RAPPORT DE LA FIRME E3 :

NEW ECONOMIC MODEL REPORT

Energy+Environmental Economics

New Economic Model Report

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About E3

- San Francisco-based consultancy with over 40 professionals focusing on electricity sector economics, regulation, planning and technical analysis
- Leading consultant to regulatory agencies and policy makers governing transport electrification, renewables, energy efficiency, demand response, and distributed generation programs
- Consultant to many of the world's largest utilities and leading technology and energy developers
- Our experience has placed us at the nexus of planning, policy and markets

E3’s transportation practice draws on our broad electric sector expertise

E3’s clients benefit from constant cross-pollination across our five working groups

DERs & Rates

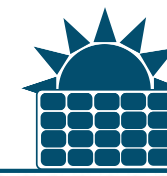
Analyzes distributed energy resources, emphasizing their costs and benefits now and in the future

Supports rate design and distribution system planning

Clean Energy

Provides market and policy analysis on clean energy technologies and climate change issues

Includes comprehensive, long-term GHG analysis



Asset Valuation

Determines grid-scale asset values from multiple perspectives and supports large user procurement

Valuations incorporate policy, regulation, economic and technology variables.

Planning

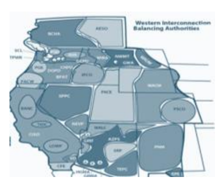
Develops and deploys proprietary tools to aid resource planners

Informs longer-term utility system planning and forecasting

Market Analysis

Models wholesale energy markets both in isolation and as part of broader, more regional markets

Key insights to inform system operators and market participants



Recent Transportation Electrification Projects

- **Hawaiian Electric Electrification of Transportation Strategy**
  - Filed March 2018: bit.ly/HECOEoT
- **Benefits of EVs for AEP Ohio**
  - Filed April 2017: http://bit.ly/AEPReport
- **Benefits of EVs for New York**
  - Report sponsored by NYSDERA forthcoming
- **Provided regulatory support to SCE and SDG&E applications implementing California's ambitious transportation electrification goals**

General Structure

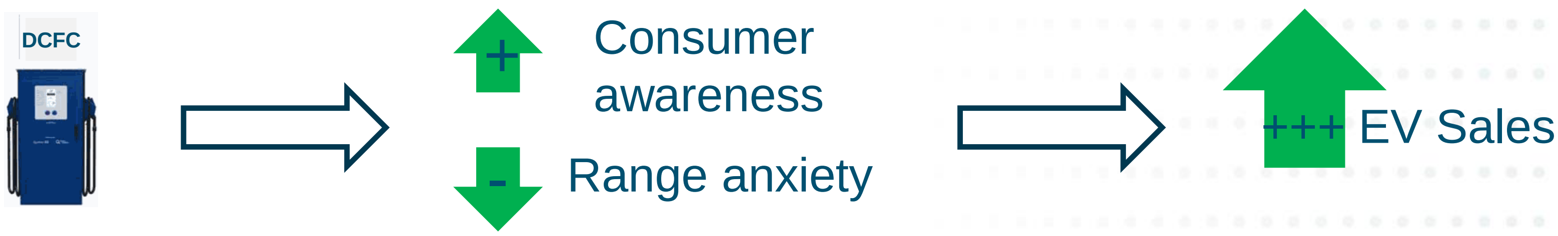
- **Model Objective**
- **Background on the induced effect**
  - Measuring the induced effect
  - Literature
- **Modelling Method**
  - Theory and approach
  - Scenario and global assumptions
  - Results

Model Objective

- The overall objective of the model is to calculate the additional kWh of home charging that occurs because of Hydro Quebec's proposed public DCFC deployment program.
- To establish this, the "Induced Effect" needs to be modelled showing how HQs DCFC program impacts the cumulative stock of EVs in Quebec.

Induced Effect - Theory

- **There is evidence suggesting that building DCFCs <u>causes</u> more EV sales, this is the basis of the "induced effect".**



  - Increases in consumer awareness and decreases in range anxiety are suspected to be the reasons why DCFC deployment causes additional EV sales.

- **The only quantitative real world evidence that the induced effect exists is through econometric / statistical studies.**

- **The theory has also been implemented in a small number of forecasting studies for EV adoption where the authors make implicit or explicit assumptions about the size of the induced effect.**

Induced Effect – The Evidence

- In statistical literature, the induced effect is often referred to as an "indirect network effect" emphasizing a two way interaction between two parameters. We focus here only on the impact of DCFCs on EVs, a very simple econometric model to represent this for a country / region in year $\boldsymbol{t}$:

$$Total\ EVs_t = \beta_0 + \beta_1 Total\ DCFCs_t + \beta_2 Other\ factors_t + \varepsilon_t$$

Constant

EV growth due to DCFCs

EV growth due to other factors

Error term

- Where "Other factors" could be: gas prices, government policies, battery costs, or anything else that could influence consumers decision to purchase an EV.

- Assuming **<u>all else is held constant</u>** the induced effect can be isolated:

$$\frac{\Delta EV}{\Delta DCFC} \approx \beta_1$$

Induced effect

$$Where:\ \Delta EVs = Total\ EVs_{t\ end\ year} - Total\ EVs_{t\ start\ year}$$

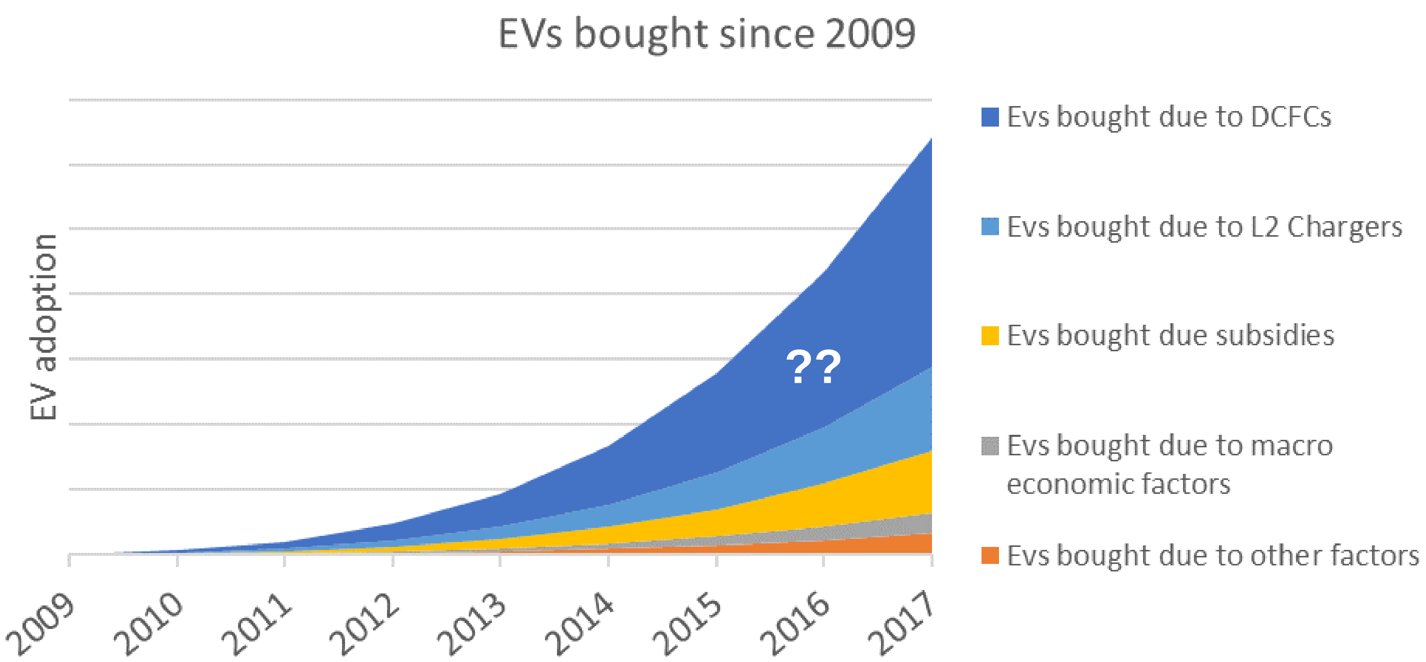
$$\Delta DCFC = Total\ DCFCs_{t\ end\ year} - Total\ DCFCs_{t\ start\ year}$$

- A handful of statistical studies have attempted to estimate β_1 using historical data, these studies provide the only quantitative real world evidence that an induced effect exists.

- However estimating β_1 poses many technical challenges, consequently there are only two studies that are robust enough to be good benchmarks for our analysis (see slide 26).

Induced Effect – Visual Representation

- Econometric methods use historic data to essentially calculate the dark blue portion of EV growth shown in the graph below:



*Not actual data – used for demonstrating theory, the data categories are suspected influencers of EV adoption, relative sizes are estimates

Defining The Induced Effect

- For our modelling purposes we can define a simplified version of the induced effect as follows:

$$Induced\ Effect\ (IE) = \frac{Change\ in\ EV\ Sales\ Due\ to\ DCFCs}{Change\ in\ DCFC\ deployment}$$

effect

cause

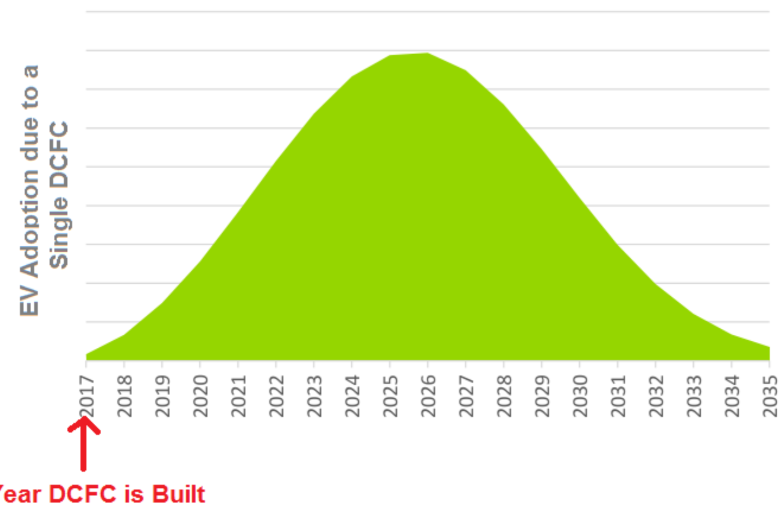
- The induced effect can further be thought of either in terms of absolute change (as in the above equation) or relative change:

$$Relative\ IE = \frac{\%\ Change\ in\ EV\ Sales\ Due\ to\ DCFCs}{\%\ Change\ in\ DCFC\ deployment}$$

Additional notes on the Induced Effect (IE)

+ **The size of the IE is likely to decrease over time:**
  - Since the IE is proportional to how much DCFCs reduce **range anxiety**, other factors which influence range anxiety will also influence the IE.
    - For example, as the average range of an EV changes, range anxiety is reduced, and the marginal impact of a DCFC on EV adoption (the IE) will therefore likely decrease
  - The IE is also proportional to how much DCFCs raise **consumer awareness** of EVs, therefore other factors which influence consumer awareness will also influence IE.
    - For example over time EVs will become more prevalent in the market, and the marginal impact of a consumer seeing a DCFC on their decision to buy an EV will be less

+ **The impact of the IE is likely to be dispersed over time**
  - A DCFC built in year 1 will not immediately have maximum impact EV adoption:
    - Consumers vehicle purchasing lifecycle is long (5 – 10 years).
    - Over time more consumers are exposed to the DCFC therefore consumer awareness builds over time.

