FOR A GLOBAL INITIATIVE TOWARD

GREEN COLLIDERS

International and Multidisciplinary

Energy for Research and Research in Energy

LCWS, Strasbourg Oct. 2017

Denis Perret-Gallix (LAPP-IN2P3/KEK)

HEP future will be Green or will not be

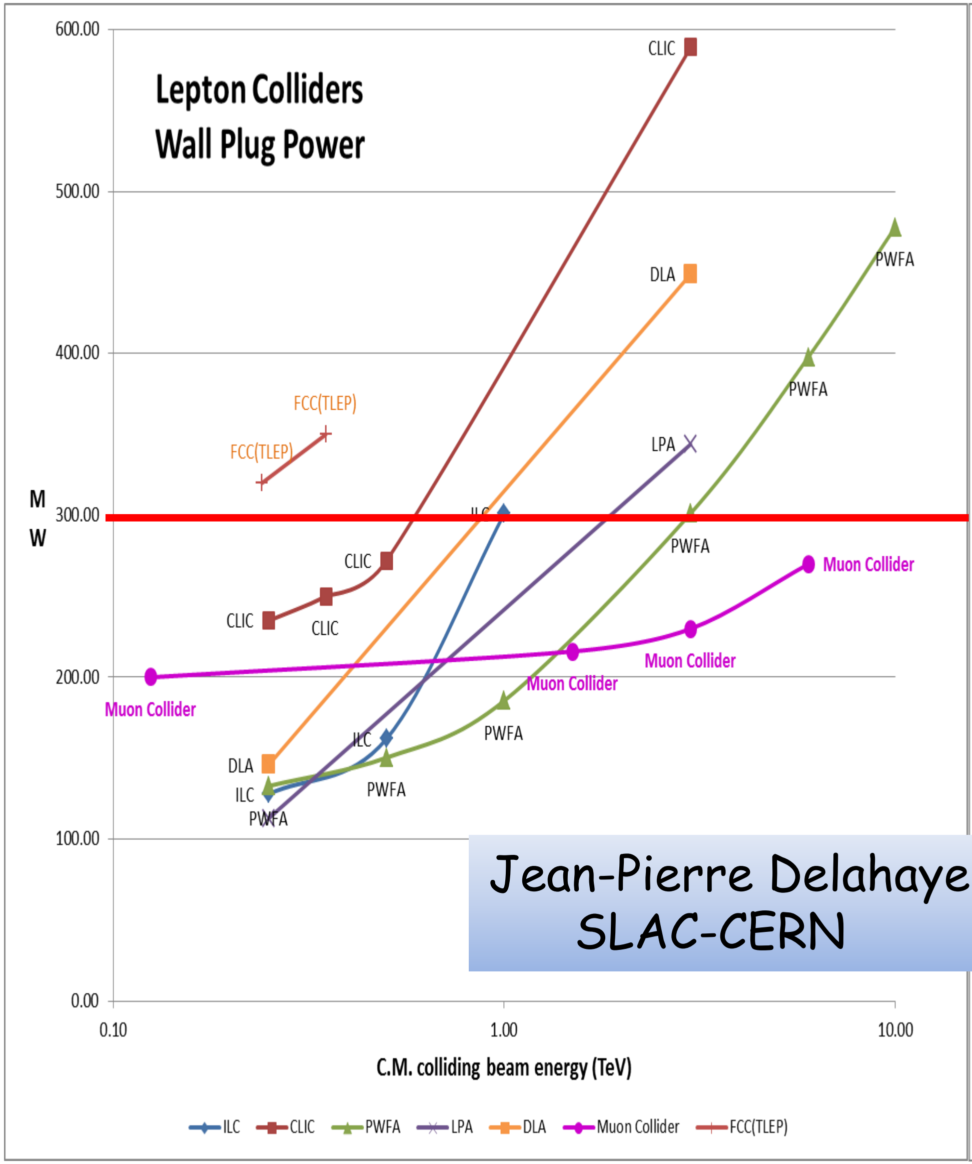
Efficient, Recyclable and Renewable

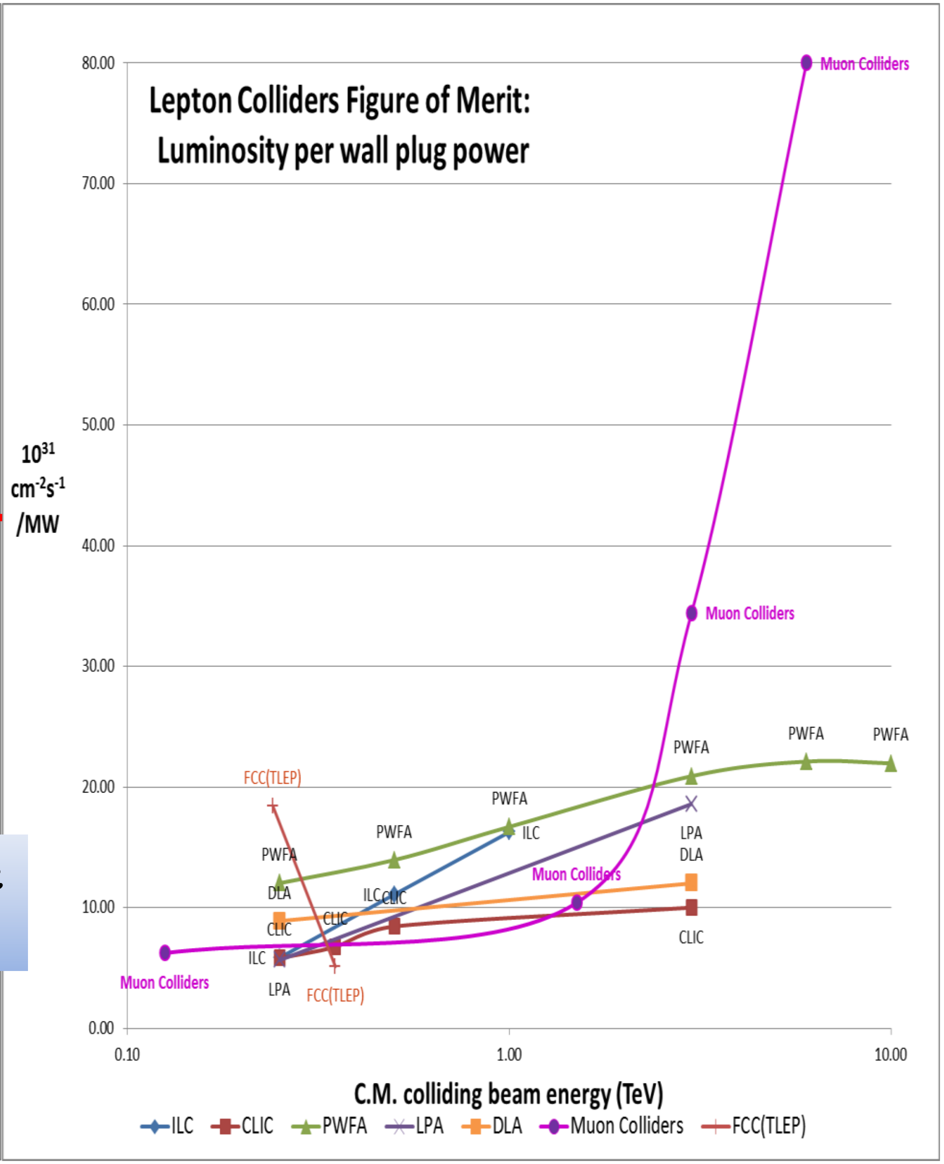
Scientific, Technical, Cost, Societal

- Scientific: A road-block to the highest energies:
  - 300 MW is the accepted upper limit for electricity consumption
  - Limit to: ~ 1 TeV for e+e-, < 10 TeV for $\mu+\mu-$, 20 TeV pp, Wakefield acceleration may do better
  - LHC@180MW CERN consumes 1.3 TWh/y (-> 1.5 HL-LHC) 1/2 Geneva or 0.3M UK homes
- Technical: From eV to TeV

  Colliders: the last link in the energy concentration chain: a huge success of technology, probably the most complex industrial system ever
  - Historically, to reach higher energies, new concepts were used to overcome the wall-plug power limitations
    - From linear to circular for proton (adding progressively energy to the beam and reusing the beam zillion times)
    - Collider versus fixed target
    - From warm to cold RF and magnet (1/2 the consumption)
    - Muon collider projects
  - Power Efficiency ~ 10% (ILC), room for improvement ?
  - Vicious circle: Poor efficiency -> overheating -> complex cooling -> more power needed

Lepton colliders “wall plug power”





Jean-Pierre Delahaye
SLAC-CERN

HEP future will be Green or will not be

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HEP future will be Green or will not be

Efficient, Recyclable and Renewable

- Running Cost vs Capital investment:
  - Electricity tariff trend is to the rise (IEA[1] up 14% or 123% (inflation) to 2050)
  - ILC: the least power-hungry ~ 15%[2] of its capital cost after 10y@500GeV (2015 Japan industrial tariff)
  - Optimize running cost vs capital investment
- Social/Political/Environmental:
  - Promoting $10-20 B projects on "fundamental research only" is not enough.
Underline the many technical benefits brought to the society. Energy should be put among them.
  - Some are green field projects (ILC, CEPC, SPPC) and a perfect test bench for "Energy R&D"
Moving from pure "High-Energy Research" to an inclusive "Energy R&D"
  - New Colliders should adopt the Green engineering paradigm for:
    - Energy efficiency and recycling, storage, production/use of renewable energy, environmental impact and safety
    - Gas and water management, …

Green engineering is the design, commercialization, and use of processes and products that minimize pollution, promote sustainability, and protect human health without sacrificing economic viability and efficiency.

