HydroCen

NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY

NVE – Samlet Plan mimreseminar

Oslo 23. januar 2019

Hege Brende, Senterleder FME HydroCen

NTNU SINTEF NINA Norsk institutt for naturforskning NVKS NORSK VANNKRAFTSENTER

Effekter av energiforskningen

Hovedfunn

«Dokumentere effekter fra investeringene i FoU på miljøvennlig energi siden 2008»

→ RENERGI/ENERGIX, CLIMIT og FME

Utarbeidet av Impello Management
i samarbeid med Menon Economics

18.01.2019

MENON ECONOMICS

IMPELLO

Noen få prosjekter utgjør størsteparten av effektene

Modeller for korttids-planlegging av europeisk vannkraftproduksjon

EFFEKTER I NORGE

- **6,8 mrd. kr** i økt salgsverdi av produsert kraft

CO_2 tatt i bruk som kulde-medium i kjøleanlegg hos 18.000 supermarkeder

- **1 mrd kr** i energikostnad
- Redusert energibruk
- Lavere klimagassutslipp

Optimal utbygging og drift av transmisjons-nettet

- **3 mrd. kr** i reduserte investeringer

Forlenget levetid for krafttransformatorer

- **2,5 mrd kr** i utsatte reinvesteringer

Solcellesilisium og wafers fra Norge. Drift av solparker.

Omsetning >3 mrd kr/år

- Nær 100 % eksport
- REC, Norsun, Scatec ...

…og flere har store potensielle effekter fremover

ZEB-definisjon for klassifisering av null- og lavutslippsbygg

Vil gi strenge regulatoriske føringer for byggenæringen fremover

Redusert energibruk og klimagassutslipp fra norsk aluminiumsindustri

Potensial:
Energibruk: 2 TWh/år
Energikostn: 1 mrd kr/år

Redusert sannsynlighet for havari i nye høytrykks Francis vannkraftturbiner

Potensial (nåverdi):
- 2 mrd. kr for eksisterende turbiner
- >5 mrd. kr for nye turbiner

Energieffektiv CO_2-fangst. 35 % lavere energiforbruk

Aker Solutions etablert som ledende global aktør

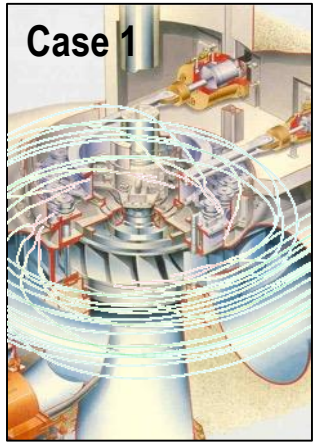
Batterier til elektriske skip

30 norske fartøy er allerede kontrahert

70 el- og hybridferger i drift i Norge i 2022

Vannkraft: 6 utvalgte case

- **7 mrd. kr realisert gevinst for kraftbransjen**
- **Nærmere 25 mrd. kr i fremtidig potensial**



Redusert sannsynlighet for havari i nye Francis vannkraftturbiner

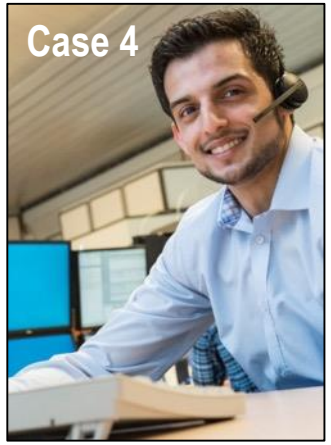
Reduserte havarikostnad:
2 mrd kr (eksist. turbiner)
>5 mrd kr (nye turbiner)

Miljødesign-håndboka

Nåverdi av investeringer i miljødesign i SKK:
0,2 mrd kr (ett vassdrag)

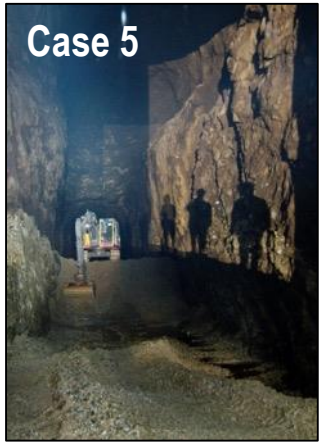
Økt kunnskap om stabilitet av plastring på fyllingsdammer

Ikke kvantifiserbart



Feildeteksjon og prediksjon av levetid

4,7 mrd kr (Norge)
Reduserte reinveste-ringskostnader og redusert prod.tap



Oppgradering av sandfang i vann-krafttuneller

1,5 mrd kr (Norge) pga. økt kapasitet og høyere oppnådd gj.snittlig kraftpris

SHOP: Korttidsplan-legging av vannkraft-produksjon

Økt verdi av kraft:
6,8 mrd kr (realisert)

12 mrd kr (potensial)

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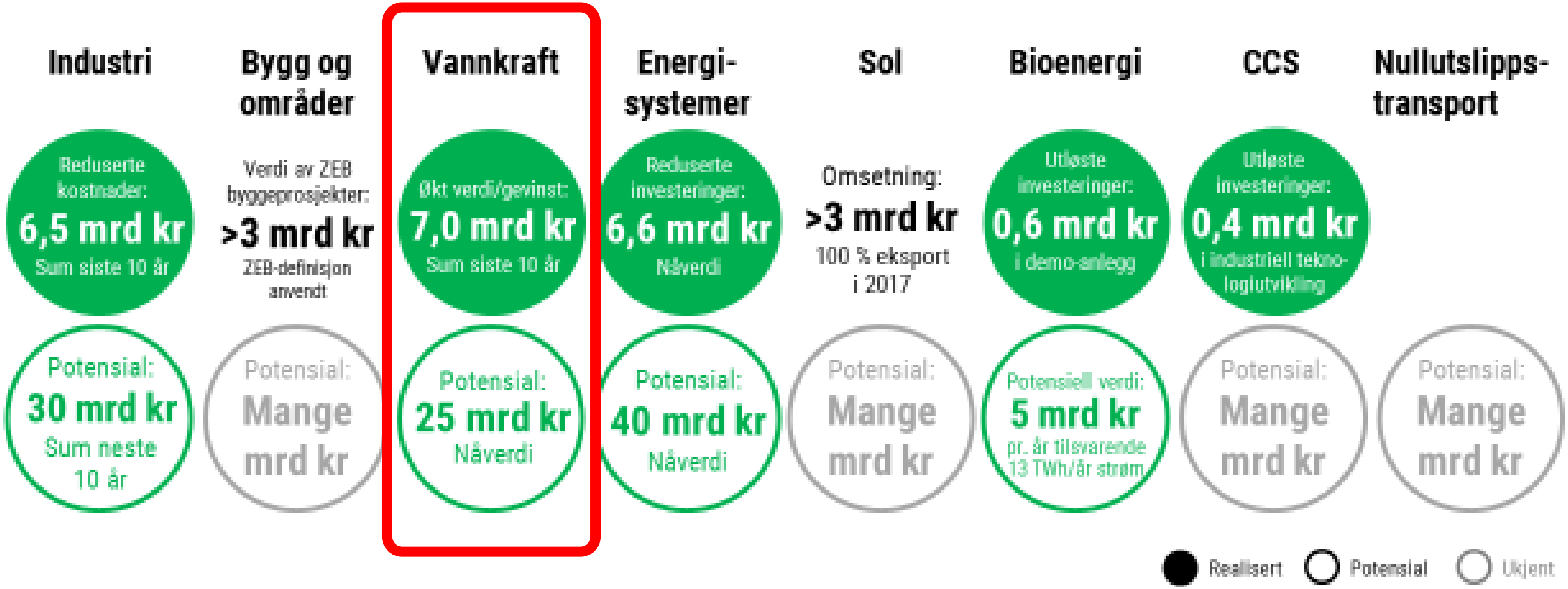
Realisert økonomisk effekt: 16 mrd. kr i Norge (21 mrd. inkl. Europa)



= 4 ganger Forskningsrådets bevilgninger

Effektkart for 48 case

NB: Kartet gjelder kun for 48 utvalgte case fra en portefølje på ca. 670 prosjekter som har mottatt bevilgninger fra Forskningsrådet 2008-2017. Det er en visualisering/illustrasjon og ikke en helhetlig vurdering av hele energiforskningsområdet.

