

Hydrogen IloW Causation Loops for AWE Products

January 26, 2022

Hydrogen Turbine Fuel Example



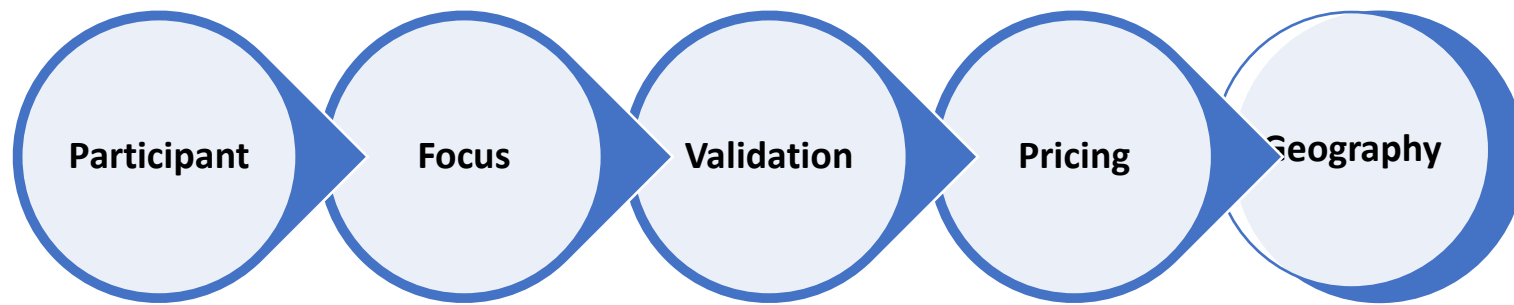
Decisions about the creation and use of hydrogen are critical to climate protection. There is a rapid generation of insights and new technology regarding the raw materials, processes and products needed to cost effectively meet the goals.

The Industrial Internet of Wisdom (IIoW) can be leveraged in multiple interlocking IIoW Causation Loops on air, water, and energy products and services.

Hundreds of hydrogen loops are being pursued.

This specific analysis focuses only on Hydrogen Combustion in Turbines.

Here are five interlocking Causation Loops relative to hydrogen combustion in turbines.



Management consultants such as Bain and LEK guide the overall strategy.

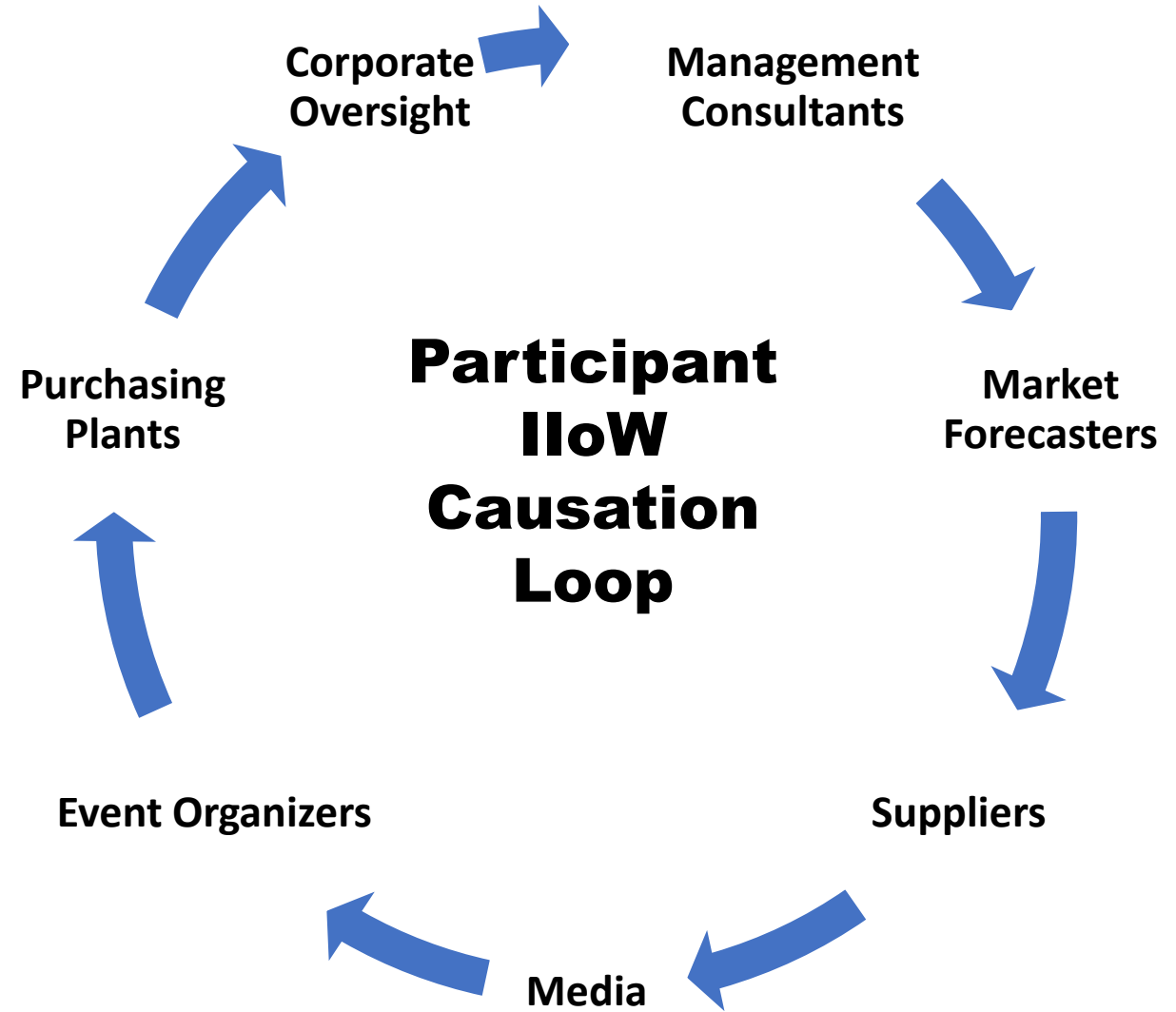
McIlvaine forecasts the use of hydrogen at each power plant and industrial power generator.

