Re-purposing Fossil Fuel Infrastructure and Expertise for Low-carbon Energy Systems

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California Air Resources Board
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Decarbonization pathways are as much about infrastructure as they are about technology. The transition to a low-carbon future could potentially be improved by seeking opportunities to leverage California’s existing physical and intellectual infrastructure, technological expertise and its skilled and ready workforce.

<table>
<thead>
<tr>
<th>Negative Emissions Technologies / Carbon Capture, Utilization, and Storage (CCUS)</th>
<th>Renewable Natural Gas (RNG)</th>
<th>Smart Systems/Platforms</th>
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</thead>
<tbody>
<tr>
<td>- Applying industry expertise to CCUS technologies for direct-air capture (DAC) and bioenergy with carbon capture and storage (BECCS)</td>
<td>- Processing technologies are similar to NG processing</td>
<td>- Applying process automation for improved refinery performance</td>
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<tr>
<td>- Applying industry expertise: CCUS technologies for DAC and BECCS</td>
<td>- Minimal processing for using RNG for power generation in gas turbines</td>
<td>- Creating smart generation solutions: NG-battery and NG-solar</td>
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<td>- Using compression technologies similar to those in NG infrastructure for CO₂</td>
<td>- Doping in NG pipelines</td>
<td>- SCADA expertise</td>
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<td>- Rail and roadway = existing infrastructure</td>
<td>- Leveraging pipeline rights-of-way</td>
<td>- Improving the efficiency of transport of RNG, H₂, CO₂</td>
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<td>- Leveraging pipeline rights-of-way</td>
<td>- Utilizing existing fuel storage and transportation hubs</td>
<td>- Enhanced leak detection</td>
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<td>- Transport and transport of LPG/LNG for liquid CO₂</td>
<td>- Leveraging similarities with NG storage, acid gas disposal, and CO₂-EOR</td>
<td>- Using transport management systems and other IoT applications</td>
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<td>- Marine vessels for CO₂ using the same technology as existing LPG or LNG tankers</td>
<td>- Optimizing revenues from grid-scale storage systems</td>
<td>- Data tracking of supply chains</td>
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<td>- Port infrastructure for loading</td>
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Example of a “Hydrogen Hub”: Ports of LA and Long Beach, Hydrogen Technology Readiness Levels

- Onshore Sequestration
- Steam Methane Reformers with CCS
- H₂ Storage
- Combined Cycle Power Plant
- Electrolysis
- 100,000 kg H₂/day

- Natural Gas
- CO₂
- H₂

- Retail Gas

- Half of ports’ drayage fleet (5,000 trucks)
- Entire ports’ electricity requirement (50MW/h)
- 80% of SCG’s petroleum refiner demand
- 10% of SCG’s residential gas demand (as blend)
- CO₂ sequestration equivalent to half an average coal plant emissions

- N. Gas Reforming w/ CCUS
- Coal gasification w/CCUS
- Methane Splitting
- Electrolysis
- Pipelines
- Ammonia Tanker
- Refueling Stations
- Storage in Salt Caverns
- Blending in NG Network
- Liquid Organic Hydrogen Carrier
- Liquid Hydrogen Tanker
- Combined Cycle Power Plant
- Full Hydrogen Direct Reduced Iron

- Fuel Cell Light Duty Road Vehicles
- Fuel Cell Heavy Duty Road Vehicles
- Fuel Cell Ships
- Ammonia-fueled Ships
- Hydrogen Boilers
- Fuel Cells
- Hydrogen-driven Heat Pumps
- High-temperature fuel cells
- Hydrogen-fired Gas Turbines
- Co-firing Ammonia in Coal Power Plants

- Fossil-based Hydrogen w/ CCUS in Oil Refining
- Synthetic Methane
- Synthetic Liquid Hydrocarbons
- Fossil-based Ammonia w/ Carbon Capture
- Fossil-based Methanol w/ Carbon Capture
- Electrolysis for Methanol & Ammonia
- High Levels of Blending into Commercial Iron Processes

- Hydrogen Use In Transportation
- Hydrogen Use In Industry
- Hydrogen Use In Fuels Transformation
- Hydrogen Use In Buildings
- Hydrogen Use In Power Generation
- Hydrogen Use In Buildings

- Mature
- Early Adoption
- Demonstration
- Large Prototype

- Need Hydrogen Incentive/Loan/Innovation Programs
- Hydrogen Infrastructure
- Hydrogen Production

- Low Carbon Hydrogen Products
- Electrolysis
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- Coal gasification w/CCUS
- Methane Splitting

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- One central steam methane reforming facility and one central electrolysis facility could supply:

- 3.3 million kg H₂/day

- Fuel Cell Light Duty Road Vehicles
- Fuel Cell Heavy Duty Road Vehicles
- Fuel Cell Ships
- Ammonia-fueled Ships

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Enhanced Recovery & Other

Geologic Sequestration
Saline Formations

Oil and Gas Reservoirs
Unmineable Coal Seams

Potential Carbon Sequestration Sites: California has Excellent Options

Source: EFI, 2019, compiled using data from the EPA and NETL
Federal and private clean energy innovation are complementary
Key platform technologies hold great potential to unlock significant clean energy innovation
A four-step process is used to identify breakthrough technologies that have the potential to aid government, industry and thought leaders in efforts to transform the energy sector

Critical innovation areas identified are:
- Storage and battery technologies
- Advanced nuclear reactors
- Technology applications for industry and buildings as sectors that are difficult to decarbonize including hydrogen, advanced manufacturing technologies; and building technologies
- Systems: electric grid modernization and smart cities
- Deep decarbonization/large-scale carbon management; carbon capture, use and storage at scale; sunlight to fuels; enhanced biological and oceans sequestration

Source: Advancing the Landscape of Clean Energy Innovation, 2019, EFI, IHS Markit
Meeting the Clean Energy Ministerial’s target of 30 million electric vehicle sales by 2030 would require 314 kt/yr. of cobalt, almost three times the 2017 level for all uses. At those rates, reserves would last 23 years.

Lithium, Cobalt, Nickel Production/Reserves, Need for Expertise in Global Supply Chains

The oil industry is one of the few truly global industries...Along its supply chain, oil passes through different legal frameworks as it moves from one country to another. The oil and gas global supply-chain includes activities such as domestic and international transportation, ordering and inventory visibility and control, materials handling, import/export facilitation and information technology.

US should –

- Increase its diplomatic and investment focus on Western Hemisphere and Africa
- Protect supply chains for minerals/metals needed for wind, solar and batteries
- Support new domestic environmentally-responsible mining activities for key minerals/metals
- Support innovation in mining efficiency and in earth abundant materials for wind, solar and batteries
- Use renewable energy for electricity needed in mining operation
- Promote humane mining conditions around the world
- Start metals and minerals recycling programs now

Source: USGS, 2019