EFFEKTER:	Industri	Bygg og områder	Vannkraft	Energi-systemer	Solenergi	Bioenergi	CCS	Nullutslipps-transport
1 Redusert energibruk	●	◉		◉	●	◉	◉	○
2 Reduserte kostnader	◉	○	●	●	●	◉	◉	◉
3 Reduserte utslipp	●	◉		•	●	◉	◉	◉
4 Redusert materialbruk	◉	◉		○	●	○	◉	○
5 Mer fornybar energi (prod/bruk)	◉	•	○	•	●	◉	○	◉
6 Bedre sikkerhet, risiko, helse	•	◉	○	◉	•	◉	◉	○
7 Økt forsyningssikkerhet	○	•	◉	●	●	●		○
8 Reduserte miljøinngrep	◉		•	•	●	○	◉	○
9 Bedre beslutninger	●	●	◉	●	●	◉	◉	◉
10 Industrielt potensial	●	○	●	◉	●	◉	◉	◉

Andre viktige dokumenterte effekter

- **Økt energiforsyningssikkerhet**, utbygging/drift/vedlikehold, smarte nett
- **Økt sikkerhet**/helse, redusert risiko – f.eks. muliggjøring av sikker lagring av CO_2
- **Reduserte naturinngrep** – miljømessig skånsom utbygging av infrastruktur
- **Bedre beslutningsunderlag** – nye verktøy, metoder, kunnskap
- **Nye byggestandarder** og verktøy for lav- og nullutslippsbygg
- **Nye bedrifter** og sysselsetting

- **Styrking av FoU-miljøene**, og der flere er i front internasjonalt
- **Utdanning og rekruttering** (Master, PhD)
- **Publikasjoner**, siteringer, mv.

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Vannkraft er ryggraden i det norske kraftsystemet

Hydropower in Norway:
A valuable system and natural preconditions

- Over **1600 power plants**
- Installed capacity of **~32 000 MW**
- Annual generation: **~135 TWh,** covering **96% of consumption**
- Total **storage capacity of >87 TWh (62 000 mill m3)**
  - ~70% annual domestic production and 50% of European capacity
- Over **800 water reservoirs**
- Close to **3500 dam constructions**
- More than **4000 km** of water tunnels
- High precipitation, low evaporation, solid rock
  - typically 1 000-2 000 mm/year
- Altitudes: **40% of land areas above 600 masl**.

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The Blåsjø reservoir = 7.8 TWh (multi-annual storage)

- Norway has 50% of the European hydro storage capacity.
- Equally, 50% of the renewable electric generation share in Europe is from hydropower.
- Globally, hydropower delivers ~65% of renewable electricity production.

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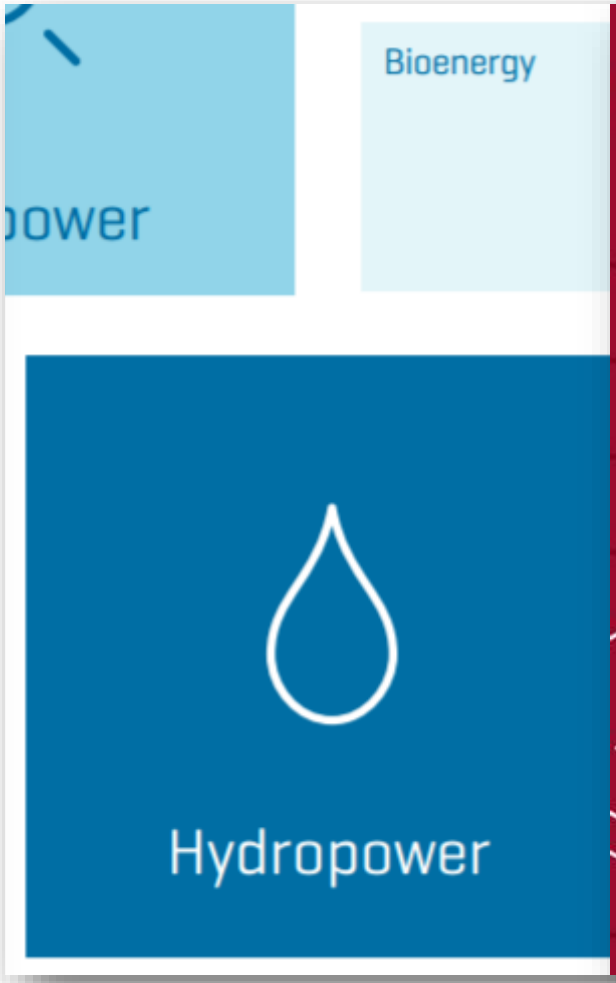
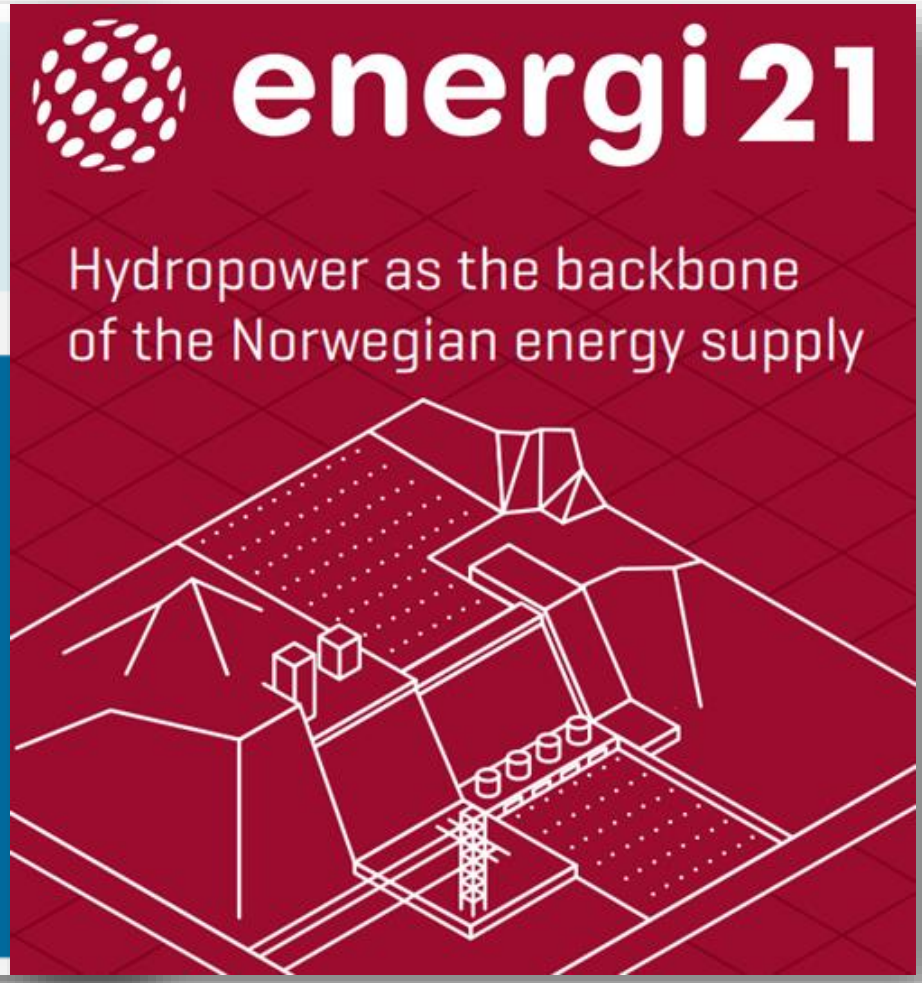
Hydropower back on the renewable agenda