System suppliers such as MHI and Siemens provide the complete systems whereas Howden, Baker Hughes and Honeywell provide components such as compressors, molecular sieves and valves.

Materials suppliers such as Yara furnish ammonia.

Media such as Power Magazine and WorldPumps provide cost factors and validate products.

Event organizers provide the forum for decision making discussions not just education.



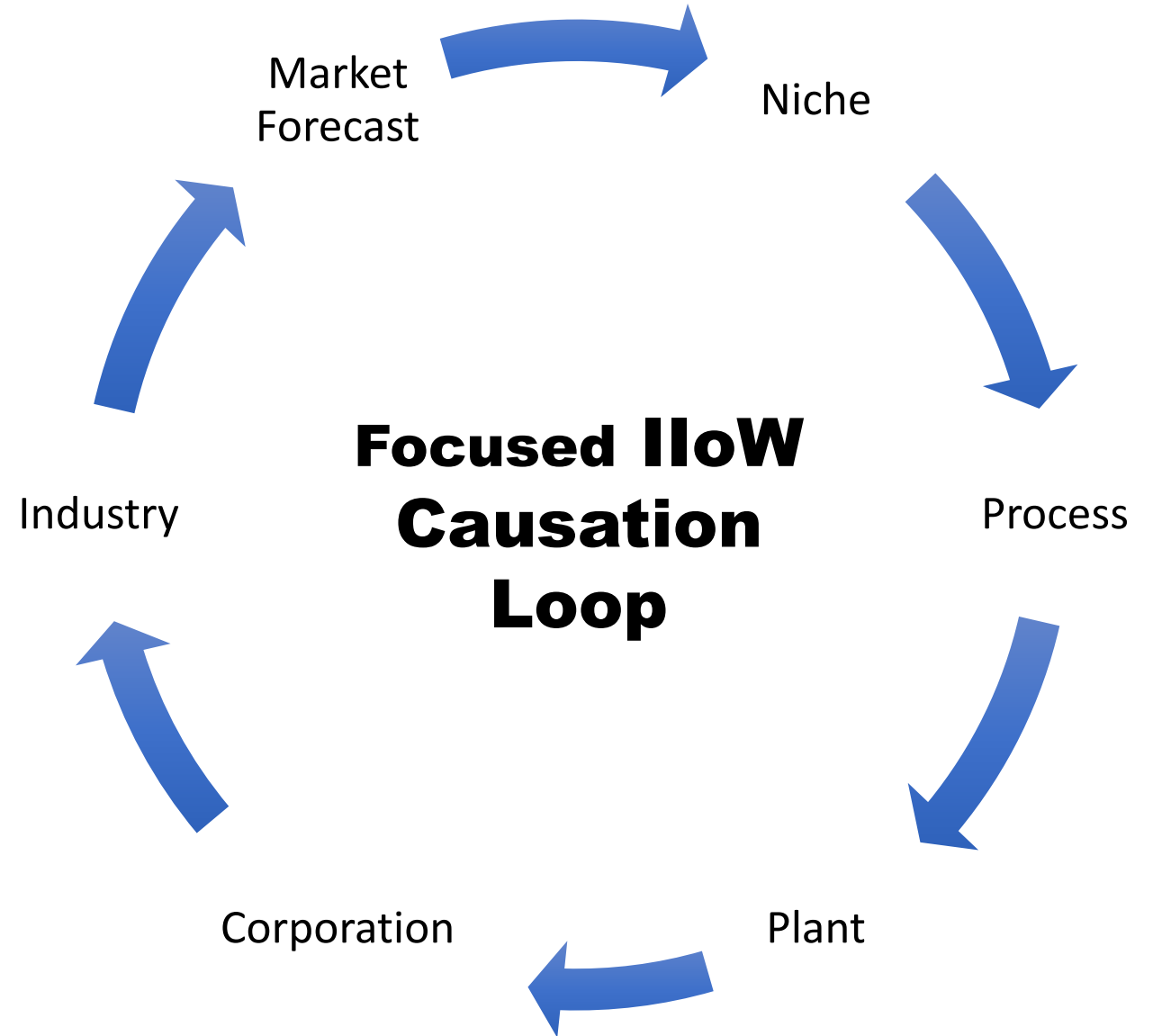
Each niche starts with a product such as a low NOx burner, compressor, or valve.

