Energy efficiency of particle accelerators – a network in the European program EUCARD-2

M.Seidel, PSI

3nd EuCARD-2 Annual Meeting, Univ. of Malta, April 27, 2016

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

Outline

Energy Efficiency of Particle Accelerators

- Workshops and Examples
  - Workshop sustainable science at DESY
  - Dedicated session on energy storage systems
  - Workshop on efficiency of Proton Driver Accelerators
- Outlook ARIES Program
- Status Milestones and Deliverables

tasks within EnEfficient

task 1: energy recovery from cooling circuits, Th.Parker→ A.Lundmark (ESS)

[workshop April 14, survey of European Labs, applications of heat, T-levels etc.]

task 2: higher electronic efficiency RF power generation, E.Jensen (CERN)

[workshop Daresbury in June 14, Klystrons, Multi Beam IOT's]

task 3: short term energy storage systems, R.Gehring (KIT)

[non-interruptable power, short term storage, session in Hamburg workshop]

task 4: virtual power plant, J.Stadlmann (GSI)

[adaptation of operation to grid situation – context renewables…]

task 5: beam transfer channels with low power consumption, P.Spiller (GSI)

[pulsed magnets, low power conventional magnets, permanent magnets, parameter comparison etc.]

www.psi.ch/enefficient

Energy for Sustainable Science at Research Infrastructures, Oct 29-30 2015, DESY Hamburg

- ERF, ESS, DESY, Eucard-2 were organisers (program committee)
- boad spectrum of topics, see website: http://erf.desy.de/energyworkshop/programme/

citation from summary Wolfgang Sandner*:

We have collected best-practice examples on

- Energy management
- Energy efficiency, recovery, quality
- Green technology development at RIs and “Dreams coming true”

A total of 32 (2011), 44 (2013) and 37 (2015) presentations and talks from international RIs, organisations and politics

*Chair, Association of European-Level Research Infrastructure Facilities ERF-AISBL, † 5.12.2015

Transition to Renewable Energies
- a challenge for Research Infrastructures

TECHNISCHE UNIVERSITÄT DARMSTADT

Jutta Hanson

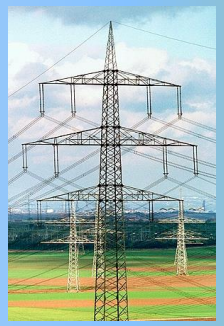
Generation

Conventional power plants

Solar power plants

Wind farms

Transmission and distribution



Consumption

Intelligent Measurement

Home automation

Electromobility

Elektrische Energieversorgung unter Einsatz Erneuerbarer Energien

Energy Storage Systems
EuCARD-2 Session within DESY workshop

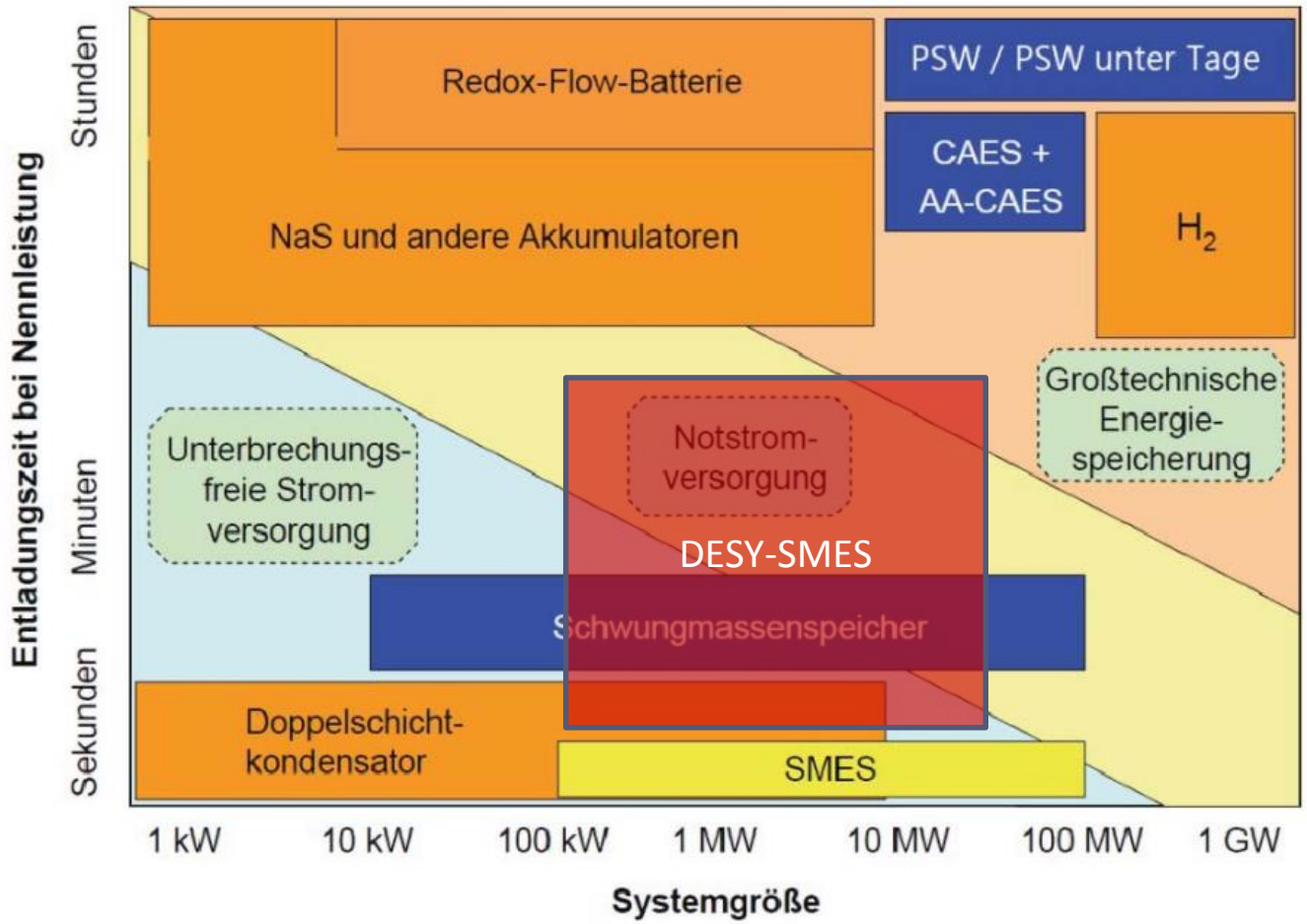
- **average the power load of pulsed systems**
- **bridging grid interruptions avoiding many inefficient start-ups**
- **future: strong cost variations due to fluctuations on grid → could save cost and help society through large storage systems**

