

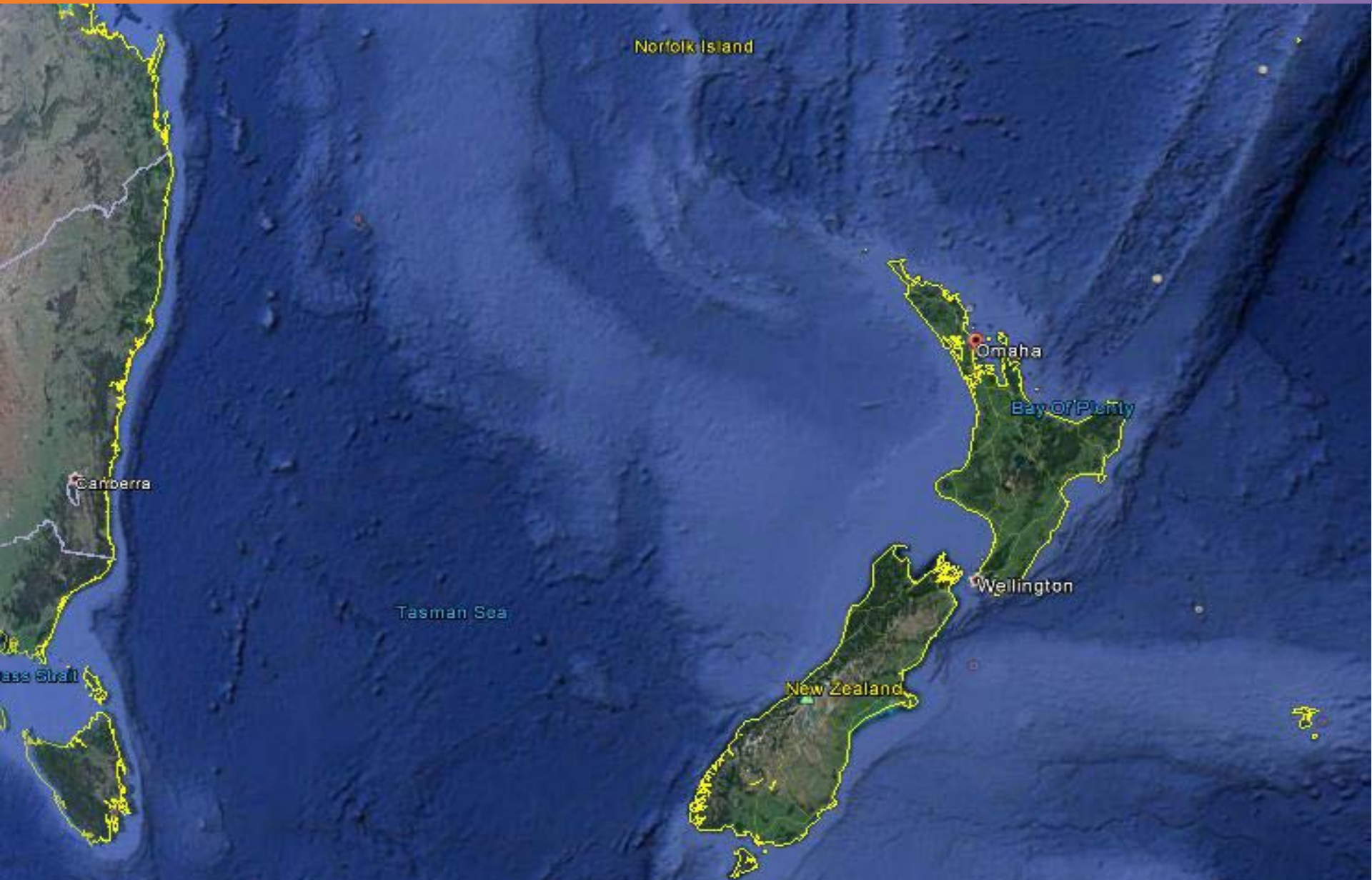
# Multi-regional system-dynamics modelling of integrated energy-system and transport sectors using UniSyD

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# New Zealand Site



# Overview

- **UniSyD Background**
- **UniSyD Structure**
- **Case Study & Sample Results**
- **Conclusions**

# UniSyD Model Background

**2002-2005:** 1<sup>st</sup> stage development by Stanford University (USA) and Unitec (NZ)

**2006-2008:** 2<sup>nd</sup> stage development by Stanford University (USA) & Unitec (NZ)

**2009-2011:** 3<sup>rd</sup> stage by Asia Pacific Energy Research (Japan) & Unitec (NZ)

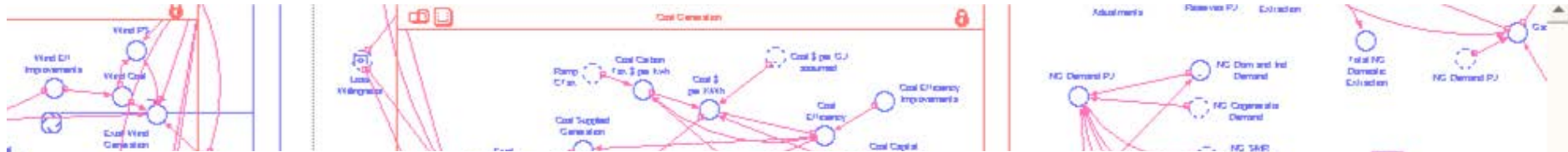
**2012-2015:** 4<sup>th</sup> stage by Iceland University, Reykjavik University, Massachusetts Institute of Technology (USA) & Unitec (NZ)

**2015-present:** 5<sup>th</sup> stage by Iceland University, Unitec (NZ), Reykjavik University & Kanagawa University (Japan)

64 Sectors, ~ 11,000 lines of code

Models of New Zealand, Iceland, Japan, +5 Scandanavian countries.

