PROJECT ACRONYM: SyrNemo

PROJECT FULL TITLE: "SYNCHRONOUS RELUCTANCE NEXT GENERATION EFFICIENT MOTORS FOR ELECTRIC VEHICLES"

GRANT AGREEMENT NO: 605075

Deliverable number: D6.3

SyrNemo project presentation

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Dissemination level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission)	
RE	Restricted to a group defined by the consortium (including the Commission)	
CO	Confidential, only for members of the consortium (including the Commission)	

TABLE OF CONTENTS

1 SUMMARY

A short document for SyrNemo presentation to 3rd parties was prepared. The document is reported in Section 3 of this document

The document reports the project targets, in qualitative and quantitative terms, the solutions that will be implemented to achieve these targets.

During the development of the document, it became clear that a presentation could be useful to spread the SyrNemo project concept in meetings. From the above document, a Powerpoint presentation was extracted. The slides are also reported in Section 3.

Up to now a short Powerpoint presentation (8 slides), plus a more comprehensive Powerpoint presentation (30 slides) were generated.

2 TARGETS

The SyrNemo documents/presentations contain information concerning

1. Project scope
2. Targets
3. Solutions adopted to achieve the targets
4. Impact

This material will be distributed to project partners to facilitate the dissemination of the SyrNemo project.

Furthermore it is aimed to extend and sharpen the more comprehensive Powerpoint presentation, as the project progresses. The latest achievements will be included continuously to have an up to date version available for dissemination events, such as conferences, symposiums, networking events, and the like.

3 IMPLEMENTATION OF WORK – RESULTS

SyrNemo Short Project Presentation

TARGET

The SyrNemo project (2013-1016) will deliver an innovative synchronous reluctance machine (SYRM). The drivers of the project are:

1. Avoid the use of rare earth permanent magnet (PM) in the rotor, as rare earth market is under a monopoly regime.
2. Design the rotor bearing in mind that retrofitting with PMs could become a viable option if the magnet material market changes (new materials, new providers outside the current monopoly).
3. Achieve higher power density at lower cost than state of the art permanent magnet synchronous machines (PMSM). Target: mass and volume specific power densities increased by approximately 5%.
4. Achieve higher driving cycle efficiency over a wide range of speed and torque. Target: overall driving cycle efficiency of SYRM can be improved by 5–15% compared to PMSMs.
5. Minimum environmental and social impact, and hidden costs.
6. Emphasis in providing a machine that is easy to manufacture, dismantle, and recycle. This way manufacturing cost can be reduced by 20% and more compared to PM synchronous machines (PMSMs).
7. Simple rotor design ensures that the machine is very robust.

IMPACT

Aspect	Magnitude
Mass and volume specific power densities	+5%
Manufacturing cost	-20%
Driving cycle efficiency improvements	+5-15%

The SyrNemo project, in developing a mass- producible motor by 2015/ 2016, would be instrumental in achieving the “Intermediate” milestone of the European Industry Roadmap for Electrification of Road Transport of 2016, i.e., the “2 nd generation EV updated powertrain”.

SOLUTIONS

To achieve these targets, the following solutions will be adopted

1. Innovative magnetic reluctance rotor design with optional ferrites.
2. Smart packaging of power electronics and integrated thermal management.
3. Drive control implemented to achieve the maximum possible efficiency in each operating point.
4. Bar windings, used to increase the slot fill factor.
5. Insulation system designed for a total lifetime of 10 years and 10,000 operating hours under automotive conditions with regard to the typical environment in the installation space of a vehicle.
6. Integrated liquid cooling circuit, to cool both the power electronics and the motor.
7. Ecodesign throughout the project's duration. The ecodesign includes an eco-scan, a full LCA of the motor and the power electronics, assessment of recyclability, assessment of total cost performance of the motor, investigation on social impact.

TO PROBE FURTHER

It is important to stress that the design should be targeted to real world driving usage, taking the impact of the power electronics and the energy storage into account. To achieve this, the maximum efficiency region of the machine has to be located where the highest probability of operation and the higher amount of energy exchange in driving situations is to be expected. **Figure 1** emphasizes how the proposed machine (SYRNEMO) is more efficient (darker red region) compared to an induction machine (IM) in correspondence of the typical operating point loci (green dots) of a segment A vehicle. The design will include an efficiency based control scheme that commands the drive actuating quantities such way that, while performing high performance torque control the overall electric drive losses are minimized.