critical: cost, efficiency, reliability, size …

Presentations:

1. Energy storage systems in research institutes, Hans-Jörg Eckoldt, *DESY*
2. LIQHYSMES: a Novel Hybrid Energy Storage System, Rainer Gehring, *KIT*
3. Capacitive Energy Storage for the PS Booster Synchrotron, Fulvio Boattini, *CERN*
4. Development of new high slew-put and high energy efficient power supplies for J-PARC upgrade, Yoshi Kurimoto, *KEK/J-PARC*

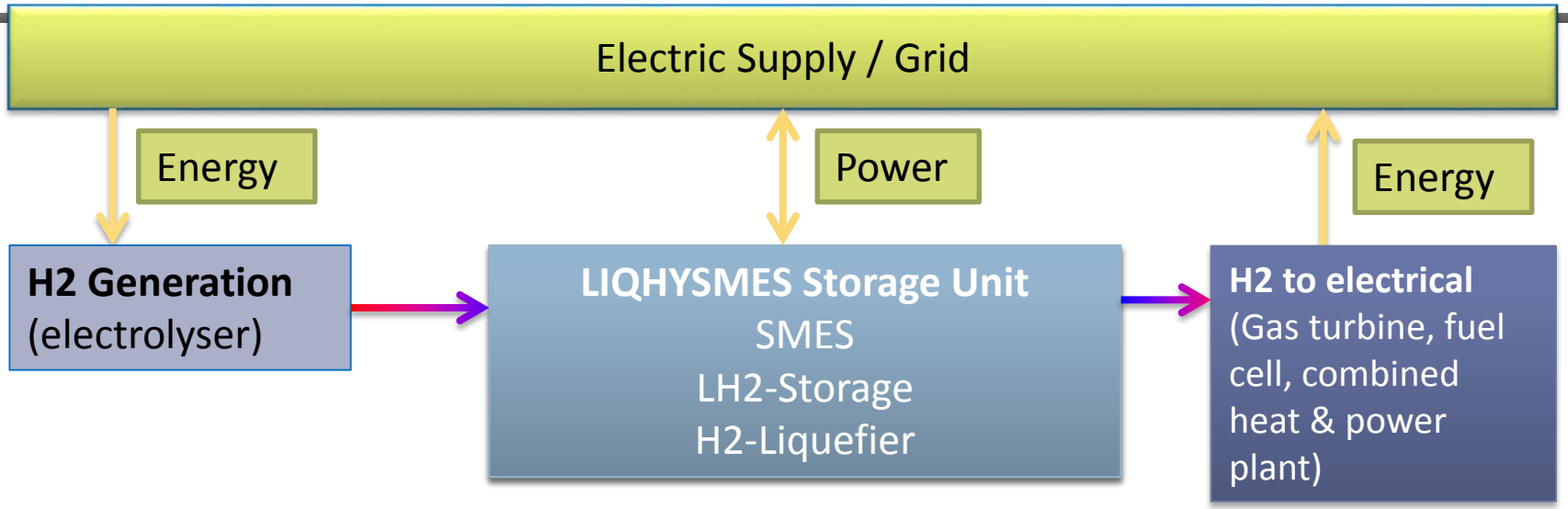
Electrical energy storages



Typical power and discharge times of technical storages [NEU-11]