# UniSyD\_NZ Model



## Models NZ's Energy-System

Detailed technological specificity and

- 2000 primary variables
- Simulates in biweekly time steps
- 2 islands with 13 NZ regions

## Primary Sectors

- Electricity Market
- Hydrogen Market
- Biofuel Market
- Vehicle Fleet Market



# Electricity Market - Overview

## ● Demand

- Dynamic interaction with price signals in residential, commercial and industrial sectors
- Dynamics of consumer behaviour in transport sector

## ● Supply: generation options (+sequestration option)

- Coal
- Natural gas
- Hydro
- Geothermal
- e-/H2 Cogeneration
- Biomass
- Solar PV
- Wind
- Solar Thermal
- Combined Heat and Power
- Microgeneration



Huntly. Source: Genesis Energy

# Electricity Generation

## ● New capacity is installed as follows:

- Find region with most expensive retail prices
- Determine least expensive technology for that region
- Build a plant if
  - a) the region does not already a plant under construction
  - b) the production cost is below the capital planning wholesale price (i.e. lowest cost additional generation)

## ● Technology learning curves lower production costs of future plants

# Hydrogen Market Overview

- **There are 4 centralised plant types, each with 5 sizes:**
  - Biomass gasification.
  - Coal gasification.
  - Coal co-generation of hydrogen and electricity using a solid oxide fuel cell topping cycle and sequestering CO<sub>2</sub>.
  - Large steam methane reforming.
- **Delivery is modelled via liquid hydrogen tankers considered to be the dominant delivery method for New Zealand**
- **Forecourt generation includes SSMR and electrolysis**
  - Steam methane reforming is unavailable in the South Island, where there is no reticulated gas.
  - Forecourt generators are must-use, or base load.

# Vehicle Market: Nested Multinomial Logit Framework

## Utility of Vehicle Choice:

$$U_{k,t} = \beta_1 \cdot P_{k,t} + \beta_2 \cdot M_{k,t} + \beta_3 \cdot F_{k,t} + \beta_4 \cdot R_{k,t} + \beta_5 \cdot B_{k,t} + \beta_6 \cdot e^{\beta_7 \times A_{k,t}}$$

$P_{k,t}$  Vehicle Price (\$)

$M_{k,t}$  Maintenance Cost (\$/yr)

$F_{k,t}$  Fuel Cost (\$/km)

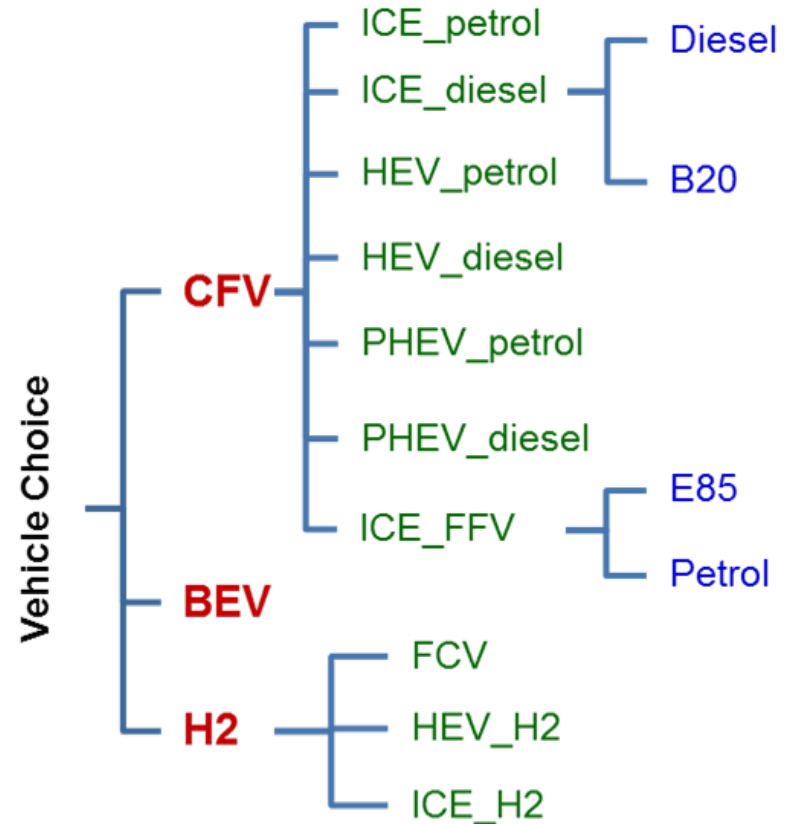
$B_{k,t}$  Battery Replacement Cost (\$)

$R_{k,t}$  Vehicle Range (km)

