Sustainable Energy Economy Workshop

Research & Development of Light Water Reactor and Hydrogen Hybrids

January 14, 2020

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<tr>
<td>DBNPS</td>
<td>Davis-Besse Nuclear Power Station</td>
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<td>DOE</td>
<td>U.S. Department of Energy</td>
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<tr>
<td>HTSE</td>
<td>High Temperature Steam Electrolysis</td>
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<td>LTE</td>
<td>Low Temperature Electrolysis</td>
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<td>LWR-H₂</td>
<td>Light water reactor-hydrogen</td>
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<td>PEM</td>
<td>Polymer Electrolyte Membrane</td>
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<td>R&amp;D</td>
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1. Executive summary

The University of Toledo's College of Engineering hosted a workshop that was free and open to the public on January 14, 2020. The workshop summarized the idea of repurposing the nation's commercial light water nuclear reactors (LWR) for hydrogen production through a LWR-H₂ hybrid systems design integrated into the electric grid infrastructure. A central aim is to use the nation's commercial light water reactors to feed electricity into the grid when needed, then, when electricity demand is low, maintain nuclear operations to split water electrolytically to produce hydrogen. This hydrogen can be used as a transportation fuel, in industrial applications to reduce overall carbon emissions, and as an energy carrier. Hydrogen produced at nuclear power plants through ‘water splitting’ has a much lower carbon emissions footprint than hydrogen produced by steam methane reforming, the dominant industrial process.

This workshop centered on The Idaho National Laboratory’s (INL) hydrogen production demonstration project at the Davis-Besse Nuclear Power Station (DBNPS) and other nuclear power locations. Attendees were from the U.S. Department of Energy (DOE) National Laboratories, DBNPS, the U.S. Department of Energy, additional industry representatives, university faculty, and other stakeholders. The demonstration project provides a key platform for national programs focused on development of resilient, sustainable energy delivery solutions that support industry, transportation and regional economic growth. The workshop outlined current work with a leading DOE laboratory, the Idaho National Laboratory, and discussed current work underway as well as future plans. The workshop attracted 108 participants from throughout the country and was met with keen community interest, as shown by local participation and extensive media coverage of the event.

This report summarizes the presentations at the workshop and recommends next steps to advance the Department of Energy’s nuclear to hydrogen initiative by creating a Western Lake Erie Energy Innovation Hub focused on the Davis-Besse Nuclear Power Station in Northwest Ohio. Opportunities for collaborative industry, National Laboratory, and university projects emerging from the workshop and the DBNPS hydrogen production demonstration include:

- **Commercialization projects** that demonstrate new technologies and systems integration. The DBNPS hydrogen production pilot plant can be leveraged and used for additional manufacturing pilot facilities that are connected to hydrogen production. This will provide a test bed for a manufacturing and energy complex, used to develop and demonstrate systems that interact with the electricity grid in a new, transactive manner.

- **Technology development** and commercialization acceleration at the device level, with advanced technologies that take advantage of both the electricity and steam produced by nuclear power plants. In addition, novel concepts related to CO₂ conversion, production of renewable and/or value-added chemicals, and recycling of plastics can be implemented by utilizing hydrogen, steam, and electricity produced.

Fundamental R&D conducted by universities and National Laboratories such as: computational fluid dynamics and multi-physics modeling of thermal hydraulic systems and chemical reactors; development of materials and novel catalysts for hydrogen production and use; methods development for data fusion, large data analytics, decision systems, process controls, and cyber intrusion detection
and protection; development of power electronics and controls to enable transactive power markets and integrate wind and solar energy with flexible nuclear power plant operations.

A number of key points emerged from the Workshop:

- The nation’s commercial nuclear power plants are major assets that, if used in a hybrid system, can continue to produce both low-carbon electricity and low-carbon produced hydrogen.
- Using commercial nuclear power plants in this hybrid operation may prevent the retirement of capacity.
- Hydrogen produced at nuclear sites can be used as a fuel and industrial feedstock to offset high carbon emission sources of transportation fuels and the high-carbon steam methane reforming approach to produce hydrogen.
- Hydrogen production at commercial nuclear plants can be accomplished without disrupting the facilities role in providing power to the grid, but it is important to balance timing of power supply to the grid against hydrogen production to maximize economic benefit of the nuclear hybrid operation.
- Demand for hydrogen for transportation uses is increasing, particularly in select regional markets. It is expected that hydrogen demand will continue to expand nationally as hydrogen enters more markets.
- Northwest Ohio is a promising location for an energy innovation hub. A report by Argonne National Laboratory found that DBNPS is located within 150 miles to major industrial hydrogen consumers, with demand by major users exceeding 1.8 million metric tons. The region has major oil refineries, steel manufacturers, syngas and chemical plants, markets for fuel cell vehicles, and methanol and ethanol plants as potential major consumers of hydrogen.
- Ohio is in a strong position to support a hydrogen-based energy innovation hub. Ohio has a strong base of fuel cell component and material suppliers and has demonstrated hydrogen use in public buses. Dayton is a major producer of hydrogen fork-lift vehicles and Ohio has numerous large warehouses where such vehicles can be used. Trucking is an important Ohio industry that will benefit by hydrogen-powered fuel cell trucks and Ohio is close to major automotive centers (Detroit and also in Ohio).
- Catalytic hydrogenation of CO₂ using hybrid hydrogen production at nuclear plants provides a low carbon emission path for production of high-value fuels and chemicals such as methanol, higher alcohols, formic acid, methane, and higher hydrocarbons. The potential for conversion of CO₂ to synthetic fuels and value-added chemicals is abundant; however, considerable R&D is required to develop commercial and economically viable processes.
- High volume, pure hydrogen streams provide opportunities for production of a variety of co-products including plastics, chemicals, and syngas from algae and biomass. However, basic research in design and development of catalysts for high selectivity of branched hydrocarbons and applied research in process development and scale up is needed to advance the technical readiness levels for these processes.
- A hydrogen-based energy innovation hub requires investment in hydrogen infrastructure to store, transport and use hydrogen. Research is needed on the economics of this infrastructure as well as on ways to incorporate hydrogen into existing infrastructure, such as introducing hydrogen into natural gas pipelines. Developing this infrastructure in select regions of the country provides needed experience in expanding infrastructure to a wider national market.
The use of hydrogen for transportation and industrial uses requires workforce training programs on hydrogen safety, material compatibility and code issues related to storage, transport and maintenance of hydrogen end uses (such as in fuel cells).

Key Recommendations from the Workshop:

- Time is of the essence in using the nation’s commercial nuclear reactors for a hybrid system before plants are retired. The federal government needs to accelerate investment into demonstration projects to address research challenges and gain experience needed for nationwide deployment of hybrid nuclear systems for power and hydrogen production.
- The U.S. Department of Energy should provide leadership to this initiative that spans both its Office of Nuclear Energy and Office of Fuel Cell Technologies and both should commit funds to accelerate the initiative. The research and development needs are significant, and a comparable financial commitment is needed.
- Industry must participate in a meaningful way to drive down the cost of technologies and overcome challenges in hydrogen use. Industry should participate on federally-funded projects.
- The program must be led by a National Laboratory with proven leadership in supporting the nation’s commercial nuclear facilities with contributions from other laboratories to bring the best research assets forward.
- The program must include university support, particularly from a university with a strong College of Engineering, to help address fundamental research challenges but also to involve students who will move into industrial roles upon graduation.
- Federal and state policies can help spur commercial interest in both the generation of hydrogen at nuclear facilities and the use of clean hydrogen from nuclear as an alternative to hydrogen from steam methane reforming. Policies such as renewable energy standards to favor hydrogen will encourage use.
- A regional demonstration project of a hydrogen energy innovation hub will help show how hydrogen can be used for both transportation and industrial uses without jeopardizing the commercial nuclear power plant safe operations. Northwest Ohio is an ideal location for a demonstration project given its home to the Davis-Besse Nuclear Plant, the commitment of the plant owner, the rich industrial landscape of potential hydrogen consumers, the support of The University of Toledo, and a supportive state government.
2. Introduction

2.1. The light water nuclear reactor fleet & the U.S. energy & manufacturing landscape

Many cities, states, utilities, and public commissions are seeking to maintain a resilient, reliable power grid while setting clean energy standards that embrace low emissions generation sources. At the same time, leading petrochemical, steel making, and other energy-intensive manufacturing companies are developing strategies to reduce their emissions, while looking for energy sources that are both sustainable and cost-competitive.

The U.S. transportation sector and manufacturing industries currently consume over 70% of the total energy used by the nation. This amount includes one-fourth of retail electricity provided by the electrical grid. Since the advent and demonstration of solar and wind energy, the cost of renewable power generation has dropped significantly and is currently expanding in regions of the country where there is an abundance of solar insolation and wind, respectively. At the same time, natural gas has reached historically low costs that are projected to continue for decades to come. This has put pressure on baseload coal-fired and nuclear power plants that are often difficult to ramp up and down without causing significant wear on the plants, and reducing the coping time of nuclear fuel rods. Consequently, these plants are losing revenue and need to come up with new markets beyond the electricity grid.

Flexible nuclear plant operations can help support U.S. industries and the transportation sector by providing low-cost, low-emissions energy. Potential nuclear plant connections to large U.S. industries are shown in Figure 1, where the nuclear power plant is the primary source of energy for producing fuels, ammonia, steel, polymers, and hydrogen. In this schema, hydrogen is a key energy currency and can effectively incorporate nuclear energy into existing or new U.S. industries.

Several of the processes featured in Figure 1 are reaching a high technology commercialization readiness level and are benefiting from the interests of technology developers, industrial gas supply companies, and industry associations. For example, manufacturers of heavy-duty trucks, passenger vehicles, and forklifts have started building hydrogen fuel cell-powered drive systems. Over the past decade, dozens of ethanol plants and bio-digesters have been established throughout the Midwest. Nuclear plants in this region can increase the revenues for biofuels produced by ethanol and bio-digesters by diverting their CO$_2$ by-product to a process that makes synthetic motor fuels. These synthetic fuels are compatible with existing gasoline and diesel fuel supply systems. As domestic and global demand for steel continues to rise, nuclear power plants can provide hydrogen and electricity to produce direct-reduced iron briquettes and to operate electric arc furnaces. With nuclear power, steel-making emissions can be reduced 95% as compared to traditional integrated blast-furnace and open-hearth steel plants.
The meeting at The University of Toledo helped bring local and regional stakeholders together to discuss the opportunities, challenges, and research needs of integrated energy systems. Hydrogen production can provide an important energy carrier and storage medium. Transactive power strategies can be developed to balance electrical demands throughout the grid, meet hydrogen product needs, and energy storage requirements, while optimizing revenues in the broad industrial energy complex, significantly enhancing the reliability and resilience of national energy systems.

The University of Toledo has established strong ties to the industrial sector. Six departments in the core engineering disciplines offer bachelor and graduate programs that are well-positioned to support an academic-industry-DOE collaboration for the advancement of technology innovation and the acceleration of commercial demonstrations that can be carried out in the Toledo region. These
projects can be completed in association with the Davis-Besse Nuclear Power Station hydrogen production demonstration.

The University of Toledo and the Idaho National Laboratory, together with other National Laboratory participants, anticipate developing a consortium that can rally industry to advance many of the options and recommendations discussed at the meeting.

2.2. Workshop goals and objectives

The University of Toledo workshop explored opportunities in repurposing the nation’s light water nuclear reactors (LWR) for hydrogen production through a LWR-H₂ hybrid systems design integrated into the electric grid infrastructure² (Figure 2). A central aim of this hybrid system is to use the nation’s commercial light water reactors to split water electrolytically to produce hydrogen that can be used as a transportation fuel, in industrial applications to reduce overall carbon emissions, and as an energy carrier. Hydrogen produced at nuclear power plants through ‘water splitting’ has a much lower carbon emissions footprint than hydrogen produced by steam methane reforming, the dominant industrial process.

Figure 2. Illustrative example of the synergistic potential of hydrogen production and utilization in industry with integration of nuclear power based LWR-H₂ hybrid systems into the electric grid infrastructure. (From the presentation by Mark Ruth, NREL, H₂@Scale: Opportunities for Hydrogen as an Energy Intermediate)

In the Midwest, the Davis-Besse Nuclear Power Station (DBNPS) in Oak Harbor, Ohio will anchor pilot plant demonstrations and can establish a Western Lake Erie Energy Innovation Hub, supported by Department of Energy (DOE)-sponsored, industry cost-shared, and academic-collaborative research.
The workshop also pointed to DBNPS’s location with respect to local infrastructure and access to markets, making Northwest Ohio a prime location for an energy innovation hub.

The workshop connected industry, government, university and national laboratory stakeholders to discuss the national energy landscape, identify regional opportunities and challenges, and areas for cooperation and collaboration, with goals that included:

- Create public and industry awareness of the Light Water Reactor Sustainability Program and the Davis-Besse LWR-H₂ hybrid demonstration project
- Identify opportunities for future growth in commercial sectors emerging from this project
- Identify risks and challenges for LWR-H₂ hybrid systems, including technology acceleration needs
- Explore emerging markets and processes for conversion of CO₂ and H₂ to value-added products
- Explore issues relating to grid operations and integration and smart grid opportunities
- Identify opportunities for research and roles for university researchers
- Identify opportunities for collaboration between industry, Department of Energy lab scientists and representatives, and academia to address knowledge gaps, technology hurdles, and other challenges.

