CHBC BRIEFING: HYDROGEN RAIL PROJECT SHOWCASE

MAY 19, 2021
WEBINAR SPEAKERS

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Development Specialist  
California Hydrogen Business Council

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Senior Consultant - Sustainable Motive Power & Zero-Emission Technologies  
DB Engineering and Consulting USA

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Market Development Manager, US  
Ballard Power Systems

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Sierra Railroad / Sierra Energy

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Office Chief, Equipment and Assets  
Caltrans
HOUSEKEEPING

- **Two Audio Options: Streaming Audio and Dial-In.**
  - Streaming Audio/Computer Speakers (Default)
  - Dial-In: Use the Audio Panel (right side of screen) to see dial-in instructions. Call-in separately with your telephone.

- **Question & Answers**
  - Ask questions using the Questions Panel on the right side of your screen.

- **Recording & Slides**
  - The recording of the webinar and the slides will be available after the event. Registrants will be notified by email.

- **Troubleshooting**
  - Contact Peter Thompson | pthompson@californiahydrogen.org
Our Vision:
- CHBC is committed to advancing the commercialization of hydrogen in the energy and transportation sectors to achieve California’s climate, air quality, and decarbonization goals.

Our Mission:
- Provide clear value to our members and serve as an indispensable and leading voice in promoting the use of hydrogen in the utility and transportation sectors in California and beyond.

Our Principals:
- Leadership, Integrity, Teamwork and Inclusion.

Our Objectives:
- Enhance market commercialization through effective advocacy and education of policymakers and policy influencers
- Be “the” trusted “go to” resource on Hydrogen and Fuel Cell technology for policymakers and policy influencers
- Accelerate market growth via networking opportunities and information exchange for the industry and its customers
OUR MEMBERS

Platinum

Gold
VALUE IN MEMBERSHIP

- Active representation in all relevant California policy making venues
- A trusted and knowledgeable industry resource
- Access to policymakers, policy influencers and industry
- Track record of success
- Platform for industry collaboration
- Learn more: www.californiahydrogen.org

BECOME A MEMBER AND MAKE A DIFFERENCE
TOGETHER WE CAN INFLUENCE PUBLIC POLICY AND GROW YOUR BOTTOM LINE
NEXT UP:

Lynn Harris
Senior Consultant - Sustainable Motive Power & Zero-Emission Technologies
DB Engineering and Consulting USA
DB Group
Deutsche Bahn

Around 13 million passengers a day on trains and buses in Germany and Europe

On weekdays over 1 million metric tons of goods by rail in Germany and Europe

On 33,400 kilometers more than 25,000 bridges and 740 tunnels in the railway network of the DB

On 33,400 kilometers more than 25,000 bridges and 740 tunnels in the railway network of the DB

5,700 stations in Germany

26,000 buses worldwide

Around 7,600 locomotives and multiple units worldwide

320,000 employees worldwide

74 maintenance facilities in Germany

More than 23,000 trains a day

More than 23,000 trains a day

Around 13 million passengers a day on trains and buses in Germany and Europe

Around 13 million passengers a day on trains and buses in Germany and Europe

"Deutsche Bahn" is German for "German Railway"

Data as of March 2020

DB Engineering & Consulting USA, Inc. | May 2021
DB Engineering & Consulting USA leverages the expertise of the world’s largest integrated transportation operator, improving the quality of life in the U.S. by introducing sustainable mobility solutions.
Greenhouse gases (GHG) contribute to climate change and criteria air pollutants (CAP) pose a high risk to people’s health.

GHG:
- CH₄
- N₂O
- CO₂
- Fluorinated gases
- H₂O

Increases:
- allergies
- airborne carcinogens
- lung irritation
- risk of premature death
- ...

CAP:
- NOₓ
- PM
- HC
- CO

(1) 90th Percentile AQI per county, 2019

DB Engineering & Consulting USA, Inc. | May 2021
**History of hydrail**

A selection of milestones

**Global Hydrail initiative** (A)
- First international Hydrail conference, since then annually
- Initiated in the US, events world-wide

**BNSF Project** (C)
- First hydrail switcher as proof-of-concept
- Locomotive built by Vehicle Projects

**CRRC** (E)
- First commercial operation of high-speed rail vehicle /tram

**Alstom iLINT** (C)
- First commercial regional hydrail multiple unit

**NC DOT** (4C)
- Hydrail study
- Piedmont passenger: from diesel to hydrail

**SBCTA & Stadler** (G)
- First commercial hydrail in the US
- Anticipated service in 2024

**Vehicle Projects**
- Mining locomotive (B)
  - First hydrail vehicle globally
  - Built in the US, demonstrated in Canada

**JR East & RTRI** (D)
- Technology demonstration in multiple units/railcars

**TIG/m Modern Street Railway** (F)
- First commercial operation of hydrail streetcar/tram

**5 Commercial mining locomotives** (B)
- Built in the US by Vehicle Projects and operated in South Africa

**BCRRE** (3C)
- First practical hydrail locomotive in Europe

**H2goesRail** (H)
- Anticipated trial operation in 2024
- Siemens Mireo Plus H

(1) Fuel cell Propulsion Institute, predecessor to Vehicle Projects  
(2) Railway Technical Research Institute  
(3) Birmingham Centre for Railway Research and Education  
(4) North Carolina Department of Transportation  
Illustration Source: (A) Global Hydrail Initiative, (B) Vehicle Projects, (C) Andreas Hoffrichter, (D) RTRI, (E) XinhuaNet, (F) TIG/m, (G) SBCTA, (H) H2goesRail