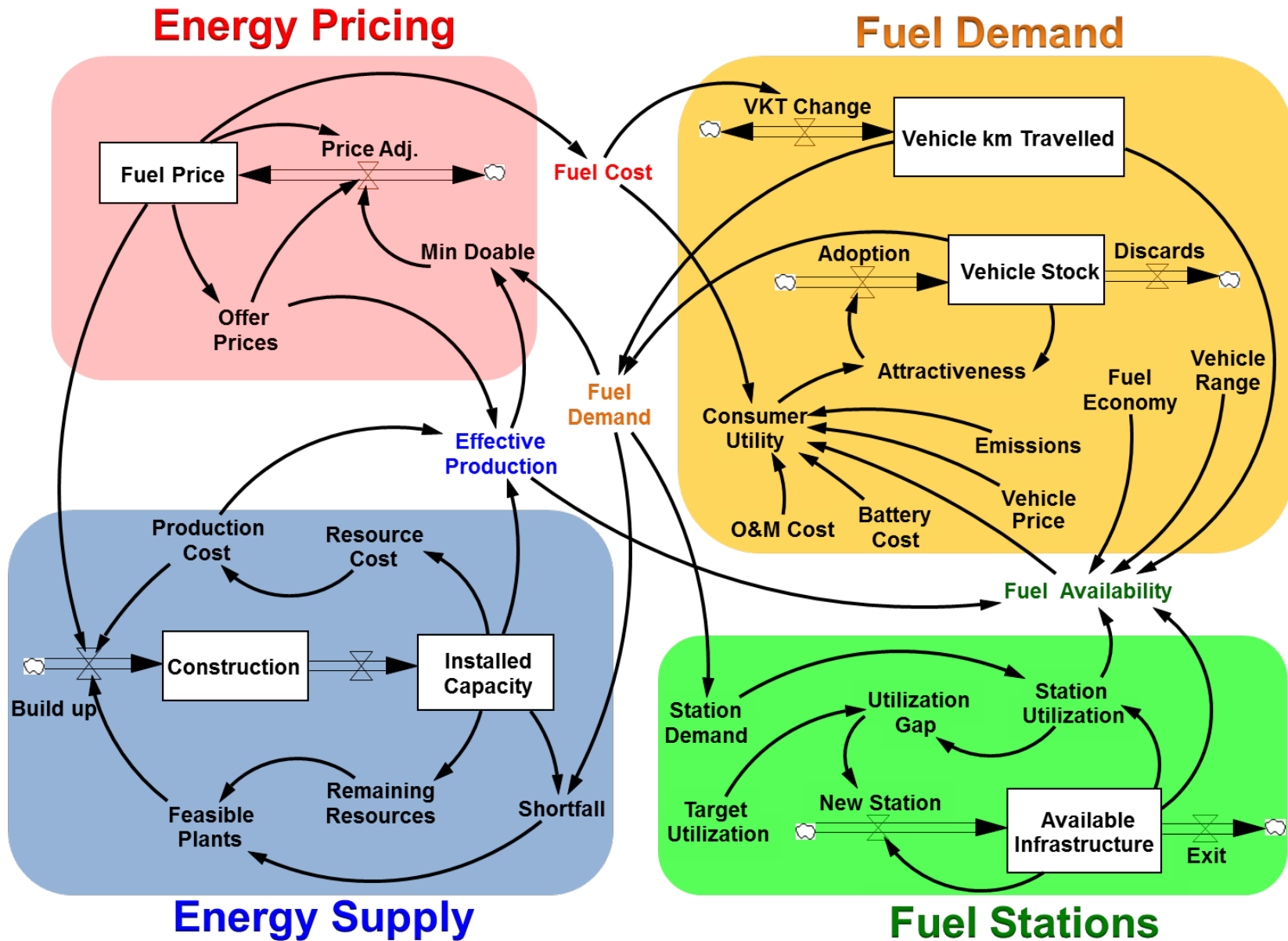
$A_{k,t}$  Fuel Availability

## Probability of Vehicle Choice

$$S_{k,t} = \exp(U_{k,t}) / \sum_{k=1}^V \exp(U_{k,t})$$



# UniSyD: Modules and Key Variables



# UniSyD Main Outputs

- Fleet mix (contribution of AFVs in LDV and HDV fleets)
- Fuel demand (fuel mix, share of renewable fuels and total fuel demand reduction)
- GHG emissions (WtT, TtW, and WtW)
- Energy supply system cost (petroleum fuel costs, alternative fuel cost, infra cost)
- Alternative fuel prices
- Total capacities and new installations
- Production scheduling
- Consumer costs (fuel use cost, vehicle capital and ownership costs)
- Government costs/revenues
- Transition net benefits (from fuel supply and consumer economic perspectives)
- Mitigation costs (from energy system and consumer perspectives)

# Main Strengths of UniSyD Model

- Detailed resource and technology specificity
- Capable of utilizing a high level of regional resolution
- Endogenous analysis of energy market dynamics
- Capable of capturing highly non-linear consumer behaviors
- High degree of computational and code transparency
- Short model run time
- Flexible time intervals
- Flexible regions
- Ease of use

# UniSyD Control Panel

### Vehicle Fleets

Start Year H2ICEV: 2051  
Start Year BICEV: 2015  
Start Year HEV: 2010  
Start Year PHEV: 2015  
Start Year FCV: 2020  
Start Year EV: 2015  
EV Range km: 320  
PHEV Range km: 40  
Start Year H2HEV: 2051  
Battery Learning Curve: 3  
FC Learning Curve: 2

1 = Low cost 2 = Med cost 3 = High

### Fossil/Bio Fuels

Oil & NG Price Increase %: 2.0  
International Oil Price USD per Barrel: 50  
Year of Oil & NG Price Increase: 2015  
Max Oil & NG Price Increase %: 200  
Start Year New Coal?: 2051  
Start Year New Bio?: 2015  
Start Year New Gas?: 2015  
New Gas Discovery Rate[Other New]: 125

### Carbon

CTax Increase %: 4  
Start CTax\$ per T CO2: 25  
Year of CTax Increase: 2015  
Max CTax \$ per T CO2: 200