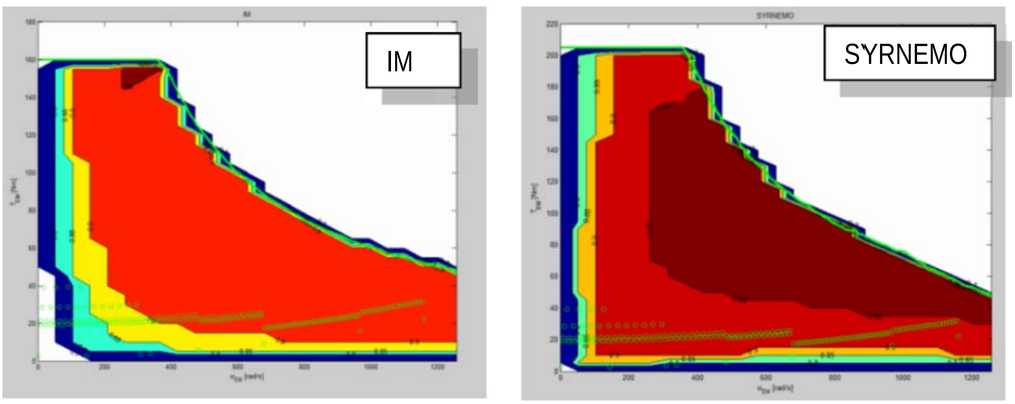

Figure 1. Efficiency tables used for the comparison of electric machine technology for a 1,000 kg "A segment" vehicle. Green dots depict operating points (electric drive torque and speed) for NEDC; darker red = higher efficiency. Further driving cycles including real world usage.

A comparison with other machine technologies is reported in **Figure 2**. It can be observed that the power density of SYRM is higher than induction machines but not as high as interior permanent magnet motor. However, its higher revving capability combined with a higher gearbox ratio can yield to power dense integrated electric power trains. In addition to that, it can be noted that the small increase in terms of weight in comparison with permanent magnet synchronous machines, can be balanced by an improvement in real EV efficiency. If the power density becomes a concern for some specific application, such as for the premium segment, the SYRM can be assisted by permanent magnets.

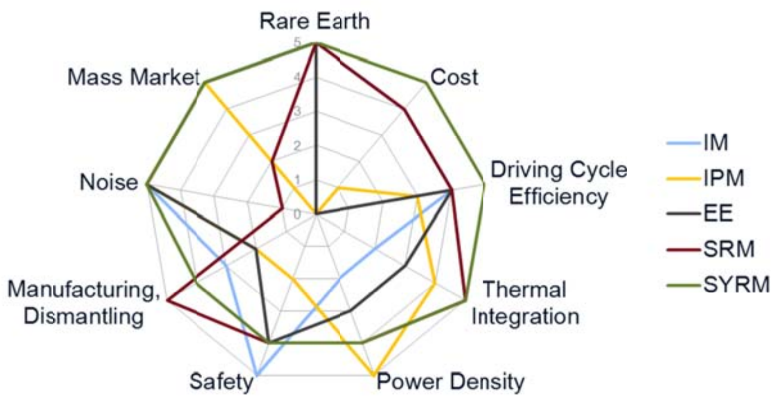

Figure 2: Comparison of different motor technologies

- IM = induction motor
- IPM = interior permanent magnet motor
- EE = electrical excited synchronous machine
- SRM = switched reluctance motor
- SYRM = synchronous reluctance motor

Lifetime of the machine chosen according to the life expectancy of the vehicle (10 years and 10,000 operating hours), thus allowing minimum cost, and maximum specific machine performance, or, minimum used space within the car.