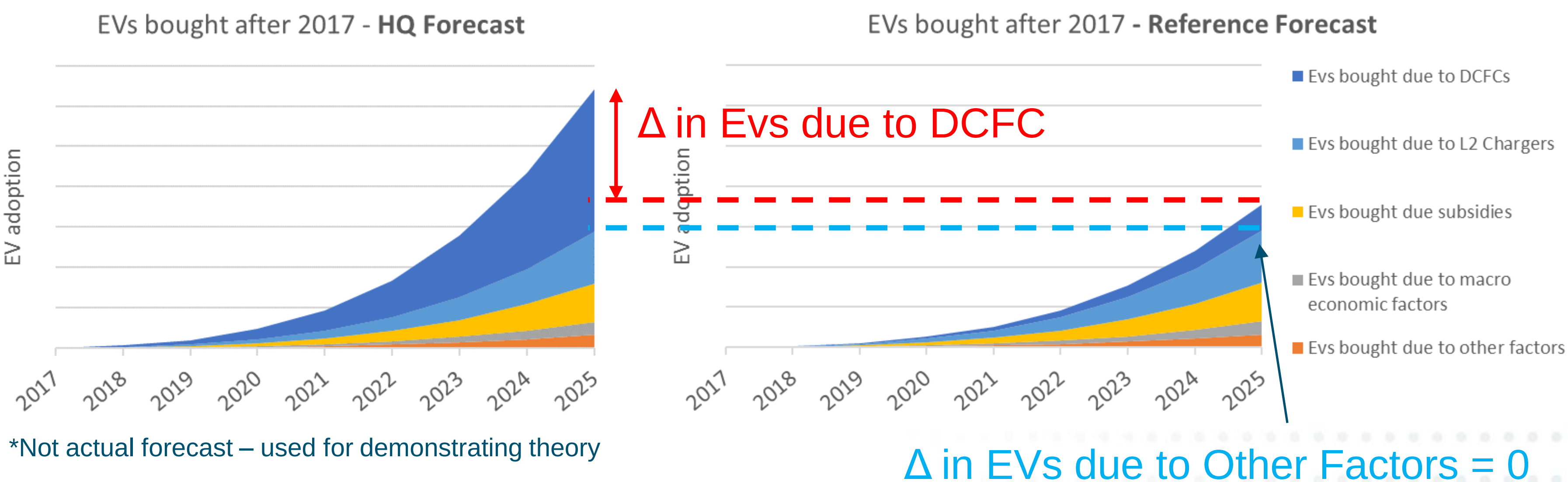


Graph adapted from PGE Transportation Electrification Plan

MODELING THE INDUCED EFFECT

Isolating Induced Effect of DCFC

- To isolate the effect of the HQs DCFC program we compare an EV forecast under HQs DCFC program to a EV forecast that is exactly the same but with no HQ DCFC program (the control group)
- **Using our visual representation from the introduction, ideally we are trying to create two forecasts similar to this:**



*Not actual forecast – used for demonstrating theory

Econometric Model

- Translating this to the econometric model, for a given year:

HQ Scenario: $\boldsymbol{Total\ EVs_{HQ} = \beta_0 + \beta_1 Total\ DCFCs_{HQ} + \beta_2 Other\ factors_{HQ} + \varepsilon_{HQ}}$

Ref Scenario: $\boldsymbol{Total\ EVs_{ref} = \beta_0 + \beta_1 Total\ DCFCs_{ref} + \beta_2 Other\ factors_{ref} + \varepsilon_{ref}}$

<u>Assuming:</u> $\boldsymbol{Other\ factors_{HQ} = Other\ factors_{ref}}$

And that the interaction between DCFCs and EVs is unidirectional, and there is only a small interaction between DCFCs and the other factors

Then subtracting HQ scenario from the Ref Scenario and rearranging:

$$\boldsymbol{\frac{Total\ EVs_{\ HQ} - Total\ EVs_{\ ref}}{Total\ DCFCs_{\ HQ} - Total\ DCFCs_{\ ref}} \approx \beta_1}$$

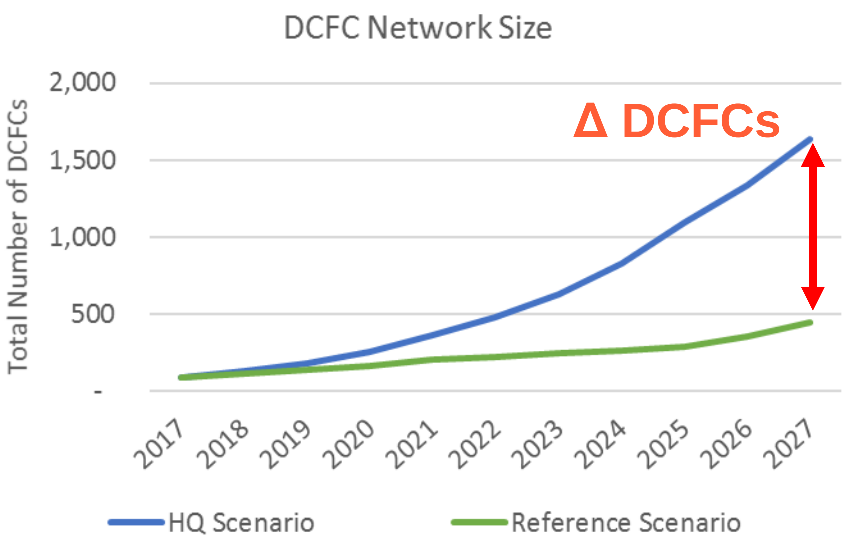
Induced effect

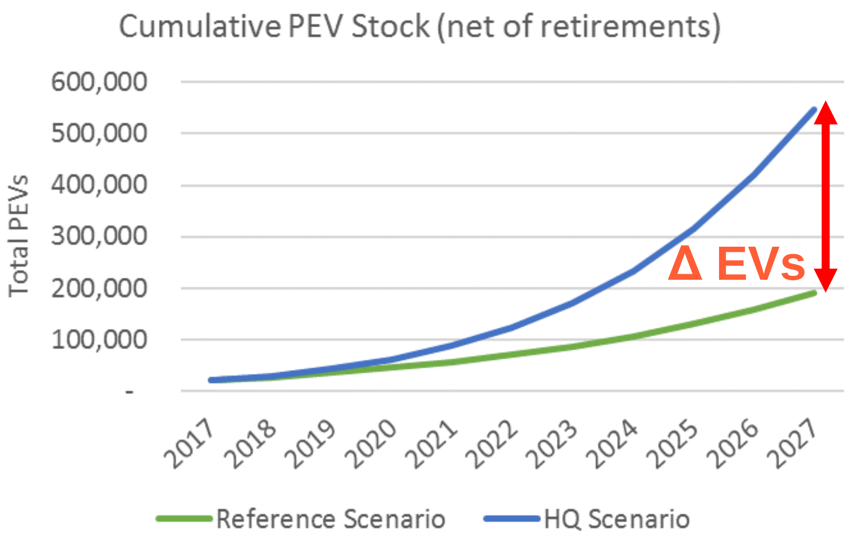
So total EVs and total DCFCs for both scenarios are inputs to get the induced effect as an **<u>output,</u>** this can then be compared with literature to ensure the size of the induced effect is aligned with historical data and other forecasting studies.

