Challenge for the Efficient and Sustainable Design of ILC

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4th Workshop Energy for Sustainable Science at Research Infrastructures

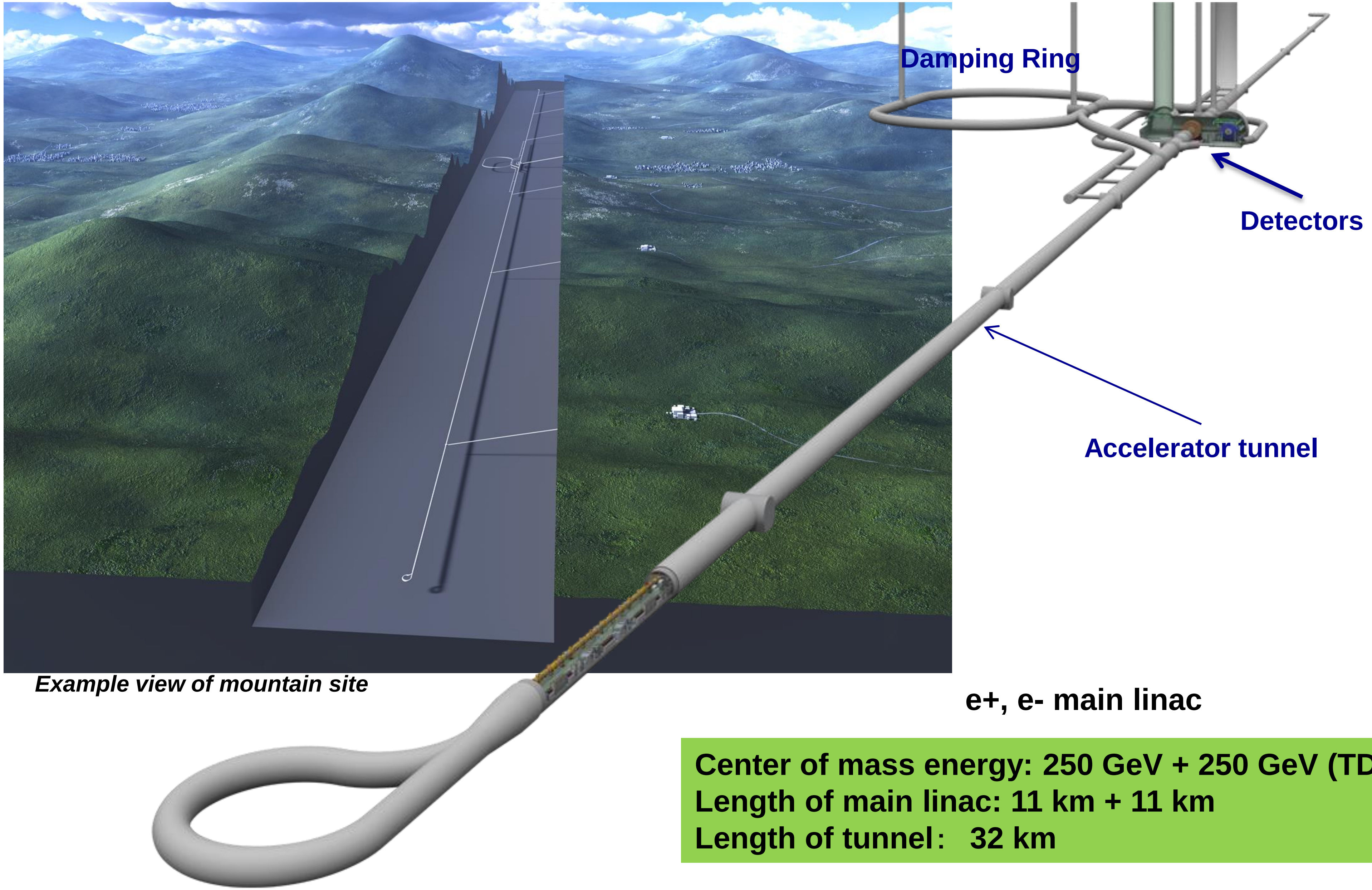
23-24 November 2017, Magurele, Romania

Contents

Abstract

The design of International Linear Collider (ILC) is based on the Superconducting RF (SRF) technology, which is more efficient than the normal conducting technology in terms of the energy consumption. However, still the total energy consumption of ILC (500 GeV) is 164 MW, which is much larger than those of existing accelerators in the world. In such a situation, the reduction of energy consumption in ILC, thus the efficient and sustainable design of ILC, is the crucial issue to realize it in the near future in a Japanese site. In order to challenge the issue, we organized a working group, so called "Green-ILC WG" in the Advanced Accelerator Association (AAA) in Japan, which involves 112 companies from industry and 42 organizations from academia. The Green-ILC WG is also collabotrating with the international team of ILC. The activities are covering the studies on the efficient design of componets, accelerator sub-systems, ILC-system, and even ILC-city. This presentation will report the current status of these studies.

ILC Overview (from ILC Technical Design Report)

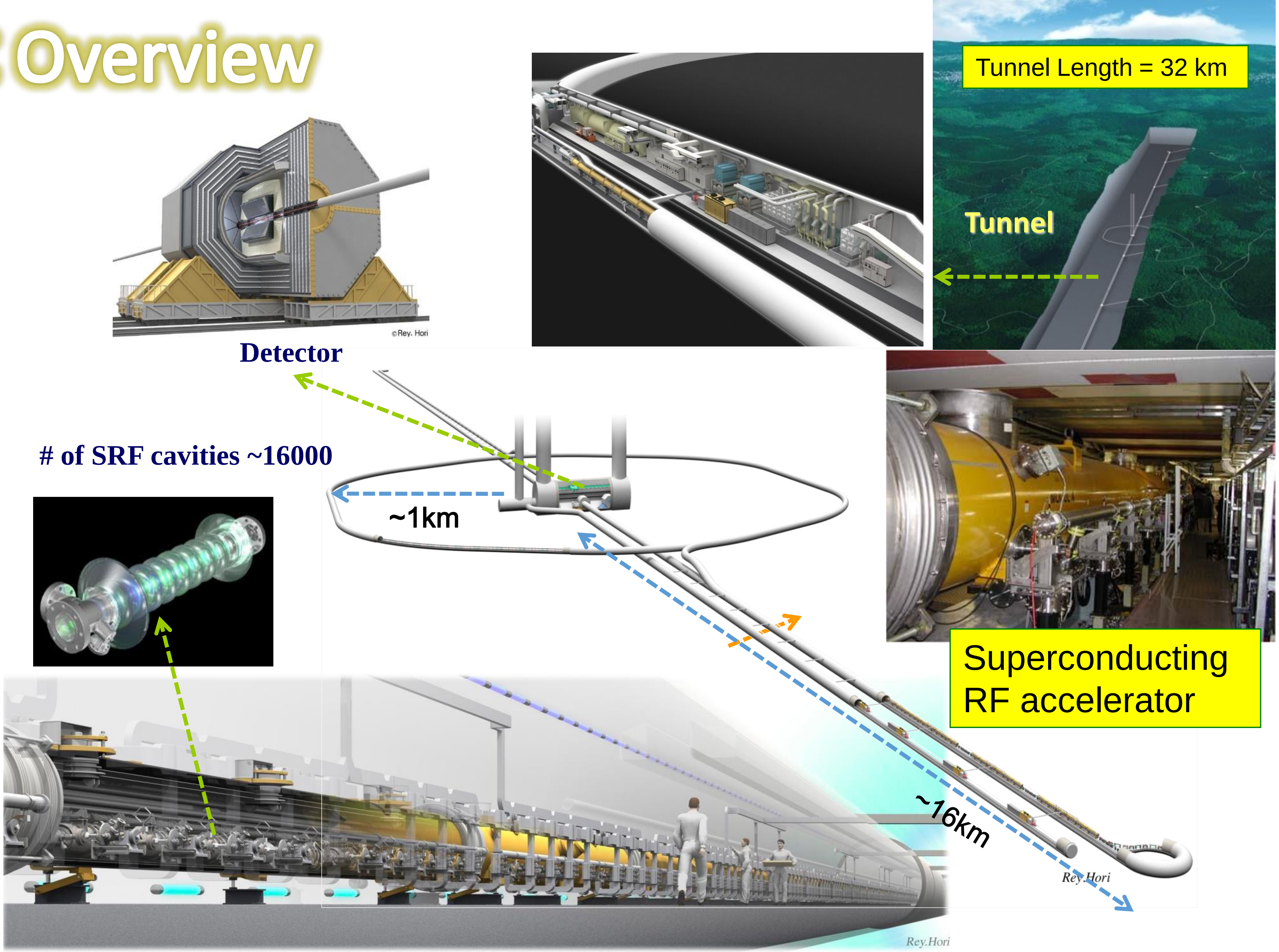


Example view of mountain site

e+, e- main linac

Center of mass energy: 250 GeV + 250 GeV (TDR)
Length of main linac: 11 km + 11 km
Length of tunnel： 32 km

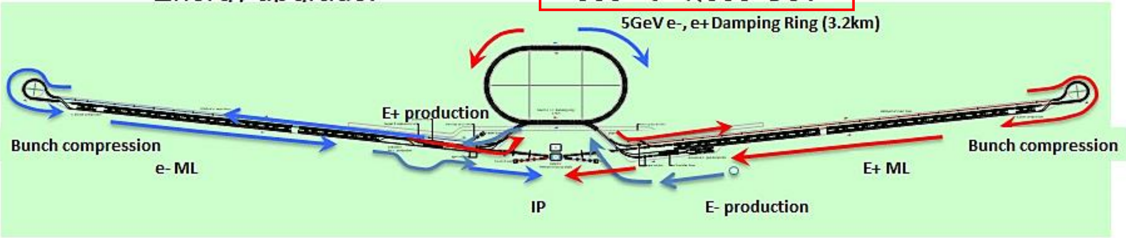
ILC Overview



Power Consumption of ILC

Requirements from Physics Exp.

- Basic requirements:
  - Luminosity: $\int Ldt$ = 500 fb^{-1} in 4 years
  - E_{cm}: 200 – 500 GeV and the ability to scan
  - E stability and precision: < 0.1%
  - Electron polarization: > 80%
- Extension capability:
  - Energy upgrade: 500 → 1,000 GeV



ILC (500 GeV) Total Power ～164 MW

The cost of energy consumption (electricity) is serious issue for the realization of ILC.

Accelerator section	RF Power	Racks	NC magnets	Cryo	Conventional Normal	Conventional Emergency	Total
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

Efficiency from wall-plug to beam-power is ~10 %

We are challenging for higher efficiency

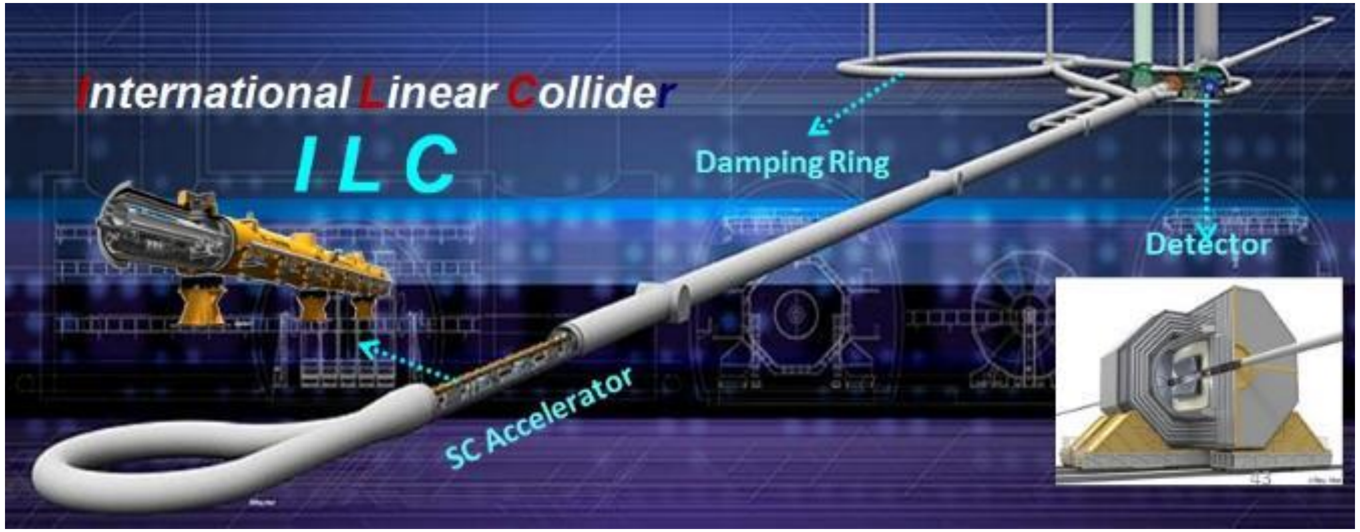
Introduction

ILC design for more efficient energy consumption (in accelerator operation)

We need Green ILC

to have the green sign for ILC !

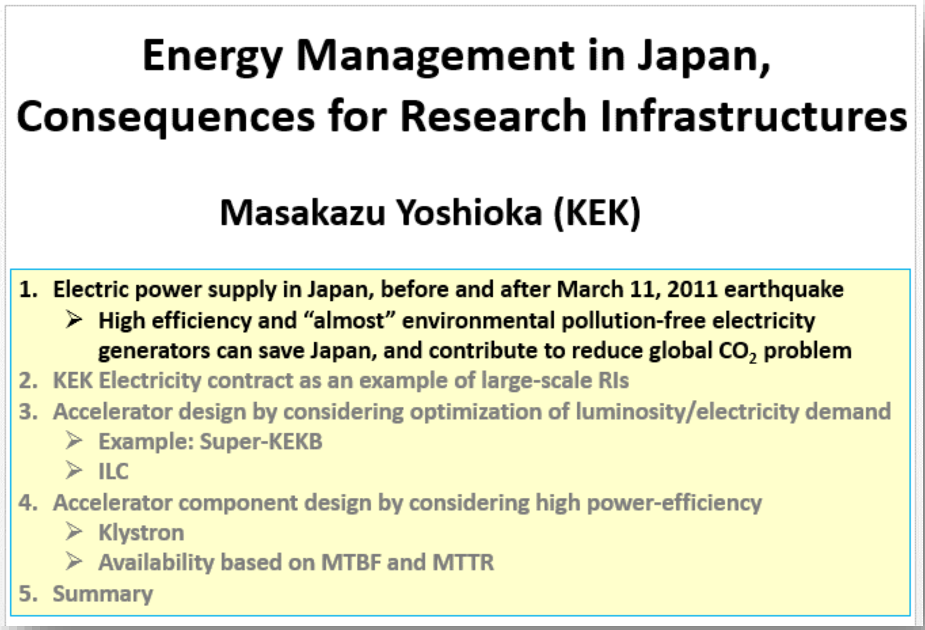
Serious issue for the realization of ILC

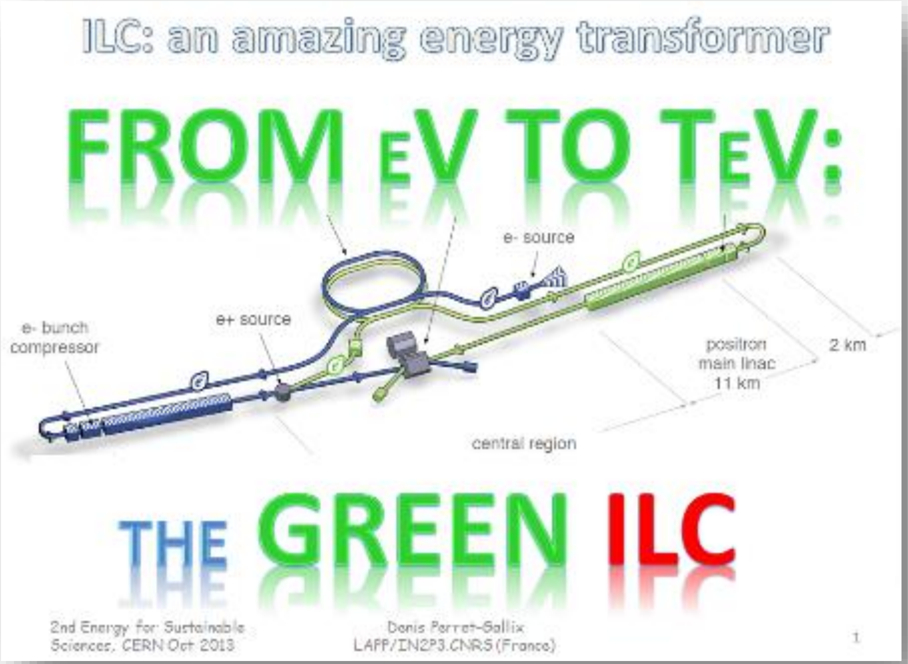


2nd ESS WS (Oct. 2013) triggered our activities !