Figure 3.1 SyrNemo document for short project presentation

SyrNemo short Powerpoint presentation slides

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Introducing the
EU FP7 Project SyrNemo
(2013-2016)

Synchronous Reluctance Next Generation Efficient Motors for Electric Vehicles

CONSORTIUM

Code	Partner	Country
AIT (*)	Austrian Institute of Technology GmbH	Austria
AVL	AVL List GmbH	Austria
1.CRF	Centro Ricerche Fiat SpA	Italy
TEC	Fundación Tecnalia Research & Innovation	Spain
BOL	University of Bologna	Italy
HAN	Leibniz University of Hannover	Germany
THIEN	Thien eDrives GmbH	Austria
VUB	Vrije Universiteit Brussel	Belgium

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TARGETS

- The SyrNemo project will deliver an innovative synchronous reluctance machine (SYRM). The drivers of the project are:
  1. Avoid the use of rare earth permanent magnet (PM).
  2. Design the rotor bearing in mind retrofitting with PMs
  3. Achieve higher power density at lower cost than state of the art permanent magnet synchronous machines
  4. Achieve higher driving cycle efficiency over a wide range of speed and torque.
  5. Minimum environmental,social impact, and hidden costs.
  6. Easy to manufacture, dismantle, and recycle.
  7. Simple rotor design ensures that the machine is very robust.

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IMPACT

- The SyrNemo project, in developing a mass- producible motor by 2015/ 2016, would be instrumental in achieving the “Intermediate” milestone of the European Industry Roadmap for Electrification of Road Transport of 2016, i.e., the “2 nd generation EV updated powertrain”.

Aspect	Magnitude
Mass and volume specific power densities	+5%
Manufacturing cost	-20%
Driving cycle efficiency improvements	+5-15%

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SOLUTIONS

- The following solutions will be adopted
  1. Innovative magnetic reluctance rotor design with optional ferrites.
  2. Smart packaging of power electronics and integrated thermal management
  3. Drive control implemented to achieve the maximum possible efficiency in each operating point.
  4. Bar windings, used to reduce the required winding space.
  5. Insulation system designed for a total lifetime of 10 years and 10,000 operating hours.
  6. Integrated power electronics-motor liquid cooling circuit
  7. Eco-design throughout the project’s duration

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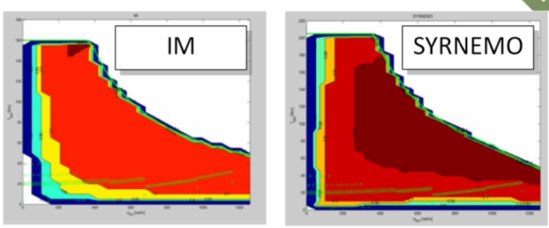
EFFICIENCY TABLES



- Efficiency tables used for the comparison of electric machine technology for a 1,000 kg “A segment” vehicle. Green dots depict operating points (electric drive torque and speed) for NEDC; darker red = higher efficiency.