## PRIMARY VARIABLES

ALL PRICES IN 2014 NZD

### Fuel Stations

H2 Station Introduction Year: 2021  
H2 Program Duration Year: 5  
LDV H2 Station per yr: 10  
HDV H2 Station per yr: 4  
EV Chargers Introduction Year: 2051  
EV Program Duration Year: 0  
LDV EV Charger per yr: 0  
HDV EV Charger per yr: 0  
E85 Station Introduction Year: 2051  
Bio Program Duration Year: 0  
E85 Station per year: 0  
B20 Station Introduction year: 2051  
B20 Program Duration Year: 0  
LDV B20 Station per yr: 0  
HDV B20 Station per yr: 0

### Consumer Valuation

Annual Vehicle Cost Discount Rate: 0.00  
Payback Period yr: 5  
WTP NZ\$ per km@ Initial Range 100km: 100

### Hydrogen Production

Mandate H2 pipelines:   
Allow Small SMR?:   
Ignore LNG:

### Carbon

Carbon Sequestration Base Cost US\$: 1.6  
Maximum Cost US\$ Carbon Sequestration: 16.3

### Other

NZ to US Long Term Exchange Rate: 0.70  
Percentage of Predicted Biomass Resource: 100

### Electricity

Loss Willingness: 10  
Random Rainfall:   
Industry Electricity Demand Growth Ratio: 0.30  
Micro NG CHP?:   
LNG Importation Begins: 2051  
Micro H2 CHP?:   
Start price Coal \$ per GJ: 4.0  
Tag Demand to Pop?:   
Start Year Ramp Down Existing Coal: 2020  
Tag Coal to Oil?:

### Vehicle Parameters

Mandate Vehicle Price Parity?:   
HEV Drive Cycle Regen Factor(Heavy): 0.50  
Vehicle Price Parity Year: 2040  
Mandate Fuel Economy L per 100 KM: 8.0  
H2 Vehicle Capital Price Subsidy %: 0  
Fuel Mandate Year: 2051

### Plant

EnthusiasticH2 Plant Building: 1.5  
Capital Cost Red Target Year: 2050  
Capital Cost Red Factor %: 0  
Allow Efficiency Improvement:

### Outputs

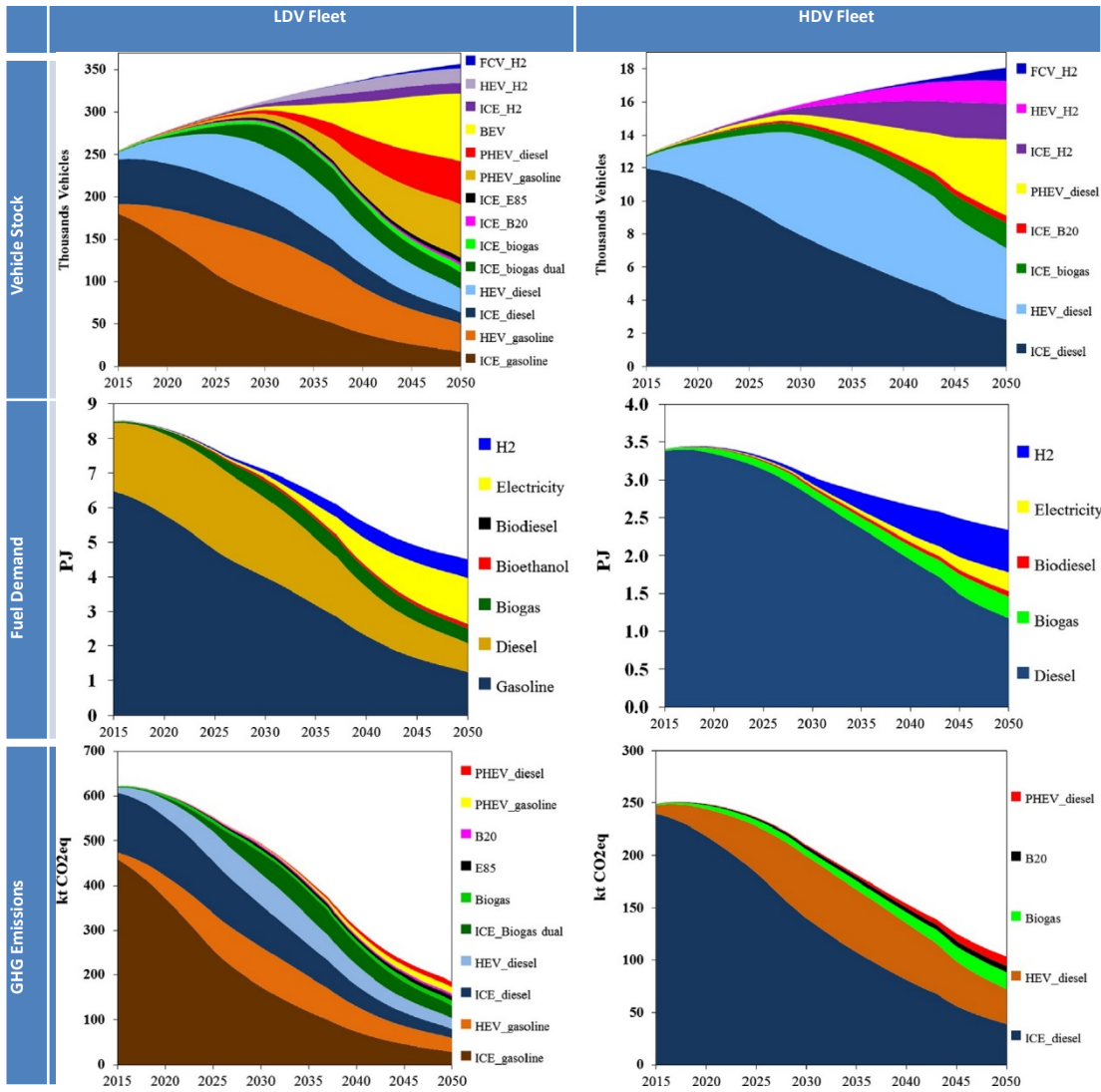
NatEnergy  
ElecData  
H2Data  
Natfleet