This is part of a process which might be hydrogen, blended gas or ammonia combustion.

Each plant has unique cost factors which may be analyzed at the local or corporate level.

The industry may be electricity generation or combined heat and power.

Forecasters such as McIlvaine can estimate the market opportunities for those products which have the lowest total cost of ownership

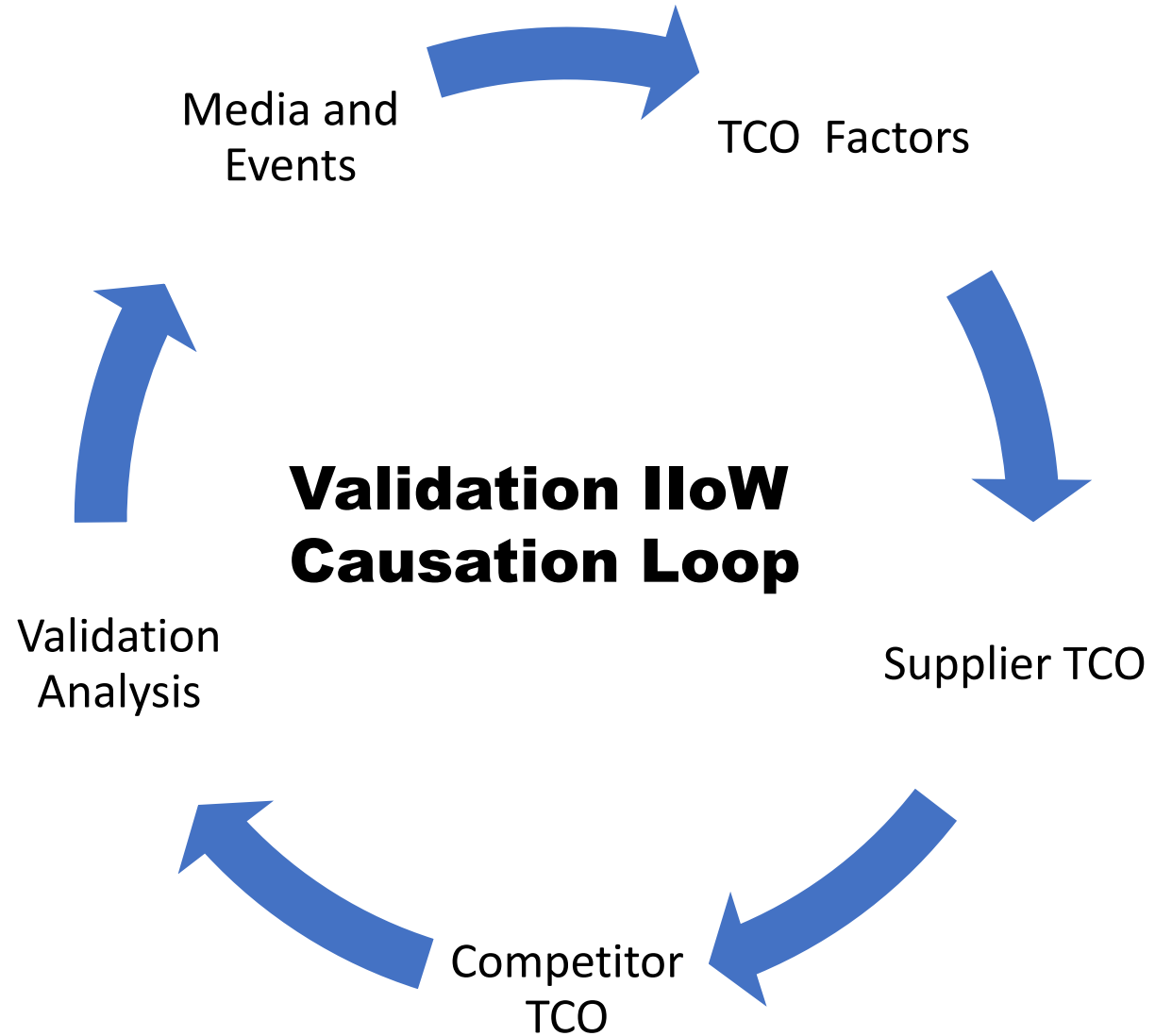


With the interconnected wisdom it is possible to accurately determine and convey total cost of ownership for each product including that of each supplier.