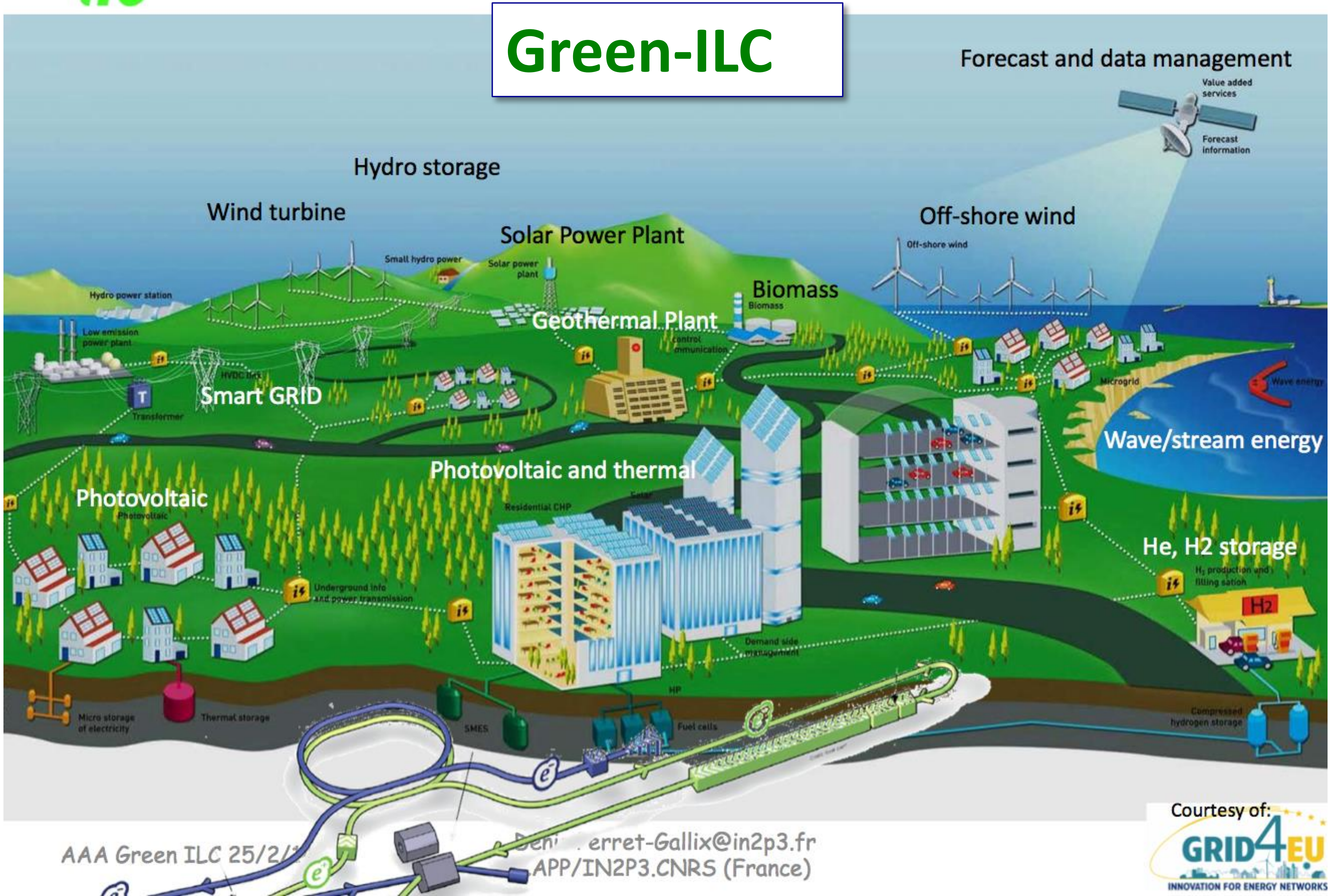
2nd Workshop
Energy for Sustainable Science
at Research Infrastructures

CERN, GENEVA, SWITZERLAND, 23-25 OCTOBER 2013





ILC center futuristic view



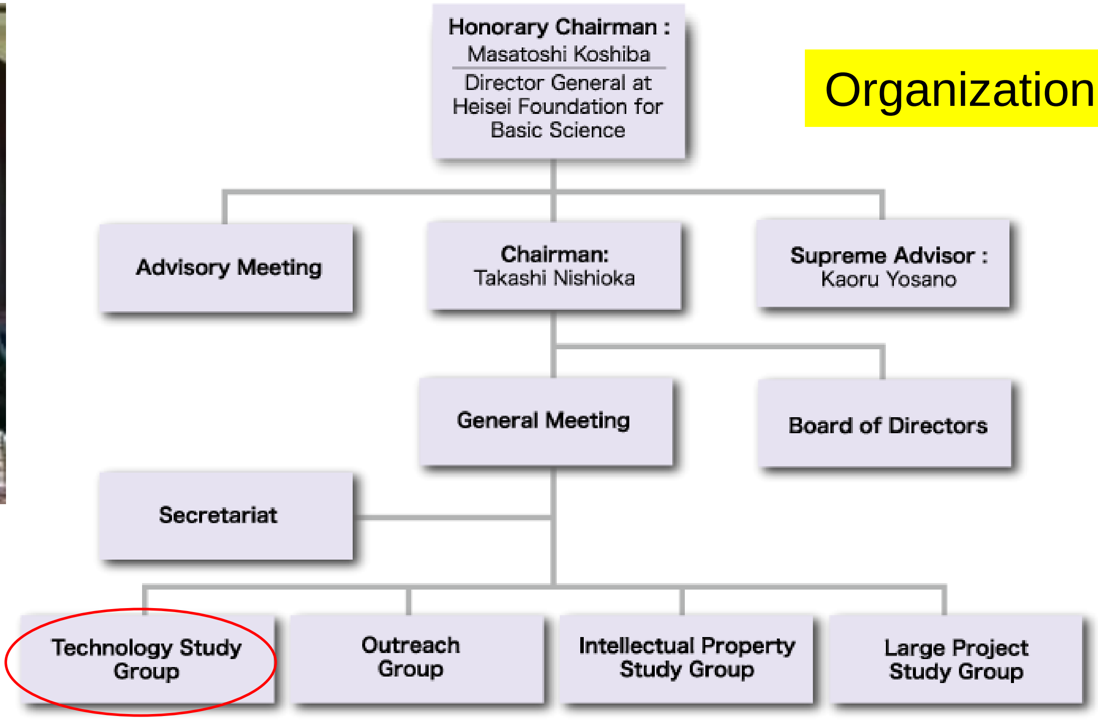
Deni... erret-Gallix@in2p3.fr
APP/IN2P3.CNRS (France)

Advanced Accelerator Association promoting science & technology (AAA) in Japan

Association by industries and scientists established in 2008

- 112 corporate organizations involved from industries（MHI, Toshiba, Hitachi, Mitsubishi Electric, etc.) as of Nov. 2017.
- 42 institutional organizations involved from universities and laboratories（KEK, Univ. of Tokyo, Univ. of Tohoku, Univ. of Kyoto, Riken, etc.) as of Nov. 2017.

Organization of AAA

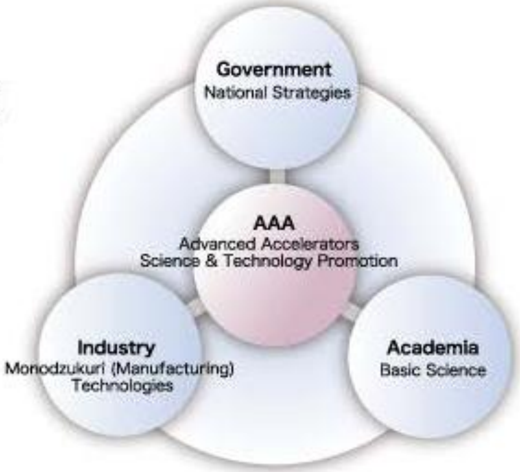


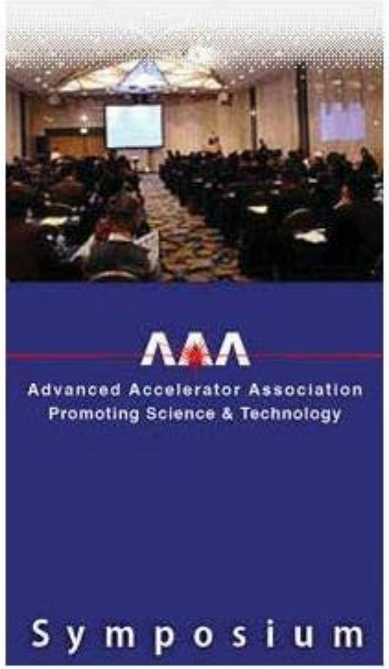
Green-ILC WG started in Technology Study Group on 25th Feb. 2014.

Industry-Research: Getting Organized

- Advanced Accelerator Association Promoting Science & Technology (AAA) in Japan is an example

- Workshop series with presentation to the industry and by the industry (4-5 /year)





- Set a World Wide Consortium

Towards a Global "Energy for Accelerators" R&D coordinated program

Industry-academy collaboration is essential to realize the Green-ILC.

Activities for Green ILC

- Three presentations were given (by A. Suzuki, D. Perret-Gallix, and M. Yoshioka) in 2nd WS "Energy for Sustainable Science at Research Infrastructure" at CERN in Oct. 2013.
- A session (four presentations) was organized for Green-ILC activities in LCWS 2013 at Tokyo in Nov. 2013. A. Suzuki also presented Green-ILC activities in the plenary session in LCWS 2013.
- Green-ILC Working Group was organized in "Advanced Accelerator Association promoting science & technology (AAA) in Tokyo/Japan. The 1st meeting for the Green-ILC WG of AAA was held on 25th February 2014. (AAA home page = https://aaa-sentan.org/en/about_us.html)
- 2nd – 15th Green-ILC WG meetings were held on May 2014 – until now in Tokyo/Japan.
- Various realistic technologies of energy-saving for ILC were proposed and discussed by industries and scientists.
- D. Perret-Gallix, T. Saeki, and H. Hayano opened the interactive home page for Green-ILC activities. Please visit http://green-ilc.in2p3.fr/ and http://green-ilc.in2p3.fr/documents/ .

Green ILC

Energy for Innovation, Innovation in Energy

Green-ILC Project

http://green-ILC.in2p3.fr

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The Green ILC Project

ILC, the International Linear Collider, is the next fundamental science project in high energy physics and the first ever true global basic science center.

What CERN did for the European HEP community, ILC will do for the world. But the e+e- ILC project may go even beyond mere fundamental science and contribute to one of the world most pregnant issue: Energy, not merely high-energy but, more generally: energy for the society.

Artistic view of the ILC center in Kitakami (Japan) ILC-Iwate

The ILC scientific goal is simple: high precision study of the Higgs particle recently discovered at LHC (CERN) and other signals LHC could possibly single out. New effects will also be searched for, effects which could have been missed by the LHC due to the heavy background. Higher precision here concerns, more particularly, the various Higgs couplings, limited at LHC, in part, by the complex structure of the interacting particles, the protons compared to the elementary electrons.

Recent Posts

- Green-ILC in LC Newsline
- New Hydraulic Wind Turbine
- Green Session at LCWS 2014
- EUCARD2 EnEfficient
- Liquid Air in the Energy and Transport Systems

Links

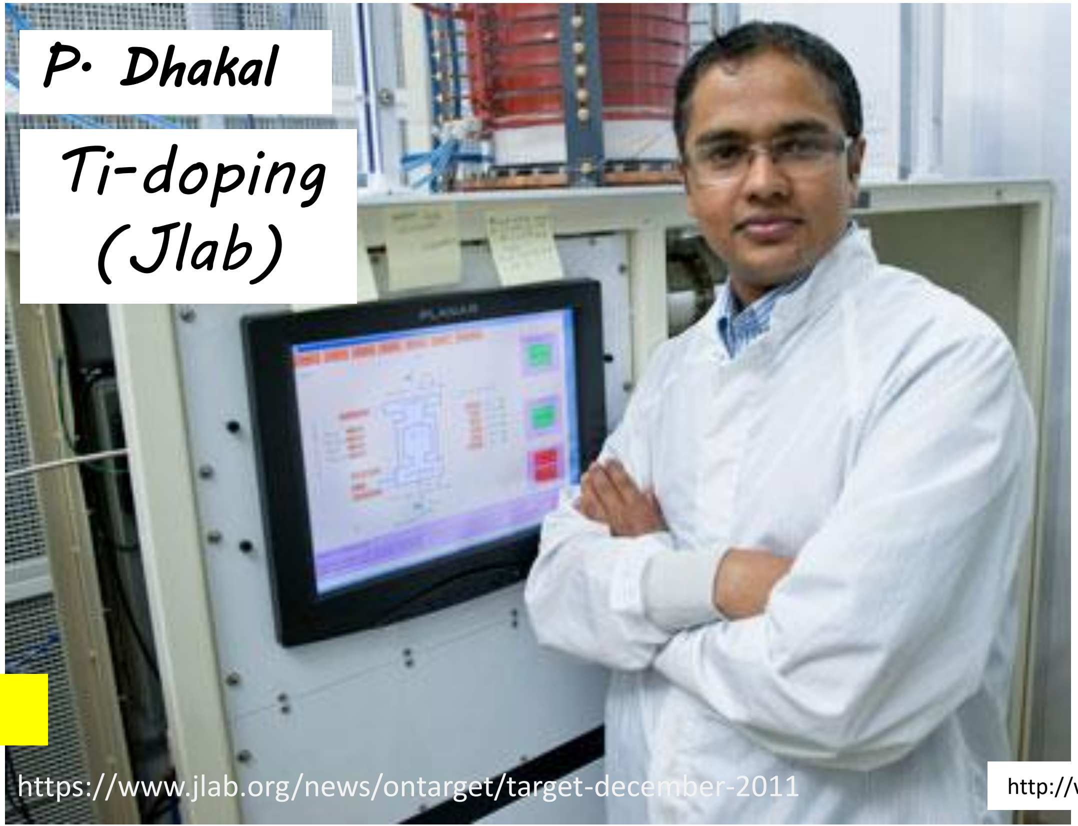
- email: green.accelerators@gmail.com
- Green-ILC wiki
- Green-ILC group discussion

Green-ILC WG (AAA) report-2016 in English and all presentations related to Green-ILC are found on http://green-ILC.in2p3.fr/documents/.