Calculating Induced Effect

+ **In order to know the size of the induced effect the associated DCFC deployment under each forecast must be forecasted. Therefore our IE equation translates to:**

$$IE = \frac{EV\ Sales_{HQ\ Program} - EV\ Sales_{No\ HQ\ program}}{DCFC\ deployment_{HQ\ Program} - DCFC\ deployment_{No\ HQ\ Program}}$$





Approach Overview

+ **Simple iterative scenario based approach:**

  1. Generate a **HQ scenario** representing the "world with the HQ program" which forecasts DCFC deployment, EV adoption, and kWh sales from EV charging.

  2. Generate a **Reference scenario** representing the "world without the HQ program" also forecasting DCFC, EVs and kWh Sales, but where all factors influencing EV adoption are assumed to be the same apart from the number of DCFCs deployed.

  3. The difference between the kWh Sales in the two scenarios is the induced effect → benchmark this figure against the literature

The Narrative Behind the Scenarios

HQ Scenario

- HQ projects a realistic EV growth path that allows Quebec to meet the provincial government's 2030 goal of 1M EVs. This path involves market share of new PEVs sold growing from 1.2% in 2016 to 19% by 2025. Cumulative PEVs reach 546,418 by 2027
- HQ calculates the size of a DCFC network needed to support an EV fleet this large based an extensive literature review on the optimal ratio of BEVs to DCFCs.
- HQ establishes **Target Ratios** for 2021, 2025 and 2030 which in turn provide targets for the DCFC network size needed by these years.

Reference Scenario

- In absence of HQ's DCFC program, Circuit Électrique continues to build DCFCs at a slow rate.
- Private sector 3rd parties also establish DCFC stations mainly in densely populated areas where their business model is profitable.
- DCFC network growth therefore is slow at first, following similar trends to previous years. EV growth initially outstrips DCFC growth so the ratio of DCFCs to BEVs rises rapidly. By 2025 DCFC costs have come down sufficiently that the private sector plays a bigger role and DCFC growth starts to climb, stabilizing the BEV:DCFC ratio at 300. By 2027 there are 489 DCFCs
- The market share of new PEVs sold therefore grows slowly from 1.2% in 2016 to 7.5% by 2025 and the total number of EVs in Quebec by 2027 is 231,585.

Generating scenarios

Generate EV market share forecast

- Targets for PEV % of new car sales
- Fit S curve (diffusion curve)

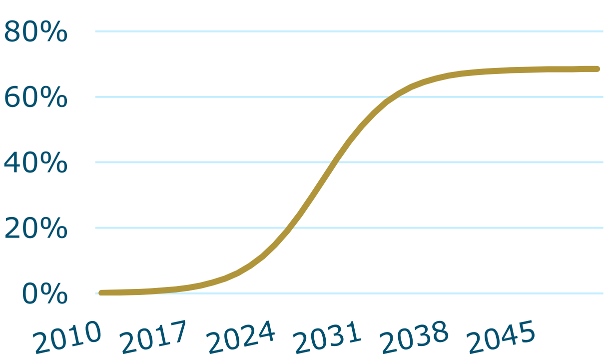
DCFC network needed to support EV forecast

- Forecast PEV retirement
- Estimate BEV % for new PEV sales
- BEV/DCFC Ratio needed to support PEV fleet

Home Charging from EV

- Estimate EVMT
- Estimate charging at home

PEV market share of new vehicle sales in Quebec



Generating scenarios - Assumptions

EV market share forecast Assumptions:

Both

- PEV market share maxes out at 69% (80% for passenger cars, 60% for light duty trucks)

HQ

- Fitted an S-curve to historical data in Quebec (2012 - 2016)
- Ensured the S-curve at least reach the government target of **1M Evs by 2030**.

Reference

- Fitted an S-curve to historical data in Quebec only for 2016
- Used a "low-growth" market share scenario for PEVs where market share by 2025 is **7.5%.**

DCFC network Assumptions

Both

- PEVs have 8yr life in 2010, 12 yr life in 2030

HQ

- BEV/DCFC Target Ratio needed to support PEV fleet:

2021	2025	2030
125	225	250

- HQ program is designed to reach 1 DCFC per 250 BEVs by 2030 – optimal according to literature
- Market share of BEVs vs PHEVs grows to 90% by 2027

Reference

- BEV/DCFC ratio for PEV fleet:

2021	2025	2030
175	300	300

- PEV growth faster than DCFC growth initially - ratio rises quickly, post 2025 DCFC costs lower so private sector builds DCFCs faster and ratio stabilizes
- Market share of BEVs vs PHEVs grows to 80% by 2030

Home Charging from EV Assumptions

Both

- 18,000 EVMT for BEVs (constant over time)
- 5,400 EVMT for PHEVs (constant over time)
- 20 kWh / 100km (2017) 15 kWh/ 100km (2030)

HQ

- 93% charging is at home in 2017, dropping to 80% by 2030 as more public charging becomes available

Reference

- 93% charging is at home (constant over time)

PEV Adoption Forecast – S Curve

- **Diffusion curves are one of the most widely used methods to forecast the adoption of new technology in an economy.**
  - Many different technologies across many industries have had their market share grow in the form of an S-curve.
- **E3 has used the following S-curve in previous studies for EV adoption**

$$Market\ Share\ (\%) = \frac{Market\ Saturation\ (\%)}{\left(1 + constant^{\frac{\left(f + \frac{g}{2} - y\right)}{g}}\right)}$$

Where: $f = Start\ year\ of\ fast\ growth$

$g = period\ of\ fast\ growth\ (years)$

$y = current\ year$

- **This S-curve was fitted to hit certain targets using excels solver**
  - For the HQ scenario, the S-curve was optimized to follow historical data for the years 2012 – 2016 and to ensure the cumulative number of Evs were above the government target by 2030.
  - This gives a realistic growth path for EVs to hit the government target.