The supplier needs to assess his costs versus those of the competitors.

The supplier with the superior product needs validation through the media and the loop.

Due to gas characteristics, higher NOx emissions and material risks, burning hydrogen has unique challenges.

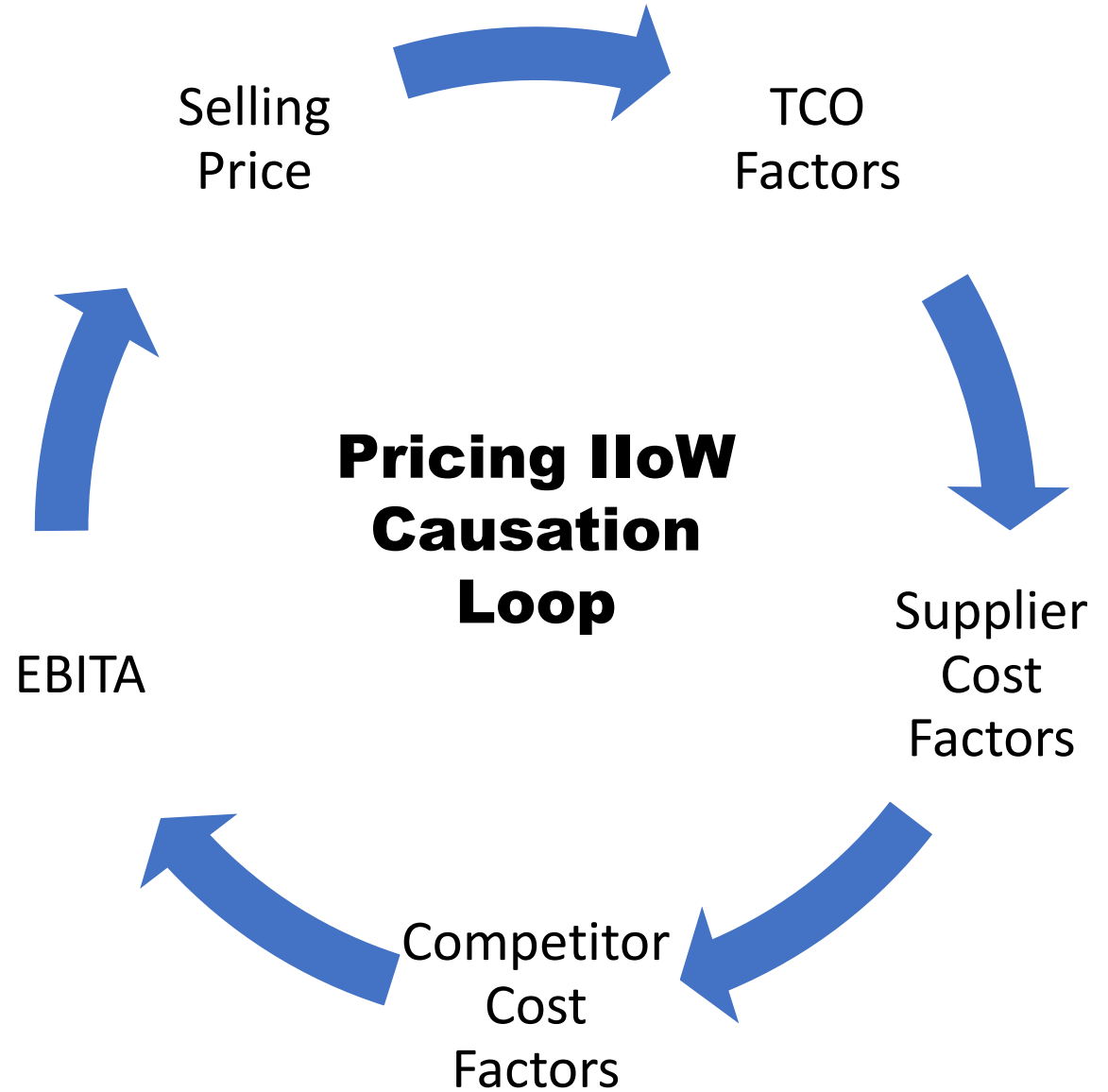


With the validation of better products, it is possible for suppliers to incorporate higher margins into their pricing and still save the customer money as opposed to alternatives.

With the dynamic situation in the use of hydrogen and the cost impact of CO2 emissions, there is a big potential for product differentiation.

Unless the superior product is validated, higher pricing and margins can not be obtained.

The loop is the most effective way for validation, higher EBITA and lower cost of ownership for the operator.