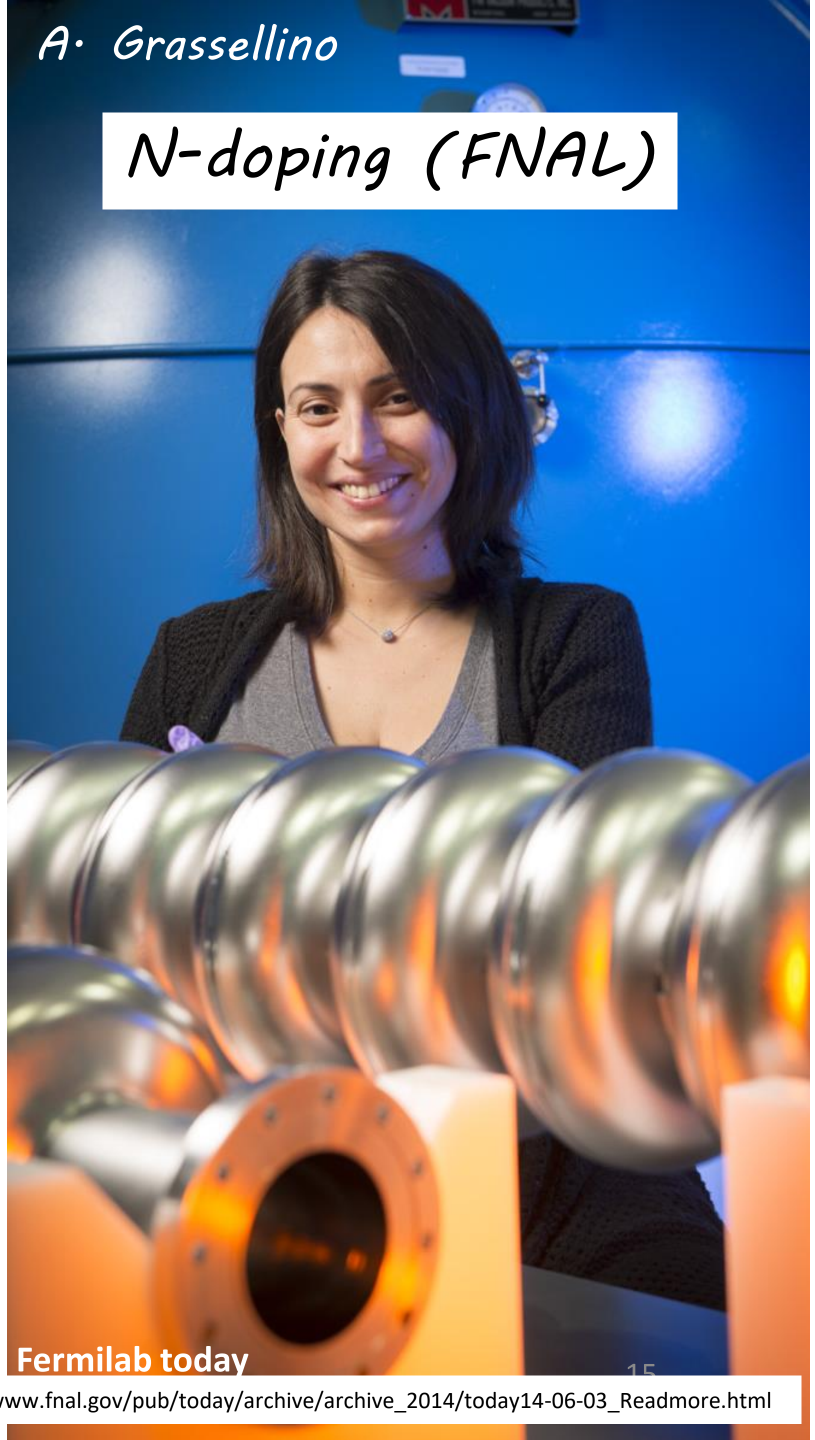
Efforts on components

International efforts in academia: Nitrogen doping for SRF cavity

Good technology for ILC ?



https://www.jlab.org/news/ontarget/target-december-2011

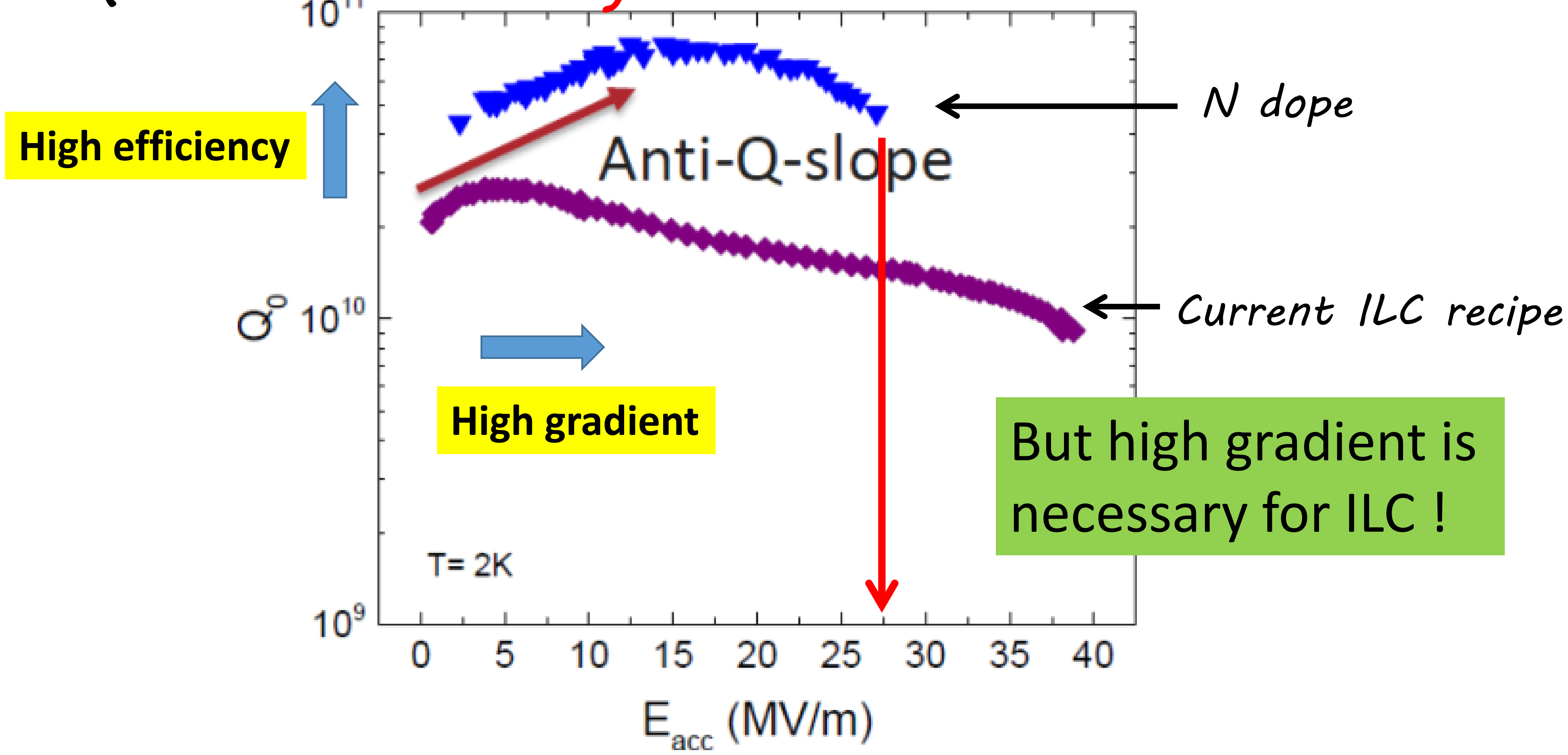


http://www.fnal.gov/pub/today/archive/archive_2014/today14-06-03_Readmore.html

Slide by T. Kubo

Disadvantage of N-dope:

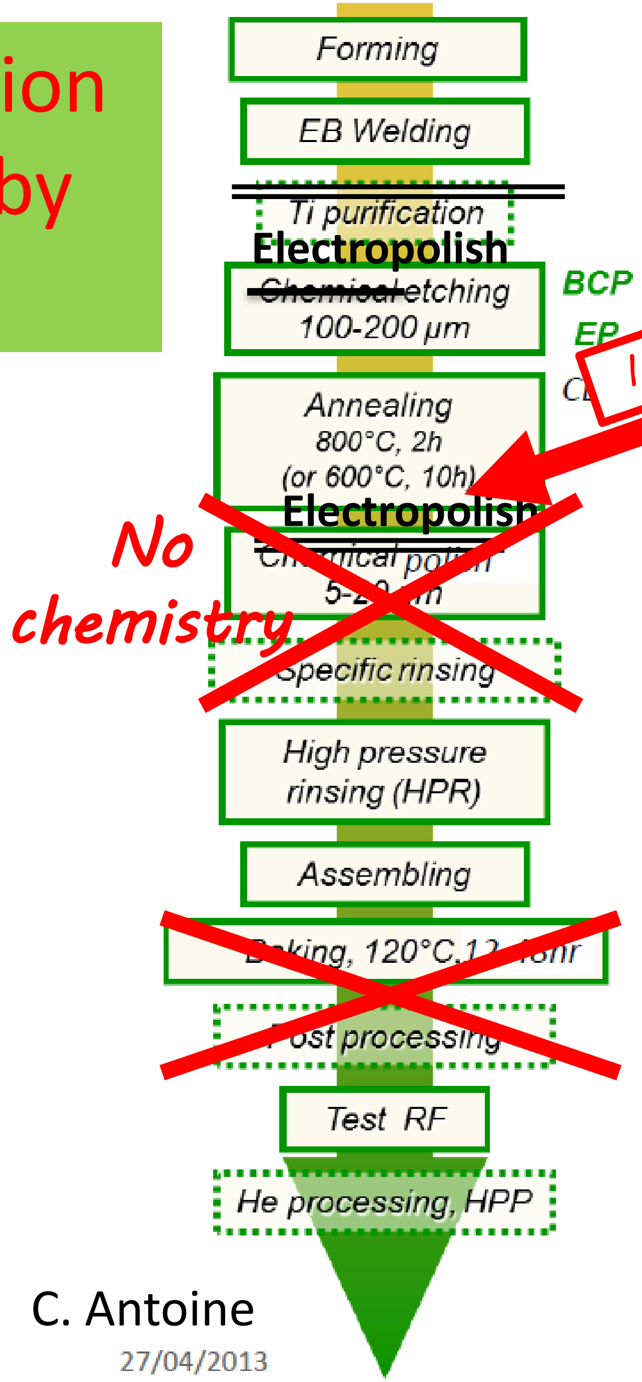
Q increases but gradient decreases.



A. Grassellino et al, Supercond. Sci. Technol. **26** 102001 (2013)

Slide by T. Kubo

N infusion recipe by FNAL



C. Antoine
27/04/2013

WHY

Clean welding

RRR enhance

Get rid of hydrogen

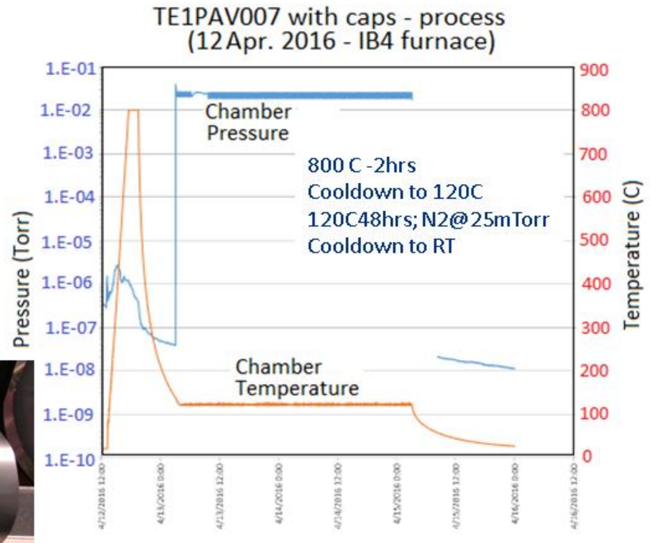
H segregates near surface in form of hydrides (= bad SC)

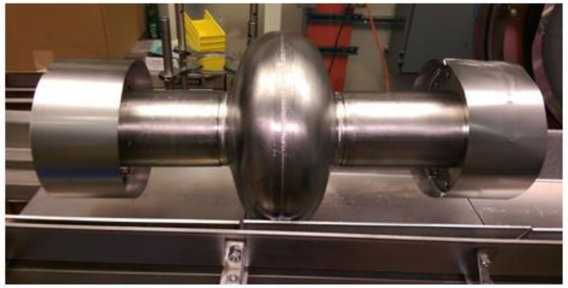
Inject N_2 gas
(～3×10^{-5} Pa)
at 120°C
for 48 hours

Slide by T. Kubo

The surface processing sequence

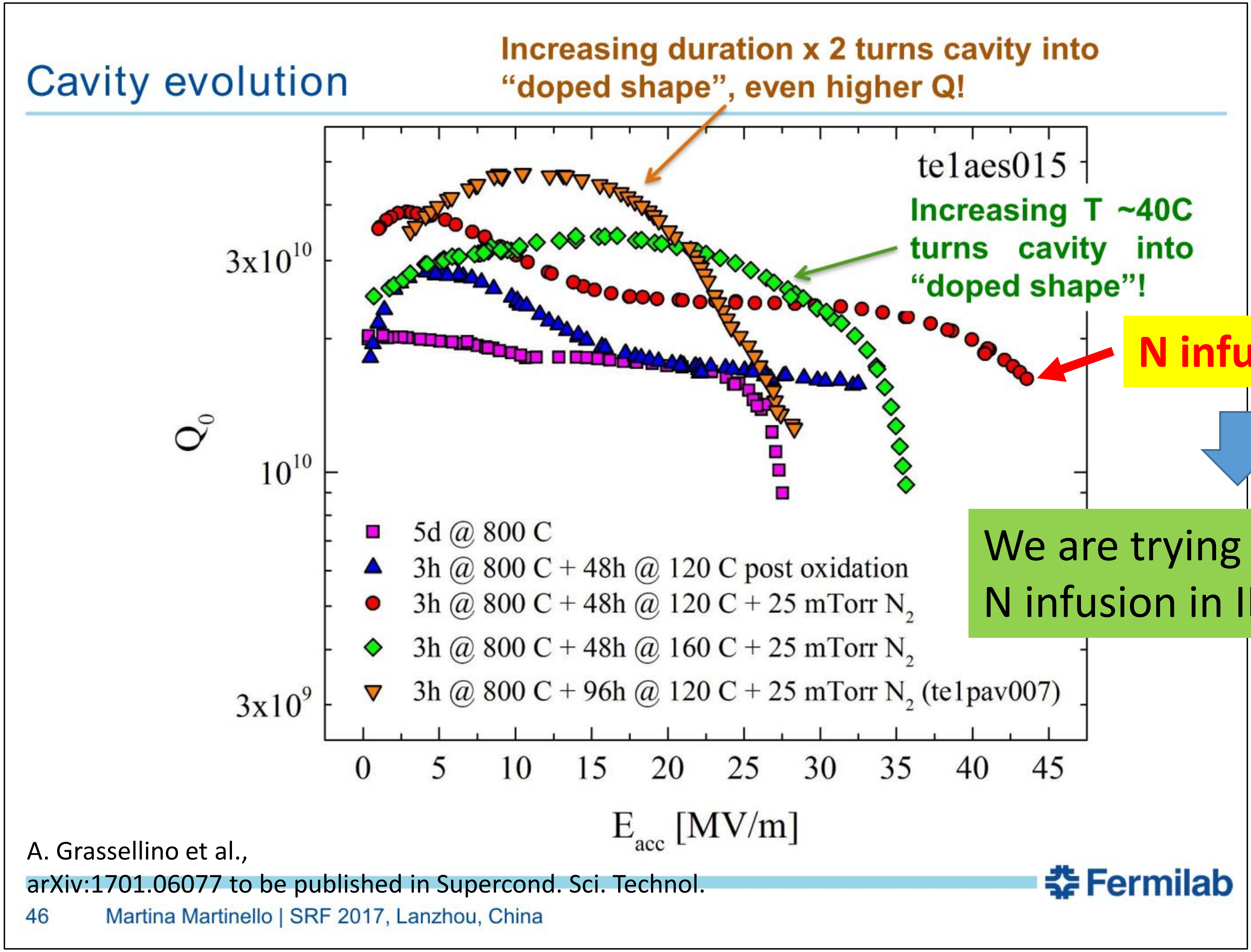
- Bulk electro-polishing
- High T furnace with caps to avoid furnace contamination:
  - 800C 2 hours HV
  - 120C 48 hours with N2
- NO chemistry
- HPR, VT assembly





Fermilab

Then "high-Q & high gradient" are realized



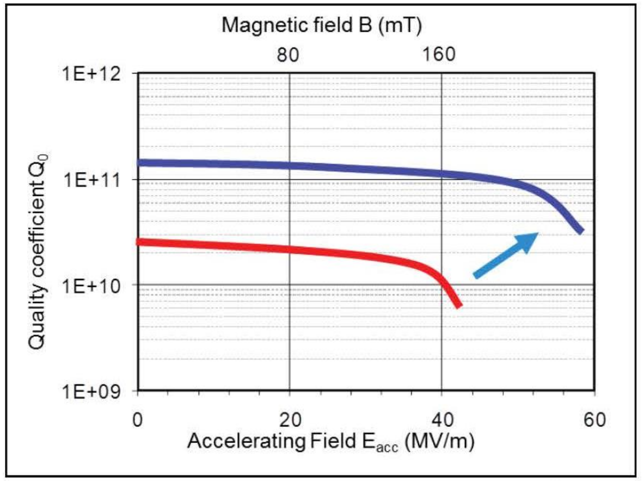
N infusion

We are trying to involve N infusion in ILC recipe.

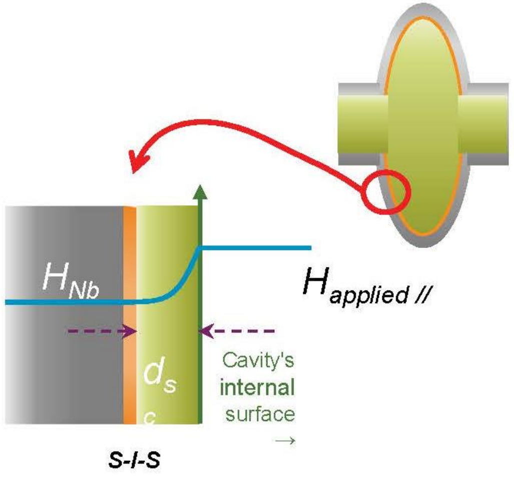
More efforts for higher Q and higher G. Thin-Film Coating Technology.