DB or DB E&C USA team member involvement

DB E&C USA team member emission assessment contributions
Current Worldwide Hydrail Projects

Canada
- Canadian Pacific, AB
- Southern Railway of British Columbia, BC

USA - California
- SBCTA
- TIG/m
- Caltrans
- Sierra Northern

Spain
- Talgo
- X'Trapolis

Germany
- iLINT
- H2goesRail, Siemens & DB

United Kingdom
- HydroFlex, BCRRE & Porterbrook
- Breeze, Alstom & Eversholt
- Vivarail

Austria
- iLINT
- HyTrain
- Switcher

Japan
- JR East, Hitachi & Toyota

South Korea
- KRRI² & Hyundai
- KRRI mainline locomotive

China
- CRRC tram
- CRRC Switcher

Source: DB research, as of Spring 2021
(1) Alstom Coradia iLint 2-car multiple unit in commercial operation in 2018
(2) Korea Railroad Research Institute

DB Engineering & Consulting USA, Inc. | May 2021
California is the leader in hydrail efforts in North America with three large ongoing projects

**CA regulations**
- Off-road vehicles, including rail, are required to be ZE\(^1\) by 2035 according to EO N-79-20
- CARB proposes a spending account for rail emission
- Overall CA targets to reduce GHG by 80\(^%\)\(^2\) by 2050, carbon neutral by 2045
- Significant hydrogen efforts for other transportation modes and power generation in CA

**On going hydrail projects in CA:**
- Caltrans plans to transition their fleet to hydrail
- San Bernardino County Transportation Authority (SBCTA) has ordered the first commercial hydrail vehicle in the country
- Sierra Northern Railway is rebuilding a switcher to hydrogen power

(1) zero-emission
(2) compared to 1990 levels
THANK YOU!
If you have any questions, please feel free to reach out.

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NEXT UP:

Tim Sasseen
Market Development Manager, US
Ballard Power Systems
Fuel Cell Innovators for Over 40 Years

An introduction to Ballard and our unique value proposition
Global decarbonization is putting the focus on hydrogen

The fight against climate change and air pollution is driving the demand for fuel cell technology that converts hydrogen in clean electricity.

Hydrogen is a flexible energy carrier and fuel:

- in cars, trucks, buses, trains and ships
- in industry and for critical infrastructure
Hydrogen powered trains are poised to disrupt the rail industry

The environmental gains of electrification with performance and refueling time comparable to diesel

- Long range and route flexibility
- Short refueling time
- Cost effective route electrification
Nearly any train route served by diesel trains can be served by a hydrail train

- Suitable applications include multiple units for regional passenger service and locomotives for shunting or freight.
- No requirement for overhead catenary infrastructure and power substations
- Enables gradual electrification (one train at the time) aligned with budget availability
A fuel cell acts like a battery cell, but you feed it hydrogen instead of charging.

Hydrogen from water or renewable natural gas

Electrical Load
Motor inverter or grid power

Oxygen, from the air

Heat

Water out
We continuously invest in our technology and product development

Unit cell components
MEA, bipolar plates

Fuel cell stacks
14th generation

Fuel cell modules
8th generation

Fuel cell vehicle integration
application engineering/ after sales service

Humidified and pressurized system

Freeze-start from -25°C

IP67 protection

>30,000 hours life time
Case Study: Foshan Gaoming Modern Hydrogen Tram Line

- Agreement with CRRC Sifang to develop 5 fuel cell trams
- Each roof top mounted system is powered by two FCveloCity®-XD fuel cell modules
  - Robust design is weight and noised optimized, with easy service access and built-in fire suppression systems
- Six onboard hydrogen cylinders provide a range of 125 kilometers between refueling
- Maximum speed of 70 kilometers/hour
- Tram line began service in December 2019
  - Has operated >7,400 hours and >73,000 kilometers as of Aug 2020
Case Study: Siemens Rail Module Development

• Multi year agreement to develop a fuel cell system for Siemens Mireo® regional commuter train

• Roof top mounted system that leverages Ballard’s FCmove™ module with optimized weight and footprint for maximum range

• Prototype module expected to be delivered in September 2021

• Achievements:
  • Freeze start from -25°C
  • Peak efficiency >55%
  • Peak power >200 kW
  • Incorporates rail standards
  • Incorporates Ballard’s long life FCgen®-LCS fuel cell stack technology and advanced balance of plant

• Siemens is offering Mireo® fuel cell powered trains to customers
Case Study: Sierra Northern Rail Switching Locomotive

• Sierra Northern Rail will build and deploy a hydrogen-powered switching locomotive, working with Railpower Tech, Optifuel and Ballard
• The fuel cells will work with battery technology to power the locomotive's electric traction motors
• Two 100-kilowatt fuel cell modules will deliver 200kW of electricity to power the locomotive
• Switching locomotives have been identified as the largest contributors to emissions in rail by CARB
Case Study: CP Hydrogen Locomotive Program