### Fuel Taxes

BioEth Fuel Price Tax %: 0  
H2 Fuel Price Tax %: 0  
Biodiesel Fuel Price Tax %: 0  
Petrol & Diesel Fuel Price Tax %: 100

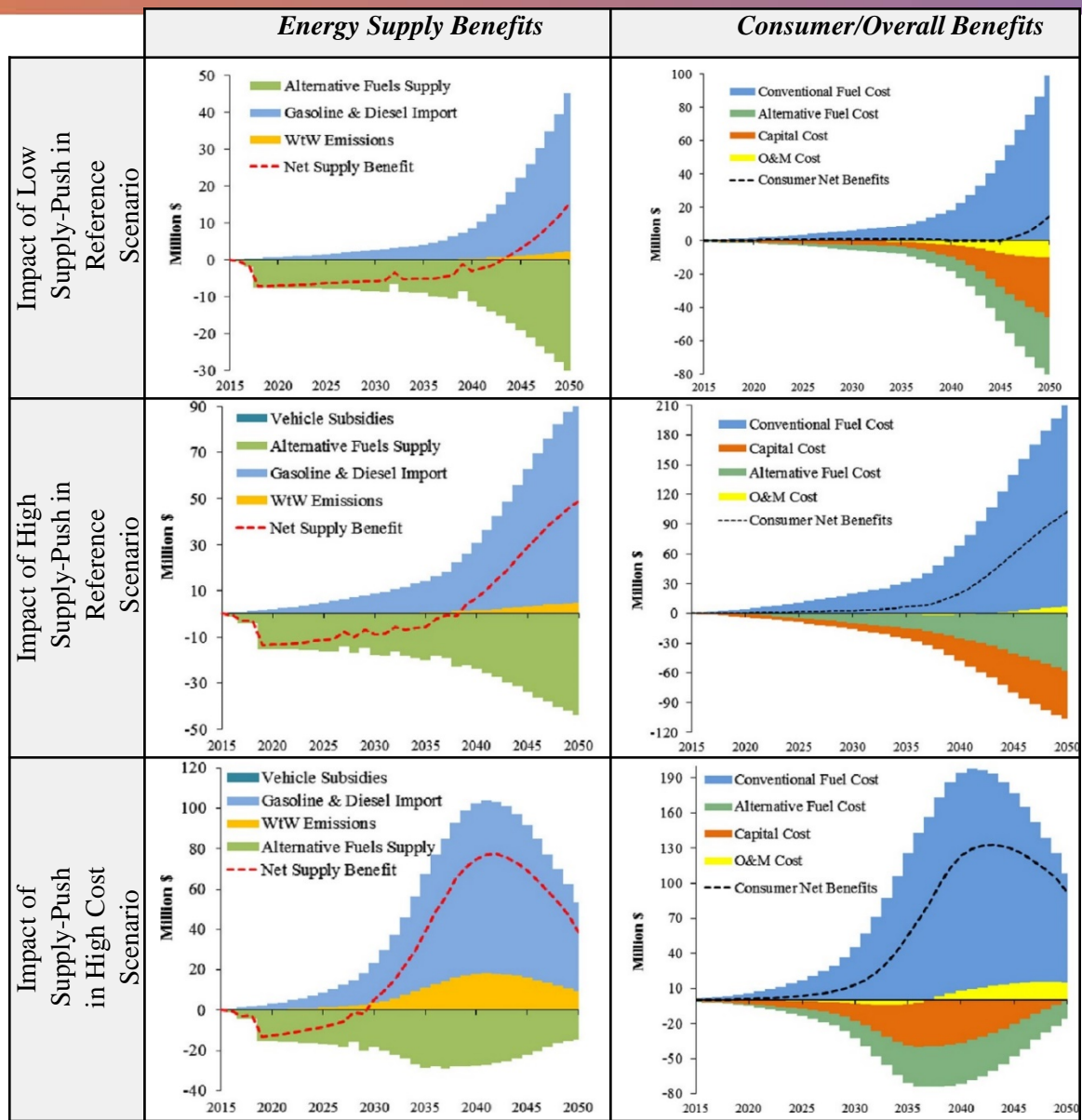
## SECONDARY VARIABLES

# Simulation Results: Evolution of Vehicle Fleets and Fuel Demand



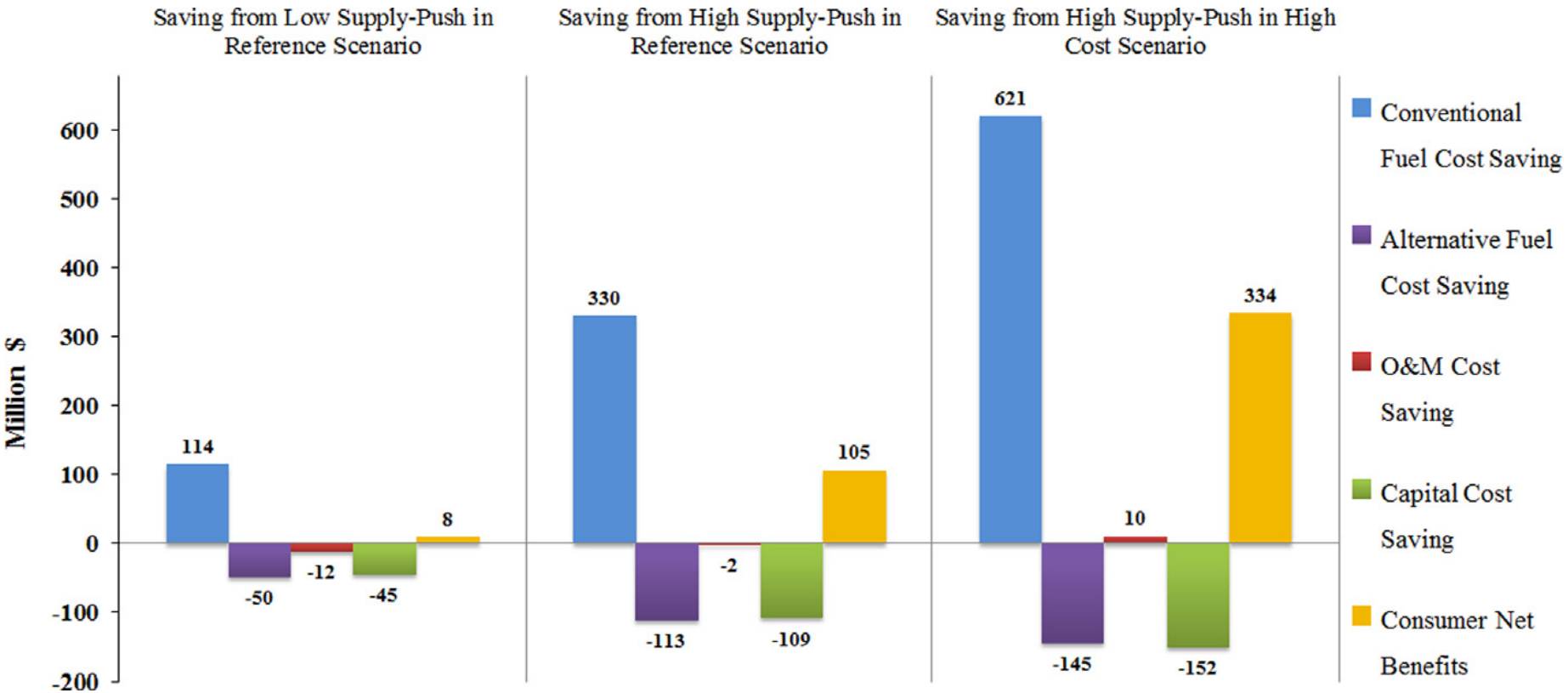
Source: Ehsan Shafiei, Brynhildur Davidsdottir, Jonathan Leaver, Hlynur Stefansson, Eyjolfur Ingi Asgeirsson Potential impact of transition to a low-carbon transport system in Iceland Energy Policy, Volume 69, June 2014, Pages 127-142