2016 **2015** → **2018**

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HYDROPOWER CAPABILITIES:

FLEXIBILITY

- → Energy storage
- → Availability and supply
- → System resilience
- → Water management
- → Climate adaptation

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shall enable the hydropower sector to meet complex challenges and exploit new opportunities

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NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY

43 partners

8 years

400 mill. NOK

NTNU
is host for HydroCen

Main research partners:

SINTEF Energy

Norwegian Inst. for Nature Research (NINA)

Research partners

NTNU

SINTEF

NINA
Norwegian Institute for Nature Research

HSN University College of Southeast Norway

NGI

NTNU Technology Transfer as

The Research Council of Norway

User-partners from industry and government

NVKS
NORSK VANNKRAFTSENTER

agder energi

BKK

ECO

Eidsiva

EnergiNorge

GLITRE ENERGI

HELGELAND KRAFT

Hydro

Lyse

NTE

SFE

Sira-Kvina KRAFTSELSKAP

Skagerak Energi

SKL

SKS

Sognekraft

Statkraft

SUNNFJORD ENERGI

TAFJORD

TrønderEnergi

TUSSA

ØSTFOLD ENERGI

ABB

ANDRITZ Hydro

GE Renewable Energy

RAINPOWER

VOITH HYDRO POWER GENERATION

DR. TECHN. OLAV OLSEN

Multiconsult

Norconsult

SWECO

DYNAVEC AS

EDR MEDESO

FOB

SediCon
Removing sediments

NVE

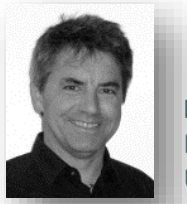
MILJØ-DIREKTORATET

HydroCen

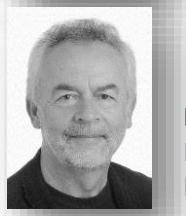
INNOVATION MANAGER
Jonas Bergmann-Paulsen

INNOVATION FORUM

SCIENTIFIC COMMITTEE



Prof. Markus Aufleger
Hydraulic engineering
University of Innsbruck



Prof. Thomas Staubli
Mechanical engineering
Hochschule Luzern

Prof. Juan Ignacio Pérez-Díaz
Power systems and -scheduling
Technical University of Madrid

Sr. Researcher Dr. Niels Jepsen
Aquatic ecology
Technical University of Denmark

EXECUTIVE DIRECTOR
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INDUSTRY REP.
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NTNU
Ole Gunnar Dahlhaug

SINTEF Energy
Michael Belsnes

NINA
Tonje Aronsen

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Rune Flatby (NVE)
Knut Samdal (Sintef Energi),
Norunn Myklebust (NINA)
Ole Morten Midtgård (NTNU)
Harald Rikheim (observer, NFR)

CENTRE COORDINATOR
Anette Havmo

COMMUNICATIONS OFFICER
Juliet Landrø

FINANCE
Birk Fiveltun

WP 1
HYDROPOWER STRUCTURES

Prof. Leif Lia

TECHNICAL COMMITTEE
Industry members

WP 2
TURBINE AND GENERATOR

Prof. Arne Nysveen

TECHNICAL COMMITTEE
Industry members

WP 3
MARKET AND SERVICES

Dr. Birger Mo

TECHNICAL COMMITTEE
Industry members

WP 4
ENVIRONMENTAL DESIGN

Dr. Torbjørn Forseth

TECHNICAL COMMITTEE
Industry members

Upscaling of the hydropower project portfolio

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HydroCen
-directly financed:

- **19 projects**
- **18 PhD, 2 Post doc.**
- **>65 scientists**
- **~60 Master students**
- **400 mill. NOK**

Hydropower,
-associated projects
(NFR, H2020, Norad, other)

- **29 projects**
- **21 PhD, 1 Post doc.**
- **>300 mill. NOK**

Last updated: January 2018

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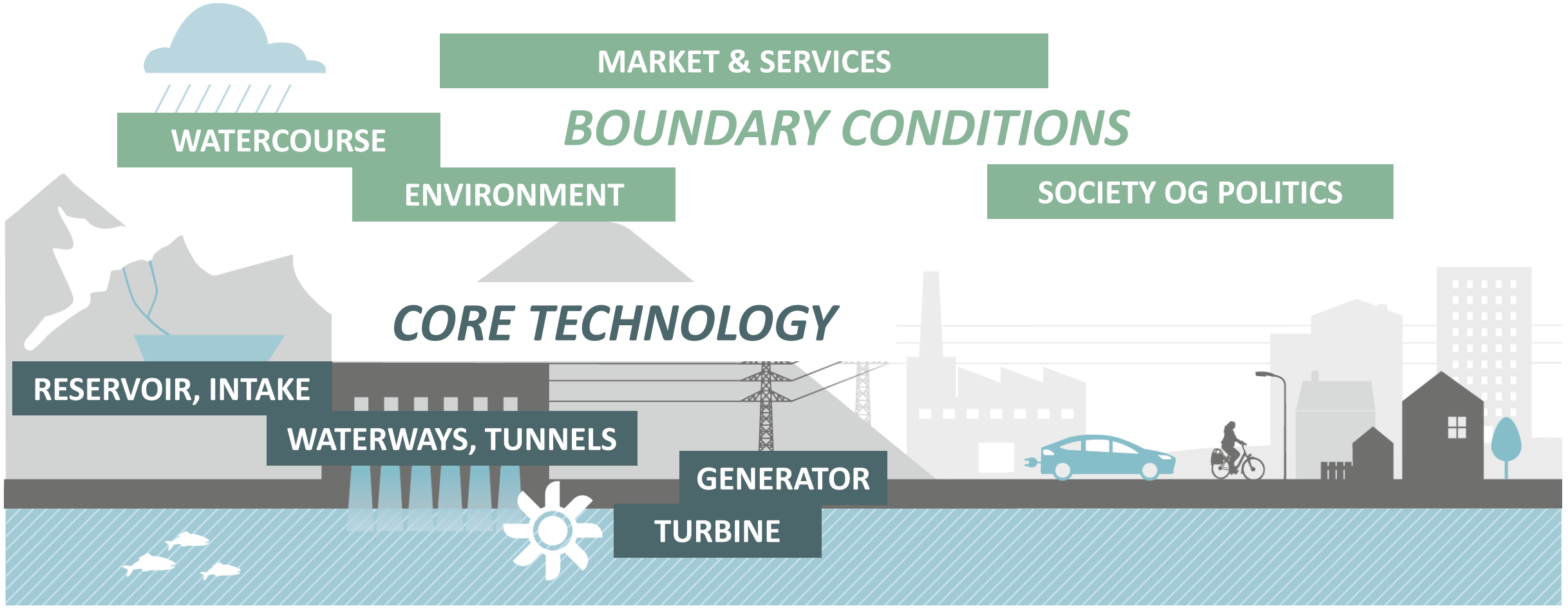
RESEARCH