3. Western Lake Erie Energy Innovation Hub opportunities and challenges

Integration of LWR-H₂ hybrids enable the use of nuclear power plants as the primary source of energy for water splitting and subsequent hydrogen supply for production of low-carbon fuels, ammonia, steel and ethylene (two of the largest commodities produced in the United States). Hydrogen is a key energy currency and can provide pathways to effectively incorporate nuclear energy into existing or emerging U.S. industries, as illustrated in Figures 1 and 2. Potential benefits include:

- storage of energy in hydrogen for use in a dynamically-controlled, optimized smart grid
- increased biofuels yields from biodigesters and ethanol plants
- reduced life cycle emissions from hydrogen-synthesized ammonia
- reduced carbon footprint for hydrogen-reduction of raw iron ore
- elimination of carbon emissions for ethylene production
- production of synthetic natural gas (SNG) or value-added chemicals from nuclear power-produced hydrogen and waste CO₂ generated in ethanol production
- creation of a clean source of hydrogen for direct transportation uses

3.1. Hydrogen production

Hydrogen will be produced at DBNPS from a water feedstock using a proven Low Temperature Electrolysis (LTE) Polymer Electrolyte Membrane (PEM) technology for the pilot demonstration. Roughly two MW of electricity from the nominal output of 925 MWe of the nuclear power station will be used to produce 800 to 1000 kg of hydrogen per day. Future plans include scale up to 100 MWe dedicated to electrolysis with a proportional increase in hydrogen production. Scale-up can provide an economic driver for the region, supporting existing and emerging markets for green hydrogen and power.
Capital and operating costs for water electrolysis present challenges that require further investments in research and development. Electrical efficiency improvements in hydrogen production can be achieved by operating the LTE units at higher temperatures (e.g. up to 90°C). Further electrical efficiency is possible through the use of High Temperature Steam Electrolysis (HTSE), using solid oxide ceramic materials, with operating temperatures up to 800°C. Combining higher operating pressures with electrolysis can reduce hydrogen product compression costs and improve economics.

Opportunities for collaborative R &D include the following

- **Integration and evaluation of existing technologies pilot demonstration systems:** Initial evaluation of the DBNPS hydrogen demonstration project and associated hydrogen production storage and transport options, and transactive operating strategies will guide efforts in efficiency improvements and identify key roadblocks in scale-up.

- **Impregnation of nano-composites for high temperature solid oxide electrolysers:** High temperature electrolysers (solid oxide) coupled with both thermal and electrical input from the LWR can provide improved efficiencies and economics due, in part, to the low cost of thermal energy. Despite these improvements, hydrogen production by HTSE faces challenges, particularly in maintaining high operating performance and extending the lifetime of the hydrogen electrode. The electrode material (or PEM membrane in the case of LTE) can undergo degradation due to formation of free radicals during electrolysis. Nano-composites of cerium oxide and graphene developed by University of Toledo researchers have demonstrated excellent free radical scavenging. The nano-composite also enhances electron transfer, which facilitates electrolysis processes. Impregnation of the nano-composite into ceramic solid oxide electrolysis cells (SOEC) is expected to increase the lifetime of electrodes. The nano-composite can also be applied to low or intermediate temperature PEM membrane electrolysis for hydrogen generation.

- **Advanced technology development needs include:** Manufacturing and cost improvements for commercial electrolysers. This includes embedded sensors, coatings for and increased durability of PEM membranes, and improvements in chemical vapor deposition for metal oxide and high temperature electrolysers.

3.2. **Hydrogen demand and utilization**

3.2.1. **Overview of existing & potential hydrogen demand in the western Lake Erie region**

Research conducted by Argonne National Laboratory shows that DBNPS is located in close proximity (within 150 miles) to major industrial hydrogen consumers (Figure 3), with demand by major users exceeding 1.8 million metric tons. The region has major oil refineries, steel manufacturers (for DRI, direct reduction of iron or HBI, hot-briquetted iron), syngas and chemical plants, markets for fuel cell vehicles (FCV), and methanol and ethanol plants as potential major consumers of hydrogen. Additional research is needed to identify other markets for industrial hydrogen in the region and associated storage needs; the current source for hydrogen demands; the business case and environmental impacts for substituting clean nuclear-produced hydrogen; and the costs and methods of transporting the hydrogen to regional users. Hydrogen, with low volumetric energy density, can incur significant costs in transportation and storage for ultimate users compared to other energy alternatives. The University of Toledo has expertise in evaluating commodity transportation with data on transportation infrastructure and costs. Transportation studies coupled with technoeconomic and life cycle analysis
are important in optimizing the performance and impact of energy hubs on regional economic growth and the environment.

![Graph showing projected demand for hydrogen within 150 miles of DBNPS.](image)

**Figure 3**: Projected demand for hydrogen within 150 miles of DBNPS (from the presentation by Amgad Elgowainy, ANL, *Hydrogen for production of clean transportation fuels & industrial processes*)

Development of a Western Lake Erie Energy Innovation Hub will lead to broad economic impacts for the region surrounding DBNPS. Assessment of the effects of a new hydrogen supply produced by the LWR can be performed through input-output models that account for existing local and regional supply chains and industrial linkages. Computational software linked to databases for a wide range of industrial sectors across Northwest Ohio can be used to assess employment and income multipliers resulting from a hydrogen distribution chain from DBNPS. These multipliers account for linkages between firms, households, and governments in the local economy as those effects spill out of the region. With this information, regional economic impacts such as the total value added (GDP) and county-to-county trade flows for commodities can be examined. University of Toledo faculty can play a leading role in this assessment.

### 3.2.2. Transportation and vehicles

Hydrogen for transportation provides a leading alternative to fossil fuel-derived gasoline and diesel for automobiles, heavy and light-duty vehicles, buses, materials handling vehicles (e.g., forklifts) and other forms of personal transportation (e.g., scooters). Use of hydrogen fuel produces water as a byproduct, as opposed to an array of harmful emissions from gasoline or diesel-powered vehicles. As presented by Pat Valente of the Ohio Fuel Cell Coalition, Ohio is poised for expansion in the use of hydrogen fuels.
Buses: The Stark Area Regional Transit Authority (SARTA), located in Canton, OH, has current hydrogen fuel needs for 12 hydrogen fuel cell-powered buses and four planned paratransit vehicles. A SARTA bus was brought to the workshop. The Ohio State University Center for Automotive Research (CAR) also has hydrogen fuel demands with a station designed to service the first hydrogen fuel cell bus in Columbus as part of the university’s Campus Area Bus Service.

Heavy and light-duty vehicles: The only light-duty hydrogen vehicles operating in Ohio and SE Michigan are the automotive OEM (Original Equipment Manufacturers) engineering test vehicles. The number of heavy-duty hydrogen trucks in the U.S. is currently very small with no heavy-duty hydrogen trucks operating in Ohio as of January 2020. In Michigan, the military (TARDEC with refueling stations) and General Motors are the two biggest stakeholders. However, Nikola Motors (based in Phoenix, Arizona) attended the workshop because they have an interest in building a network of hydrogen filling stations in the U.S. to service their hydrogen-powered fuel cell trucks. They are ready to move these trucks into production as soon as they have established hydrogen fueling stations in strategic market locations for the fleet. Nikola has entered into pre-contract agreements with large companies, such as Anheuser-Bush, to provide up to 30,000 trucks for local and long-haul freight deliveries. Nikola’s interest in hydrogen production at nuclear plant sites was piqued by the announcement of the demonstration at Davis-Besse. Consequently, they are investigating areas, such as the western Lake Erie region, to center the dispatch of their hydrogen fuel cell trucks. Nikola Motors is ready to partner and cost-share a demonstration of hydrogen compression and filling stations.

Fuel cell lift trucks: Plug Power, with Headquarters in Latham, NY, and a National Service Hub in Dayton, OH, holds 90% of the U.S. hydrogen fuel cell market in the materials handling industry. Currently, Plug Power has over 32,000 fuel cell-powered lift trucks in the field, with over 2,000 in Ohio and SE Michigan. The following companies have deployed fuel cell lift trucks in Ohio, primarily in warehouses: Ace Hardware (West Jefferson), Wal-Mart (Washington Court House, Grove City, and Winterville), Home Depot (Luckey), Honda (Marysville), and Amazon (Wilmington). In SE Michigan there is deployment with Amazon (Monroe, and four locations in Detroit) and Chrysler. Plug Power’s fuel cell-powered lift trucks serve seven warehouses in Ohio and six in Michigan. All warehouses have hydrogen refueling stations.

Additional information on projected hydrogen fuel use is summarized in the 2017 “Hydrogen Roadmap for the Midwest US Region.” This report4 provides forecasts for hydrogen refueling stations and hydrogen vehicles in Ohio and indicates that a lack of hydrogen fueling stations can hamper light-duty vehicle expansion. As production of hydrogen vehicles expands, driven by demand in select regions nationally (e.g., California), Ohio can see increased market penetration if fueling stations are available. Ohio has a strong base of fuel cell component and material suppliers and is well-positioned to be a national leader in fuel cell use with supportive state policy.

3.2.3. Conversion of CO₂ to value added chemicals

The Midwest location of DBNPS is in close proximity to ethanol plants. The plants produce a unique source of pure and highly concentrated carbon feedstock in the form of CO₂ by-product. With a very limited market for CO₂ from ethanol plants, there are opportunities for conversion of this low value carbon by-product to an array of more valuable chemicals.
The potential for conversion of CO₂ to synthetic fuels and value-added chemicals is abundant; however, considerable R&D is required to develop commercial and economically viable processes. Jamie Holladay (workshop speaker from PNNL) summarized routes for direct electrolysis of CO₂ and water to syngas, a platform chemical for manufacture of alcohols and fuels. High temperature electrolysis routes were found to be critical for cost-effective production.

Catalytic hydrogenation of CO₂ using a sustainable H₂ source from LWR-H₂ hybrid systems provides a low carbon emission path for production of high-value fuels and chemicals such as methanol, higher alcohols, formic acid, methane, and higher hydrocarbons. These chemical reaction pathways require catalysts to make the processes selective towards the desired product. For example, multifunctional catalysts under development by University of Toledo researchers provide a route for synthesis of alcohols and conversion to value added products, such as dimethyl ether. Other routes being explored include photochemical and electrochemical reduction and fixation of CO₂ into methanol or alkanes. Transition metal catalysts can be used to insert CO₂ into renewable monomers to produce polymer precursors. These routes require further development and evaluation of catalysts that will enable conversion at mild conditions and can provide an alternative use for off-peak electrical power produced by DBNPS.

Commercial conversion of carbon dioxide into chemicals requires the following

- Assessment of regional carbon sources
- Fundamental R&D for development of novel catalysts and processes (chemical or electrochemical) to lower costs of synthesis
- Formation of partnerships between academic and national lab researchers and industry investors to bring promising technologies to commercialization

### 3.2.4. Other chemicals and materials

High volume, pure hydrogen streams provide opportunities for production of a variety of co-products including plastics, chemicals, and syngas from algae and biomass. Pyrolysis of algal/lignocellullosic biomass feedstocks or waste plastics in the presence of H₂ can be used to directly produce high quality saturated and stable hydrocarbons for jet fuels. However, basic research in design and development of catalysts for high selectivity of branched hydrocarbons and applied research in process development and scale up is needed to advance the technical readiness levels for these processes.

Olefins (i.e., alkenes) for polymer production can be synthesized using solid oxide electrocatalysts. Off-peak electricity generation can be used to power these processes, providing additional revenue streams for nuclear power plants. For cost-effective production, electrochemical reactions must be coupled with alkane/alkene separation and unreacted feed recycle. Research and development of polymeric membranes for these separations will advance deployment of olefin production processes. For example, membrane technologies and other physical engineered processes can selectively separate and concentrate ethylene and potentially propylene from the effluent of an electrochemical non-oxidative deprotonation of ethane. University of Toledo researchers have expertise in an array of membrane separations that can be applied to these processes.
3.3. **Hydrogen distribution/infrastructure**

Storage, distribution and transport of hydrogen produced at DBNPS will depend on a combination of many factors such as demand schedule for users, hydrogen delivery pressure requirements, distance, and distribution of user facilities from DBPNS combined with techno-economic analysis of infrastructure alternatives.

One alternative for regional transport of product is direct injection of produced hydrogen into the natural gas (NG) pipeline\(^5\). Hydrogen could then be extracted from the NG/hydrogen pipeline mix at the point of use (using membrane separation, for example). Alternatively, the NG/hydrogen blend could be directly combusted. The performance of NG/hydrogen mixture turbine combustion can be assessed using resources such as those associated with the NASA Glenn Research Center in northern Ohio. An example of this is the Open National Combustion Code (OpenNCC), which is the publicly released version of the National Combustion Code (NCC), a state-of-the-art prediction tool that employs unstructured grids combined with a highly efficient parallel processing capability in order to simulate flow and combustion through turbines and combustors. The OpenNCC code has been recently validated on a realistic combustor configuration with a downstream high-pressure turbine. University of Toledo faculty have expertise in associated computational fluid dynamics to support modeling and experimental research in this area.

Regional production of hydrogen can enhance the development of warehouse and distribution facilities in Northern Ohio and Southeast Michigan. Use of hydrogen-powered forklifts in closed warehouse operations is rapidly growing due to the benign emissions (water) from hydrogen combustion. Local hydrogen production can lead to reduced forklift fueling costs. DBNPS is in close proximity to the interstate 80/90 corridor connecting New York City to Chicago and points west to California. The nuclear facility is also in close proximity to I-75 connecting U.S. and Canadian markets and running south to Atlanta, GA and Florida. Infrastructure investments for hydrogen fueling of light and heavy fuel cell electric vehicles (FCEV) can support the technology developments and deployments in the Midwest automotive sector.