AFTER NIOBIUM : NANOCOMPOSITES MULTILAYERS

Structures proposed by A. Gurevich in 2006, SRF tailored



- **Dielectric layer**
  - Small ⊥ vortex (short -> low dissipation)
  - Quickly coalesce (w. RF)
  - Blocks avalanche penetration
  - => **Multilayer** concept for RF application
- **Nanometric I/S/I/ layers deposited on Nb**
  - SC nanometric layers (≤ 100 nm) => H_{C1}↑ => Vortex enter at higher field
  - Nb surface screening => allows high magnetic field inside the cavity => higher E_{acc}
  - SC w. high T_C than Nb (e.g. NbN): $R_s^{NbN} \approx \frac{1}{10} R_s^{Nb}$ => $Q_0^{multi} >> Q_0^{Nb}$



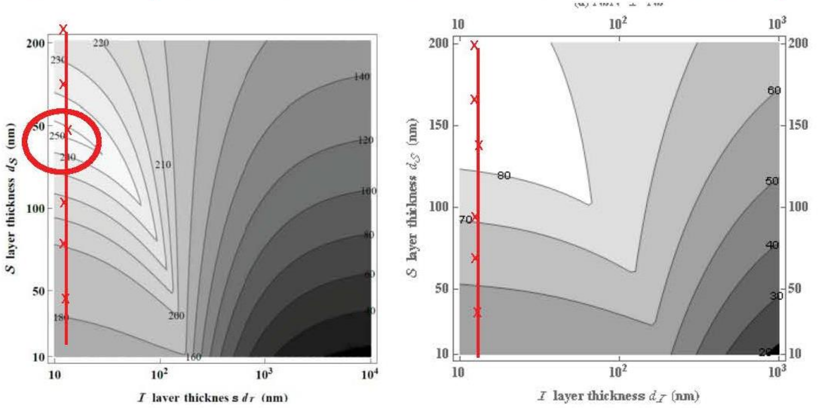
Slide by C.Z.Antoine

Collaboration among CEA/Saclay, KEK, Kyoto Univ, and Utsunomiya Univ.

COMPARAISON WITH THEORY

Theoritical predictions from T. Kubo (KEK)

Ideal Nb substrate with B_{C1}=170 mT

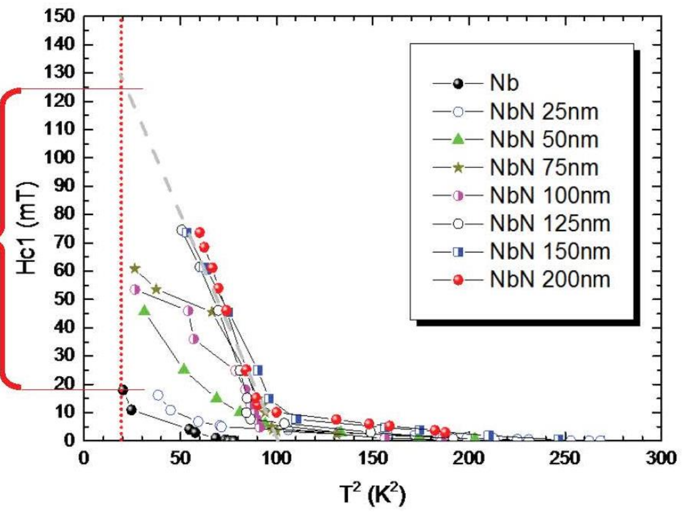


Nb with defects, with B_{C1}=50 mT*

** e.g. morphologic defects that allow earlier vortex penetration See SST paper cited earlier*

Coating sample test.

@ 4.5 K
~ + 110 mT?
~25-30 MV/m
ILC shape

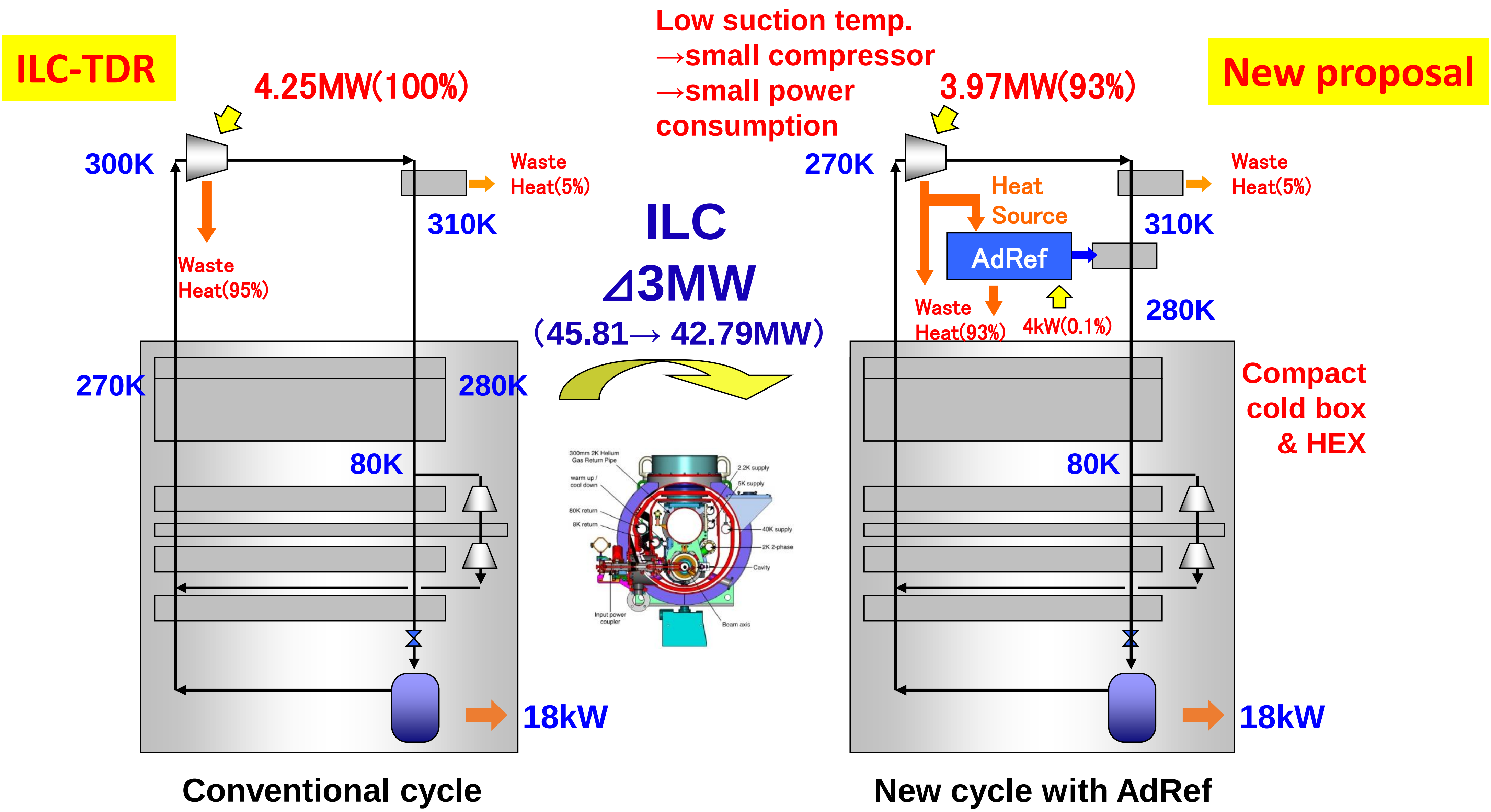


- The enhancement of the field penetration increases with thickness of NbN
- It reaches a saturation at thicknesses > 100 nm

Slide by C.Z.Antoine

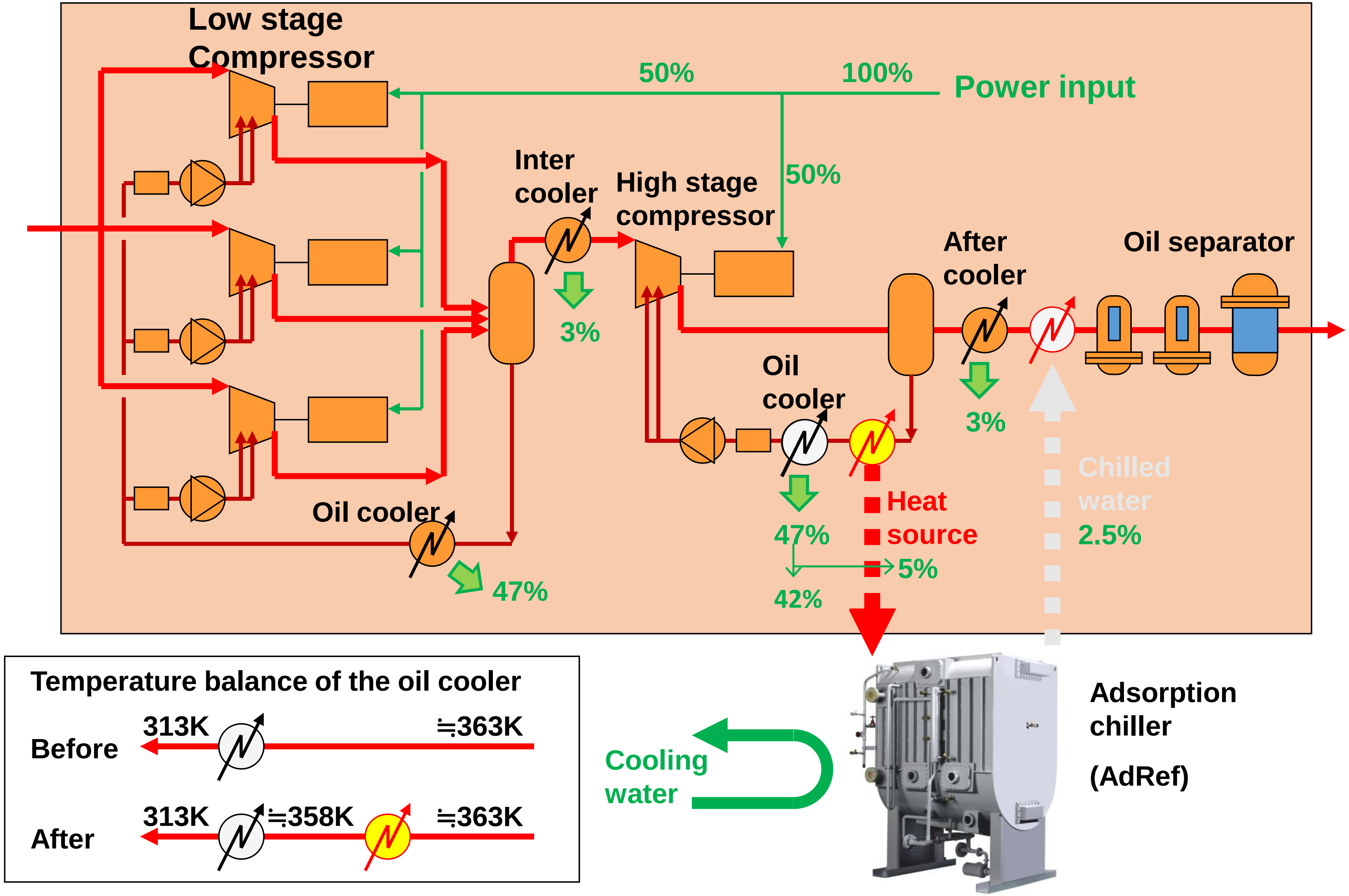
Example of effort by industry
New refrigeration cycle with AdRef

MAYEKAWA



MAYEKAWA

Heat source from the helium compressor

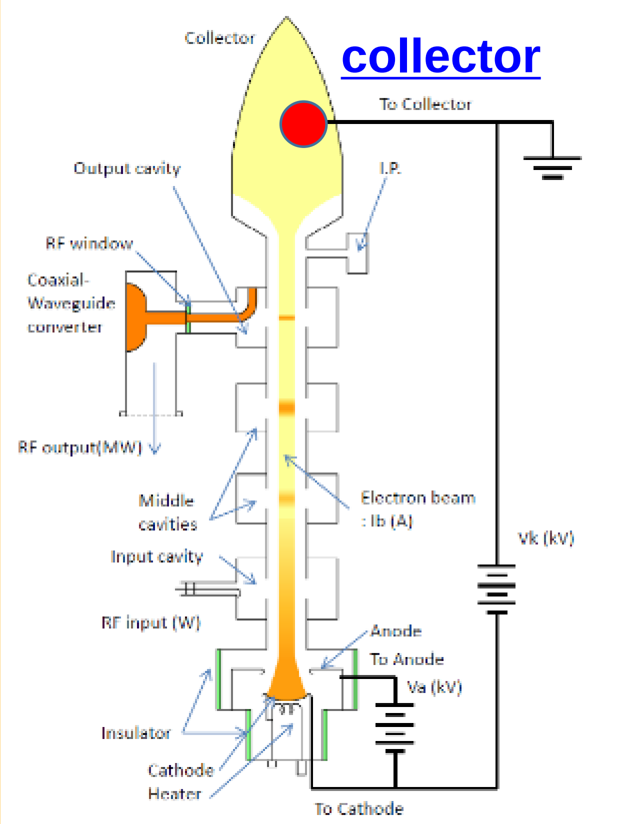


How to Improve RF Efficiency

R&D of CPD (Collector Potential Depression) Klystron

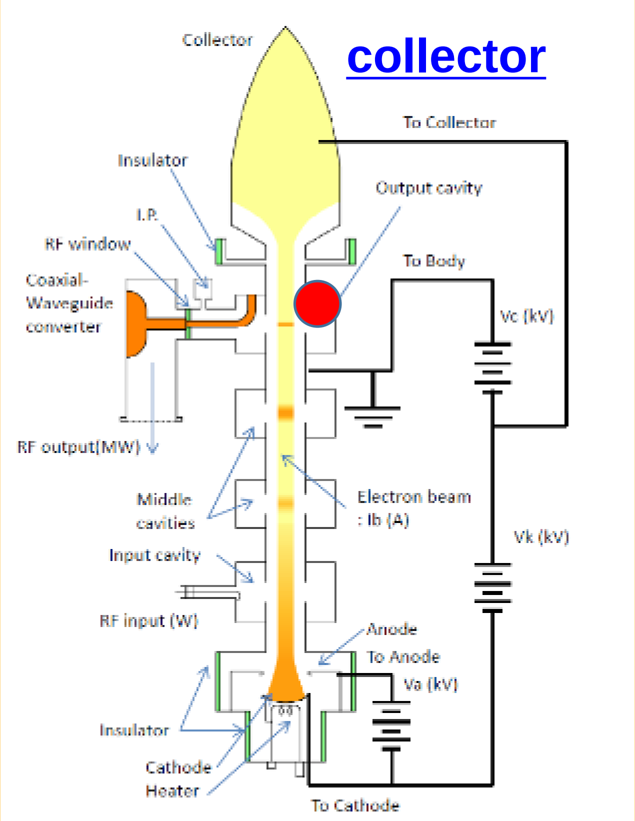
CPD is an energy-saving scheme that recovers the kinetic energy of the spent electrons after generating rf power.

Conventional



* Solenoid magnets set at outside of the cavities to focus the electron beam.

Schematic diagram of CPD

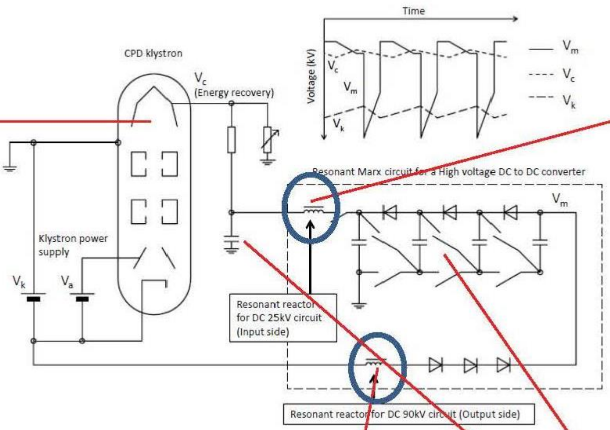


* Solenoid magnets set at outside of the cavities to focus the electron beam.

