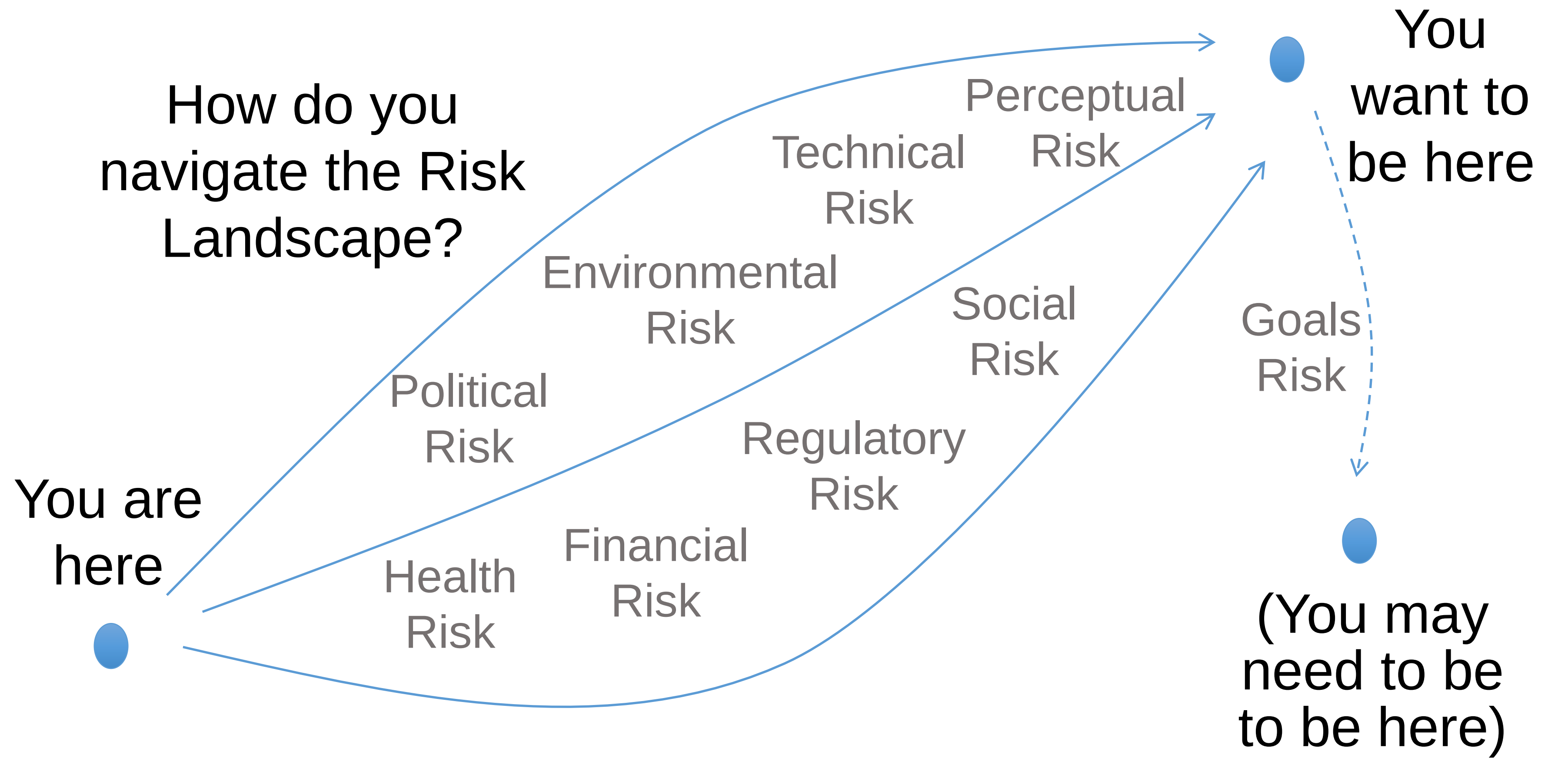
ASU School for the Future of Innovation in Society
Arizona State University

RISK

PRESENT

FUTURE

How do you navigate the Risk Landscape?

