Sizing Algorithm Validation for Several Vehicle Powertrains

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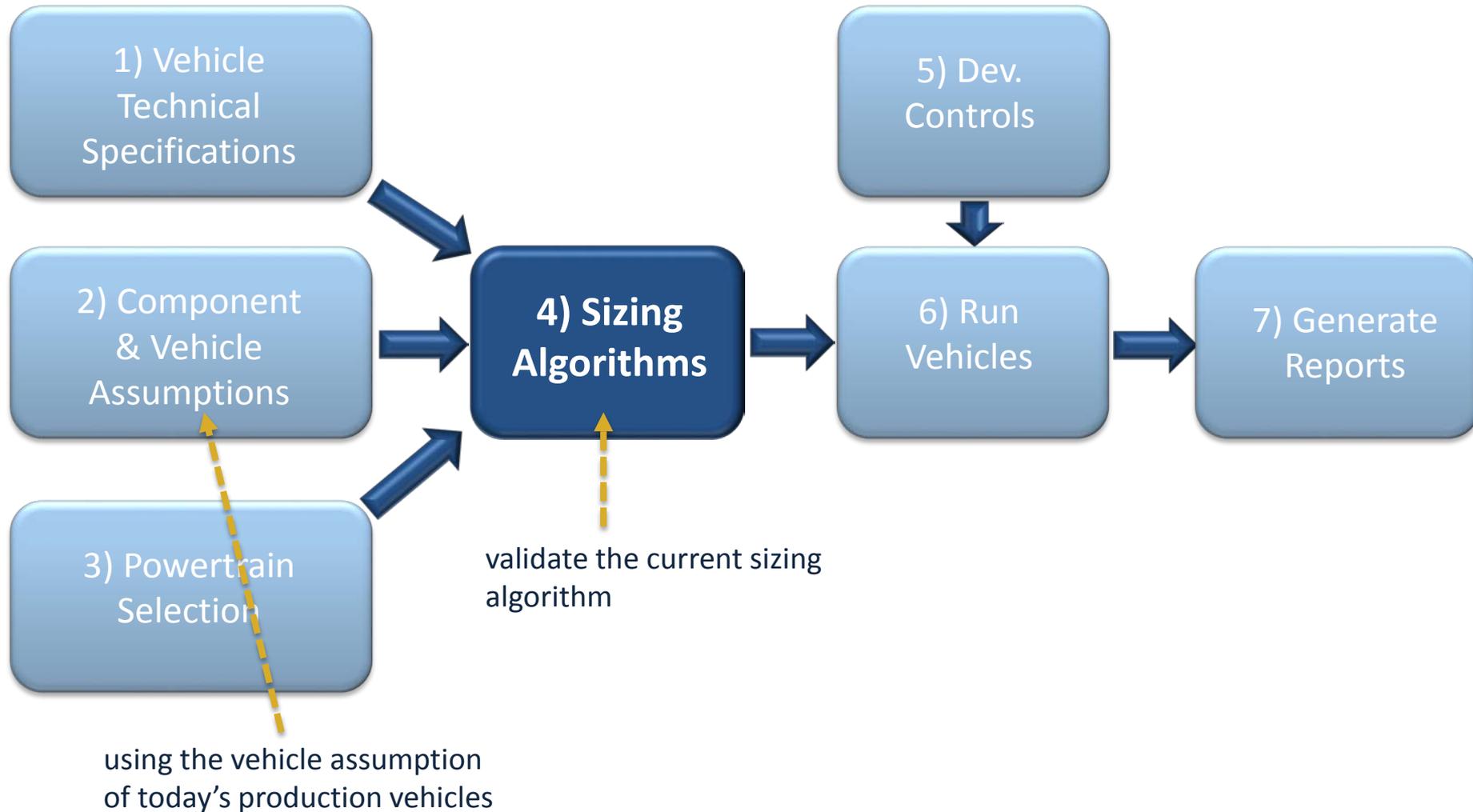
U.S. DEPARTMENT OF **ENERGY**

Approach

> ## *The objective is to validate the current sizing algorithms using today's production vehicles assumptions.*

- Use publicly available vehicle assumptions for each powertrain.
- Size the vehicles to meet each vehicle technical specifications (I.e. performance, range…) with following assumptions.
  - Conventional vehicle with MY2013 Hyundai Sonata 6 ATX vehicle
  - HEV with MY2010 Toyota Prius HEV
  - PHEV with MY2013 Toyota Prius PHEV and MY2012 GM Volt
  - BEV with MY2013 Nissan Leaf
- Compare sizing results for each powertrain to their respective production vehicles.