- CP will develop North America’s first hydrogen-powered line-haul freight locomotive by retrofitting a formerly diesel-powered locomotive with Ballard hydrogen fuel cells
- The fuel cells will work with battery technology to power the locomotive's electric traction motors
- Six 200-kilowatt fuel cell modules will deliver 1.2 MW of electricity to power the locomotive
- Nearly the entire freight locomotive fleet of all railway operators in North America consists of diesel-powered units, representing the industry's most significant source of greenhouse gas emissions
Buses powered by Ballard

- Over 1,000+ buses deployed are powered by Ballard
- Multiple bus platforms with OEMs in Europe, US and China
- Over 25 million kilometers in service
- > 30,000 hours fuel cell stack life demonstrated
Trucks powered by Ballard

- Over 2,200 urban delivery trucks (3 to 9 tons) in service in China
- Class 8 demonstration truck at Port of Long Beach
- UPS class 7 trucks for California
- 60t truck demonstration project – Alberta
- Refuse trucks in Europe
- Mining trucks in China and South Africa
Ballard Marine Projects in Europe

- Megawatt scale systems for cruise ships with ABB
- HySeas III, the world’s first sea-going renewables-powered ferry
- Hjelmland ferry in Norway
- FLAGSHIPS project to power:
  - Norled ferry in Norway
  - River barge in France (ABB)
- ELEKTRA fuel cell river barges in Germany
Cost effective route electrification

“The hydrogen train is already more competitive than electric catenary for a use case with relatively long distance and low frequency.”

*Hydrogen Council, 2020*
Ballard by the Numbers

- 42 years
- 900 employees
- 1,400 patents & applications
- Publicly listed Company
- 4 strategic shareholders
- 1,000+ transit buses
- 2,200+ trucks
- 5 train projects on track
- 6 ships in development
- 850 MW fuel cell products delivered
- >6.5 million MEAs produced
- >75 million kilometers in operation
- >35,000 hours operation of fuel cell stack in London buses
- 2030 commitment to carbon neutrality
FCmove™
8th generation fuel cell power module

- 35% reduction in total life cycle cost
- 40% reduction in product volume
- >30,000 hr operating lifetime
- 50% reduction in number of components
- 35% reduction in product weight
- -25°C freeze start capability
- Fuel cell stack is recyclable
Introducing FCwave™

The future of zero-emission marine vessels
FCwave™ Modular Installation Layout
Thank you

Please contact Ballard for more information

Tim.Sasseen@ballard.com

www.ballard.com

Power to Change the World®
Hydrogen is most competitive in heavy duty motive applications

Our focus is on applications where hydrogen fuel cells have a clear advantage

Buses & Coaches  Trucks  Trains  Vessels

Fuel cell technology is needed to decarbonize the heavy duty transportation sector
Addressing the cost reduction challenge:

Ballard's road map to 70% cost reduction

- **Strategic industrial partnerships**: will accelerate fuel cell industrialization and integration
- **Supply chain**: partnership with Mahle will increase access to the automotive supply chain
- **Ballard’s cost reduction initiatives**: include 6x increase in manufacturing capabilities through continuous manufacturing automation
- **Recycling/refurbishments**: will increase lifecycle and improve FCEV residual value
Today we have three platforms of liquid cooled stacks to address mobility applications.

<table>
<thead>
<tr>
<th>Power Level</th>
<th>Features</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 29kW/stack</td>
<td>- &gt;10,000 stacks produced&lt;br&gt;- 15,000hrs&lt;br&gt;- 2.2kW/L&lt;sup&gt;*&lt;/sup&gt;&lt;br&gt;- Operating 70°C</td>
<td>Mobility Stack</td>
</tr>
<tr>
<td>up to 96kW/stack</td>
<td>- &gt;25,000hrs&lt;br&gt;- 4.5kW/L&lt;sup&gt;*&lt;/sup&gt;(M2)&lt;br&gt;- Freeze start (-30°C)&lt;br&gt;- Operating 80°C</td>
<td>Heavy-Duty Stack</td>
</tr>
<tr>
<td>Up to 140 kW/stack</td>
<td>- Stack technology demonstration platform&lt;br&gt;- 4.3kW/L&lt;sup&gt;*&lt;/sup&gt;&lt;br&gt;- Freeze start (-28°C)&lt;br&gt;- Operating &gt;90°C</td>
<td>High Power Stack</td>
</tr>
</tbody>
</table>

* Power density excluding compression hardware
HyZET Hydrogen -Powered Tug Design Study

- CEC funded project with Ballard, ABB, DNV-GL, Crowley/Jensen, Chart Industries
- 90’ Tug with 5MW propulsion, 1.2MW fuel cell + 800kWh battery
- Liquid hydrogen fuel
- Design to assess optimal drive configuration, leading to a ready-for-manufacture design
### Ballard’s current fuel cell module offering for HD mobility