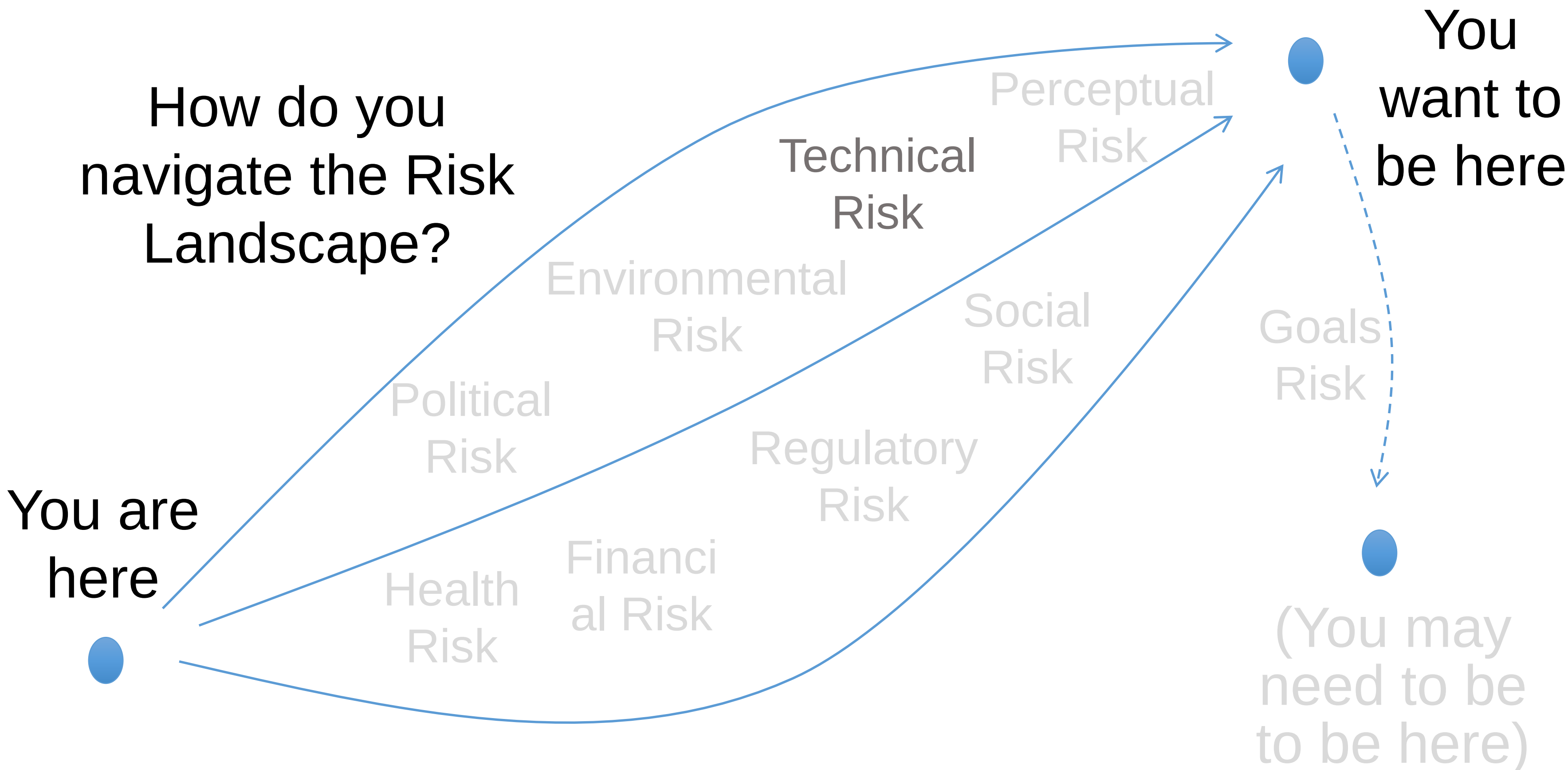


PRESENT

RISK

FUTURE