Proposed Methodology

1) Vehicle Technical Specifications

2) Component & Vehicle Assumptions

3) Powertrain Selection

4) Sizing Algorithms

5) Dev. Controls

6) Run Vehicles

7) Generate Reports

validate the current sizing algorithm

using the vehicle assumption of today's production vehicles

Vehicle Technical Specification

- IVM – 60 mph at X sec (+/- 0.1 sec)

- Grade 6% at 65 mph at GVW (engine / fuel cell only)

- Maximum vehicle speed >= 100 mph – exception for BEV and FCHEV at 80mph

- 50 to 80 mph of X sec (+/- 0.1 sec)

- Max grade launch from a stop forward and reverse 30%

Component Assumptions

- All component performance data are public information.

- The other vehicle assumption of today's vehicles are used for
  - Vehicle coefficient of drag (http://ecomodder.com/wiki/index.php/Vehicle_Coefficient_of_Drag_List)
  - Vehicle front area
  - Transmission
  - Wheel radius
  - Battery energy density, Wh/kg (only for BEV)

- Acceleration performance (IVM – 60 mph at X sec) of today's vehicles.

Overall Sizing Philosophies

- Engine/fuel cell sized to meet 70% of peak power required to meet VTS
- HEV
  - Battery power sized to recuperate 100% energy on UDDS
  - Electric machine power sized to meet performance
- Low Energy PHEVs (blended)
  - Battery energy sized to meet AER on UDDS based on unadjusted values
  - Electric machine & battery powers sized to be able to follow the UDDS in EV mode at low SOC (beginning of CS)
- High Energy PHEVs (extended range)
  - Battery energy sized to meet AER on UDDS based on unadjusted values
  - Electric machine & battery powers sized to be able to follow the US06 in EV mode at low SOC (beginning of CS)
- BEV (100 miles range)
  - Battery energy sized to meet range on UDDS based on unadjusted values

Conventional Vehicle Assumptions

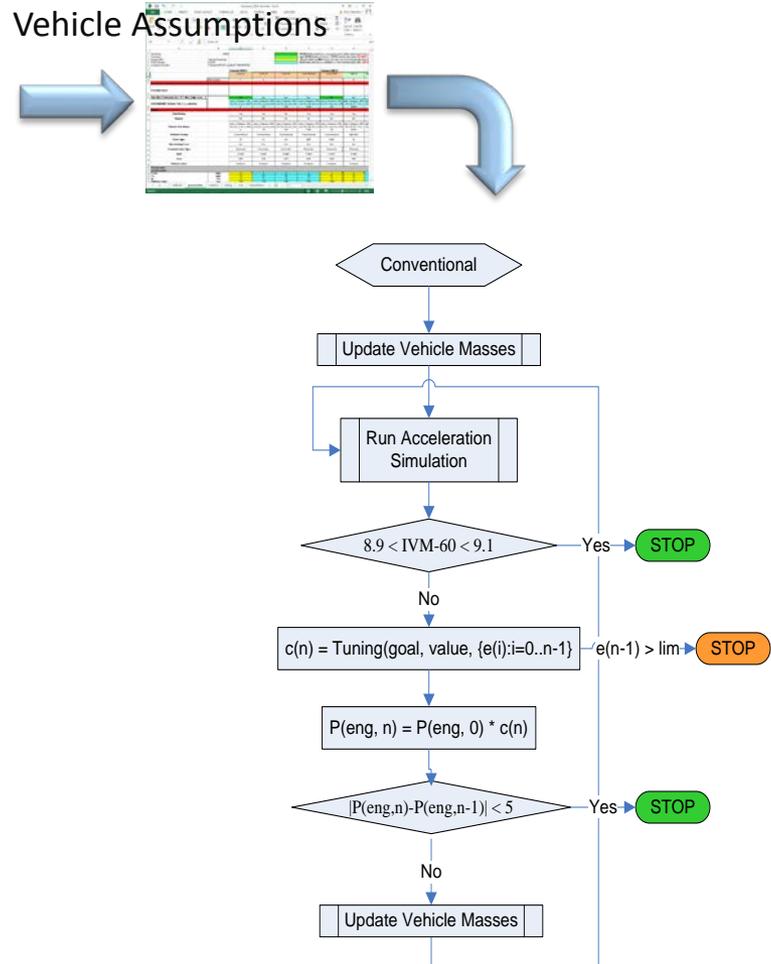- Conv. auto trans 2wd vehicle : Hyundai Sonata 6 ATX MY2013