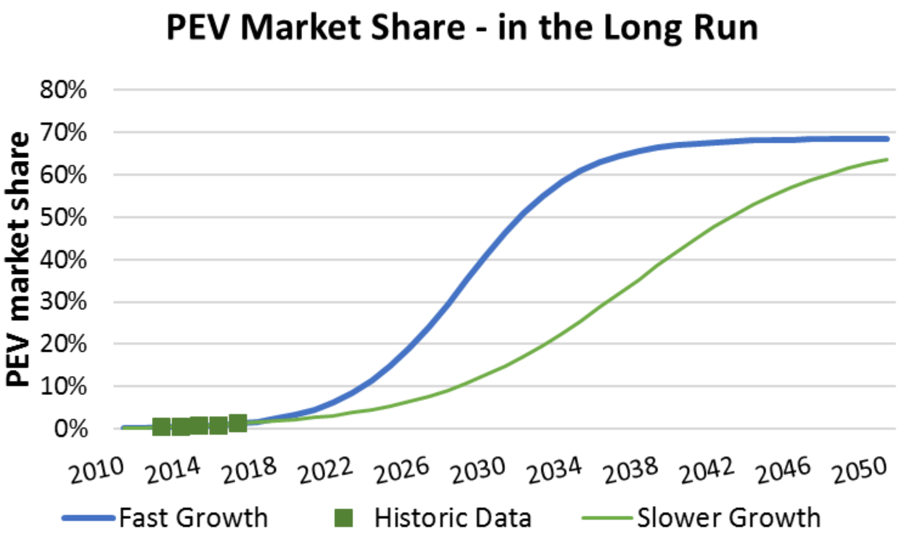
Developing S-Curve

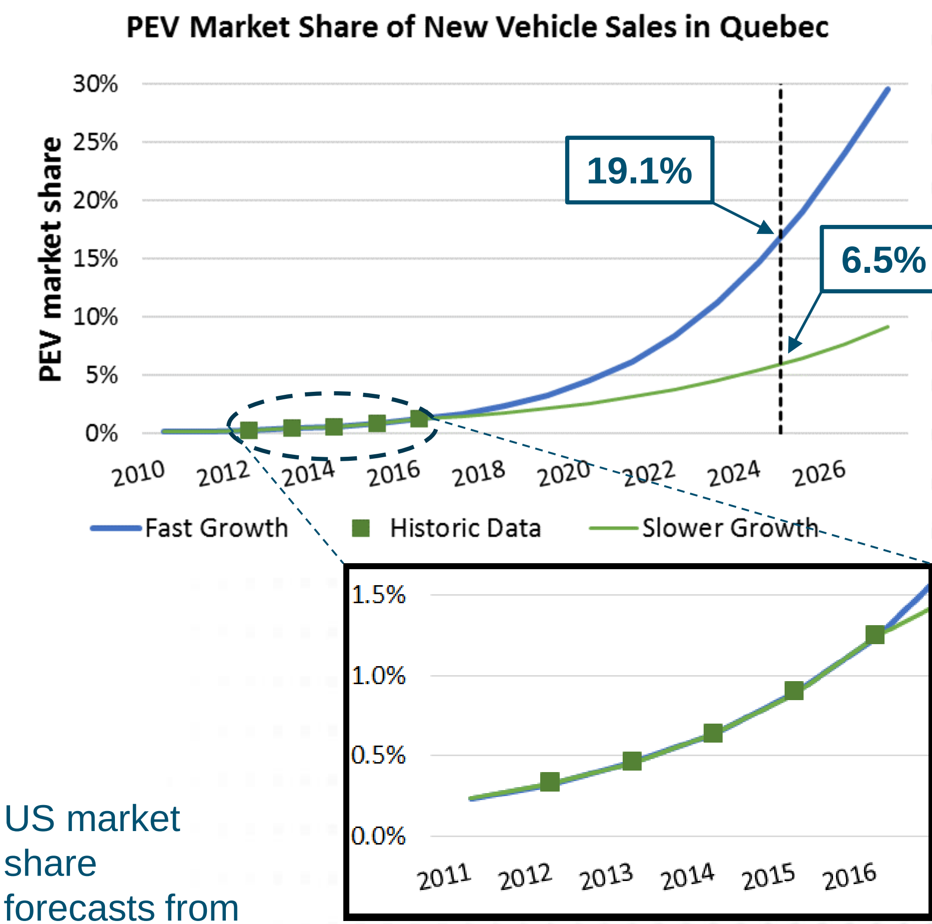
$$Market\ Share\ (\%) = \frac{Market\ Saturation\ (\%)}{\left(1 + constant^{\frac{\left(f + \frac{g}{2} - y\right)}{g}}\right)}$$

Variable	HQ Scenario	Ref Scenario	Description
Market Saturation	69%	69%	Market Saturation is the maximum market share the product reaches. The values here are a weighted average for Quebec where PEV market share for passenger vehicles reaches 80% and PEV market share for light duty trucks reaches 60%
Constant	90.3	89.8	Denominator in the equation used to generate the S-curve
f	2021	2025	Year accelerated adoption phase begins
g	13.3	23.3	Length in years of accelerated adoption

+ **This S-curve was fitted to hit certain targets using the solver**
  - The constant, f, and g parameters were varied.
  - For the HQ scenario, the variables were optimized to follow historical data for the years 2012 – 2016 and to ensure the cumulative number of EVs reached the government target by 2030 giving a realistic growth path for EVs to hit the government target.
  - For the Reference scenario, a market share target was chosen for 2025 of 7.5%. A constraint was also added to ensure the diffusion curve passed through a historic data point for 2016 (1.24%).