Cross-disciplinary approach



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1. HYDROPOWER STRUCTURES

Foto: Multiconsult

Foto: Norconsult

Illustrasjon: Kaspar Vereide, NTNU

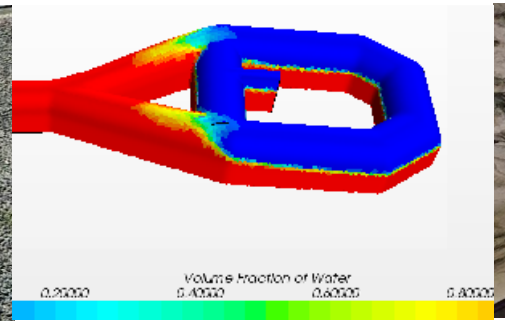


Foto: Marius Madsen

Foto: Elkem ASA

Work Package Manager: Leif Lia

1.1 Tunnels, penstocks and surge chambers	Bjørn Nilsen, NTNU
1.2 Dam and dam safety	Fjola Sigtryggsdottir, NTNU
1.3 Sediment handling	Nils Ruther, NTNU
1.4 Fish-friendly hydropower intakes	Leif Lia, NTNU

2. TURBINE AND GENERATOR

Foto: Rainpower

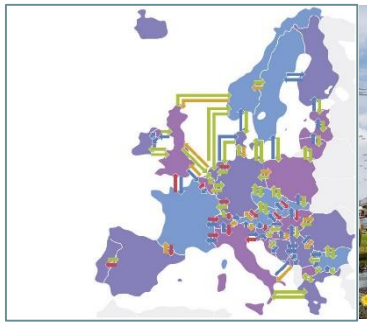
Foto: Helge Hansen/BKK

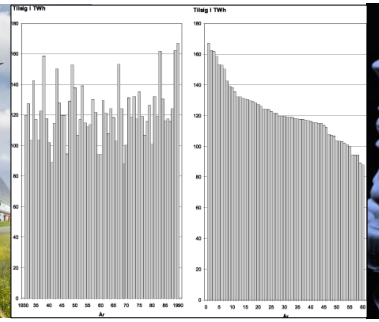
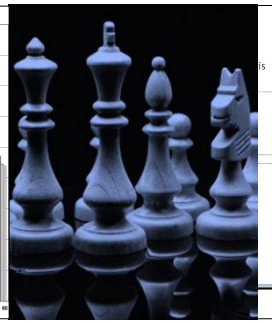
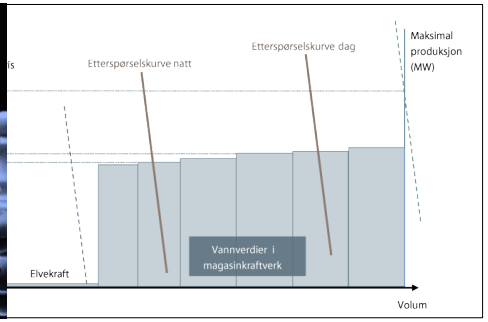
Foto: E-CO

Work Package Manager: Arne Nysveen

2.1 Variable speed, turbine and generator	Arne Nysveen, NTNU
2.2 Turbine fatigue	Torbjørn Nielsen, NTNU
2.3 Pump turbines (Boosterpump)	Pål-Tore Storli, NTNU
2.4 Turbine and generator lifetime	Thomas Welte, SINTEF Energi
2.5 Flexible hydropower unit	Kjetil Uhlen, NTNU
2.6 New design of guide vanes	Pål-Tore Storli, NTNU

3. MARKET & SERVICES

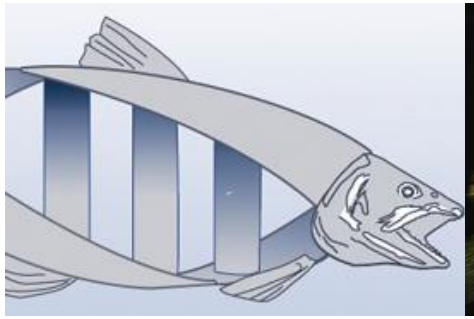


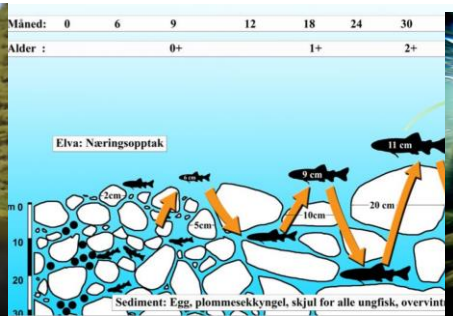
Work Package Manager: Birger Mo

3.1 Future market and prices	Birger Mo, SINTEF
3.2 Operational cost, remaining lifetime and reliability	Arnt Ove Eggen, SINTEF
3.3 Optimal design of the future hydropower system	Birger Mo, SINTEF
3.4 Environmental restrictions and uncertainties for revenues	Arild Helseth, SINTEF
3.5 Water resource management	Tor Haakon Bakken, NTNU

4. ENVIRONMENTAL DESIGN



Videostills CEDREN



Illustrasjon: Ulrich Pulg, UNI Miljø

Foto: Halldor Kolbeins

Work Package Manager: Torbjørn Forseth

4.1 Social acceptance	Audun Ruud, NINA
4.2 Two-way fish migration	Ana da Silva, NINA
4.3 Environmental Design	Atle Harby, SINTEF Energi

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Some examples of global activities in HydroCen