[1] International Energy Agency

[2] 160-180 MW, 200 days/year 24h/d 0.77-0.86 TWh, 180$/MW 138-155 M$/year, 10 years@0.5TeV 1.38-1.55B$

Where do Green issues stand today?

- In the HEP lab. triggered by National laws, running cost saving or environmental concerns (FermiLab or SLAC SSP*, CERN, KEK, …)
- Most of the progress is coming from dedicated projects: ILC, ESS, CLIC (see Steinar's Talk), FCC's
- EU Workshop: "Energy for sustainable science", sessions in conf./workshops
- Networks/committees
  - Europe: EUCARD2 - WP3: Energy Efficiency (EnEfficient)
  - International: ICFA panel: "Sustainable accelerators/Colliders"

* Site Sustainability Plan

Green-ILC Objectives

started Oct. 2013

ILC : lower running cost, better operational flexibility, environment friendly

Revisiting all ILC components:

1. Energy Saving: improving efficiency …. 90% lost as heat waste
2. Operational saving
3. Energy Recovery and Recycling

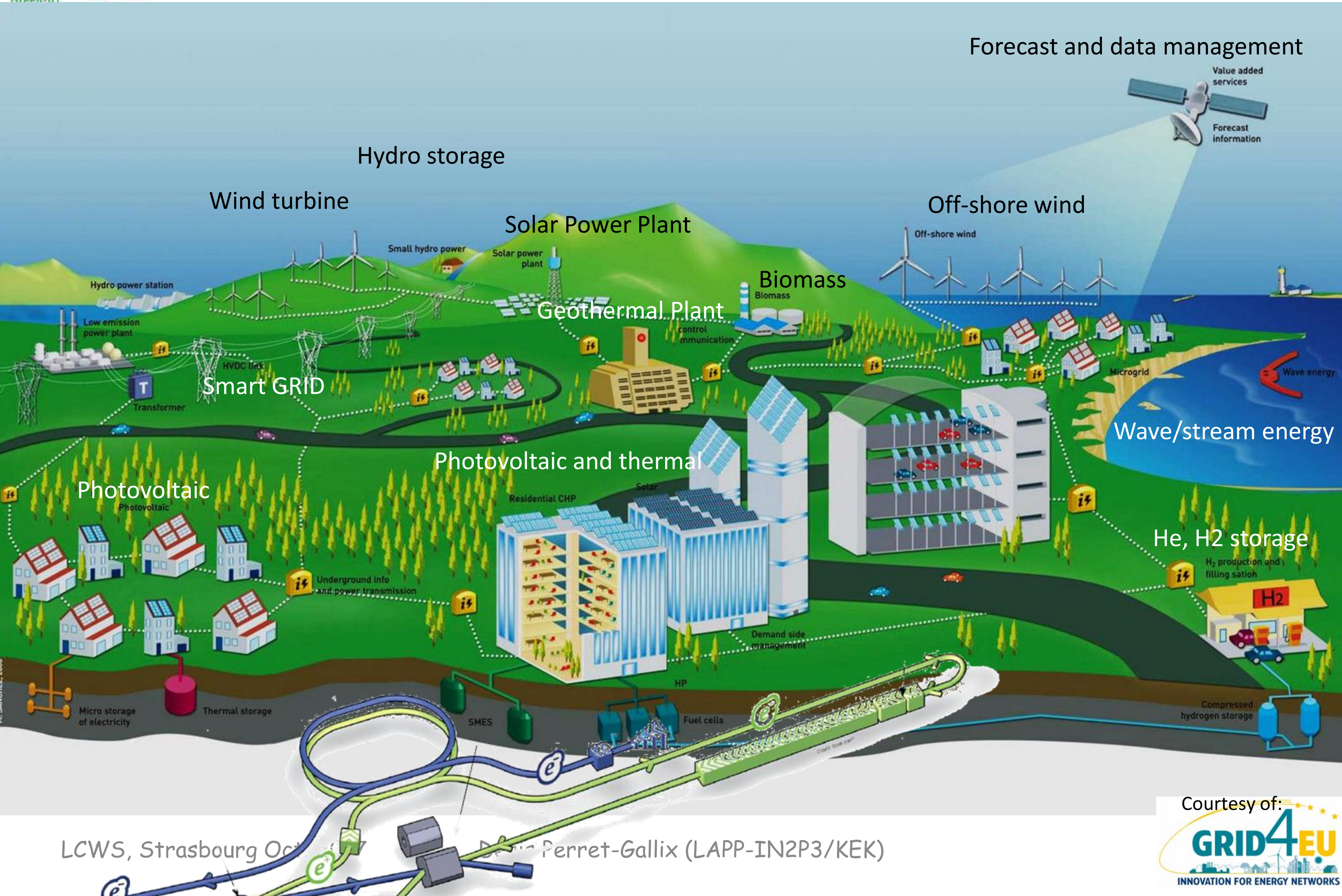
Alternative energies:

1. Renewable energy production, best for ILC and ILC site
2. Energy Storage (for energy recovery and intermittency)
3. Distribution and Management: Smart Grid

Energy for: societal needs and world economy,

1. Basic Research
2. Synergies: expertise (SC, magnets, beams, computing), photon, neutron factories
3. Technology innovation
4. ILC as a test bench: building pilot power plants for ILC

ILC “Energy Research Center” with its dedicated energy production



Forecast and data management

Hydro storage

Wind turbine

Solar Power Plant

Off-shore wind

Biomass

Geothermal Plant

Smart GRID

Wave/stream energy

Photovoltaic and thermal

Photovoltaic

He, H2 storage

Courtesy of: GRID4EU

INNOVATION FOR ENERGY NETWORKS

ILC baseline energy budget
164 MW @ 500 GeV

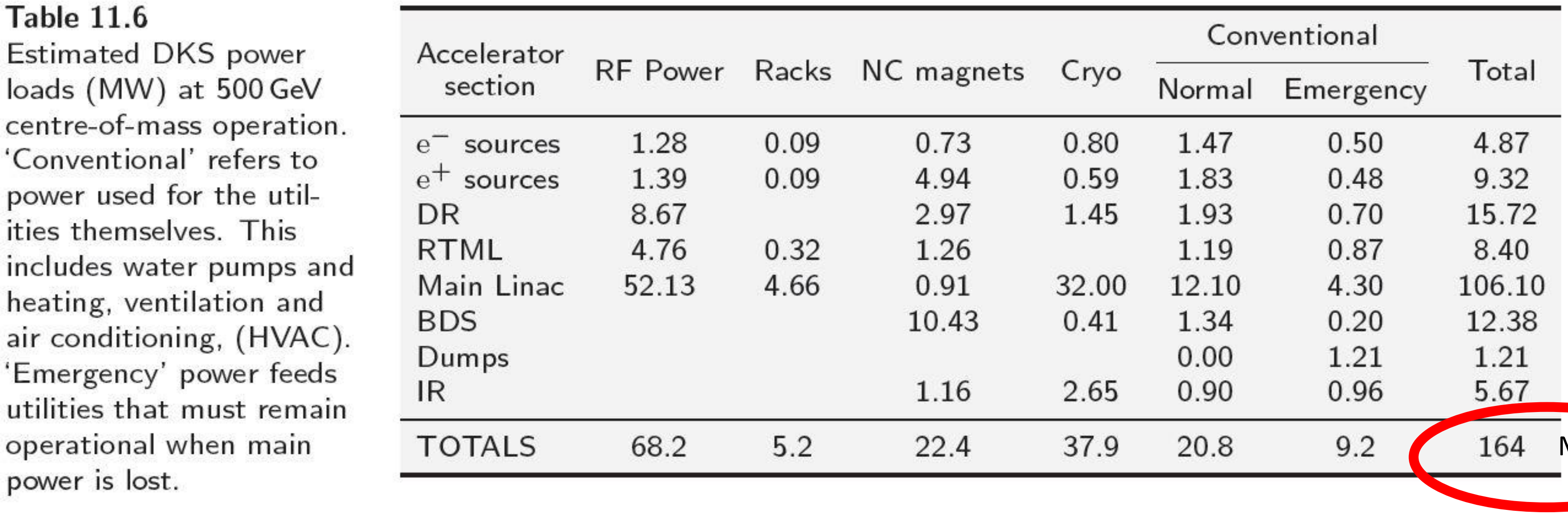


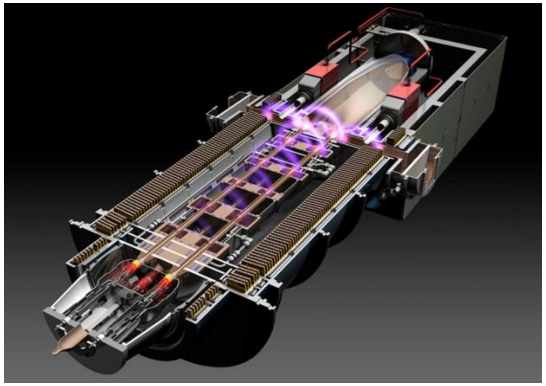
Table 11.6
Estimated DKS power loads (MW) at 500 GeV centre-of-mass operation. 'Conventional' refers to power used for the utilities themselves. This includes water pumps and heating, ventilation and air conditioning, (HVAC). 'Emergency' power feeds utilities that must remain operational when main power is lost.