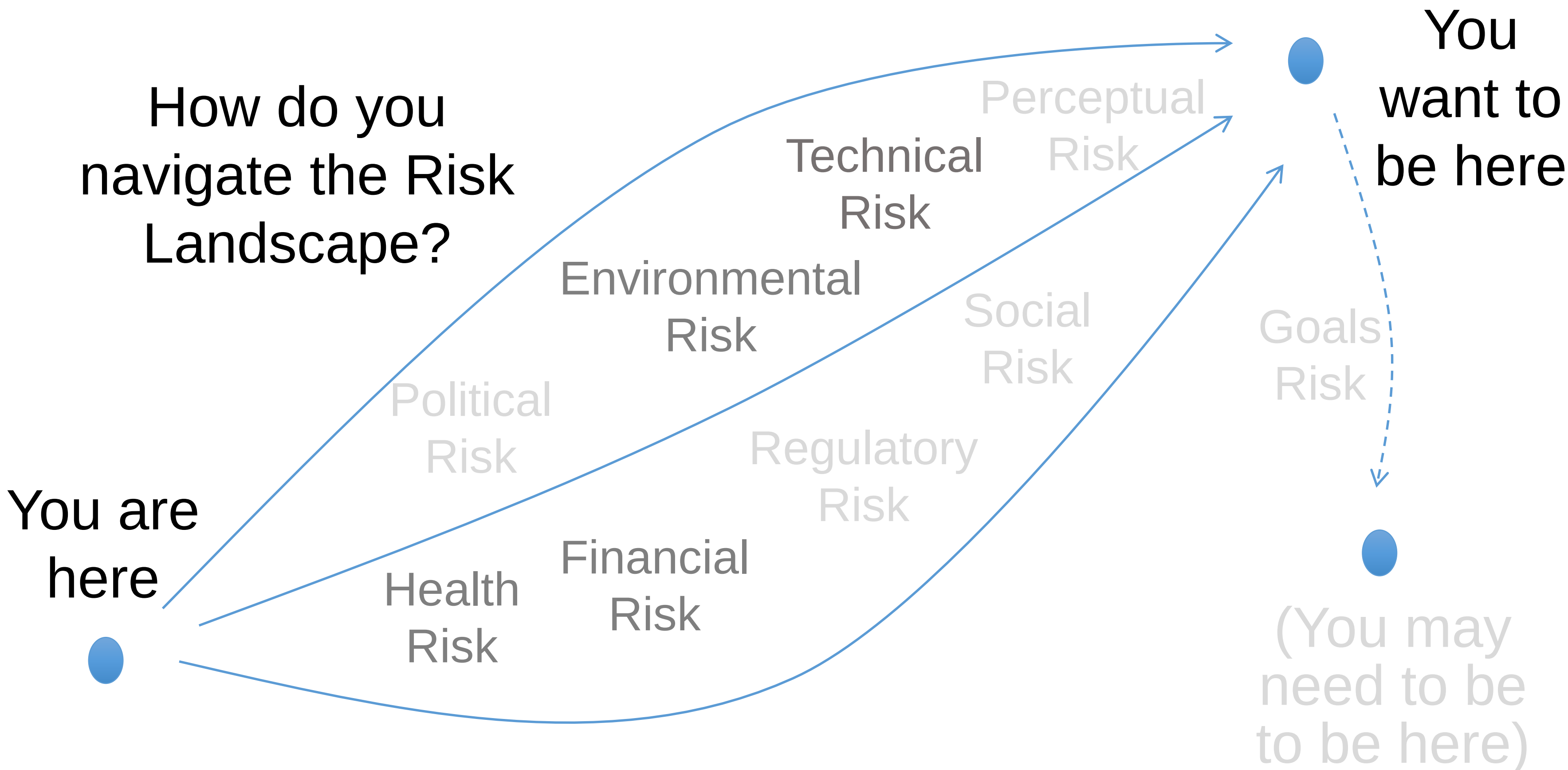
How do you navigate the Risk Landscape?