NTNU SINTEF NINA Norsk institutt for naturforskning NVKS NORSK VANNKRAFTSENTER

New Joint Programme Hydropower

SP X Digitalisation

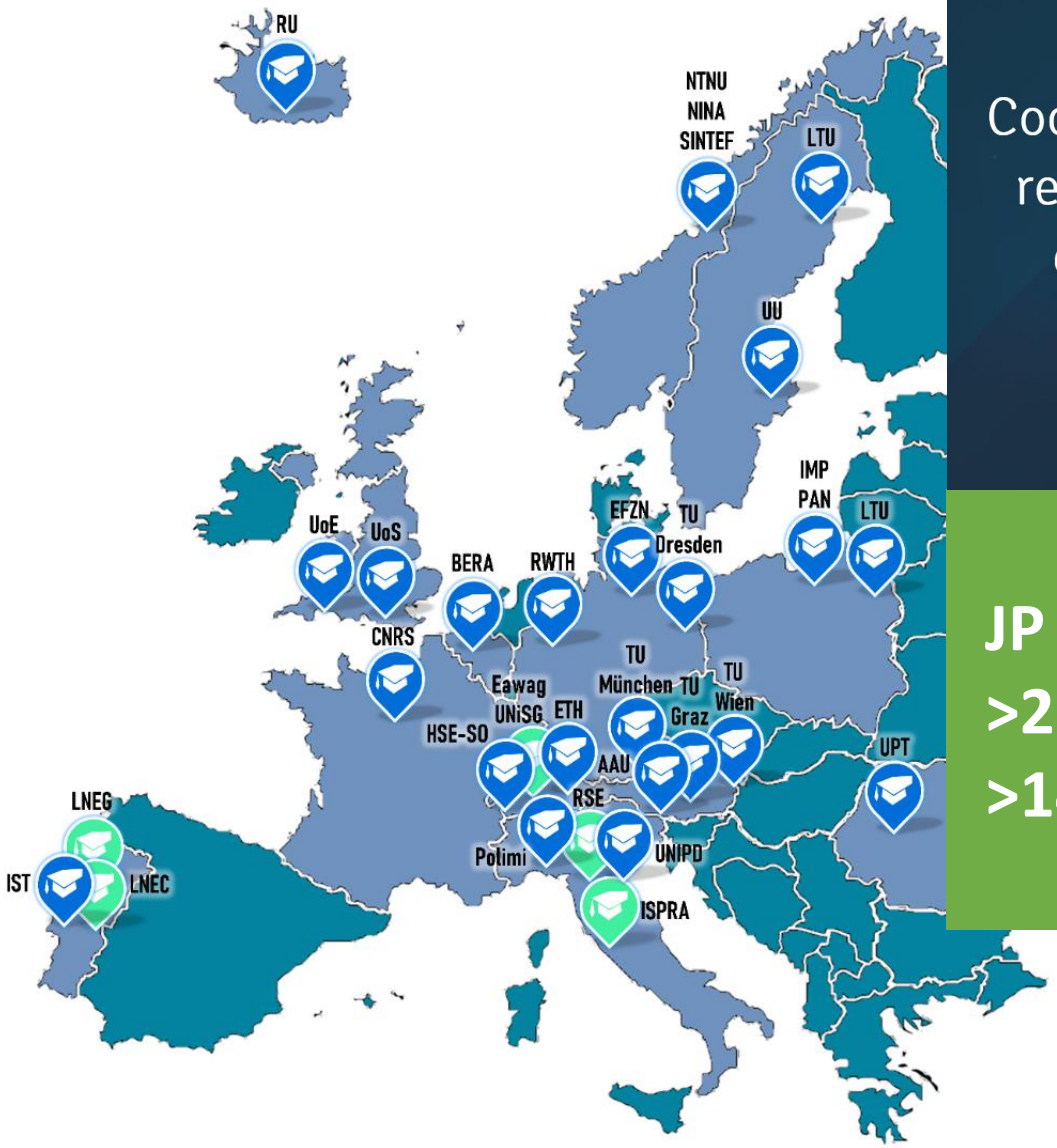
SP 3 Grid, System Integration and Markets

SP 1
Mechanical, Hydraulics & Electrical

SP 2
Hydropower Structures

SP 4 Environmental Impacts and Climate Adaption

SP 5 Policy Making and Social Acceptance



EERA
European Energy Research Alliance

Coordinating energy research for a low carbon Europe

JP Hydropower:
>25 partners
>14 countries

ANNEX IX Phase II – Valuing Hydropower Services

Utilization of Hydropower Flexibility Capability in Evolving Energy Systems

- HydroCen is Operating Agent:
  - Atle Harby
  - Linn Emelie Schäffer
- Kick-off December 2018, work ongoing.

THE INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME ON HYDROPOWER

IEA Hydropower

Framework/scope

- The role of hydropower in producing significant amount of firm renewable energy and storage to support IRES/VRE, and providing flexible energy and balancing services to support electricity systems – collectively termed 'hydro balancing'.
- In addition, it will investigate hydropower's potential role for water management and climate change mitigation.

TASK 1 – Energy and Grid Services
TASK 2 – Climate Change Adaptation Services:
TASK 3 – Hydropower Balancing and Flexibility Roadmap

LEAD: Norway (NVE → HydroCen)
DURATION: 2018-2020
ACTIVE PARTNERS p.t.: Norway, USA, Australia/Tasmania, Japan, China, EU, and more.

FINLAND JAPAN NORWAY BRAZIL USA EU CHINA AUSTRALIA

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Horizon 2020: HydroFlex

- Objective: To enable hydropower to operate with very high flexibility in order to utilize the full power and storage capability.
  - Identification of key bottlenecks of hydropower units that restrict operating range and limit flexibility.
- Cross-disciplinary approach:
  - mechanical, electrical,
  - environmental and socio-economic

HydroFlex

- **H2020 RIA project: 2018-2021**
- **Led by NTNU**
- **16 partners**
- **5 European Countries**
- **6 mill. Euros**
- **4 years**

https://www.h2020hydroflex.eu/

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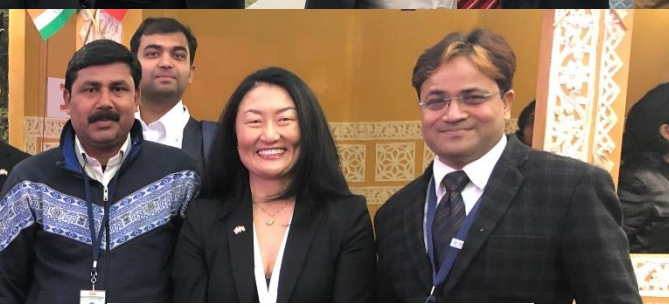

India – Norway Collaboration

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FOR HYDROPOWER TECHNOLOGY

Hydropower Technology
Development in Nepal

Kathmandu University 1990→

- Established Master programs within hydropower electrical and mechanical engineering
- Key personnel at KU has received PhD.-degrees from NTNU and returned to KU.
- Now, KU offers master and Ph.D.-education
- Collaboration on research projects together with NTNU and many other universities.
- The Turbine Testing Lab at KU is jointly managed by KU and NTNU
- This enables joint scientific publications, student exchanges and annual scientific conference in Nepal.
- The first spinoffs for new businesses within hydropower technology have been established in Nepal from KU


agder energi
BKK
ECO
Eidsiva
EnergiNorge
GLITRE
KRAFT
Hydro
Lyse
NTE
SFE
Sira-Kvina
Skagerak Energi
SKL
Sognekraft
Statkraft
TrønderEnergi
TUSSA
ABB
ANDRITZ Hydro
RAINPOWER
VOITH HYDRO
Multiconsult
Norconsult
SWECO
FOB
SediCon
The Research Council of Norway
NORWEGIAN MINISTRY OF PETROLEUM AND ENERGY
Norad
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Iceland
Norway
United Kingdom
Poland
Germany
France
Italy
Turkey
Russia
Kazakhstan
Mongolia
China
Japan
South Korea
Iraq
Iran
India
Thailand
Algeria
Libya
Egypt
Saudi Arabia
Mali
Niger
Sudan
Chad
Nigeria
Ethiopia
Kenya
DR Congo
Tanzania
Angola
Namibia
Botswana
Madagascar
South Africa
Indonesia
Papua New Guinea
Australia
New Zealand
United States
Canada
Mexico
Venezuela
Colombia
Brazil
Peru
Bolivia
Chile
Argentina
North Atlantic Ocean
South Atlantic Ocean
South Pacific Ocean
Indian Ocean
Google


agder energi
BKK
ECO
Eidsiva
EnergiNorge
GLITRE
KRAFT
Hydro
Lyse
NTE
SFE
Sira-Kvina
Skagerak Energi
SKL
Sognekraft
Statkraft
TrønderEnergi
TUSSA
ABB
ANDRITZ Hydro
RAINPOWER
VOITH HYDRO
Multiconsult
Norconsult
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Accelerating the Clean Energy Revolution
iha
international hydropower association
HORIZON 2020
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Hydro Tasmania
Finland
Iceland
Norway
Russia
Germany
Kazakhstan
Mongolia
Japan
South Korea
Canada
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Mali
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Ethiopia
Kenya
DR Congo
Tanzania
Angola
Namibia
Botswana
Madagascar
South Africa
Venezuela
Colombia
Peru
Brazil
Bolivia
Chile
Argentina
Indonesia
Papua New Guinea
Australia
New Zealand
North Atlantic Ocean
South Atlantic Ocean
Indian Ocean
South Pacific Ocean
Google