Accelerator section	RF Power	Racks	NC magnets	Cryo	Conventional		Total
					Normal	Emergency	
e^- sources	1.28	0.09	0.73	0.80	1.47	0.50	4.87
e^+ sources	1.39	0.09	4.94	0.59	1.83	0.48	9.32
DR	8.67		2.97	1.45	1.93	0.70	15.72
RTML	4.76	0.32	1.26		1.19	0.87	8.40
Main Linac	52.13	4.66	0.91	32.00	12.10	4.30	106.10
BDS			10.43	0.41	1.34	0.20	12.38
Dumps					0.00	1.21	1.21
IR			1.16	2.65	0.90	0.96	5.67
TOTALS	68.2	5.2	22.4	37.9	20.8	9.2	164 MW

Rank:	1	6	3	2	4	5
% :	42	3	15	23	13	5

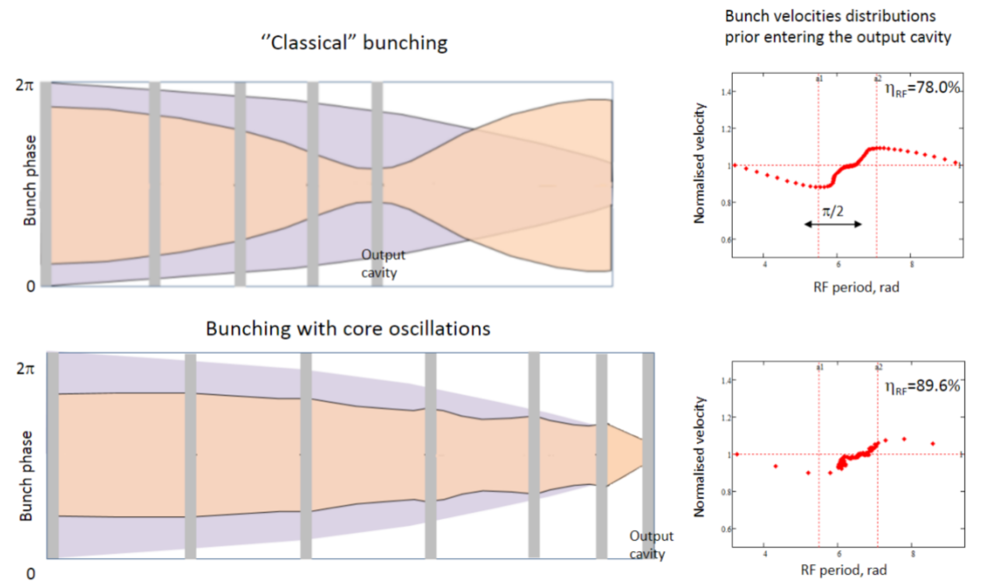
Energy Saving and recovery

RF Klystron



- Better efficiency: from 60% to 80%
  - 90% HEIKA CERN see I. Syratchev's talk)
  - Kladistron (EUCARD2,CEA)

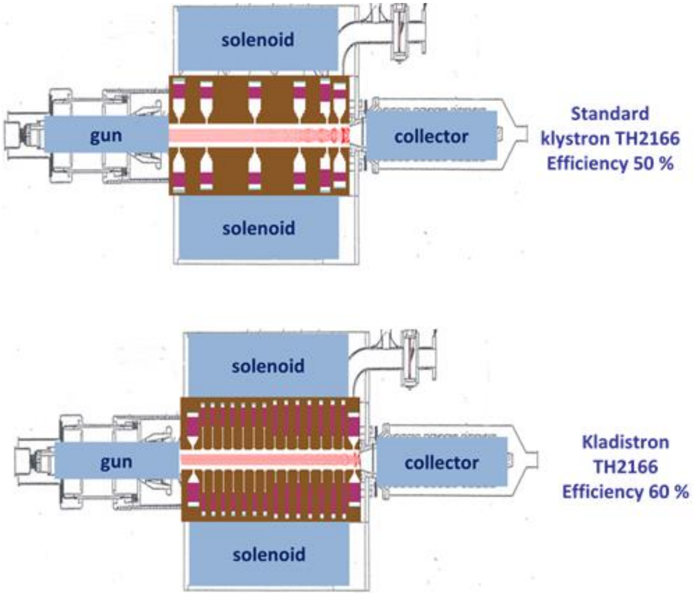
HEIKA



I. Syratchev, June 2015, HG Workshop, Beijing.

HEIKA

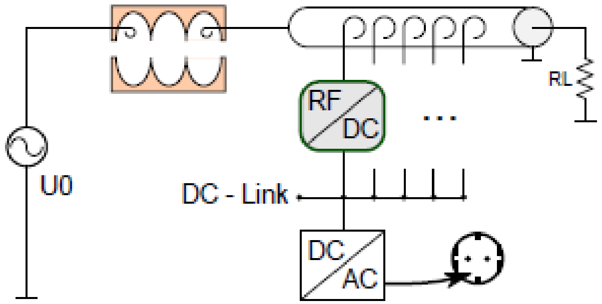
Kladistron



Energy Saving and recovery
RF Klystron

- Klystron Energy recovery
  Recover non-used RF power: Smart RF loads

Idea 1) – reconvert to DC power!



AC 50 Hz, to distribution grid

1) http://accelconf.web.cern.ch/AccelConf/IPAC10/papers/wepd090.pdf

Generator for REcovering ENergy from RF: **GREEN-RF**
SLAC-CPI R&D Partnership

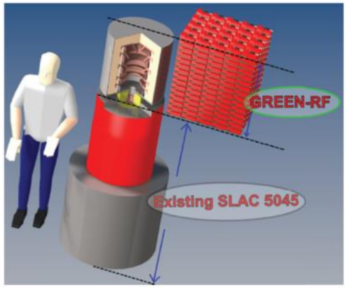
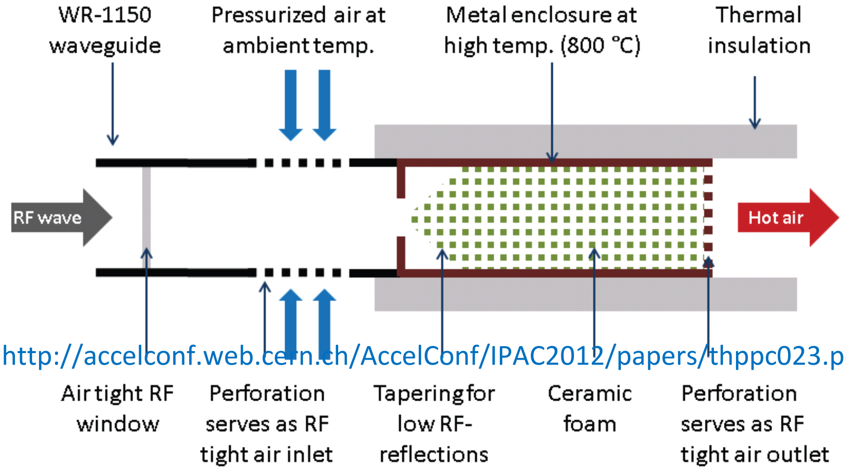


Figure 12: Solid model of the 5045 depressed collector paired with an inverse Marx energy recovery modulator

Claude Van Dalle, CPI

Idea 2) – use high-*T* loads!



WR-1150 waveguide

Pressurized air at ambient temp.

