Advanced Transmission Selection to Provide Accurate VTO Benefits

2015 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

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Sponsored by David Anderson

Project ID #VSS166

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project Overview

Timeline

- Start – September 2015
- End – September 2016
- 50% Complete

Budget

- FY15
  - $250K

Barriers

- Constant advances in transmission technology.
- Unbiased evaluation of VTO technology benefits need proper selection of transmission technology.

Partnership

- Argonne APRF
- Automotive manufacturer (technical guidance)

Relevance

OEMs Have Announced Numerous Advanced Transmission

7ATX

8ATX

The new 7+ speed transmission features a wide ratio spread, high numerical first-gear ratio, and quick shifting.

The transmission efficiency and wide ratio spread improve fuel economy by operating at a lower engine rpm in both city and highway environments

DCT certainly offers smooth acceleration by eliminating the shift shock that accompanies gearshifts in manual transmissions and even some automatics

DCT

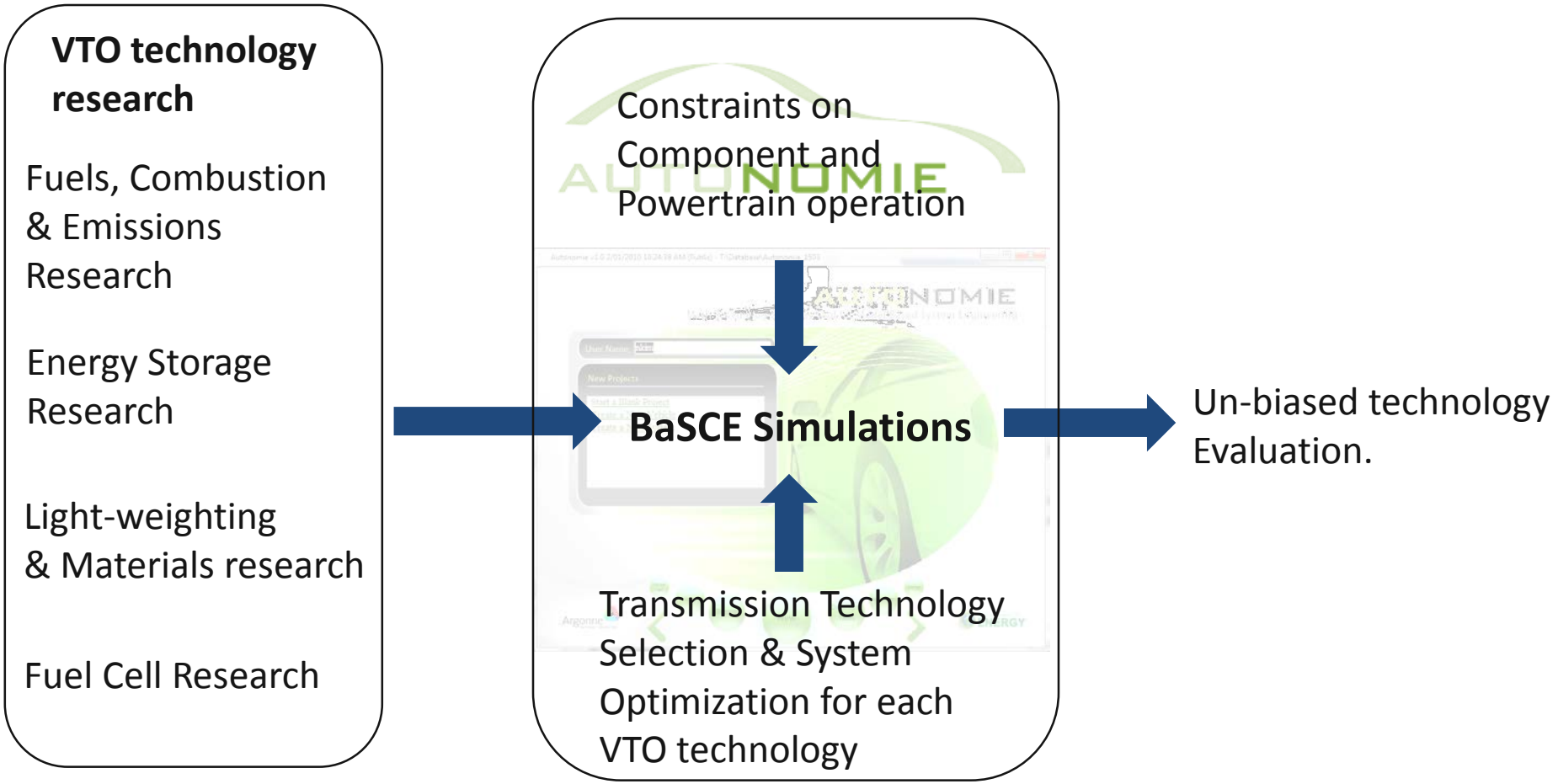
Interest in dual-clutch transmissions is particularly strong among OEMs in Europe and major growth markets in Asia, China in particular

CVT

A new continuously variable transmission (CVT) has been developed for midsize vehicles that significantly enhances both driving performance and fuel economy

Relevance

Unbiased Evaluation of VTO Technology Requires a Rigorous Process of Transmission Parameter Selection and Optimization



Relevance

The objective is to develop algorithms for proper transmission selection and shift parameter optimization to rigorously evaluate impact of VTO technologies on fuel displacement and cost of advanced vehicles

