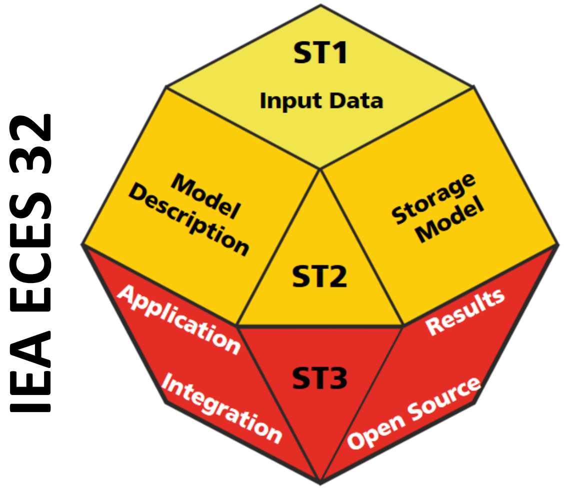
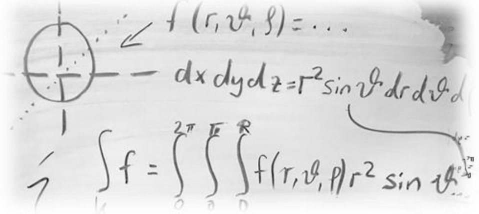
PLANNED ECES ANNEX 32:

MODELLING OF ENERGY STORAGES FOR SIMULATION/OPTIMIZATION OF ENERGY SYSTEMS

Open Sesame – Open Source Energy Storage Models

Prof. Dr.-Ing. Christian Doetsch, Fraunhofer UMSICHT





IEA ECES 32 , Presentation at XC86, Nov 15th/16th, Jeju Island, South-Korea

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What is the problem we want to solve – what are the projected results – what is the overall aim

- **The situation** is, that the energy system is **changing due to variable energy production**, which requires new and more storage devices to balance demand and production and additionally to increase flexibility.
- **The aim** is to select always the best fitting storage systems with the best fitting operation mode to balance the energy system.
- **The challenge** is, that there is hardly any scientifically proven, source models for energy storage systems, which are an indispensable prerequisite for operation or structural optimization and for assessing the value of storage systems.
- **The task** is to develop a standardized **and** scientifically proven approach and methodology to asses various **storage devices** for various applications:
  grid connected and grid operated, island grids/remote areas, industrial sites, residential areas.
- **The results** are **generic open source models** and **data sets**. These scientifically proven models should be used to find answers to current storage questions (technical, economical, regulatory).

The overall aim of this Annex is smart energy conservation and to understand and foster the role of energy storages in the energy system by optimizing applications and operation modes and by assessing the benefit to the energy system.

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1. Introduction

Key Performance Indicators (KPI) like LCOE*, LCOS** and efficiency allow assessing and comparing different technologies. Contrary to other energy technologies **all KPI** of energy storages **depend on** the chosen **application, operation mode** and **economic/regulatory "environment".** Therefore, detailed knowledge about the application and "environment" is indispensable to design and optimize storage devices.

Modelling energy storage devices (electrical or thermal) for simulation and optimization is absolutely needed to choose, assess and design the best fitting solution.

Current **challenges** are

- No common, scientifically proven, open source models exist
- No common, scientifically proven, open source data sets exist

There are only various, incoherent, mostly proprietary models and software solutions

*levelized cost of energy; * * levelized cost of storage

1. Introduction

Additionally there are

- many structural differences of the models; e.g. thermal storages are often very special designed and highly integrated in the system/plant, whereas electric storages are mostly "stand alone" solutions.
- mental barriers between modelers, because the scientific communities are highly divided by their specific technologies (thermal/electrical)
- no or only very simple storage models for total energy systems models, because it is not easy to integrate more complex models in these "big" optimization models

Therefore there is

- a particular need for an international collaboration between thermal and electrical modelers and between storage specialists and total systems modelers.
- the need for common, **scientifically proven, open source models and model descriptions** for energy storage devices and related **data sets* as input parameters** for simulations

*e.g. regional or industrial site demand or supply curves from PV on an hourly level

2. Aim

The **overarching aim** of Annex32 is smart energy conservation and to **identify the crucial role of energy storages** in the energy system by **optimizing applications, structures and operation modes** and by **assessing** the benefit to the energy system.