Metal enclosure at high temp. (800 °C)

Thermal insulation

RF wave

Hot air

2)http://accelconf.web.cern.ch/AccelConf/IPAC2012/papers/thppc023.pdf

Air tight RF window

Perforation serves as RF tight air inlet

Tapering for low RF-reflections

Ceramic foam

Perforation serves as RF tight air outlet

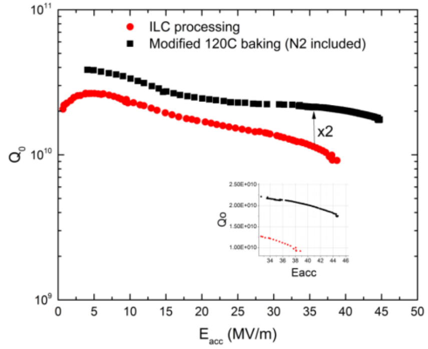
2)http://accelconf.web.cern.ch/AccelConf/IPAC2012/papers/thppc023.pdf

Energy Saving and recovery
Cavities

- Very active R&D: Great saving potential

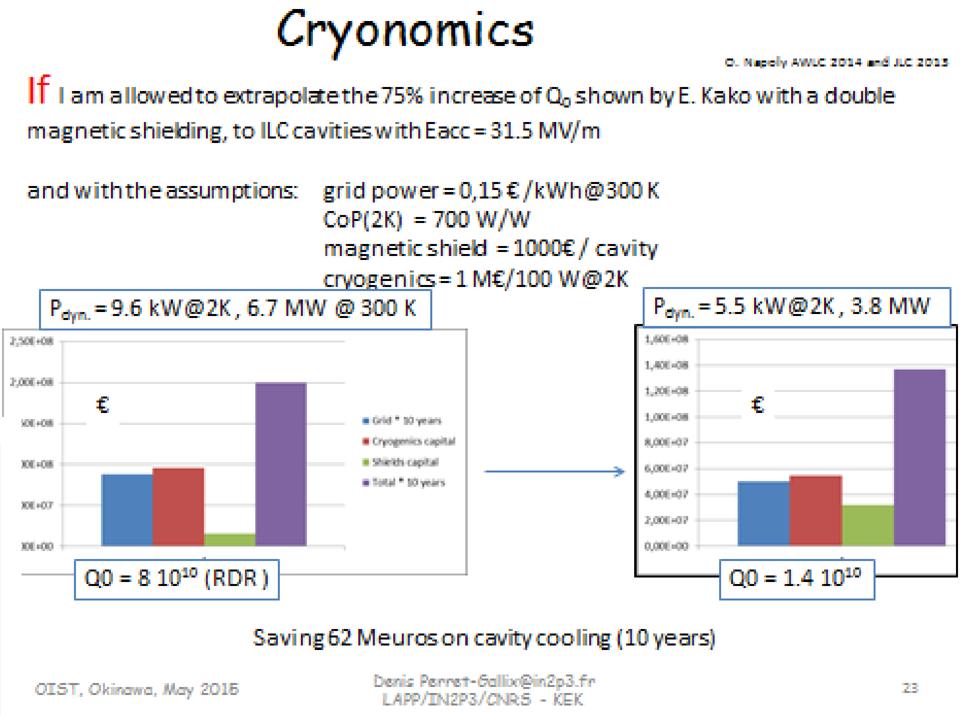
- Additional Magnetic shields increase cavity Q_0
  -> decrease cryo -> save 62 ME (10 years)
  O. Napoly AWLC 2014 and JLC 2013)
- Type I SN Meissner shielding (Kyoto Univ., Cornell, …

- Nitrogen Infusion/Doping (FNAL,ANL, JLAB, Cornell)
  - Higher Q_0
  - Larger Gradient



- Coarse grain (D. Kostin, R. Porter) -> 39 MV/m

- 4.2K cooling instead of 1.9K Q_0 2 10^{10} 26 MV/m



Cryonomics

O. Napoly AWLC 2014 and JLC 2013

If I am allowed to extrapolate the 75% increase of Q_0 shown by E. Kako with a double magnetic shielding, to ILC cavities with Eacc = 31.5 MV/m

and with the assumptions: grid power = 0,15 € /kWh@300 K
CoP(2K) = 700 W/W
magnetic shield = 1000€ / cavity
cryogenics = 1 M€/100 W@2K

$P_{dyn.}$ = 9.6 kW@2K , 6.7 MW @ 300 K

$P_{dyn.}$ = 5.5 kW@2K , 3.8 MW

Q0 = 8 10^{10} (RDR)

Q0 = 1.4 10^{10}

Saving 62 Meuros on cavity cooling (10 years)

OIST, Okinawa, May 2016
Denis Perret-Gallix@in2p3.fr
LAPP/IN2P3/CNRS - KEK
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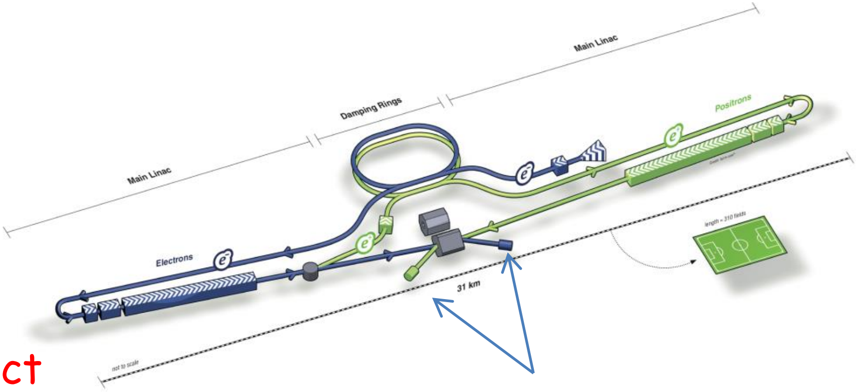
Very promising,
great saving capital and running cost
But More R&D needed.

Energy Saving and recovery

- Beam dumps

- 14 MW (1TeV) @5 hertz
- 10 m Water 155°C, 1000m gas



Main Beam dumps
10m water, 1000m gas

Wakefield deceleration for beam dump project

Study on the International Linear Collider Beam Dump by plasma-wakefield deceleration

T. Saeki, J. Fujimoto, H. Hayano, K. Yokoya (KEK/Sokendai)
T. Tajima, D. Farinella, X. Zhang (University of California at Irvine)
M. Zeng (ELI-NP, Romania)
A. W. Chao (SLAC)
D. Perret-Gallix (LAPP/IN2P3 – KEK)

1st Nov. 2016
Academia meets industry forum
IEEE-NSS/MIC
Strasbour, France

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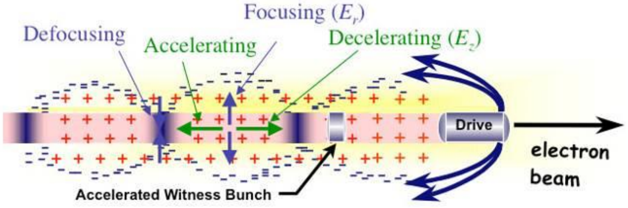
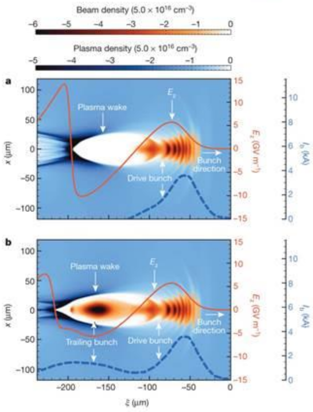
Inter-University Research Institute Corporation High Energy Accelerator Research Organization
高エネルギー加速器研究機構
KEK
2016/10/30

Plasma Acceleration, wakefield acceleration





Preliminary result of beam deceleration simulation

$beam:$

$\sigma_x = 300\mu m; \sigma_r = 50\mu m;$

$E = 250G\,\mathrm{eV}(\gamma_0 = 5\times10^5)$

$\mathrm{dE/\,E} = 0.1\%$

$\mathrm{N}_b = 2\times10^{10}\,(3.2nC)$

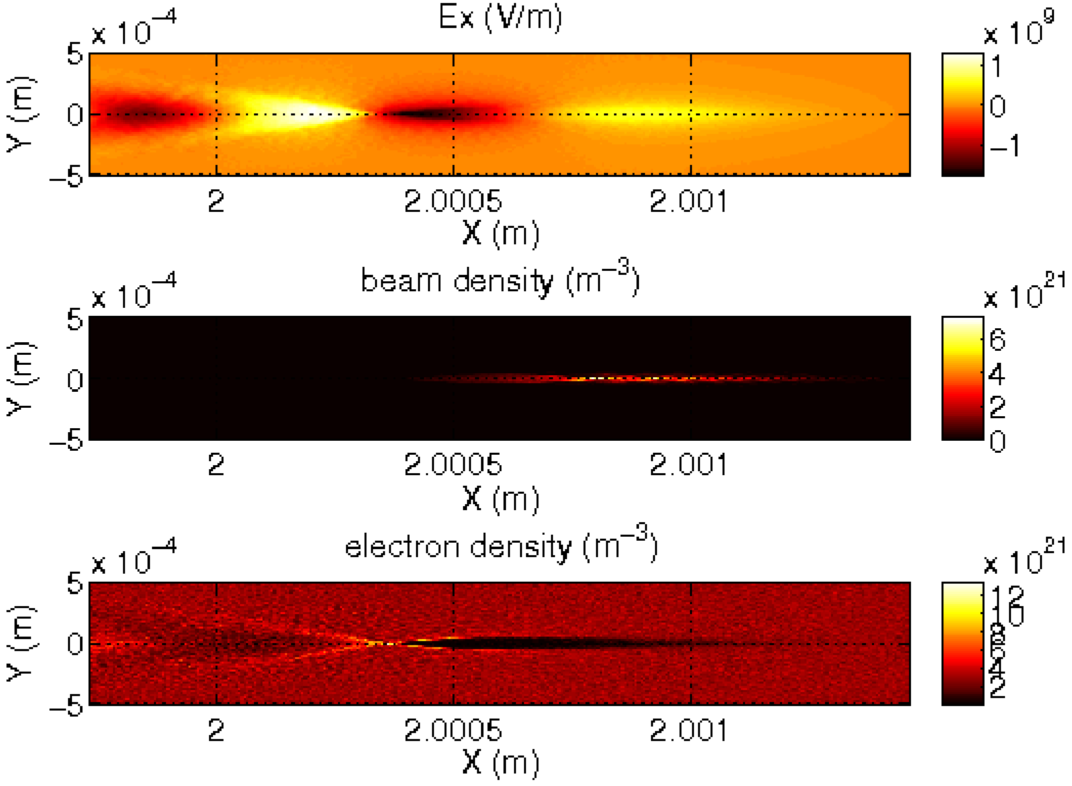
$$n_b = \frac{N_b}{(2\pi)^{3/2}(\sigma_x\sigma_r\sigma_r)} = 1.7\times10^{21}\,/\,m^3$$