RISK

PRESENT

FUTURE



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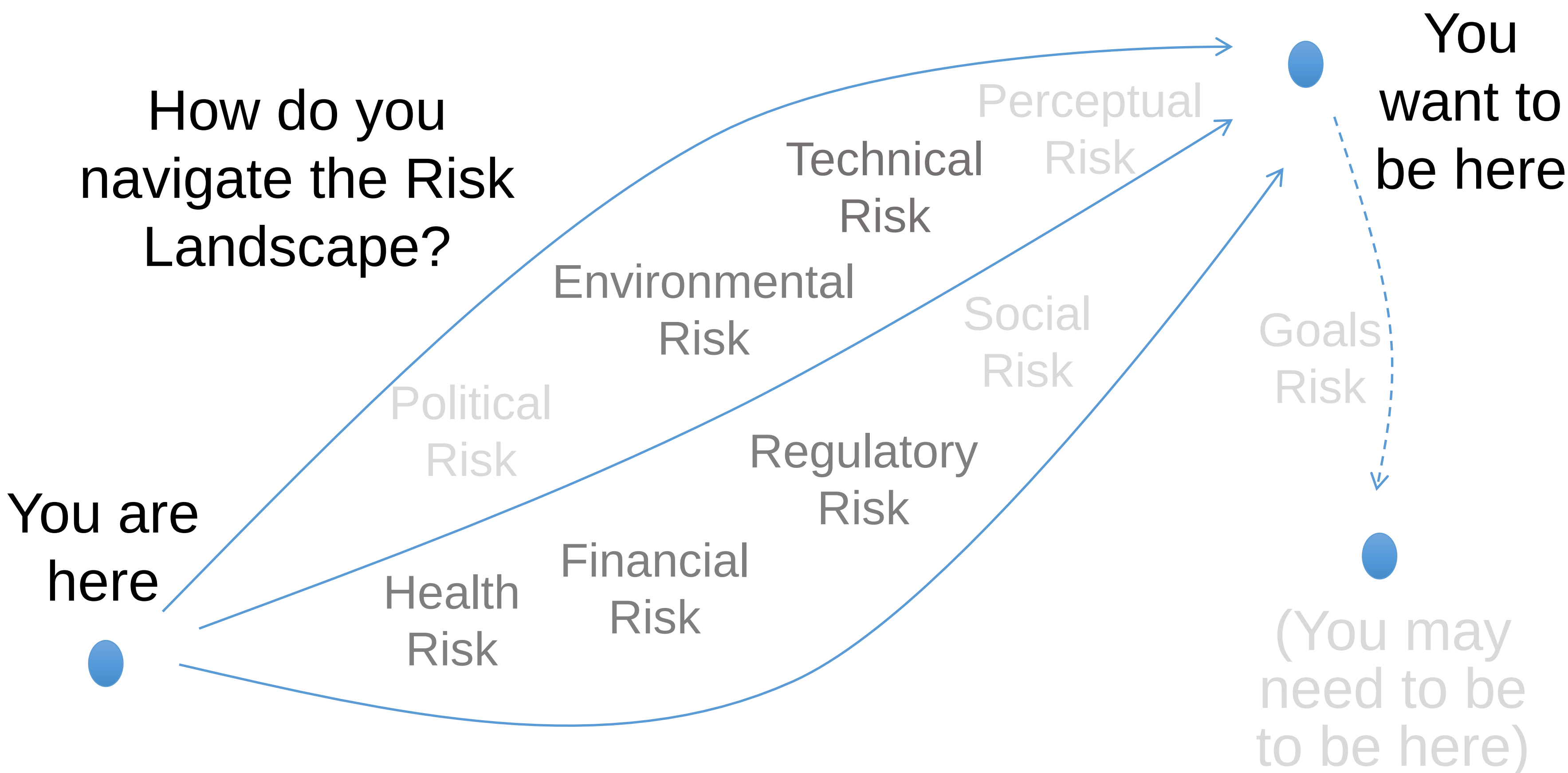
RISK