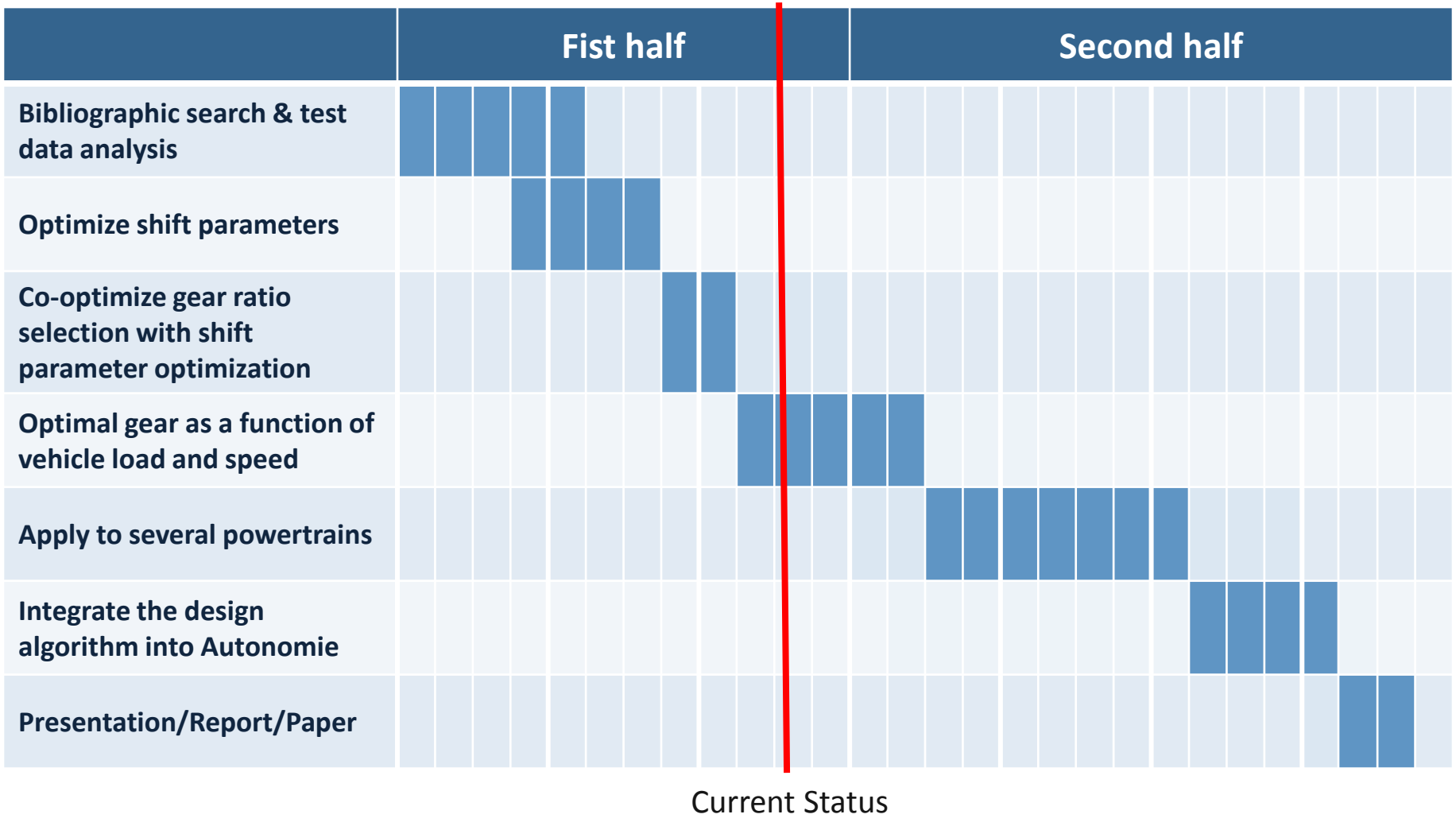
- Provide solid foundation to assess the impact of advanced transmissions and accurate evaluation of VTO benefits & targets Guide future R&D
- Develop transmission selection (i.e. gear selection, gear spread, final drive ratio...) that are dependent on the component and powertrain configurations

Approach

Enhance Transmission Selection Process to Merge with Control Optimization and Vehicle Sizing Process

FY13	Update automatic transmission and shifting algorithm in Autonomie based on current trends in industry
FY14	Develop detailed DCT and CVT transmission models
FY15	Develop process to optimize shift parameters and gear ratio selection for auto transmissions for engine technology. Leverage Autonomie optimization methods to optimize gear ratios for alternate powertrains.
Future	Combine gear ratio selection and transmission optimization with energy management parameter optimization and vehicle sizing algorithm for VTS.

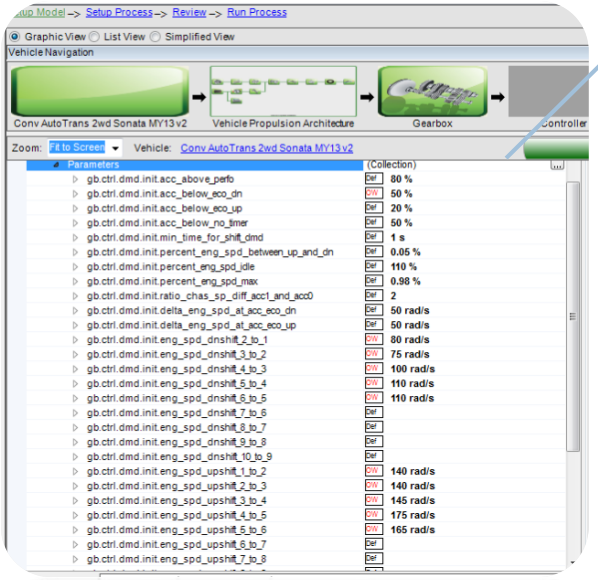
Milestones


Fist half
Second half
Bibliographic search & test data analysis
Optimize shift parameters
Co-optimize gear ratio selection with shift parameter optimization
Optimal gear as a function of vehicle load and speed
Apply to several powertrains
Integrate the design algorithm into Autonomie
Presentation/Report/Paper
Current Status

Technical Accomplishment

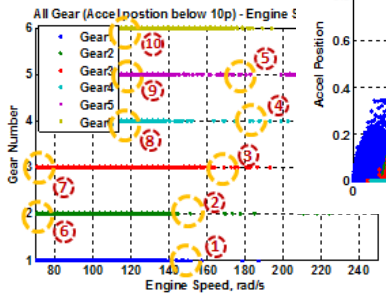
Shifting Algorithm Updated based on ANL APRF Test Data

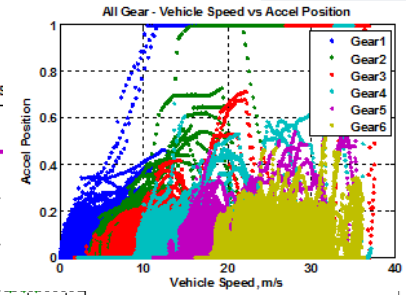
- Refined Shifting Algorithm / Calibration

