Jonathan Cristiani
Bioenergy & Hydrogen Technology Mgr.
Black & Veatch
Green - Renewable

Luis DePavia
Innovation Manager
NuScale Power
Purple/Pink/Red - Nuclear

Chris Mesrobian
Sr. Director of Business Development
Monolith Corp.
Turquoise - Pyrolysis

Jay Dauenhauer
Host
Energy Cast Podcast

"The Many Colors of Hydrogen"

4:15-5:20pm | March 27, 2023

UNC CLEAN TECH SUMMIT

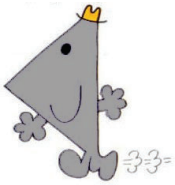
Colors, defined

Green:
Electrolysis using renewable electricity

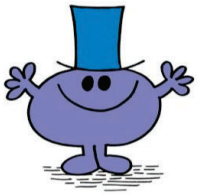
Blue:
Fossil fuels w/Carbon Capture

Turquoise:
Pyrolysis, separating H_2 from solid carbon

Brown:
Coal with no CO_2 control

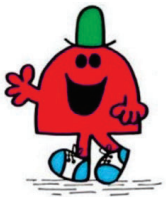


Gray:
Fossil fuels (i.e. gas) with no CO_2 control



Purple:
Nuclear, power + heat electrolysis

Pink:
Nuclear electricity for electrolysis



Red:
Nuclear heat for electrolysis

White:
Naturally-occurring H_2

Reference: Hydrogen colours codes - H2 Bulletin