PRESENT

FUTURE



Sustainable Transportation Fuels – *Challenges and Opportunities for Designing Good Metrics to Assess Promise. September 22 2015*

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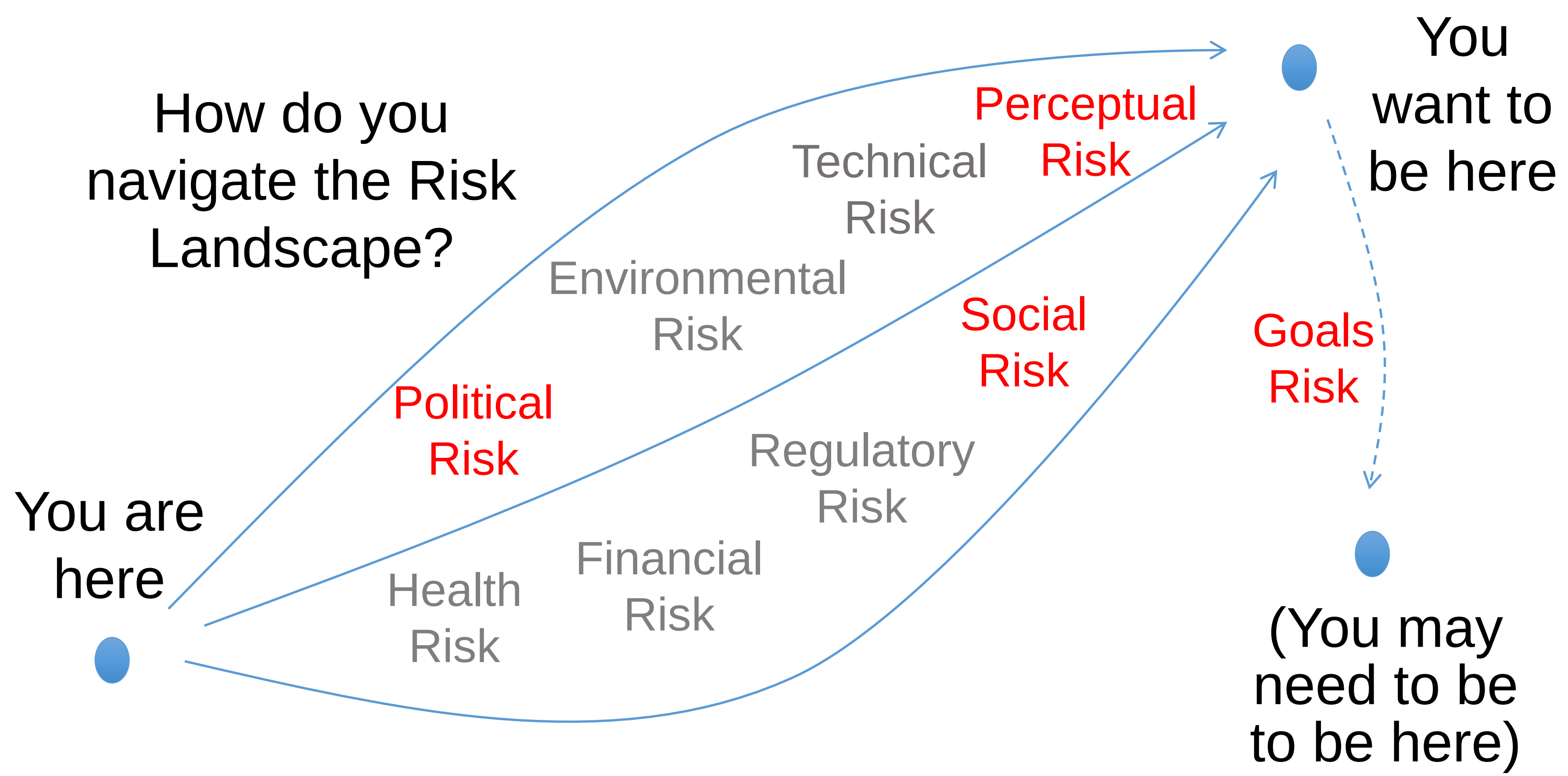
PRESENT