The cost factors and validation include a number of geographic variables.

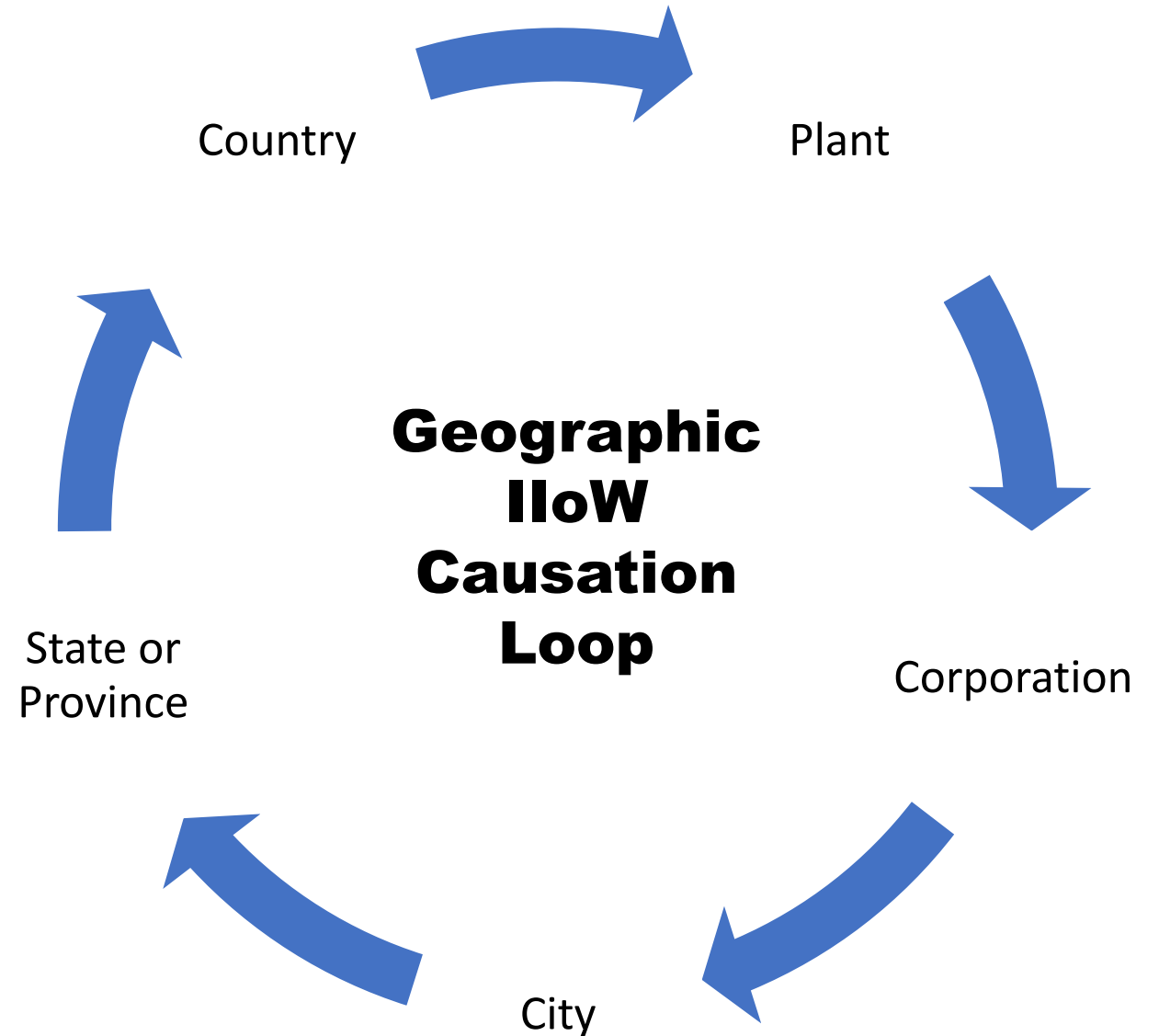
Decisions may be made by the corporation on a different continent.

Regulations and demand vary geographically with Europe leading the way on climate change.

The market opportunity needs to be matched with sales territories which may be as narrow as a city or province.

From the purchaser's perspective the location of the plant is significant.

From a causation loop perspective new and better technology is likely to expand to developing countries from the developed.



Hydrogen Combustion IIoW Causation Loop Program



Media Provide the Basic Intelligence with McIlvaine in a Catalyst Role

- Articles in industry magazines such as *Power* or in product magazines such as *Valve World* can provide the news and developments which are the basic intelligence. They can also provide the white papers and webinars to validate the TCO of a product.
- There is lots of basic intelligence. For example, *Power* magazine has 833 articles relating to hydrogen.
- The utilization of this information in a form convenient for decision making is needed.
- Webinars, white papers, and event discussions can convert this intelligence into wisdom.