Conventional Sonata 6 ATX
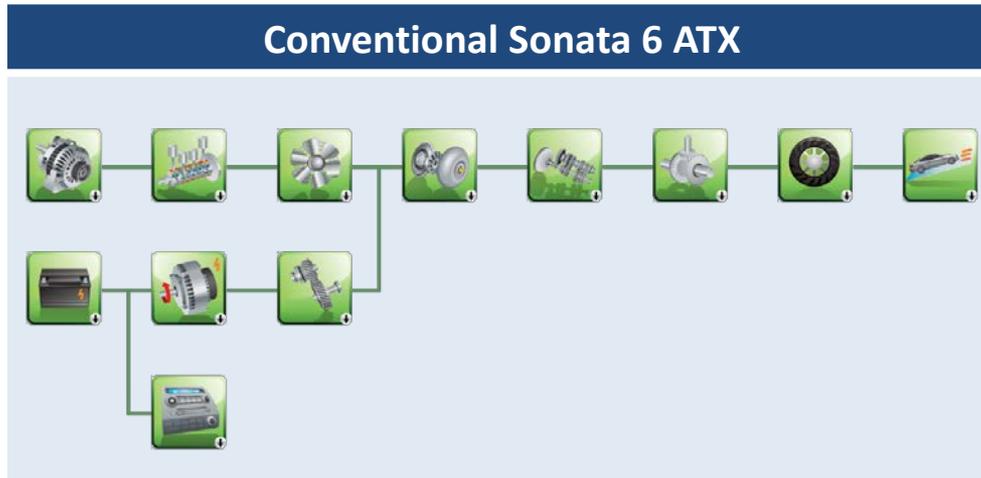
Spec.

Gear ratio	Final drive	Wheel radius
4.21, 2.64, 1.80, 1.39, 1.00 0.77	2.89	0.3218 m
Drag coefficient	Front area	0-60 mph
0.32 *	2.18 m^2 *	7.9 sec **

* http://ecomodder.com/wiki/index.php/Vehicle_Coefficient_of_Drag_List
** https://en.wikipedia.org/wiki/Hyundai_Sonata

Vehicle Assumptions

Conventional

↓

Update Vehicle Masses

↓

Run Acceleration Simulation

↓

$8.9 < IVM\text{-}60 < 9.1$ — Yes → STOP

No ↓

$c(n) = Tuning(goal, value, \{e(i):i=0..n\text{-}1\})$ — $e(n\text{-}1) > lim$ → STOP

↓

$P(eng, n) = P(eng, 0) * c(n)$

↓

$|P(eng,n)\text{-}P(eng,n\text{-}1)| < 5$ — Yes → STOP

No ↓

Update Vehicle Masses

Conventional Vehicle Results

- Sizing comparison results for conv. auto trans 2wd vehicle

	OEM Source : Hyundai Sonata 6 ATX MY2013	Sizing results form Autonomie	Comparison
Vehicle weight	1588 kg	1593 kg	0.3 %
Engine Power	154 kW	144 kW	-6.4 %
Acceleration Performance: 0-60 mph	7.90 sec	7.89 sec	-

- Baseline vehicle specification : Hyundai Sonata 6 ATX MY2013
- Sizing results from the same acceleration constraint