RISK

FUTURE



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RESPONSIBLE INNOVATION

“taking care of the future through collective stewardship of science and innovation in the present”

Stilgoe, Owen and Macnaughton, Research Policy 42:1563-1580. 2015

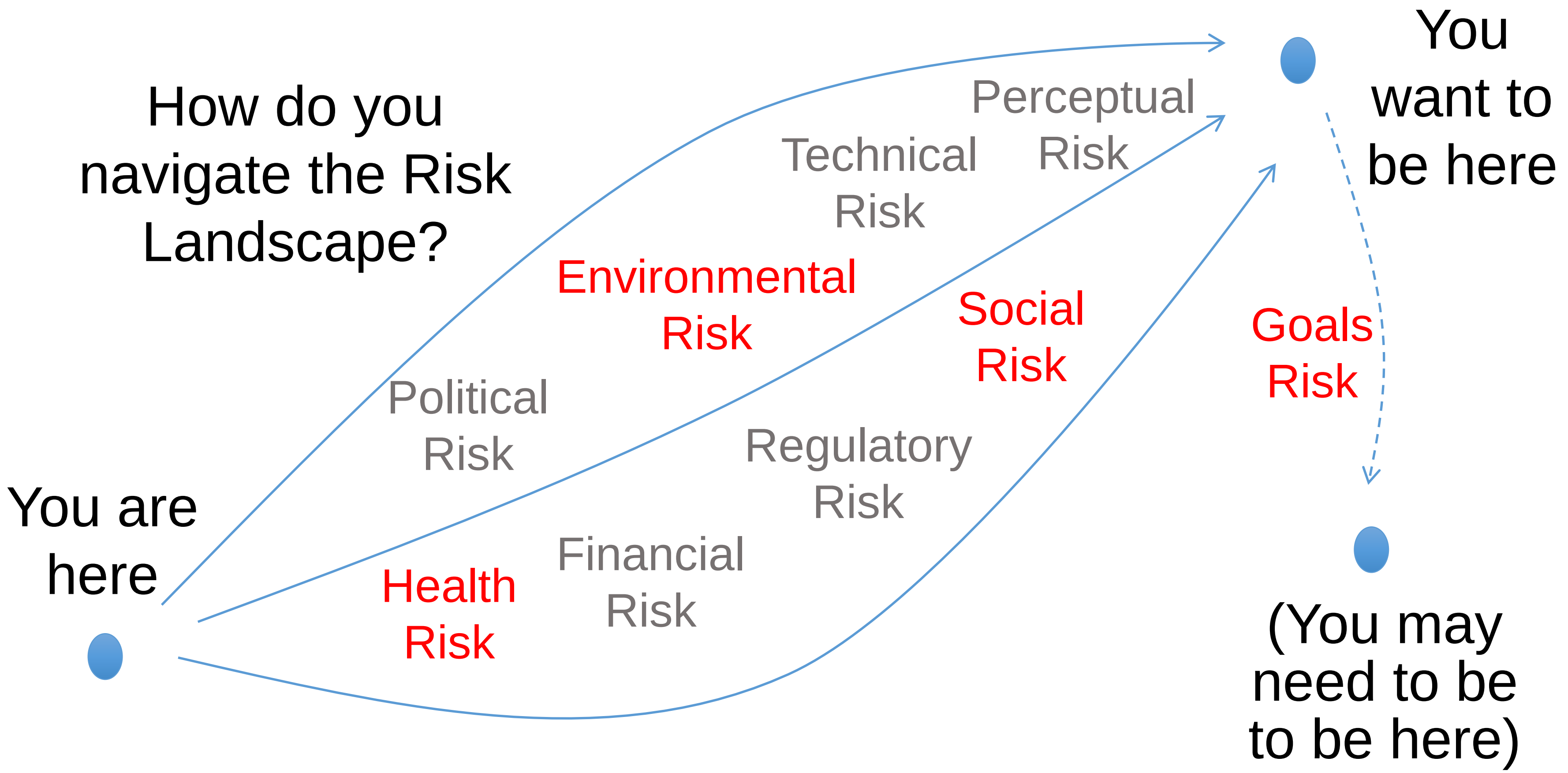
- Anticipation
- Reflexivity
- Inclusion
- Responsiveness