McIlvaine Utility Alert and Tracking System

- The weekly *McIlvaine Tracking System Alert* has a section devoted to hydrogen.
- The hydrogen headlines for the last six months are provided on following slides.
- The articles which cover the combustion of hydrogen in turbines are in **red**.
- These headlines will continue to be available publicly.
- Subscribers can search and locate specific articles with multiple key word combinations to narrow the display to relevant ones.

The Alert can be searched by key word combinations. Searching on just Howden results in articles in 180 issues.

When a four-word combination is used there are 47 results.

When you search on Howden and Haru there are just two Alerts

1. [UTILITY E-ALERT](#)

... Anjala-Ingerois Sites in Finland HYDROGEN Howden to Supply Hydrogen Storage Compressors ... Steel Producer Howden Supplying Compressors For Everfuel Green Hydrogen Plant in ... MHI Using Hydrogen as an Effective Form of Renewable Power Storage ...

8. [UTILITY E-ALERT](#)

... BECCS to Fish Food HYDROGEN Howden Supplying Compressors to Everfuel for ... Hydrogen Howden Supplying Compressors for Haru Oni efuel Plant 1600 MW ... to produce "fossil-free" steel has successfully completed test production ...

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Hydrogen Headlines in the Alert

Hydrogen combustion is in red

August 2021 - January 2022



January 21, 2022

Five Imperatives to Thrive in a Hydrogen Future

January 14, 2022

Haldor Topsoe Signs €45 Million Funding Deal With European Investment Bank to Drive Green Energy Transition

Novatek and Uniper Will Collaborate to Supply of Large Volumes of Low-Carbon Ammonia

Howden Completed Acquisition of CPI and Cites Hydrogen Synergies

Chart Industries Incorporating Howden Systems into Chart Hydrogen Offerings

January 7 , 2022

Calumet Announces Close of Renewable Hydrogen Project Financing

Many Facilities Will Utilize Methane Pyrolysis

Turning Natural Gas into Hydrogen and Carbon Black

Doosan Heavy Embarks on Blue Hydrogen Production Together with Changwon City



December 31, 2021

Bloom Energy to Power India's First Green Hydrogen Microgrid
KBR Awarded Study to Support Green Hydrogen Growth in Trinidad and Tobago

The First Nuclear Power Plant in Russia for the Production of Hydrogen Can be Commissioned by 2036

Mote to Create H₂ From Wood Waste and Sequester the CO₂

SMR Requires Severe Service Valves

EDPR, Engie and Vestas Join 'Unprecedented' Green Hydrogen Plan in Portugal

Out of the Lab': Green Hydrogen Biggest Winner as US Forms \$21bn Office of Clean Energy Demonstrations



December 17, 2021

SoCalGas and Bloom Energy Showcase Technology to Power Hydrogen Economy with Gas Blending Project

Certarus and Plug Power Partner on Green Hydrogen Supply and Expansion of Distribution Infrastructure

ThyssenKrupp Signs Contract to Install Over 2-GW Electrolysis Plant for Air Products in NEOM

National Grid and Town of Hempstead to Develop One of the First Green Hydrogen Blending Projects in the Country

Proteum Energy and Istmo Energy Sign MOU For Production of Low Cost, Clean Hydrogen in the Permian Basin



December 10, 2021

- Zeeco Will Discuss Impacts Of Firing Hydrogen at Power-Gen Next
- Howden and Chart Industries Collaborate on Delivering Advanced Hydrogen Solutions
- Tracking the Hydrogen Market in Detail
- BayoTech and New Mexico Gas Company Partner to Build State's Largest Clean Hydrogen Production Hub
- Low Carbon Hydrogen Cost to Drop 40% by 2025
- Tokyo Gas and MC to Explore Feasibility of International Synthetic Methane Supply Chain for Carbon Neutrality

December 3, 2021

- Sinopec Lands World's Largest Photovoltaic Green Hydrogen Production Project in Kuqa, Xinjiang
- L&T and Renew Announce Partnership to Focus on the Green Hydrogen Business in India
- Avoiding the Hydrogen Pitfalls
- 6-GW Green Ammonia Project Initiated in Australia
- Caterpillar to Launch Demonstration Project Using Hydrogen Fuel Cell Technology for Backup Power at Microsoft Data Center
- INNIO Technology Selected for First 100% Hydrogen Engine Power Plant in Asia Pacific

November 19, 2021

- Heliogen and Bloom Energy Lead the Way to Produce Low-Cost, Green Hydrogen Following Successful Demonstration
- Bipartisan Infrastructure Legislation Signed into Law, Includes \$9.5 Billion for Hydrogen Industry

November 12, 2021

- Posco Aims to Go Carbon Neutral With Hydrogen-Based Steel
- Baker Hughes Invests in Ekona Power to Accelerate the Delivery of a Lower-Carbon Hydrogen Production Solution
- Fluitron Acquires Bethlehem Hydrogen to Build Global Platform of Hydrogen Infrastructure Solutions