PEV Adoption Forecast Results





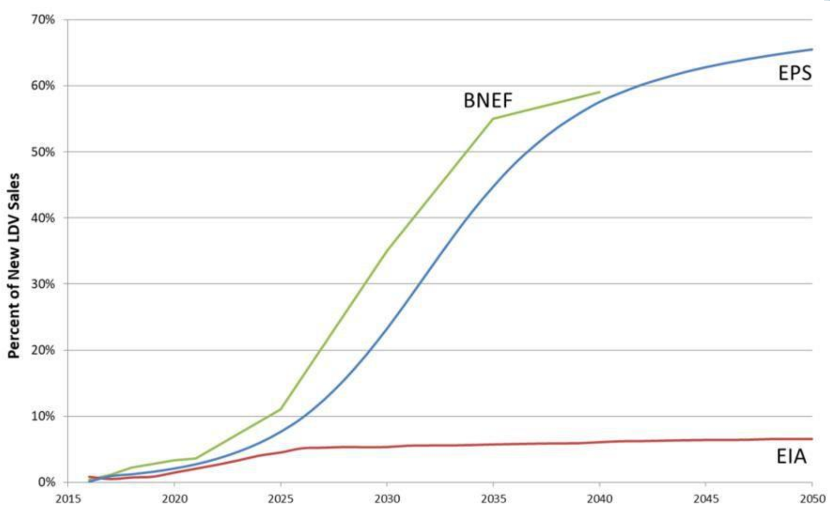


Figure 1. Projections of U.S. market share of EVs from three sources: the Energy Policy Simulator (EPS) 1.3.1 BAU case, the Energy Information Administration (EIA) Annual Energy Outlook 2017 "No Clean Power Plan" side case, and the Bloomberg New Energy Finance (BNEF) Electric Vehicle Outlook 2017.

US market share forecasts from other sources

S-curves fitted to historical market shares in Quebec (source: fleetcarma)

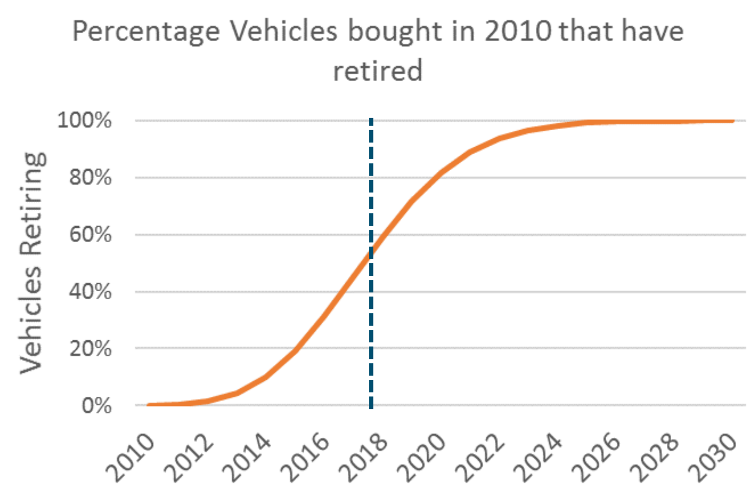
Market Share Assumptions

- For the reference scenario in which fewer DCFCs are deployed, the S-curve deviates
- The biggest challenge with this method is creating a reference scenario – following the narrative created for our reference scenario ideally we would forecast DCFC deployment and then calculate EV growth from that using induced effect data. However much less data is available to forecast DCFC growth compared to data on EV growth.
- Therefore the same method was used for the reference scenario as for the HQ scenario – the DCFC network is calculated based on the forecasted EV fleet size.
- The reference market share forecast represents a slower growth scenario where EV growth is constrained by a slowly evolving DCFC network.
- Most current EV forecasts' central scenario assume a DCFC network will grow sufficiently to support EV growth. These vary from around 5% - 15% by 2025 (see previous slide). The reference scenario here represents a "low growth" scenario. A typical estimate for 2025 market share for a low growth scenario is 5 – 10%. Therefore **7.5%** was used for the reference scenario in this case.

EV Retirement Assumptions

- Since new car sales estimates are used as the primary input data to generate our EV fleet, assumptions must be made about vehicle retirement.
- An average vehicle lifetime of 8 years in 2010 was used, growing to 12 years by 2030.
- A cumulative distribution function is used to model how many vehicles bought in year y, will have retired by year x.
- This generates a matrix with vehicles retired where the columns are date year (x) and rows are the year the vehicle was bought (y)

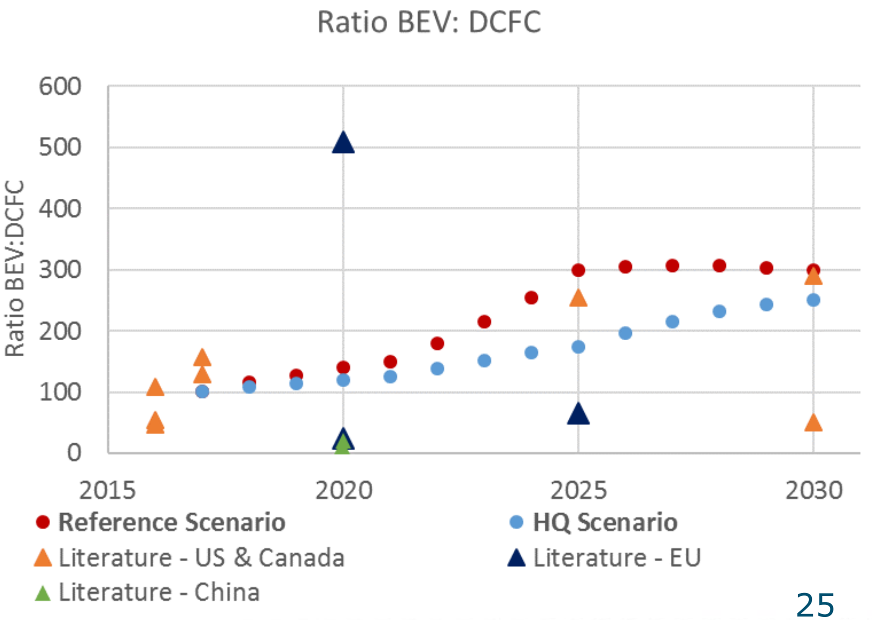
Vintage of PEV	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
2010	0	2	9	27	65	124	203	293	384	464	529	575	606	626	637	642	645	647	647	648	648
2011	-	0	2	11	34	81	158	263	386	512	627	722	792	840	871	888	898	903	905	907	907
2012	-	-	0	3	13	41	101	202	343	512	689	855	994	1,100	1,175	1,223	1,252	1,268	1,276	1,280	1,282
2013	-	-	-	0	3	15	50	125	253	438	664	907	1,140	1,340	1,496	1,608	1,682	1,728	1,754	1,768	1,775
2014	-	-	-	-	0	4	19	62	157	325	572	881	1,222	1,555	1,848	2,083	2,255	2,371	2,444	2,487	2,511
2015	-	-	-	-	-	0	5	23	79	206	433	774	1,213	1,706	2,200	2,644	3,007	3,280	3,468	3,590	3,663
2016	-	-	-	-	-	-	1	6	29	99	261	560	1,018	1,619	2,311	3,018	3,669	4,213	4,630	4,925	5,119
2017	-	-	-	-	-	-	-	1	5	28	99	267	582	1,076	1,740	2,519	3,333	4,098	4,752	5,264	5,634
2018	-	-	-	-	-	-	-	-	1	6	29	106	290	643	1,208	1,983	2,913	3,905	4,857	5,688	6,353
2019	-	-	-	-	-	-	-	-	-	1	6	31	113	314	708	1,352	2,254	3,359	4,561	5,740	6,790
2020	-	-	-	-	-	-	-	-	-	-	1	6	32	120	339	778	1,510	2,555	3,861	5,312	6,763
2021	-	-	-	-	-	-	-	-	-	-	-	1	6	33	126	362	844	1,664	2,858	4,380	6,106
2022	-	-	-	-	-	-	-	-	-	-	-	-	1	6	34	132	385	913	1,827	3,186	4,952
2023	-	-	-	-	-	-	-	-	-	-	-	-	-	1	6	35	137	409	984	2,000	3,539
2024	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	6	36	143	432	1,057	2,181
2025	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	6	36	148	455	1,130
2026	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	6	37	151	472
2027	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	6	37	154
2028	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	6	37
2029	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	6
2030	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0