$plasma:$

$n_p = 3\times10^{21}\,/\,m^3$

$\lambda_p \sim$ 600 μm

$\sigma_x \sim \lambda_p\,/\,2$



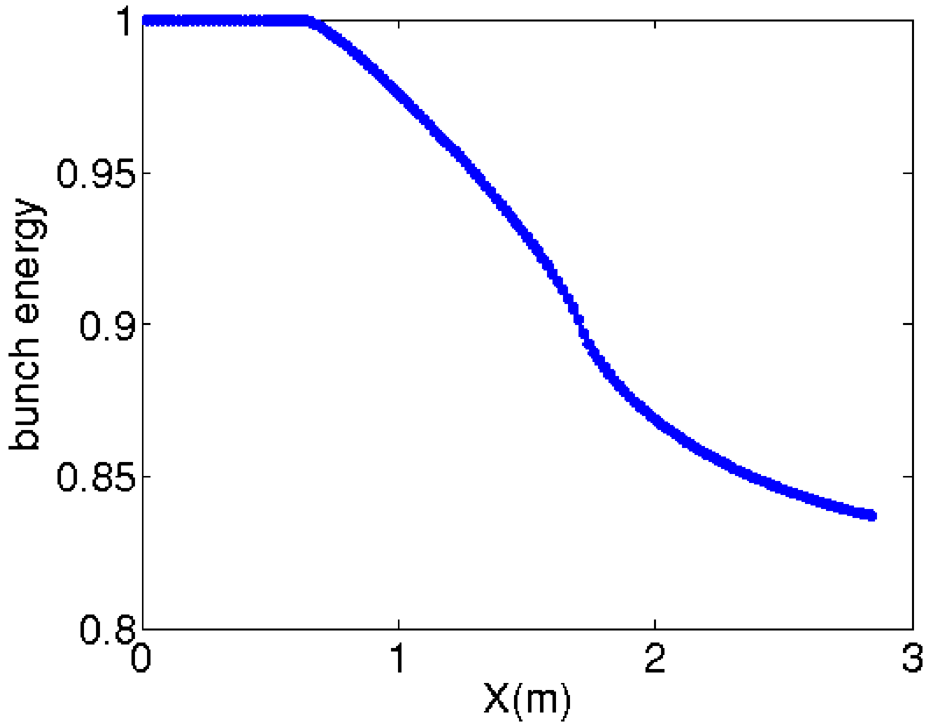
Simulation code: EPOCH

Dr. X. Zhang (UCI)

Preliminary result of beam deceleration simulation

Dr. X. Zhang (UCI)

More than 15% energy loss after 3m

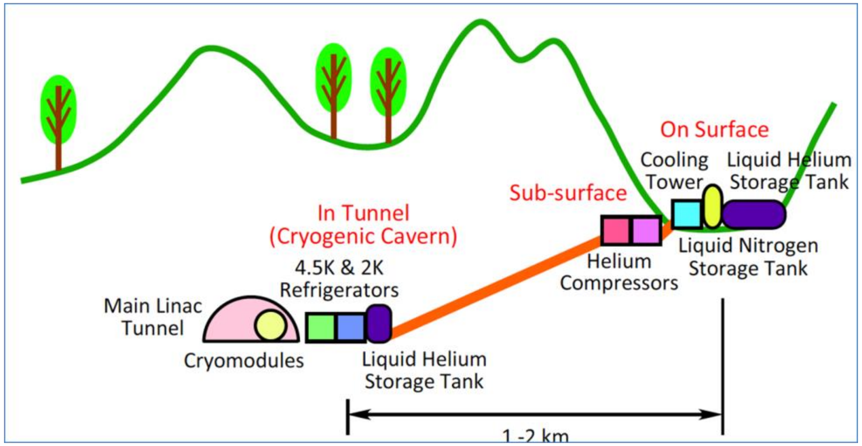


First result of simulation is encouraging. Working is continuing with priority.

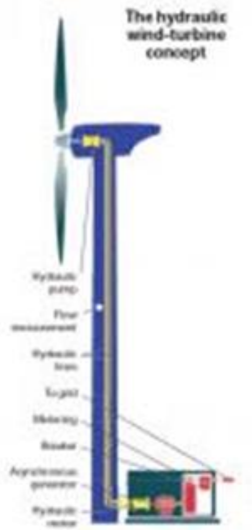
Energy Saving and recovery

Cryogenics

- LN2 pre-cooling
  - Producing LN2 on site from wind turbine



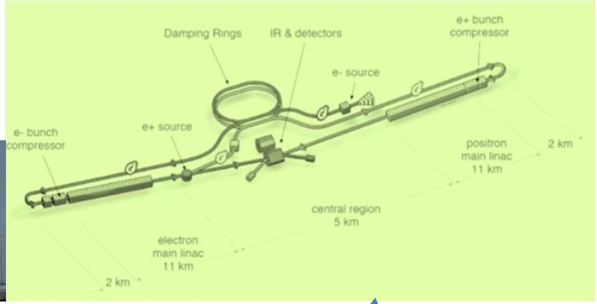
LN2 process cycle



LN2 ⇒

- Cryocooler may save 30-50% electrical power
- Cooling water
- HTc power Transmission lines

Energy storage



LN2

heat waste

Turbine → electrical generator

N2 gas applications

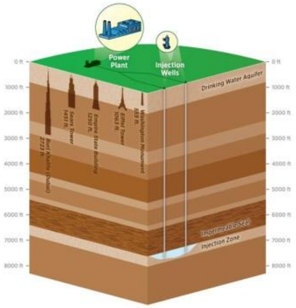
Electricity Back to ILC/GRID

i.e. Drying and preservation industry

LO2, LAr, SCO2 Dry ice

To Industry

For Cooling or Sequestration



www.shutterstock.com · 35843785

Air cleaning !!!

Denis Perret-Gallix@in2p3.fr
LAPP/IN2P3/CNRS - KEK

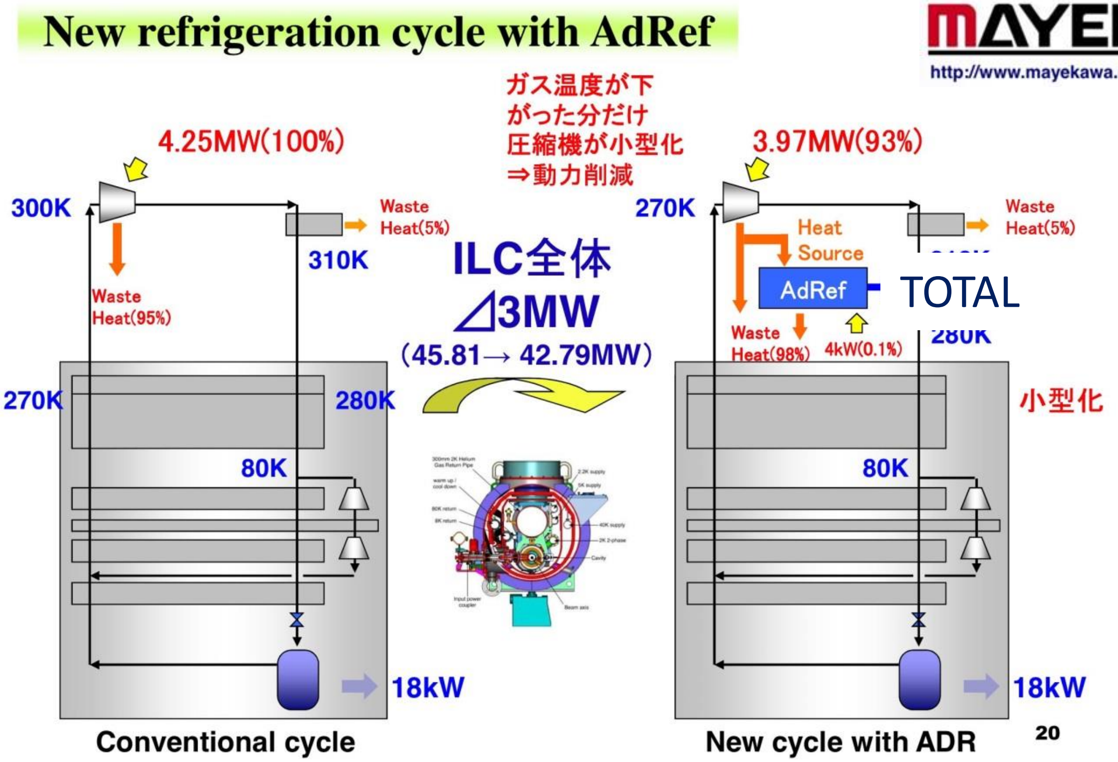
Helium cryocooler power saving

Green-ILC AAA meetings (H. Hayano, T. Saeki)