H.J. Eckoldt, DESY

LIQHYSMES I: Concept



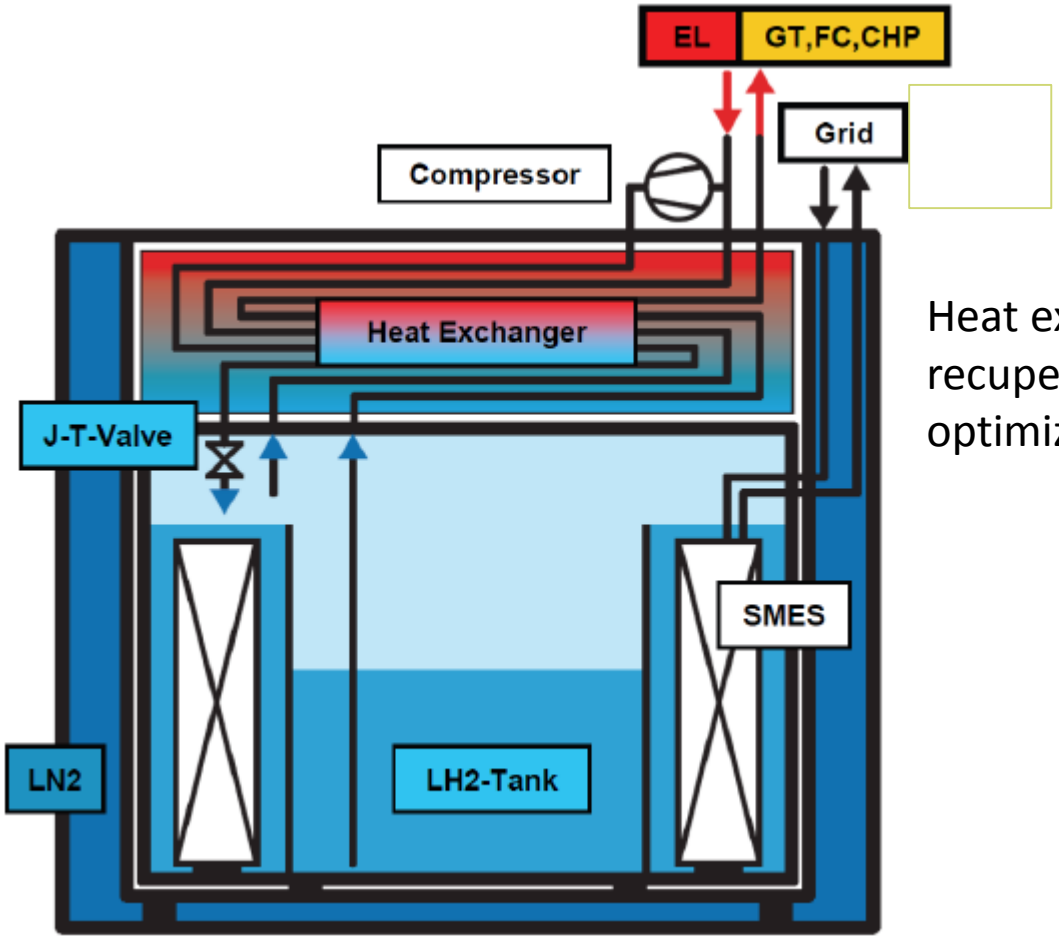
R.Gehring, KIT

Rough cost estimate:
300 MW / 69 GWh with gas turbines:
~1900 €/kW ~8.25 €/kWh

Patents: DE 10 2007 042 711 B4 2011.02.17 and DE 10 2011 013 577 B4 2013.02.28

LIQHYSMES II

LIQHYSMES Storage Unit



Heat exchanger and recuperator can be optimized

R.Gehring, KIT

EuCARD² capacitive storage for PS booster

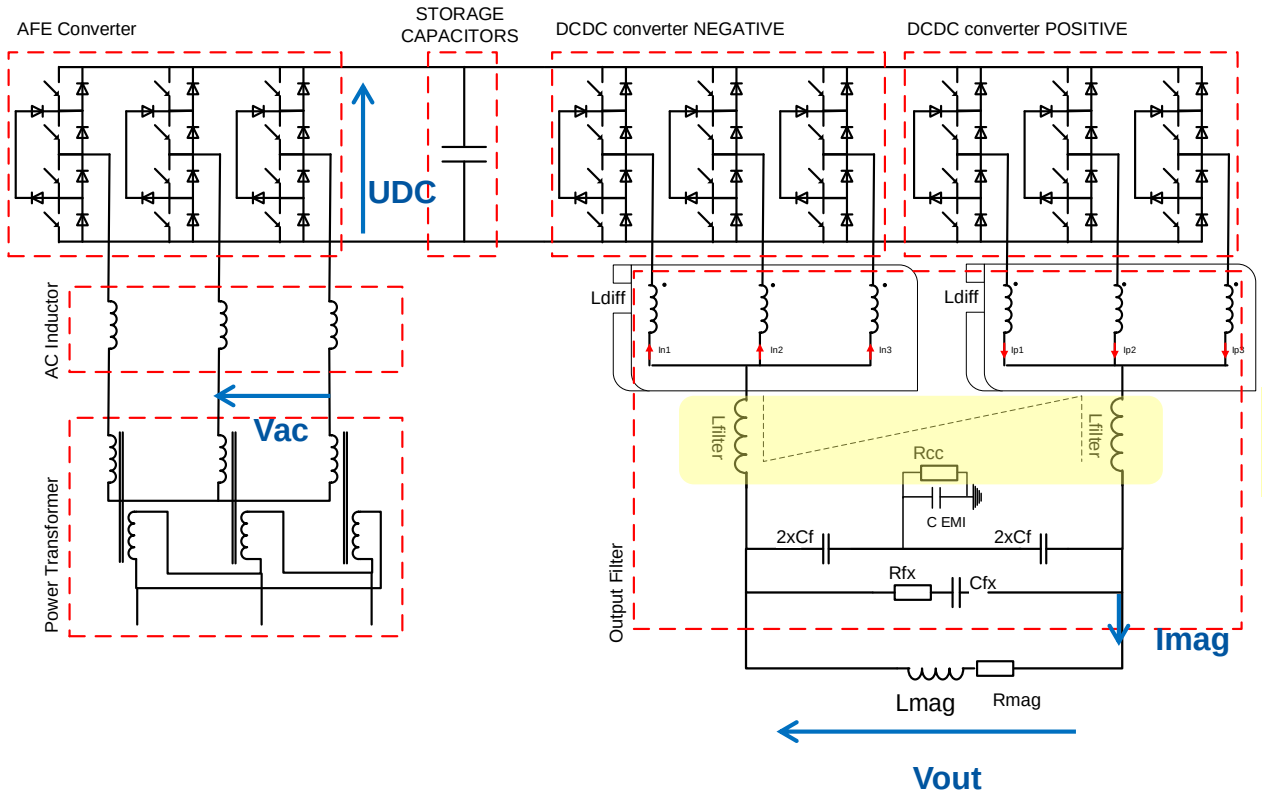
Power transformer:
Power=2.5MW
Vac=2000Vrms