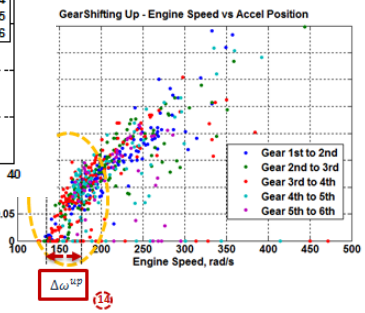


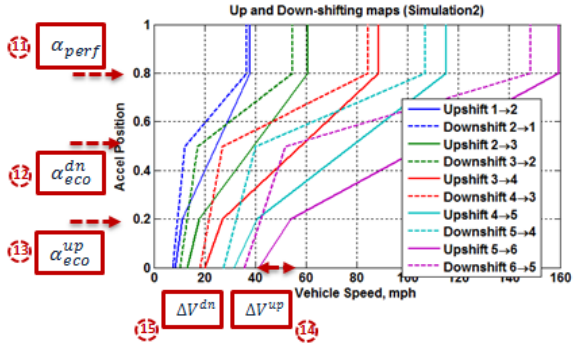
Refined shifting calibration

From test data

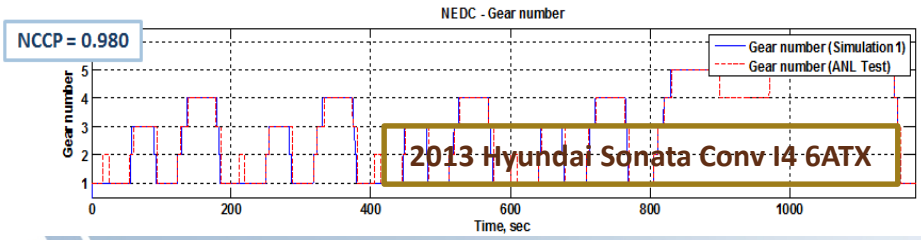


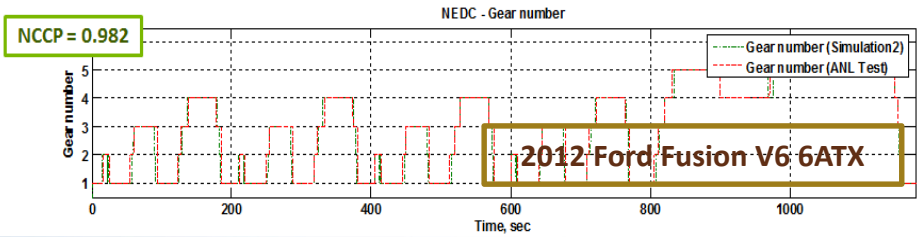






Validation with test data





Technical Accomplishment

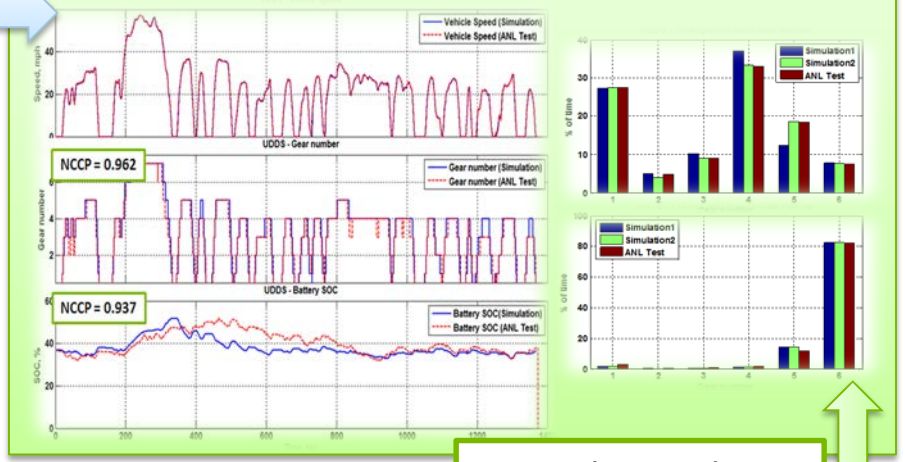
Process Developed to Generate & Validate Transmission Models

Test data from APRF (ANL)