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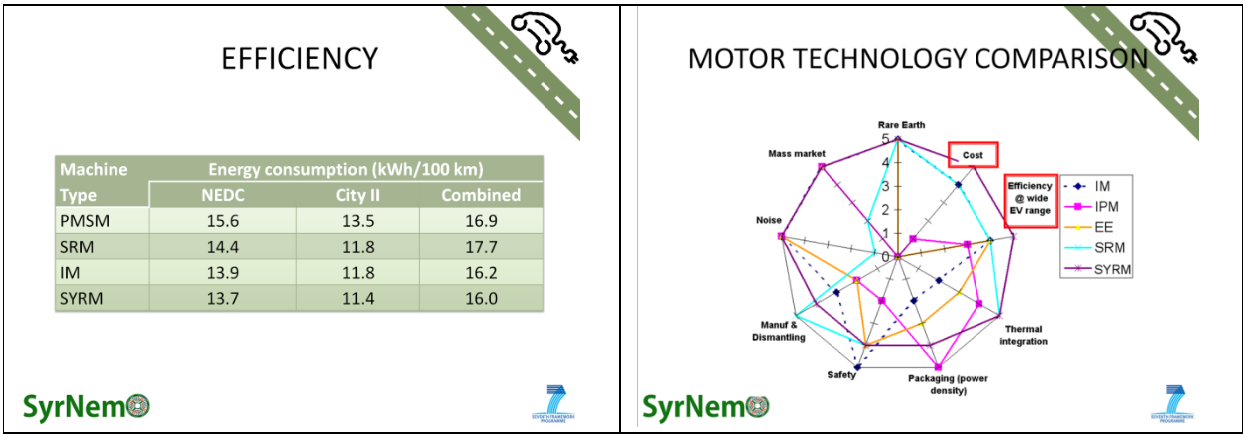
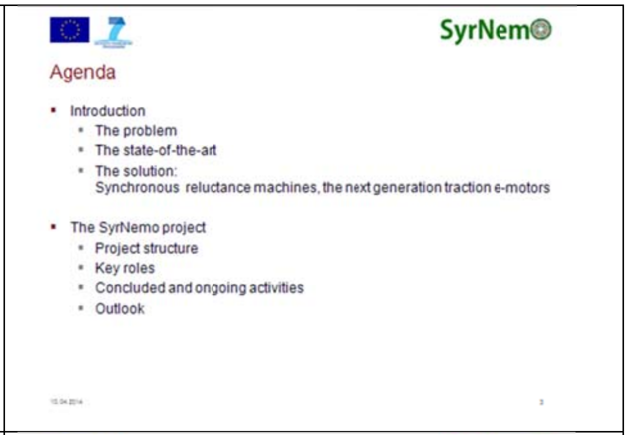
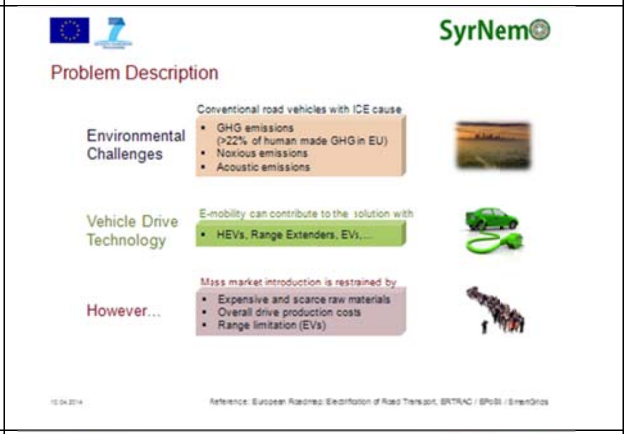


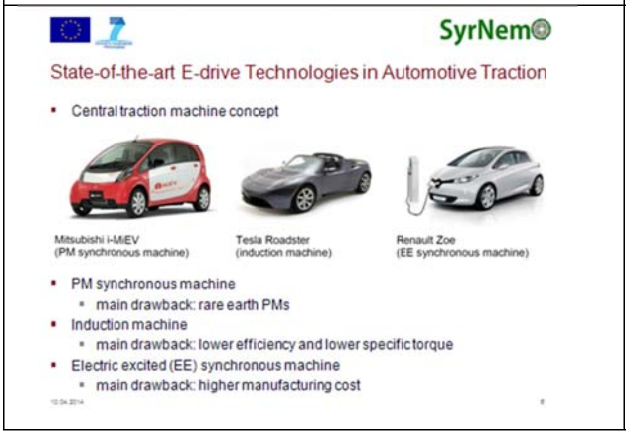
Figure 3.2 SyrNemo short Powerpoint presentation

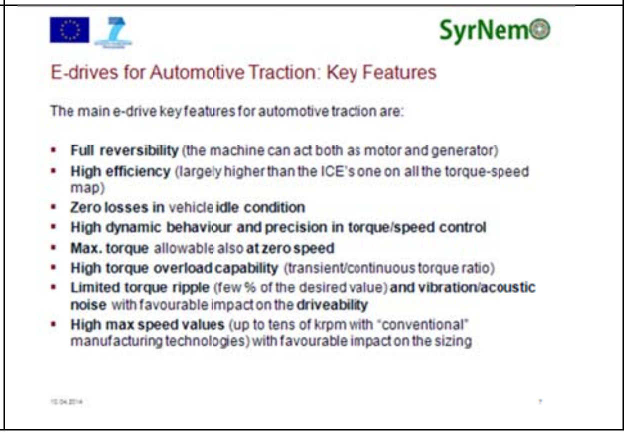
SyrNemo comprehensive Powerpoint presentation slides

will be continuously extended









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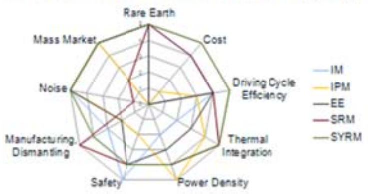
Competing E-machine Technologies