7% saving

Adsorption Refrigerator

MAYEKAWA
http://www.mayekawa.co.jp/ja/


New refrigeration cycle with AdRef

Characteristics;
1. non-CFC gas, but use water
2. Low temperature heat exhaust
3. Economy operation (only water pump)
4. Easy maintenance
5. Safe operation

New Technology, new saving

- 3D turbine construction
- LN2 stage

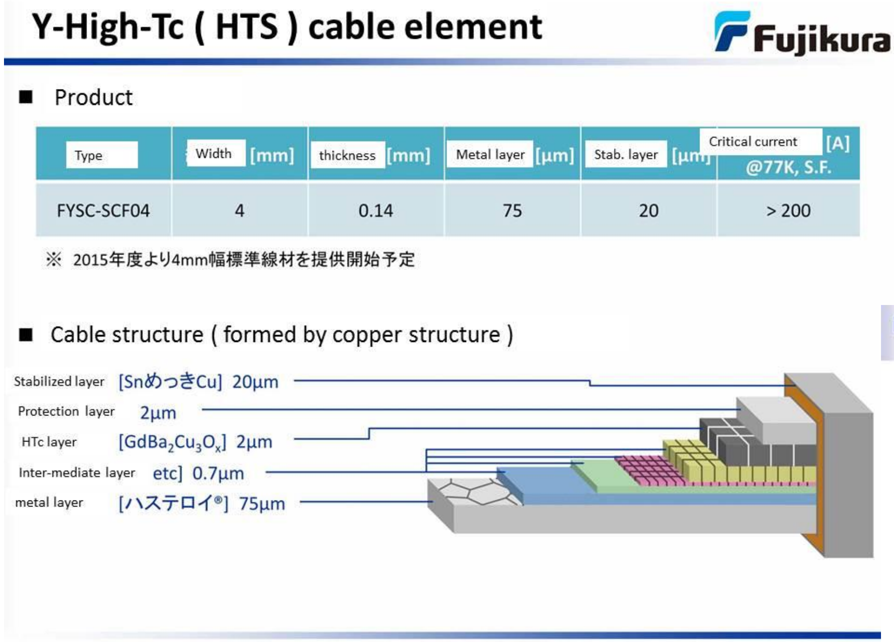
Cryocooler for 1 W cooling power at 4.5K: went from 600 W to 250 W (2.4 saving)

Dimitri Delikaris (CERN)

Energy Saving and recovery

Transmission power lines

Green-ILC AAA meetings (H. Hayano, T. Saeki)



Y-High-Tc (HTS) cable element

Fujikura

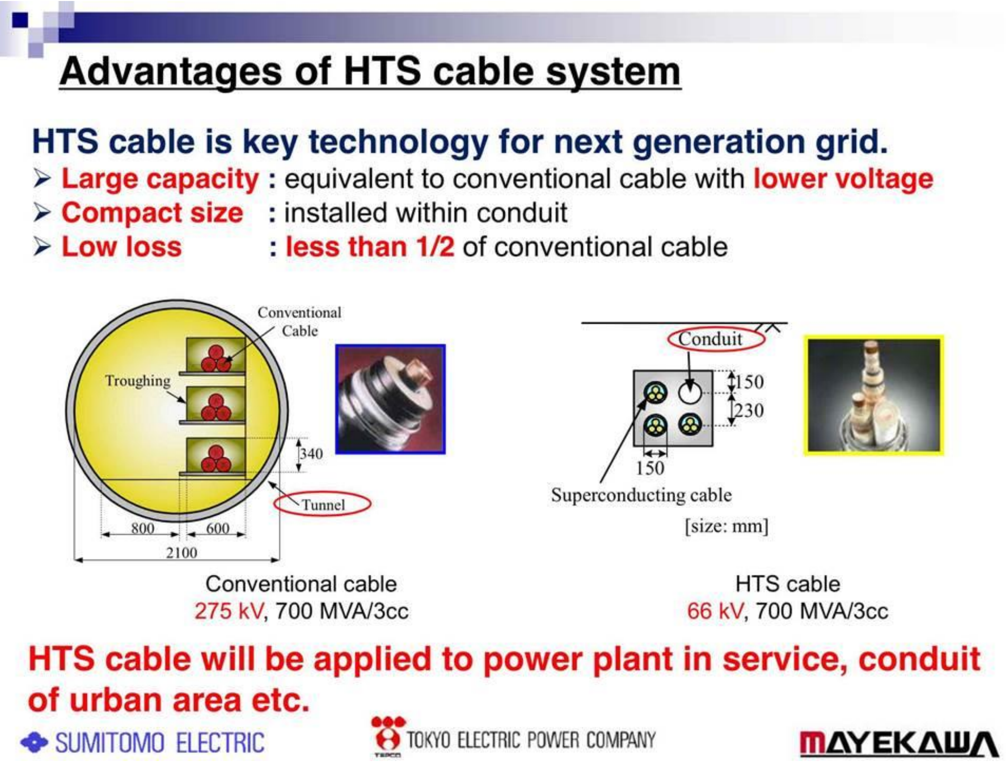
- Product

Type	Width [mm]	thickness [mm]	Metal layer [µm]	Stab. layer [µm]	Critical current [A] @77K, S.F.
FYSC-SCF04	4	0.14	75	20	> 200

※ 2015年度より4mm幅標準線材を提供開始予定

- Cable structure (formed by copper structure)

Stabilized layer [SnめっきCu] 20µm
Protection layer 2µm
HTc layer [$GdBa_2Cu_3O_x$] 2µm
Inter-mediate layer etc] 0.7µm
metal layer [ハステロイ®] 75µm



Advantages of HTS cable system

HTS cable is key technology for next generation grid.

- **Large capacity** : equivalent to conventional cable with **lower voltage**
- **Compact size** : installed within conduit
- **Low loss** : **less than 1/2** of conventional cable

Conventional cable
275 kV, 700 MVA/3cc

HTS cable
66 kV, 700 MVA/3cc

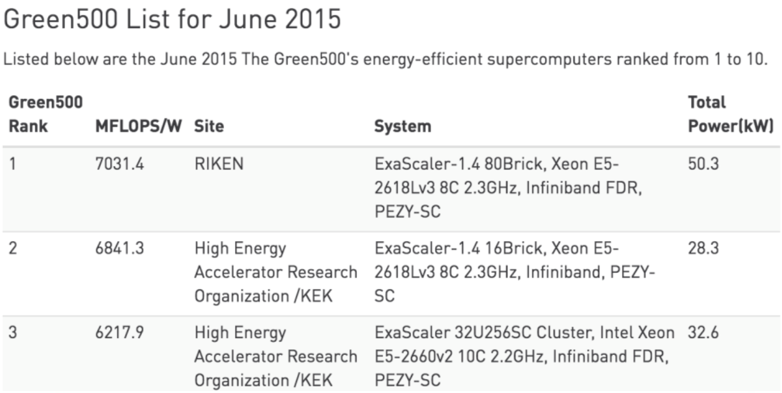
HTS cable will be applied to power plant in service, conduit of urban area etc.

