Incorporating Resilience into Transportation Planning

Elizabeth Connelly (Presenter)
Marc Melaina (P.I.)
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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
Motivation: 2017 Opinion Survey

From KPMG’s Global Automotive Executive Survey 2017:

“Battery electric vehicles (BEVs) will fail due to infrastructure challenges while fuel cell electric vehicles (FCEVs) are seen as the real breakthrough for electric mobility.”

There is a need for tools to inform robust, resilient investment and policy decisions for transportation infrastructure.

Executive opinion

- Absolutely agree: 22%
- Partly agree: 40%
- Neutral: 20%
- Partly disagree: 12%
- Absolutely disagree: 6%

Executive opinion

- Absolutely agree: 33%
- Partly agree: 45%
- Neutral: 16%
- Partly disagree: 5%
- Absolutely disagree: 1%
For Priority-Setting:

Evaluating alternatives/investments with consideration given to system resilience

Suggested considerations:
- Sustainability criteria for decision-making
  - Economic
  - Environmental
  - Social
- Regional needs/impacts

Of Priority-Setting:

Evaluating how priorities/preferences change due to future uncertainties

Suggested considerations:
- Scenarios of emergent conditions
- Changes in mindsets/values
- Technological advances
- Introduction of laws and regulations
Resilience, in the context of policy making means assessing alternatives with respect to multi-dimensional, interrelated sustainability criteria.
“It should be clear that developing appropriate risk- and life-cycle based decision frameworks that are operable in highly uncertain research domains should be a high policy priority.”

Source: Linkov and Seager (2011)
What scenarios are influential to the technology/infrastructure life cycle and disruptive to decision-maker priorities?
Application: Hydrogen Regional Sustainability Analysis (HyReS)
Data Sources and Models

ANL’s **Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET)** model describes emissions and resource use associated with hydrogen fuel and vehicle cycles.

NREL’s **Automotive Deployment Options Projection Tool (ADOPT)** estimated technology improvement impacts on future vehicle sales, petroleum use, and GHG emissions.

NREL’s **Future Automotive Systems Technology Simulator (FASTSim)** estimates the impact of technology improvements on vehicle efficiency, performance, cost, and battery life.

NREL’s **Scenario Evaluation, Regionalization and Analysis (SERA)** model is a geospatially and temporally oriented model that determines optimal production and delivery scenarios for hydrogen, given resource availability and cost.

The EPA’s **Benefits Mapping and Analysis Program (BenMAP)** assesses the health impacts resulting from changes in air pollution concentrations.
Model Framework

**SERA Model**

- **Vehicle stock**: Base vehicle stock $N$
  - Survival rate $\gamma$
  - New vehicle sales $S$
  - Advanced vehicle penetration rate $R$
  - Vehicle traveled distance $A_{VMT}$
- **Fleet VMT & distribution**
- **Retired vehicles**

**Fuel & Emissions**

- Fuel Consumption per VMT by vehicle type $FE$
- Emissions per VMT by vehicle type $EM$

**Total Fuel Consumption $T_{FE}$**

**Total Emissions $T_{EM}$**

**Scenario Results**

**Legend**

- Input data
- Model results

**BenMAP Model**

**Air quality model results**

- Base scenario air quality data at each region
- User-defined scenario air quality data at each region

**Health impacts estimation $\Delta H$**

- Population incidence rates $\beta$
- Health impact functions $Ln(H)$
- Valuation functions $A$

**Human health benefits**

**Environmental Benefits Mapping and Analysis Program**
Case Study Pathways

Feedstock/Resource Extraction

GH2 from NG via Truck
- NA NG from Shale and Regular Recovery for Central Plant
- Gaseous H2 Production

LH2 from NG via Truck
- NA NG from Shale and Regular Recovery for Central Plant
- Gaseous H2 Production

GH2 from Poplar via Pipeline
- Biomass (100% Poplar) for GH2 Production

GH2 from Wind via Pipeline
- Electricity from Wind

Hydrogen Production

GH2 Production from NG without Co-products (H2A Model without CO2 Sequestration)

GH2 Production from NG without Co-products (H2A Model without CO2 Sequestration)