Collector Potential Depression (CPD) Klystron

Preparation of CPD Klystron test at KEK in collaboration with Toshiba (industry)

CPD Klystron



DC 90kV oscillator circuit for output

Dummy resister

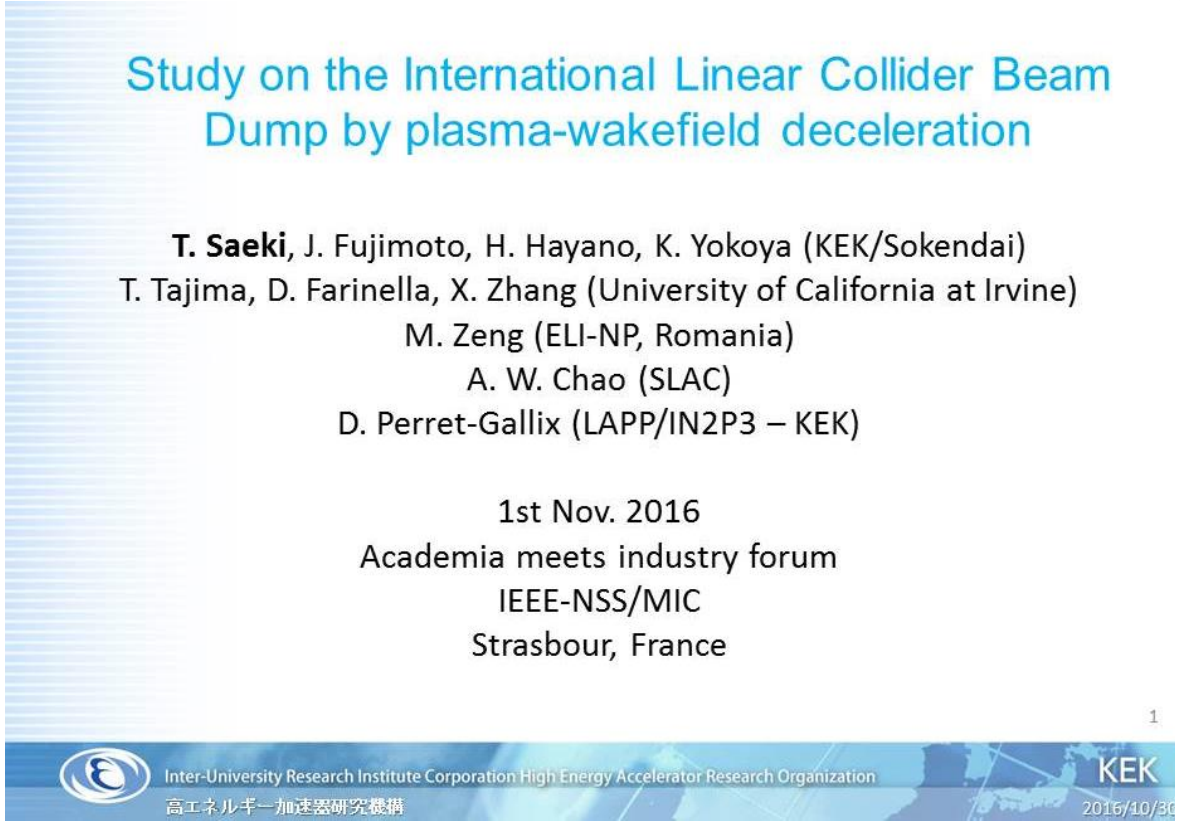
DC 25kV oscillator circuit for input

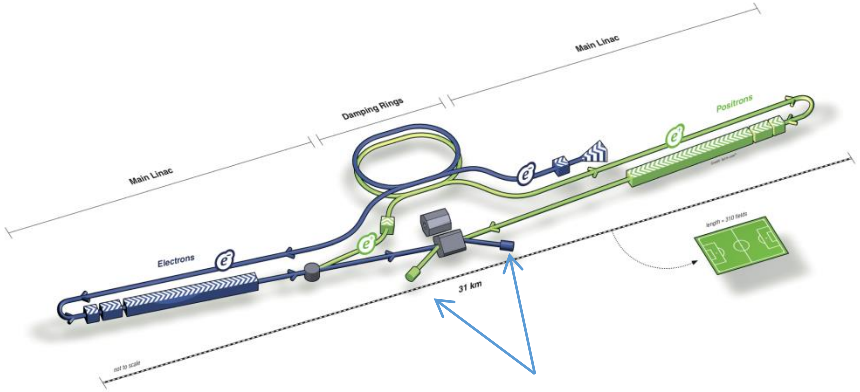
Capacitor for circuit

R&D on Plasma Beam Dump

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

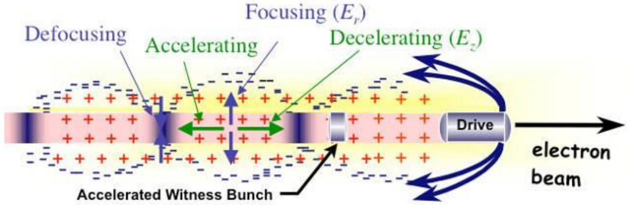
Wakefield deceleration for beam dump project

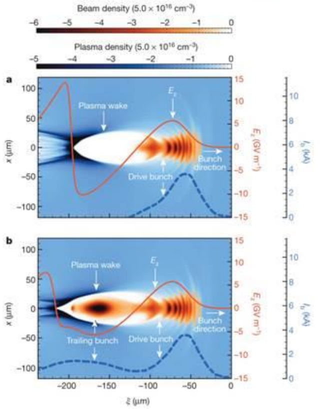




Main Beam dumps
10m water, or1000m gas

Plasma Acceleration, wakefield acceleration





- Collective deceleration dump
  (1) No dump window problem
  (2) No hydrogen gas production problem
  (3) Less radioactivation
  (4) Compact facility
  (5) Energy might be extracted as electric energies
- From the view point of Green-ILC, it is worth to study the possibilities to apply collective deceleration dump system.
- It should be checked that it works for the ILC long beam condition.
- If introducing the bunch compression after the collision point, it is possible to shorten the length of the beam dump facility.
- Efficiency of recovering energy is important from the view point of Green-ILC

6. Preliminary result of beam deceleration simulation

beam :

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

$E = 250GeV(\gamma_0 = 5\times10^5)$

$dE/E = 0.1\%$

$N_b = 2\times10^{10}\,(3.2nC)$

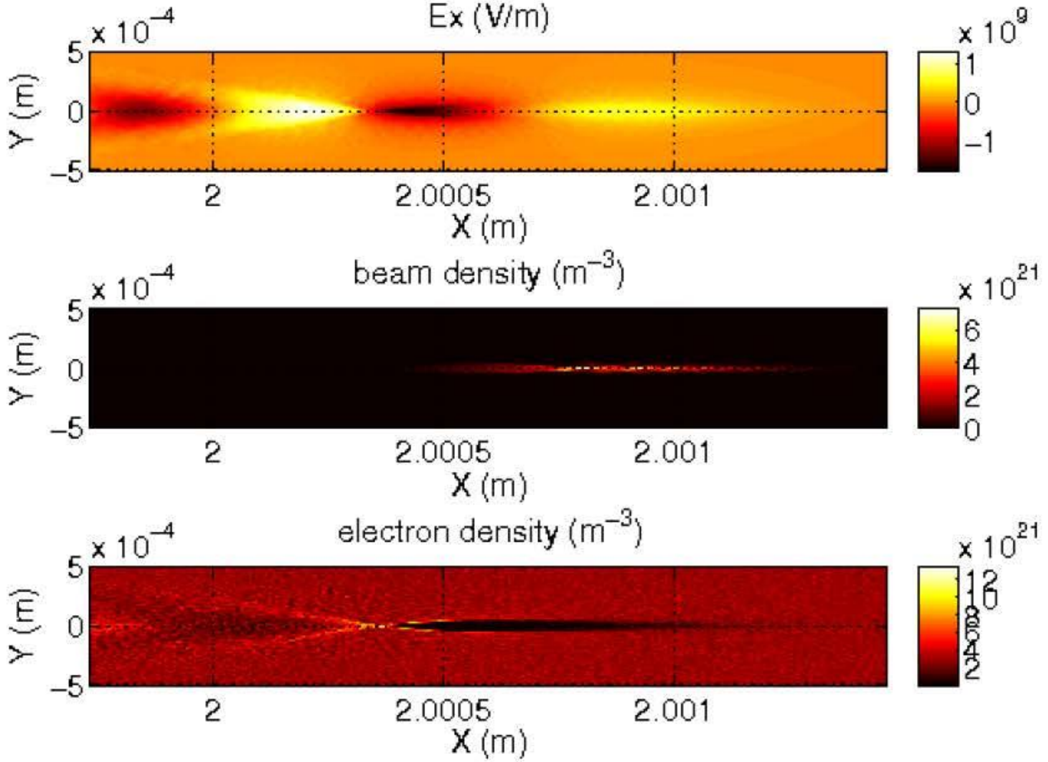
$n_b = \frac{N_b}{(2\pi)^{3/2}(\sigma_x\sigma_r\sigma_r)} = 1.7\times10^{21}/m^3$

plasma :

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

$\lambda_p \sim 600mm$

$\sigma_x \sim \lambda_p/2$



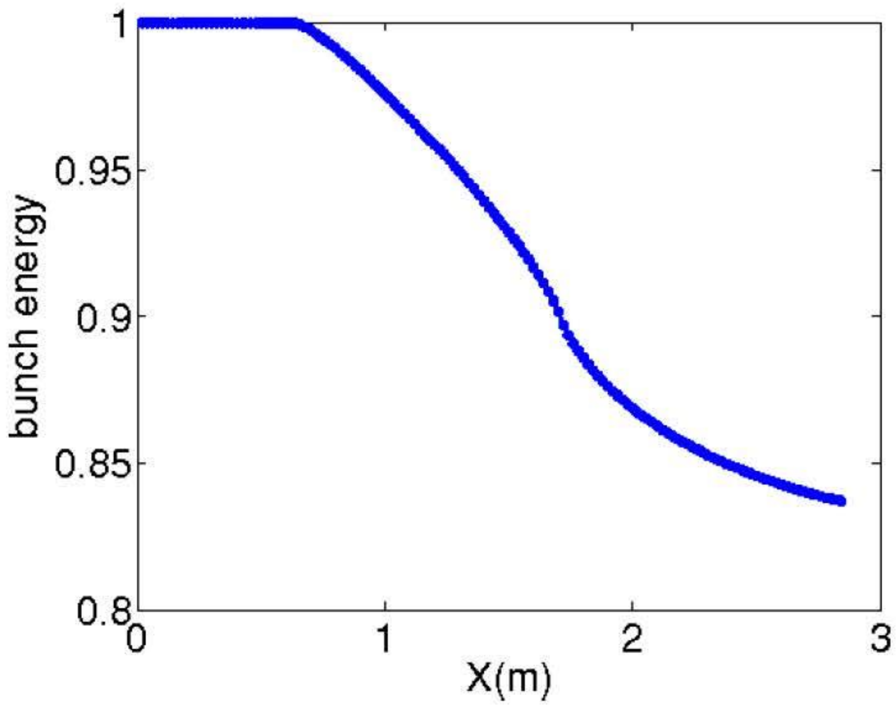
Simulation code: EPOCH

Dr. X. Zhang (UCI)

Preliminary result of beam deceleration simulation

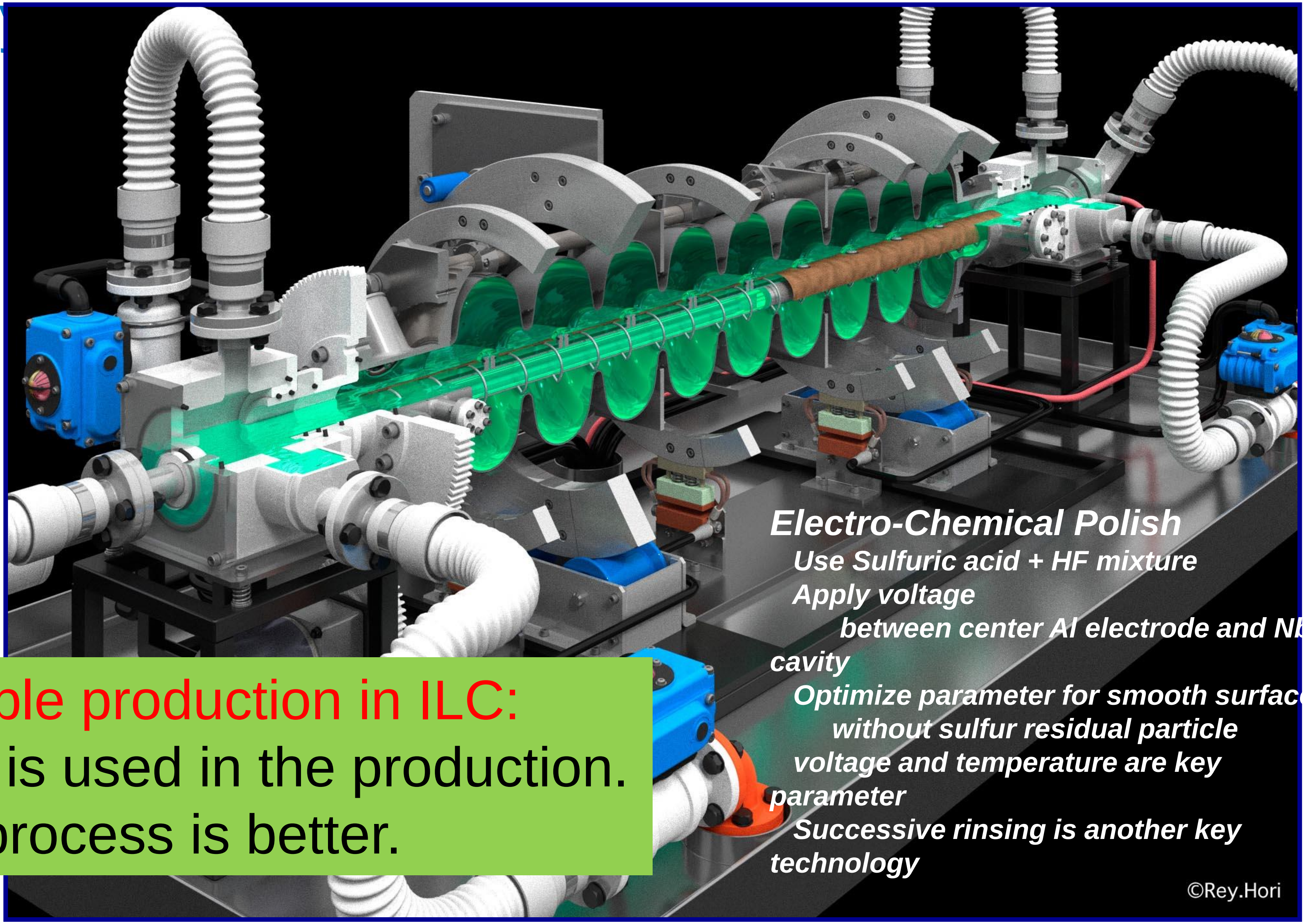
Dr. X. Zhang (UCI)

More than 15% energy loss after 3m



First result of simulation is encouraging !

Electro-chemical Polishing (EP) inside SCRF 9-cell cavity



Sustainable production in ILC:
Toxic HF is used in the production.
HF-free process is better.

R&D on EP process with NaCl water (salt water), instead of HF mixture.

ID :TUPB097

SRF2017

R&D of Electro-Polishing (EP) process with HF-free neutral electrolyte by Bipolar-Pulse (BP) method.

J. Taguchi [1], K. Ishida [1], Y. Mochida [1], T Nakajima [1], M. Kunieda [2], S. Kakudo [2], H. Hayano [3], T. Saeki [3]

[1] NOMURA PLATING CO., LTD , Nishiyodogawa, Osaka Japan [2] The University of Tokyo , Tokyo, Japan [3] KEK / The Graduate University for Advanced Studies, Tukuba, Ibaraki Japan

Abstract

Currently the Electro-Polishing (EP) process of Superconducting Radio-Frequency (SRF) accelerating cavity is performed with the electrolyte that is the mixture of hydrofluoric and sulfuric acids. However, the ... disposal ... igh cost ... process ... ing the ... formed ... Bipolar- ... val rate, ... coupon samples that were processed by the BP-EP with HF-free neutral electrolyte.

Collaboration of Nomura plating (industry) and KEK. Sample test seems OK.

Conventional EP method

(1)Solution : H_2SO_4(60%)/HF(40%)

- Very dangerous
  - Severe burn on skin
  - Toxic gas(HF, H_2S , SO_x)
- High cost
- By-product of Sulfar
  - Performance degradation

$$2H_2S + SO_2 \rightarrow 2H_2O + 3S$$

(2)DC voltage with Nb anode and Al cathode

Bipolar(BP)-EP with neutral electrolyte

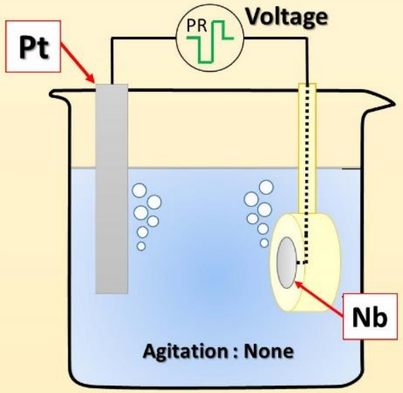
(1) Neutral electrolyte

- Safer
- Low coat
- No by-product

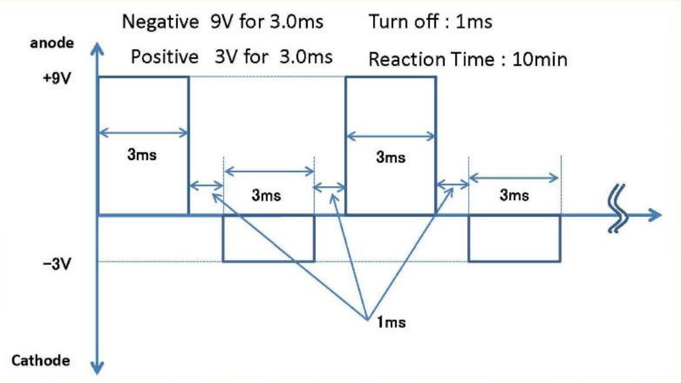
(2)Periodic Reverse (PR) voltage

Studies on BP-EP process with neutral electrolyte

(1) The selection of the anion in neutral electrolyte for the electro-polishing process of Nb coupon samples.
(2) Study on the concentration of NaCl neutral electrolyte.
(3) Study on the shape of bipolar pulse voltage.