Collaborative teams of DOE laboratory scientists, hydrogen end users, regional businesses and development agencies, government leaders, and university researchers are needed to address potential challenges in providing hydrogen transport and storage infrastructure by:

- Determining low and high-volume regional hydrogen markets (for initial pilot demonstration and scale-up)
- Establishing hydrogen production and demand schedules for regional users
- Assessing requirements, codes and standards for hydrogen transport, addition to NG pipelines, and storage and identifying regulatory hurdles in product transport
- Using technoeconomic analysis tools to evaluate multiple market supply / demand scenarios and hydrogen infrastructure scenarios for the Western Lake Erie Energy Innovation Hub to inform opportunities for efficiency improvement and cost reduction
  - Assessing efficiency improvements and economic impact on integrated hydrogen product delivery systems (e.g., liquefaction or compression systems)
3.4. Nuclear hybrids & renewable power integration into the energy distribution grid

The significant penetration of intermittent renewable power such as solar photovoltaics (PV), wind, and other Distributed Energy Resources (DERs) in some markets is causing concerns related to the stability and financing of the nation’s electricity generation and distribution system. Nuclear power generation can play a significant role in maintaining the stability, reliability, and resiliency of the grid as renewable energy and distributed power generation becomes more prevalent. LWR-H₂ hybrids will provide low-emissions energy to the industrial manufacturing and transportation sectors.

In an effort to develop an ecosystem in which Distributed Energy Resources (DERs), buildings, and larger base load generators and loads can coordinate to enable the electrical grid to facilitate a transition to lower carbon emissions, the University of Toledo initiated a Building-to-Grid demonstration project in 2016 with DOE support. Some key features of this demonstration that can facilitate the Davis-Besse Nuclear Power Station integration are as follows: a transactive energy system using VOLTTRON nodes to interface ten buildings has been deployed and integrated with a 1 MW solar array, and a 125 kW/135 kW-hr Li-ion battery energy storage system. Data is collected continuously from more than 8,000 points at ~1 min intervals and stored in a database; transactive algorithms are deployed at the various nodes to allow collaboration among the entities in the system. Two significant benefits from this integration are the ability to mitigate the variability of the array output power due to solar intermittency and to implement demand-response on the campus buildings. With this experience in hand, University of Toledo researchers can work with utilities and INL to deploy similar strategies to the Western Lake Erie Energy Innovation Hub, including:

- **Transactive decision making for advanced integration of distributed energy resources:** Transactive control will be necessary to rapidly switch the nuclear power plant online/offline with electricity directed to the grid or used by electrolyzers producing hydrogen (or other electrolysis products) when electricity prices are depressed. University researchers have developed substantial expertise in dynamically interfacing the electricity generated from DERs to the power distribution grid in the presence of controllable loads. LWR-H₂ hybrids bring hydrogen utilization into the mix. Collaborative opportunities for research and development include: (i) develop an understanding of the economic value and regional demand for produced hydrogen for transactive models, (ii) determine how hydrogen could best be used by (e.g., providing for dispatchable generation via a grid-tied fuel cell), and (iii) develop the hardware and software control architectures to enable dynamic manipulation. An essential element for implementation is understanding and mitigating potential impacts on grid stability in terms of frequency and/or voltage support, particularly during instances of ramp-up or ramp-down. The envisioned simulation models will lead to improved techniques for rapidly bringing a nuclear plant online/offline with minimal impact to grid-stability. These techniques can be readily extendible to various DERs, such as wind and solar.

- **Advanced power electronics for energy hubs:** Experience derived from familiarity with photovoltaic inverter design can be generalized to design electrolysis and other power electronic systems that will interface to the surrounding network and operate with the needed characteristics. Of particular interest are designs that use higher switching frequencies and components with improved thermal management within the converter topologies in order to reduce the size and cost of the needed components. The Davis-Besse hydrogen production project will require various instances of switching in and out loads, integrated with the nuclear
power plant. These transition periods will be facilitated by real-time power electronic simulations. University of Toledo researchers can perform various real-time simulations with advanced component models that offer improved thermal management capabilities resulting in overall system size and cost reductions. The proposed simulations can lead to optimized system performance with respect to cost, reliability, and lifetime for nuclear energy hub applications.

3.5. Nuclear plant interfaces and integration

As nuclear power plants take on the role of providing heat and power directly to industrial users, several benefits have been recognized, including higher revenue generation, low-emissions energy production and utilization, and preservation of the plants for electrical power generation for the grid during periods of high need (for example, during extreme weather events). Nuclear plants such as the DBNPS can provide valuable heat and steam to industrial plants. INL and NREL have recently published on the energy needs of industry that can be provided by nuclear, concentrating solar, and geothermal sources. For nuclear plants, this requires the development of new interfaces to deliver this energy. The value of the nuclear plants increases further if the energy can be apportioned between the industrial user and the electricity grid at times when the grid needs peak power generation. Hence, it is important to develop rapidly-responsive physical connections between the nuclear plants and the industrial processes. These connections need to be proven effective and reliable to be sure the nuclear plants continue to be operated in a safe manner. These interfaces can be developed and proven in small pilot plants without impacting the operations of the nuclear plant. Once proven, these interfaces can be scaled up by applying the “science of scale-up” that University of Toledo and the National Labs can assist nuclear plants in performing. The main interfaces include:

- Electrical switch gear and transmission relays to dynamically direct a portion of the electrical power produced by the nuclear power plant to the hydrogen plant power converters and associated gas compressors, motors, etc.
- Thermal hydraulic systems that extract thermal energy from the nuclear power plant steam circulation systems for delivery to the hydrogen plant and associated industrial processes.
- New control systems that enable the nuclear power plant operator to manage the dispatch of electricity and thermal energy between power generation and transmission to the grid or dispatch to the hydrogen plant. Operator training models that implement these controls should be developed and tested prior to scale up of pilot plants to commercial-scale operations.
- New communications interfaces with the grid operators are needed to enable nuclear plants to quickly adjust the apportionment of energy between power generation and transmission to the grid and the closely-coupled hydrogen plant and associated chemical processes. This will likely involve modern techniques in data analytics to anticipate changes in the direction of the nuclear plant’s energy streams.

3.6. Hub design and operation

Deploying hybrid systems (e.g., LWR-H$_2$ systems) centered on low carbon emission power sources such as the Davis-Besse Nuclear Power Station requires combined analyses across many factors including current and future supply and demand markets, transactive power models, infrastructure and human resources, and direct and indirect economic impacts. These assessments must be completed on a regional scale to optimize the energy hub design, operation and growth. A successful energy hub will
provide an engine for regional economic growth while strengthening electricity grid stability and increasing flexibility to adapt to intermittent power sources and seasonal variations in power supply and demand. The Davis-Besse plant and surrounding industries in the Toledo area and the western Lake Erie region provide an ideal location to demonstrate the use of nuclear power plants, as well as solar and wind energy, for U.S. manufacturing industries. When these concepts are proven, commercial applications can be extended to other regions of the country. Given the large diversity of options among different regions of the nation, it will be advantageous for other utility partners to establish coinciding demonstration projects that benefit from the R&D and scale-up principles that are proven at Davis-Besse, and that are developed by the research at the University of Toledo working with INL and the other national laboratories. To this end, the University of Toledo and the national labs can collaborate in the following relevant research studies:

- Techno-economic analyses (TEA) and life cycle assessments (LCA) that prove the value proposition of hybrid nuclear plants and other clean energy inputs to integrated energy systems.
- Transactive and logistics decision making that changes the paradigm for nuclear energy as providers of clean, affordable energy.
- Holistic energy systems integration modeling that addresses the highest value/benefit regionally; for instance, how to best utilize the hydrogen for production of co-products such as alcohols and syngas, in making steel that goes into cars and trucks or in making fuels for these vehicles' transportation, and extending a hydrogen-derived fuels and materials system to cargo shipping by trucks, railroads, and maritime systems.
- Options analysis and systems optimization; for example, moving electricity versus hydrogen, hydrogen as an energy storage media, adding hydrogen to natural gas to power gas turbines and to burn in industrial heaters.

3.7. Education & workforce development

Development of a Western Lake Erie Energy Innovation Hub will lead to broad economic impacts for the region surrounding DBNPS. Education and workforce development will be an important element in supporting an energy innovation hub centered on hydrogen. A technical workforce knowledgeable about hydrogen safety, material compatibility and code issues related to storage, transport and end uses, such as for fuel cells is needed. Additional skills will be needed for design, operation and maintenance of electronics complex control systems, computer systems and information technology. A workforce training program will be required involving trade schools, community colleges, and universities.

The University of Toledo College of Engineering (COE) has a mandatory, integrated co-operative education program (co-op) in all of the engineering science disciplines. This program provides a strong foundation for workforce training and preparation to support clean energy industrial complexes in the Toledo region and across the United States. Embedding co-op students and graduate students (through internships and fellowships) in regional companies and national labs that are engaged with the energy hub can provide training for the next generation of engineers that will be working in a hydrogen energy economy and hybrid power systems. Undergraduate and graduate students contribute to research projects that support the development of the energy hub by addressing current technology gaps. The COE also has an online MS program in energy engineering tailored to working professionals;
development of courses based on hydrogen economy and the energy hub would support continuing education of practicing engineers as well as engineers in training.

Technical schools and community colleges will also need to be engaged to develop training programs for technicians, such as those working with fuel cell technologies. Skill gaps will need to be identified for students trained at all levels and specific certifications or certificate programs developed.

Public outreach to the community and educational outreach to K-12 will be needed to promote awareness of the changing energy landscape and career opportunities in this arena. The University of Toledo has a long history of engagement with K-12 schools through teacher training programs and educational outreach promoting STEM education. The University also has a variety of forums for engaging the public, such as Science Saturdays hosted by the College of Natural Science and Mathematics, educational forums for students and the community such as Technology Takes the Wheel, and hosting conferences such as the National Lab Day Conference in October, 2019. The University can lead outreach activities related to the Western Lake Erie Energy Innovation Hub with education of the public on improvements in air quality and reduced carbon emissions.

An important item of note is that hydrogen generated from nuclear power stations does not contribute to the generation of greenhouse gases. Rebranding nuclear energy and hydrogen generated from nuclear electricity as green energy sources will require changes to how these hybrid systems are defined within the renewable framework at a regulatory and governmental level.

4. Summary of gaps / challenges /opportunities

Based on the information presented and the dialogue brought forward in this unique meeting with utilities as owners of nuclear power plants, providers of hydrogen production technology and gas suppliers, and commercial companies that either need hydrogen or hope to use hydrogen, some important challenges or gaps in technology readiness and systems integration were noted. The gaps and challenges can be categorized at three levels, as follows:

- **Commercialization projects** that demonstrate new technologies and systems integration. These projects are needed to demonstrate that nuclear energy can reliably and effectively deliver high quality thermal energy and steam to industrial users while integrating seamlessly into nuclear power plant operations. The pilot plant demonstration of hydrogen production at the Davis-Besse Nuclear Power Station is a key step to meeting this objective. The hydrogen pilot plant production can be leveraged and used to further demonstrate hydrogen use in additional pilot facilities that are connected to hydrogen production. This in turn will provide a test bed representing an industry manufacturing and energy complex that can be used to develop and demonstrate systems that interact with the electricity grid in a new, transactive manner. This will require new controls systems for tightly coupling unit operations with the grid. The benefits of demonstration projects include:
  - Providing important data for technology and systems scale up to the full capacity of nuclear power plants,
  - Reducing the risk of first-of-a-kind projects and commercial investments,
  - Establishing industry collaborations that are mutually beneficial,
  - Demonstrating the technical systems that can be applied at nuclear power plants across the United States,
Demonstrating a higher value of nuclear power plants beyond baseload electricity production, supplementing intermittent energy sources such as wind and solar, and the ability of nuclear-hybrid systems to help regulate and balance the grid, and

Establishing interest in future advanced nuclear technology development that is tailored for combined heat and power systems to provide greater energy security as affordable, clean, reliable energy.

- **Technology development and commercialization** acceleration at the device level, followed by bench-scale testing in preparation for moving up to pilot demonstrations. Relative to hydrogen production, some emerging technologies discussed during the meeting include high temperature steam electrolysis, pressurized-water electrolysis, and reversible fuel-cell/electrolysis systems. These advanced technologies will take advantage of both the electricity and steam produced by nuclear plants. In addition, novel concepts related to CO₂ conversion, production of renewable chemicals from biomass, and production and recycling of plastics can be implemented by utilizing the hydrogen, steam, and electricity produced. Opportunities for university and National Labs collaborative research include:
  - Developing new electrochemical reactors that can be operated dynamically to take advantage of electrical and thermal energy,
  - Designing and testing novel catalytic reactors for hydrogen utilization for fuels, chemicals and plastics,
  - Conducting technoeconomic assessments using computational tools that model the dynamic operations of integrated systems,
  - Testing component equipment with hardware-in-the-loop, emulating power systems, and verifying control-systems before implementation in pilot plant operations, and
  - Testing long-term durability of components in representative environments. This will reduce the risk of technology demonstration failures by conducting tests at the smallest scale possible and making modifications that are needed to ensure successful commercialization.