November 5, 2021

- Air Products Gardner is a Leader in Liquid Hydrogen Storage
- **E.ON and Enel Will Create a Hydrogen Production and Distribution Network**
- **SCR Needed When You Convert a Gas-Fired Power Plant to Hydrogen?**
- Burckhardt Compression is One of the Finalists Selected by Shell New Energies For Hydrogen Compressors
- 32 Countries Agree to Accelerate the Development of Hydrogen
- The World's First High-Purity Hydrogen From Biogas
- Honeywell and ZoneFlow Reactor Technology to Collaborate on Breakthrough Structured Catalyst for Hydrogen Production
- ABS, HHI and KSOE Collaborate on Green Hydrogen Production and Carbon Capture and Storage
- Mitsubishi Power and DT Midstream Announce Clean Energy Strategic Partnership to Advance Hydrogen Infrastructure Across the United States
- **Doosan Working On 'Green' Hydrogen Power Plant**
- **Babcock & Wilcox Signs Exclusive Global Licensing Agreement with Ohio State Innovation Foundation for Innovative Chemical Looping Technology for Decarbonization and Hydrogen Production, Further Enhancing B&W's BrightLoop™ Offering**



October 27, 2021

- B&W Renewable Signs Agreement to Jointly Develop Innovative Biomass-to-Hydrogen Clean Energy Project in Australia Using BrightLoop™ Technology
- Hy Stor Energy Developing First-Ever U.S. Zero-Carbon Green Hydrogen Storage Hub
- Saulsbury Awarded Front End Engineering Study for Hydrogen Liquefaction Facility



October 15, 2021

- Bakken Energy Converting Dakota Gasification to Hydrogen
- Use LNG Wasted Energy to Make Hydrogen
- Costain to Design a Hydrogen Storage Facility in the UK
- **Japanese Utility to Co-Fire Ammonia and Coal**
- **JERA to Provide Ammonia Cofiring at U.S GTCC Plants**
- Shell-Led Consortium Selected by DOE to Demonstrate Feasibility of Large-Scale Liquid Hydrogen Storage
- Louisiana Governor Edwards and Air Products Announce Landmark U.S. \$4.5 Billion Blue Hydrogen Clean Energy Complex in Eastern Louisiana
- Hydrogen and High Value Carbon From Natural Gas
- GKN Hydrogen Selected to be Part of U.S. Department of Energy H2@Scale Cooperative Projects to Help Reach Hydrogen Shot
- Technip Energies Awarded India's Largest PEM Based Hydrogen Project by NTPC



October 8, 2021

- Ballard & HDF Energy Announce World's First Multi-Megawatt Scale Baseload Hydrogen Power Plant
- Sasol Announces Lead Role in Feasibility Study for the Boegoebaai Green Hydrogen Project

October 1, 2021

- HDF Energy Breaks Ground on World's Largest Green Hydrogen-Power Project
- New Waste-to-Hydrogen LOI between Ways2H and VALECOM Positions the Island of Martinique as a Blueprint for the Caribbean
- **UK CHP Plants Will Use Hydrogen**
- Coal Power Plant in Spain to be Turned into Green Hydrogen Hub
- WattBridge Breaks Ground on Peak-Power Facility To Support Nearly 200,000 Homes in Brazoria County, Texas
- US Firm Says Agreement Finalized for Acquisition of Yugadanavi Power Plant and Right To Build New LNG Terminal

September 24, 2021

- UPC-Hydrogen Acquires Exclusive License in Asia-Pacific Region from Proton Technologies
- New Class of Nanoengineered Materials Could Store Hydrogen Produced as Byproduct of Industrial Processes Onsite For Later Use as Energy at Same Facility
- **Erex Opens Japan's First Commercial Hydrogen-fired Power Plant**
- **Dover Blackmer Sliding Vane Pumps Have Advantages For Ammonia Handling**
- **Special Pumps Are Needed To Move Ammonia**
- **Hydrogen Compatibility Study Characterizes Performance of Rubber Additives**
- Nuclear Power For Low Carbon Hydrogen
- Permascand and Verdagy Sign Collaboration Agreement For the Co-Development of a Novel Electrochemical Cell For Green Hydrogen Production



September 17, 2021

- 10,000 Green Hydrogen Generators Per Month: Groundbreaking for Enapter Electrolyzer Mass Production in North Rhine-Westphalia
- Howden Developing Diaphragm Compressors for Fueling Stations
- A Number of Companies are Pursuing the Diaphragm Compressor Market for Hydrogen Applications
- UK Homes Heated With 30% Hydrogen in Successful Trial
- GenH2, Hydrogen Infrastructure Solutions Leader, Closes on New Global Headquarters Campus in Titusville, Florida