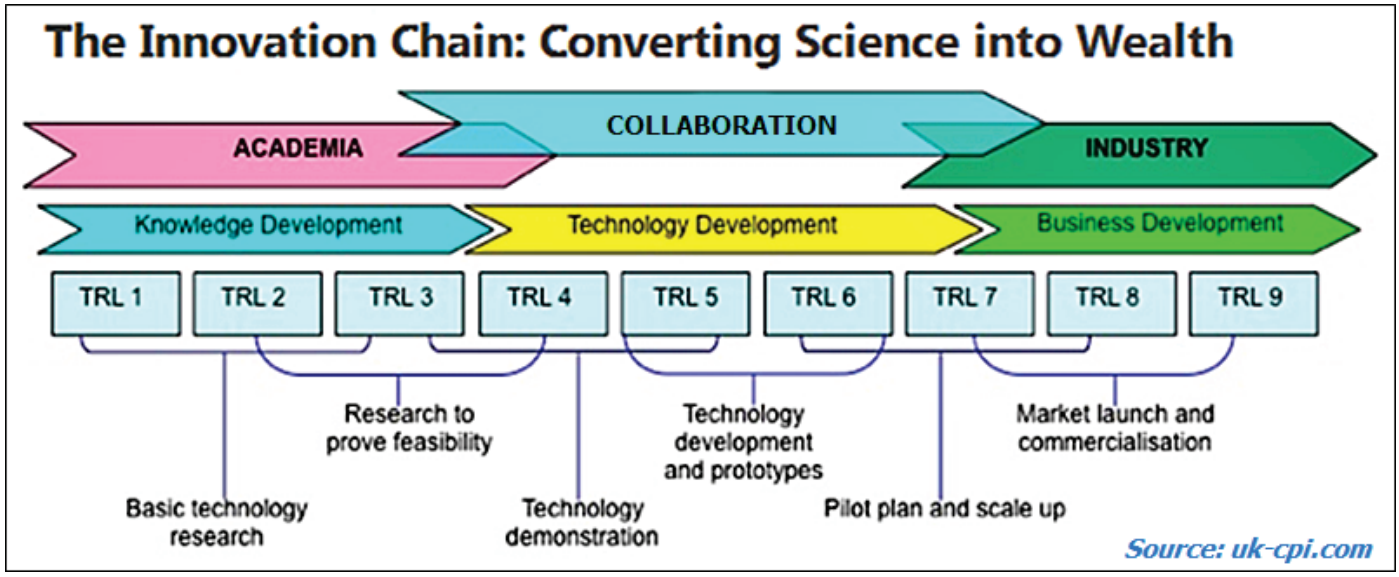
UNC CleanTech 2023

"The Many Colors of Hydrogen" Panel

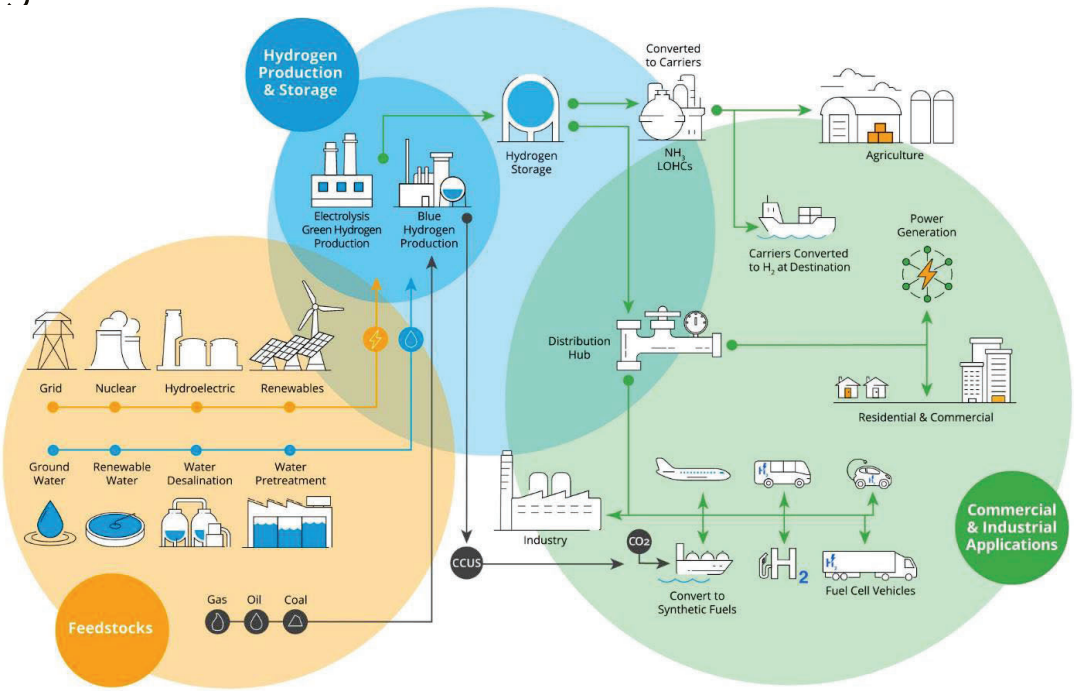
CENTER FOR Hydrogen SAFETY
Executive Member

Jonathan Cristiani
Bioenergy and Hydrogen Technology Manager
Black & Veatch

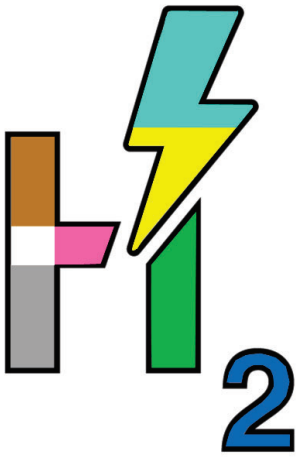
Technology Readiness Levels



Hydrogen Value Chain



Carbon Reduction Before Color



Coal

Petroleum

Natural Gas

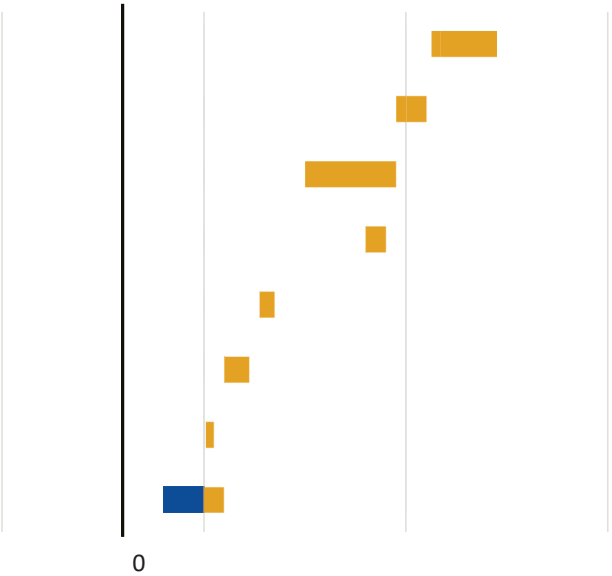
Hydrogen - Grid

Coal Gasification w/CCS

Blue Hydrogen (SMR)

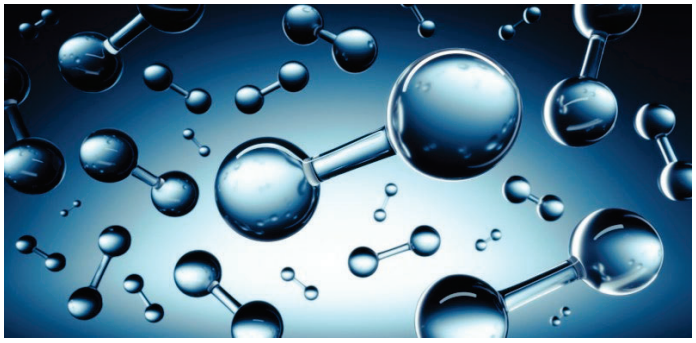
Green Hydrogen Electrolysis

Blue Hydrogen + Biogas with Credits



Relative Carbon Intensity

Underground/Geophysical Storage



Salt caverns, depleted natural gas/oil reservoirs, and aquifers all possible

Salt caverns most used and typically cost ~$0.60/kg

Gas/oil reservoirs subject to reaction with microorganisms, fluids, minerals, etc.