Storage Capacitors:
Cap=0.3F
Vmax=5000V
Vmin=3000V

≈3MJ

Output:
Imag_pk=6000A
Imag_rms=3000A
Vout_pk=3000V

Load (Mag):
Lmag=100mH
Rmag=250mOhm

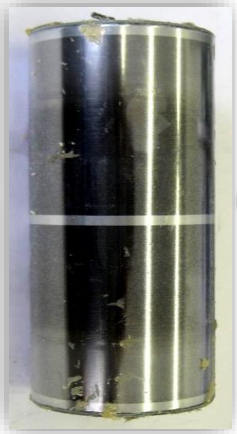


F.Boattini, CERN

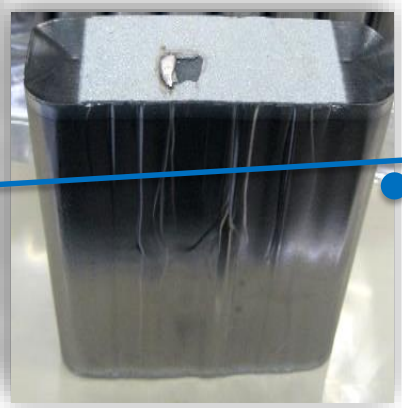
Additional common mode filter inductance required for DVripple

Storage capacitors: technology

NON-IMPREGANTED CAPACITORS

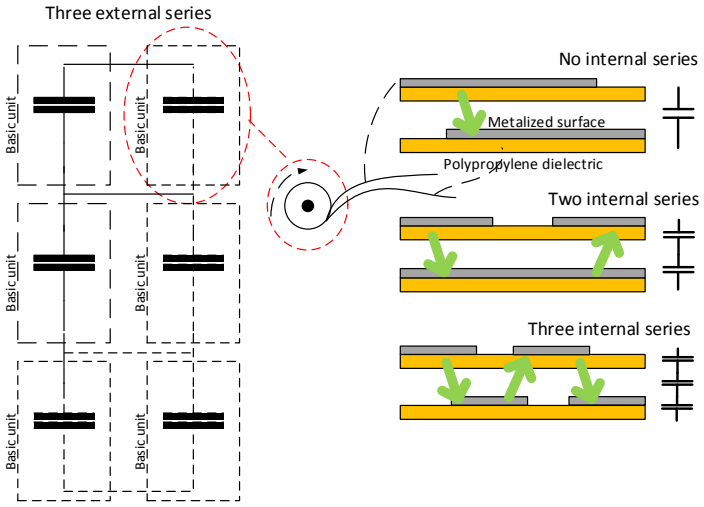


OIL IMPREGNATED CAPACITORS



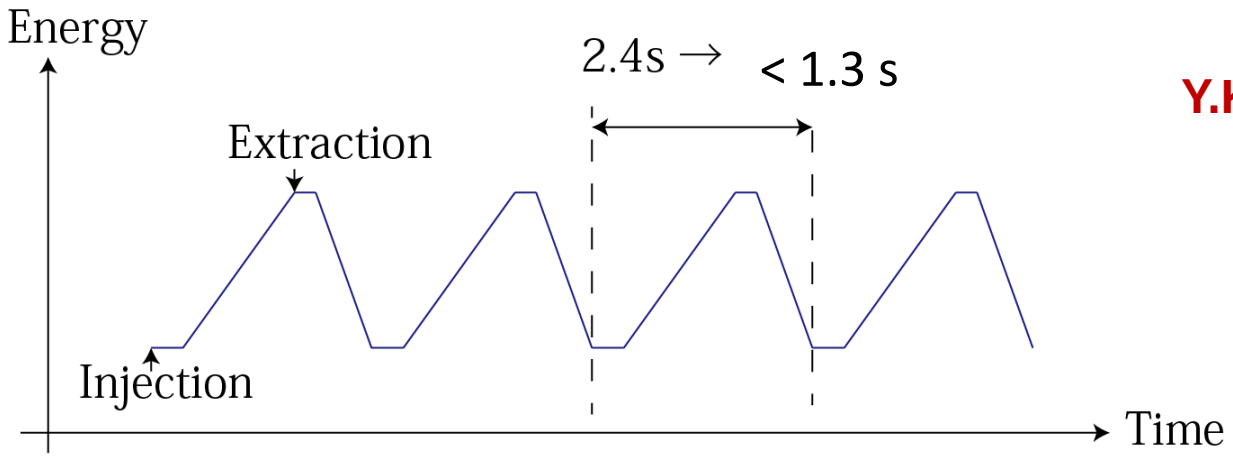
POPS capacitor bank at CERN.
6 Containers 65 tons

Series-parallel connection



F.Boattini, CERN

J-PARC Main Ring



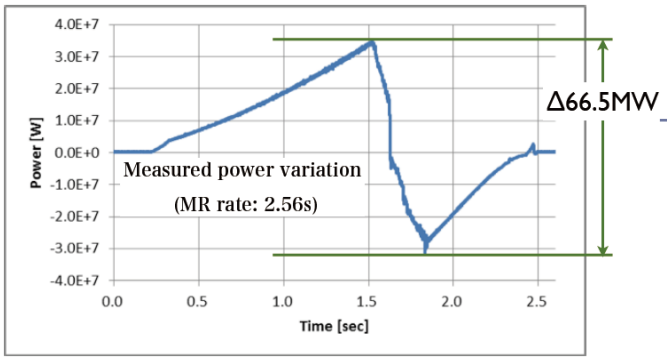
Y.Kurimoto, J-PARC

Increasing Repetition Rate from 0.4 Hz to approximately 1 Hz

Requirement : Energy Storage

Issue : Large power variation @ AC main grid $P = VI = \left(L\frac{dI}{dt} + RI\right)I$

2.56sec cycle



1sec cycle

~Δ140MW

Not allowed by Tokyo Electric Power Company

Energy Recovery with Bank Capacitor

Why a Workshop on Proton Driver Efficiency?