# Simulation Results: Benefits in energy supply and to the consumer



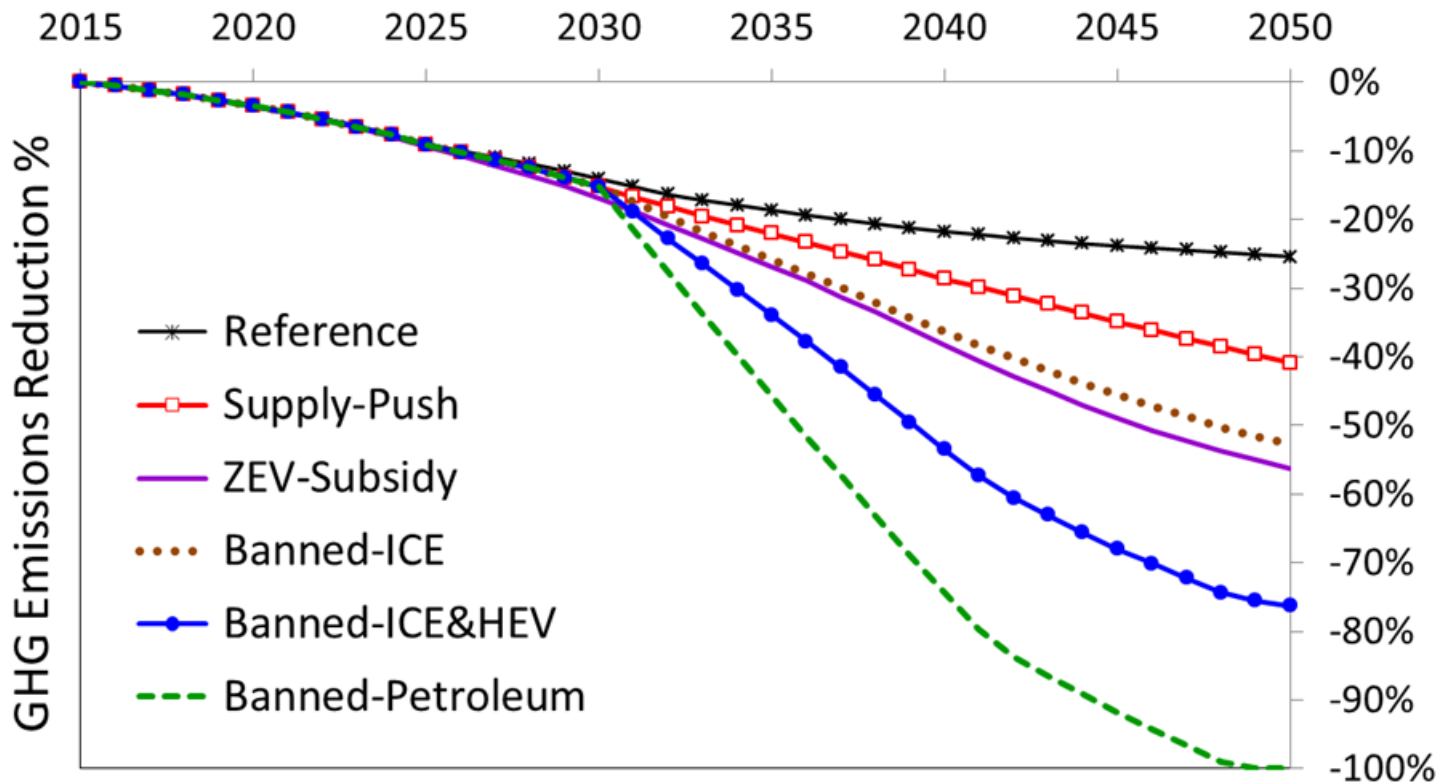
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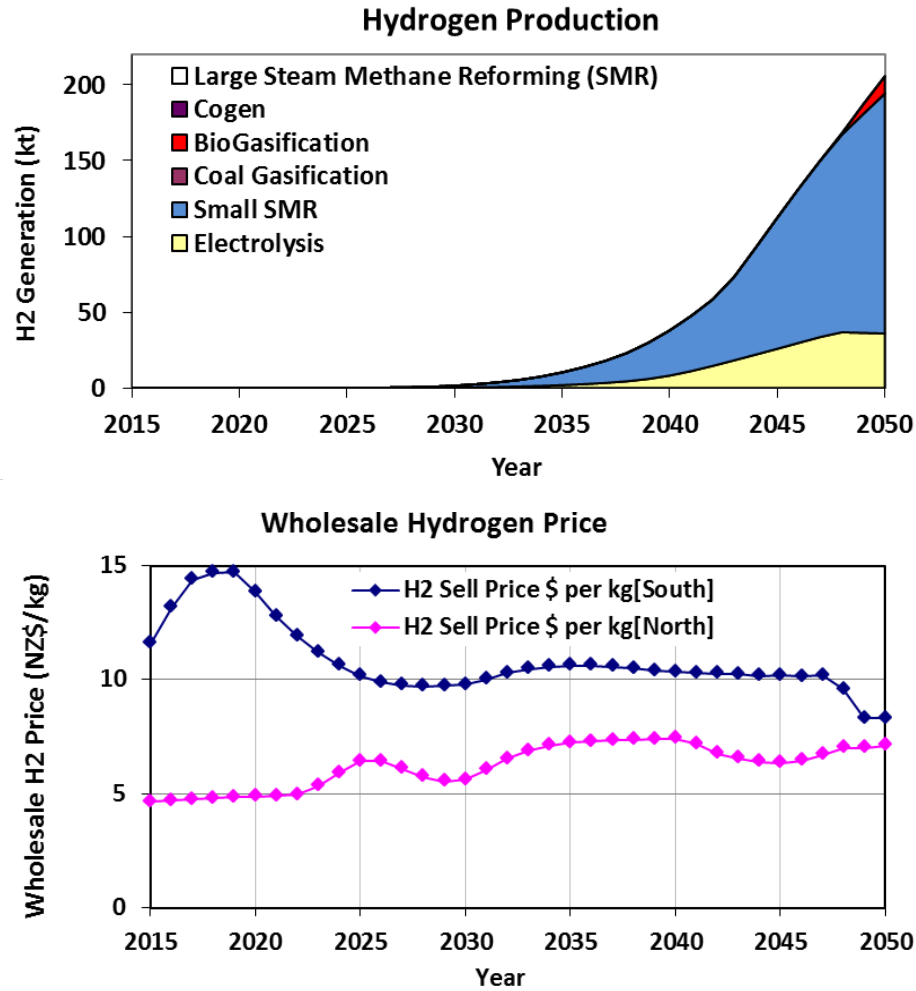
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# Simulation Results: GHG Emissions