ANL APRF

Test data

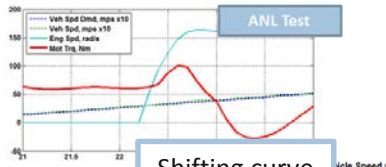
Model Validation



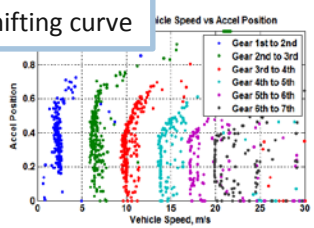
Simulation data

Control and Shifting Analysis

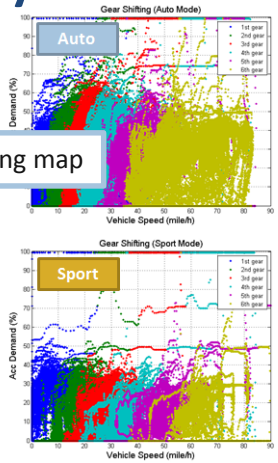
Transient control during shifting



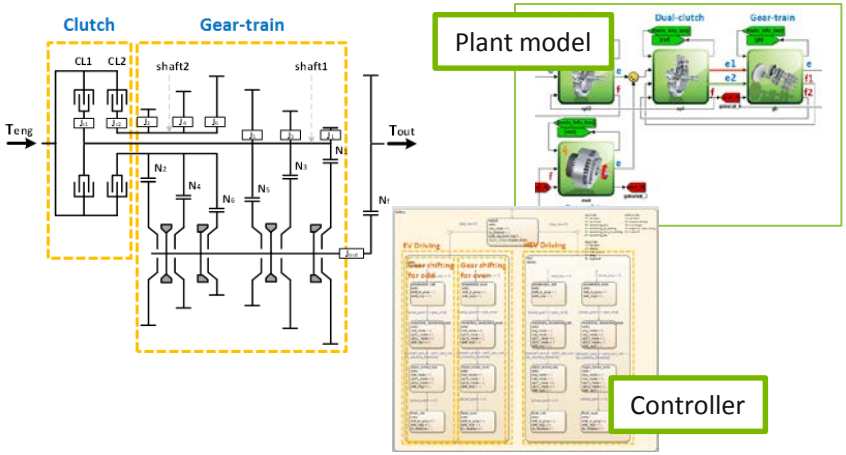
Shifting curve



Shifting map



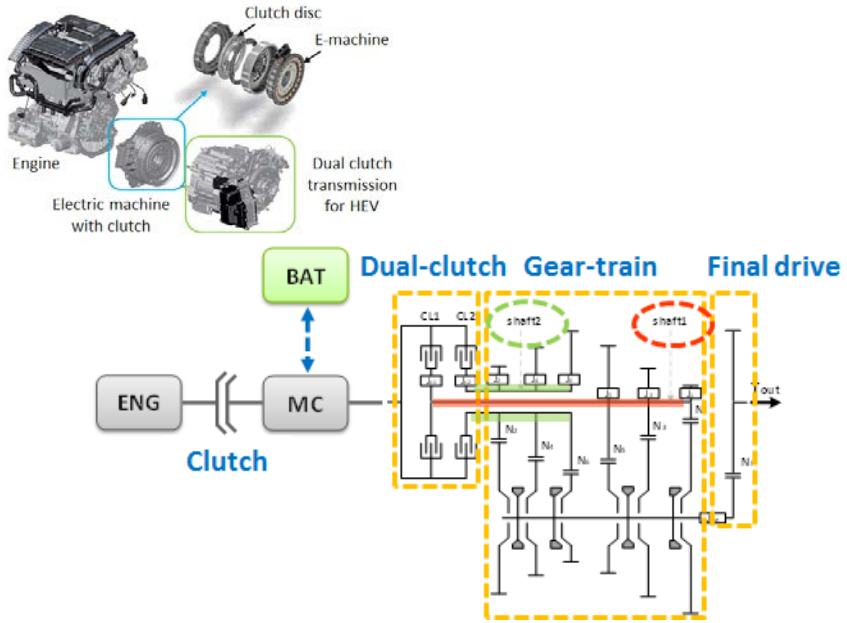
Model Development (Autonomie)

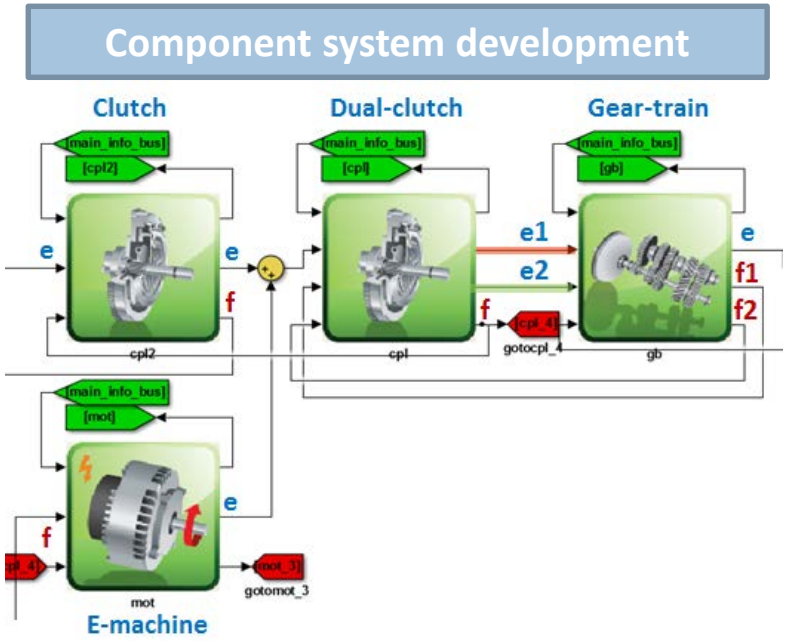


Technical Accomplishment

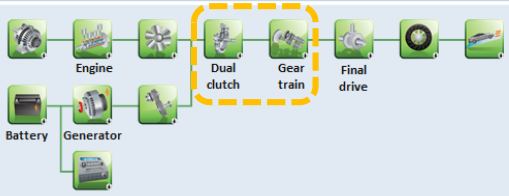
Dual Clutch Transmission Model Developed

- Plant and controller models for the DCT have been developed in Autonomie





System Integration and vehicle level validation

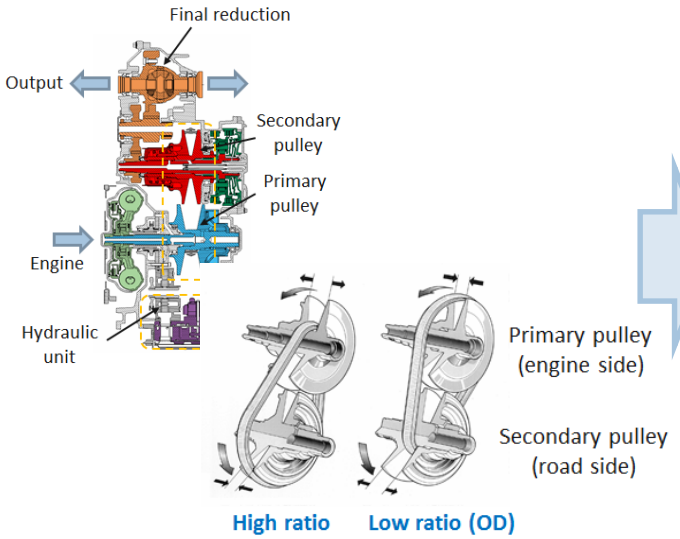
2013 VW Jetta TDI Conv. (6DCT)	Spec.		
	Curb weight	Engine	Battery
	1,595kg	2.0L, 104kW	PB
	Motor	Gear ratio	Final drive
	-	3.46 2.05 1.30 0.90 0.91 0.76	4.12 (for 1,2,3,4) 3.04 (for 5,6)