HEV - Split Powertrain Assumptions

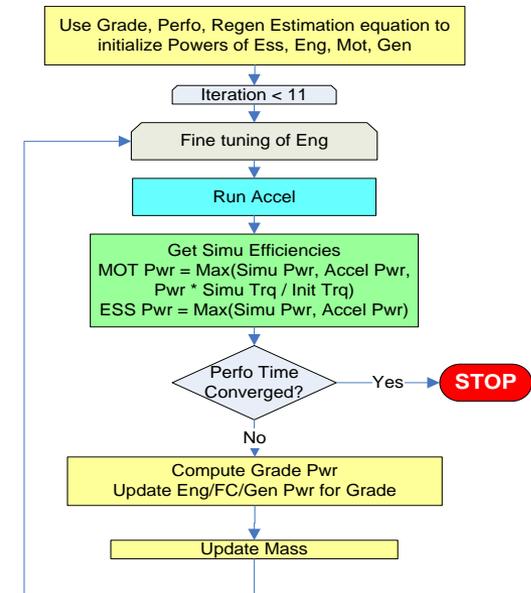- Split HEV 2wd vehicle : Toyota Prius HEV MY2010
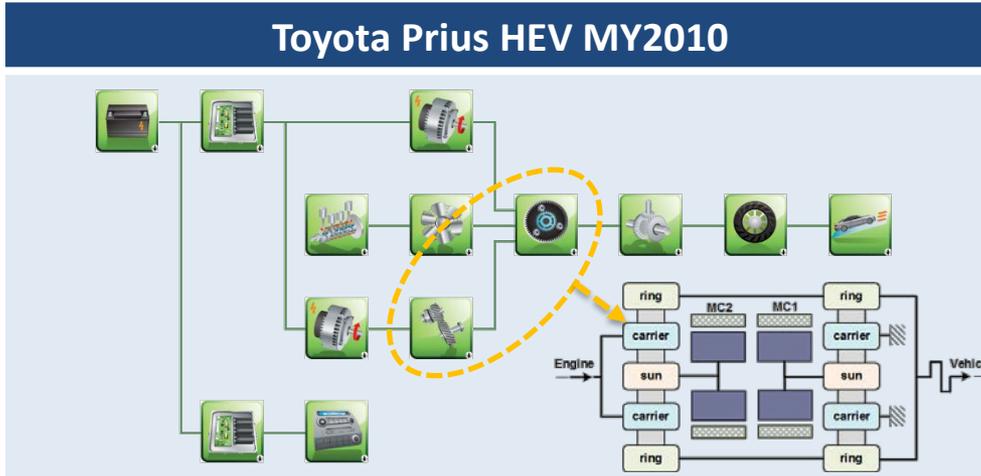
Toyota Prius HEV MY2010

Spec.

Gear ratio	Final drive	Wheel radius
RG1/SG1 = 2.6, RG2/SG2 = 2.64	3.268	0.317 m
Drag coefficient	**Front area**	**0-60 mph**
0.25 *	2.25 m^2 *	9.7 sec **

* http://ecomodder.com/wiki/index.php/Vehicle_Coefficient_of_Drag_List
** http://www.zeroto60times.com/vehicle-make/toyota-0-60-mph-times/

Vehicle Assumptions

Use Grade, Perfo, Regen Estimation equation to initialize Powers of Ess, Eng, Mot, Gen

Iteration < 11

Fine tuning of Eng

Run Accel

Get Simu Efficiencies
MOT Pwr = Max(Simu Pwr, Accel Pwr, Pwr * Simu Trq / Init Trq)
ESS Pwr = Max(Simu Pwr, Accel Pwr)

Perfo Time Converged? — Yes → **STOP**

No

Compute Grade Pwr
Update Eng/FC/Gen Pwr for Grade

Update Mass

Run Simulation
Tune Variable
Update Values using Simulation Results
Update Values using Equation

HEV - Split Powertrain Results

- Here is the sizing comparison results for Split HEV 2wd vehicle

	OEM Source : Toyota Prius HEV MY2010	Sizing results form Autonomie
Vehicle weight	1530 kg	1463 kg
Engine Power	73 kW	75 kW
Motor1 Power	60 kW	66 kW
Motor2 Power	40 kW	43 kW
Battery Power	27 kW	36 kW
Acceleration Performance: 0-60 mph	9.7 sec	9.74 sec

- Baseline vehicle specification : Toyota Prius HEV MY2010
- Specific power for electric motor and battery is from BaSceFY15 assumptions
- Sizing results from the same acceleration constraint