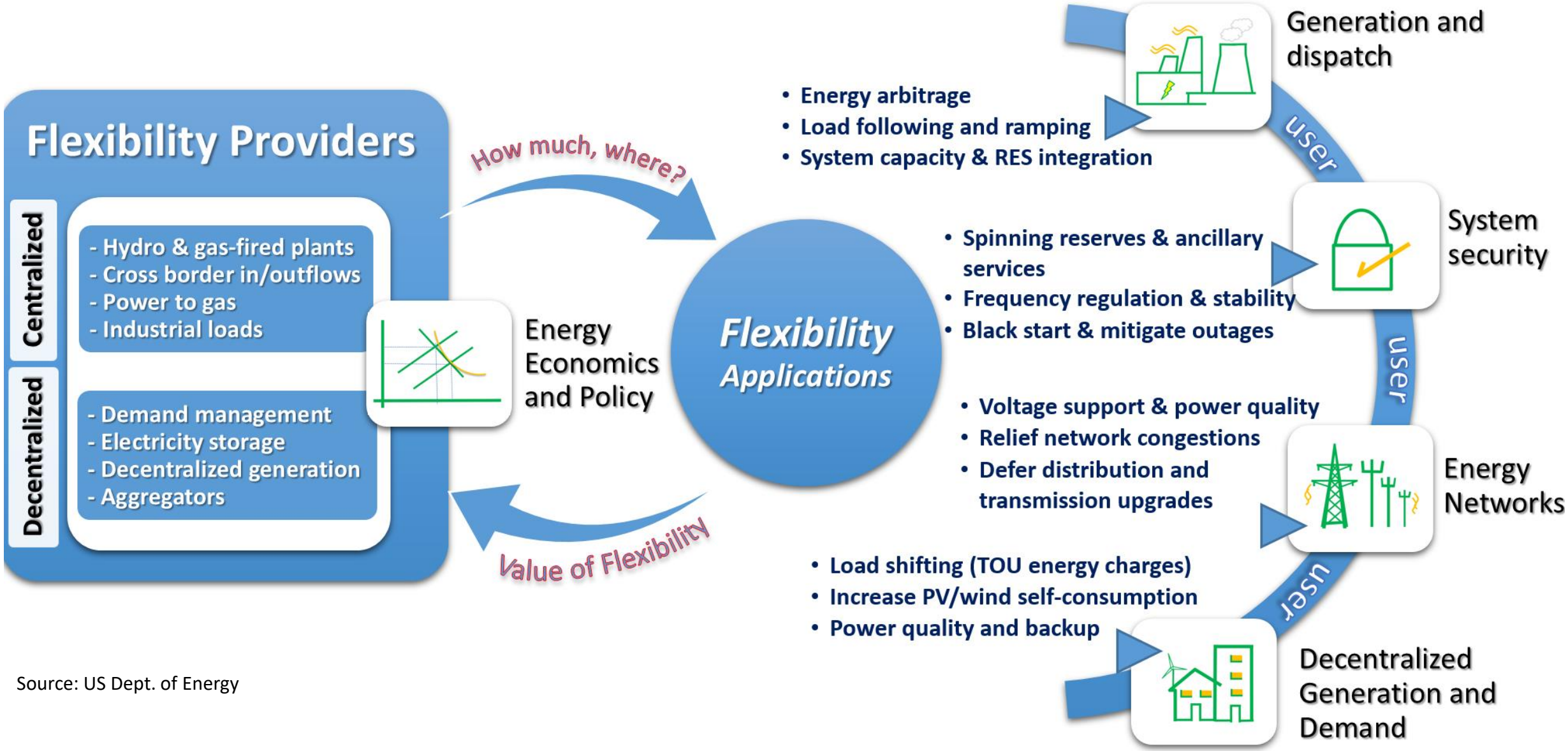
COMMON CHALLENGES WITH ENERGY STORAGE, GRID/SYSTEM RESILIENCE AND PEAKING DEMANDS

«Look to Norway»

- Norge er foregangsland for utvikling av vannkraft
  - Utdanning og kompetanse
  - Forskning
  - Teknologiutvikling
  - Forvaltning
  - Miljødesign

Samtidig ser vi nye utfordringer fremover.

How to act on the new role in the system?



Source: US Dept. of Energy

New Research Challenges

From energy to capacity and frequency? Pump storage and new technology development?

Upgrade, expansion & new technologies

Integrated Systems and Market design

Competition from new technologies and new demands. How to compete and optimize for new markets and energy systems?

430 hydropower licenses to be revised before 2020. Loss of production?

Licence to operate and relicensing

Water management regulation

How to balance hydropower production against EU environmental targets

HydroCen

Norge er fortsatt en vannkraftnasjon

www.hydrocen.no
Twitter: @FMEHydroCen
Facebook: @HydroCenFME
LinkedIn: HydroCen
Flickr: HydroCen

Office:
The Waterpower Laboratory, NTNU
Alfred Getz vei 4, Gløshaugen
Trondheim
Norway

HydroCen Projects

		Period	Project Manager
WP 1	1.1 Tunnels, penstocks and surge chambers	2017 – 2022	Bjørn Nilsen, NTNU
	1.2 Dam and dam safety	2017 – 2021	Fjola Sigtryggsdottir, NTNU
	1.3 Sediment handling	2018 – 2021	Nils Ruther, NTNU
	1.4 Fish-friendly hydropower intakes	2018 – 2021	Leif Lia, NTNU
WP 2	2.1 Variable speed, turbine and generator	2016 – 2024	Arne Nysveen, NTNU
	2.2 Turbine fatigue	2017 – 2020	Torbjørn Nielsen, NTNU
	2.3 Pump turbines (Boosterpump)	2017 – 2020	Pål-Tore Storli, NTNU
	2.4 Turbine and generator lifetime	2017 – 2021	Thomas Welte, SINTEF Energi
	2.5 Flexible hydropower unit	2018 – 2021	Kjetil Uhlen, NTNU
	2.6 New design of guide vanes	2017 – 2020	Pål-Tore Storli, NTNU
WP 3	3.1 Future market and prices	2016 – 2019	Birger Mo, SINTEF Energi
	3.2 Operational cost, remaining lifetime and reliability	2016 – 2020	Arnt Ove Eggen, SINTEF Energi
	3.3 Optimal design of the future hydropower system	2017 – 2023	Birger Mo, SINTEF Energi
	3.4 Environmental restrictions and uncertainties for revenues	2018 – 2023	Arild Helseth, SINTEF Energi
	3.5 Water resource management	2016 – 2023	Tor Haakon Bakken, SINTEF Energi
WP 4	4.1 Social acceptance	2018 – 2021	Audun Ruud, NINA
	4.2 Two-way fish migration	2018 – 2020	Ana da Silva, NINA
	4.3 Environmental Design	2016 – 2024	Atle Harby, SINTEF Energi
WP5	5.x AlternaFuture	2019 – 2019	Kaspar Vereide, NTNU