2013 VW Jetta HEV (7DCT)	Spec.		
	Curb weight	Engine	Battery
	1,647kg	1.4L, 110kW	1.1kWh li-ion
	Motor	Gear ratio	Final drive
	20kW	3.50 2.09 1.34 0.93 0.97 0.78 0.65	4.44 (for 1,2,3,4) / 3.23 (for 5,6,7)

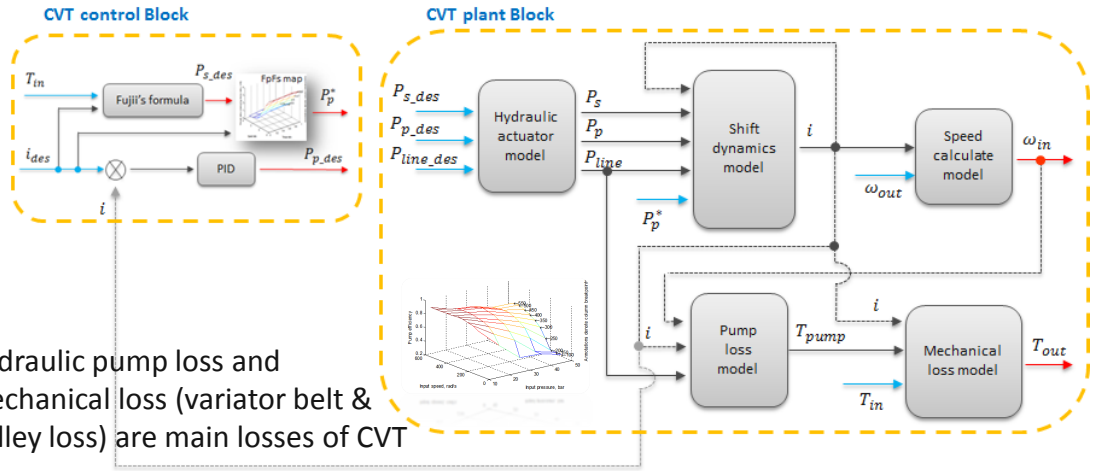
Technical Accomplishment

Continuously Variable Transmission Model Developed

- Plant and controller models for the CVT have been developed in Autonomie

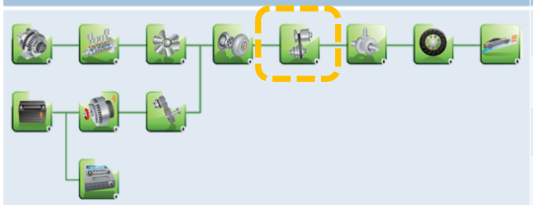


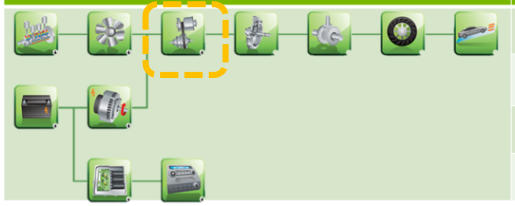
Component system development



Hydraulic pump loss and mechanical loss (variator belt & pulley loss) are main losses of CVT

System Integration and vehicle level validation

2013 Nissan Altima I4 Conv. (CVT)	Spec.		
	Curb weight	Engine	Battery
	1,588kg	2.5L, 110kW	PB
	Motor	Gear ratio	Final drive
	-	0.39~2.35	4.828

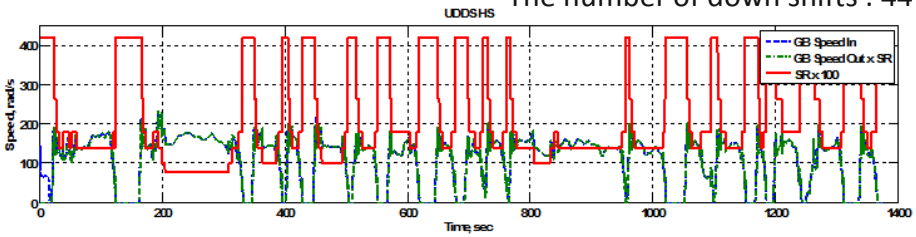
2013 Honda Civic HEV (CVT)	Spec.		
	Curb weight	Engine	Battery
	1,455kg	1.5L, 82kW	0.675kWh, Li-ion
	Motor	Gear ratio	Final drive
	17kW	0.529~3.172	3.94

Technical Accomplishment

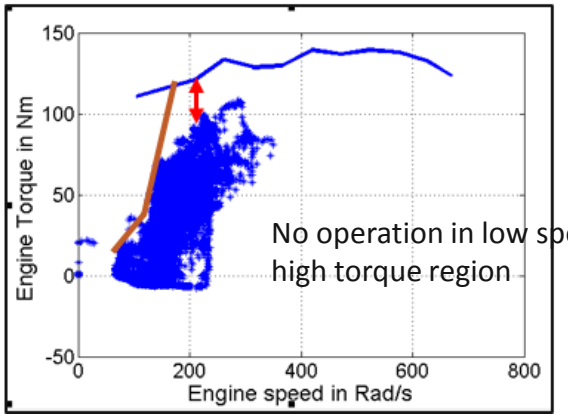
Leverage APRF Test Data, Literature and Transmission Experts for Constraints on Shift Parameter and Gear Selection

- Shift parameter optimization is important to ensure efficient operation within the following constraints:
  - Switch to top gear around 45 MPH under normal drive cycle conditions.
  - Top gear operates above 1250 RPM to prevent lugging.
  - Gear shifting number is around 110 – 120 (UDDS), 6 speed Automatic.
  - Engine Speed does not exceed 3300 RPM in first gear (UDDS Cycle).
  - Limited operation in low speed high torque region (NVH).
  - Torque reserve for UDDS cycle.
  - Industry trends on gear span, final drive ratio.

The number of up shifts : 62
The number of down shifts : 44



Test data – 2013 Sonata 6speed automatic



Test data – 2012 Fiat 500 6speed automatic

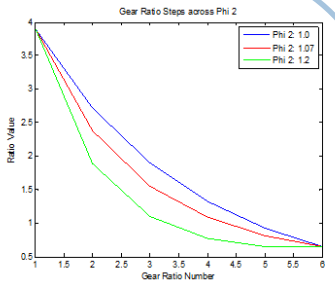
Technical Accomplishment

Algorithm Developed to Co-optimize Gear Ratios and Shift Parameters, based on Industry Trends in Autonomie.