- **Fundamental R&D** conducted by universities and National Laboratories. The meeting confirmed that The University of Toledo is especially well-suited to support the development of technology and pilot demonstrations. The Colleges of Engineering and Natural Sciences & Mathematics are already engaged in power systems research, mechanical systems development, and chemical process research relevant to the nuclear energy hub concept, and hence that are important to the DBNPS clean energy industrial complex demonstrations. Specific R&D needs for the contemplated projects include:
  - Modeling of thermal hydraulic systems and chemical reactors with computational fluid dynamics models and multi-physics models,
  - Developing materials for hydrogen storage and chemical reactors,
  - Developing novel catalysts for hydrogen use in chemical reactions and related fundamental engineering studies in catalysis,
  - Developing coatings and studying solid-oxide and ceramics microstructure evolution through lab-scale cell testing, advanced diagnostics, molecular dynamics modeling, and other efforts,
  - Modeling of new process designs and plant economics, systems optimization, scale-up, and evolution of transient systems,
  - Developing methods for data fusion, large data analytics, decision systems, process controls, and cyber intrusion detection and protection,
Developing power electronics and controls that enable transactive power markets and maximize the capacity of wind and solar energy with flexible operations of the nuclear plant,

Developing new electrochemical reactor concepts, including studying and exploiting transient chemical reaction phenomena during dynamic, non-steady-state operations,

Developing separation membranes that enable non-steady operation of electrochemical reactors, and

Developing advanced manufacturing techniques that help lower the cost of the supply chain of materials and component assemblies.

In summary, The University of Toledo, as presently constituted, has the right capabilities to assist the National Labs and industry in tackling the R&D and pilot demonstration needs in preparation for, and execution of, demonstration tied to the Davis-Besse nuclear facility. The University has a well-established collegiate-industry co-operative education program that can support the technology development needs. This will help provide a workforce ready to design, construct, and operate the demonstration projects.

A research consortium comprised of The University of Toledo and the National Labs, with INL leading nuclear reactor coupling, and NREL leading renewables integration; industry partners, many of whom were present at the workshop; and utilities that own and operate nuclear power plants (starting at the Davis-Besse plant) can carry out the research needed in a graded approach. The team can efficiently address the important research gaps, test and scale-up hydrogen production and associated technologies, and demonstrate integrated systems.

5. Summary of presentations

5.1. Session 1. Welcome & LWR-H₂ hybrid overview & regional projects

Welcome and Overview
Mike Toole, Dean of College of Engineering, The University of Toledo

Dr. Toole opened with a brief summary of workshop goals towards identifying opportunities and challenges in achieving a sustainable energy economy, nationally and regionally through development of a Western Lake Erie Energy Innovation Hub. The regional focus centered on the light water reactor – hydrogen hybrid pilot project located at the Davis-Besse nuclear power station. Workshop aims included:

- Identification of regional energy hub opportunities
- Focus on critical research and technology gaps in the project
- Facilitate industry, national lab, academic collaborations

Dean Toole emphasized the strong support of The University of Toledo’s College of Engineering in supporting this project and expressed the strong interest of university faculty in contributing to its research and training goals.

NW Ohio economic development, structure & opportunities
Dean Monske, President & CEO, Regional Growth Partnership
The Regional Growth Partnership (RGP) is a leading economic development group serving the Toledo region and 17 counties of Northwest Ohio. As a 100 percent privately led organization, the RGP focuses on meeting the site selection needs of corporate clients in a confidential, innovative and time-sensitive manner. The RGP offers a full range of traditional business development services, working in conjunction with partners at the regional and state levels to most effectively manage the site selection process. These services include: Comprehensive site and facility searches; Incentive packaging; Project development, planning and expediting; Facilitating projects in collaboration with regional and state partners; Provide access to venture capital. The RGP’s business development efforts are focused on five cluster industries: energy, logistics & transportation, automotive, food processing, and advanced manufacturing. The RGP is working with The University of Toledo to identify companies in Northwest Ohio that use hydrogen and to invite them to participate in this project.

**NE-EERE Partnership for Nuclear-Renewable Hybrid Energy Systems (NRHES) development and demonstrations**

Jason Marcinkoski, Technology Manager, DOE Energy Efficiency & Renewable Energy (EERE) Fuel Cell Technologies Office / NE Light Water Reactor Sustainability

The growing partnership between the nuclear power industry and the hydrogen economy was described. Hydrogen (H₂), produced via electrolysis of water with a nuclear reactor power source, provides a low-emissions product that can help to extend the economic lifetime of nuclear power stations, and contribute to grid stability with increasing integration of variable renewable power sources (i.e., solar and wind). Approximately 10 million metric tons of hydrogen are produced in the U.S. annually with 1600 miles of hydrogen pipeline. The LWR-H₂ pilot projects are part of the effort of the DOE Light Water Reactor Sustainability (LWRS) Program and DOE Hydrogen and Fuel Cell Technologies Office to evaluate and demonstrate integrated energy systems that competitively produce electricity and non-electrical products to optimize revenue generation by nuclear power plants. Hydrogen production using LWR power can play a role in grid resiliency, deliver a controllable load with sub-second response times, and provide a long-term market for nuclear energy.

The Department of Energy, Office of Nuclear Energy led LWR Integrated Energy Systems Interface Technology Development & Demonstration project is in partnership with FirstEnergy Solutions Corp., Xcel Energy, Arizona Public Service Electric, and Idaho National Laboratory. The project ($11.5 million) was announced in September 2019 and includes installation of a 2MWe water electrolysis unit (for H₂ production) at Davis-Besse Nuclear Power Station in northwest Ohio with onsite and offsite uses of hydrogen planned. This is one of two current LWR-H₂ hybrid projects nationally.

Areas outlined for future work and research included:

- Integration of larger scale electrolysis units — 20 MW up to full reactor output (including low-temperature electrolysis)
- Use of electricity and heat (for higher efficiency) with high-temperature electrolysis
- Integration of renewable resources and grid services
- Regional market transformation (for hydrogen applications)

**Davis-Besse Hydrogen Production Demonstration Project**

Alan Scheanwald, Strategic Engineering, H₂ project Manager, First Energy Nuclear
An overview of LWR Integrated Energy Systems Interface Technology Development & Demonstration public-private partnership project at Davis-Besse Nuclear Power Station (DBNPS) was given. The project objectives include diversification and increase of the revenue streams for nuclear power plants in the face of increased competition from renewables and low-cost natural gas. This project will demonstrate the technical feasibility and economic viability of a hybrid power system producing green hydrogen co-product in order to facilitate large scale commercialization. For operation at Davis-Besse Nuclear Power Station electrical power is taken at plant output and prior to the switchyard. No grid tariffs are applied, reducing the operating cost to the hydrogen skid (water electrolysis units). Inputs for hydrogen production are electricity and water with the ability to scale up at DBNPS using existing utilities. Future scale-up activities could utilize a portion of the plant’s thermal energy to increase electrolysis unit efficiency and lower costs. The plant’s relative proximity to key markets are ideal for reducing transport distances (Toledo, I-80/I-90 Corridor, Detroit, Cleveland, Columbus, Cincinnati, Pittsburgh, etc.). Hydrogen will be generated from a “carbon-free” power source supplied by DBNPS.

A proven Low Temperature Electrolysis (LTE) Polymer Electrolyte Membrane (PEM) turn key technology has been selected for the hydrogen skids to reduce risk for the pilot demonstration. The skids require roughly 2 MW of electricity and 2,400 gallons of water per day at maximum operating capacity with expected hydrogen production of 800 to 1000 kg per day. Operation of the 2 MW units are expected to come on line by 2022. DBNPS has a nominal output of 925 MWe (2,817 MW thermal).

Idaho National Laboratory is preparing a Technical Economic Assessment (TEA) for DBNPS to evaluate the business case for bulk hydrogen distribution in Toledo, Ohio area (fuel cell vehicles, petroleum refineries, iron-ore plants, fertilizer production facilities, etc.). Hydrogen transportation costs are a significant portion of the expected price of this product. Reducing the transportation distances is important to the success of the Davis-Besse project and future scale up activities.

- There are opportunities to leverage the production facility’s proximity to major transportation corridors and potential consumer base for hydrogen.
- There is a need to identify and cultivate emerging regional hydrogen markets.

**Industry Energy Hubs with Integrated Energy Systems**


Dr. Boardman gave a broad overview of the LWR integrated energy system pathway and discussed coordination needed between nuclear, renewable and fossil power sources to ensure grid reliability and security in the US, particularly as intermittent renewable power generation increases in capacity. The Toledo area energy hub anchored through the LWR at Davis-Besse, integrated with renewable power sources such as solar and wind, has the potential to be an economic and innovation driver for the region. The impacts of the hub can be strengthened through fundamental R&D with universities, technology development and acceleration efforts and DOE Cost-Share Demonstrations. Industry led projects, such as the Davis-Besse LWR-H₂ hybrid pilot demonstration, play an important role in demonstrating the commercial feasibility of low carbon emitting nuclear power combined with green hydrogen production. Industry pull, combined with academic push, is needed to move the LWR-H₂ hybrid systems to full integration into the U.S. energy landscape.

Hydrogen supports a number of industries and applications in current and emerging markets. A number of these key applications were discussed including, clean transportation (hydrogen fuel cells for heavy
and light vehicles and forklifts), hydrogen demand for refineries and direct-reduced steel manufacture, and ammonia production. Syngas or alcohol can be synthesized through conversion of CO₂ with hydrogen, providing a platform for production of a variety of value-added chemicals. The Midwest region is uniquely positioned to provide a CO₂ pipeline from bioethanol plants and bio-digestors. Emerging electrochemical routes, using low carbon emitting nuclear power, for ethylene and propylene with application in polymer manufacturing were outlined.

**Participant Input Summary**

1. How much hydrogen storage capacity will be required for demonstration projects such as the one at Davis-Besse Nuclear Power Station? What partners may be required to handle distribution of hydrogen for these early stage demonstration projects?

No specific customers and partners have been identified for the pilot demonstration units (800 to 1000 kg of hydrogen per day) expected to come on line in 2022. Storage and transportation of H₂ will depend on end use.

2. It was mentioned that the H₂ skid would be in operation during very low power price environments. What is your estimate for hours/days that this skid would be in operation?

Seasonal variations are expected to be more significant with respect to operation than hourly variation. For example, it’s expected that the electrolyzers will operate at higher capacity in spring and fall. Prices for electricity are not the only variable to be considered in operation.

3. What is involved in using electrolysis as a power smoothing asset?

Electrolysis has a high response rate to take up the load of electricity. It can be switched on or off fast enough to correct instabilities in the grid, including at the distribution level.

4. How will the LWR-H₂ hybrid project at DBNPS be affected by the changing of plant ownership?

The new ownership through First Energy Nuclear is still committed to, and excited about the project.

5. Since we have not completely closed the nuclear fuel cycle, does this present a roadblock for the future implementation of these concepts for nuclear energy?

No. Technical solutions to nuclear fuel reprocessing have been developed but could be improved.

6. What is the extent of the NRC’s regulations that may affect hydrogen production at Davis Besse?

As part of the demonstration project, the DBNPS site will show how the facility is effectively addressing operation of the reactors in conjunction with the electrolyzers producing hydrogen.

7. Are there opportunities for the direct use of thermal energy and electrons from DBNS? Is this a more complex integration?

It is possible, but more challenging than the LWR-H₂ hybrid. Studies are underway on how to do that. An example of this is taking thermal energy from the nuclear reactor to improve efficiency using high temperature steam electrolysis (HTSE).

8. What is the timeline for the Davis Besse demonstration project and associated future projects?

The initial phase is completion of demonstration of water electrolyzers at the 2 MW scale, with execution in 18-24 months to prove it’s operational. The next phase is to consider adding electrolysis units depending on industry and customer demand for H₂.
9. Is steam being considered as the feed to the electrolysis units?

Water is being used now for Low Temperature Electrolysis (LTE) since it’s a proven technology. Future development and demonstrations using HTSE are needed. There are opportunities for efficiency and cost reduction with higher temperature operation of LTE. Demonstrations are key to expanding LWR-H₂ hybrids.

10. How do you propose to store and transport hydrogen economically from the nuclear plant?

Idaho National Laboratory and Argonne National Laboratory will be conducting a techno-economic analysis on storage and transport of H₂ from a nuclear plant to the end use location. This depends on the quantities produced, the volume and delivery distance and if the H₂ is in gas or liquid form. For large volumes, a pipeline may be economical, but needs assessment. There is a team assembled to study this – with analysis coming soon. There are opportunities to study optimization of converting hydrogen to liquid and mitigation of transportation and storage costs.

11. Wouldn’t it be more efficient to establish electrolyzers at the point of use in a distributed fashion, rather than centralizing them at a power plant?

A large centralized plant can bring economy of scales. Production at the nuclear power station site is more efficient and economical due, in part, to lower electric costs without tariffs. It is best to have a hub location close to H₂ users. However, this is an area that could benefit from further technical and economic evaluation.

12. How do you motivate industrial users to use this as a hydrogen source?

A premium on carbon-free sources to produce hydrogen will be a value added to the product compared to current dominant production via steam reforming of natural gas (with a very large carbon emission footprint).

5.2. Session 2. DOE Crosscutting hydrogen initiative & University of Toledo research overview

H₂@Scale: Opportunities for Hydrogen as an Energy Intermediate
Mark Ruth, Chief Analyst and Lead for H₂@Scale Analysis Team, National Renewable Energy Lab (NREL)

Mr. Ruth provided estimates of the serviceable consumption potential (maximum opportunity) and economic potential for hydrogen. First, he outlined the 2015 market demand for hydrogen and the serviceable consumption potential considering expanding current applications and entering emerging applications. The serviceable consumption potential in 2050 is estimated to be over nine times the current market size. The current dominant applications for hydrogen are in crude oil refineries, the chemical process industries and ammonia production with synthetic fuels and chemicals constituting about 10% of the demand (totaling ~10 MMT/year in 2015). The applications with the largest growth opportunity are use of hydrogen for seasonal energy storage for the grid, metals production (e.g. direct reduction of iron ore), and production of synthetic fuels and chemicals (e.g. reduction of CO₂ with hydrogen to produce alcohols and other products). Hydrogen production via water splitting (electrolysis) driven by essentially carbon free nuclear power can provide a means to meet much of the market demand, for example, through LWR-H₂ hybrid systems.
To estimate the economic potential, Mr. Ruth developed demand curves (how much consumers are willing and able to pay for a good at various prices) and supply curves (threshold prices showing how much are producers willing and able to produce at each price). The economic equilibrium is at the intersection of the two -- where the supply and demand price and quantities overlap. Range of price and annual demand across five scenarios was developed based on a variety of economic and R&D success assumptions. The conclusion of the analysis was that the economic potential of hydrogen demand in the U.S. is 1.8-4 times current annual consumption. Hydrogen production & utilization technology R&D or other market drivers are needed to achieve those potentials.