<table>
<thead>
<tr>
<th>Power Level</th>
<th>Features</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>30, 85 &amp; 100 kW</strong>&lt;br&gt;Legacy Mobility Platform (7th generation)</td>
<td>▪ &gt;1,500 modules produced&lt;br&gt;▪ 15,000hrs&lt;br&gt;▪ IP 55&lt;br&gt;▪ Air and cooling kits</td>
<td><img src="image1" alt="Bus" />, <img src="image2" alt="Train" />, <img src="image3" alt="Truck" /></td>
</tr>
<tr>
<td><strong>70 &amp; 100 kW</strong>&lt;br&gt;HD Mobility Engines (8th generation)</td>
<td>▪ &gt;25,000hrs&lt;br&gt;▪ Freeze start (-25°C)&lt;br&gt;▪ Engine bay and roof top&lt;br&gt;▪ IP6K9K</td>
<td><img src="image4" alt="Van" />, <img src="image5" alt="Truck" /></td>
</tr>
<tr>
<td><strong>200kW</strong>&lt;br&gt;HD Power System Marine &amp; Rail</td>
<td>▪ &gt;25,000hrs&lt;br&gt;▪ Marine certified&lt;br&gt;▪ Cabinet configuration&lt;br&gt;▪ Stand alone or containerized&lt;br&gt;▪ Multiple modules to MWs</td>
<td><img src="image6" alt="Ship" />, <img src="image7" alt="Train" /></td>
</tr>
</tbody>
</table>
As Result of ICT Planning, there is Growing Demand for FCEBs

First 18 ICT plans approved by CA transit agencies as of Jan 2021 shows that:

- 24% of all ZEBs deployed will be fuel cell electric buses
- 46% will be battery electric
- 30% will be decided by performance

This represents an opportunity for 2,800 to 6,500 fuel cell electric buses in service, or 71 to 163 tons per day of renewable hydrogen consumption
Trains powered by Ballard

- Light rail systems in China
  - with OEM partner CRRC (Goaming, China)
  - light rail in passenger service since January 2020
- Development project underway with Siemens for hydrogen EMU (MIREO)
- Hydroflex retrofit project in UK with EMU – Porterbrook
- Scottish Rail project UK – EMU retrofit
- North America’s first hydrogen-powered line-haul freight locomotive
- Sierra Northern Railway switching locomotive
Fuel Cell Electric Buses are Spreading Across US
Fuel cell system generates power onboard the bus

Fuel cell power modules provide 30kW - 100kW of DC power for the transit bus powertrain.

Generate electricity from air and hydrogen to recharge batteries and power the electric drive.

Ballard has produced over 1,500 power modules for buses and trucks.
A fuel cell acts like a battery cell, but you feed it hydrogen instead of charging

Each fuel cell power module provides 30kW - 200kW of DC power for the powertrain.

Generates electricity from air and hydrogen to recharge batteries and power the electric drive.

Ballard has produced over 1,500 power modules for buses and trucks.
NEXT UP:

Carrie Schindler
Director of Transit and Rail
San Bernardino County Transportation Authority
NEXT UP:

Carrie Schindler
Director of Transit and Rail
San Bernardino County Transportation
Carrie Schindler, PE
Director of Transit & Rail
Redlands Passenger Rail / Arrow

Metrolink connects to:
- Los Angeles
- Orange County
- San Diego

San Bernardino Santa Fe Depot
San Bernardino Transit Center
Tippecanoe Ave. Station
New York St. Station
Downtown Redlands Station

4 BRIDGE REPLACEMENTS
9 MILES OF TRACK REPLACEMENT
26 GRADE CROSSINGS
Performance and Energy Usage Modeling

Primary inputs
- Vehicle characteristics (mass, loading condition, tractive & braking curves, rotating inertia, electrical efficiencies and auxiliary loads)
- Track characteristics (distances, grades, curves, speed limits and restrictions)

Applications
- Quantify key requirements – power charge/discharge rates and energy storage capacity
- Assess technology feasibility
Energy Usage & Modeling Scenarios

Scenario 1: 2-Car FLIRT H₂

Scenario 2: 4-Car FLIRT H₂

Scenario 3: 2-Car FLIRT H₂ + 2-Car FLIRT DMU

Dimensions:
- 2-Car FLIRT H₂: 50 m
- 4-Car FLIRT H₂: 81 m
- 2-Car FLIRT H₂ + 2-Car FLIRT DMU: 100 m
<table>
<thead>
<tr>
<th>Journey (Round Trip)</th>
<th>Section Length (Miles)</th>
<th>Energy Between Terminals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Scenario 1 2-Car ZEMU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scenario 2 4-Car ZEMU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scenario 3 2-Car + 2-Car</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Regen. Braking (kWh)</td>
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<tr>
<td></td>
<td></td>
<td>With Regen. Braking (kWh)</td>
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<tr>
<td></td>
<td></td>
<td>No Regen. Braking (kWh)</td>
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<tr>
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<td>With Regen. Braking (kWh)</td>
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<td></td>
<td></td>
<td>No Regen. Braking (kWh)</td>
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<tr>
<td></td>
<td></td>
<td>With Regen. Braking (kWh)</td>
</tr>
<tr>
<td>Redlands - SBTC</td>
<td>17.8</td>
<td>236</td>
</tr>
<tr>
<td></td>
<td></td>
<td>173</td>
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<td></td>
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<td>338</td>
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<td>339</td>
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<td>216</td>
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<tr>
<td>SBTC - LA</td>
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<td>1492</td>
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<td></td>
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<td>1497</td>
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<td>2083</td>
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<td></td>
<td>1579</td>
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<tr>
<td>Redlands – LA</td>
<td>133.0</td>
<td>1728</td>
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<td>1342</td>
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<td>2422</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1794</td>
</tr>
</tbody>
</table>
Selection of Preferred Technology