September 10, 2021

- Chevron Agrees on Framework to Join Hydrogen Joint Venture With Magnum Development and Mitsubishi Power
- Chevron, Caterpillar Announce Collaboration Agreement on Hydrogen
- Thiozen Raises \$3 Million to Advance Low Emission Hydrogen
- Caterpillar Launching Gen Sets Running on 100 Percent Hydrogen



September 3, 2021

- **Kansai Electric Power Has Big Hydrogen Plans**
- Caterpillar to Expand Hydrogen-Powered Solutions to Customers
- Mitsubishi Heavy Industries (MHI) Has Completed Tests of its First Hydrogen-Fueled Engine
- Mitsubishi Power Retains Citi as Strategic Financial Advisor to Help Expand Hydrogen Infrastructure across North America
- Caterpillar Has Over 20 Years of Experience Burning Hydrogen in Generator Sets
- Sinopec Has to Invest in Low-Carbon Businesses Over The Next Five Years, Focusing on Hydrogen



August 20, 2021

- Biomass to Hydrogen Has Lots of Advantages
- Wood Captures Growth Linked to Thriving Hydrogen Market
- Hydrogen-Ready SmartBurner for Heat Treatment Furnaces
- Macrotek Inc. to Provide Gas Quality Control System for OMNI CT's First-of-its-Kind Waste to Hydrogen Product in the Fight Against Climate Change
- Rio Tinto and Sumitomo to Assess Hydrogen Pilot Plant at Gladstone's Yarwun Alumina Refinery
- Dual Green and Blue Hydrogen Track Described in JM Podcast
- JM Low Carbon Hydrogen: Paving The Way to Net Zero
- Honeywell UOP to Support Reduction in CO₂ Emissions and Production of Clean Hydrogen Energy at Wabash Valley Plant
- Blue Hydrogen is Essential to the UK Net Zero Plan
- Raven SR Partners With Republic Services to Produce Commercial Green Hydrogen in Northern California, Starting Summer 2022
- Unifrax Flexcat Promises to Improve Hydrogen Output
- Pajarito Powder Says New Hydrogen Fuel Cell Catalyst is a Game Changer

August 13, 2021

Howden Supplying Compressors to Everfuel for Green Hydrogen

Howden Supplying Compressors for Haru Oni efuel Plant

1600 MW Hamburg Plant could be Purposed to Wind Based Green Hydrogen

Shell Starts Up 10 MW Electrolyzer in Wesseling

SSAB to Make Sponge Iron Using Hydrogen and Not Coal in Lulea

GE Supplying 316 MW Hydrogen Capable Turbine to NSW.

Plug Power will Produce Green Hydrogen in GA

BP Could Export Green Hydrogen from Australia

JM to Manufacture Components for Green Hydrogen

Haldor Topsoe SynCOR to be Used by Air Products in Blue Hydrogen Production

Doosan Developing Ammonia/Hydrogen Turbines

Cummins and Chevron Pursing Hydrogen for Transportation

Linde Starts Up Fifth Hydrogen Plant in the U.S.

Mitsui & Co., Inc. and CF Industries to Jointly Explore Development of Blue Ammonia Projects in the United States



August 6, 2021

- HydrogenNext Conference to be Held in San Antonio in October
- Trillium Successes to be Covered at the Conference
- Largest Transit Hydrogen Fueling Station in Santa Anna California
- 1.2 GW Dedicated Hydrogen-Fired Power Plant Starts Taking Shape in Texas
- Washington Utility Provider Douglas PUD Turns to Renewable Hydrogen for Backup Power
- Mitsubishi Making Turbine Plants Hydrogen Ready
- Sundyne's Pumps & Compressors Offer Functionality Specifically Suited to Hydrogen Applications
- The Strengths of the PPI Compressor Line Address the Key Requirements for Hydrogen Applications

July 2021

July 30

Johnson Matthey Acquires Assets to Accelerate Green Hydrogen Scale-Up

Kansai Electric Power Will Study Ways of Producing CO₂-Free Hydrogen in Japan

GCL to Make Ammonia and Hydrogen in Ethiopia

BP Expects Hydrogen to Account for 16% of Worlds Energy by 2050

July 23

Tallgrass Energy Awarded U.S. Department of Energy Funding to Advance Next Generation Clean Hydrogen Technologies

Saudi Arabia, Oman, and Australia Have Big Hydrogen Plans

Air Products Chooses Haldor Topsoe's SynCOR Technology For World-Scale Blue Hydrogen Energy Complex in Canada

Heliogen and Bloom Energy (BE) Announced a Partnership to Produce "Green Hydrogen"

July 1

Howden to Supply Hydrogen Storage Compressors to Steel Producer

Howden Supplying Compressors For Everfuel Green Hydrogen Plant in Denmark

MHI Using Hydrogen as an Effective Form of Renewable Power Storage