1) Proton Drivers need high power and have many applications, are in the focus of interest.

particle/nucl. physics
- neutrino sources
- muons
- RIB production

structure of matter
- neutron sources
- muon spectroscopy

nuclear energy / ADS
- transmutation
- subcritical reactor
- Thorium reactor

2) energy efficiency is one of the critical aspects for high intensity accelerators

critical for high intensity accelerators:
- cost/feasibility
- low losses
- reliability
- energy efficiency

Proton Driver Efficiency Workshop, PSI, Feb 2016

new concept of combining all factors in the power conversion chain of a p-driver:
RF generation, acceleration, targets, auxiliary systems

→ positive experience and feedback of participants

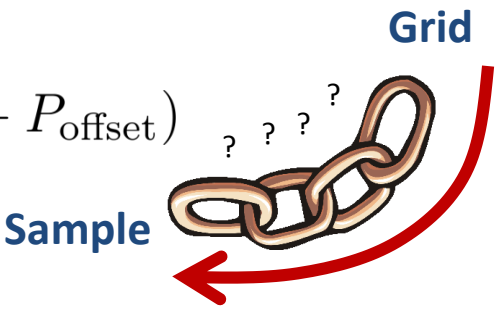
Workshop on Proton Driver Efficiency

idea: comprehensive approach to cover the entire power chain from Grid to secondary radiation at the user.

goal: Assess state of the art and development potential for each stage.
(comparison of potential of each link in the chain)
R&D recommendations in each field.
Workshop, not Conference.

at each power conversion step:

$$P_{\mathrm{out}} = \eta(P_{\mathrm{in}} - P_{\mathrm{offset}})$$



Sessions and Chairs:

Mon, morning	**Applications of proton drivers, physics requests**	J. Grillenberger, PSI
Mon, afternoon	**Targets, conversion to secondary radiation**	Ch. Densham, STFC
Tue, morning	**RF generation, methods and efficiency**	F. Gerigk, CERN
Tue, afternoon	**Accelerator Concepts**	V. Yakovlev, FNAL
Wed, Morning	**Conventional systems and cryogenics**	A. Lundmark, ESS

Proton Drivers – Concepts & Applications

	Neutrino	Muons	Neutrons	ADS	RIB's
Cyclotron	Daeδalus[1]	PSI-HIPA TRIUMF	PSI-HIPA	AIMA[2] TAMU-800[3]	TRIUMF RIKEN
RCS		J-PARC	J-PARC ISIS CSNS		
FFAG				KURRI +ongoing studies[4]	
s.c. Linac	PIP II [5]	PIP II [5]	SNS ESS ISNS[6]	ADSS[7] CIADS[8]	FRIB

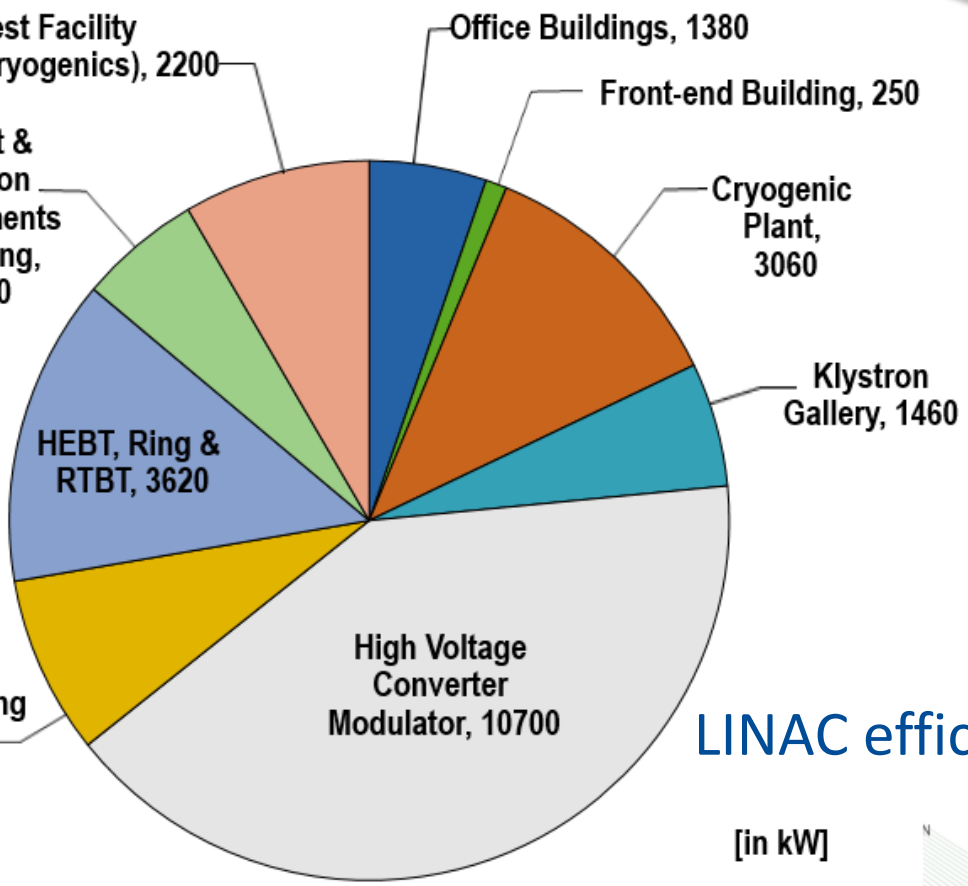
1 Decay-at-Rest Experiment for δcp studies At the Laboratory for Underground Science, MIT/INFN-Cat. et al
2 Accelerators for Industrial & med. Applications, reverse bend cyclotron, AIMA company
3 Cyclotron 800MeV, flux coupled stacked magnets, s.c. cavities, strong focusing channels, Texas A&M Univ.
4 FFAG studies, e.g. STFC, talk by S.Machida
5 SRF linac, Proton Improvement Plan-II (PIP-II), Fermilab, Batavia
6 Indian Spallation Neutron Source, Raja Ramanna Centre of Advanced Technology, Indore, India
7 Accelerator Driven Sub-critical System at Bhaba Atomic Research Centre (BARC), Mumbai,India
8 China Initiative Accelerator Driven System, Huizhou, Guangdong Prov. & IMP, Lanzhou, China