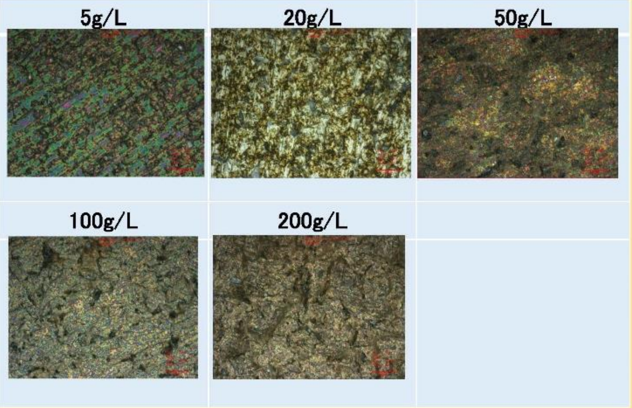


Electrode setting



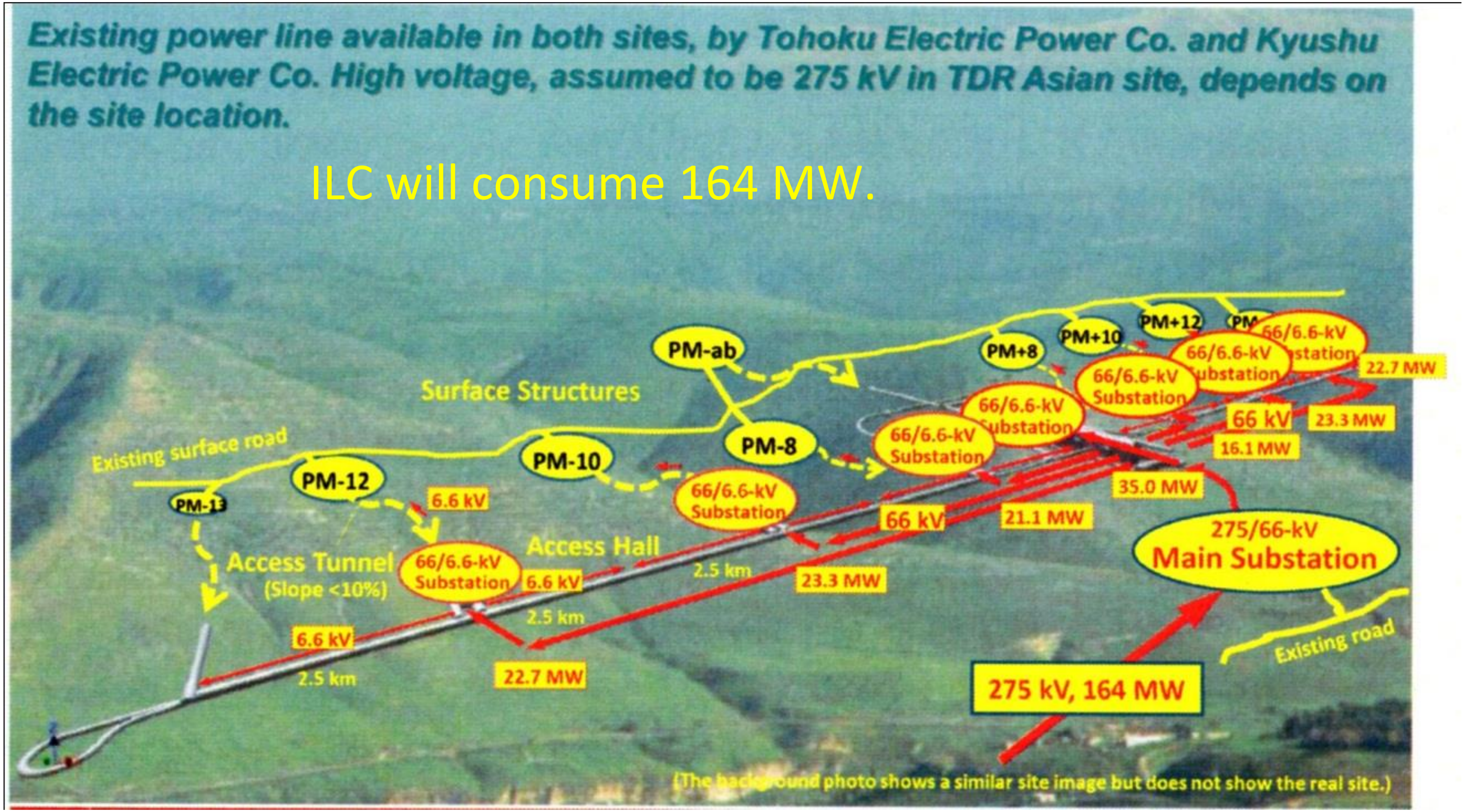
The condition of pulse shape for experiments with HCl electrolyte

The results of PR-EP surface for various concentrations of NaCl neutral electrolyte.



Efforts on sub-system, ILC-system and ILC-city

Considerations on Power Supply System in ILC-TDR



Study on DC power transfer by High Tc superconductor for ILC by Fujikura (Industry).

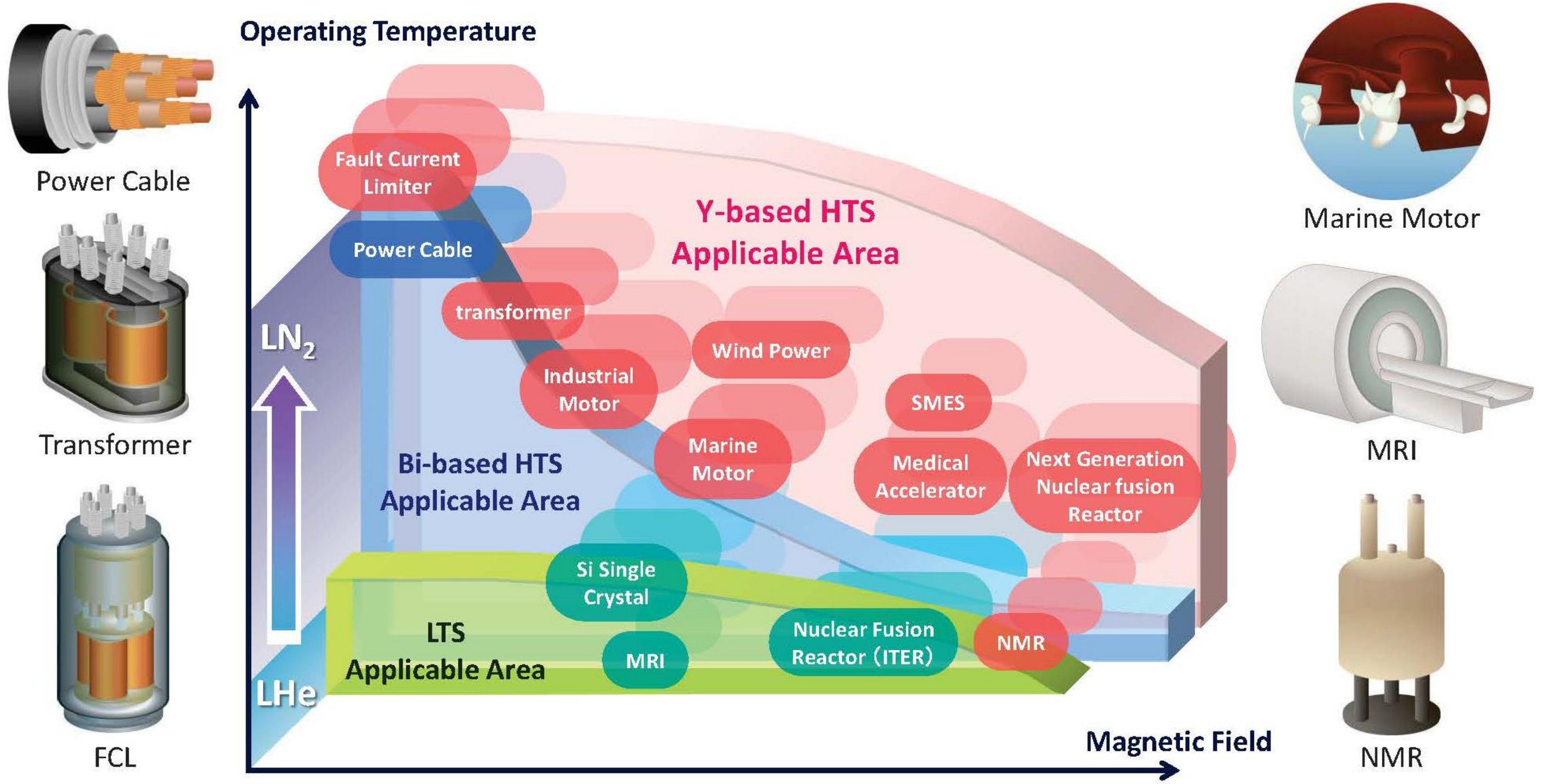
SCS71-10-16-038(1)

Applications of Superconductor

Fujikura

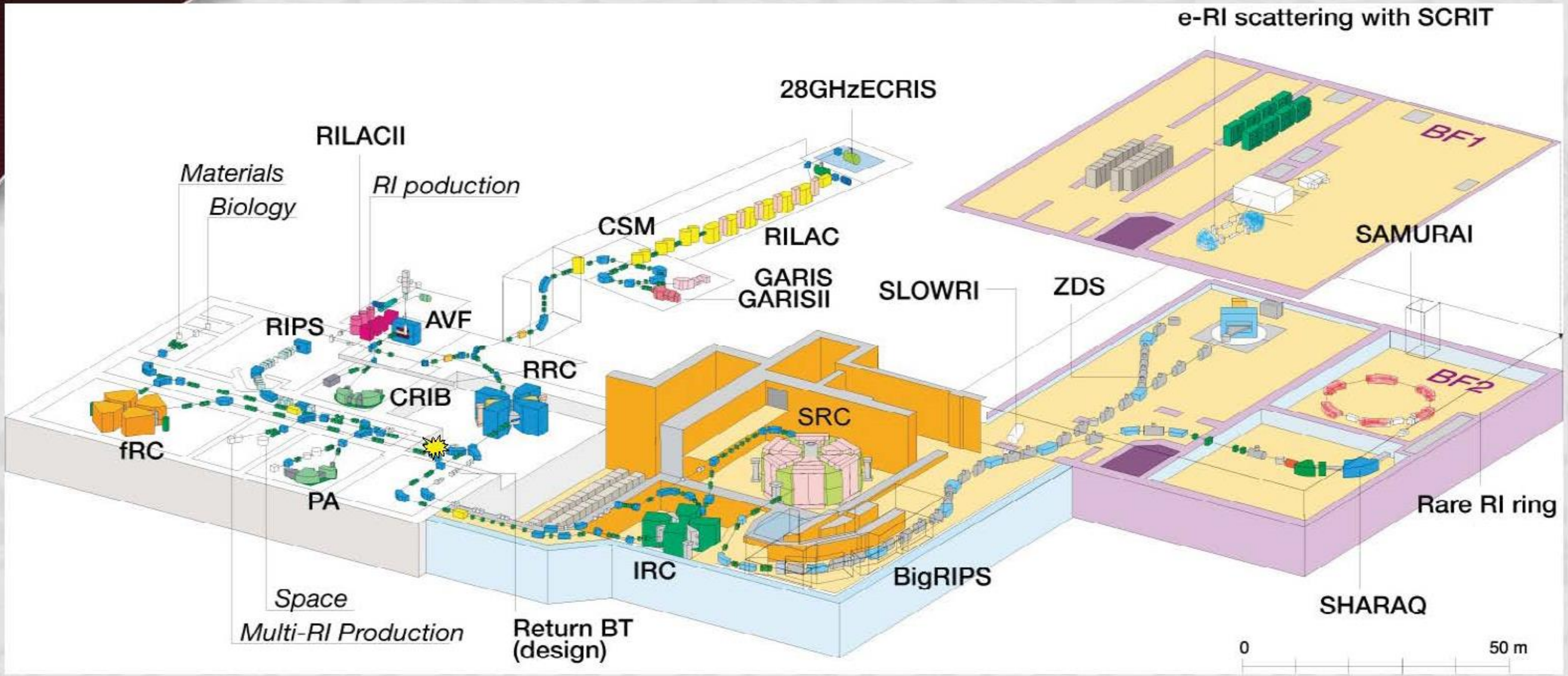
Advantages of Y-based HTS

- Higher operating temperature (<u>no use of liquid helium</u>)
- Higher critical current at higher magnetic field
- Size reduction and lighter weight



RIKEN RI Beam Factory (RIBF)

Member in AAA



The Radioactive Isotope Beam Factory (RIBF) is a facility generating unstable nuclei of all elements up to uranium and studying their properties.

Element 113 is Nh

Element 113.
(Nihonium)

- RIKEN RIBF created the nuclei of element 113, and RIKEN got the naming right of element 113.

Nihonium

Sustainable and high-efficiency accelerators in RIKEN

Member in AAA

Motors (Toshiba Co. Ltd.) for cooling water are in high efficiency.

30 kW: 92.62%(High-efficient type), 91.35%(Normal type)

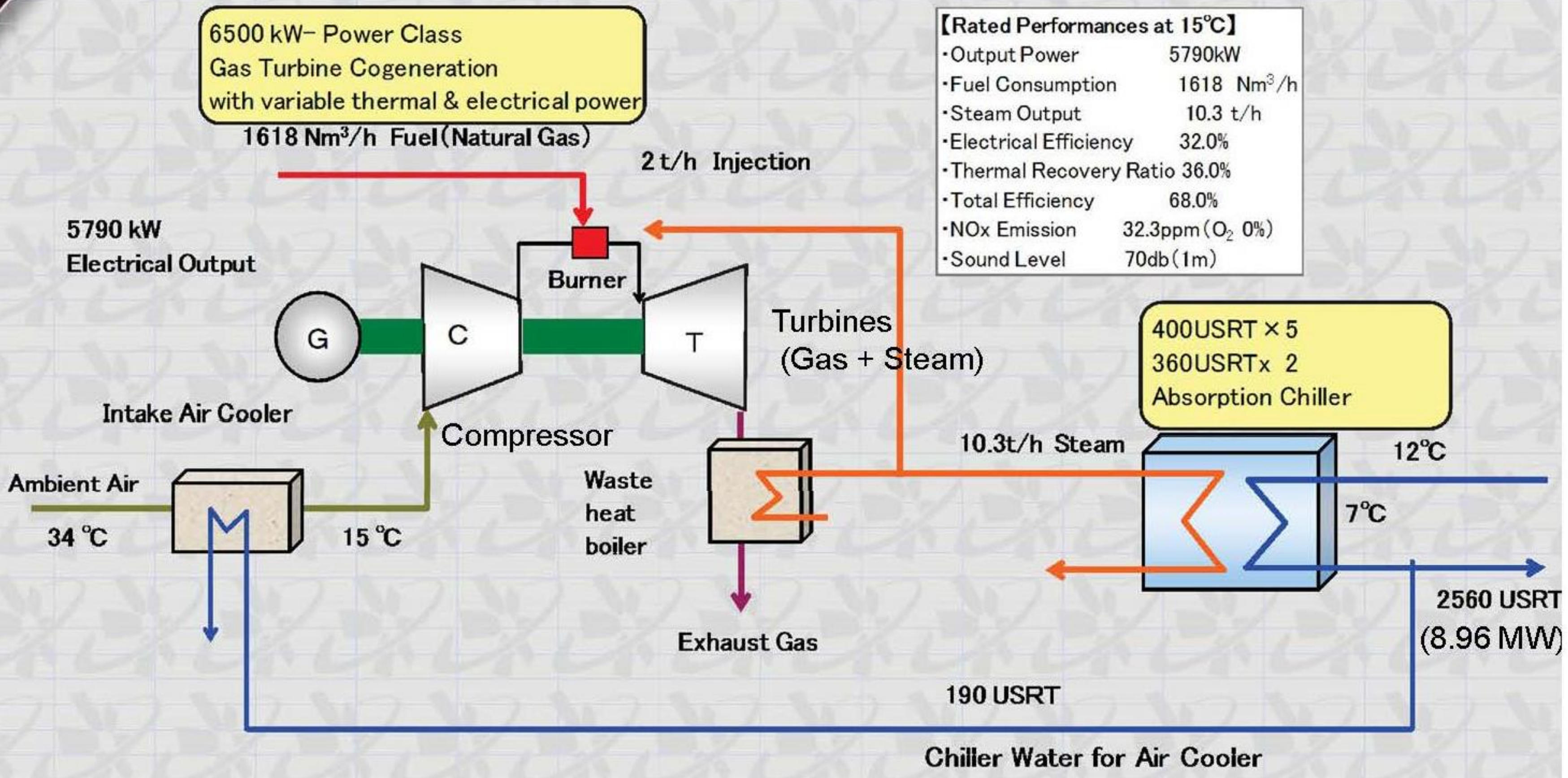
55 kW: 94.20%(High-efficient type), 92.30%(Normal type)