PRESENT

RISK

FUTURE

How do you navigate the Risk Landscape?



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RISK INNOVATION

An organizing framework for generating new knowledge, understanding, or capabilities with respect to risk, and translating these into products, tools, or practices that protect societal, environmental, economic, and other value, as well as enabling value creation and growth

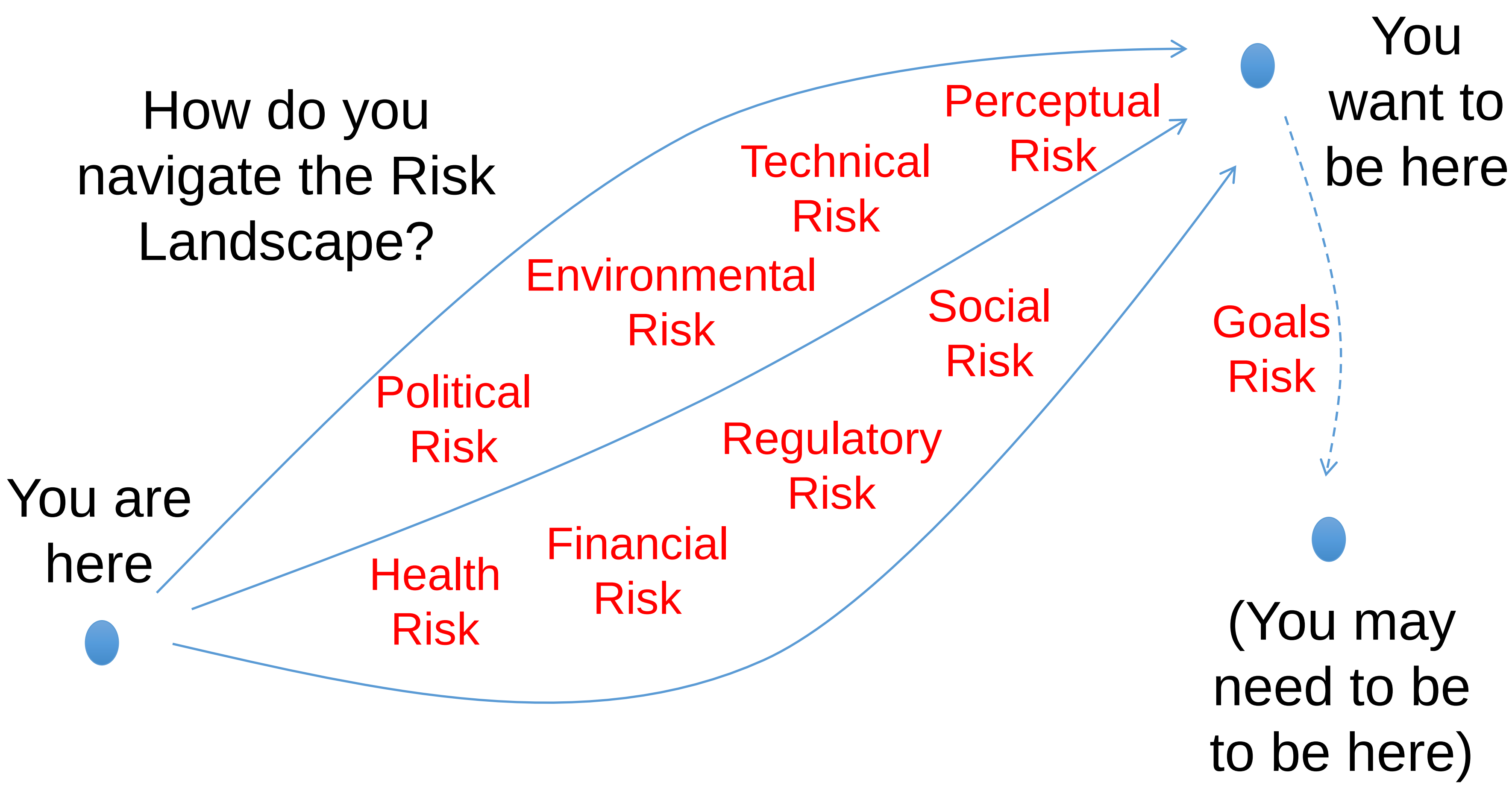
- Risk as a threat to existing or future “value” (multiply defined)
- Invention and innovation to reduce or avoid “value deficits”
- Creativity, serendipity, and eclecticism