PHEV - Split Powertrain Assumptions

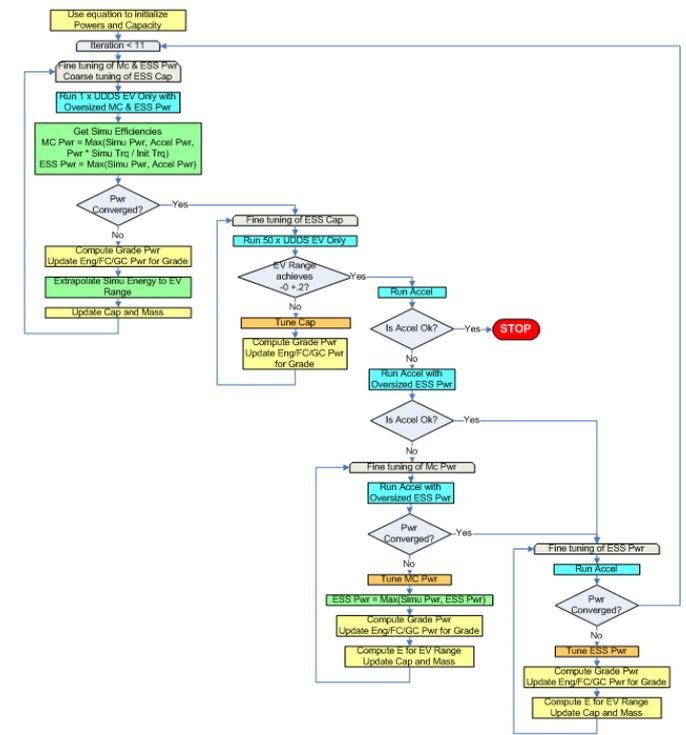- Split PHEV 2wd vehicle : Toyota Prius PHEV MY2013
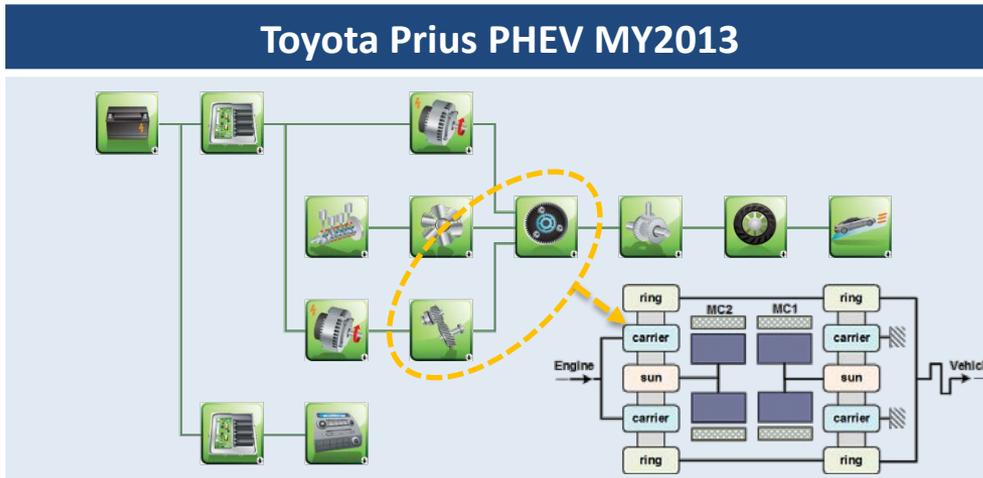
Toyota Prius PHEV MY2013

Vehicle Assumptions

Spec.

Gear ratio	Final drive	Wheel radius
RG1/SG1 = 2.6, RG2/SG2 = 2.64	3.268	0.317 m
Drag coefficient	Front area	AER (UDDS)
0.25 *	2.25 m^2 *	15 mile **

* http://ecomodder.com/wiki/index.php/Vehicle_Coefficient_of_Drag_List
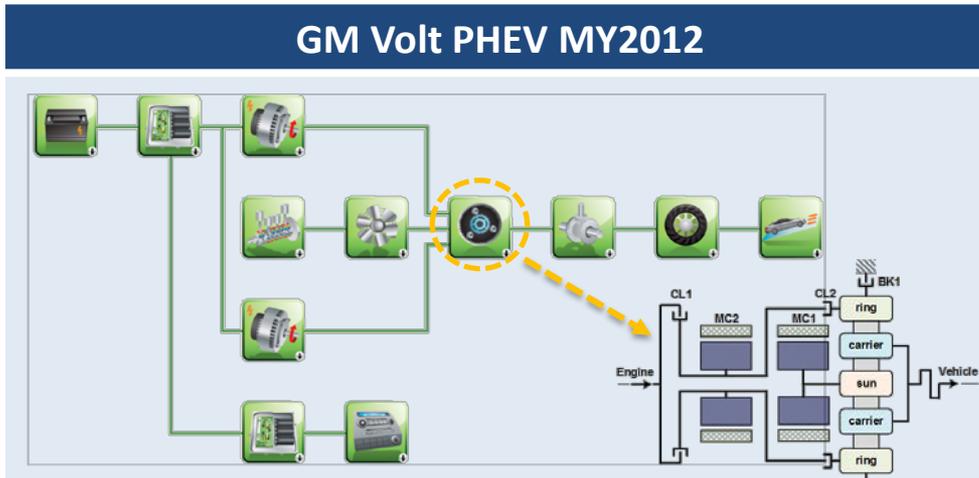** APRF