The technological aim of annex 32 is the development of comprehensive models for relevant energy storage devices and input data sets for simulation. These models must be scientifically proven, open source and implementable.

3. Objectives

The objectives are:

- **Mathematical description** (strongly generic for total system simulations) of thermal and electrical **energy storage devices** on two levels. The first level addresses mostly fixed values or linear relations (e.g. efficiency for one conversion step) for the model parameters. The second one is more complex and uses functions (e.g. efficiency=f(DOD*, Power Output, …..). The first level is needed for rough calculations or for huge system models, which cannot handle descriptions that are more complex. The second one could be used for more detailed analysis and single plants.
- **Data sets** for **RE supply** and customer **demand** for various countries on an hourly level and typical/needed operation modes.
- **Integration** of the models **in open source simulation software** for **demonstration** and for answering various "storage" questions (system, economically, regulatory).
- Dissemination of **scientifically proven, open source models, datasets** and their **application.**

* DOD: Depth of Discharge

4. Scope

The scope of Annex 32 covers the following types of storage devices:

- Electrical Storages (Power-to-power):
  - Pumped Hydro (PH),
  - Compressed Air Storage (CAES) including Adiabatic CAES (ACAES) and Liquefied AES (LAES),
  - Lead Acid Battery (LA),
  - Lithium-Battery (Lithium-Metal, Lithium-Ion, Lithium-Polymer),
  - Vanadium-Redox-Flow-Battery (VRFB),
  - Flywheels (FW),
  - Supercaps (SC)
- Thermal Storages (Heat-to-heat):
  - hot water tank,
  - PCM vessel,
  - tbc
- Optionally: selected complex systems: e.g. power2gas, power2heat, tbd.

5. Activities: Big picture

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IN	Model	OUT
Various data sets (time series) in different granularity, different applications, regions etc.	**ST 1** **INPUT DATA** Technical data sets and economic/operational data	Scientifically proven, double checked technical and economical data sets/time series incl. operation modes
Existing and new models for thermal, electrical storage devices	**ST 2** **STORAGE MODEL** mathematical description, fixed parameters and functionalized parameters	Scientifically proven, robust models as generic models with fixed parameters (1st level) and more complex models (2nd level)
Various questions regarding technology, combination, R&D and company aspects	**ST 3** **APPLICATION** Demonstration, design optimization, assessing of storages, publication / open source	Demonstration of the models; Messages to policy makers, stakeholders, companies, scientists, technicians etc.; publication / open source

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5. Activities: Subtask 1 – INPUT DATA

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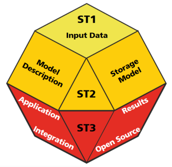
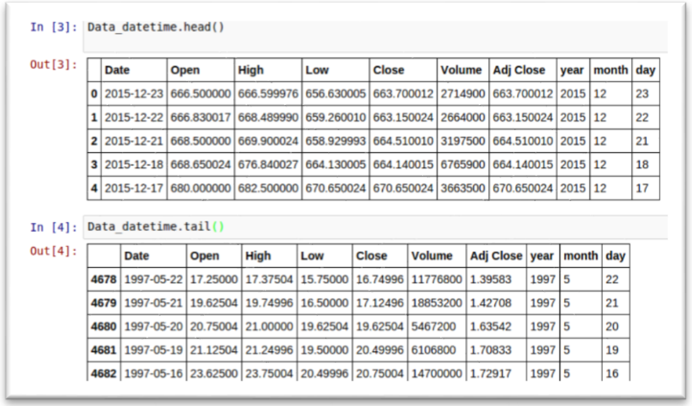


ST 1
INPUT DATA
Technical data sets and economic/operational data



```
In [3]: Data_datetime.head()
```

Out[3]:

	Date	Open	High	Low	Close	Volume	Adj Close	year	month	day
0	2015-12-23	666.500000	666.599976	656.630005	663.700012	2714900	663.700012	2015	12	23
1	2015-12-22	666.830017	668.489990	659.260010	663.150024	2664000	663.150024	2015	12	22
2	2015-12-21	668.500000	669.900024	658.929993	664.510010	3197500	664.510010	2015	12	21
3	2015-12-18	668.650024	676.840027	664.130005	664.140015	6765900	664.140015	2015	12	18
4	2015-12-17	680.000000	682.500000	670.650024	670.650024	3663500	670.650024	2015	12	17

```
In [4]: Data_datetime.tail()
```

Out[4]:

	Date	Open	High	Low	Close	Volume	Adj Close	year	month	day
4678	1997-05-22	17.25000	17.37504	15.75000	16.74996	11776800	1.39583	1997	5	22
4679	1997-05-21	19.62504	19.74996	16.50000	17.12496	18853200	1.42708	1997	5	21
4680	1997-05-20	20.75004	21.00000	19.62504	19.62504	5467200	1.63542	1997	5	20
4681	1997-05-19	21.12504	21.24996	19.50000	20.49996	6106800	1.70833	1997	5	19
4682	1997-05-16	23.62500	23.75004	20.49996	20.75004	14700000	1.72917	1997	5	16

This subtask forms the basis for this annex. The following databases have to be collected/developed:

- Data sets (time series, ¼ to 1 hourly level) for typical generation curves for renewable energies in various countries
- Data sets (time series , ¼ to 1 hourly level) for typical consumption curves for typical end-users (private and/or industrial) in various countries
- Database for storage operation modes for typical (national) applications and business cases
- National economical key figures (energy cost etc. but no details to local regulations)

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5. Activities: Subtask 2 – STORAGE MODEL

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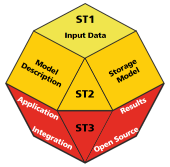
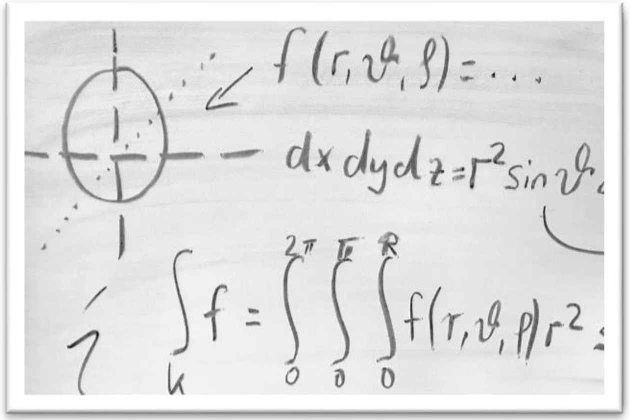
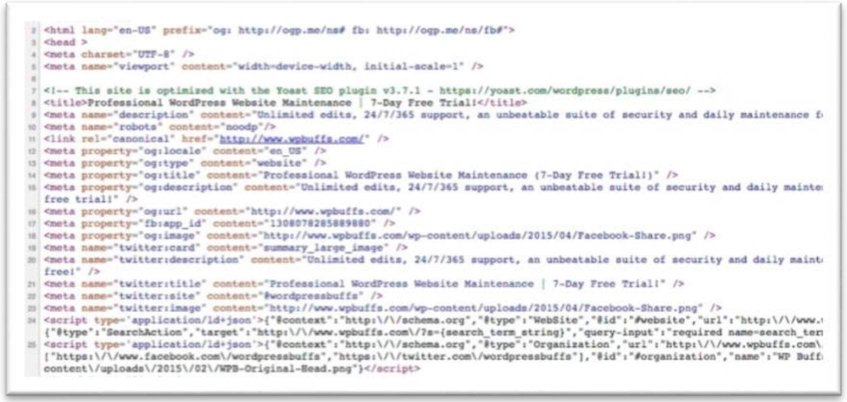


ST 2
STORAGE MODEL
mathematical description,
fixed parameters and
functionalized parameters





In this subtask, an overall mathematical description of energy storages has to be made. These generic descriptions base on scientific proven results and will be done on two different levels. The 1st level is more generalized and uses mostly fixed or linearly related parameters. The 2nd level is more complex and includes functions for most of the parameters e.g. efficiency=f(DOD*, Power Output, …..)