SUMITOMO ELECTRIC TOKYO ELECTRIC POWER COMPANY MAYEKAWA

Energy Saving and recovery

Computing

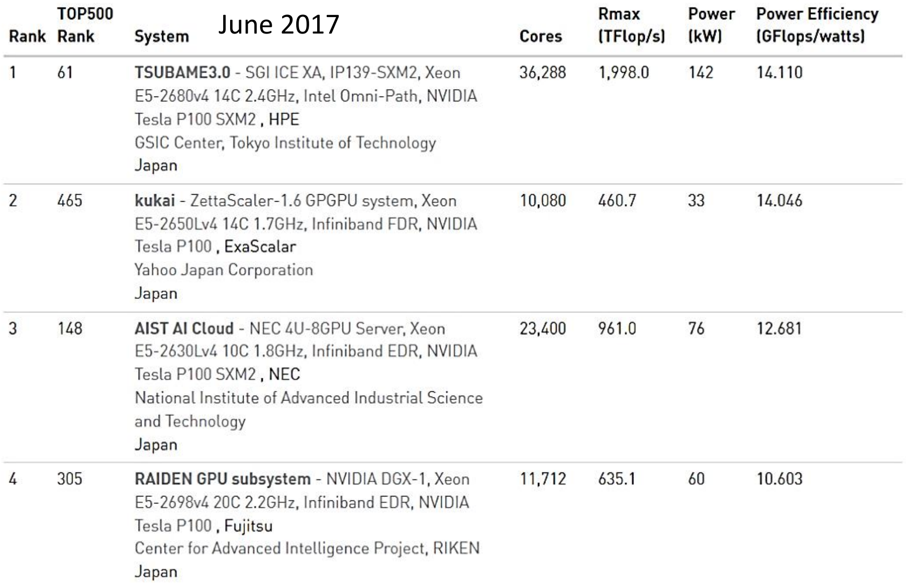
- Suiren, KEK computer ranking 2nd GREEN500 2014 2015
- ~ 6.8 GFLOP/S/W for a 0.193 PFLOP/S Rmax
- Submersion liquid coolant fluorinet



Green500 List for June 2015

Listed below are the June 2015 The Green500's energy-efficient supercomputers ranked from 1 to 10.

Green500 Rank	MFLOPS/W	Site	System	Total Power(kW)
1	7031.4	RIKEN	ExaScaler-1.4 80Brick, Xeon E5-2618Lv3 8C 2.3GHz, Infiniband FDR, PEZY-SC	50.3
2	6841.3	High Energy Accelerator Research Organization /KEK	ExaScaler-1.4 16Brick, Xeon E5-2618Lv3 8C 2.3GHz, Infiniband, PEZY-SC	28.3
3	6217.9	High Energy Accelerator Research Organization /KEK	ExaScaler 32U256SC Cluster, Intel Xeon E5-2660v2 10C 2.2GHz, Infiniband FDR, PEZY-SC	32.6



June 2017

Rank	TOP500 Rank	System	Cores	Rmax (TFlop/s)	Power (kW)	Power Efficiency (GFlops/watts)
1	61	**TSUBAME3.0** - SGI ICE XA, IP139-SXM2, Xeon E5-2680v4 14C 2.4GHz, Intel Omni-Path, NVIDIA Tesla P100 SXM2 , **HPE** GSIC Center, Tokyo Institute of Technology Japan	36,288	1,998.0	142	14.110
2	465	**kukai** - ZettaScaler-1.6 GPGPU system, Xeon E5-2650Lv4 14C 1.7GHz, Infiniband FDR, NVIDIA Tesla P100 , **ExaScalar** Yahoo Japan Corporation Japan	10,080	460.7	33	14.046
3	148	**AIST AI Cloud** - NEC 4U-8GPU Server, Xeon E5-2630Lv4 10C 1.8GHz, Infiniband EDR, NVIDIA Tesla P100 SXM2 , **NEC** National Institute of Advanced Industrial Science and Technology Japan	23,400	961.0	76	12.681
4	305	**RAIDEN GPU subsystem** - NVIDIA DGX-1, Xeon E5-2698v4 20C 2.2GHz, Infiniband EDR, NVIDIA Tesla P100 , **Fujitsu** Center for Advanced Intelligence Project, RIKEN Japan	11,712	635.1	60	10.603

THE GREEN 500™

sponsored by SUPERMICRO

This certificate is in recognition of your organization's achievements in reducing the environmental impact of high-performance computing.

High Energy Accelerator Research Organization /KEK

is ranked

2nd

on the world's Green500 List of computer systems as of

November 2014

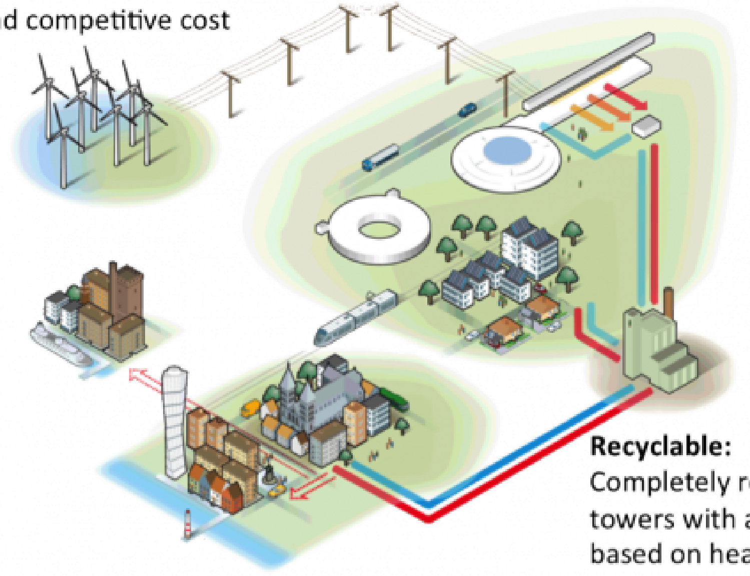
Wu-chun Feng, Co-Chair

Kirk Cameron, Co-Chair

Fig. 2. Suiren(left) and Suiren-blue(top right) and its components(bottom right)

Efficiency doubled in the last 2 years

The Green ESS
European Spallation Source -- 4R



Renewable:
All energy from new, dedicated renewable production at a stable and competitive cost

Responsible:
Reduce energy use to under 270 GWh per year

"ESS will not just be one of the world's most modern research facilities; It will also be one of the most sustainable and energy-intelligent.

The objective is that the facility will use a minimum amount of energy, that all energy will derive from renewable energy sources and that a maximum amount of residual energy is recycled. "

Recyclable:
Completely replace cooling towers with a cooling system based on heat recycling.

Reliable
stable electricity and cooling supplies

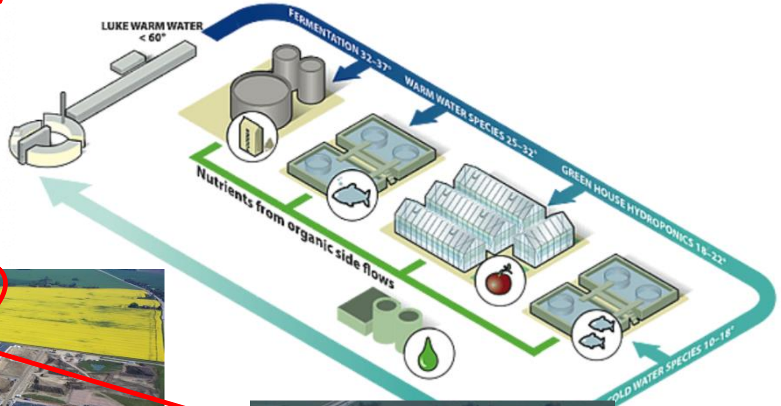


IMAGE: ESS

ESS: 18 May 2017

Wind Power:100 MW
Machine: 278 GWh/y
Cooling: 265 GWh/y

China Green networking CEPC

- Ring SCRF: 168 800kW 650MHz CW klystrons are needed with efficiency ~85%.
- A national network composed of institutes of CAS and Industries has been established and financed for R&D and industrialization.
- An international workshop " High Efficiency High Power Frontier,, or HEHPF2018, is planned to be held in Beijing, 2018.

- Networking for High performance large Cryogenic system

(From Jie Gao, IHEP)

ICFA: International Panel on "Sustainable colliders and accelerators"

ICFA: International Committee on Future Accelerators has setup a panel:
20 people chaired by Mike Seidel (PSI, Switzerland)

- strategy & coordination
- energy efficient accelerator concepts
- energy efficient and sustainable accelerator technology
- energy management for large research facilities

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"Sustainable colliders and accelerators"

- strategy & coordination
  - ✓ quantification of accelerator efficiency, formulation of figures of merit, steps towards establishing a carbon footprint for complete facilities, e.g. assessment of fabrication of specific components
  - ✓ public communication and outreach, assessment of societal and political relevance in different regions
  - ✓ assessment of economy & reliability vs. sustainability aspects
  - ✓ Involvement of industry partners, managing IP rights
- energy efficient accelerator concepts
  - ✓ energy recovery concepts, e.g. energy recovery linac
  - ✓ improving brightness in light sources, luminosity in colliders,
  - ✓ brightness of desired secondary radiation (e.g. Muon cooling)
  - ✓ using advanced concepts, i.e. "gaining output per kWh"
  - ✓ assessment of new/advanced acceleration techniques

PECPAC

(in development)

Amaterasu
Goddess of the sun and of the Universe
Mother of all Energy
And a famous Manga figure

Power and Energy Consumption for Particle Accelerator and Colliders
An open-source full-fledged calculation package

Currently, only scattered and ad hoc tools, under individual expertise (not transparent)

Needed: an independent, integrated and open-source program,

- To support the design and modeling of accelerator/colliders lattice and technology.
- A benchmark to compare the efficiency of various projects (Higgs/MWh)
- To monitor project progress
- To estimate the impact on consumption when planning hardware or operation changes.
- To implement known scaling laws for extrapolation to future projects (higher/lower energies, intensities, …)
- To manage a database of past, current and future accelerator/collider planed and measured power and energy consumption,

Based on Jupyter notebook

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- energy efficient and sustainable accelerator technology
  - ✓ efficient RF sources (klystron, magnetron, solid state, IOT)
  - ✓ s.c. cavity advancements relevant for efficiency (low cryo losses: high Q, HTC materials)
  - ✓ efficient beam transport (permanent magnets, optimized electromagnets and pulsed magnets, s.c. magnets)
  - ✓ optimization of large cryogenic systems
  - ✓ technology for energy recovery: heat recovery in accelerator facilities, high T cooling circuits, recovery of RF power, recovery of pulsed magnet field energy, recovery of spent beam energy (ILC)
  - ✓ efficient targets for neutron, neutrino, muon production
  - ✓ minimizing the consumption of cooling water
  - ✓ long term equipment and infrastructure sustainability, e.g. suitable selection of materials and re-usable modular components
- energy management for large research facilities
  - ✓ using excess energy in an era of fluctuating sustainable sources; best mix of conventional and renewable sources
  - ✓ dynamic operation avoiding periods of low supply, efficient standby modes and fast recovery
  - ✓ integration of energy recovery and storage techniques in the overall energy management concept

Conclusion

Where do Green issues stand today?