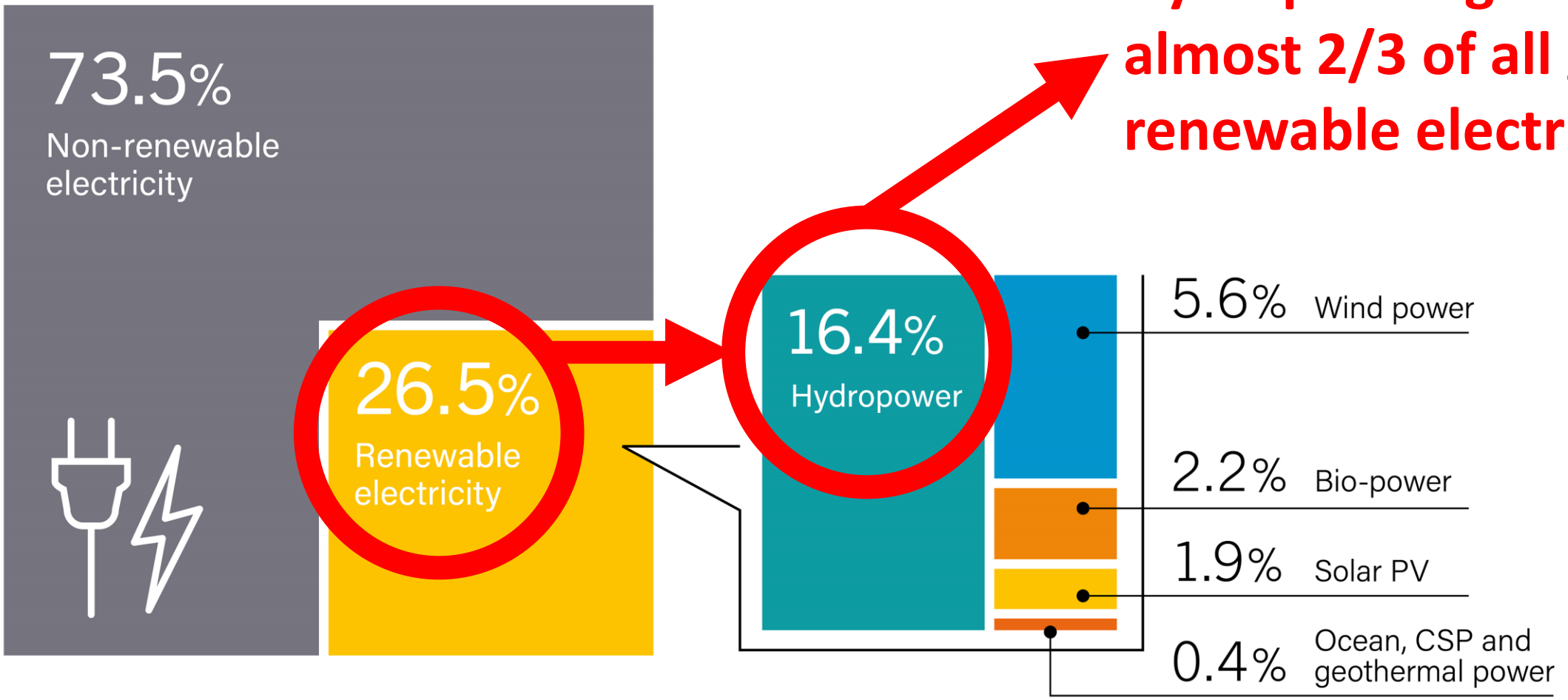
HydroCen

Overview, international collaboration

- **New Joint Program on hydropower in EERA**
  - Led by Norway, NTNU-HydroCen
- **HydroFlex, H2020 project**
  - Led by Norway, NTNU
- **Hydropower-Europe, H2020 project**
  - Norwegian participation coordinated through HydroCen → NNCOLD
- **New Annex IX, IEA Hydro**
  - HydroCen responsible for project execution, on behalf of NVE, Norway
- **Addendum on hydropower to existing MoU between OED Norway and US Dept. of Energy**
  - HydroCen responsible for the collaboration on behalf of Norway
- **MoU signed with Hydro Tasmania**
  - Common intent for Hydro Tasmania to join as full member in HydroCen
- **MoU signed with IIT Roorkee, India**
  - New project initiated: FranSed
- **MoU signed with NHPC Limited (utility) in India**

Int. aktør	Rammeverk	HydroCen rolle	Aktivitet, prosjekt	Land
EERA **European Energy Research Alliance**	EU SET-plan, H2020/HE, europeisk posisjonering	Programkoordinator	Etablering av nytt Joint Program Hydro	14 europeiske land 27 FoU-partnere
EU H2020	H2020 utlysning	Prosjektleder (koordinator)	'HydroFlex' RIA-prosjekt	5 land 16 partnere
EURCOLD **og NNCOLD**	H2020/HE, europeisk posisjonering	Prosjektdeltaker: koordinerer norsk deltakelse på vegne av NNCOLD	HYDROPOWER-EUROPE2030 H2020 CSA-prosjekt	4 europeiske land 8 europeiske organisasjoner
IEA Hydro	Internasjonal posisjonering	Operating Agent for Annex IX	Annex IX, Phase II	Australia, USA, Japan, Kina, EU, Norge (m.fl.)
US Department of Energy, DoE	IEA Hydro, nasjonale strategier	Samarbeidspartner	-Etablering av vannkraftsamarbeid under eksisterende MoU mellom UD DoE og OED i Norge -Samarbeid i IEA Hydro Annex IX.	USA
Hydro Tasmania	Avtale: Memorandum of Understanding	Samarbeidspartner, med Intensjon om å inkludere HydroTasmania som partner i HydroCen	Etablering av vannkraftsamarbeid under eksisterende MoU mellom UD DoE og OED i Norge	Australia, Tasmania
IIT Roorkee	Avtale: Memorandum of Understanding	Prosjektledelse	FransSed, EnergizeNepal, HydroCen prosjekt 1.3	India
NHPC Limited, hydropower utility, India	Avtale: Memorandum of Understanding	Samarbeidspartner	-Etablering av vannkraftsamarbeid med idustriaktør.	India
Kathmandu University	Partner i HydroCen	Prosjektledelse	WP 2, EnergizeNepal, FranSed	Nepal
Himalayan University Consortium, HUC	Partner i konsortiet	Medlem	Medlemskap	Himalaya-regionen