By 2018, ~50% of Evs bought in 2010 have retired since the mean lifetime of these vehicles is 8 years

BEV:DCFC Ratio Assumptions

- **A broad range of BEV: DCFC ratios were derived from the literature**
- **The large variation is primarily because the ratio is so dependent on a wide variety of uncertain variables:**
  - For example – future market shares of BEV/PHEV/hybrid EV, driver preferences and behavior, EV range, availability of home charging
  - Hence US & Canadian estimates were deemed the most indicative of Quebec's optimal ratio.
- **The Difference between the ratios:**
  - **HQ Case:** HQ plan a DCFC program to ensure Quebec's DCFC network is of sufficient size to support government EV goals using Target BEV:DCFC ratios for 2021, 2025 and 2030.
  - **Reference Case:** No HQ program, DCFCs built by 3rd party and Circuit Électrique resulting in slower DCFC growth that cannot keep up with EV growth. This results in the ratio of BEVs to DCFCs in Quebec growing quickly to a maximum value of around 300.



Comparing the Induced Effect

- **The induced effect arising from the difference between the EV and DCFC forecasts for the HQ and Reference Scenarios was then measured to ensure it is consistent with the literature:**
- **Assuming all else is constant and only the number of DCFCs change in the two scenarios, literature suggests:**

Relative Elasticity of DCFCs vs PEVs: **>0.84**

- i.e. if number of DCFCs increases by 10%, the number of PEVs should increase by at least 8.4%
- **Source (statistical study):** Li, Tong, Xing et al. The Market for Electric Vehicles: Indirect Network Effects and Policy Impacts

Additional PEVs sold per additional DCFC built: **195 – 308***

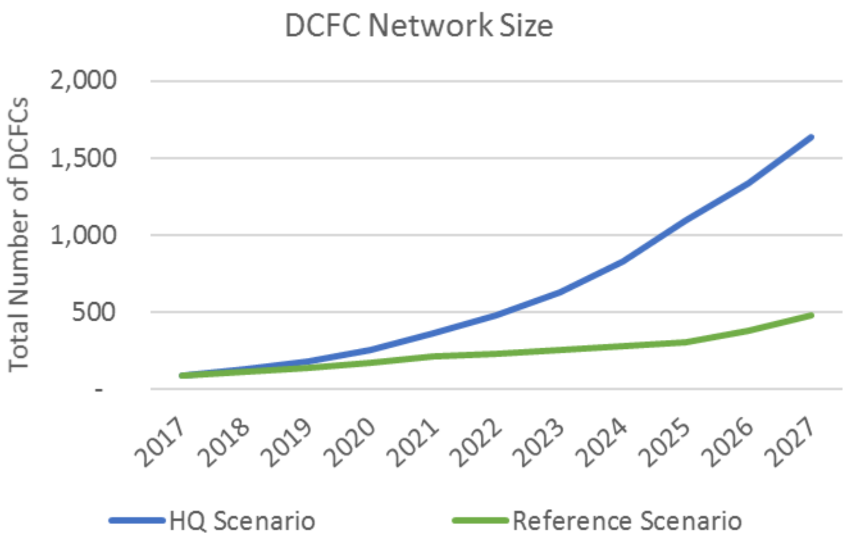
- **Source (forecasting study):** PGE & Navigant – Transportation Electrification Plan

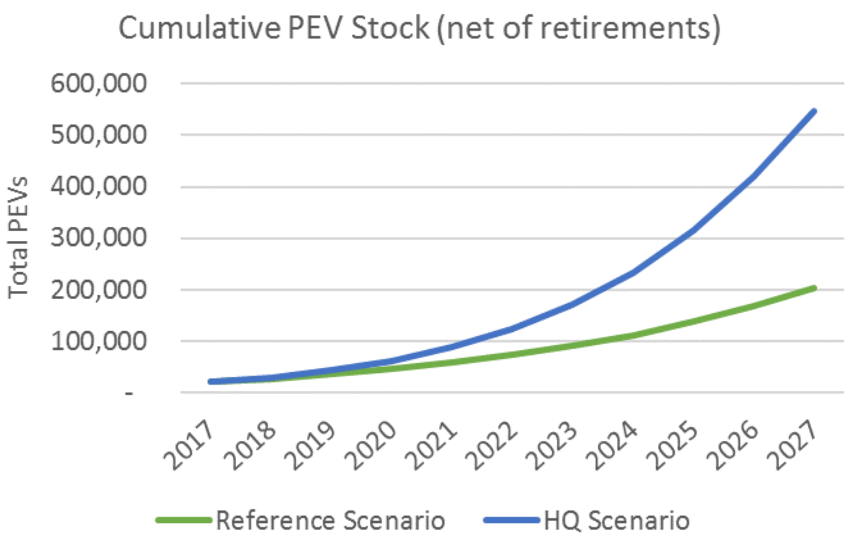
Market share growth per DCFC: **~ 0.019%***