Constraints based on industry trends

$$i_n = i_z \left[\frac{Span}{\phi_2^{0.5(z-1)(n-1)}} \right]^{\frac{z-n}{z-1}} \quad z \neq 1$$

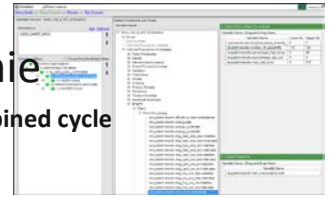
Where
Z = total number of gears.
n = gear number in consideration for design (varies from 1 to z).
φ_2 = progression factor (independent variable – normally between 1 and 1.2
i_z = top gear ratio
i_n = nth gear ratio

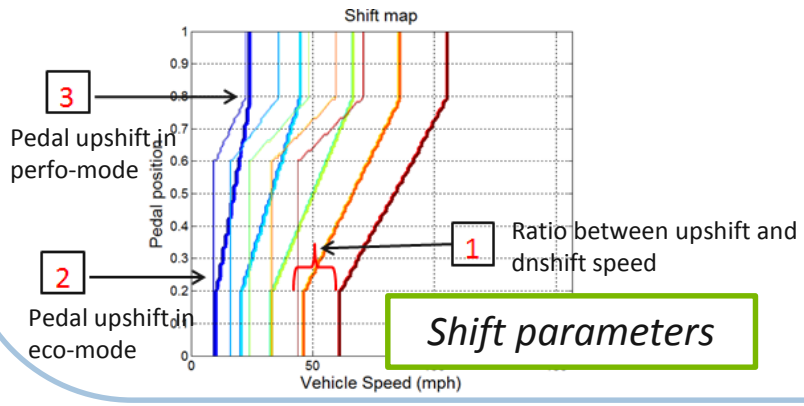


Gear ratio selection

Co-optimize in Autonomie

Minimize the fuel consumption over the combined cycle



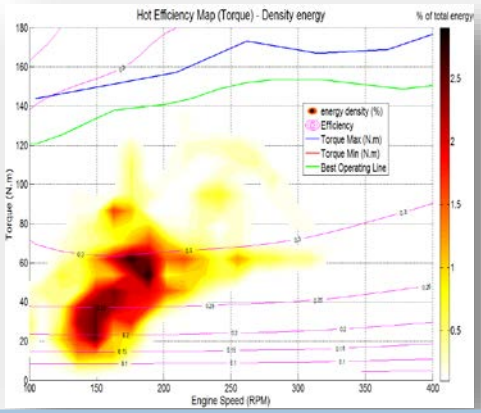


Shift parameters

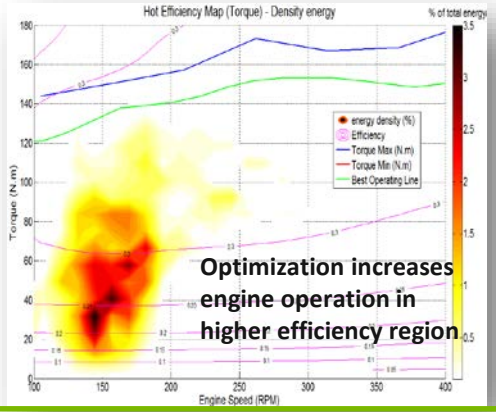
Unbiased FE evaluation for VTO Technologies.

Technical Accomplishment

Gear Selection and Shift Parameter Optimization Ensure Efficient Operation within Engine and Drivability Constraints