Estimated Renewable Energy Share of Global Electricity Production, End-2017



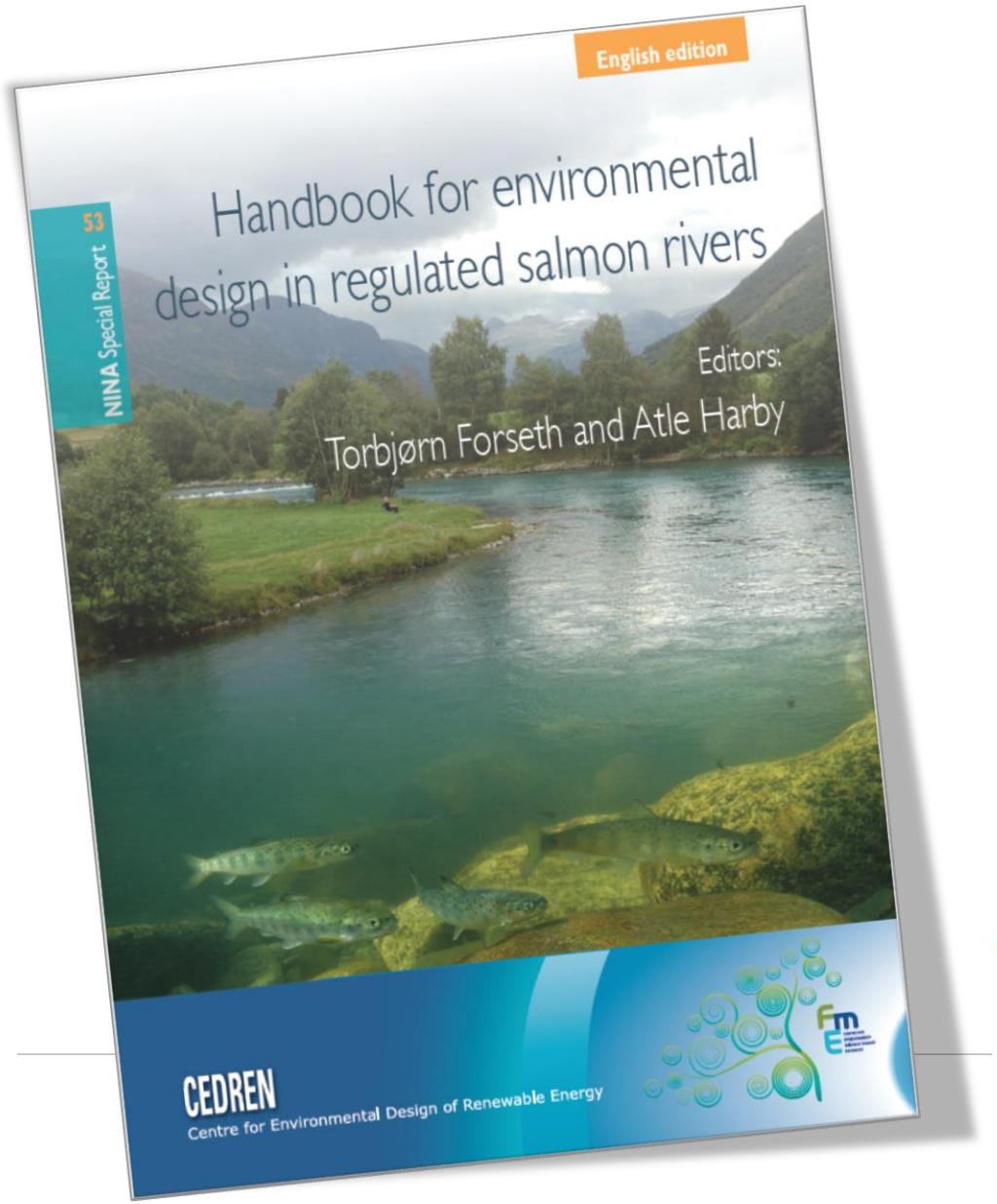
Hydropower generates almost 2/3 of all global renewable electricity

REN21 RENEWABLES 2018 GLOBAL STATUS REPORT

Source: REN21 2017

HydroCen

Handbook on Environmental design of hydropower in salmon rivers



Implemented in several cases:

- In some cases Norwegian Environment Agency demands use of the methodology
- Some hydropower companies have implemented it, with substantial economic benefit
- The handbook exists in Norwegian, English and Chinese
- Concept expected to be transferable to other species and ecosystems
- HydroCen continues the work on expanding the concept

CEDREN

www.cedren.no

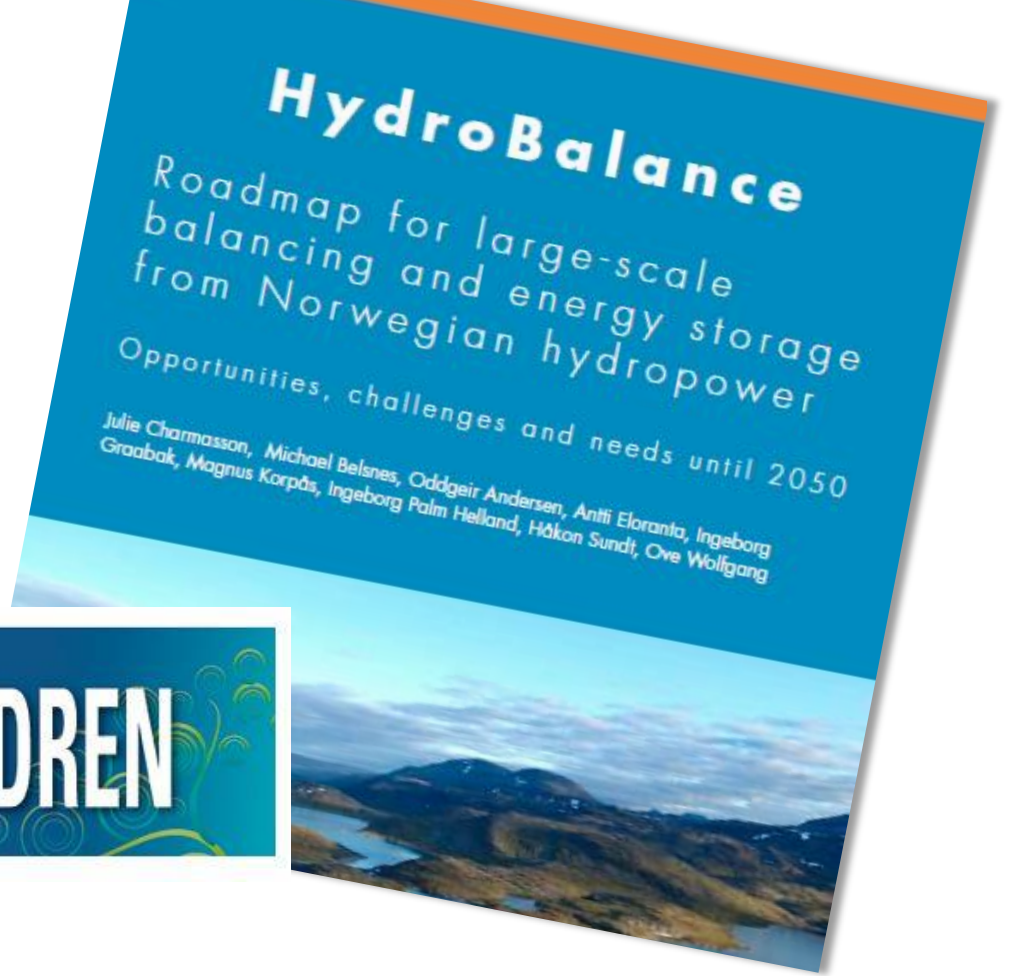
HydroCen

HydroBalance

”Roadmap for *large-scale balancing and energy storage from Norwegian hydropower*”

Key questions:

- What are hydropower capacity needs and future operations?
- What are the effects on pricing and markets?
- Will investments in new pumped storage be profitable?



Part of the CEDREN portfolio, led by SINTEF Energy

- **Duration: 2013 - 2017**
- **Budget: 25 million NOK**
- **R&D partners: SINTEF, NINA, NTNU**

www.cedren.no