PHEV - Split Powertrain Results

- Sizing comparison results for Split PHEV 2wd vehicle

	OEM Source : Toyota Prius PHEV MY2013	Sizing results form Autonomie
Vehicle weight	1531 kg	1532 kg
Engine Power	73 kW	74 kW
Motor1 Power	60 kW	57 kW
Motor2 Power	40 kW	47 kW
Battery capacity	4.4 kWh	4.8 kWh
Acceleration Performance: 0-60 mph	10.7 sec	10.59 sec

- Baseline vehicle specification : Toyota Prius PHEV MY2013
- The specific power for electric motor and energy density for battery are from BaSceFY15 assumptions.
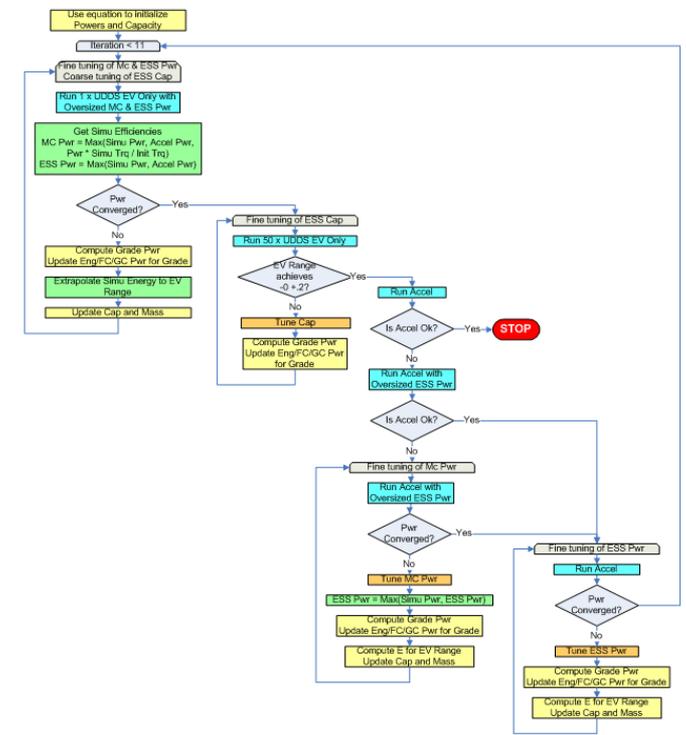- Sizing results from the same all electric range and acceleration constraint.
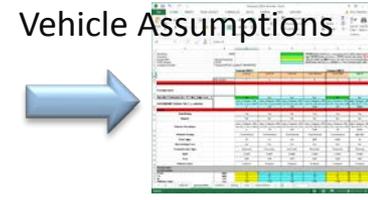
PHEV – Voltec Powertrain

- Erev PHEV 2wd vehicle : GM Volt PHEV MY2012

GM Volt PHEV MY2012		
Spec.		
Gear ratio	Final drive	Wheel radius
RG/SG = 2.24	2.17	0.323 m
Drag coefficient	Front area	AER (UDDS)
0.28 *	2.16 m^2 *	44.5 mile **

Vehicle Assumptions

* http://ecomodder.com/wiki/index.php/Vehicle_Coefficient_of_Drag_List
** APRF or https://en.wikipedia.org/wiki/Chevrolet_Volt

PHEV - Voltec Powertrain

- Here is the sizing comparison results for Voltec PHEV 2wd vehicle

	OEM Source : GM Volt PHEV MY2012	Sizing results form Autonomie
Vehicle weight	1867 kg	1979 kg
Engine Power	64 kW	93 kW
Motor1 Power	111 kW	108 kW
Motor2 Power	54 kW	93 kW
Battery capacity	16.0 kWh	15.8kWh
Acceleration Performance: 0-60 mph	9.0 sec	8.97 sec

- Baseline vehicle specification : GM Volt PHEV MY2012
- The specific power for electric motor and energy density for battery are from BaSceFY15 assumptions.
- In Autonomie, engine/motor2 sized to meet 70% of peak power required to meet VTS.
- Sizing results from the same all electric range and acceleration constraint.