- Induction machine (IM)
- Permanent magnet synchronous machine (IPM)
- Electric excited synchronous machine (EE)
- Switched reluctance machine (SRM)
- **Synchronous reluctance machine without rare earth magnets (SYRM)**



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Efficiency Study using Different Drive Cycles

E-machine Type	NEDC	CityII	Combined
PMSM	15.6	13.5	16.9
SRM	14.4	11.8	17.7
IM	13.9	11.8	16.2
SYRM	13.7	11.4	16.0

Comparison of numerical simulation results obtained for four different machine types driving a 1000 kg full electric vehicle. Combined cycle consists of a mix of USA-FTP75, USA Highway and NEDC, it can be considered as a medium high speed combination.

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Synchronous Reluctance Machine – a History Review

- First mentioned in scientific literatures
  - 'Polyphase reaction reluctance machine' – 1920
  - 'Unexcited synchronous machine' – 1930

SYRM principle

- Long history with scientific contributions to design, stability and inverter interaction throughout the last century mainly for industrial applications.
  - Lipo (1991) T.A.: "Synchronous reluctance machines – a viable alternative for AC drives," Electr Mach Power Syst, vol. 19, pp. 659-671.
  - Vagati (1994) A.: "The synchronous reluctance solution: a new alternative in A.C. drives," Proc IEEE IECON (Bologna), vol. 1, pp. 1-13.
  - Kamper (2013).: "Reluctance synchronous machine drives – a viable alternative?," IEEE Joint IAS/PELS/IES Chapter Meeting, (Graz)

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Synchronous Reluctance Machine for Industrial Applications

- Successful commercialization of synchronous reluctance machines by ABB for pump and fan applications

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Synchronous Reluctance Machine Construction Types

Reference: J. Kaenmanen: „Synchronous Reluctance Motor With Form Blocked Rotor", IEEE Transactions on Energy Conversion, vol. 25, 2010

Salient pole	Axially Laminated	Transversely Laminated
Simple design Low cost Low saliency ratio Rigid structure Reluctance torque only	Complex manufacturing High cost Highest saliency ratio Low speed only	Easy manufacturing Low cost High saliency ratio Variable speed

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The SyrNemo Project

We believe that mass market introduction of e-mobility can be accelerated significantly with a
- high performance,
- high efficient,
- low-cost and
- ecologically sustainable

synchronous reluctance machine drive.

And we will have realized this innovative e-drive by 2016.

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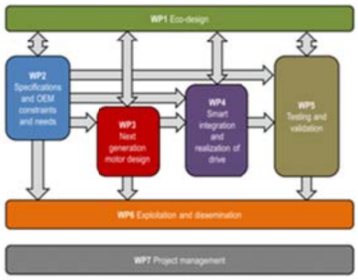
Project Goals

- Systematic development of the next generation **synchronous reluctance machine drive** for EV with:
  - **Applied eco-design** during the whole project
  - **Increased specific power and power density** by 5 %
  - **Cost effective production**, dismantle and recycle technologies to reduce the manufacturing cost by 20%
  - **No rare earth PM utilization**, possibility to retrofit ferrite PMs to increase the performance
  - Robust rotor design and **cost optimized insulation system** designed for a total lifetime of 10 years and 10,000 operating hours
  - High efficiency over a wide range of speed and torque
  - Drive control to achieve the maximum possible efficiency in order to **improve the overall driving cycle efficiency** by 5 – 15 %
  - **Smart integration** and realization of the drive
  - Wide spread exploitation and dissemination