Key challenges and opportunities in development of hydrogen markets and economy include:
- Reducing electrolyzer capital costs while maintaining or increasing flexibility in operation
- Meeting R&D targets for hydrogen utilization technologies across broad applications: fuel cell electric vehicles, metals production, biofuels, synthetic fuels/chemicals

**Hydrogen for production of clean transportation fuels & industrial processes**
Amgad Elgowainy, Senior Scientist/Electrification and Infrastructure Group Leader, Argonne National Lab (ANL)

Dr. Elgowainy gave an overview of Ohio’s economy, environmental footprint, and potential hydrogen markets. Ohio gross domestic product (~$680 billion) ranks seventh among states in the U.S. and is the third-largest coal-consum ing state after TX and IN. ~ 90% of the coal is used for power generation. Ohio’s two nuclear power plants located along Lake Erie, supplied about 15% of the state’s net generation in 2018. There has been a rapid increase in Ohio’s natural gas production (Utica shale). Ohio has the 7th largest crude oil-refining capacity. Ohio is the 8th largest ethanol-producing state, which can provide a high purity concentrated carbon feedstock (CO₂) when combined with hydrogen to produce synfuels and other chemicals.

Production of green hydrogen with renewable and nuclear power sources enables grid flexibility with the increasing contributions of intermittent renewables (e.g. solar and wind), while creating green opportunities across many industrial and transportation sectors. These include ammonia production (used for fertilizer), hydrogen fuel cells for transportation, petroleum refinery processes, metals refining, and production of synfuels. If ammonia currently imported is produced in the U.S. using green hydrogen, domestic production can be increased by ~40% without an increase in ammonia demand while significantly lowering carbon emissions. In the transportation sector, medium and heavy-duty vehicles used in pick-up and delivery services contribute significantly to critical air pollutant emissions, even though accounting for a small portion of on-road vehicles. Conversion to hydrogen fuel would significantly reduce those as well as greenhouse gas emissions. Reduction in carbon emissions using green hydrogen were summarized across the industrial and transportation sectors.

Competing and displacing hydrogen production via carbon emitting steam methane reforming of natural gas is challenging due to the low cost of natural gas. Established applications (refineries and ammonia) are more likely for adoption of green hydrogen (from LWR-H₂ hybrids) in the near term compared to newer applications such as synfuel production or direct reduction of iron. New applications that may leverage existing infrastructure and can readily absorb H₂ production at scale include mixing H₂ with natural gas for power generation or industrial applications. Markets will likely demand a steady supply of hydrogen with storage necessary. Proximity of hydrogen production to
demand sites is key to its economic potential in the energy system and will reduce infrastructure cost per unit energy delivered.

**Overview of University of Toledo Research**

Patricia Relue, Associate Dean for Research and Graduate Studies, College of Engineering, UToledo

Dr. Relue provided a high-level overview of research within the University that is complementary to the DOE-funded hydrogen demonstration project at Davis-Besse and the Energy Hub concept. She stated that UToledo is a comprehensive R2 institution with twelve Colleges. Faculty from the Colleges of Engineering (COE) and Natural Science and Mathematics (NSM), the two colleges most closely aligned to this project, are highly research-active with funding predominantly from federal sources and significant funding from industry. The university leads the State of Ohio in invention disclosures and license agreements normalized to research expenditures. Areas where UToledo faculty have expertise related to the integration of nuclear energy into the production of hydrogen and other value-added products from LWR-H2 hybrids in a regional energy hub were outlined.

- **Polymers** – The Polymer Institute has been working with a consortium of industries for many years on packaging plastics, particularly polyethylene terephthalate (PET). More recently, research has focused on development of polymers that will integrate into a circular economy for plastics, including fibers and textiles, with an emphasis on chemical recycle and monomer recovery. Research in Chemical Engineering and Chemistry includes polymer synthesis, polymer processing, and plastics and materials recycling. Additional efforts include design of bi-functional catalysts that support polymerization and recycle via catalytic degradation and generating high-value polymers from CO\(_2\) and renewable monomers. Faculty also have expertise in rheology, particularly in the mixing and flow of solids and slurries that are encountered in polymer processing or materials handling.

- **Renewable biomass and chemical synthesis** - The College of Engineering has been working in renewable biomass for over a decade, with work spanning from biomass deconstruction to the generation and utilization of sugars for ethanol production and higher value products such as furans, fuels, and polymer precursors. Projects in COE and NSM that focus on CO\(_2\) utilization include design of materials for CO\(_2\) capture and hydrogenation to alcohols and catalyst development. Other research projects focus on photo-catalysts for reduction of CO\(_2\) to methanol and development of approaches for incorporation of CO\(_2\) insertion into unactivated C–H bonds for synthesis of polymer precursors. Atmospheric CO\(_2\) capture for algae cultivation and high-value product production has been ongoing for more than a decade. The College of Engineering also has expertise in life cycle assessment and sustainability analysis of value-added products and manufacturing processes.

- **Electricity grid, electricity storage, and renewables integration** – Faculty associated with the Wright Center for Photovoltaic Innovation and Commercialization have extensive expertise in photovoltaics design, manufacture, and grid integration. As a group, these faculty have been addressing issues associated with renewables integration into the grid. They have demonstrated the use of battery storage systems to minimize high frequency harmonic input into the grid resulting from variable power output of solar arrays. Much of this work involving transactive control is in collaboration with PNNL using the Scott Park Campus solar array. This group of researchers has experience that is relevant to integration of renewables from a wide
range of sources, including electricity generated from hydrogen consumption in fuel cells or in gas turbines.

- **Battery storage systems** – Faculty in electrical engineering and engineering technology have developed voltage equalization technologies to increase the longevity of battery storage systems. Integration of these technologies extend the life of cell packs at a significantly lower cost than active equalization, increasing the usable life and voltage storage capacity of these systems.

- **Gas turbines** – Faculty in the Mechanical, Industrial, and Manufacturing Engineering (MIME) Department have significant aerospace and turbomachinery expertise with long-term funding through NASA Glenn and industry. The Small Turbine Institute (STI) has been the home for high-speed testing of small turbine engines for missile applications. Faculty have expertise in developing and validating fluid dynamics models for high-speed fluid and turbomachinery, such as jet engines and helicopter fans. Faculty also have experience in design and analysis of electronics integration associated with aircraft control systems. While much of the expertise lies with aeronautical and aerospace applications, it is translatable to hydrogen mixture gas turbines and computation fluid dynamics applications. Faculty also have experience in structural design and analysis of piping systems for nuclear applications and design of nuclear infrastructure for earthquake specifications.

- **Advanced materials** – Faculty in the COE have expertise in advanced materials design and synthesis. Expertise in membranes extends to gas/gas separations, ultrafiltration for water purification which would be applicable to the water supply for the electrolysis unit, as well as the electrolysis cell membranes. This membrane expertise is applicable to fertilizer production using membrane reactors to achieve zero CO₂ emissions. Hydroxyl radical scavenging nanomaterials developed in chemical engineering have the potential to reduce membrane damage in fuel cells and prolong their useful life. These materials may also benefit higher temperature PEM electrolysis. COE faculty have expertise in coatings that improve heat transfer and reduce metal failure in boiling units, which is directly applicable to the steam generation unit within the reactor system. Faculty are also working on the design of metal surfaces to enhance heat exchange in phase change systems; this work can benefit utilization of thermal energy generated by the reactor.

**Participant Input Summary**

Comments by Richard Hess, Director, Energy Efficiency & Renewable Energy (EERE) Office Program, DOE: Dr. Hess briefly summarized EERE interests in energy storage, nuclear reactor system advances, microreactor development, process intensification and advanced applications in harnessing electrons. He stated that LWR-hydrogen hybrids present one starting point to integrated technology development towards a sustainable energy and manufacturing economy. He mentioned that the each of the Program Offices under DOE-Energy Efficiency and Renewable Energy have a stake in the opportunities afforded by nuclear energy as a source for industrial processes. He commented that advanced manufacturing developments will be important to the success of technology competition and commercialization. He also stressed the importance of national lab partnerships with universities and industry to advance the science of technology scale-up and systems integration, utilizing the capabilities that include scientists, engineers, and systems integrated modeling and testing.
1. Are there other CO\textsubscript{2} sources for reaction with H\textsubscript{2} to produce synfuels and other products such as cement plants?

Viable CO\textsubscript{2} sources will need to meet needs for purity and concentration to be economical. More concentrated sources of CO\textsubscript{2} from bio-ethanol facilities may be more near term than more dilute and less pure sources.

2. Can hydrogen (or CO\textsubscript{2}) feedstock or product be stored in salt caverns?

Economics of storage depends on the scale of production and end use. If there is a market demand for a large H\textsubscript{2} volume, then investments in pipelines may be viable. Storage is a challenge that will impact hydrogen pricing and economics.

3. What is the timeline for buildout scenarios for hydrogen use nationally?

DOE lab analysis groups will be working on this, particularly in the vehicle and transportation sectors. Projections are that wind capacities for energy will be doubling over a short term. Analysis is needed in how nuclear energy sources complement this growth in renewable energy and how H\textsubscript{2} production from nuclear fits into power and hydrogen supply demands.

4. Do you plan to follow up your national-level economic analysis and estimate future western Lake Erie regional supply and demand for hydrogen?

Regional analysis reduces the scope a bit. We are hoping to launch a preliminary study in spring/summer of 2020 after a review process.

5. Do you foresee the market price of electricity remaining stable over the foreseeable future? What factors do you see coming into play in the near future that will affect market prices?

For the wholesale market, prices are coming down with a great deal of variability. There are a variety of different market prices for electricity -- some stable, some trending down, some flattening out -- depending on many variables. Natural gas (a large energy source of overall grid power) prices likely will not go down, contributing to an increase in volatility.

6. Has a combination of hydrogen production from steam methane (NG) reforming from nuclear (LWR) been looked at?

Demand and supply curve development over various scenarios of natural gas pricing and technology development indicates limited market penetration from LWR with low hydrogen prices. Under a number of quite realistic scenarios, hydrogen from natural gas is projected to supply $\frac{1}{2}$ to $\frac{3}{4}$ of the hydrogen demand, with the remainder from water splitting via nuclear of renewable energy, depending on the area of the country.

7. Can you comment on storing energy produced above grid demand with batteries versus hydrogen?

Hydrogen storage is cheaper than battery by an order of magnitude at \$20 \text{ kWh} for hydrogen and \$200 \text{ kWh} for batteries. Storage of hydrogen gas is less costly than liquid storage.

8. Does the University of Toledo have R & D interests in carbon capture or conversion?

Several faculty in Chemical Engineering and Chemistry departments are working on projects related to CO\textsubscript{2} capture or conversion to synfuels, alcohols and chemicals.
6. Summary of panel / facilitated discussions


David Hasse, Senior Research Associate, Air Liquide
In a presentation entitled “Hydrogen - At the heart of the energy transition” Dave Hasse described Air Liquide’s hydrogen business. He emphasized the commitment of the company to hydrogen and the role of hydrogen in limiting carbon emissions and adverse climate change. Air Liquide envisions that by 2050 hydrogen will account for up to 18% of energy demand and reduce CO₂ emissions by 6 Gt. The economic impact of increased hydrogen use is projected to be $2.5 billion with the creation of 30 million jobs. Current and future hydrogen markets were discussed as well as Air Liquide’s strategic investments in hydrogen production (steam methane reforming and electrolysis) and distribution networks (hydrogen pipelines and vehicle recharging stations around the world).

Stephen Szymanski, Director of Business Development, Nel Hydrogen
Steve Szymanski described the work of Nel Hydrogen. Based in Oslo, Norway. Nel is a global supplier of electrolysis and hydrogen fueling products. Nel offers both alkaline and proton exchange membrane (PEM) electrolyzers and is the sole supplier of PEM electrolysis cells for all new US, UK, and French nuclear submarines. Steve discussed the huge potential of hydrogen markets especially in the ammonia, methanol, steel, and petroleum industries. Several grid scale applications up to 30 MW were described. He concluded by reviewing several projects in the transportation sector, especially for heavy duty vehicles.

Ryan Sookhoo, Director of New Initiatives, Hydrogenics- Cummins
Ryan Sookhoo described the work of Hydrogenics which has 70+ years of experience in delivering top-tier hydrogen solutions. Hydrogenics is owned 80% by Cummins and 20% by Air Liquide. They design and build fuel cell power modules and electrolyzer systems. Ryan gave examples of their facilities from Ontario, Denmark and Germany. He also showed how the electrolyzer plant rapidly can respond to the grid dispatch signal setpoint every two seconds. He also gave some highlights of their storage facility.

Vincent Chevrier, General Manager, Business Development, Midrex Technologies, Inc
Vincent Chevrier described Midrex as a world leader for direct reduction iron making technology and aftermarket solutions for the steel industry. Their headquarters are in Charlotte, NC. They have 50 years of commercial operations and they have a total of 93 modules in 21 countries.