- Mathematical descriptions of energy storage devices on said two different levels
- Economic key figures for storage devices (CAPEX)
- Energy storage applications / operation modes description
- Demonstration of all models in an open source programming language

Comment: Modelling is always **on storage device level** (e.g. whole battery, whole hot water tank etc.) and **neither on physical detailed level** (e.g. PCM capsules like in Annex29) **nor building level** (e.g. heat pump, building etc.). **Modelling of buildings etc. is NOT included and no objective.**

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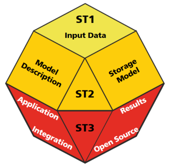
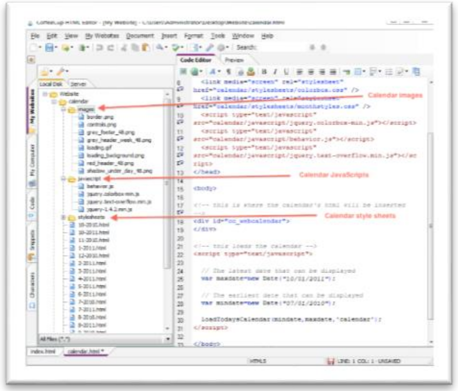
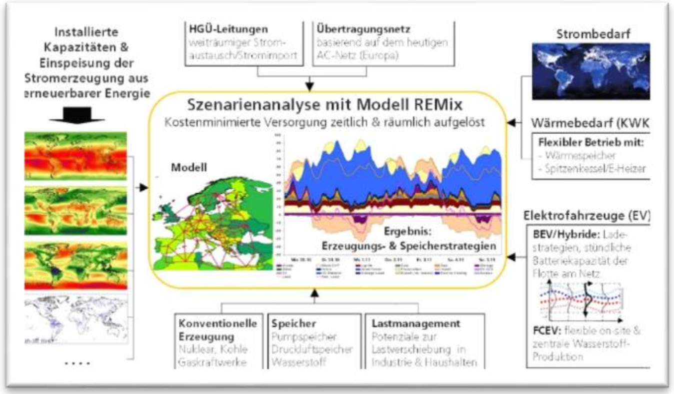


5. Activities: Subtask 3 - APPLICATION

ST 3
APPLICATION
Demonstration, design optimization, assessing of storages, publication / open source





The main point of ST3 is the application of the developed models including data sets and operation modes in existing open source system models. On the one hand this is a demonstration of the models, on the other hand – which has the main focus – main questions of the annex regarding value, design, application and regulatory framework are answered.

- Application and validation of said models (1st and 2nd level) on different levels*
- Design optimization (Power to capacity relation; hybrid storages etc.)
- Publication of open source models (download / webpage) in cooperation with stakeholder, e.g.
  - https://open-power-system-data.org/
  - https://wiki.openmod-initiative.org/
  - https://iea-eces.org/

* grid level, at industrial sites or residential areas, and as "island"-systems

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5. Activities: Subtask 3 - APPLICATION

ST 3
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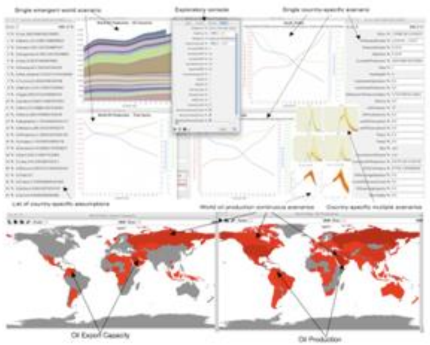
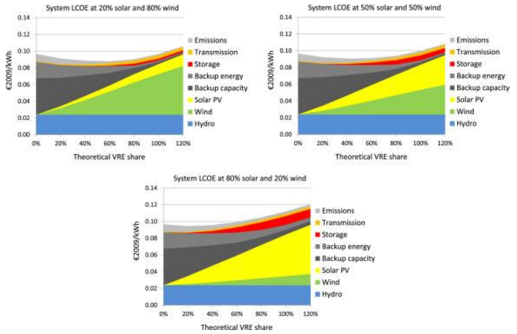
Demonstration, design optimization, assessing of storages, publication / open source





- Using the open source models to find answers to various technical, economical questions

E.g. questions to be answered (tbc.)