operating
in construction
concept study

Operating Accelerators, SNS SRF linac, San-Ho Kim

Breakdown of electric power consumption by systems during 1.4 MW operation; 26.3 MW

overall: 5.3%, M.S.



Accelerator: 20.5 MW
LINAC portion: 16.3 MW

LINAC efficiency is 8.6%

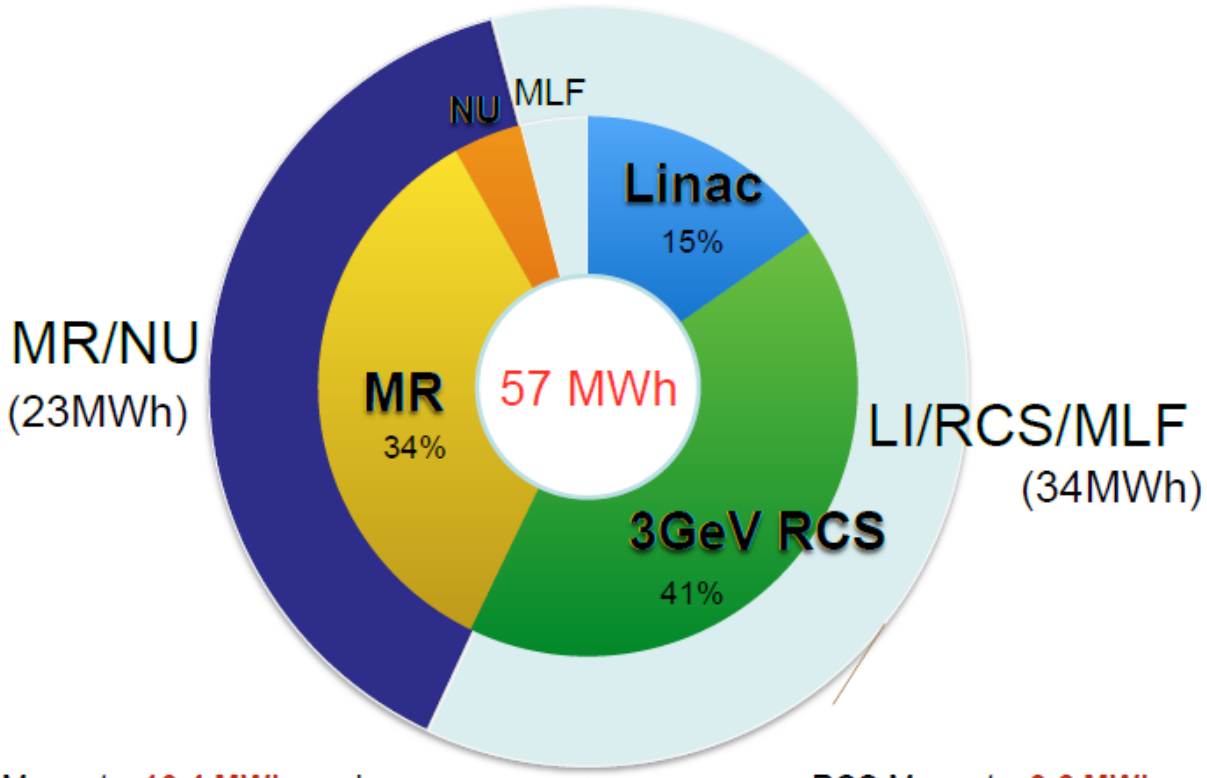
[in kW]

8 SNS, S-H. Kim

Fermilab

Operating Accelerators, 3 GeV RCS, Masahito Yoshii (JPARC)