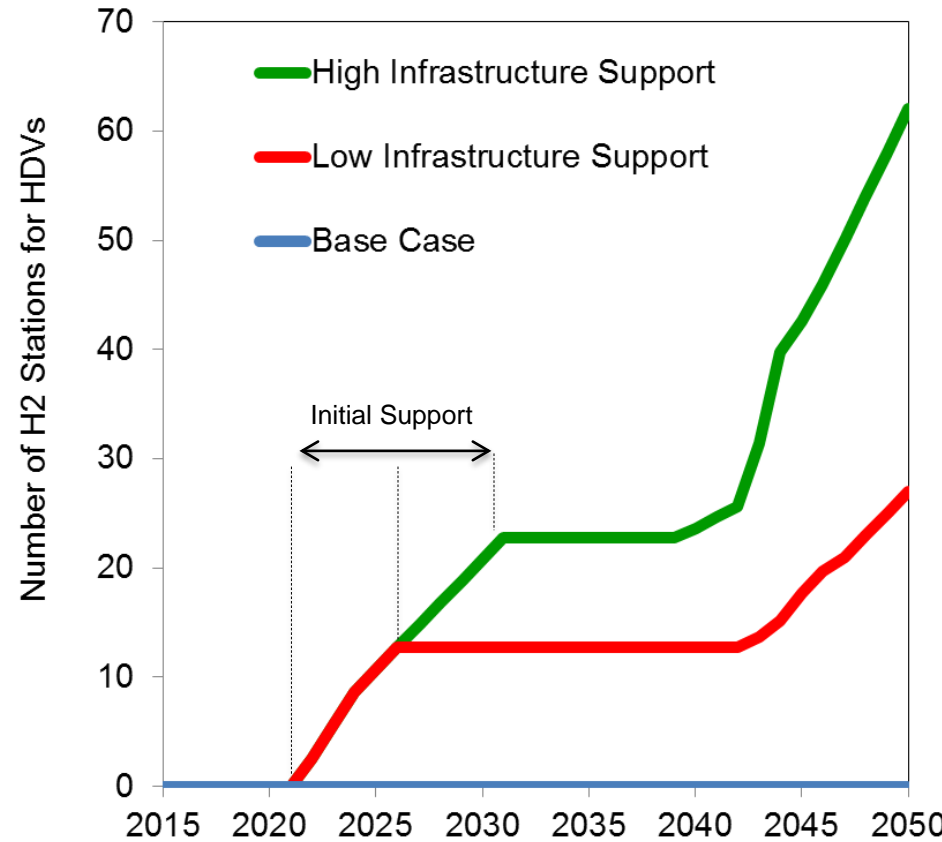
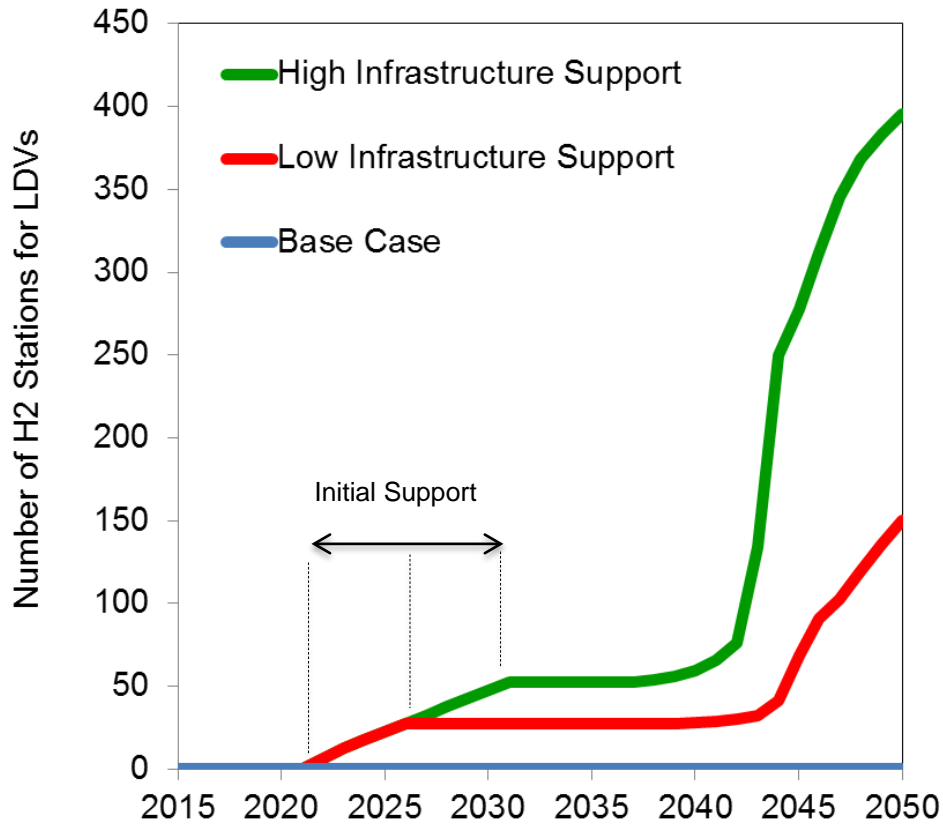
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<http://www.sciencedirect.com/science/article/pii/S0959652617304675>

# Simulation Results: Hydrogen Supply and Wholesale Price



Source: Ehsan Shafiei, Jonathan Leaver, Brynhildur Davidsdottir, Cost-effectiveness analysis of inducing green vehicles to achieve deep reductions in greenhouse gas emissions in New Zealand," *Journal of Cleaner Production*, Available online 6 March 2017. <http://www.sciencedirect.com/science/article/pii/S0959652617304675>

# Simulation Results: Evolution of H2 Refueling Infrastructure



Source: Ehsan Shafiei, Jonathan Leaver, Brynhildur Davidsdottir, Cost-effectiveness analysis of inducing green vehicles to achieve deep reductions in greenhouse gas emissions in New Zealand," *Journal of Cleaner Production*, Available online 6 March 2017. <http://www.sciencedirect.com/science/article/pii/S0959652617304675>

# Conclusions

- **UniSyD model is useful for analysis of transition to alternative fuel markets:**
  - Partial equilibrium techno-economic system-dynamics model
  - Detailed resource and technology specificity
  - Market-oriented economic system, which fuel supply viability is determined by market price
  - Supply capacity is driven by endogenous demand curves
  - Transport sector includes four important measures of **travel demand, efficiency improvement, shift to alternative powertrains** and **fuel switching**
  - Dynamic market conditions influenced by the complex interactions among **resource supply costs, technology costs, infrastructure evolution, demand patterns (consumer behavior),** and **market prices**
  - Enabling policy analysis at both supply and demand sides, as well as simulating the impact of policy instruments on both fuel and vehicle sectors.

UniSyD website: [www.uniSyD.org](http://www.uniSyD.org)

Thank you