Aquifers least proven

Most appropriate for seasonal/regional storage

Challenges in Hydrogen Co-Firing

Rate of change in Wobbe index and associated monitoring equipment

Design of mixing drum and blending skid

Replacement of combustors, including premixing devices

- Flashback
- Fluid dynamics/pressure fluctuations
- Combustion stability

Scope split between CTG/power island OEM and engineer

Higher density exhaust gas and air quality control implications

Increased NOx production

Hazardous gas detection

Hazardous area classification

CTG OEMs have been working diligently to resolve these issues and Black & Veatch is at forefront of integration issues associated with hydrogen/natural gas blending

Delivering **Innovative** Projects

Project Highlight:
ACES-Delta Advanced Clean Energy Storage

- World's largest green hydrogen production and storage hub
- Black & Veatch is EPC contractor, partnering with Mitsubishi Power for major equipment
- 220 MW Electrolysis
- Hydrogen stored in 2 salt caverns, each storing 150GWh of energy

Image courtesy of ACES-Delta

NuScale at a Glance

1st
And Only SMR to Receive NRC Standard Design Approval

$1.4B
Cumulative Capital Invested to Date

545
Employees with Unparalleled Nuclear Experience

28
PhDs

180
Masters in Engineering/ Science Degrees

650
Total Patents

459
Granted

191
Pending

Extensive Trade Secrets

15
Years of R&D and Testing
Founded in 2007

9
Strategic Investors Supporting Global Customer Adoption[1]

Smarter | Cleaner | Safer | Cost Competitive

1. Established Supply Chain Network with Continued DOE Support

Proven LWR Technology

- The NuScale reactor design is based on proven light water reactor (LWR) technology as used in > 350 commercial LWRs globally, and 83 nuclear-powered ships: (72 submarines, 10 aircraft carriers and one research vessel).
- NuScale technology leverages 67 years of civilian and naval operational experience.
- It is a natural circulation, light water, Pressurized Water Reactor (PWR) packaged in a small integral reactor vessel.
- Uses commercially available low-enriched uranium dioxide fuel, control rods, off-the-shelf skid mounted turbine generator sets, cooling towers, balance of plant and electrical distribution systems.
- NuScale has expended over $100M is assessing and demonstrating all of the reactor's key components.
- All novel features of the design were tested and audited by NRC:
  - Main Control Room
  - NuScale Fuel Bundle (Framatome)
  - Helical Coil Steam Generator (SIET)
  - Integral System Safety (NIST)
  - Full Scale Safety Valves (NTS)
  - Module Assembly equipment (PAR)

Environmental Footprint

Carbon Dioxide Emissions

- Operating emissions: 0 g CO2 per kWh
- Life-cycle: 12 grams of CO2 per kWh (equal to wind)

Land Use

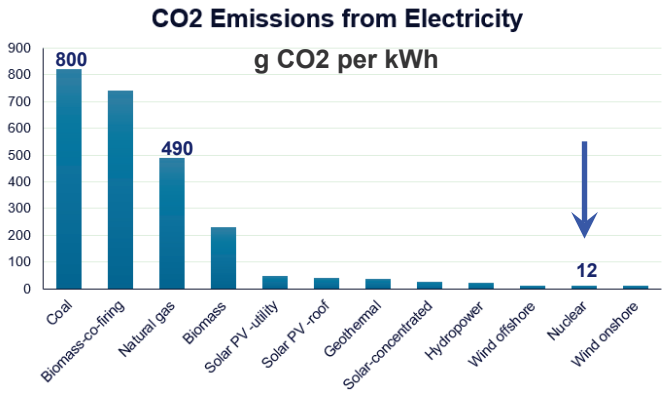
- 924 MW NuScale Plant: 34 Acres (fence line)
- Land usage: < 0.04 Acres per MW

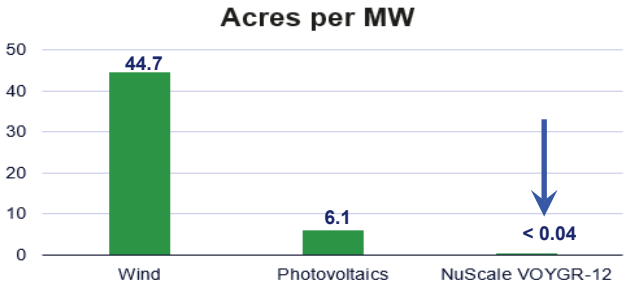
Used Fuel Storage for the Life of the Plant