Maynard, Nature Nanotechnology 10:730-731. 2015

RISK

PRESENT

FUTURE



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PRESENT

RISK

FUTURE

You want to be here

RISK INNOVATION

Seeing differently

Thinking differently

Acting differently

You are here

(You may need to be to be here)

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THANK YOU

NAVIGATING AN UNCERTAIN FUTURE

Risk, responsibility, and technology innovation

Andrew Maynard
Director, Risk Innovation Lab

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Panel Discussion

- Are there enablers that could accelerate the adoption of sustainable transportation fuels emerging technologies?
- What considerations, if any, should be given to legacy infrastructure in policy making? What strategic considerations should be given to the timing of investment in new infrastructure? Do you think governments should invest to maintain a competitive edge?
- Assuming that the market can be efficient at finding equilibriums, what metrics should be considered if policy and business are to accelerate changes?
- What principles or methodologies could be used to create an investment scorecard for policy makers?

Discussion Questions:

- What are the key analyses, technical metrics, benchmarking procedures and reporting standards a given technology? How well are they defined and are they used consistently by the RD&D community to identify and address the key barriers to commercialization?

- What advances and learnings can be leveraged to avoid re-inventing the wheel? How can established procedures and lessons learned from commercial- and near-commercial technologies be best leveraged to accelerate development of emerging technologies?

- What are the specific collaborative opportunities for technical cross-cuts in the sustainable energy space, including fuel cells, batteries, flow batteries, H_2 production, solar cells, etc., all facing technical challenges in functional materials and interfaces?

Webinar Panelists

Cheryl Martin, Founder, Harwich Partners and previous Deputy Director for Commercialization of the Advanced Research Projects Agency - Energy (ARPA-E) at the US Department of Energy cheryl@harwichpartners.com

Eric Miller, Program manager for hydrogen production delivery at the US Department of Energy eric.miller@ee.doe.gov

James Hinkley, Research Scientist at CSIRO in solar thermal technologies for power and fuels in Australia Jim.Hinkley@csiro.au

Andrew Maynard, Professor in the School for Future of Innovation in Society at Arizona State University amaynar2@asu.edu

Webinar Series Concluded

Thank you for joining

Webinar videos, registration information and more

Light*Speed*Solutions.org

Keep the conversation going!

The Future of Sustainable Transportation Fuels Group

Please complete the follow-up questionnaire