The transformer's highest efficiency is 99.4% (1.5 MVA)

CGS (Co-Generation System) at RIKEN

Member in AAA

CGS output = 5.79 MW (Electric / 66 kV) + 8.96 MW (Chiller)

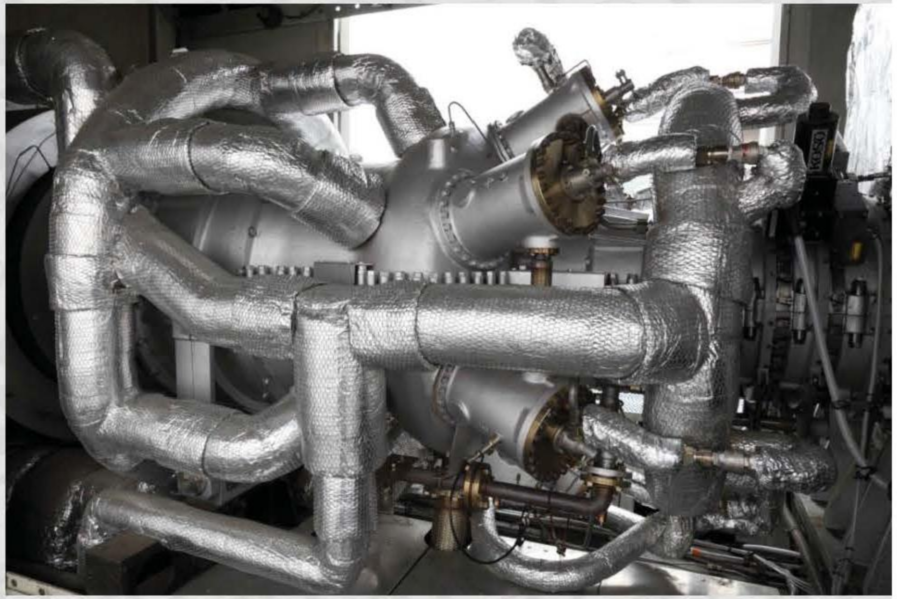


Co-Generation System (CGS) at RIKEN

Member in AAA

* RIKEN RIBF consumed 18 MW when using Uranium acceleration with the world's heaviest and most powerful SRC.
* CGS supports RIBF as UPS.

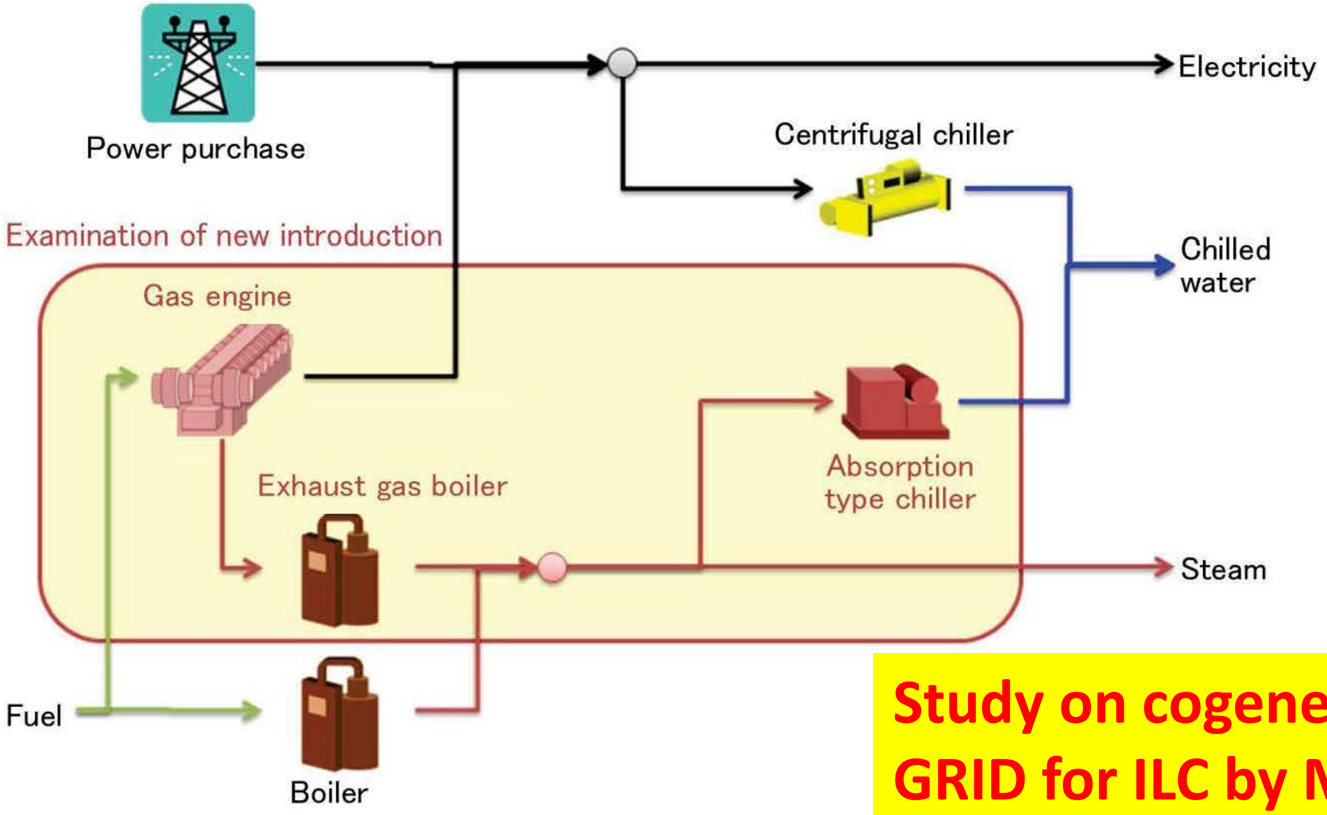
Waste Heat Boiler :WHB



Gas Turbine Generator : GTG

Adaptation case (considering the introduction of gas engine cogeneration)

It estimates a new introduction effect of the gas engine. The evaluation function as a cost (initial + running), consider the optimal method of operating the gas engine turbo chillers and absorption chiller-boiler



Study on cogeneration in energy GRID for ILC by MHI (Industry).

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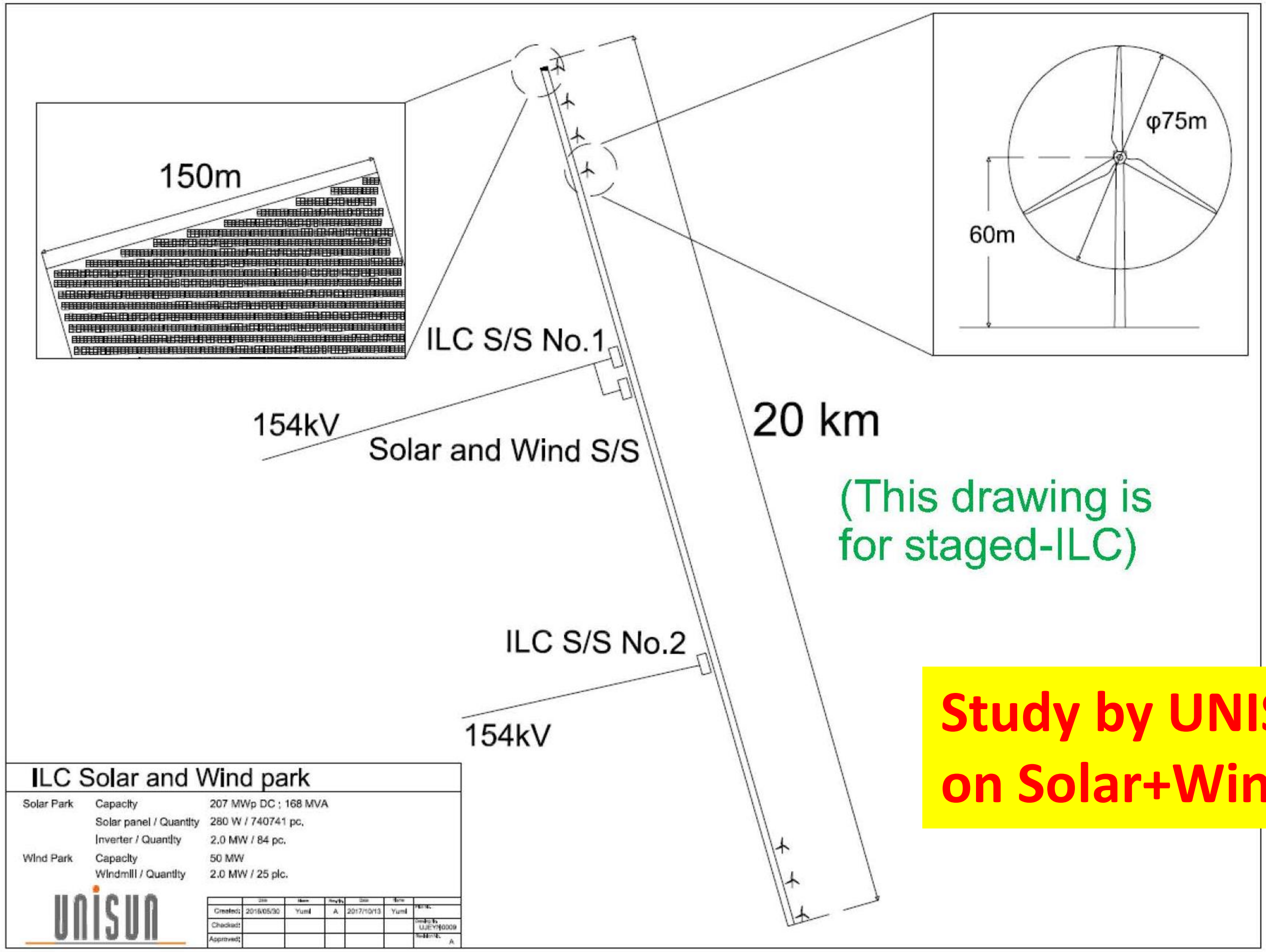
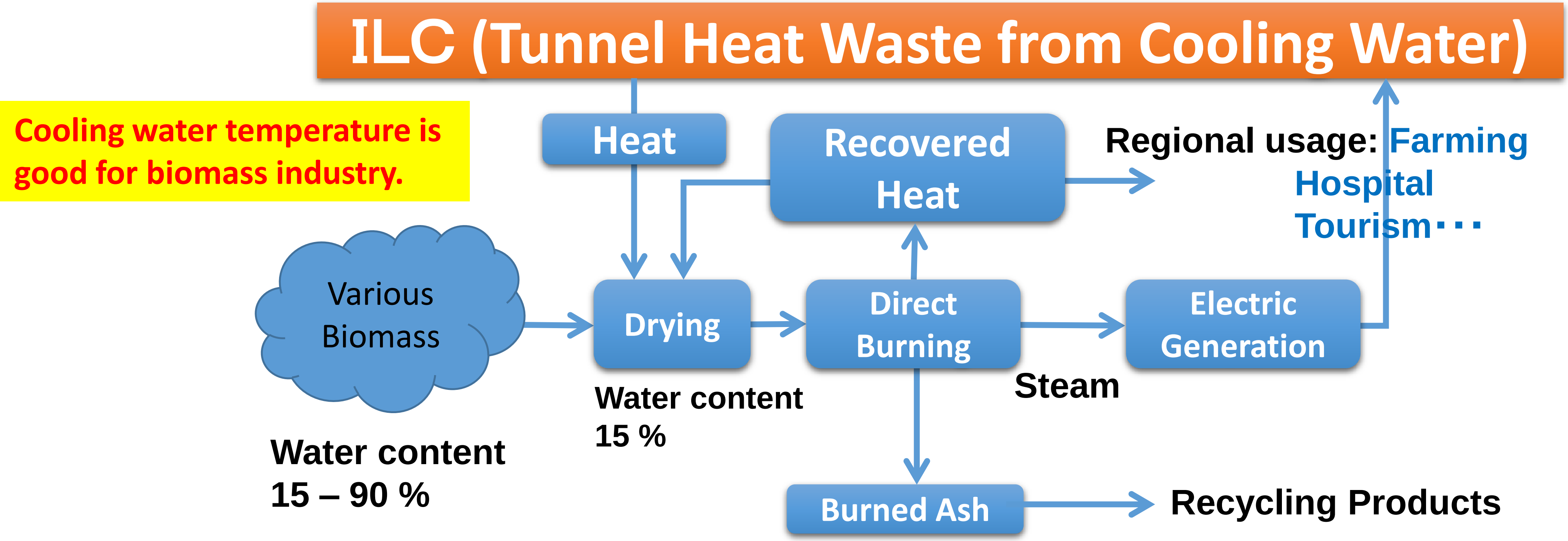
A proposal of Solar and Wind Park for ILC

UNISUN



Study by UNISUN (Industry) on Solar+Wind park for ILC.

Estimate of Biomass Electric Power



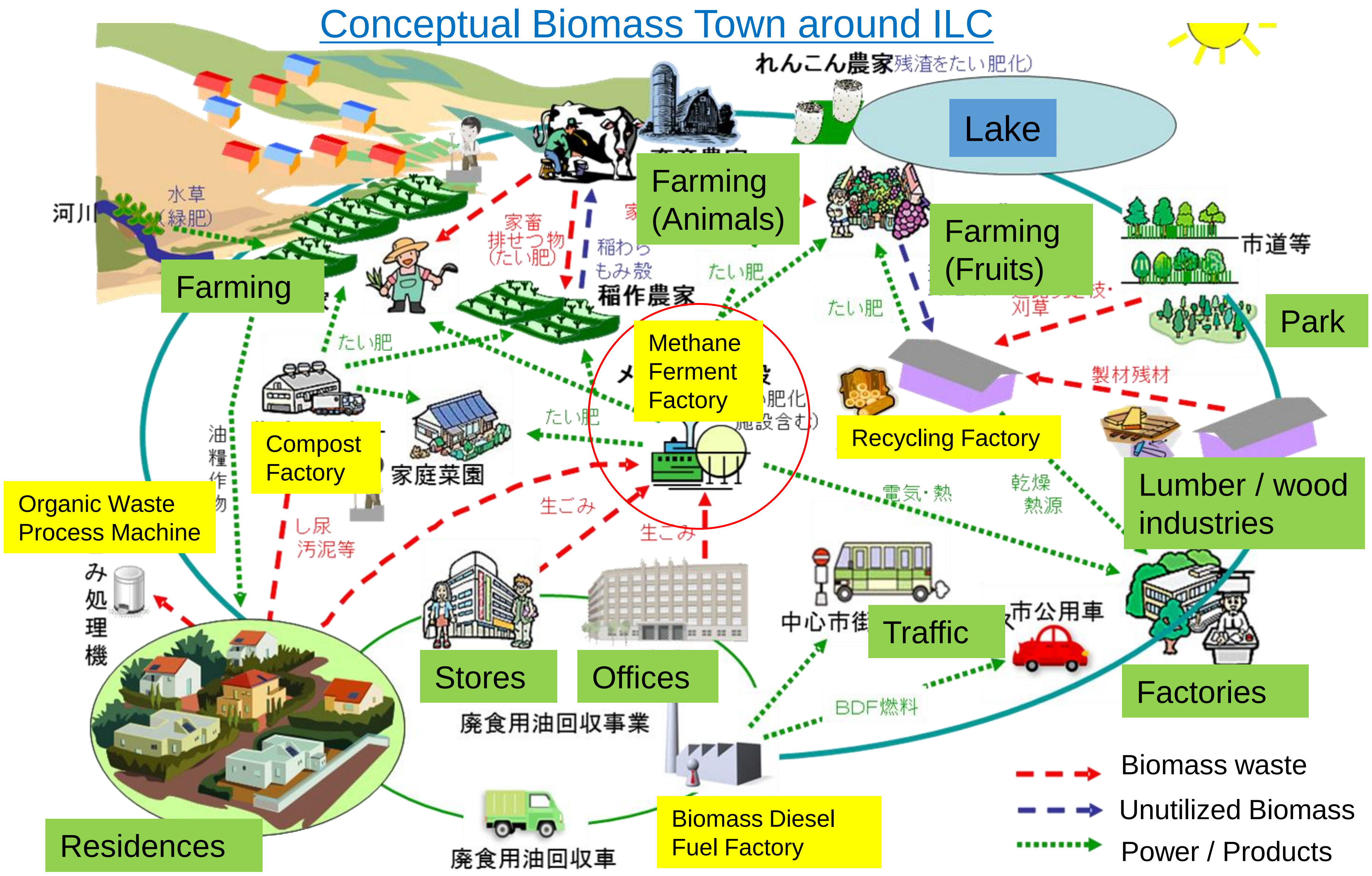
Study by Kabuki Construction Co. Ltd.