- 0.8 Acre, on-site

NuScale Plant Operating Life

- 60 years (Continuous, Uninterrupted Power Generation)





Carbon Dioxide Emissions From Electricity - World Nuclear Association (world-nuclear.org)

Land Use by System Technology | Energy Analysis | NREL

Monolith Presenter

Chris Mesrobian
Senior Director of Business Execution

Clean Hydrogen from Electricity and Natural Gas

Renewable electricity

Natural gas (CH_4)
renewable or pipeline

Protected Methane Pyrolysis Technology

Olive Creek 1 (OC1)

H_2

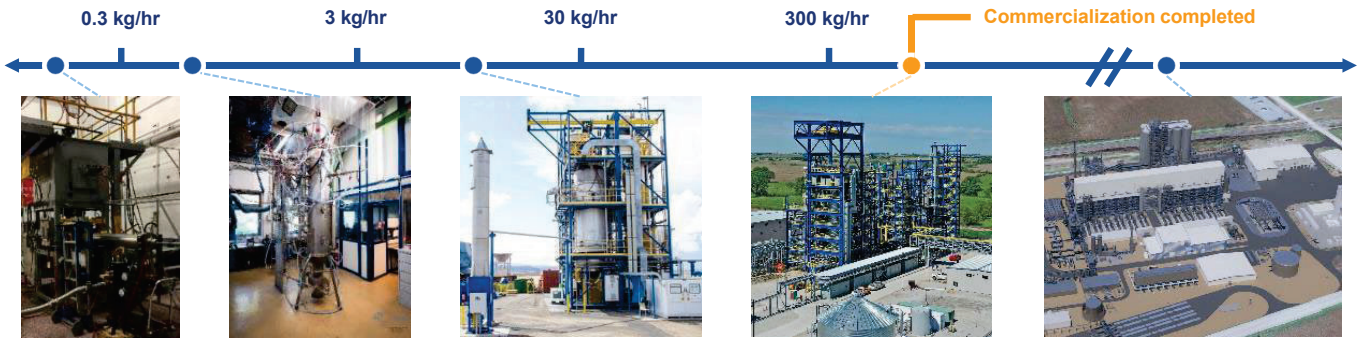
Green Hydrogen

Carbon Black

Monolith's proprietary methane pyrolysis technology uses renewable electricity to split natural gas into hydrogen and highly valuable solid carbon materials without emitting CO_2.

Successful Technology Scale-Up

CLEAN HYDROGEN PRODUCTION



LAB 1	MINES ParisTech	Seaport 1	Olive Creek 1	Olive Creek 2
Laboratory Scale	*Pilot Scale*	*Demonstration Scale*	*Commercial Scale*	*Commercial Scale*
up to 0.3 kg/hr 2016 – 2018	0.3 – 2 kg/hr 2018 – Present	12 – 18 kg/hr 2014 – 2018	540 – 620 kg/hr 2020 – Present	6,390 – 7,440 kg/hr 2026

Replicate Rx 12 Times
No technology scaling required

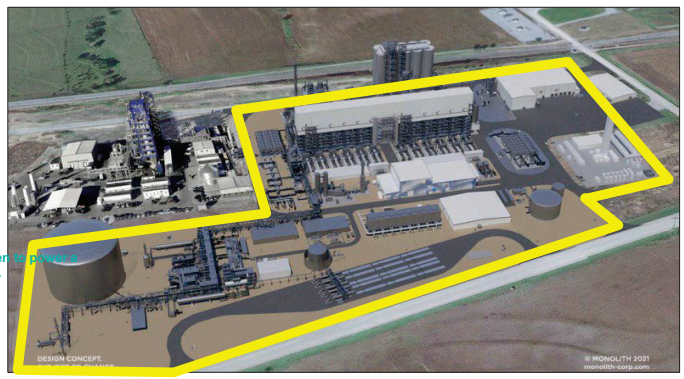
Demonstrated ability to scale-up *patent protected*, *commercially viable* technology

Note: Assumes 0.31kg of hydrogen is produced for every kg of carbon black

Monolith Expansion (Olive Creek 2)

Olive Creek I (OC1)	
Production Capacity	**Hydrogen:** ~5 ktpa **Valuable Carbon:** ~15 ktpa
Completion	June 2020
Location	Nebraska, United States
Technology	Full, commercial-scale reactor

Olive Creek II (OC2)	
Production Capacity	**Hydrogen:** ~60 ktpa **Valuable Carbon:** ~180 ktpa
Completion	2026 (target)
Location	Nebraska, United States
Technology	Two 6-reactor trains (same scale as OC1)



Thank you

The hydrogen to power a green world. monolith

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