BEV100 Single Gear

- BEV100 single gear 2wd vehicle : Nissan Leaf BEV MY2013
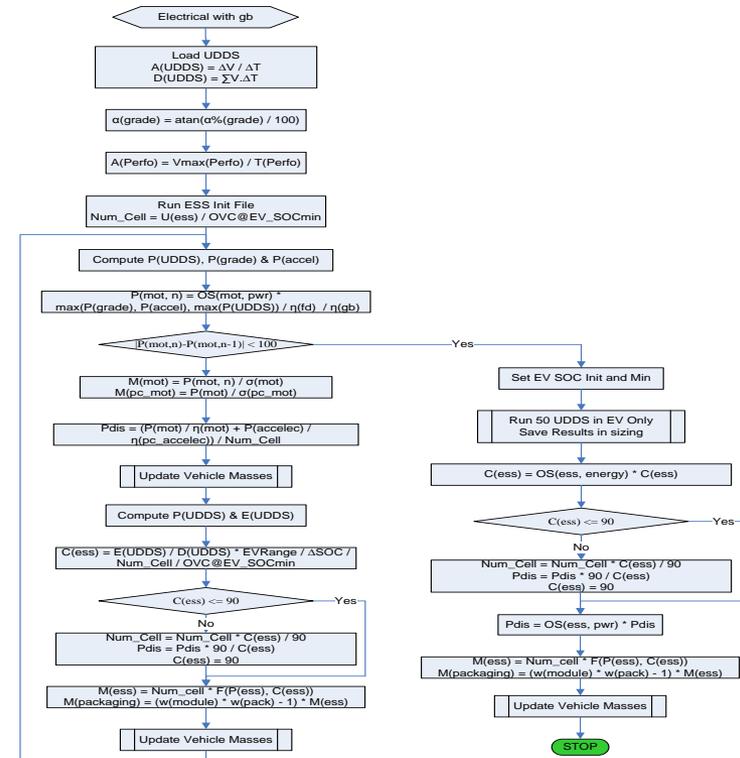
Nissan Leaf BEV MY2013

Vehicle Assumption

Spec.		
Single speed constant ratio	Wheel radius	Energy Density
7.94	0.316 m	100 Wh/kg
Drag coefficient	Front area	AER (UDDS)
0.29 *	2.27 m^2 *	100 mile **

* http://ecomodder.com/wiki/index.php/Vehicle_Coefficient_of_Drag_List
** APRF or https://en.wikipedia.org/wiki/Nissan_Leaf

BEV100 Single Gear

- Here is the sizing comparison results for Nissan Leaf BEV MY2013

	OEM Source : Nissan Leaf BEV MY2013	Sizing results form Autonomie
Vehicle weight	1521 kg	1537 kg
Motor1 Power	107 kW	95 kW
Battery capacity	24 kWh	25.6 kWh
Acceleration Performance: 0-60 mph	9.7 sec	9.68 sec

- Baseline vehicle specification : Nissan Leaf BEV MY2013
- The specific power for electric motor is from BaSceFY15 assumptions, but the energy density for battery is from Leaf (100 Wh/kg)
- The SOC windows is also same value as Leaf (80%)
- Sizing results from the same all electric range and acceleration constraint.

Summary

- Vehicle sizing results for several vehicles were compared with the vehicle assumption of today's production vehicles.

- The results of our sizing algorithms are pretty close considering many component characteristics are different, except for the engine peak power of the GM Volt, which is much smaller than the one we predicted.
  - → The reason is that we now assumed that engine/motor2 sized to meet 70% of peak power required to meet VTS.

- Using similar vehicle assumptions that today's vehicles, we obtain similar component sizes for several vehicles.