Cost (20%)  
Capital, Operations & Maintenance

Infrastructure (10%)  
Right-of-Way, Charging & Fueling, Utilities

Environmental (15%)  
Land use, GHGs, Aesthetics, Noise, Socio-Economic

Operations (25%)  
Range, Scalability, Reliability, Operations, Life Span

Regulatory Compliance (10%)  
FRA, NFPA, CPUC

Implementation Schedule (10%)  
Timeline for Planning, Design, Construction phases

Risk Analysis (10%)  
Identify and document risks for further analysis
# High Level Pre-Screening

<table>
<thead>
<tr>
<th>Category</th>
<th>Baseline – Arrow DMU</th>
<th>Wayside Power Supply</th>
<th>On-Board Energy Storage System</th>
<th>Hybrid System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail Technology</td>
<td>Diesel</td>
<td>Overhead Contact System (OCS)</td>
<td>Battery</td>
<td>Super capacitor</td>
</tr>
<tr>
<td>Relative Capital Costs</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Moderate</td>
</tr>
<tr>
<td>Relation Life Cycle Cost</td>
<td>Moderate/ Poor</td>
<td>Good/Moderate</td>
<td>Good/Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>GHG Emissions</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Good</td>
<td>Poor</td>
<td>Moderate</td>
<td>Good</td>
</tr>
<tr>
<td>Range</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Moderate</td>
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<tr>
<td>Scalability</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Moderate</td>
</tr>
<tr>
<td>Life Span</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
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<tr>
<td>Regulatory Compliance</td>
<td>Good</td>
<td>Moderate</td>
<td>Poor</td>
<td>Moderate</td>
</tr>
<tr>
<td>Result</td>
<td>Baseline</td>
<td>Incompatible</td>
<td>Incompatible</td>
<td>Compatible</td>
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### 2-Car Vehicle Characteristics

<table>
<thead>
<tr>
<th>Powertrain Configuration</th>
<th>HFC Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (tonnes)</td>
<td>132</td>
</tr>
<tr>
<td>Max. Power at Wheels (kW)</td>
<td>700</td>
</tr>
<tr>
<td>Powerplant Power (kW)</td>
<td>300</td>
</tr>
<tr>
<td>Average Duty Cycle Powerplant Efficiency (%)</td>
<td>49</td>
</tr>
<tr>
<td>Battery Power (kW)</td>
<td>828</td>
</tr>
<tr>
<td>Battery Capacity (kWh)</td>
<td>138</td>
</tr>
<tr>
<td>Battery Charging Efficiency (%)</td>
<td>86</td>
</tr>
</tbody>
</table>

### Mass & Volume of Powertrain Types for 16 hour Service Day

<table>
<thead>
<tr>
<th>Powertrain Type</th>
<th>HFC Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel Cell System</strong></td>
<td></td>
</tr>
<tr>
<td>Power (kW)</td>
<td>300</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>825</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Hydrogen Tanks</strong></td>
<td></td>
</tr>
<tr>
<td>Pressure (bar)</td>
<td>350</td>
</tr>
<tr>
<td>Hydrogen stored (kg)</td>
<td>220</td>
</tr>
<tr>
<td>Mass of tanks and hydrogen (kg)</td>
<td>3,150</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>16.5</td>
</tr>
<tr>
<td><strong>Battery System</strong></td>
<td></td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>4,000</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>7,975</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>22</td>
</tr>
</tbody>
</table>

- Runtime performance will be equivalent to the DMU
- Required hydrogen storage and powertrain components could be installed on 2-car vehicle with potentially only daily refueling
## Battery vs. Hydrogen Fuel Cell Hybrid

<table>
<thead>
<tr>
<th></th>
<th>Battery</th>
<th>Hydrogen Fuel Cell Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traction Power Substation (TPSS)</td>
<td>$29 M</td>
<td>$33 M</td>
</tr>
<tr>
<td>Wayside Energy Storage System (WESS)</td>
<td>$31 M</td>
<td>$33.8 M</td>
</tr>
<tr>
<td>On-Site Steam Methane Reforming</td>
<td>$33 M</td>
<td>$34.6 M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Battery</th>
<th>Hydrogen Fuel Cell Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual O&amp;M Cost (to operate full ZEMU Arrow service 2 vehicles)</td>
<td>$769 K</td>
<td>$1.2 M</td>
</tr>
<tr>
<td>Annual O&amp;M Cost (to operate full ZEMU Arrow service 2 vehicles)</td>
<td>$690 K</td>
<td>$540 K</td>
</tr>
<tr>
<td>On-Site Electrolysis</td>
<td>$856 K</td>
<td>$856 K</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emissions Reduction (Percentage in Comparison to DMU Benchmark)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>60% ↓</td>
</tr>
<tr>
<td>75% ↓</td>
</tr>
<tr>
<td>98% ↓</td>
</tr>
<tr>
<td>97% ↓</td>
</tr>
<tr>
<td>93% ↓</td>
</tr>
<tr>
<td>90% ↓</td>
</tr>
</tbody>
</table>

*EMISSIONS LEGEND:
- Energy
- GHGs
- NOx
- PM2.5
- PM10
- CO

June 2019
Key FRA elements

- Crashworthiness
- Fire safety
- Inspection
- Vehicle Maintenance
- Record keeping
Key areas of research needs:

- Life cycle costs as compared to other alternative fuels
- Hydrogen storage – ways to increase capacity and flexibility
- Cost reduction regarding renewable hydrogen
- Maintenance facility design – best practices for building facilities of the future
- Component durability and impact resistance (e.g. FRA testing of an LNG tender car)

www.goSBCTA.com  
909.884.8276  

@goSBCTA
NEXT UP:

Mike Hart

CEO
Sierra Railroad / Sierra Energy
Advancing Hydrogen Rail in California
Sierra Northern Railway and California Rail

- Sierra Northern Railway (SNR) operates 160+ miles of track in California and owns 37 switcher locomotives
- There are 260 Switcher locomotives operating in California
- More than 500 long-haul locomotives operate in the State

Source: CA.gov

Map of California Rail Lines
$8 Million for H2Rails Demonstration

The California Energy Commission has awarded $8 million to build and test H2 locomotive and multi-modal fueling station

- **$4M for SNR** to design and build a H2 locomotive demonstrating integration of advanced H2 fuel cell, H2 storage, advanced battery, and systems control technologies

- **$4M for Shell** to develop a multi-purpose H2 fueling station to support locomotives and on-road vehicles, including high-flow H2 dispensing equipment and fueling protocol

- **Project partner, Shell**, commits to building first H2 fueling facility for rail use to be built at the Port of West Sacramento.
Sierra Northern, is converting a diesel locomotive with a zero-emissions H2 locomotive.

- H2 locomotives have **greater energy efficiency** (1.8x) and **lower long-term maintenance costs** (25%) compared to diesel locomotives.

- H2 prices are relatively **stable** vs. diesel costs fluctuate based on economic conditions.

- **2,550 MT CO2** displaced per locomotive over lifetime, in addition to air pollution reductions.
### California Energy Commission grant funding for H2 Locomotive Project

<table>
<thead>
<tr>
<th>Partner</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTI</td>
<td>Formal applicant to California Energy Commission &amp; Hydrogen safety plan and design review</td>
</tr>
<tr>
<td>Railpower Technologies Corp</td>
<td>Locomotive controls/electronics design. Locomotive design and analysis. System integrator.</td>
</tr>
<tr>
<td>Ballard®</td>
<td>Manufacture of fuel cell technology</td>
</tr>
<tr>
<td>SoCalGas</td>
<td>Funding Partners and Technical Advisory Committee Members</td>
</tr>
<tr>
<td>Sierra Energy</td>
<td>Future: Gasification technology to convert waste into renewable hydrogen</td>
</tr>
<tr>
<td>Demonstration site owner and operator. Construction and testing of locomotive. Commercialize of locomotive technology.</td>
<td></td>
</tr>
<tr>
<td>Manufacture of locomotive modules. Analysis and integration.</td>
<td></td>
</tr>
<tr>
<td>Operational analysis of the demonstration locomotive</td>
<td></td>
</tr>
<tr>
<td>Fueling station for H2 locomotive</td>
<td></td>
</tr>
<tr>
<td>Provide analysis of impacts and out to disadvantage community surrounding Port of West Sacramento.</td>
<td></td>
</tr>
</tbody>
</table>
Zero-emission H2 locomotives provide meaningful health and carbon benefits

- Significant decrease in criteria pollutants contributing to air pollution from displacing diesel
- Noise reduction due to H2 locomotives emitting zero noise or vibration from power generation

<table>
<thead>
<tr>
<th>Emissions Displaced with Zero-Emission Locomotive</th>
<th>PM 10</th>
<th>HC</th>
<th>NOx</th>
<th>CO</th>
<th>CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Savings (lbs)</td>
<td>147</td>
<td>338</td>
<td>4,222</td>
<td>613</td>
<td>225,000</td>
</tr>
<tr>
<td>Lifetime Savings (lbs)*</td>
<td>1,031</td>
<td>2,356</td>
<td>29,530</td>
<td>4,288</td>
<td>1,574,229</td>
</tr>
</tbody>
</table>

* An estimated useful fuel cell locomotive life of 25 years.
Sierra Railway Corporation is the only company in the world with a short line railroad and a gasification technology

- **2018**: *Sierra Energy* successfully commissions Fort Hunter Liggett project, in partnership with Department of Defense and the U.S. Army, for a 10 ton-per-day system.

- **2019**: Breakthrough Energy Ventures, Cox, BNP Paribas, Twynam, Formica, and the March Fund lead oversubscribed $38M Series A round in *Sierra Energy*.

- **2021**: *Sierra Northern Railway*, receives alongside partners, $8M from the California Energy Commission for locomotive conversion to hydrogen fueling.
Waste and railroad decarbonization problems that exist nationwide

- Waste sector contributes 110.3M tons CO2e annually
- All short line railroads would benefit from federal incentives to reduce emissions and waste tie disposal issue

Source: US Environmental Protection Agency

Source: Association of American Railroads
“Negative-emissions hydrogen” has a structural cost advantage relating to feedstock supply and is poised to meet expanding hydrogen fuel demand

1. Major cost advantage driven by use of waste materials as feedstock
   56M annual tons of biomass waste in CA with landfill reduction goals + increasing waste tipping fees = continuously improving project economics.

2. Structurally increasing demand for clean hydrogen as fuel
   CA’s statutory goals to build the H2 fuel economy ensure growing demand for FCEVs. CARB can achieve rail decarbonization through H2 locomotive conversion.