Vincent explained the process of iron making from lump ore to direct reduction to direct reduced iron (DRI) products. There are three types of DRI products and steel can be made using electric arc furnace (EAF), blast furnace or basic oxygen furnace. World DRI production is increasing and Midrex produces about 80% of it globally. Cleveland-Cliffs in Ohio is under construction with an expected startup in the second quarter of 2020.

Midrex technologies reduces the CO₂ emissions from steel making by 50-80% compared to traditional BF-BOF. Direct reduction can be a bridge technology for ironmaking as hydrogen becomes available at scale. New plants can be built or existing plants can be converted to 100% H₂ as the hydrogen economy evolves. Green hydrogen production volumes need to increase by 30 to 100 times to supply one MIDREX® plant.
Participant Input Summary, and Q & A

1. What are the lifetimes of today’s best-in-class electrolyzers?

Typically lifetimes of commercial stack electrolyzers is 20 years. Stack overhaul is typically needed about half way through the operating lifetime.

2. What differences in overall efficiency can be expected in high versus low temperature electrolyzers for hydrogen production from water splitting?

Active research programs are on-going for both high and low temperature electrolyzers. Temperature increases can be significant even in the range of 50 to 100°C for PEM (LTE) units. High temperature steam electrolyzers (HTSE) use different technologies (solid oxide materials) with operating temperatures up to 800°C where increased efficiencies can reduce electricity costs by up to 30%. On-going testing for durability and reliability of these units is needed. Efficiency gains for HTSE versus the established reliability of LTE need to be taken into account in electrolyzer selection. It is a tradeoff.

3. Have your companies been pursuing high temperature steam electrolysis technology?

Leaders in the industry need to explore high temperature electrolysis but there isn’t a great deal of immediate opportunity. Most of the current focus is on low temperature electrolysis due to its proven performance and reliability. Emphasis is on the development of large scale electrolyzers for water splitting using low temperature (i.e. PEM) units, with an emphasis on driving costs down.

4. How does PEM compare with alkaline for low temperature electrolyzers?

Alkaline electrolysis is a robust product that has been on the market for over 50 years. However, PEM offers greater opportunities for scale up, has a greater dynamic range and offers more flexible modes of operation than alkaline units. PEM systems can provide rapid response to grid fluctuations. Both are good, reliable technologies.

5. From industry’s view, what is the minimum capacity factor for electrolyzers?

There is no single answer – a lot depends on where you are regionally and end uses. It’s dependent on frequency regulation, spinning reserves and applications – for example production of hydrogen for transportation fuels instead of direct substitution for natural gas. It also depends on the interconnecting utility and revenue to run the overall power system.

6. What advances are needed to reduce CO₂ emissions and bring down hydrogen costs?

A large part of hydrogen costs depend on how it is shipped. In shipment by truck, hydrogen constitutes one to two percent of the net weight of the truck and hydrogen product. Liquid hydrogen is more costly to produce (compression and liquefaction) and ship than vapor. End user groups, located in geographical clusters, are needed to provide hydrogen in high capacity. Collaboration is needed. The reductions in CO₂ emissions is proven in many technologies and for many applications.

7. What is the optimal size electrolyzer for DBNPS produced hydrogen?
The electrolyzers are modular and the optimal scale depends on the size of the regional hydrogen market. There is the need to develop electrolyzer modules to produce higher levels of hydrogen for large power needs. There is no optimal size.

6.2. Session 4: H₂ for transportation

Kurt Wellenkotter, Senior Manager, Strategic Fuel Cell Business Initiatives, General Motors Corporation
Kurt Wellenkotter represented General Motors Corporation. He shared a story of how Horatio Nelson Jackson was the first to drive a gasoline car across the country in 1903 - without the aid of fueling stations. This introduction led to a discussion related to the hydrogen paradox - hydrogen fuel cell cars should be produced as hydrogen fueling stations, and infrastructure is being developed. General Motors' current vision for 0 crashes, 0 emissions, and 0 congestion will be achieved with hydrogen powered fuel cells, electric, and autonomous vehicles.

Tim Terrill, VP, Aftermarket Services NA, Plug Power
Tim Terrill spoke about Plug Power as a leader in hydrogen fuel cell technologies with over 150 awarded patents. Plug Power has over 30,000 hydrogen fuel cell powered forklifts in current operation; maintains over 80 hydrogen fueling stations and supports other fueling centers; and provides service and maintenance creating 98+% uptime. They have achieved over 70% cost reduction since 2013. Their customers include many Fortune 100 companies including Walmart and Amazon. One future opportunity for an expanded market for Plug Power is with hybrid electric + hydrogen fuel cell commercial delivery trucks.

Pat Valente, Executive Director of the Ohio Fuel Cell Coalition and previously Deputy Director of the Ohio Department of Development.
Pat Valente represented the Ohio Fuel Cell Coalition. Recently, Ohio was named a Top 5 fuel cell state with supportive incentives and policies to maintain or grow this position. The Coalition finds that U.S. manufactured fuels cells have some or many components built or produced in Ohio. Ten companies with Ohio operations contribute to the fuel cell supply chain. Honda’s facility in Marysville, Ohio was highlighted due to its large employee base (14,000 people). Honda and GM are collaborating on fuel cell vehicles and some of this manufacturing is expected to occur in Ohio. Finally, the Stark Area Regional Transit Authority (SARTA) in Canton, Ohio area operates the 3rd largest fleet of hydrogen powered fuel cell buses in the U.S. A current opportunity for fuel cells in Ohio is for forklifts used in warehouse operations, as noted by the presentation by Tim Terrill of Plug Power. A new Amazon warehouse coming to Toledo offers a large market for such vehicles.

Q&A, and Participant Input Summary

A panel discussion concluded the session. Some ideas from the questions and answers are summarized here: The hydrogen infrastructure needs development to fully realize the potential for hydrogen fuel for an array of transportation and warehousing needs. Fuel cell electric vehicles (powered by a combination of hydrogen and batteries) can travel at least 300 to 400 miles on a full tank of hydrogen. Hydrogen vehicles operate many different ways with the ability to use battery power in concert with
the fuel cell’s power. A question about the recently announced electric Hummer including a hydrogen fuel cell was redirected to a future time. Many variations of hydrogen refueling installations are available; while some standards exist, the local needs, regulations, and economics dictate the type of refueling stations being built.

Question: Are there any fuel cell partnerships between automobile manufacturers?

GM and Honda (leaders in fuel cell vehicle development) are partnering and have other collaborations. The U.S. has leading technologies in hydrogen and battery powered vehicles-- sharing technology and standards is the key to advancing development and markets.

Question: Are there connections between GM and the hydrogen infrastructure?

GM produces hydrogen for their vehicle testing on site. Infrastructure is available for forklifts operating in warehouses, but need is lacking for light and heavy duty vehicles across the US.

6.3. Session 5A: Holistic energy systems evaluation & optimization

Cristian Rabiti, Lead of Energy Systems Modeling and Simulation, Idaho National Laboratory (INL)

Cristian began by illustrating how the overlap between energy demand and net-demand is projected to decrease significantly by the year 2048, particularly as wind and solar penetration continues to grow. He then provided an optimization example of an energy hybrid system showing the inverse relationship between hydrogen storage levels and grid-electricity prices. When the hydrogen storage level is at its minimum, the grid price is maximized. He concluded by offering three important strategies for an optimized hybrid energy system: (i) Artificial intelligence should be used to learn patterns, such as intermittency in wind and solar, (ii) Improving the ability to solve stochastic processes and, (iii) Development of physical models for faster time response.

Pat Burke, Vice President, Excel Nuclear Energy

Pat delivered a bold vision for reducing carbon emissions. In 2018, Xcel energy had 38% lower carbon emissions – and it was projected that by 2030 Xcel energy would reduce carbon emissions by 80%. Finally, Pat envisioned a 100% carbon reduction by the year 2050. Pat noted that Xcel has been retiring coal-fired power plants and that the company did not believe that there was a future for coal in electricity generation. Pat delivered compelling statistics relevant to the energy sector, showing that nuclear energy accounts for 25% of energy generation. He concluded his presentation by discussing how new energy technologies tend to decrease prices, illustrating that since 2016, wind and solar have seen a 24% and 33% reduction in costs, respectively. These trends are expected to continue particularly as hydrogen fuel cells penetrate the energy market.

Scott Swartz, Chief Technology Officer, Nexceris

Scott delivered a presentation on solid oxide fuel cells (SOFC) and their potential as an attractive alternative option in the fuel cell energy market. SOFCs have several potential advantages, as Scott mentioned. These advantages include a relatively thin membrane, which enables improved electrochemical performance, a more dense cell periphery which facilitates sealing, and a mechanically supported membrane which can withstand pressure differentials better than state of the art.
approaches. At the system level, Scott argued, a number of advantages are offered by SOFC technology. For example the gravimetric power offered by SOFCs reduces material costs and thermal mass. Scott concluded with discussion of the “Li-ion tamer” which can detect fires in Lithium ion batteries. This is particularly helpful in the grid energy storage arena.

Mike Heben, PVIC and McMaster Endowed Chair and Professor of Physics, University of Toledo
Mike discussed the on-going grid modernization effort at the University of Toledo, Scott Park Campus. The campus has a 1 MW solar photovoltaic (PV) array and a 125 kW Battery Energy Storage System (BESS). This integration is used to provide electrical power to the eight buildings located on the campus. The BESS is used in combination with a novel adaptive control algorithm to mitigate the output power seen in the PV array, due to excessive cloud cover. The achieved mitigation is comparable to state-of-the-art algorithms - however, using significantly less battery energy. Mike also discussed the intelligent load control (ILC) being deployed on the HVAC systems of various buildings on the campus. This ILC is able to activate the building heating system in such a manner, that energy costs are reduced, with minimal harm to the comfort of building occupants. This is accomplished by curtailing the energy delivered to various zones on the campus that are not occupied, and redistributing the energy to zones where occupancy is high, in a cost-effective manner.

Comments and Recommendations
As Professor Heben discussed the grid modernization effort at the university, and recently demonstrated capabilities to mitigate high-frequency harmonics due to excessive cloud cover on the Scott Park campus, Dr. Boardman inquired if such frequency control tactics could be applied to the Davis-Besse project. Indeed, University of Toledo has the expertise and capabilities to apply frequency regulation as well as load-following strategies to the Davis-Besse project. Several personnel from Davis-Besse including Alan Scheanwald and Robert Garber confirmed that frequency regulation and load following is a significant area where the university could offer substantial contributions.

Later, a major challenge discussed was the power electronics design in fuel-cells. Specifically, the cost of power electronics technologies in fuel cells has been a major hindrance. This cost is typically driven by the size and reliability of the power electronic components. The University of Toledo has developed substantial expertise in reducing the size of next generation power electronic technologies, by using advanced components that allow for smaller cooling equipment, improved high voltage tolerance and more resilience and has expertise in characterization and modeling of these power electronic technologies that have the potential to reduce costs.

6.4. Session 5B: Chemical processes R&D for H₂ technologies and CO₂ management

Jamie Holladay, Manager of Solid Oxide Technology Development, Pacifica Northwest National Laboratory (PNNL)
Dr. Holladay discussed opportunities and challenges to utilizing hybrid nuclear power facilities for production of synfuels. Recycle of CO₂ to fuels or chemicals requires a large amount of low-cost local CO₂ and energy so there are opportunities for nuclear power. The convergence of nuclear power (Davis-Bessie) to provide low cost electricity, nearby abundant high-purity CO₂ from ethanol plants provide opportunity for colocation of processes to convert CO₂ to fuels and chemicals. High and low temperature electrolysis can utilize the abundant nuclear power to produce H₂, syn-gas and syn-products. Low temperature electrolysis is relatively mature and requires minimal R&D investment. High
temperature electrolysis has the promise of reduced capital costs and higher efficiency, thus lower costs, but requires further R&D investments to realize its potential. Three primary take-aways: (i) CO₂ to fuels and products require a large amount of energy, (ii) Nuclear power is well-positioned to provide low-cost energy, hydrogen and thermal energy for recycle of CO₂ to syn-fuels/products, and (iii) detailed techno-economic analysis is necessary to establish the business case.

Todd Brix, CEO, OCO Inc.
Mr. Brix discussed opportunities to address three big challenges including (i) growing renewable electricity mix with high storage cost, (ii) abundant low value CO₂ emissions and (iii) rising electricity generation and transmission costs for power producers and utilities. OCO is commercializing technology that addresses all three challenges by storing electricity in a load-following manner through the direct electrocatalytic reduction of CO₂ for the economic production of formic acid (HCOOH). The formic acid is used as a long-duration ambient condition liquid hydrogen carrier that can be exergonically and endothermally converted back to CO₂ and high-pressure H₂ using several technologies with the recycle of CO₂. There are several fungible applications in direct formic acid fuel cells, dehydrogenation reformers and as a platform building block chemical feedstock. Catalyst development is important but high Faradaic efficiency and selectivity have been already been achieved but the separation processes and supply chain scale are the keys to capital cost reduction. Similar opportunities are available for other specialty chemicals.