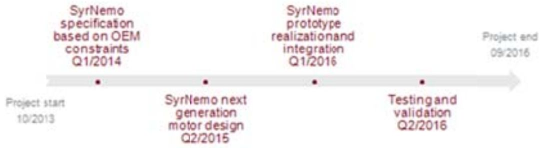
Project Structure



Project Consortium and Key Roles

Partner	Keyrole	Country
AIT Austrian Institute of Technology GmbH	Coordinator, thermal motor design and power electronics	Austria
AVL List GmbH	Industrial partner for requirements engineering	Austria
Centro Ricerche Fiat SpcA	Specifications, support in design, testing and validation activities	Italy
Fundación Tecnalia Research & Innovation	Testing and validation, control algorithm	Spain
University of Bologna	Designing, testing and qualifying of the electrical insulation system	Italy
Leibniz University of Hannover	SyrNemo electromagnetic design	Germany
Thien eDrives GmbH	Prototype manufacturing	Austria
Vrije Universiteit Brussel	Eco design - LCA	Belgium

Project Schedule and Expected Results



- SyrNemo next generation motor design
  - Electromagnetic and thermal design optimization considering manufacturing technology constraints
  - Insulation system development
  - Power electronic and optimal control development incl. robustness and reliability

Beyond the Consortium

- Involvement of interested parties
  - Material suppliers
  - Component manufactures
  - Application providers
- Dissemination activities
  - EVS Barcelona
  - Website www.syrnemo.eu
  - Transport Research Arena 2014, Paris
  - Publications of project results to the scientific community
- Networking activities on EU Level
  e.g. http://www.criticalrawmaterials.eu

Ongoing and Completed Activities

- Ecodesign
- Drive scalability and vehicle applications study
- Real world usage energy efficiency targets
- Vehicle (A-B) segmente-drive specifications
- Testing and validation requirements
- First machine design studies
- Dissemination in Workshop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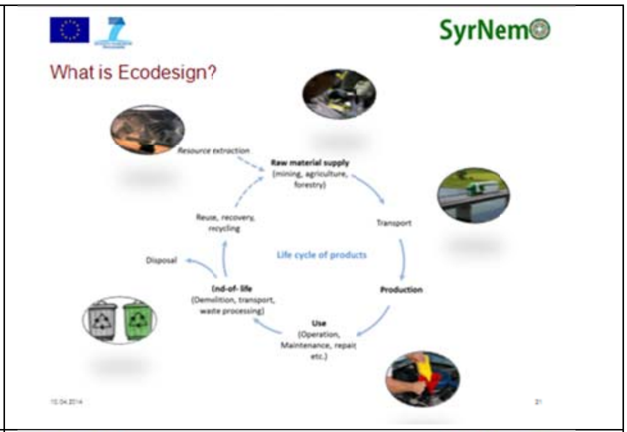
Ecodesign
Ecodesign is an approach to design of a product with special consideration for the environmental impacts of the product during its whole lifecycle.
It helps to identify critical environmental burdens, and improvement paths, across the development cycle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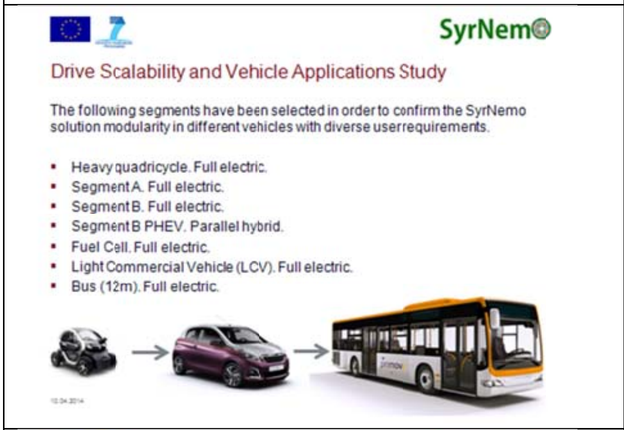
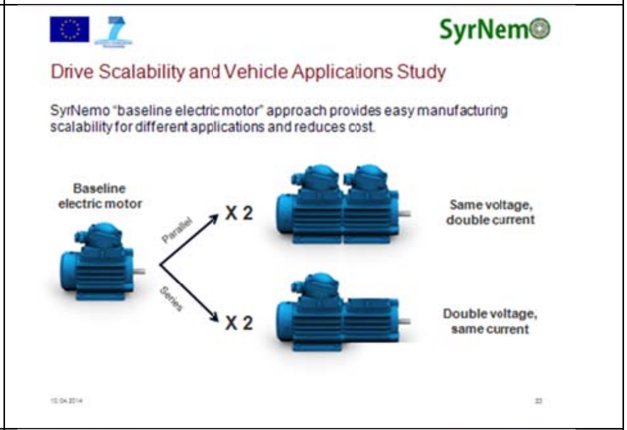
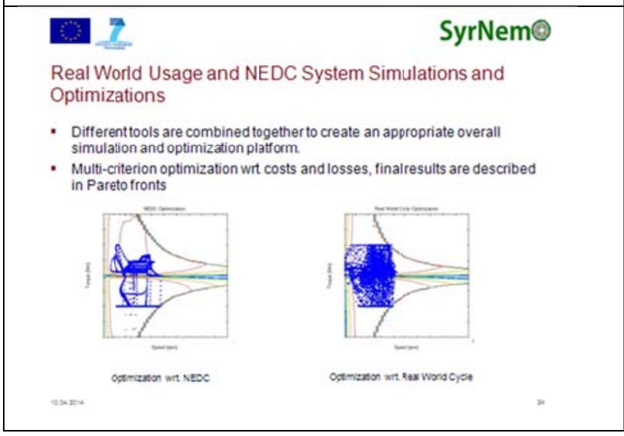
What is Ecodesign?
Resource extraction
Raw material supply (mining, agriculture, forestry)
Transport
Production
Use (Operation, Maintenance, repair etc.)
End-of-life (Demolition, transport, waste processing)
Disposal
Reuse, recovery, recycling
Life cycle of products