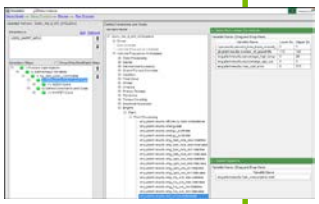


Non-optimized engine operation

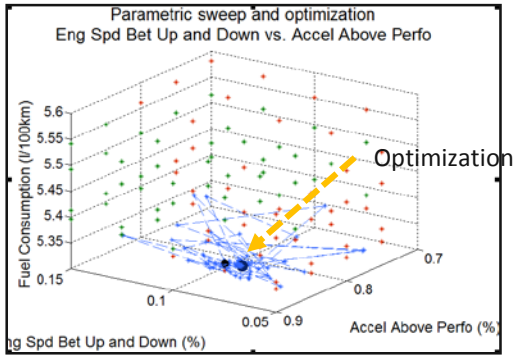


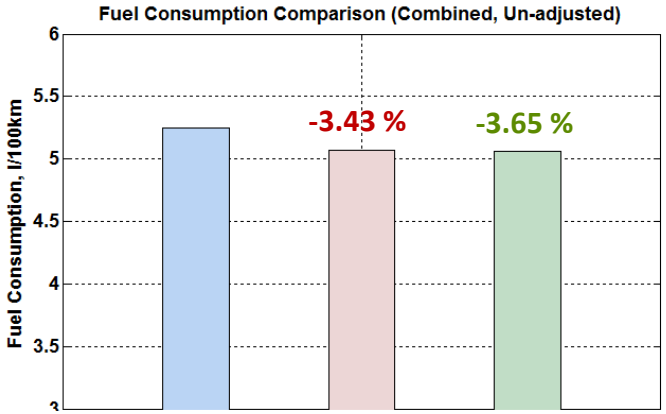
Optimized engine operation

Co-optimize in Autonomie



Minimize the fuel consumption over the combined cycle

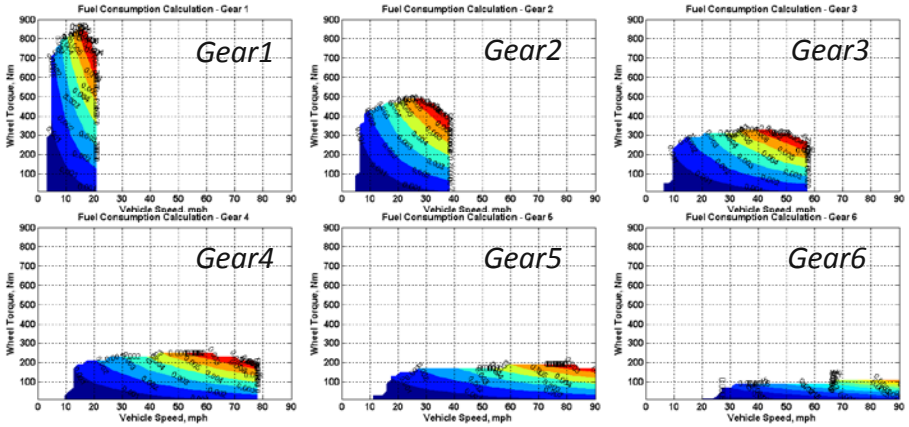




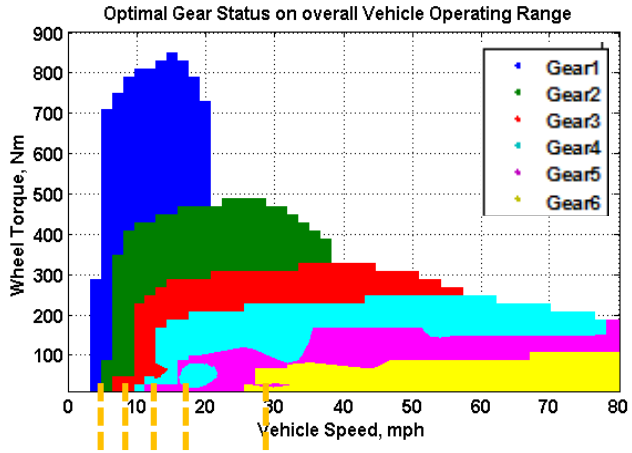
Technical Accomplishment

Pre-definition of Gearshift Pattern: Optimization Procedure

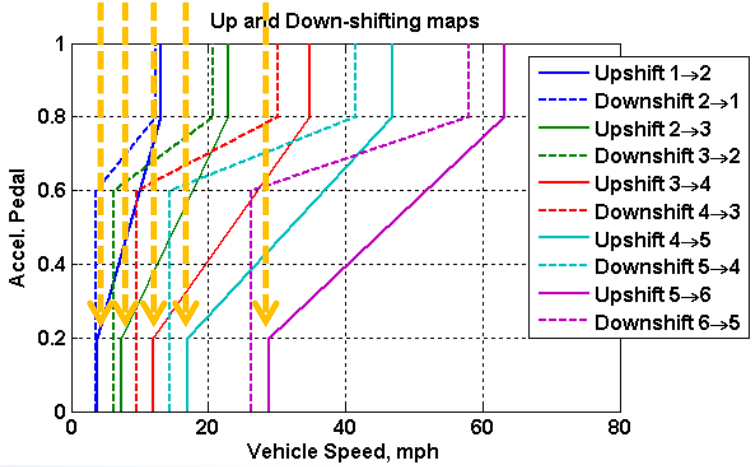
- To understand which gear is the most beneficial, we compare the efficiency of each gear as a function of vehicle speed and output wheel torque



Overlapping Range



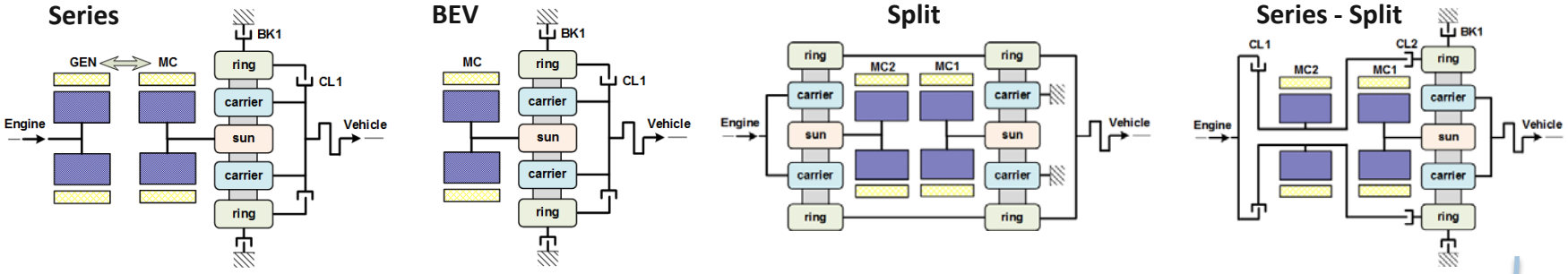
This graphic gives optimal gear on the overall vehicle operating range. This can be very helpful to determine shifting points on the lower areas (low acceleration pedal) along optimum region.

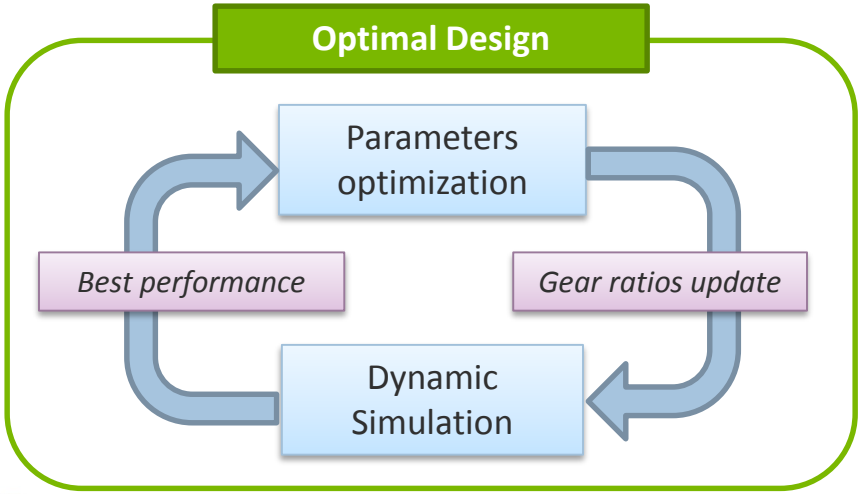


Ongoing Work FY15

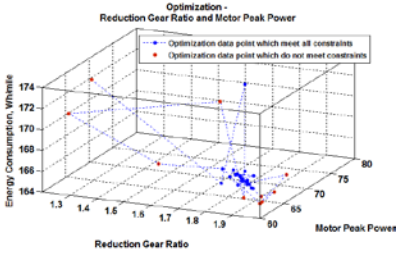
Autonomie Optimization Leveraged to Optimize Gear Ratios for Electrified Powertrains

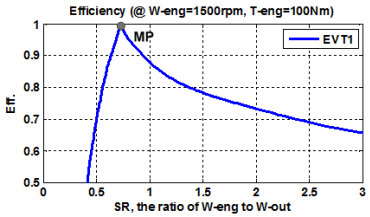
- The same principal we applied to the conventional transmission would be applied to other electrified powertrains.