Gaseous Hydrogen Production via Biomass Gasification (H2A Model)

GH2 Production by Electrolysis from Wind Electricity

Storage and Delivery

GH2 Electric Compression Tube Trailers Loading

LH2 Bulk Terminal Storage

Liquefied Hydrogen (LH2) Transportation

Transportation of Central Plant GH2 via Pipeline

Gaseous Hydrogen (GH2) via Pipeline Produced in Central Plant from Wind Energy

Retail Dispensing

GH2 Electric Compression for Refueling Station

LH2 Electric Compression for Refueling Station

GH2 Compression at Refueling Station (for Pipeline Distribution)

GH2 Compression at Refueling Station (for Pipeline Distribution)
# Emissions and Water Demand Case Study Results

## Life Cycle GHG-100 Emissions

<table>
<thead>
<tr>
<th>LC Impacts (g/mi)</th>
<th>GH2 from NG via Truck</th>
<th>LH2 from NG via Truck</th>
<th>GH2 from Poplar via Pipeline</th>
<th>GH2 from Wind via Pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG-100</td>
<td>335.83</td>
<td>414.47</td>
<td>144.89</td>
<td>106.22</td>
</tr>
<tr>
<td>CO</td>
<td>0.28</td>
<td>0.29</td>
<td>0.24</td>
<td>0.19</td>
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<tr>
<td>NOx</td>
<td>0.26</td>
<td>0.27</td>
<td>0.21</td>
<td>0.09</td>
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<tr>
<td>PM10</td>
<td>0.07</td>
<td>0.09</td>
<td>0.05</td>
<td>0.05</td>
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<tr>
<td>PM2.5</td>
<td>0.04</td>
<td>0.05</td>
<td>0.02</td>
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<tr>
<td>SO2</td>
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<td>0.00</td>
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<tr>
<td>CH4</td>
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<td>1.07</td>
<td>0.35</td>
<td>0.27</td>
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<tr>
<td>SOx</td>
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<td>0.55</td>
<td>0.41</td>
<td>0.34</td>
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<tr>
<td>N2O</td>
<td>0.003</td>
<td>0.004</td>
<td>0.016</td>
<td>0.002</td>
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<tr>
<td>VOC</td>
<td>0.25</td>
<td>0.25</td>
<td>0.23</td>
<td>0.22</td>
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<tr>
<td>Water Use</td>
<td>662.84</td>
<td>1,077.76</td>
<td>1,304.02</td>
<td>803.80</td>
</tr>
</tbody>
</table>

GREET defaults were varied so that transportation of hydrogen is consistent across modes (100 miles).

## Life Cycle Water Demand

- GH2 from NG via Truck: 662.84 cm³ H₂O/MMBtu H₂
- LH2 from NG via Truck: 1,077.76 cm³ H₂O/MMBtu H₂
- GH2 from Poplar via Pipeline: 1,304.02 cm³ H₂O/MMBtu H₂
- GH2 from Wind via Pipeline: 803.80 cm³ H₂O/MMBtu H₂

GH2 from poplar is most water intensive.

LH2 from NG is most GHG intensive.
Importance of Spatial and Temporal Scale: Sensitivity to Electricity Grid Mix

WTP GHG-100 Emissions

- GH2 from NA NG via Truck
- LH2 from NA NG via Truck
- GH2 from Poplar via Pipeline
- GH2 from Wind via Pipeline

WTP Water Usage

- GH2 from NA NG via Truck
- LH2 from NA NG via Truck
- GH2 from Poplar via Pipeline
- GH2 from Wind via Pipeline
Future Work

- Prioritization of hydrogen supply chain configurations under scenarios of differing assumptions on:
  - Electricity generation
  - Technological efficiencies
  - Population densities
  - Consumer adoption rates

- Comparison of fuel cell electric vehicles against gasoline, biofuel, and electric vehicles on the basis of:
  - Cost to consumer
  - Economic impacts (job creation, GDP growth)
  - Environmental impacts
  - Health impacts, etc.
Questions?

Contact Information:
Elizabeth.Connelly@NREL.gov