Estimate of Electric Power

Assuming the efficiency of 10～20%

Kitakami Site	58,104 kW×10 ～20% = 6,000～10,000kW
Sefuri Site	43,280 kW×10 ～20% = 5,000～10,000kW

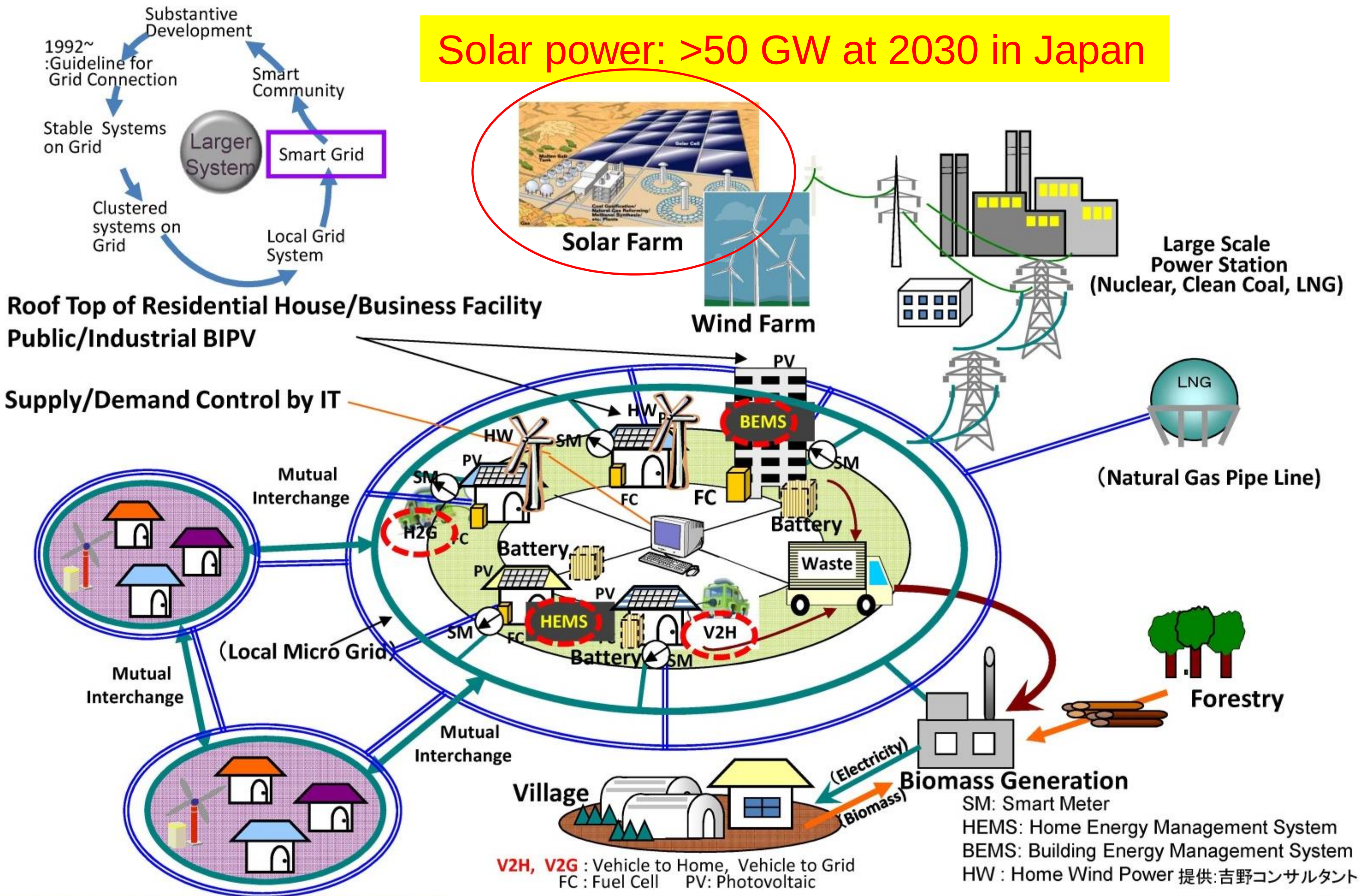
Biomass Power Plant using Organic Waste



出典:土浦市バイオマスタウン構想書

Smart ILC-City by Smart GRID

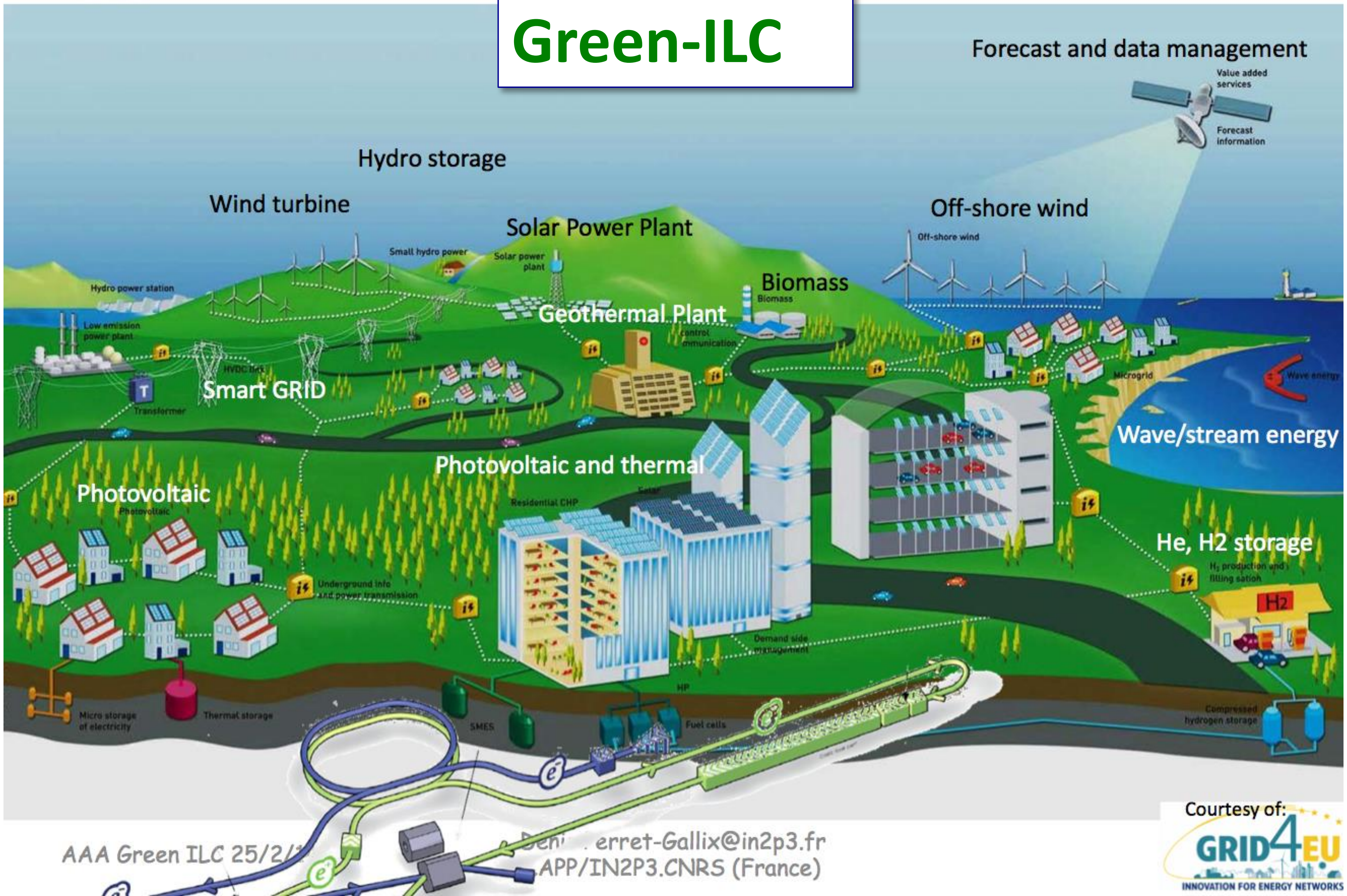
Solar power: >50 GW at 2030 in Japan



SM: Smart Meter
HEMS: Home Energy Management System
BEMS: Building Energy Management System
HW : Home Wind Power 提供:吉野コンサルタント

V2H, V2G : Vehicle to Home, Vehicle to Grid
FC : Fuel Cell PV: Photovoltaic

ILC center futuristic view



Courtesy of: GRID4EU INNOVATION FOR ENERGY NETWORKS

Deni erret-Gallix@in2p3.fr
APP/IN2P3.CNRS (France)

Efforts on communication with international LC teams, other projects, and other scientific regions


LCWS
STRASBOURG
2017
CERN
DESY
cnrs
cea
IPHC
Institut Pluridisciplinaire Hubert CURIEN STRASBOURG
UNIVERSITÉ DE STRASBOURG
CENTRE EUROPÉEN D'ÉTUDES JAPONAISES D'ALSACE
CEEJA
23-27 October
Convention Center
(Palais des Congrès)
Strasbourg, France
he workshop will be devoted to the study of the
sics case for a high energy linear electron-positron
y, taking into account the recent results from
to review the progress in the detector and
designs for both ILC and CLIC projects.
International Advisory Committee
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J. Bagger (TRIUMF)
U. Bassler (IN2P3)
S. Bentveldsen (NIKHEF)
G. Blair (STFC)
E. Elsen (CERN)
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H. Yamamoto (Tohoku Univ.)
S. Yamashita (Tokyo Univ.)

Green-Accelerator Session in LCWS2017

Sharing information between ILC and CLIC teams

281. Introduction
Takayuki SAEKI (KEK)
26/10/2017, 08:30

ILC
282. A site-specific green ILC design for Kitakami candidate site
Masakazu Yoshioka (KEK)
26/10/2017, 08:40

General
285. International Studies on Green-Accelerator
Denis Perret-Gallix (Centre National de la...)
26/10/2017, 09:10

CLIC
286. CLIC power ansi energy studies, permanent magnet studies
Steinar Stapnes (CERN)
26/10/2017, 09:40

CLIC
287. High efficiency klystron studies
Walter Wuensch (CERN)
26/10/2017, 10:10

ILC
288. Study on thin-film structure for high-Q and high-gradient SRF accelerator
Claire Antoine (CEA)
26/10/2017, 11:00

ILC
289. A proposal of the energy saving in the power supply system for Green-ILC
Takayuki SAEKI (KEK)
26/10/2017, 11:30

International Panel on "Sustainable colliders and accelerators"

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

Denis Perret-Gallix, Takayuki Saeki

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

Also providing close and active communication among various projects.

Annual IEEE NSS/MIC/RTSD Symposium (since 1969)

NSS: Nuclear Science Symposium / MIC: Medical Imaging Conference
RTSD: International Workshop on Room-Temperature Semiconductor Detectors

The IEEE NSS/MIC/RTSD offers an outstanding opportunity for detector physicists and other scientists and engineers and provides a comprehensive review of the latest developments in technology and data processing, covering a wide range of applications from radiation and accelerator instrumentation and new detector materials, to complex detector systems for physical sciences, and advanced imaging systems for biological and medical research.

2016 IEEE NSS/MIC

Where: **Strasbourg, France**
When: **29 October – 6 November, 2016**

~2500 participants from industry/academia

General Chair – Maxim Titov (CEA Saclay, France)
Chair of the Loc. Org. Committee / EU Liaison – Marc Winter (IPHC Strasbourg)

2016 IEEE NSS/MIC: Program Overview

Oct 29	Oct 30	Oct 31	Nov 1	Nov 2	Nov 3	Nov 4	Nov 5	Nov 6

Nuclear Science Symposium

Plenary

instrumentation and techniques in the fields of nuclear science, radiation detection, high energy physics, astrophysics, security, energy, and related instrumentation and software

Green Particle Physics Session

Medical Imaging Conference

scientific medical imaging meeting on the physics, engineering and mathematical aspects of nuclear medical imaging

Industry Exhibition

AAA Green-ILC activities are presented in this session.

AAA activities are presented.

Other programs:

- RTSD: International Workshop on Room-Temperature Semiconductor Detectors (1 plenary, 20 oral, 2 poster sessions)
- Special Focus Satellite Workshops (~ 4 workshops of 0.5-1 day each)
- Educational Program/Short Courses (4 NSS and 4 MIC courses of 1 day each)
- Outreach Lecture / "Science and Art for Society" Exhibition for general public

Summary

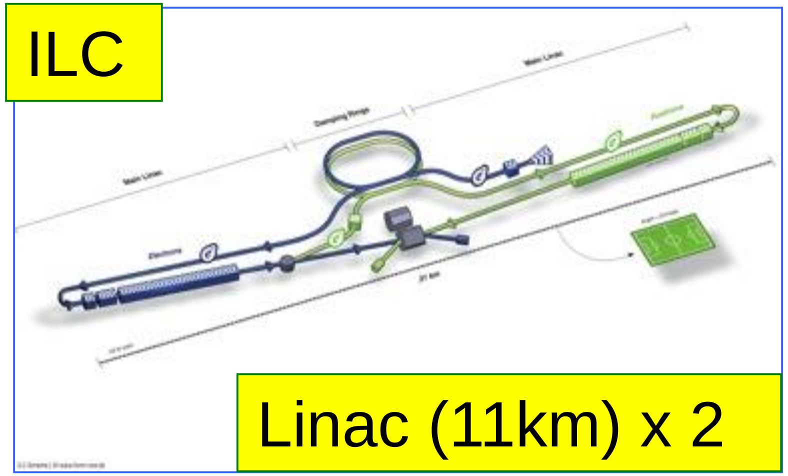
- ILC (500 GeV) will consume 164 MW. The improvement of energy efficiency is the crucial issue for the realization of ILC.
- The 2nd ESS WS (Oct. 2013) triggered the Green-ILC activities. The 1st meeting for the Green-ILC WG in AAA was held on 25th February 2014 to launch the Green-ILC activities in collaboration between industry and academia.
- The series of Green-ILC meetings have been held since then, and various technologies of energy-saving for ILC were proposed and discussed.
- The energy-saving technologies in Green-ILC are ranging from the components, sub-system, ILC-system, and to ILC-city.
- Green ILC activities are on the web page now. Please visit http://green-ILC.in2p3.fr .
- Efforts on communication in this subject is very important, because we have limited budget, man-power, and resources. This is the reason why the Green-ILC WG is interacting with international LC teams, other projects, and other scientific regions.

Backup slides

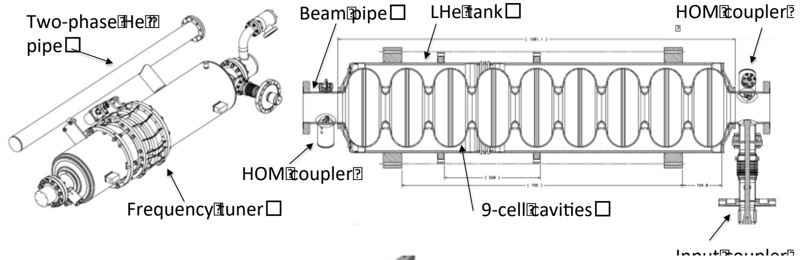
Superconducting RF specification for ILC

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.5 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
Av. field gradient	31.5 MV/m +/-20% Q_0 = 1E10
# 9-cell cavity	16,024 (x 1.1)
# cryomodule	1,855
# Klystron	~400

ILC



Linac (11km) x 2



High quality

16024 x 1.1(Yield = 90%)
~ 17600 cavities of mass-production

CGS (Go-Generation System) at RIKEN

- 6.5 MW + 2720 USRT
- 1Hz (20msec) power switch for blackout.
- Efficiency：68%, as of June 2010.

- G：7MVA. 6.6kV. 50Hz.
- T :1100℃/480℃. 14000rpm. 6.6MW /12℃.
- B :480℃/160℃. 1.6MPa(210℃)12.5t/h
- C :400 USRT x 5 + 360 USRT x 2, 7℃ at outlet (1 USRT=3.52kW.)