MLF 500kW / FX 390kW operation

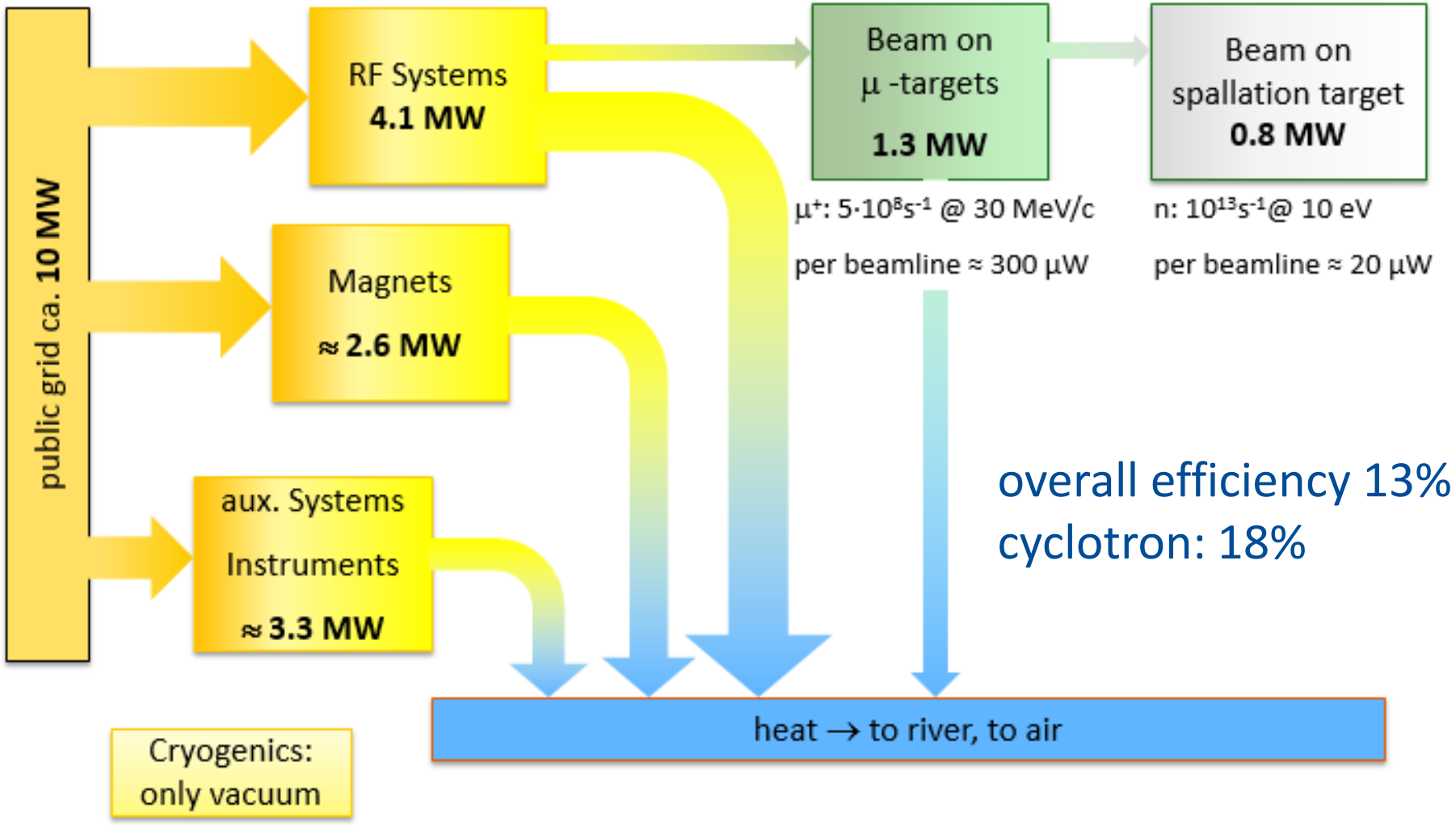


- MR Magnets: **10.4 MWh** per hour
- MR RF: **3.8 MWh** per hour
- RCS Magnets: **9.6 MWh** per hour
- RCS RF: **7 MWh** per hour

Efficiency 1.5%

Fermilab

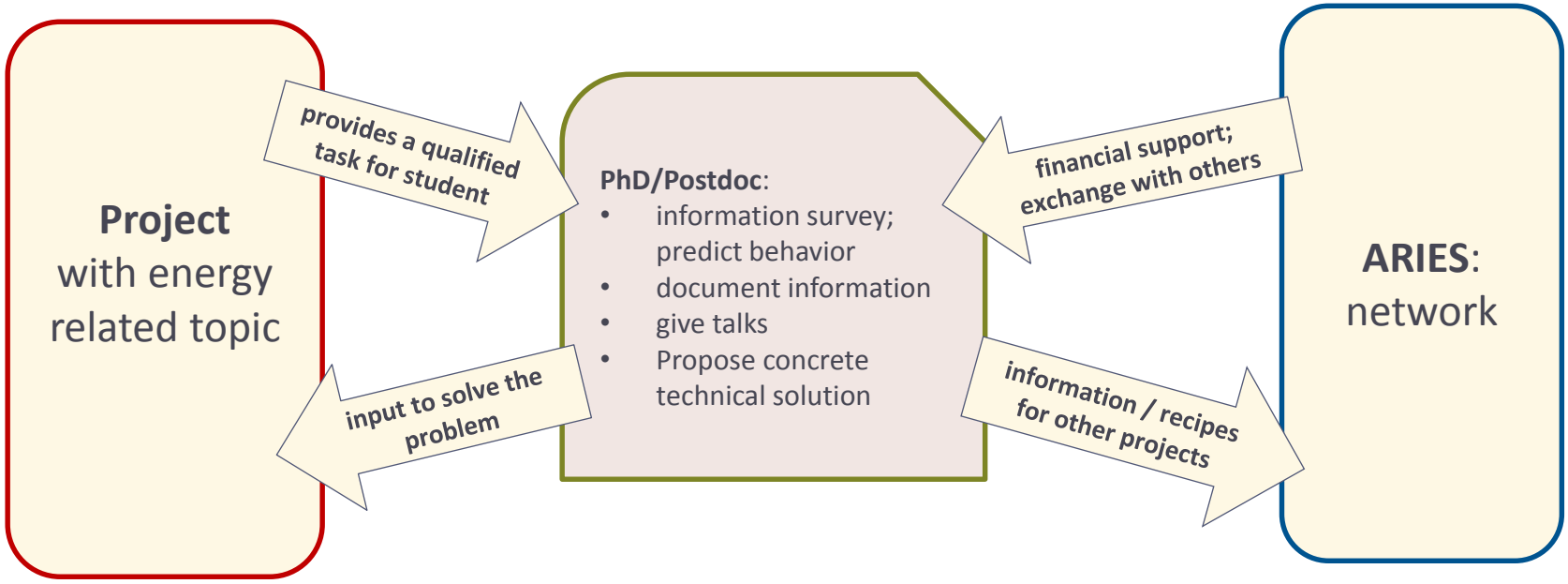
Operating Accelerators, PSI Cyclotron, J. Grillenberger