- **Source(statistical study):** Sierzchula, Bakker, Maat et al. - The influence of financial incentives and other socio-economic factors on electric vehicle adoption

*These figures were have been translated from the study results to Quebec specific estimates using Quebec population data and DCFC: L2 ratios

Results

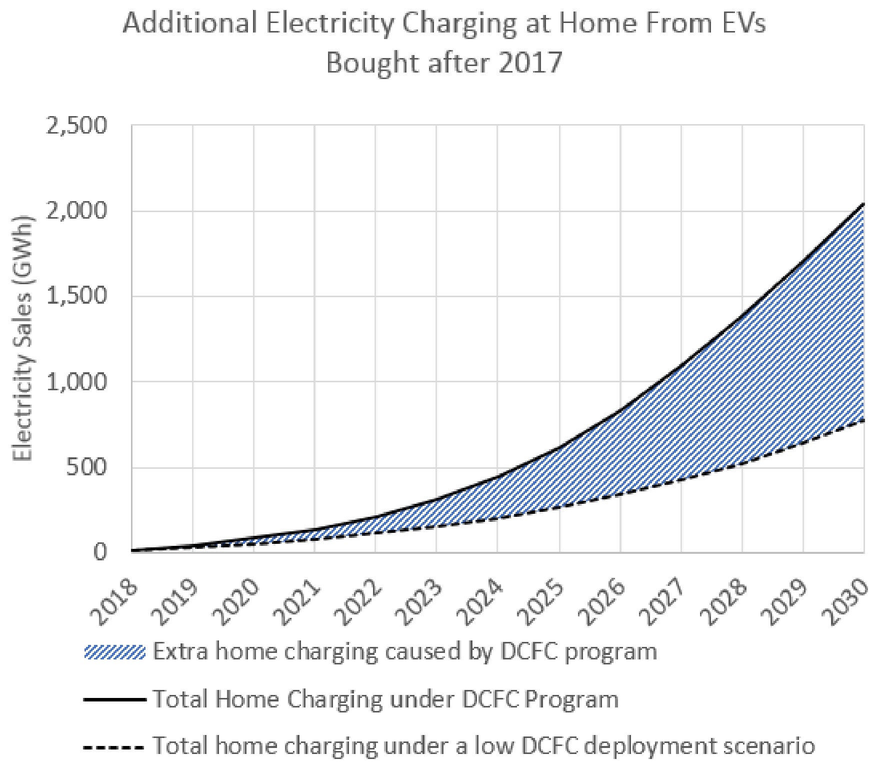


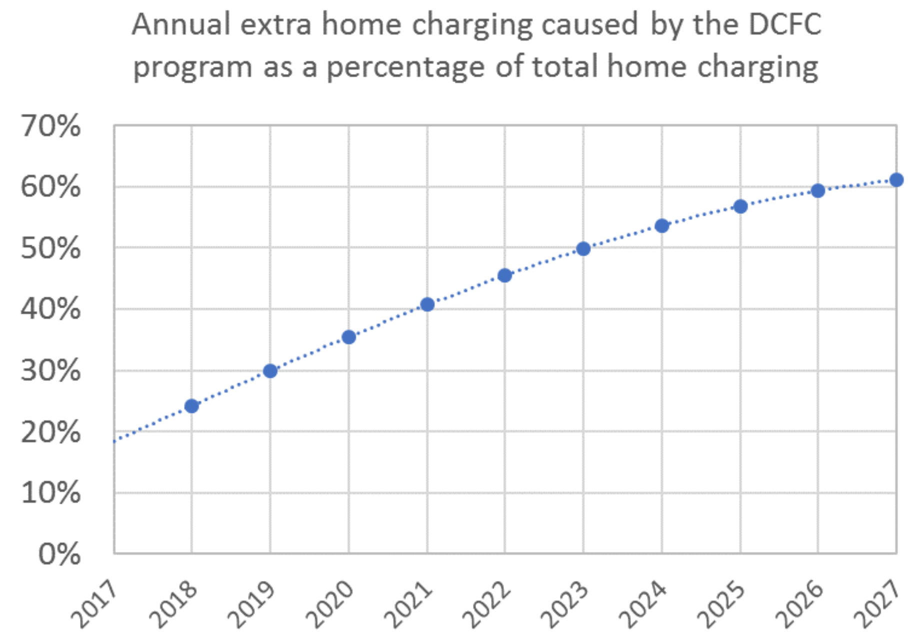


	DCFC				PEVs			
Year	Reference	HQ	Difference	Relative Difference	Reference	HQ	Difference	Relative Difference
2021	178	394	216	121%	60,977	87,566	26,589	44%
2025	305	1,012	707	232%	152,461	316,450	163,989	108%
2027	489	1,689	1200	245%	231,585	546,418	314,833	136%

Induced Effect Measure	Value	Literature Value
Absolute Induced Effect: PEVs /DCFCs added	271	195 - 308
Relative Induced Effect	1.10	0.84 (lower bound)
Market Share Increase per DCFC added	0.0161%	0.0190%

Cumulative Results





Description	Cumulative Totals	Units
Cumulative Sales in the Reference Scenario	1,753	GWh
Cumulative Sales in the HQ Scenario	3,859	GWh
Difference in Scenarios	2,106	GWh
% of new Home Charging due to HQ program	55%	

The "Difference in Scenarios" represents the added value HQ program has in Quebec instead of an alternative scenario involving Circuit Électrique and/or private sector 3rd parties

Energy+Environmental Economics

Thank You!

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