3. Gasification can solve multiple environmental problems in California
   Universal win for CA with sector strategies for waste, H2 supply, and rail decarbonization — reducing carbon emissions and air pollution, particularly in fence line communities.
Hydrogen Fuel
Sierra Northern Railway
Advancing Hydrogen Rail in California
NEXT UP:

Momoko Tamaoki
Office Chief, Equipment and Assets
Caltrans
Caltrans Intercity Passenger Rail

ZE Strategy

Innovations in Hydrogen Rail

Sacramento, CA | May 19, 2021 | Momoko Tamaoki | Office Chief, Assets and Equipment, DRMT, Caltrans
momoko.tamaoki@dot.ca.gov
Become an innovation leader in zero-emission mobility
Contributing to a livable environment.
Caltrans is following the State Rail Plan to develop a comprehensive ZE strategy – starting with Intercity, other segments will follow.

State Rail Plan requirements and objectives

**RAIL PLAN (2018)**
California State Rail Plan

**FRA Requirements**
- Simple collection of reporting data
- Meeting FRA Guidelines
- Closer to the 2013 and other states’ rail plans in look and feel

**Advancing California’s Vision**
- Making the case for our strategic Vision
- Communicating through dynamic storytelling
- Providing critical resources to stakeholders
- Shifting compiled lists and basic overviews to appendices

**Caltrans Intercity ZE strategy**
- ✓ Provide leadership and guidance and serve as a positive benchmark for other railways to act quickly in a coordinated manner
- ✓ Enable the launch of important initiatives and accelerate the progress
- ✓ Set goals / targets and provide a structured approach to move towards ZE, incl. setting technological cornerstones
- ✓ Respond to urgent need and legislation / state mandates

ZE strategy developed
ZE strategy to be developed / under development
Strategic goals for our intercity fleet to become an innovation leader in zero-emission mobility

Decarbonizing our transportation system and improving our air quality
- Gradually substitute fossil fuel with renewable diesel and hydrogen, thereby reducing GHG emissions well-to-wheel
- Upgrade our diesel locomotives with after-treatment systems and introduce hydrogen, thereby progressively decreasing criteria pollutants that have an adverse effect on air quality

Increasing our energy efficiency
- Invest in technology and procedures to enable energy-efficient driving as well as regenerative braking
- Invest in ground power for expanded use at layover facilities
- Invest in energy efficient railcars, reducing HEP\(^1\) requirements

Fostering leadership and facilitating collaboration in sustainable mobility
- Lead and promote pioneering initiatives in zero-emission vehicles
- Integrate state-wide efforts to accelerate implementation
- Engage in public outreach and promote the benefits of rail

Reduce GHG and criteria pollutants by 2035
\(-100\%\)

Reduce fuel usage per train mile by 2025
\(-15\%\)

Work with passenger rail agencies to coordinate zero-emission action plan by 2021

(1) HEP = head-end power (e.g., for HVAC, lighting)
Our goal for intercity rail: Achieve a 100% emission-free fleet by 2035 – taking the lead among other modes of transportation

Existing regulations

**Intercity rail**

Caltrans DRMT\(^1\) goal: Complete intercity fleet ZE by 2035

**Buses**

Innovative Clean Transit Regulation:
- New buses ZE from 2029 onwards
- Bus fleets of public transit agencies fully ZE by 2040

**Medium- and heavy-duty vehicles**

EO N-79-20:
- Trucks fully ZE by 2045 wherever feasible

**Light-duty vehicles**

EO N-79-20:
- In-state sales of new passenger cars and trucks 100% ZE from 2035

(1) DRMT = Division of Rail and Mass Transit
Sources: CARB, Caltrans, Governor’s Office

Caltrans DRMT ZE Initiatives | April 2021
Responsibilities for California’s intercity rail are divided between state, JPAs and railway undertaking operators.

**State of California (Caltrans)**
- Long-term strategic planning (e.g. California Transportation Plan 2040)
- Provide funding for IPR\(^1\)
- Rolling stock procurement and ownership
- Planning, organizing, coordinating and directing rail related projects
- Oakland maintenance facility oversight including improvement plans

**Joint Powers Authorities (JPA)\(^2\)**
- Oversight and management of the day-to-day operations
- Negotiating changes to the current contract or selecting another qualified operator
- Management and administration of the rolling stock
- Marketing and establishment of fares
- Planning for future service improvements

**Railway Undertaking Operators\(^3\)**
- Procurement of rolling stock
- Operation of passenger/freight trains (on board staffing, station services, ticketing)
- Maintenance of rolling stock (in some cases different company/legal entity)

**Right-of-Way Owner (Host Railroads)**
- Provide access to rail infrastructure
- Maintenance of infrastructure
- Provide train dispatching services
- Provide station operations and maintenance
- Transport freight

---

1 IPR = Intercity Passenger Railway
2 Capitol Corridor, San Joaquin, LOSSAN
3 Currently only Amtrak for intercity lines; commuter lines have other operators.
Our fleet: Caltrans provides the equipment for three intercity corridors – services are managed by regional Joint Powers Authorities

California's Intercity Passenger Rail

Intercity diesel-electric locomotive fleet

F59PHI (EMD)
Year introduced: 1991 / 2001
Emission standard: Tier 2
Active fleet: 13

SC-44 (SIEMENS)
Year introduced: 2017
Emission standard: Tier 4
Active fleet: 24

Focus of our zero-emission (ZE) strategy
Targets will be achieved through a mix of measures: reducing energy consumption combined with technological changes and use of renewable power.