- **Economic Value:** What is the economic value of storage devices in different applications (LCOE, LCOS)?
- **Technological Value**: Which storage technologies are in competition, which are synergetic?
- **Operation mode**: Which operation mode will be most economic?
- **Game Changer:** Will a rapid cost reduction be a game changer or is storage efficiency the crucial point?
- **Hybrid Storage:** Are hybrid storages (combining different technologies) the silver bullet?
- **Regulatory Framework**: Is the energy storage market over-regulated or hindered?

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6. Outcomes

The major **technical** outcomes will be:

- **Data sets** (time series) for **input parameters** and for various applications (energy consumption / production curves) and data regarding operations modes, restrictions, cost figures)
- **Scientifically proven, open source, energy storage models**
- Practical **application** and **demonstration** of these models and answers to **burning questions**
- **Recommendation** for economic, structural, or operational optimization of energy storages
- **Outlook**: Cooperation with IEA Headquarter simulation group (Luis Munuera) and apply said models to TIMES/Markal and/or OSeMOSYS*

The results will be a common understanding of "energy storage" and their value for the energy system.

Finally yet importantly, the collaboration between "thermal" and "electrical" storage researchers could be strengthened.

* http://www.osemosys.org

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7. Collaboration and Reviewing

Collaboration with other ongoing annexes will be crucial.

- ECES29 (ongoing) OA: Andreas Hauer
  "Compact Thermal Energy Storage"
- ECES30 (ongoing) OA: Antje Seitz
  "Thermal Energy Storage for Cost-Effective Energy Management and CO_2 Mitigation."
- ECES31 (ongoing) Subtask Lead: Paul Tuohy
  "Energy storage with Net Zero Energy Buildings and Districts: Optimization and Automation"
  Survey on software for energy modelling is existing (building and district level)
- Checking ECBCS Annex42 regarding a comparable approach for standard load curves for HP and µCHP

IEA "reviewer" for Annex 32 progress from the Executive Committee:

- Halime Paksoy (Turkey)
- Shane Long (UK)

8. Participating / Interested Countries (April 24th, 2018, XC85)

Planning to participate

1. Germany (coordination) (UMSICHT; DLR)
2. Denmark (PlanEnergi)
3. Netherlands
4. Belgium (VITO, KEU Leuven, EnergyVille)
5. Ireland (DIT)
6. Canada
7. Japan (Questions open for the task definition workshop)
8. Korea
9. UK
10. China (Decision after task definition workshop)
11. Spain

Interested (depending on financing, national partners etc.)

- Switzerland (FH Bern, HS Luzern)
- Finland
- Turkey
- Slovenia
- Sweden

9. How to participate

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Recommendations

- Be engaged and interested today and for the next 3-4 years
- Participate at nearly all meetings
- Have your own (national) budget
- Cooperate and deliver your promised contribution in time on a high scientific level
- Plan time and a part of your budget for cooperating in the IEA ECES Annex 32
  (less than 3 month/year for a minor part, more for a bigger part or for leading a subtask)
- Involve – besides the leading partner – also the “working” partner (e.g. PhD student)
- Subtask leader should have funding for the whole Annex32 period, to have a chance to finalize the subtask report

10. Planned Contributions (1 of 2)

	Germany, Fraunhofer UMSICHT	Germany, DLR Stuttgart	Denmark PlanEnergi	Denmark, EMD International	Netherlands tbd.	Canada Carleton University Ottawa
ST 1 INPUT DATA Technical data sets and economic/operational data		RE times series for EU (¼ h, high spatial resolution, today and 2030, 2040)				
ST 2 STORAGE MODEL mathematical description, fixed parameters and functionalized parameters	Electrical Storage models: PH, CAES, ACAES, LAES, LA, LI, VRFB, FW, SC		Thermal Storage: Pit Storage			
ST 3 APPLICATION Demonstration, design optimization, assessing storages, publication/open source	Application in OpenModelica; Design optimization of electrical hybrid storages	Application in ReMix; Assessing electrical storages; publication in openmod initiative	Application in PlanEnergi			
Other tasks /Remarks	Operating Agent	Subtask Leader ST3 or ST1				
Contact Person	Christian Doetsch	Yvonne Scholz		Anders Andersen		Ian Beausoleil-Morrison