- Getting momentum, driven by large projects
- Some brilliant and encouraging new R&D… but still **greenifying** is often seen as

side issues… by the wayside, when not in-the-way !

- In the labs, minimal progress mainly pushed by regulations
- Most efforts are scattered, not globally coordinated
- Committees/networks activities and influence are weak

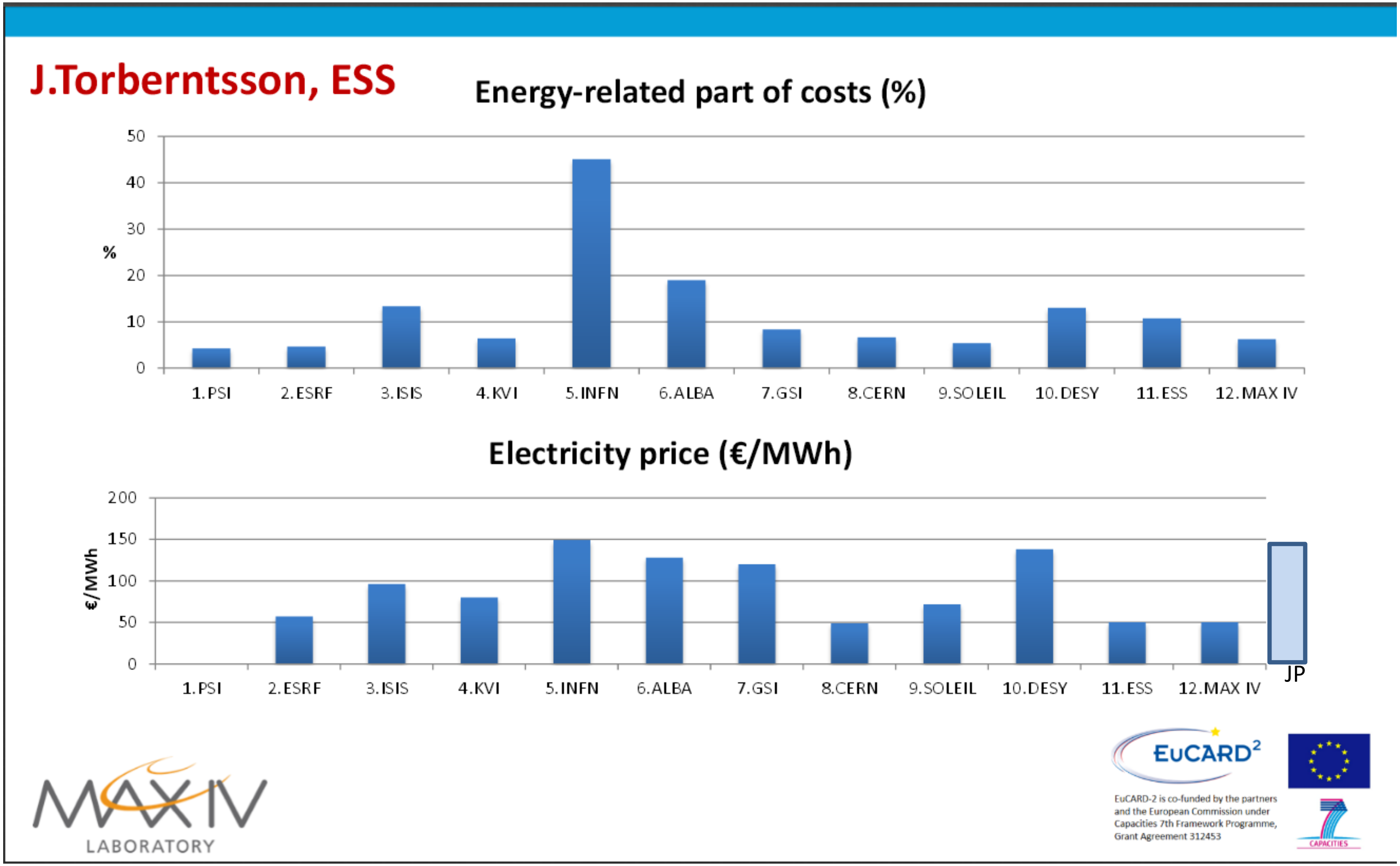
So What ?

1. Green issues must be integrated to the core of the projects from design to promotion
2. Collaborations with energy experts from academy or research organizations are definitely needed (Applied Physics)
3. Partnership with the Industry is mandatory

Green is Key to HEP future

Thank you

Presentation May, 2014… Data date ??



J.Torberntsson, ESS

Energy-related part of costs (%)

Electricity price (€/MWh)

MAX IV LABORATORY

EuCARD²

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

Power and Energy

LHC-CERN ~ 180 MW - 1.35 TWh/year, 50% Geneva electr. consumption (~ 250,000)

FCC-ee : 354 MW @ 350 GeV (top ring and pre-injection not included)
FCC-hh : 468 MW @ 100 TeV (pre-injection NOT included (+100 MW ??) (P. Collier)

ILC: 164MW @ 500GeV – 300MW @ 1TeV (TDR)
ILC lab. (Experiment, Computing, Buildings) => 180 MW @ 500 GeV, 320 MW @ 1 TeV.
TDR takes a large margin: 300 MW 500 MW
(240 MW @ 500 GeV, RDR estimation)

ILC 500 GeV 18% of Iwate prefecture electricity consumption, ~ Morioka (300,000)
ILC 1 TeV 32%

- 180$/MWh 2011 for industry (JP OECD 2013 report, special discount?, price volatility (2024))
- CERN (2011, ~ 70 $/MWh), ESS (Sweden, 110 $/MWh)

ILC (500)+ILC lab: Yearly electricity cost: ~ 240 M$ (10 years, ~25% of ILC capital cost)
1 TeV ~ 430 M$ (scaling on power)

HEP future: To be Green … or not to be !!

Green-ILC Objectives

ILC : lower running cost, better operational flexibility, environment friendly

Revisiting all ILC components:

1. Energy Saving: improving efficiency: 90% lost (if not 100%) as heat waste
2. Saving on ILC operation
3. Energy Recovery and Recycling

Renewable energies:

1. Renewable energy production, which are best for ILC and ILC site ?
2. Energy Storage (recovery, intermittency)
3. Distribution and Management: Smart Grid

Energy: for societal needs and world economy,

1. Basic Research (most needed for Energy Research)
2. HEP-Energy synergies:
   SC, HF magnets, RF, vacuum, surface treatment, computing, photon, neutron factories
3. ILC will boost technology innovation
4. ILC as a perfect test bench for energy research

PECPAC main features

- Modular in terms of:
  - Subsystems (RF, cryo, water cooling ….)
  - Accelerator components (sources, injectors, main linac,…)
- Designed for a generic accelerator or collider but with the ILC as a prototype
- Implementing also the approximate scaling laws
- Integrating existing tools when possible
- Set standard definitions: technology, parameters and units
- Standard input and output format for data exchange.
  - Use particle accelerator codes i/o format
- Simple User Interface and Graphics output

Conclusions

Advances in Nb3Sn coatings: Ryan Porter (Cornell) LCWS 2017

- Can reach **$2\cdot10^{10}$ at 4.2 K**
- Achieve 16-17 MV/m in continuous mode
- Achieve **26 MV/m** in pulsed mode

- Have identified main sources of performance limitations
  - Quality Factor
    - Trapped external flux and thermal gradients
  - Quench Fields
    - Surface roughness
    - Vortex entry at grain boundaries

Looking Forward

- Reducing surface roughness may gain us 50% improvement in quench fields
  - Continuous: **17 MV/m** → **25 MV/m**
  - Pulsed: **26 MV/m** → **39 MV/m**
- If we can fix grain boundaries
  - Continuous & pulsed: → **90 MV/m**?
- Improving in magnetic shielding and cooldown could **~1.5x Q** at 4.2 K