Fermilab

plan for ARIES: synergies with projects and students

our practical experience: PhD. students or Postdocs could be financed by network, have time to focus on a technical problem, provide excellent documentation



win-win for student, project, ARIES!

tasks in ARIES Proposal

Title:
Efficient Energy Management

concept:
- perform a study per task, one Postdoc or PhD is financed by 50% from ARIES
- organise one or several workshops per task

1	High Efficiency RF Power Sources	CEA Saclay Univ. Uppsala	C. Merchand R. Ruber
2	Increasing energy efficiency by increasing the efficiency of the spallation target station	PSI ESS	M. Wohlmuther E. Pitcher
3	High Efficiency SRF power conversion	CERN	F.Gerigk
4	Efficient operation of pulsed magnets	GSI	P.Spiller

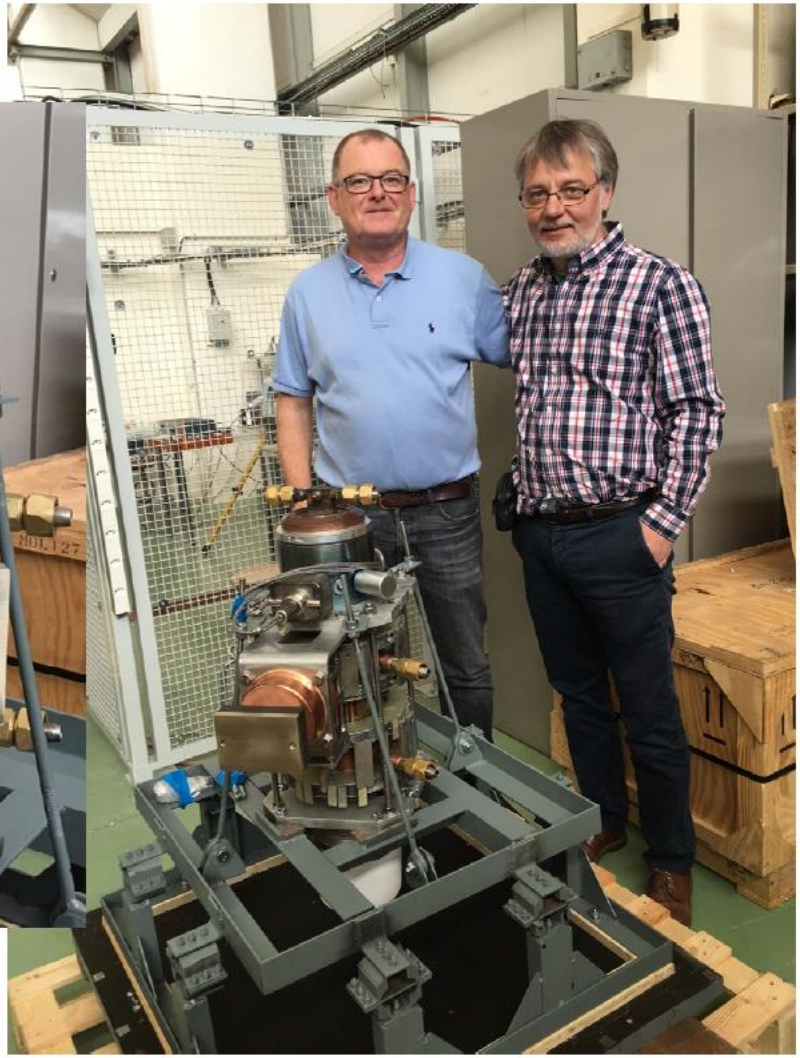
Status EnEfficient WP3,

M.Seidel, PSI

Task	Workshops / Deliverables	
heat recovery	Workshop ESS 3/14 Lab Inventory, Master Thesis ESS 3/14	✓ ✓
efficient RF generation	Workshop STFC 7/14 Session FCC week write up / summary 2/17	✓ ✓ o
energy storage	Session in DESY workshop 10/15 write up document (?)	✓ o
virtual power plant	Workshop (in prep) Lab survey on volatility, GSI, TUD (ongoing) write up document (12/16)	o ✓ o
efficient beam transfer systems	Workshop CERN 11/14 pulsed magnets work GSI (ongoing) concept comparison, Master Thesis GSI (10/15 ongoing)	✓ ✓ ✓
others that evolved	Workshop DESY : sustainable energy for large RI's 10/15 Workshop Proton Driver Efficiency ca 3/16 summary publication in journal, under discussion	✓ ✓ o

EuCARD²

CERN, 22.04.2016



S-band
BAC MBK
(VDBT, Russia)

40 beam klystron; 66% efficiency; 7MW peak; I.Syratchev, VDBT et al.