10. Planned Contributions (2 of 2)

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	Belgium KU Leuven The SySi	Belgium KU Leuven System integration	Belgium VITO Interfaces for electrical storage	Belgium VITO Thermal systems	Belgium U Antwerpen EMIB-HVAC	Belgium ULiège
ST 1 **INPUT DATA** Technical data sets and economic/operational data	Lab test data of water tank (ref: PhD Brecht Baeten, Section 2.5.1)			-Measurements of sensible and latent heat storage from various projects	In-situ measurements of a lake (resolution of 0.5 meter, 1 hour) Ref: location	Lab tests on water tanks, ice storage systems, borehole heat exchangers, PTES, aquifer thermal energy storage (to be confirmed)
ST 2 **STORAGE MODEL** mathematical description, fixed parameters and functionalized parameters	Models of TES - Water tank - Borefield - TABS (ref: IDEAS)		Models of electrical storage - PbAc batt - Li-ion batt Supercaps	-Models of TES (either physics or SOC for control) -Water tank -PCM -BTES -Thermo-chemical -Building mass	Calibrated/ validation lake model (ref: BPACS)	- Models of sensible and latent thermal storage tanks. - Models of Pumped Thermal Energy Storage - Models of aquifer thermal energy storage (to be confirmed).
ST 3 **APPLICATION** Demonstration, design optimization, assessing storages, publication/open source	Modesto – a multi-objective district energy systems toolbox for optimization (ref: paper) with application to THERNET, DR, flexibility			-Linked to subtask 1: operational data from demonstration projects. In the field only for sensible TES	-Validation of a practical method to size thermal storage tanks -hydronic integration of thermal storage tanks Ref: ongoing PhD	To be defined among ongoing projects about design of micro-grids.
Other tasks /Remarks				Open-source cannot be guaranteed		Funding not yet clear
Contact Person	Lieve Helsen	Kenneth Bruninx	Jeroen Büscher	Jan Dirken	Ivan Verhaert	Vincent Lemort

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10. Planned Contributions (2 of 2)

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	Croatia University of Zagreb	DIT Ireland	UK tbd.	Spain tbd.	Austrian Institute of Technology	Turkey tbd.
ST 1 **INPUT DATA** Technical data sets and economic/operational data						
ST 2 **STORAGE MODEL** mathematical description, fixed parameters and functionalized parameters						
ST 3 **APPLICATION** Demonstration, design optimization, assessing storages, publication/open source						
Other tasks /Remarks						
Contact Person	Hrvoje Pandžić				Olatz Terreros	

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10. Planned Contributions (2 of 2)

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	Japan tbd.	Korea tbd.	China tbd.	Tbd.	Tbd.	Tbd.
ST 1 **INPUT DATA** Technical data sets and economic/operational data						
ST 2 **STORAGE MODEL** mathematical description, fixed parameters and functionalized parameters						
ST 3 **APPLICATION** Demonstration, design optimization, assessing storages, publication/open source						
Other tasks /Remarks						
Contact Person						

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11. Next Steps

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Proposal

- Applying 2nd stage project proposal QIII/2018 (1st stage proposal was submitted on July 20th 2018)

Task Definition Workshop

- 2nd Task definition workshop (building the “final” group), 2018 October 24th or 25th (tbc !)

Project Schedule

- Kick-off Meeting 2019, March 12-14 (one day, tbd.), Germany, Duesseldorf (near Airport DUS) joined with “Energy Storage Europe” expo and conference, same place https://www.energy-storage-online.com/

- Annex 32 will have two annual experts meetings / workshops.

Next ExCo Presentations

- XC86, Jeju Island/RK, 2018, November 15th/16th: Findings from the 2nd Task definition workshop
- XC87, London/UK, 2019, April 23rd/24th : Presenting results from the kick-off meeting

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