Ana Alba-Rubio, Assistant Professor of Chemical Engineering, University of Toledo
Dr. Alba-Rubio discussed the rational design and synthesis of nanomaterials for catalysis and sensing applications with emphasis on the use of H₂ to convert CO₂ into value-added products. Her group is developing dual-function materials for simultaneous capture and hydrogenation of CO₂ into methanol and higher alcohols for use as chemical feedstock and fuels. The necessary H₂ could be obtained from the electrolysis of water using the energy produced in the nuclear plant. In collaboration with Dr. Dong-Shik Kim, she is also developing materials for the detection and scavenging of hydroxyl free radicals. Hydroxyl free radicals are generated in PEM fuel cells, and contribute to the degradation of the membrane, shortening its life. In addition to the sensing properties, this nanomaterial can be used as an excellent scavenger of hydroxyl free radicals to avoid the degradation of the membrane to extend the lifetime of fuel cells.

Glenn Lipscomb, Professor of Chemical Engineering, University of Toledo
Climate change due to emission of greenhouse gases is one of the grand challenges facing society. This presentation discusses the sources of greenhouse gas emissions, the relative importance of carbon dioxide emissions, and approaches to recovery of carbon dioxide from electric power plant flue gas. A major challenge to capture from flue gas or direct from air is the low concentration and pressure of the CO₂. Efforts to identify optimum process designs for a membrane based capture process were highlighted and potential for carbon dioxide removal from air, direct air capture, also were discussed.

Comments and Recommendations
The regional confluence of low-cost electricity, opportunity for a hydrogen source and abundant carbon dioxide from ethanol plants provides significant opportunity for development of processes fuels and chemicals. Challenges associated with the cost of transportation of CO₂ highlighted the importance of consideration of safety and cost in location of facilities and potential advantage of colocation. While focus of work on abundantly available high purity CO₂, there are opportunities for
utilization of flue gas and direct from air sources because of the high cost of shipping. Careful
consideration of locations of facilities and gases transported will be critical for economic
development of specialty chemicals and syn-fuels.

There is a need for improvements in catalysts for chemical conversion and use in electrolyzers. A better
anode material than iridium, which is costly and is available in limited supply, would dramatically
improve economics. Development of separations processes that allow for recovery of chemicals is
important to for competition with existing processes. Specialty chemicals have a relative margin and
are more competitive with existing processes should be the focus of future development. There is a
need for improvements in both high and low temperature electrolyzers to improve durability.

Both low temperature and high temperature electrolysis can be used to generate hydrogen for use in
syn-fuels/products. Low temperature electrolyzer development has been supported by the DOE
enabling the technology to mature. Multiple U.S. companies are scaling-up low temperature
electrolyzers in terms of size and manufacturing ability. High temperature electrolyzers can reduce the
cost of hydrogen by 30% or more compared to low temperature electrolysis. High temperature
electrolysis also offers the ability to do CO₂+steam co-electrolysis at very competitive costs. High
temperature electrolysis needs improvements in materials to increase durability, and protective
coatings, cell size scaleup and manufacturing improvements to realize their potential. Funding to
accelerate the R&D in this area is recommended.
7. Appendices

7.1. Appendix A: Agenda

8:30 am – 10:00 am – Session 1: Welcome and Overview, Nitschke Hall 1027
- Welcome
  Mike Toole, Dean of College of Engineering, The University of Toledo
- NW Ohio Economic Development, Structure, and Opportunities
  Dean Monske, President & CEO, Regional Growth Partnership
- Davis-Besse Hydrogen Production Demonstration Project
  Alan Scheanwald, Strategic Engineering, H2 project Manager, First Energy Nuclear
- Clean Energy Industry Hubs and LWRS Flexible Plant Operations and Generation (FROG) Overview

10:00 am – 10:15 am - Coffee break

10:15 am – 11:45 am - Session 2, Nitschke Hall 1027
- H2@Scale: Opportunities for Hydrogen as an Energy Intermediate
  Mark Ruth, Chief Analyst and Lead for H2@Scale Analysis Team, National Renewable Energy Laboratory
- Hydrogen for Production of Clean Transportation Fuels & Industrial Processes
  Amgad Elgowainy, Senior Scientist/Electrification and Infrastructure Group Leader, Argonne National Laboratory
- Overview of University of Toledo Research
  Patricia Relue, Associate Dean for Research and Graduate Studies, College of Engineering, The University of Toledo

11:45 am – 1:15 pm – Lunch

1:15 pm – 2:15 pm – Session 3: Panel Discussion, Nitschke Hall 1027
H₂ for Industrial Processes - Industry Drive for Clean Energy/Business Opportunities
- Defne Apul, Professor & Chair of Civil & Environmental Engineering, University of Toledo (Panel Facilitator)
- Glenn Lipscomb, Professor, Chemical Engineering, University of Toledo (Panel Facilitator)
- David Hasse, Senior Research Associate, Air Liquide
- Stephen Szymanski, Director of Business Development, Nel Hydrogen
- Ryan Sookhoo, Director of New Initiatives, Hydrogenics - Cummins
- Vincent Chevrier, General Manager, Business Development, Midrex Technologies, Inc.

2:15 pm – 2:30 pm – Break
2:30 pm – 3:30 pm – Session 4: Panel Discussion, Nitschke Hall 1027
H2 for Transportation
- Matt Liberatore, Professor, Chemical Engineering, University of Toledo (Panel Facilitator)
- Kurt Wellenkotter, Senior Manager, Strategic Fuel Cell Business Initiatives, General Motors Corporation
- Tim Terrill, VP, Aftermarket Services NA, Plug Power
- Pat Valente, Executive Director, Ohio Fuel Cell Coalition

3:30 pm – 3:45 pm – Break

3:45 pm – 4:45 pm – Session 5: Concurrent Facilitated Panel/Group Discussions - Process Development R&D Needs and Opportunities
Session 5A: Holistic Energy Systems Evaluation and Optimization, Brady Engineering Innovation Center
- Raghav Khanna, Assistant Professor, Electrical Engineering, University of Toledo (Panel Facilitator)
- Cristian Rabiti, Lead of Energy Systems Modeling and Simulation, Idaho National Laboratory
- Pat Burke, Vice President, Xcel Energy, Inc.
- Scott Swartz, Chief Technology Officer, Nexceris
- Mike Heben, Professor, Physics, University of Toledo

Session 5B: Chemical Processes R&D for H2 Technologies and CO2 Management, Nitschke Hall 1027
- Maria Coleman, Professor & Chair of Chemical Engineering, University of Toledo (Panel Facilitator)
- Michael Young, Assistant Professor, Chemistry, University of Toledo (Panel Facilitator)
- Jamie Holladay, Manager of Solid Oxide Technology Development, Pacific Northwest National Laboratory
- Todd Brix, CEO, OCO Inc.
- Ana Alba-Rubio, Assistant Professor, Chemical Engineering, University of Toledo
- Glenn Lipscomb, Professor, Chemical Engineering, University of Toledo

5:00 pm – 5:30 pm – Session 6: Report Out from Session 5 Group Discussions, Nitschke Hall 1027

5:30 pm – 6:30 pm – Reception and Networking, Nitschke Hall South Lobby
## 7.2. Appendix B: Workshop registrants

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<th>First Name</th>
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<tr>
<td>Hossein</td>
<td>Abedsoltan</td>
<td>PhD Candidate, Chemical Engineering</td>
<td>University of Toledo</td>
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<td>Punkaj</td>
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<td>Manager</td>
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<td>Ana</td>
<td>Alba-Rubio</td>
<td>Assistant Professor, Chemical Engineering</td>
<td>University of Toledo</td>
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<td>Professor/ Chair of Civil &amp; Environmental Engineering</td>
<td>University of Toledo</td>
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<td>Samuel</td>
<td>Babalola</td>
<td>Business Development Manager</td>
<td>Rubitec Solar</td>
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<td>Aaron</td>
<td>Bless</td>
<td>Design Engineer - Electrical</td>
<td>FES - Davis-Besse Nuclear Power Station</td>
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<td>Richard</td>
<td>Boardman</td>
<td>Chief Technology Officer for Integrated Energy Systems Initiatives</td>
<td>Idaho National Laboratory</td>
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<td>Stuart</td>
<td>Bowman</td>
<td>President</td>
<td>Hydrogeneration Inc.</td>
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<td>Tom</td>
<td>Brady</td>
<td>Founder</td>
<td>Plastic Technologies</td>
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<td>Jonathan</td>
<td>Bridges</td>
<td>Director</td>
<td>JobsOhio</td>
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<td>Todd</td>
<td>Brix</td>
<td>CEO</td>
<td>OCO, Inc.</td>
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<td>Linda</td>
<td>Buckosh</td>
<td>Assistant Executive Director</td>
<td>Ohio Fuel Cell Coalition</td>
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<td>Patrick</td>
<td>Burke</td>
<td>VP Strategy</td>
<td>Xcel Energy, Inc</td>
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<td>Frank</td>
<td>Calzonetti</td>
<td>Vice President for Research</td>
<td>University of Toledo</td>
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<td>Joseph</td>
<td>Cappel</td>
<td>VP</td>
<td>Toledo-Lucas County Port Authority</td>
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<td>Vincent</td>
<td>Chevrier</td>
<td>GM - Business Development</td>
<td>Midrex Technologies Inc.</td>
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<td>Eddie</td>
<td>Chou</td>
<td>Professor of Civil Engineering and Director of Transportation Systems Research Lab</td>
<td>University of Toledo</td>
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<td>Sorin</td>
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<td>Maria</td>
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<td>Professor/Chair of Chemical Engineering</td>
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<td>William</td>
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<td>Heben</td>
<td>Professor/ PVIC Director</td>
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<td>Thomas</td>
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<td>Environmental-Energy Writer</td>
<td>The (Toledo) Blade</td>
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<td>Raghav</td>
<td>Khanna</td>
<td>Assistant Professor, Program Director of PT-MS Energy Engineering Program</td>
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7.3. Appendix C: Speaker / panelist biographies

Ana Alba-Rubio is currently an Assistant Professor in the Department of Chemical Engineering at The University of Toledo. She received her doctoral degree from the Institute of Catalysis and Petrochemistry (CSIC) in Madrid, with research focused on base and acid catalysis for the production of biodiesel from vegetable oils. Dr. Alba-Rubio joined the Department of Chemical and Biological Engineering at the University of Wisconsin-Madison to conduct postdoctoral research with Prof. James Dumesic and Prof. Manos Mavrikakis. She focused on the controlled synthesis of metal, bimetallic and bifunctional catalysts for reactions of interest in biomass conversion and the direct synthesis of H₂O₂ from H₂ and O₂. In 2015, she joined the chemical engineering faculty at The University of Toledo. Her current research interests involve the rational design and synthesis of heterogeneous catalysts to provide fuels and materials sustainably, as well as nanomaterials for sensing applications. Dr. Alba-Rubio holds a CAREER award from the National Science Foundation studying the development of dual-function materials for capture and conversion of CO₂ into methanol and higher alcohols.

Defne Apul is a licensed engineer and a professor in the Department of Civil and Environmental Engineering and the Wright Center for Photovoltaics Innovation and Commercialization at The University of Toledo. She leads research on sustainability of food, energy, and water systems. Her research methods include technoeconomic analysis, life cycle assessment, network analysis, and ecosystem modeling. She has published extensively on rainwater harvesting systems and emerging solar cell technologies. Dr. Apul’s current research interests are in solar PV recycling, coastal communities, and urban agriculture.

Todd Brix is the CEO and co-founder of OCO Corporation. OCO is commercializing patented technology to electro-catalytically convert carbon dioxide, using water and intermittent renewable electricity, into formic acid, an intermediate chemical and hydrogen fuel carrier. Prior to OCO, Todd was a partner and general manager at Microsoft leading a succession of internal software/hardware teams to start and grow the IoT, Windows Mobile, and Windows Store product lines into multi-billion dollar businesses. Todd began his career at Chevron Research & Technology as a lead process design engineer focused on catalyst development, process control and performance prediction software, and designing and commissioning 10 different desulfurization and hydrotreating plants in East Asia. Todd earned his BS in Chemical Engineering from the University of Washington, and MBA from Harvard Business School.

Richard Boardman is the Idaho National Lab Chief Technology Officer for Integrated Energy Systems Initiatives. He has led the development of nuclear energy integration with process industries for the past 15 years. He currently leads the Light Water Reactor Sustainability Program development of LWR hybrid power plants and he is the INL Lab Relationship Manger to the Fuel Cell Technology Office. He graduated with a doctorate degree in Chemical Engineering from Brigham Young University with an emphasis in energy and environmental applications. He was employed by Exxon Production Research and Geneva Steel before joining the Idaho National Laboratory in 1990. He is now in his 30th year at the Lab.

Patrick Burke is Nuclear Vice President Strategy for Xcel Energy. He is responsible for the fleet focus on a future of continuous improvement and innovation. Patrick joined the Xcel Energy engineering organization in 1991 at the Monticello nuclear generating facility. He held numerous positions in site engineering and capital projects. After 20 years at Monticello he transitioned to a fleet role as Director Nuclear Projects managing the capital projects and project controls group, capital budgets, rate cases
and project management processes. He served as the Vice President Capital Projects leading the fleet capital projects department as well as dry fuels storage and the corporate outage department. He most recently served as Vice President Engineering and Technical Services responsible for the fleet engineering, capital projects, refueling outages, fuels and dry fuels storage functions. Patrick received his Bachelor of Science degree in Mechanical Engineering from the University of Wisconsin-Madison. He also holds a BWR Senior Reactor Operator certification, is a registered professional engineer in the state of Minnesota, and is a Project Management Professional (PMP) from the Project Management Institute.