For the series and the BEVs, the gear ratios would be optimizing so as to make sure that get the best FE for the same performance.
Similarly for the power-split device, the ratio of ring gear teeth to sun gear teeth could be optimized.





Proposed Future Activities

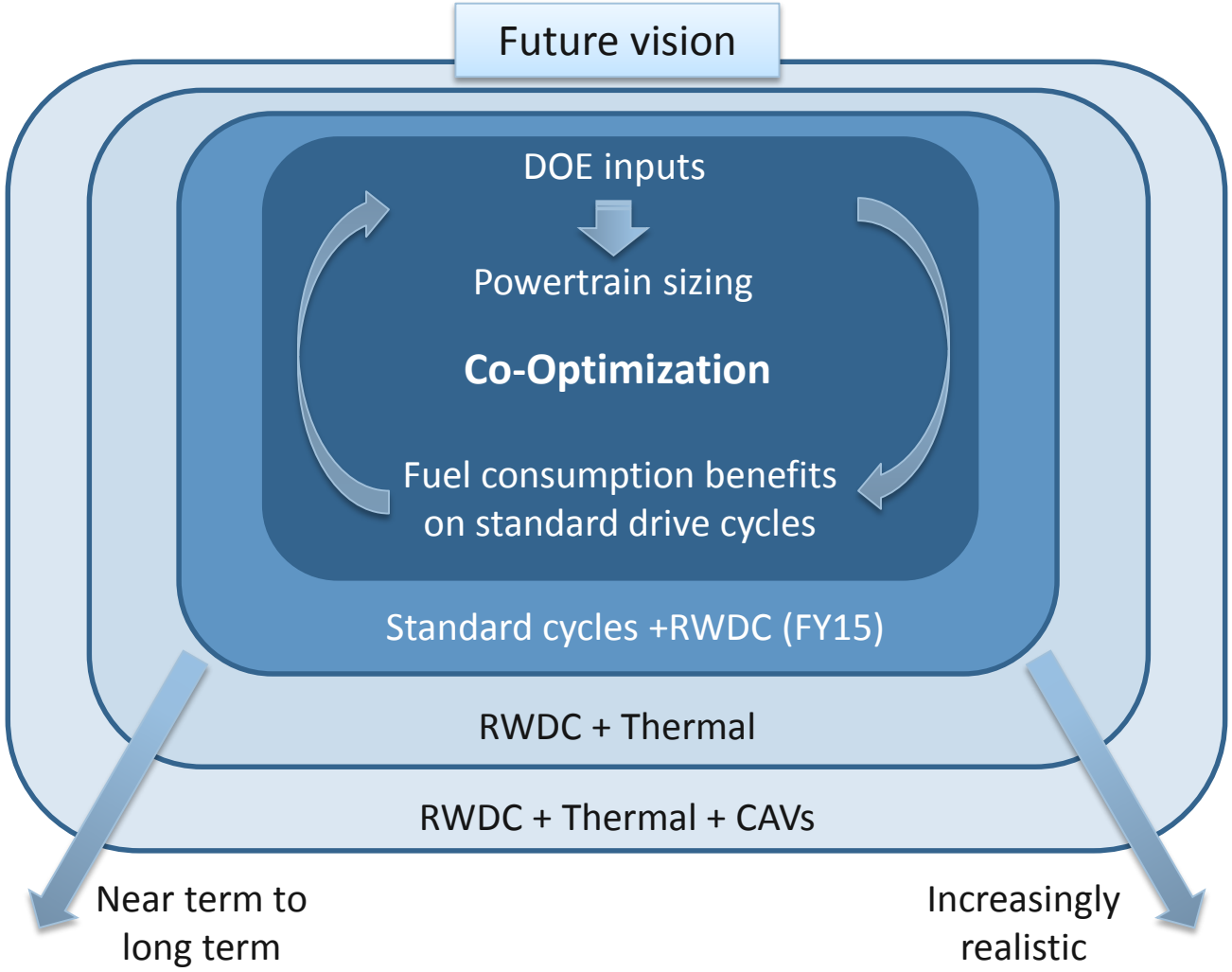
Expand Optimization Techniques to Evaluate the Benefits of VTO Technologies

Current Approach

DOE inputs

Powertrain sizing based on rules (reviewed by VSATT)

Fuel consumption benefits on standard drive cycles with rule based (fixed para values) Control.



Collaboration and Coordination with Other Institutions

Vehicle Testing Data (APRF)

Technical Guidance (OEM)

AUTONOMIE

Fuel Consumption & Cost Analysis

R & D Directions

DOE technology evaluation

Summary

- Argonne continues to develop and validate advanced transmission models.
  - Developed and validated plants and controllers for dual clutch transmission and continuously variable transmission.
  - Validated models will be used to assess the impact of advanced transmissions on other components (inc. cost considerations), evaluate VTO benefits guide and future R&D.
- Shift parameter optimization can result in significant fuel economy improvement for conventional powertrains
  - The process can be further enhanced by considering other factors like emissions
  - Optimize gear ratios for electrified powertrains to minimize fuel consumption, while meeting VTS
- Proposed Future Work
  - Co-optimization of gear ratio selection ,shift parameter optimization with energy management parameters for maximizing petroleum displacement.
  - Combine optimization with vehicle sizing algorithms to meet VTS (Vehicle Technical Specifications) and minimize fuel consumption simultaneously.