SyrNemo
Drive Scalability and Vehicle Applications Study
The following segments have been selected in order to confirm the SyrNemo solution modularity in different vehicles with diverse user requirements.
Heavy quadricycle. Full electric.
Segment A. Full electric.
Segment B. Full electric.
Segment B PHEV. Parallel hybrid.
Fuel Cell. Full electric.
Light Commercial Vehicle (LCV). Full electric.
Bus (12m). Full electric.


SyrNemo
Drive Scalability and Vehicle Applications Study
SyrNemo "baseline electric motor" approach provides easy manufacturing scalability for different applications and reduces cost.
Baseline electric motor
Parallel
Series
X 2
Same voltage, double current
X 2
Double voltage, same current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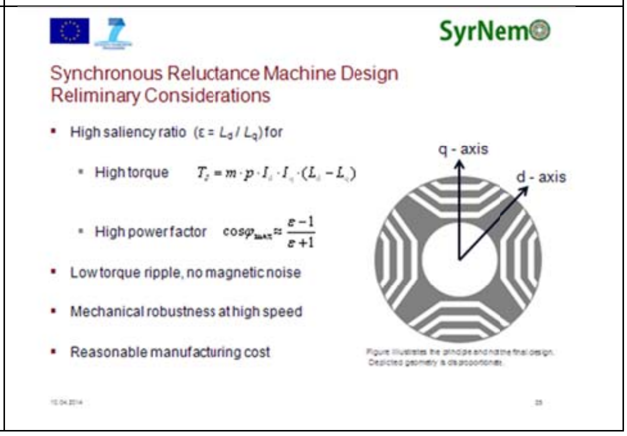
Real World Usage and NEDC System Simulations and Optimizations
Different tools are combined together to create an appropriate overall simulation and optimization platform.
Multi-criterion optimization wrt costs and losses, final results are described in Pareto fronts
Optimization wrt. NEDC
Optimization wrt. Real World Cycle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Synchronous Reluctance Machine Design
Reliminary Considerations
High saliency ratio (ε = Ld / Lq) for
High torque
High power factor
Low torque ripple, no magnetic noise
Mechanical robustness at high speed
Reasonable manufacturing cost
q - axis
d - axis

Figure 3.3 SyrNemo comprehensive Powerpoint presentation (that will be continuously extended)