**Levers**
- **Tank-to-Wheel**
  - Main on-board energy
  - After-treatment
  - Energy efficiency
- **Well-to-Tank**
  - Ground power usage
  - Feedstock sourcing

**Prioritized solutions**

**Main on-board energy**
- CA diesel
- Renewable diesel
- Natural Gas
- Renewable gas
- Batteries
- Hydrogen
- Electric

**After-treatment**
- Below Tier 4
- Tier 4
- Tier 5
- No aftertreatment, zero emission

**Energy efficiency**
- Energy-efficient driving
- Regenerative braking
- HEP reduction

**Ground power usage**
- HEP usage – no ground power usage
- At maintenance facilities only
- At maintenance and layover facilities

**Feedstock sourcing**
- Fossil sources
- Mix of fossil and renewable sources
- Renewable sources

*(1) As hybrid with Hydrogen  (2) Power supplied by complete continuous wayside electrification  (3) No dedicated investment in Tier 5 but transition to ZE immediately*
### Primary power for Caltrans intercity fleet: renewable diesel to reduce emission and hydrogen to achieve zero-emission

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not feasible</td>
<td>Not feasible</td>
<td>Not feasible</td>
<td>Not feasible</td>
<td>Not feasible</td>
<td>Not feasible</td>
<td>Not feasible</td>
</tr>
<tr>
<td>Technical / operational</td>
<td>Feasible</td>
<td>Feasible</td>
<td>Feasible</td>
<td>Feasible</td>
<td>Feasible</td>
<td>Feasible</td>
<td>Feasible</td>
</tr>
<tr>
<td>Economical (LCC)</td>
<td>Impractical</td>
<td>Impractical</td>
<td>Impractical</td>
<td>Batteries</td>
<td>Batteries</td>
<td>Batteries</td>
<td>Batteries</td>
</tr>
<tr>
<td>Synergistic</td>
<td>Status quo</td>
<td>Feasible</td>
<td>Impractical</td>
<td>Impractical</td>
<td>Impractical</td>
<td>Favored</td>
<td>Not feasible</td>
</tr>
</tbody>
</table>

- **Today**
- **Low-emission transition technologies**
- **Zero-emission technologies (incl. hybrids)**

#### Notes:
- **Status quo**: Emission targets cannot be achieved even with after-treatment systems.
- **Feasible**: Emission reduction compared to regular diesel, likely transition technology, limited modifications needed.
- **Impractical**: Possibly transition technology but requires new refueling infrastructure and motive power modifications.
- **Impractical (as stand-alone)**: Suitable for hybrid solution but not suitable as sole power source for intercity due to long range requirements.
- **Favored**: Most suited option according to initial analysis.
- **Not feasible (system-wide)**: Electrification requires large capital investment and has ROW¹ implications but can be utilized where available in dual-mode.

---

1. ROW = Right of Way
2. Considering system-wide electrification

Source: DB assessment

Caltrans DRMT ZE Initiatives | April 2021

**Rating:**
- **Excellent**
- **Good**
- **Mediocre**
- **Inferior**
- **Requirements not fulfilled**

48
Driving toward zero-emission intercity rail: Start with renewable diesel, followed by after-treatment upgrade incl. energy efficiency, and Hydrail\(^1\)

<table>
<thead>
<tr>
<th>2020-2021</th>
<th>2023</th>
<th>2025</th>
<th>2027</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop and adopt ZE strategy in accordance with EO-N79-20</td>
<td>Entire fleet is operated on renewable diesel</td>
<td>Entire fleet upgraded to Tier 4 and increased energy efficiency</td>
<td>Hydrogen pilot completed</td>
<td>Fleet transitioned to ZE All motive power vehicles use zero-emission primary energy source(^3)</td>
</tr>
<tr>
<td>Set goals and provide a structured approach to move towards ZE, incl. setting technological cornerstones</td>
<td>Start rollout of after-treatment upgrades, use renewable diesel only</td>
<td>Start trial operation of hydrogen pilot(^2)</td>
<td>Start rollout of fleet conversion towards hydrogen</td>
<td></td>
</tr>
</tbody>
</table>

-55\% \hspace{1cm} -60\% \hspace{1cm} -25\% \hspace{1cm} -60\% \hspace{1cm} -25\%

Emission reduction per train mile compared to 2020 levels: \(\downarrow\) GHG \(\downarrow\) Criteria pollutants

(1) Adjustment of strategy possible, if technological breakthrough occurs (2) Retrofitting existing F59 locomotive with H\(_2\) powertrain – if successful, consideration of rollout to remaining fleet (3) Currently, hydrogen-hybrid (hydrail) is the best option, supplemented with dual-mode where feasible
THANK YOU!
ANY QUESTIONS?
Q&A

- Submit your question in the Q&A Panel on your right.

Cory Shumaker
Development Specialist
California Hydrogen Business Council

Lynn Harris
Senior Consultant - Sustainable Motive Power & Zero-Emission Technologies
DB Engineering and Consulting USA

Tim Sasseen
Market Development Manager, US
Ballard Power Systems

Carrie Schindler
Director of Transit and Rail
San Bernardino County Transportation Authority

Mike Hart
CEO
Sierra Railroad / Sierra Energy

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