Vincent Chevrier is General Manager – Business Development for Midrex Technologies Inc., and is based at the Headquarters in Charlotte, NC. Part of his functions consist of studying of long-term market trends and evolution, which includes hydrogen ironmaking. He earned a B.S. in Chemical Engineering at the Université de Technologie de Compiègne (France), a M.S. in Mechanical Engineering at Virginia Tech (USA) and a Ph.D. in Materials Science and Engineering at Carnegie Mellon University (USA). Dr. Chevrier began his career in the steel industry at IRSID in France (now part of Arcelor-Mittal R&D) in 1992. After obtaining his doctorate, he worked in the melt-shop and scrap yard for J&L specialty Steel in various engineering and management positions. Prior to joining Midrex in 2011, Dr. Chevrier held management positions at Keywell LLC, a leading recycler of high-performance metals. Until his recent transfer to the Commercial Department, Dr. Chevrier was responsible for all innovation, R&D and technology improvements programs for Midrex and was based at the Technology Center in Pineville, NC.

Maria Coleman is a professor and Chair of Chemical Engineering at The University of Toledo and is the Associate Director of the Polymer Institute. The focus of her research group is in three broad areas of research: (i) design, synthesis and processing of polymer nanocomposites, (ii) renewably sourced polymers, and (iii) chemical recycling of mixed plastic waste. Her research has been funded by a variety of federal, state and industrial sources including the National Science Foundation Presidential Faculty Fellowship.

Amgad Elgowainy. Dr. Amgad Elgowainy is a senior scientist and the leader of the Electrification and Infrastructure Group at Argonne National Laboratory. Amgad is co-leading the analysis of the DOE H2@Scale initiative. He conducts techno-economic, energy and environmental analysis of energy systems, alternative fuels, and advanced vehicle technologies. His research work over the past 20 years covers conventional petroleum and natural gas fuels, biofuels, plug-in electric vehicles, and hydrogen fuel cell vehicles. Amgad has authored and co-authored over 200 technical publications.

David Hasse is Senior Research Associate for Air Liquide in Newark, DE. He holds a Bche from U of Delaware and has more than 25 years of R&D experience with Air Liquide. His work centers on membranes and process engineering. He also holds 15 patents.

Mike Heben is the McMaster Chair for Photovoltaics, the Managing Director of the Wright Center for Photovoltaics, and a Professor of Physics at UToledo. He earned a BS in Physics from John Carroll University, an MS in Materials Science and Engineering from Stanford, and a PhD in Chemistry from Caltech. He came to Toledo in 2008 after an 18 year career at NREL. At NREL, he founded and directed for four years a DOE Center of Excellence on hydrogen storage materials. His current interests include the science, manufacturability, and economics of photovoltaics, and the integration of distributed energy resources, buildings, and the electric grid.

Jamie Holladay joined the Pacific Northwest National Laboratory in 2000 and has been working on solving our nation’s energy problems ever since. He is a Chief Engineer and acting manager of the
Advanced Energy Systems Group, and the Sector Manager for the Fuel Cell Technologies Office. Since 1996, Jamie has worked on chemical systems ranging from electrochemical synthesis, fuel cells and batteries to thermochemical processing of methanol, natural gas and emissions reduction. Currently he is researching electrochemical approaches to produce chemicals and fuels, methane conversion to hydrogen and solid carbon, high temperature electrolysis, and magnetocaloric gas liquefaction. Jamie serves as a member of the Hydrogen Production Technical Team for USDRIVE, a government-industry partnership to accelerate the development of affordable clean vehicles, and is part of the DOE’s H2@Scale Initiative for the DOE Fuel Cell Technology Office, where he is on the executive steering committee and is leading the High Temperature Hydrogen Production Thrust. He is the Applied Electrolysis Lead on PNNL’s Chemical Transformation Initiative. Jamie received his B.S. and M.S. in Chemical Engineering from Brigham Young University and his Ph.D. from Washington State University.

Raghav Khanna received B.S., M.S., and Ph.D. degrees in electrical engineering from the University of Pittsburgh in 2007, 2010, and 2014, respectively. He has significant industry experience, including with HRL Laboratories, Malibu, CA, USA, where he was directly involved with the development of GaN-based battery chargers for electric vehicles. In 2015, he joined the Electrical Engineering and Computer Science Department at The University of Toledo. His current research interests include modeling and simulation of wide bandgap semiconductors for applications in next-generation power electronics. He is also conducting extensive research on integration of distributed energy resources with the electric power grid. He recently received grants from the U.S. Department of Defense, U.S Department of Energy, and NASA Jet Propulsion Laboratory to further develop his research activities. In addition to being the student chapter adviser of IEEE at UToledo, Raghav is a member of the Power Electronics Society, Power and Energy Society, and Electron Devices Society.

Matt Liberatore is a Professor in the Department of Chemical Engineering at the University of Toledo. His rheology laboratory specializes techniques in parallel with rheology, including high pressure, light scattering, high shear, and controlled humidity. His current research involves the rheology of complex fluids. Specializing in polymers, colloids, and surfactant systems, projects have examined biomass slurries and solids flows, bio-oils, polyelectrolyte solutions for drag reduction, methane hydrate and ice slurries, emulsions, heavy crude oils, chemical mechanical polishing (CMP) slurries, polymer membranes for fuel cells, and polymer-graphene composites. His educational research interests include studying problem solving of problems inspired by YouTube videos and data analytics from interactive textbook use. He has published over 80 peer reviewed articles and presented numerous invited talks.

G. Glenn Lipscomb is Professor of Chemical Engineering at the University of Toledo. He received a BS from the University of Missouri at Rolla in 1981 and a PhD from the University of California at Berkeley in 1987. Professor Lipscomb worked three years for The Dow Chemical Company developing a second-generation membrane process for nitrogen production from air. In 1989 he joined the University of Cincinnati and moved to Toledo in 1994. Professor Lipscomb served as chair of the Chemical Engineering Department 2004-2019. He is a past Board Member and President of the North American Membrane Society. He is also a past President and current Treasurer of Omega Chi Epsilon, the Chemical Engineering Honor Society. Professor Lipscomb is a member of the Journal of Membrane Science Editorial Board and a Fellow of the American Institute of Chemical Engineers.

Jason Marcinkoski has been at DOE for 14 years working in the hydrogen program. He has developed DOE technical target for stationary applications and vehicles (recently class 8 long haul trucks). More
recently, he has focused on hydrogen production for energy storage, for balancing the grid, and high temperature electrolysis. He is planning to start a 90 detail with Nuclear energy to reinforce collaboration between offices. He has a Master of Science degree in mechanical engineering from the University of Maryland.

**Dean Monske** was named President & CEO of the Regional Growth Partnership (RGP) in 2011 and served as Vice President of RGP from 2006-2009. The RGP is a private, nonprofit development corporation dedicated to fostering local, national, and international economic growth opportunities for northwest Ohio and southeast Michigan. His responsibilities at RGP have included engaging investors in the business community, working with regional partners from both the private and public sector responsible for business retention and expansion, and serving as a face-to-face contact across the country promoting northwest Ohio. Prior to his appointment at RGP, Dean was the Deputy Mayor for External Affairs in the administration of Toledo Mayor Michael P. Bell. His area of responsibility was coordinating the City of Toledo’s economic development efforts. He also served as the Executive Director of the Oregon Economic Development Foundation. Dean is a past board member for the Ohio Tax Credit Authority, past Executive Board member and Region 2 Director for the Ohio Economic Development Association (OEDA) and a past President of the Northwest Ohio Regional Economic Development Association (NORED).

**Cristian Rabiti** is currently the modelling simulation leader for the economical assessment of nuclear hybrid energy systems under several DOE programs and initiatives (Light Water Reactor Sustainability, Integrated Energy Systems, Tri-Lab initiative). Since 2008, he has worked at the Idaho National Laboratory where he has led several modelling and simulation efforts in the area of nuclear engineering. Before joining INL, he was a staff engineer at Argonne National Laboratory where he worked on the implementation of 3-Dimensional neutron transport codes for the UNIC project. Dr. Cristian Rabiti received an MBA in 2010 from IE Business School and a Ph.D. in Mechanical Engineering in 2006 from the University of Stuttgart (Germany).

**Patricia Relue** is a Professor of Bioengineering and Associate Dean for Research and Graduate Studies in the College of Engineering. She received her BS from the University of Toledo and her PhD from the University of Michigan, both in chemical engineering. She has been at UToldeo since 1993. Her research interests include tissue engineering, microscopy and imaging, fermentation, and utilization of biomass for production of fuels and chemicals. She also has interests in mathematical modeling of chemical reaction and transport in complex systems and non-invasive detection and measurement of metabolites and compounds.

**Mark Ruth** is the Manager of the Industrial Systems and Fuels Group in the Strategic Energy Analysis Center at the National Renewable Energy Laboratory, NREL, in Golden, Colorado. In this role, Mark is leading the multi-laboratory effort to analyze the potential of H2@Scale. Mark has also led an effort to analyze optimal configurations and operation of tightly coupled nuclear-renewable hybrid energy systems and is leading other analyses that are focused on identifying potential synergies between nuclear and renewable energy sources. Mark is also leading a number of analyses that may impact the industrial sector including ones on the potential for advanced combined heat and power technologies to benefit the grid. Over Mark’s 26 years at NREL, he has an extensive history of developing methods to value opportunities in the energy sector as well as technical analyses of hydrogen and bioenergy systems.

**Alan Scheanwald** received his Bachelor of Science from The Ohio State University where he majored in Mechanical Engineering and minored in Nuclear Engineering. Alan currently works as a Project Manager
in the Strategic Engineering department at the Davis-Besse Nuclear Power Station. He has worked at Davis-Besse since 2011 and has been in his current role since 2014. Alan is the Project Manager for the Light Water Reactor Integrated Energy Systems Interface Technology Development & Demonstration.

**Ryan Sookhoo** is the Director New Initiatives at Hydrogenics Corporation. Since joining Hydrogenics in 2006 as Project Manager for PEM fuel cell development and commercialization, he has been a dedicated member of the research and development program. In his current role, Ryan is fortunate to be involved in the early stages of new technology adaptation. As a leader in hydrogen generation and fuel cell industries, Hydrogenics has given Ryan the opportunity to work with various industries and help to define many of tomorrow’s energy and power solutions. Ryan holds a Bachelor in Electrical Engineering.

**Scott L. Swartz** is the Chief Technology Officer and a co-founder of Nexceris. Dr. Swartz led Nexceris’ early technology development activities, resulting in Nexceris’ emergence as one of the premier technology providers in the areas of solid oxide fuel cells, sensors and related technologies. He currently is focused on managing SOFC technology development projects, leading government business development, managing Nexceris’ intellectual property portfolio, and providing technical leadership and vision to the company. Dr. Swartz holds a B.S. in Ceramic Engineering from Alfred University and a Ph.D. in Solid State Science from The Pennsylvania State University. His previous affiliations include Battelle Memorial Institute and Mission Research Corporation. He has authored more than 60 papers in the technical literature and has received 20 U.S. patents.

**Stephen Szymanski** is Director of Business Development at Nel Hydrogen, with more than 29 years of technical and business development experience in the fields of specialty chemicals and hydrogen system solutions. In this role, he is responsible for developing strategic relationships and project opportunities for Government and emerging market applications for PEM and alkaline electrolysis. In addition to managing Nel’s Navy submarine business activity, he also has primary market responsibility for the hydrogen fueling and renewable energy storage sectors in North America. His previous experience includes several years as an engineer in the PEM technology group at United Technologies. In this position, he supported the development of PEM electrolyzer and fuel cell technology for space and defense applications. After moving into technical sales and sales management at Buckman Laboratories, Steve joined Nel to support the commercialization and market development efforts for its PEM electrolyzer technology. In addition to his primary responsibilities, Steve also serves on the Board of Directors and as Vice Chair of the California Hydrogen Business Council, as a Board Member and Secretary of the Ammonia Energy Association, and as Chairman of the Board of Governors for the Connecticut Hydrogen Fuel Cell Coalition. He has a Bachelor of Science in Chemical Engineering from Cornell University and a Master of Science in Operations Management from Rensselaer Polytechnic Institute.

**Tim Terrill** is Vice President of Aftermarket Services at Plug Power. He has been with Plug Power for over 11 years and works at Plug Power’s office in Dayton, Ohio.

**T. Michael Toole** is the Dean of the College of Engineering at the University of Toledo. Previous employment includes serving as a Professor of Civil and Environmental Engineering at Bucknell University, a director in a multidisciplinary engineering firm, and a commissioned officer in the U.S. Navy Civil Engineer Corps. Mike received a B.S. from Bucknell and a Masters and Ph.D. from M.I.T. He is a professional civil engineer, a Fellow in the American Society of Civil Engineers, the Chair of the Ohio Engineering Deans Council, and hosts www.designforconstructionsafety.org. His research has focused on construction innovation and construction safety.
**Pat Valente**, Executive Director of the Ohio Fuel Cell Coalition, is a leading proponent of Ohio’s fuel cell industry. Pat was appointed Executive Director of the OFCC in 2008. This appointment represents the OFCC Board of Directors' commitment to maximizing Ohio’s industry leadership, fostering active participation in collaborative opportunities, and increasing awareness of Ohio’s industry cluster through advocacy and marketing outreach. Valente’s career has included serving as Deputy Director and Assistant Deputy for the Ohio Department of Development’s Technology and Economic Development Divisions. Valente is one of the key architects of the nationally recognized Third Frontier Program and has been the leading advocate for the development of Ohio’s fuel cell industry. He also has played an instrumental role in the success of the Entrepreneurial Signature Program (ESP) to foster collaboration and change for regional economic and development entities.

**Kurt Wellenkotter** is Senior Manager of Strategic Fuel Cell Business Initiatives at General Motors Corporation, based in Michigan. He has a Master’s degree in engineering from Michigan Technological University.
7.4. Appendix E: Key references


